SUBMERSED AQUATIC VEGETATION IN A HUDSON RIVER WATERSHED: THE GREAT SWAMP OF NEW YORK

A Thesis Presented to
The Faculty of the Biology Department at the City University of New York:
Queens College

In Partial Fulfillment of the Degree of
Masters of Science

Biology Department
Queens College
65-30 Kissena Boulevard
Flushing, NY 11367

Project Advisor:

John Waldman, Ph.D.
Biology Department
Queens College
65-30 Kissena Boulevard
Flushing, NY 11367

By
Chris Cotroneo

May 2020

Abstract

Baseline information about submersed aquatic vegetation (SAV) communities and their associated fish assemblages represents a valuable information resource for use by the scientific community for comparison to other studies, documenting changes over time, or to assist with actions such as fish passage. In order to collect data throughout the entire growing season, a comprehensive six-month, submersed aquatic vegetation (SAV) study was conducted in New York's Great Swamp. Sampling sites were selected based upon the presence of SAV representative of the surrounding area and were sampled bi-weekly. Aerial percent cover was estimated for each SAV species identified within the sampling site. A total of 12 SAV stands were sampled throughout the course of the study. A total of 58 SAV samples were taken, revealing five dominant SAV species: *Potamogeton crispus*, *P. pusillus*, *P. illinoensis*, *Ceratophyllum demersum*, and *Elodea canadensis*.

Every fourth week the same sites were sampled for nekton to determine if habitat use changed with any changes in dominant SAV species. Both passive (2' and 3' fyke nets and minnow pots) and active (seine and 1m^2 throw trap) sampling methods were used to sample within the SAV stands. A total of 1,015 nekton were collected, comprised of 16 species. Nekton collections were dominated by bluegill sunfish (*Lepomis macrochirus*). Golden shiner (*Notemigonus crysoleucas*) was the second most abundant species. Rusty crayfish (*Faxonius rusticus*) was the third most abundant species. The throw trap yielded a significantly great abundance and diversity of nekton, in comparison to other methods, indicating its effectiveness in SAV dominated habitat.

TABLE OF CONTENTS

Abstract 2

INTRODUCTION 4

METHODS 14

RESULTS 20

DISCUSSION 28

CONCLUSIONS 40

ACKNOWLEDGMENTS 41

REFERENCES 42

LIST OF FIGURES AND TABLES

Figure 1. Map of Study Area.......... 10

Figure 2. USGS Water Gauge Level for Duration of This Study 11

Figure 3. SAV Site Dominance by Sampling Event 21

Figure 4. Nekton Species Richness by Sampling Type 26

Figure 5. Nekton Species Richness by Dominant Plant Species.......... 26

Figure 6. Fish Lengths by Sampling Gear Type 27

Table 1. SAV Sampling Dates.......... 14

Table 2. Nekton Sampling Dates.......... 18

Table 3. Percent Cover and Dominant Species by Sampling Event and Site.......... 22

Table 4. Finfish Collection by Dominant SAV Type and Sampling Gear Type.......... 25

Table 5. Crayfish Collection by Dominant SAV Type and Sampling Gear Type.......... 25

INTRODUCTION

The Great Swamp watershed encompasses over 60,000 acres, in which over 40,000 people live (FROGS 2016). The land is almost exclusively privately owned, with a few public parks such as Patterson Environmental Park, that offer access for passive recreation or nature study, including kayaking, fishing and bird watching. The Great Swamp itself comprises over 6,000 acres of forested and emergent herbaceous wetlands, spanning the towns of Southeast, Patterson, Pawling and Dover, in Putnam and Dutchess Counties, New York. The Swamp drains in both north and south directions, with the division in the village of Pawling, from which the Swamp River flows north to the Housatonic River, and the East Branch Croton River flows south to the Hudson River (Siemann 1999). Historically, prior to man's actions, the flow from the Great Swamp to the Hudson River was uninterrupted, but this has been curtailed for decades due to the construction of several dams. From 1886 to 1911, there were five dams erected along the East Branch Croton River from the Great Swamp to the Hudson River. Following the flow south, there is the Sodom Dam (constructed in 1892), the Diverting Reservoir Dam (1911), the Juengst Dam (1886), the Muscoot Dam (1906) and finally the New Croton Reservoir Dam (1906) (USACE 2005). Removal of small, obsolete or disused dams is gaining popularity as an aquatic habitat restoration measure in many areas (Yochum 2018, Bednarek 2001), and there is considerable interest among the natural resource management community at the municipal, State and Federal levels in dam removal along Hudson River tributaries (Hudson River Estuary Program 2017, Alderson and Rosman

2012; Yozzo 2008). Baseline information about submersed aquatic vegetation (SAV) communities and their associated fish assemblages, upstream of such obstructions represents a valuable information resource for use in the development of future dam removal programs. This study concentrated on the East Branch Croton River, which flows approximately 35 river miles from the Great Swamp to the Croton and Hudson River confluence.

The Great Swamp provides many ecological services. It is home to numerous fishes, birds, reptiles and mammals, including some that are endangered in New York State, such as wild brook trout (*Salvelinus fontinalis*) and bog turtles (*Clemmys muhlenbergii*). A 1997 study also showed longear sunfish (*Lepomis megalotis*) to be present, a threatened species in New York State (Siemann 1999). The Great Swamp stores excess runoff water and helps purify a portion of the water that eventually flows through the Croton Reservoir downstream to the Hudson River Estuary. There are ongoing efforts to preserve the ecological integrity of the Great Swamp, mostly by Non-Governmental Organizations. Groups like Friends of the Great Swamp (FROGS 2016) and The Nature Conservancy help to raise awareness about the Great Swamp's ecology and recreational opportunities.

Submersed aquatic vegetation (SAV) provides nursery habitat for juvenile fishes, protects them against predation, and replenishes water with dissolved oxygen (Mitsch and Gosselink 1993). The Swamp provides several habitat types for fishes, including large open channels of the East Branch Croton River, much of which supports SAV. The littoral zone is generally made up of sandy beaches, or steep muddy banks, with dense emergent vegetation such as lizard's tail (*Saururus cernuus*), arrow-arum*,* (*Peltandra virginica*), and smartweeds, (*Polygonum* spp.).

While the basic characteristics of the Great Swamp are well known, and fishes have been sampled in tributaries (van Holt et al. 2006) and the main stem (Cotroneo and Yozzo 2008), to date there has not been an extensive survey of the Great Swamp's SAV community. While performing the field work for a 2007 Polgar Fellowship (Cotroneo and Yozzo 2008) comparing fish usage of emergent vegetation, non-vegetated channels and SAV, it was noted that the Great Swamp's SAV community had a dynamic nature, with dominant species in a given location changing during the growing season. That study compared fish species associations among non-vegetated waters, emergent vegetation, and SAV, revealing several statistically significant associations. This study focused on SAV species dominance mapping, with fish species associations as a secondary objective.

Goals and Objectives

The goal of this project was to provide information on the SAV species distribution within the Great Swamp, for use by those who wish to further research the Great Swamp and similar habitats for conservation efforts. The following objectives supported this goal.

- The primary objective was to characterize changes among the dynamic SAV community within the Great Swamp. It was previously noted that the SAV community undergoes changes in species and percent cover throughout the growing season. SAV stands were located, mapped, and species percent cover were measured bi-weekly.

- The second objective was to carry out a comprehensive, multi-season (spring, summer and autumn) sampling program to characterize fish use of SAV habitat in the main stem of the Great Swamp. This SAV and fish survey incorporated multiple gear types and a variety of sampling sites. Every fourth week, fishes were collected within mapped SAV stands, identified to species, counted, measured, and released at the point of collection, unharmed. Repeated sampling of these areas helped identify species-SAV associations previously undescribed in the Great Swamp.
- The third objective was to note the general health of fishes collected. Noticeable signs of disease or stress, such as surface lesions, gill condition, external parasites or gill parasites, were documented for future research.

Hypotheses

- H_1- The dominant SAV species within sampled SAV stands will have statistically significant changes over the duration of this study.
- H_2- Despite significant changes in dominant SAV species, fish species usage of SAV will not significantly change.

Sites

All sites were within the East Branch Croton River main stem and were accessed via the entrance at the Green Chimneys School (Figure 1). Within the study area the East Branch

Croton River ranged in width from 8-feet to 150-feet, measuring from river edge to river edge. Sites sampled ranged 30-feet to 130-feet in width, and with samples taken in ten-foot increments across the river, perpendicular to flow. Water levels during the sampling period were the lowest on average recorded in 22 years, with the majority of the study period experiencing very low flow conditions of (<10 cubic feet/second) (Figure 2). For example, areas just upstream from site A1 had depths ranging 1-3-feet in previous years but was only inches deep in braided channels during the majority of this study. Figure 2 shows the United States Geologic Survey (USGS) data for a logger approximately 0.5-mile downstream from Site C1, the site farthest downstream in this study.

Sites were assigned names based upon the sampling dates and then increasingly numbered in an upstream direction. For example, Site A1 was sampled during the first two sampling dates and is the farthest downstream site to be sampled during those sampling dates. Whereas site C4 was sampled during the last two sampling dates and is the farther upstream site to be sampled during those sampling dates.

Average widths and depth ranges given for each site below represent the overall means for all transects sampled at that respective site for the duration of the study.

Site A1

Site A1 was located south of the Green Chimneys entrance and had an average width of 27.1-feet. Depth at Site A1 ranged 0.7 to 2.5-feet. The sediment was generally sandy in the center of the channel, with softer mud along the shores. The narrow and shallow morphology created a faster flow rate at this site than most others. This site has dense forest immediately along the banks on both sides that keep it shaded most of the day.

Site A1 was not sampled during the first sampling date due to inclement weather.

Site A2

Site A2 was located at the Green Chimneys school beach and had an average width of approximately 79-feet. Depth at Site A2 ranged 2.5-feet to six-feet. The wide and deep stream morphology at this site creates very low flow conditions compared to most of the study area. This site is wide open, with trees along the western shore, but a wide sandy beach and grass area to the east, which allows sunlight to warm the slower moving waters for most of the day.

This area is inhabited by many turtles and is frequented by people launching canoes and kayaks into the East Branch Croton River. Historically, sand was placed here to create an access point and beach, which is in contrast to the natural, unconsolidated mud bottom that exists in the majority of the River.

Site A3

Site A3 was located north of the Green Chimneys entrance and had an average width of approximately 63-feet. Depth at Site A3 ranged 0.25 to 2.5-feet. The narrow and shallow morphology created a faster flow rate at this site than most others. This site has dense forest along the southern shore, and approximately 50-feet of emergent wetland along the northern shore, which allows sunlight to fall on the site many hours of the day.

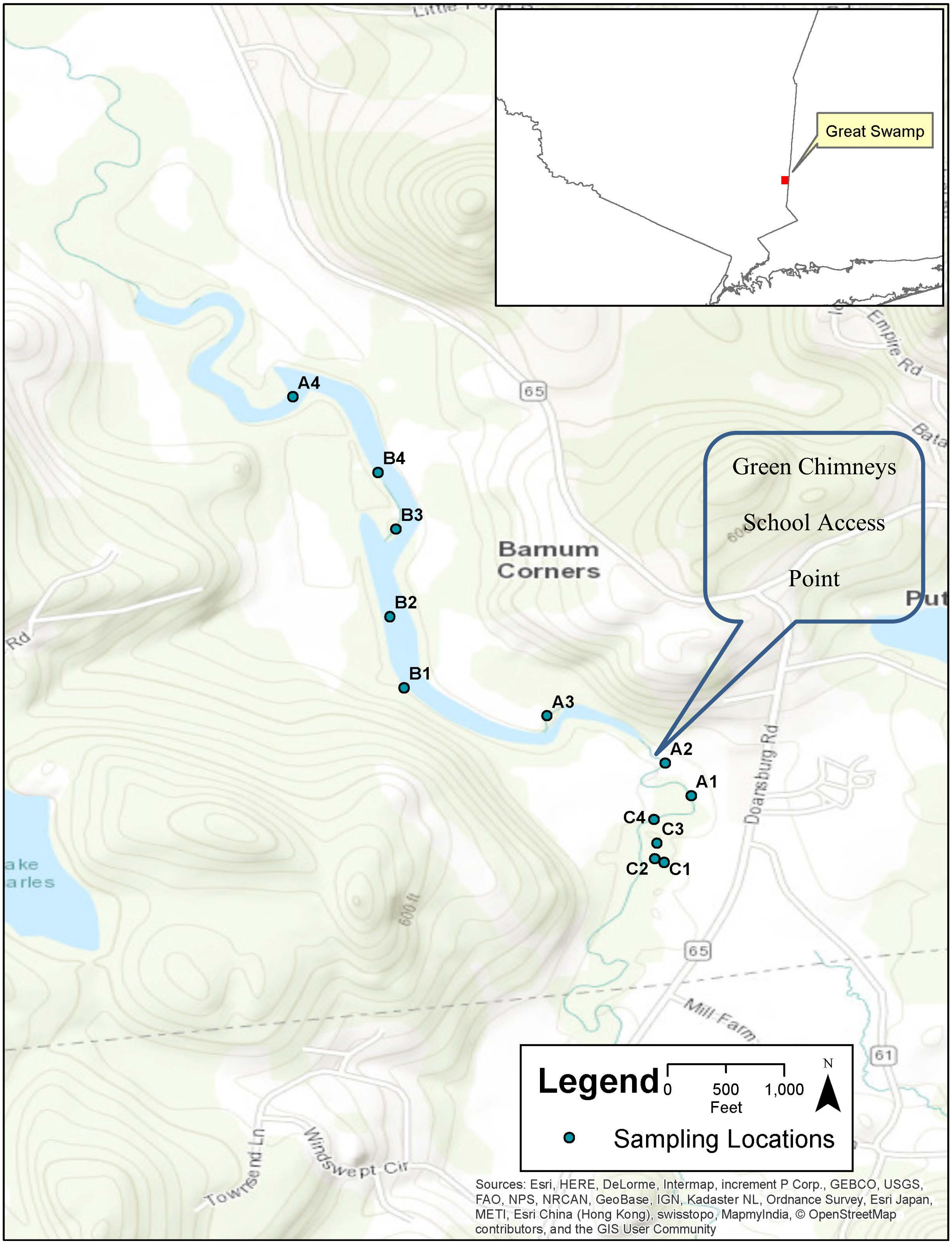

Figure 1. Map of Study Area.

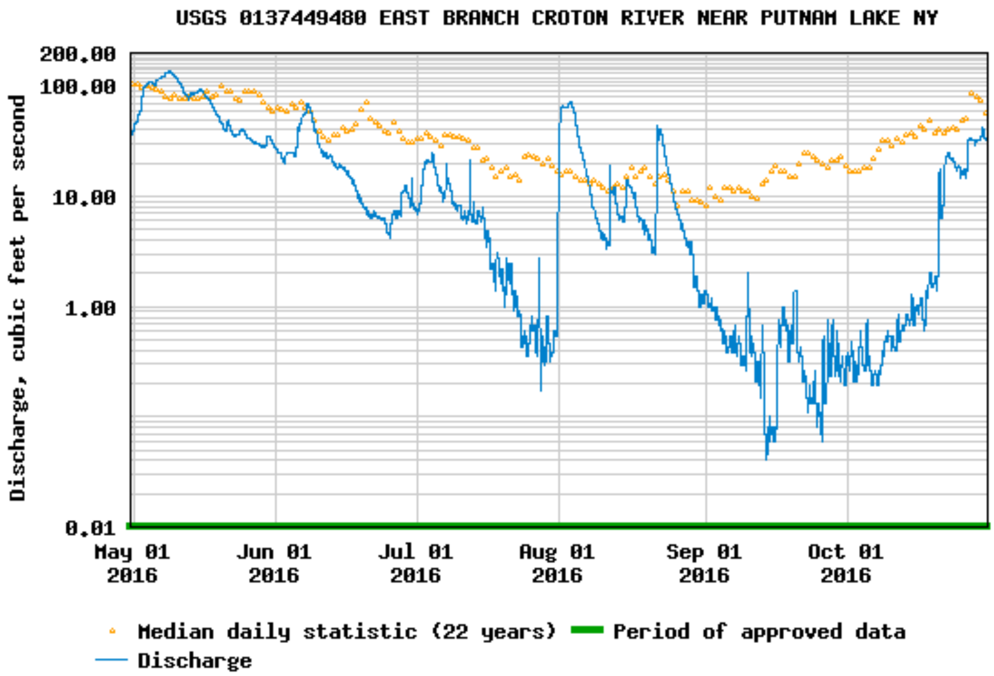

Figure 2. USGS water gauge level for duration of this study.

Site A4

Site A4 was located the farthest north of all sampling sites and had an average width of approximately 49.2-feet. Depth at Site A4 ranged 0.5 to 2.5-feet. There was a very large beaver dam approximately 200-feet upstream of Site A4. Due to this beaver dam, large amounts of water flowed in newly created channels over land, circumventing the area containing Site A4, causing flows to be lower at the site than in other areas of similar size. These low flows caused the sediment at this location to be extremely soft, in comparison to most of the system, which had a hard, sandy mud substrate. This site has sparse trees along the southern shore, and open, emergent wetlands on the northern shore, that allows sunlight to fall on the site many hours of the day.

Site A4 was not sampled during the first sampling date due to inclement weather.

Site B1

Site B1 was located north of the Green Chimneys entrance and had an average width of approximately 56-feet. Depth at Site B1 ranged 0.2 to 2.7-feet. During low flow periods, the sediment was extremely soft and muddy along the banks, however the center of the channel was generally harder, sandy mud. This site has dense forest along the western shore, and sparse trees and emergent wetlands along the eastern shore that allows sunlight to fall on the site many hours of the day.

Site B2

Site B2 was located north of the Green Chimneys entrance and had an average width of approximately 54-feet. Depth at Site B2 ranged 0.5 to three-feet. This site has dense forest along the western shore, and sparse trees and emergent wetlands along the eastern shore that allows sunlight to fall on the site many hours of the day.

Site B3

Site B3 was located north of the Green Chimneys entrance and had an average width of approximately 55-feet. Depth at Site B3 ranged 0.5 to three-feet. This site has sparse forest along the eastern shore, and sparse trees and emergent wetlands along the western shore that allows sunlight to fall on the site many hours of the day.

Site B4

Site B4 was located north of the Green Chimneys entrance and had an average width of approximately 68-feet. Depth at Site B4 ranged 0.8 to 3.5-feet. This site has sparse forest along the eastern shore, and sparse trees and emergent wetlands along the western shore that allows sunlight to fall on the site many hours of the day.

Site C1

Site C1 was located south of the Green Chimneys entrance and had an average width of approximately 20-feet. Depth at Site C1 ranged 0.5 to 1.5-feet. The narrow and shallow morphology created a faster flow rate at this site than most others. The sediment at this site was harder, sandy mud. This site has open, emergent wetlands on both sides, allowing many hours of sunlight to fall upon it.

Site C2

Site C2 was located south of the Green Chimneys entrance and had an average width of approximately 20-feet. Depth at Site C2 ranged 0.3 to two-feet. This site has dense forest on the southern shore, and sparse forest on the northern shore, keeping it shaded most of the time.

Site C3

Site C3 was located south of the Green Chimneys entrance and had an average width of approximately 20-feet. Depth at Site C3 ranged 0.3 to two-feet. This site has emergent wetlands along both shores, allowing the sun to fall upon it most of the day.

Site C4

Site C4 was located south of the Green Chimneys entrance and had an average width of approximately 25-feet. Depth at Site C4 ranged 0.5 to 2.3-feet. This site has dense forest along both southern and northern shores, keeping it shaded most of the day.

METHODS

SAV

Sites within the Great Swamp were sampled for SAV bi-weekly when possible, and for nekton every fourth week, May-October 2016. Some dates were adjusted due to thunderstorms, access permission or other logistics. Table 1 shows SAV sampling dates, while Table 2 shows nekton sampling dates. Sampling sites were located consistently through use of a Garmin GPSMap 60 CSx unit and a GIS map was made for future comparative sampling (Figure 1).

Table 1. SAV Sampling Dates.

SAV Sample Event	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Dates (2016)	6 May	20 May	3 Jun	17 Jun	1 Jul	16 Jul	30 Jul	14 Aug	27 Aug	5 Sep	23 Sep	7 Oct	14 Oct

In order to sample a wider diversity of the Great Swamp's habitat, and due to the destructive effects active nekton sampling has on SAV stands, a new set of four SAV sampling sites was selected after four SAV sampling dates and two nekton sampling dates had occurred, and again after the eighth SAV sampling dates and fourth nekton sampling dates. The first SAV sampling date consisted of sampling only two sites due to inclement weather, while dates two through twelve consisted of four sites each. The thirteenth SAV sampling date consisted of all twelve previously sampled sites, to determine if any different species were present from previous sampling dates. A total of 58 SAV sampling events were performed, at twelve sites, with a total of 771 samples collected. A sampling event was defined as the set of three transects at each sampling site during each sampling date, and a sample was defined as the data within a 1-m^2 PVC quadrat, further described below.

SAV sampling was performed in SAV stands of at least 50-m^2, larger whenever possible. SAV sampling began with collecting a GPS point at the approximate center of the SAV stand. Next, the overall species composition was visually estimated, a representative transect perpendicular to the East Branch Croton River's flow was selected, and a floating line was tied across the stream to either a tree near the shore or a piece of rebar that had been temporarily installed in the bank. A total of three transects were sampled in all SAV stands, all transects being a minimum of 3 meters apart. Sampling began at the farthest downstream transect of the SAV stand so resulting turbid waters were carried downstream and did not visually impair the remaining sampling. A 1-m^2 PVC quadrat was then placed on top of the water, attached to the floating line using two common carabiners. Each SAV species within the quadrat was identified to species, and percent cover for each species present within the quadrat was estimated.

The floating line was marked every 10 feet, and the quadrat was moved to the next 10-foot mark after identification and cover data was recorded, and the process repeated until the opposite shore was reached. The stream width and average depth at each transect was noted. When conditions limited surface visibility, a view bucket or scuba mask was used to see SAV below the surface. If conditions were not conducive to the view bucket or mask, a common garden rake was used to feel for SAV presence, and to pull up SAV for identification and percent cover estimation. The rake method was only necessary for eight samples, as depths were rarely greater than 3 ft. during the study, and flows were low enough that turbid conditions were encountered only on the first two SAV sampling dates.

When emergent vegetation was found within SAV samples, it was identified to at least genus-level, and percent cover was included in the sample data. However, all emergent data was entered and grouped simply as "emergent," not individual species. If a sample contained two or more emergent species, they were grouped together for a total emergent percent cover, as emergent species were not the focus of this study. Emergent species were not dominant in any SAV sites sampled. Common duckweed (*Lemna minor*), a floating plant, was present in very high abundance, and was included as an SAV species, since it does not root in soil, but floats freely, similar to other SAV species found in this study, such as *Ceratophyllum demersum*.

SAV data was tabulated and depicted graphically to analyze for changes over time and between stands. The Shannon-Wiener Diversity Index (*H'*) was calculated for the SAV community data. This index provides information about the vegetation community structure, taking into account the relative abundance of each taxa as well as taxa richness (Morin 1999). The diversity index *H'* values range from 0 to 4. Low values of *H*' indicate low taxa richness and an uneven distribution of abundance among species, while high values indicate high taxa richness and an even distribution of abundance among taxa. The index is computed using the following formula:

$$H' = -\sum_{i=1}^{S} (p_i \ln p_i)$$

Where *S* is the total number of species per sample (i.e., taxa richness) and p_i is the proportion of total individuals in the i^{th} species. Mathematically, p_i is defined as $\frac{n_i}{N}$ where n_i is the number of individuals of a taxa in a sample, and *N* is the total number of individuals of all taxa in the sample.

Pielou's Evenness Index (*E*) was also calculated for the vegetation community. This index measures the distribution among species within the community by scaling one of the diversity measures relative to its maximal possible value. Evenness values range from 0 (uneven distribution) to 1 (even distribution). The metric is computed as follows:

$$E = \frac{H'}{H'max}$$

where *H'* is the observed diversity (as cited above) and H'_{max} is the natural logarithm of the total number of taxa (*S*) in the sample ($H'_{max}=lnS$).

Nekton

Some nekton sampling events were performed over several days due to the duration of time required to set out passive sampling methods and then perform active sampling (Table 2). The third active fish sampling date took place over two days (18 and 22 July) due to thunderstorms making conditions unsafe to complete sampling on 18 July.

Table 2. Nekton Sampling Dates.

Sample Event	**1**		**2**		**3**		**4**	**5**			**6**		
Gear Type	MP FN TT	S	MP FN	TT S	MP FN	TT S	MP FN TT S	MP FN	TT	S	MP FN	TT	S
Dates (2016)	23 May	NP	17 Jun	20 Jun	16 Jul	18 & 22 Jul	19 Aug	5 Sep	9 Sep	NP	7 Oct	10 Oct	17 Oct

MP= Minnow Pots
FN= Fyke Nets
TT= Throw Trap
S= Seine
NP= Not Performed

Nekton sampling sites were sampled with gear appropriate to the physical environment (i.e., depth, hydrodynamics, vegetation structure), to decrease gear selectivity, increase gear effectiveness and ensure accuracy of data (Bagenal 1978). Three large channel areas were sampled using large fyke nets (3' diameter hoops, 1/8" mesh) with four- to seven-hour soak times. Three small channel areas were sampled using smaller fyke nets (2' diameter hoops, 1/4" mesh). Fyke nets of both sizes were deployed from a canoe and held in place with 10-pound mushroom anchors (Murphy and Willis 1996) and/or rebar. Wire mesh minnow pot traps (9" diameter x 18" long, 1/8" mesh) were deployed at various sites where juvenile fishes or small species were suspected (Bagenal 1978), in conjunction with fyke nets. Minnow pots also had four to seven hour soak times. Seines (15' x 4', 1/4" ace nylon mesh) were used in three channel areas where there was adequate shore space to land the seine (Bagenal 1978). A throw trap was custom made for a previous Great Swamp fish species-habitat association study (Cotroneo and Yozzo 2008) and is described in Cotroneo and Yozzo (2010). This throw trap was used in depths up to 4 feet. Whenever possible, passive sampling methods (fyke nets and minnow pots) were deployed while active sampling methods (seining and throw trapping) or SAV sampling were being performed to optimize time spent in the field.

Nekton collected were processed in the field and released as soon as possible. Only fishes and crayfishes were included in data analysis. The number of individuals, species, total length (TL), and life stage of the individual (e.g., juvenile, etc.), along with any comments (e.g., external parasites, etc.), were recorded at each sampling location. Quantitative density estimates were determined from throw trap samples and expressed as number of individuals/m^2. Catch per Unit Effort (CPUE) for fyke net and minnow pot collections were expressed as number of individuals per hour of soak time. Incidental collections, such as turtles, insect larvae, and frogs were not enumerated or measured.

When possible, dissolved oxygen, temperature and conductivity were monitored using a YSI 56 model multi-parameter water quality meter. Due to functional issues with the YSI 56, some dissolved oxygen readings were not possible, and early pH readings were disregarded due to readings outside the normal pH scale. An Oakton pH pen was used to monitor pH afterwards.

Differences in species richness and abundance of nekton between vegetation types were tested using a repeated-measures analysis of variance (ANOVA) with vegetation type as the between-subjects factor and sampling event as the within-subjects factor. Abundance data were normalized, when necessary, using a log(y+1) transformation (Sokal and Rohlf 1981). Statistical analyses were performed using the data analysis package in Microsoft's Excel 2016.

RESULTS

SAV

Twelve SAV sites were sampled repetitively over 13 sampling dates, for a total of 58 SAV sampling events. A total of six SAV species were found among 771 individual SAV samples collected: *Ceratophyllum demersum*, *Potamogeton crispus*, *Potamogeton. pusillus*, *Potamogeton illinoensis*, *Elodea Canadensis* and *Lemna minor*. Emergent species found within samples included broadfruit bur-reed (*Sparganium eurycarpum*), marshpepper knotweed (*Polygonum hydropiper*), arrowleaf tearthumb (*Polygonum sagittatum*), and other species of *Polygonum*.

In SAV sample dates one through four, *P. crispus* was the dominant species in 11 of the 14 samples, with *P. illinoensis* dominating one sample event during event four, and *P. pusillus* dominating the same site during each of events three and four (Figure 3). During SAV sampling dates five through eight, eight sampling events were dominated by *C. demersum*, six by *P. illinoensis* and two by *P. pusillus* (Figure 3). Sample dates nine through twelve sampling events were evenly split, with eight sites being dominated by *P. illinoensis*, and eight by *E. canadensis* (Figure 3). The thirteenth SAV sample date included all twelve sites previously sampled. A total of six sampling events were dominated by *C. demersum*, three by *P. illinoensis*, two by *E. canadensis*, and one site was co-dominated by *P. illinoensis* and *C. demersum* (Figure 3). Table 3 shows a summary of dominance data, including dominant species and total percent cover for the sampling events, which ranged 18.8% to 93.5%, with a mean of 47.8%. While present in many samples, neither *L. minor* nor any emergent species dominated any sampling events.

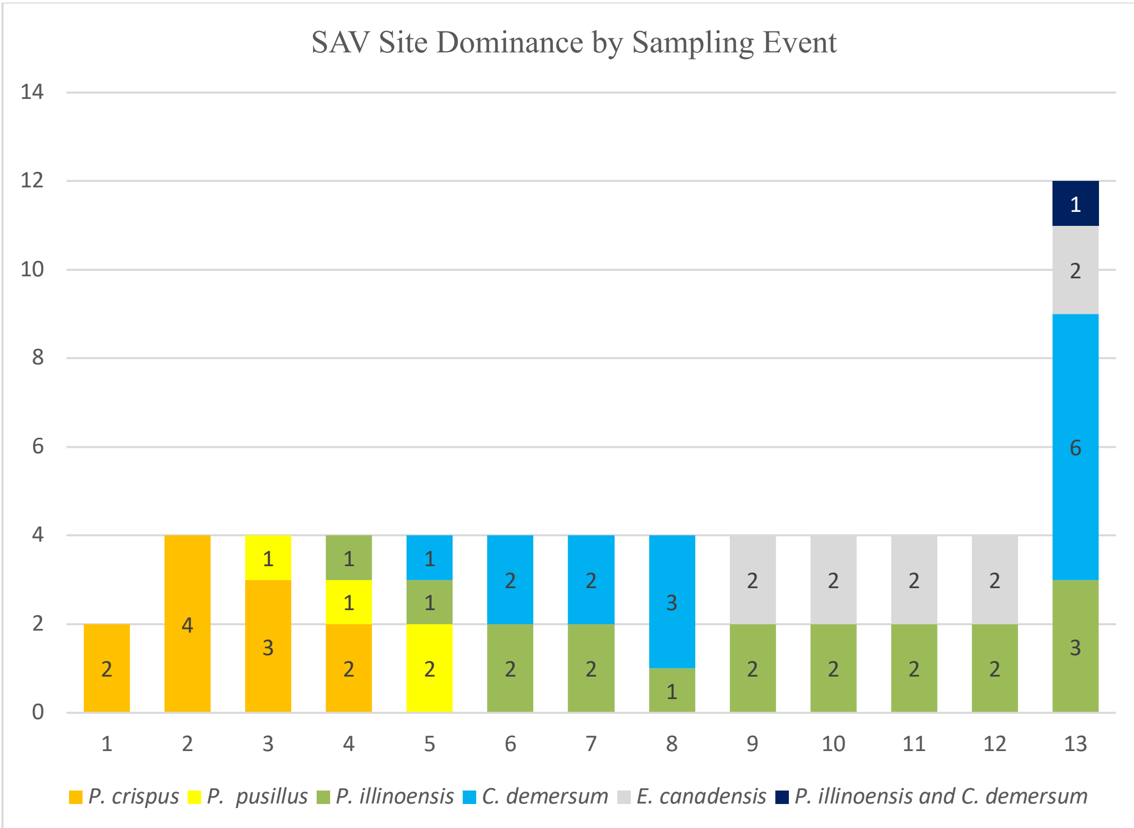

Figure 3. SAV site dominance by sampling event.

The eleven samples dominated by *P. crispus* ranged 20.0% to 66.1% cover, with a mean of 37.7% (Table 3). The four samples dominated by *P. pusillus* ranged 22.5% to 32.3% cover, with a mean of 27.0% (Table 3). The eighteen samples dominated by *P. illinoensis* ranged 24.6% to 84.1% cover, with a mean of 50.4% (Table 3). The fourteen samples dominated by *C. demersum* ranged 18.8% to 49.3% cover, with a mean of 34.1% (Table 3). The ten samples dominated by *E. canadensis* ranged 60.7% to 93.5% cover, with a mean of 81.3% (Table 3). The one sample co-dominated by *P. illinoensis* and *C. demersum* had 51.3% cover (Table 3).

The Shannon-Wiener diversity index was calculated for SAV and compiled emergent species, using the total number of quadrats each species was present in throughout the duration of the study. The result was *H'*= 1.85, approximately in the middle of the possible 0 to 4 range this calculation allows.

Pielou's Evenness index was calculated from the Shannon-Wiener diversity index results, yielding the outcome *E*=0.96. This falls very high within the possible 0 to 1 range this calculation allows.

Table 3. Percent cover and dominant species by sampling event and site.

Site ID	SAV Sampling Event												
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
A1		66.1	43.9	24.6									51.3
A2	24.4	35.3	42.8	29.5									23.9
A3	26.6	22.1	25.8	27.3									21.9
A4		50.7	53.6	20.0									43.7
B1					22.5	24.4	27.6	32.1					18.8
B2					34.9	37.5	32.7	33.4					37.8
B3					53.5	43.8	56.2	47.8					49.1
B4					32.3	48.4	44.9	31.9					49.3
C1									82.7	93.5	93.5	81.2	85.2
C2									45.5	59.7	70.2	32.3	25.5
C3									76.0	92.7	69.7	60.7	78.2
C4									67.9	84.1	80.0	46.7	54.3

Red cells= not sampled due to inclement weather.
Blank cells= not sampled.
Orange cells= dominated by *P. crispus*.
Yellow cells= dominated by *P. pusillus*.
Blue cells= dominated by *C. demersum*.
Green cells= dominated by *P. illinoensis*.
White cells dominated by *E. canadensis*.
Gray cell= co-dominated by *P. illinoensis* and *C. demersum*.

Nekton

A total of 1,015 nekton, comprised of sixteen species, were collected throughout six nekton sampling dates (Table 4, Figure 4). Bluegill was the most abundant finfish species (N=582; 64.45% of total finfish collection). The species with the second highest abundance was golden shiner (*Notemigonus crysoleucas*) (N=66; 7.31% of total finfish collection). The third most abundant finfish species was pumpkinseed (*Lepomis gibbosus*) (N=60; 6.64% of total finfish collection). The least abundant species collected were smallmouth bass (*Micropterus dolomieu*) (N=3; 0.33% of total collection), rock bass (*Ambloplites rupestris*) (N=2; 0.22% of total collection), and common carp (*Cyprinus carpio*) (N=1; 0.11% of total finfish collection). The common carp accounts for the 705 mm collection in the throw trap and is considered an outlier. Without this outlier, the maximum length of nekton collected in the throw trap was 180 mm, reducing the mean to 61.0 mm. The most abundant crayfish species was rusty crayfish (*Faxonius rusticus*) (N=62; 55.36% of total crayfish collection) (Table 5).

A total of 24 sites were sampled for nekton; six *P. crispus* dominated sites, in addition to a single site dominated by *P. pusillus*, eight sites dominated by *P. illinoensis*, five sites dominated by *C. demersum*, and four sites dominated by *E. canadensis*.

A total of eight nekton species were collected in minnow pots; eleven nekton species in fyke nets; fifteen nekton species in the throw trap; and fourteen nekton species in the seine.

A total of 231 nekton were collected in *P. crispus* dominated samples, comprised of 11 species (Figure 6). A total of 13 nekton were collected in *P. pusillus* dominated samples, comprised of six species (Figure 6). A total of 263 nekton were collected in *P. illinoensis* dominated samples, comprised of 15 species (Figure 6). A total of 224 nekton were collected in *C. demersum* dominated samples, comprised of eleven species (Figure

6). A total of 284 nekton were collected in *E. canadensis* dominated samples, comprised of thirteen species (Figure 6).

Repeated measures ANOVAs revealed no statistically significant results for vegetation x nekton interactions for minnow pots (p=0.659), fyke nets (p=0.532) or the seine (p=0.783). However, the throw trap ANOVA data revealed a statistically significant result (p=0.039). This is to say that the throw trap collected a significantly higher diversity and abundance of nekton species within SAV stands, in comparison to other sampling methods.

There was no significant difference found in fish sizes between the dominant SAV species (p=0.1672). For this analysis, the outlier common carp of 705-mm was removed, along with the data for *P. pusillus*, due to small sample size.

Table 4. Fish Collection by dominant SAV type and sampling gear type.

	P. crispus				P. pusillus				P. illinoensis				C. demersum				E. canadensis					
Finfish Species	MP	Fyke	TT	Seine	MP	Fyke	TT	Seine	MP	Fyke	TT	Seine	MP	Fyke	TT	Seine	MP	Fyke	TT	Seine	Species Total	% of Total
Bluegill	7	54	51	38		4		Never sampled. Too deep.	12	99	36	35	6	69	19	72	7	32	26	15	582	64.45%
Golden shiner	1	1		3							2							31	2	26	66	7.31%
Pumpkinseed		6	1		1	2				13		11	2	16	1	7					60	6.64%
Yellow bullhead			4	1						1	3					2			32	7	50	5.54%
Yellow perch	1		1	11		1				1	2					17			2		36	3.99%
Redbreast sunfish		6							3	9	1	1				2	3	3	3	3	34	3.77%
Redfin pickerel		16	2	5								5								6	34	3.77%
Tessellated darter							3				5	3			1			1	1	2	16	1.77%
Largemouth bass											3	4			1	1		1		2	12	1.33%
Brown bullhead			1	2								1			2		1				7	0.78%
Smallmouth bass											3										3	0.33%
Rock bass									1											1	2	0.22%
Common carp															1						1	0.11%
Totals by SAV & gear type	9	83	60	60	1	7	3	0	16	123	55	60	8	85	25	101	11	68	66	62	903	100.0%

MP = Minnow Pot
TT = Throw Trap

Table 5. Crayfish Collection by dominant SAV type and sampling gear type.

	P. crispus				P. pusillus				P. illinoensis				C. demersum				E. canadensis					
Crayfish Species	MP	Fyke	TT	Seine	MP	Fyke	TT	Seine	MP	Fyke	TT	Seine	MP	Fyke	TT	Seine	MP	Fyke	TT	Seine	Species Total	% of Total
Rusty crayfish		2	3					NS	1	2	3				1	3			26	21	62	55.36%
Ringed crayfish			2	1			1				1	1			1				21		28	25.00%
White river crayfish		2	7	2			1					1							6	3	22	19.64%
Totals by SAV & gear type	0	4	12	3	0	0	2	0	1	2	4	2	0	0	2	3	0	0	53	24	112	100.0%

MP = Minnow Pot
TT = Throw Trap

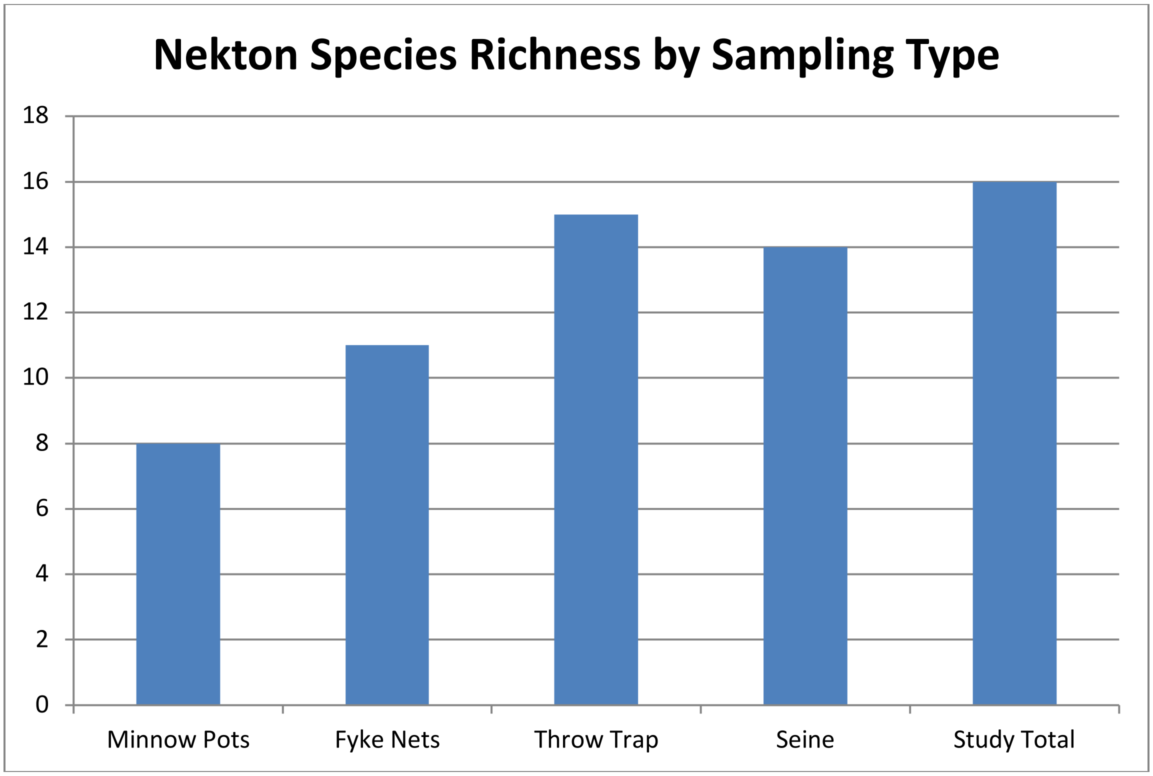

Figure 4. Nekton species richness by sampling type.

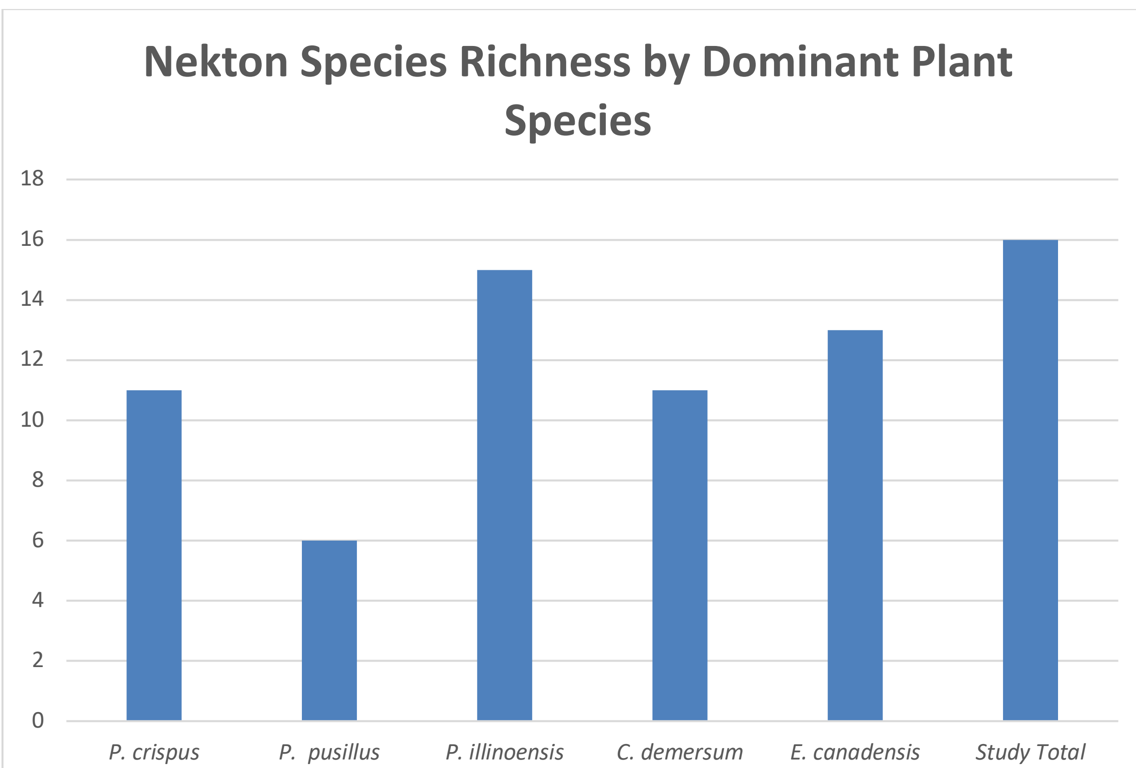

Figure 5. Nekton species richness by dominant plant species.

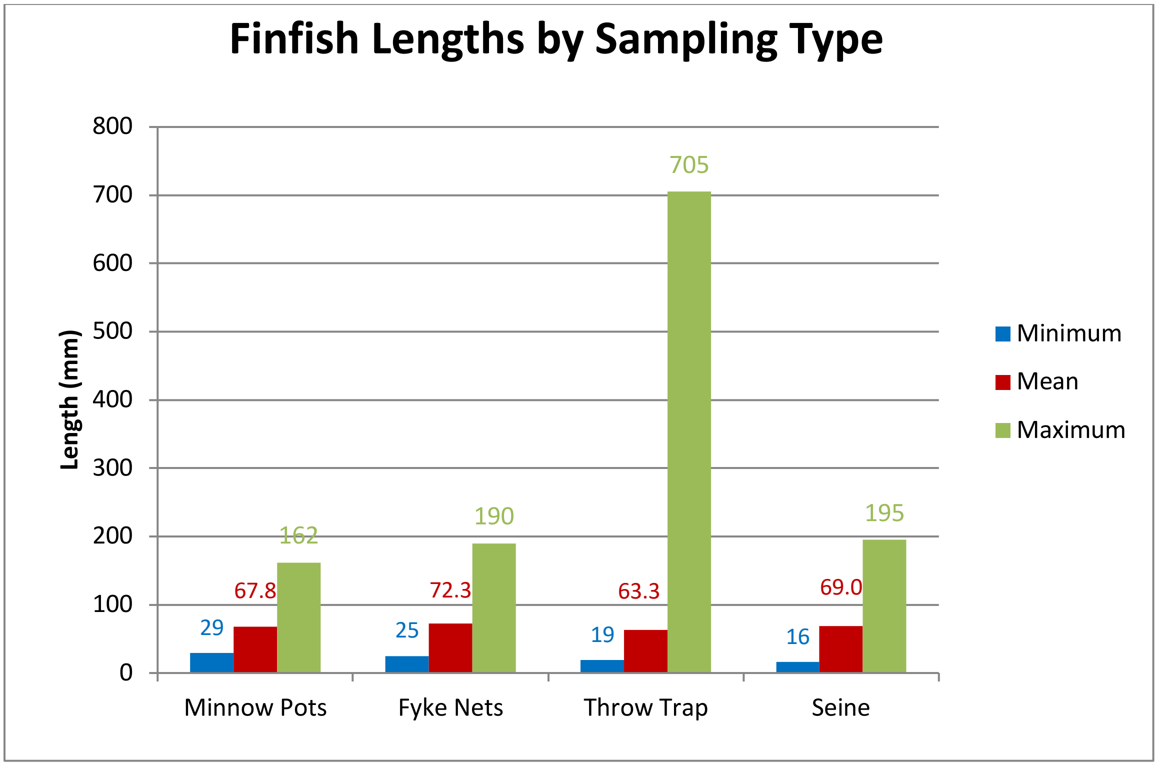

Figure 6. Finfish Lengths by Sampling Gear Type.

Water Quality

Due to equipment malfunction, pH was recorded for 40 of the 58 SAV sampling events, in addition to 20 of 24 minnow pot samples, 30 of 36 fyke net samples, 60 of 72 throw trap samples, and all eighteen seine samples. For samples obtained, pH ranged 6.5 to 9.1. Temperatures for the entire study ranged 9.13℃ to 29.3℃. Due to equipment malfunction, dissolved oxygen was recorded for 20 of 24 minnow pot samples, 30 of 36 fyke net samples, 36 out of 72 throw trap samples, and twelve of eighteen seine samples. For the samples obtained, dissolved oxygen ranged 4.32 to 13.35 mg/L. Conductivity for the entire study ranged 307 to 541 µs/cm.

Parasitism

A total of four golden shiners collected during this study were noted to have neascus, also known as black spot disease. The black spots on the scales of the infected fishes are the metacercaria (encysted stage) of a digenetic trematode (Williams 1967, Smith 1985).

DISCUSSION

SAV

A total of five SAV species dominated all the samples in this study. No other SAV species were observed, but some emergent vegetation was observed within the sample transects. However, none of these were dominant. In some cases, several SAV species were observed in large abundances within the same samples. This was especially true for *Potamogeton illinoensis* and *Ceratophyllum demersum*, which co-dominated one site during the thirteenth sampling event.

Potamogeton crispus – Curly leaf pondweed

Potamogeton crispus is a rooted submersed macrophyte that grows in freshwater lakes, ponds, rivers and streams (Catling and Dobson 1985), with a root-rhizome system characteristic of most Potamogetons (Bergstrom et al. 2006). It grows entirely underwater, except for the flower that rises above the water surface (WSDE 2001) and leaves that reach the surface but do not emerge or float (Borman et al. 1997). *Potamogeton crispus* differs from most other SAV species in that it has a three-stage life cycle, with turions germinating in the fall and the appearance of winter form foliage in

September, which remains intact through the winter (Borman et al. 1997). Turions are a type of bud capable of sprouting into a new plant. Turions typically break off of an existing plant before settling to the sediment. In spring the reddish-brown foliage appears, followed by flowering from April to June. Turions are produced in July, which is followed by a die-off of the spring foliage. The plants then remain dormant until the winter form foliage returns in the fall (Nichols and Shaw 1986; Hurley 1990; Borman et al. 1997). The winter form foliage is narrow, with a blue-green color, differing from the wide, reddish-brown color of the spring-summer form foliage (Hurley 1990). *Potamogeton crispus* is known to provide habitat for fishes during winter and spring months, when most other SAV species are reduced to rhizomes or turions. The mid-summer die-off creates a sudden loss of habitat and release of nutrients into the water column, which can increase turbidity and cause algal blooms, which are known to reduce DO when decaying (Borman et al. 1997). *Potamogeton crispus* is an introduced species in New York, with its origins in Europe and Asia (USDA 2017).

Potamogeton crispus was dominant in all samples during the first two sampling dates, nearing a monoculture. *C. demersum* and *P. crispus L. minor* were the only other species present during the first sampling date, and only in two samples each. During the second sampling date, *C. demersum*, *L. minor*, *P. pusillus* and *P. illinoensis* were present at one of the sites, and *C. demersum* and *P. illinoensis* were present at another site. By the third sampling date, which took place in mid-June, other species were becoming far more abundant, with one site being dominated by *P. pusillus*. *Potamogeton crispus* flowers were abundant during the second sampling date, with flowers remaining only in cooler, shaded areas during the third sampling date, which is consistent with the species description above. During the fourth sampling date only two of the four sites were dominated by *P. crispus*, and the percent cover at those sites had reduced considerably from the previous two sampling dates (Table 3). After the fourth sampling date, *P. crispus* did not dominate any samples, and quickly reduced in abundance, which is consistent with the species description above. *Potamogeton crispus* was not observed in any samples or even incidentally in sample dates five, six, and eight. *Potamogeton crispus* was observed in only two samples in sample date seven, and one sample in sample date nine, and accounted for only two percent cover in each of those samples. During sample events 10, 11, 12 and 13, *P. crispus* was observed in several samples, with percent cover ranging from 1 to 30 percent. The 30 percent sample was considered an outlier, with the majority of samples during these sample dates ranging one to two percent.

The observations of *P. crispus* in this study are consistent with the *P. crispus* life cycle described above. The initially high abundance and dominance of *P. crispus* was to be expected, as was the reduction and virtual disappearance of the species during the warmer summer months, and reappearance, but low abundance, of winter form leaves in late sample dates.

Potamogeton pusillus – Small pondweed

Similar to *P. crispus*, *P. pusillus* has a root-rhizome system characteristic of most pondweeds (Bergstrom et al. 2006), and is a submersed aquatic vegetation found in soft, fertile mud substrates in quiet to gently flowing waters (Hurley 1990) up to three meters deep and can tolerate turbid conditions (Borman et al. 1997). Flowering and seed development typically occur in late summer (Borman et al. 1997; Bergstrom et al. 2006). In autumn the entire plant senesces into a mass of turions, which act as a means of propagation for the following year (Hurley 1990; Borman et al. 1997). It is known to be a source of food and cover for fishes (Borman et al. 1997). *Potamogeton pusillus* is native to New York, and present throughout most of North America (USDA 2017).

Potamogeton pusillus was dominant in only four samples, all of which occurred during sample dates three, four, and five (Table 3). These sample dates occurred between 3 June and 1 July. *P. pusillus* was present in samples during sample dates two through nine, and sample date eleven.

The observations of *P. pusillus* in this study are consistent with the *P. pusillus* life cycle described above. The late spring abundance and dominance of *P. pusillus* was to be expected, as was the reduction and virtual disappearance of the species late in the summer months. *Potamogeton pusillus* was observed mostly in deeper, cooler, slower flowing areas, both within samples and in incidental observations throughout the study. This is also consistent with the species description above.

Potamogeton illinoensis – Illinois pondweed

Potamogeton illinoensis is a partially submersed perennial aquatic plant, with a root-rhizome system, with both submersed and floating foliage. From June through August, flowers protrude four to twelve centimeters above the water surface (Borman et al. 1997; Fertig and Heidel 2000). *Potamogeton illinoensis* is found in slow moving streams and ditches, shallow water of ponds and lakes (Weldy et al. 2017) with moderate to high pH. *Potamogeton illinoensis* is known to decline as turbidity increases but can be found in clear water up to 3 meters in depth (Borman et al. 1997). *Potamogeton illinoensis* overwinters through winter-hardy rhizomes (Borman et al. 1997). *Potamogeton illinoensis* is native to New York and found throughout most of North America (USDA 2017).

Potamogeton illinoensis was dominant in 18 samples, from sampling events four through thirteen (Table 3) and was co-dominant with *C. demersum* in a single sample during sampling event 13. *Potamogeton illinoensis* was present in samples from sampling event one through thirteen. Beginning in sampling event ten, as water levels dropped far below normal due to drought conditions, what would normally be *P. illinoensis* floating foliage was observed out of the water on dry creek banks. The foliage and stems appeared slightly wilted, but maintained this condition through the final sampling event, while still lying on the dry creek bank. It is assumed that the root systems were accessing the water table to keep the plants alive.

The observations of *P. illinoensis* in this study are consistent with the *P. illinoensis* life cycle described above. The late spring abundance and continued dominance of *P. illinoensis* was to be expected. *Potamogeton illinoensis* was observed mostly in clear, shallow, slower flowing areas, both within samples and in incidental observations throughout the study. This is also consistent with the species description above.

Ceratophyllum demersum - Coontail

Ceratophyllum demersum is a submersed species with no true roots (Hurley 1990), but instead has long, trailing stems that often float freely within the water column. Sometimes modified leaves will loosely anchor a plant to the sediment. *Ceratophyllum demersum* is tolerant of shade, turbidity (Bergstrom et al. 2006), and low light, and will grow in water several meters in depth. Its lack of roots allows it to drift through different depth zones, carried by slow currents in quiet streams, lakes and ponds (Hurley 1990). *Ceratophyllum demersum* overwinters as an evergreen when the tips of existing plants break off and fall to the substrate, continuing photosynthesis at a reduced rate, even beneath ice. In spring *C. demersum* resumes vigorous growth resumes (Hurley 1990; Borman et al. 1997). New plants are formed primarily through fragmentation of existing plants, with seeds rarely developing (Bergstrom et al. 2006). *Ceratophyllum demersum* is often found floating beneath or among other SAV species (Hurley 1990). *Ceratophyllum demersum* is known to be good habitat for fishes and invertebrates, due to the dense mats it creates (Hurley 1990; Borman et al. 1997; Bergstrom et al. 2006). *Ceratophyllum demersum* is native to New York and found throughout most of North America (USDA 2017).

Ceratophyllum demersum was dominant in 14 samples, from sampling events four through thirteen (Table 3) and was co-dominant with *P. illinoensis* in a single sample during sampling event 13. *Ceratophyllum demersum* was present in samples from sampling event one through thirteen.

The observations of *C. demersum* in this study are mostly consistent with the *C. demersum* life cycle described above. The early spring presence and later dominance of

C. demersum was to be expected due to its evergreen overwintering; however, it was expected that *C. demersum* would dominate several samples during sampling events one through four due to this evergreen overwintering ability, but this did not occur until sampling event five. *Ceratophyllum dermsum* was observed in various depths, turbidity levels, and temperatures, both within samples and in incidental observations throughout the study. This is consistent with the species description above.

Elodea canadensis – Canadian waterweed

Elodea canadensis is a submersed species with slender branching stems and a weak, threadlike root system (Bergstrom et al. 2006). Stems can sometimes be found broken free and floating (Hurley 1990). Leaves grow in whorls of three and are denser at the stem tips than at the base. *Elodea canadensis* is tolerant of shade, and low light, and will grow in a depth range of mere centimeters to several meters. Its lack of roots allows it to drift through different depth zones (Borman et al. 1997). New plants are formed primarily through fragmentation and branching of existing plants, as male plants are rare, reducing likelihood of sexual reproduction (Hurley 1990). Individual plants are known to survive through winter, even in ice, and begin growing again in spring. *Elodea canadensis* is known to be good habitat for fishes and invertebrates, although in some cases grows so densely that it obstructs fish movements. This species is often found in eutrophic lakes and slow moving streams (Hurley 1990; Borman et al. 1997). *Elodea canadensis* is native to New York and found throughout most of North America (USDA 2017).

Elodea canadensis was dominant in ten samples, from sampling events nine through thirteen (Table 3). *Elodea canadensis* was present in samples from sampling event three through thirteen.

The observations of *E. canadensis* in this study are consistent with the *E. canadensis* life cycle described above. *Elodea canadensis* was observed in various depths, turbidity and light levels, both within samples and in incidental observations throughout the study. This is consistent with the species description above.

Lemna minor – Common duckweed

Lemna minor is a floating species but is included herein due to its unexpected high abundance throughout the study. *Lemna minor* has one free floating root and no stems, with three floating leaves known as fronds. The fronds obtain nutrients directly from the water along with the single root. Due to its floating growth form, *L. minor* will drift with the current or wind, but is not dependent on depth, sediment type or turbidity. However, the species requires sufficient nutrients to thrive, and is often associated with eutrophic waters. *Lemna minor* is often found in quiet waters of bays and ponds, sometimes covering the surface completely (Borman et al. 1997). This can sometimes shade out SAV species below. Reproduction is mainly through vegetative off-shoots from the floating leaves, with flowering being less common (Hurley 1990). This species produces turions in the autumn that overwinter in the sediment and float to the surface as water temperatures rise in spring. As temperatures decline during autumn leaf fronds produce turions that lose buoyancy and sink to the sediment (Borman et al. 1997). *L.*

minor is native to New York and found throughout most of North America (USDA 2017).

Lemna minor was not dominant in any samples during this study (Table 3). However, *L. minor* was present in samples from sampling event one through thirteen. *Lemna minor* abundance diminished after a heavy rainfall prior to the eighth sampling date, as *L. minor* individuals were presumably washed downstream with the increased flow rate. The atypical low flow rates throughout the majority of this study allowed *L. minor* to thrive in the system, where it had not been observed anecdotally in over ten years of routine observations in the system.

The observations of *L. minor* in this study are consistent with the *L. minor* life cycle described above.

Other species

No other SAV or floating species were observed; however, several emergent species were present in samples. Percent cover was estimated for these species, but none were dominant. Emergent species present included marshpepper knotweed and broadfruit bur-reed**.** These species were found in very shallow water, near the shore.

Nekton

A total of 1,015 nekton were collected, comprised of sixteen species. In a 2007 study also performed in the East Branch Croton River, but also focusing on emergent and unvegetated open water areas, a total of 22 species were collected. However, that included one pumpkinseed-redbreast sunfish hybrid, and one centrarchid that was too small to be identified to species. (Cotroneo and Yozzo 2008). A total of fourteen species were collected in both the 2007 study and this study.

Another study focusing on the Great Swamp's north and south flows collected a total of 23 species, sampling in both the East Branch Croton River and the Ten Mile River (van Holt et al 2006). It is to be expected that these other studies collect more species, as they had broader spectrums of sampling locations. This study sampled only within SAV beds, limiting the habitat type, and had fewer sampling locations in comparison the other studies.

Bluegill were by far the most abundant nekton species collected in this study, with a total of 582 for the study, 57.34% of the total collection (Table 4). They were collected in all sampling gear types, in all dominant SAV types except *P. pusillus*, which is likely due to a small sample size as there was only four SAV samples dominated by *P. pusillus*, and the areas where *P. pusillus* was dominant were too deep to seine safely. Bluegill are known to prefer SAV as habitat (Lee et al*.* 1980; Smith 1985; Page and Burr 1991). This is consistent with the findings of this study, and Cotroneo and Yozzo (2008), where bluegill were the dominant species collected within SAV stands.

Golden shiners were the second most abundant nekton species, with a total of 66 for the study, 6.50% of the total collection (Table 4). Golden shiners are known to prefer vegetated waters (Smith 1985; Page and Burr 1991). This is consistent with the findings of this study and a previous Great Swamp studies (Cotroneo and Yozzo 2008).

Rusty crayfish were the third most abundant nekton species, with a total of 62 collected, 6.11% of the total collection (Table 4). In a previous study, rusty crayfish were associated with non-vegetated waters (Cotroneo and Yozzo 2008). That is not consistent with the findings of this study. As rusty crayfish are a known invasive species, it is very likely that they are increasing in abundance within the system and occupying additional niches (NYSDEC 2014). It should be noted that after the completion of the study the Latin name of rusty crayfish changed from *Orconectes rusticus* to *Faxonius rusticus*, as all the non-cave dwelling species of crayfishes were removed from the *Orconectes* genus and into the newly created *Faxonius* genus (Crandall and De Grave 2017).

In addition to the three species described above, additional species collected during this study which are known to have an affinity for vegetated aquatic habitats included: pumpkinseed (*Lepomis gibbosus*), yellow bullhead catfish (*Ameiurus natalis*), yellow perch (*Perca flavescens*), redbreast sunfish (*Lepomis auritis*), redfin pickerel (*Esox americanus*), ringed crayfish (*Orconectes neglectus*), largemouth bass (*Salmoides micropterus*), rock bass (*Ambloplites rupestris*), and common carp (*Cyprinus carpio*) (Cotroneo and Yozzo 2008; Page and Burr 1991; Smith 1985). The three species collected during this study which are known to not have an affinity for vegetated aquatic habitats included: White river crayfish (*Procambarus acutus*), tessellated darter (*Etheostoma olmstedi*), and smallmouth bass (*Micropterus dolomieu*) (Cotroneo and Yozzo 2008; Page and Burr 1991; Smith 1985).

Incidental collections in fish sampling gear included painted turtles (*Chrysemys picta*), musk turtles (*Sternotherus odoratus*), various insects including dragon and damsel fly larvae, and unidentified freshwater mussels.

The statistically significant results for the throw trap data may indicate that this sampling method is more effective at collecting nekton within SAV than the other sampling methods. The passive methods rely on nekton entering the trap. During this study some nekton, particularly predators, were observed to avoid entering the fyke nets. On several occasions, fishes were observed swimming into the wing-wall, as the net is designed, but as the fishes neared the opening of the containment area, they quickly swam in the opposite direction, avoiding collection. Despite the chain on the bottom of the seine weighing it down and bending SAV to the sediment, it is likely that nekton utilized the abundance of SAV as refuge and avoided collection as the seine passed over the SAV they were hidden beneath. The throw trap gets cleared entirely of SAV, thus it is possible to sort through the removed SAV to find the smallest of nekton. It was unexpected to collect a 705 mm common carp in the throw trap but is evidence of the method's effectiveness in this habitat.

There was no selection of any particular SAV species by different sized fishes. While small fishes use the cover of SAV for refuge from all predators, even larger fishes have predators in the Great Swamp, such as mink, river otters, and piscivorous birds. Larger fishes may also seek prey within the SAV beds.

Parasitism

Black spot disease is a parasite that is thought to not harm the fish, simply using them as an intermediate host (Smith 1985), but affects fish eating birds, such as kingfishers, great blue herons and green herons, all of which are present in the Great Swamp (Siemann 1999). The adult parasitic fluke worm forms eggs in the intestines of the birds and are released into the water in the host's fecal matter. Upon hatching the free-swimming larvae penetrate snails to further develop, eventually leaving the snail to burrow into the flesh of a fish, forming a cyst. The fish host surrounds the cyst with black pigment, giving the appearance and name to black spot disease. The fish is then consumed by a piscivorous bird, repeating the cycle (Williams 1967)

During a previous study performed in the Great Swamp (Cotroneo and Yozzo 2008) a large portion of redfin pickerels and golden shiners collected were noted to have black spot disease; some of these fishes were almost completely covered with the spots. During this study a small percentage of the golden shiners collected showed evidence of black spot disease, and no redfin pickerels collected showed any evidence of the disease.

CONCLUSIONS

This study is baseline data for SAV and nekton community associations in a small, freshwater stream habitat. The following are conclusions drawn from the data:

- The five dominant SAV species in the Great Swamp at the time of this study were *Potamogeton crispus*, *P. pusillus*, *P. illinoensis*, *Ceratophyllum demersum*, and *Elodea canadensis*.
- Further research into sediment conditions and stream geomorphology may reveal why certain SAV species are dominant in various reaches of the system, but not areas in between these stands.
- The five most dominant nekton species collected within the Great Swamp's SAV at the time of this study were *Lepomis macrochirus*, *Notemigonus crysoleucas*, *Faxonius rusticus, L. gibbosus* and *Ameiurus natalis*.
- Additional nekton sampling methods should be utilized in future studies; electroshocking would be a good choice as this method is not impeded by the

presence of moderately dense SAV. High SAV density would likely impede the collection of stunned nekton.

ACKNOWLEDGMENTS

I would like to thank the Hudson River Foundation and the Tibor T. Polgar Committee for providing funding. My wife, Colleen Sheehy, and daughters, Sophia and Eileen Cotroneo, for supporting my efforts. Sophia put up with a 10-hour day of field work and assisted with seine hauls and throw trap sampling. Thanks to the Green Chimneys School staff for allowing access to the East Branch Croton River. Thanks to Dr. Ryan Taylor at SUNY Purchase who lent water quality testing equipment. Thanks to Dr. Dave Osgood for lending the fyke nets. Thanks to Dave Brizzolara for GIS assistance. Special thanks for Dr. John Waldman for excellent advice on the study and Dr. PoKay Ma for insightful advice on the report. Thanks to Dr. Dave Yozzo for field assistance and additional excellent advice on the study.

REFERENCES

Alderson, C., and L. Rosman. 2012. River Herring: Assessment of Fish Passage Opportunities in Lower Hudson River Tributaries (2009-2012). Presentation to NY Region River Herring Workshop. Hudson River Foundation. October 22, 2012.

Bagenal, T. (Ed.) 1978. Methods for Assessment of Fish Production in Fresh Waters. 3rd Ed. Oxford: Blackwell Scientific Publications, Ltd. 365 pp.

Bednarek, A.T. 2001. Undamming rivers: a review of the ecological impacts of dam removal. Environmental Management 27:803-814.

Bergstrom, P.W., R.F. Murphy, M.D. Naylor, R.C. Davis and J.T. Reel. 2006. Underwater Grasses in Chesapeake Bay and Mid-Atlantic Coastal Waters: A Guide to Identifying Submerged Aquatic Vegetation. Maryland Sea Grant College. UM-SG-PI-2006-01. College Park, MD. 76 pp.

Borman, S., R. Korth and J. Temte. 1997. Through the looking glass: A field guide to aquatic plants. The Wisconsin Lakes Partnership. Stevens Point, Wisconsin. 248 pp.

Catling, P.M. and I. Dobson. 1985. The biology of Canadian weeds. 69. *Potamogeton crispus* L. Canadian Journal of Plant Science 65:655-668.

Cotroneo, C. and D.J. Yozzo. 2008. Fish Species-Habitat Associations in New York's Great Swamp. Section VIII: 35 pp. In C.A. McGlynn & J.R. Waldman (eds.), Final Reports of the Tibor T. Polgar Fellowship Program, 2007. Hudson River Foundation.

Cotroneo, C. and D.J. Yozzo. 2010. W-Fold throw trap: a folding, transportable 1-m^2 throw trap for use in densely vegetated aquatic habitats. Journal of Freshwater Ecology. 25: 73-78.

Crandall, K.A. and S. De Grave. 2017. An updated classification of the freshwater crayfishes (Decapoda: Astacidea) of the world, with a complete species list. Journal of Crustacean Biology 37:615-653.

Fertig, W., and B. Heidel. 2000. State Species Abstract: *Potamogeton illinoensis*. Wyoming Natural Diversity Database.

Friends of the Great Swamp (FROGS). 2016. www.frogs-ny.org Web site accessed 18 March 2016.

Hudson River Estuary Program (HREP). 2017. 2016 Annual Report. New York State Department of Environmental Conservation, Albany, NY.

Hurley, L.M. 1990. Field Guide to the Submerged Aquatic Vegetation of Chesapeake Bay. U.S. Fish and Wildlife Service. Annapolis, MD. 51 pp.

Lee, D.S., C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr. 1980. Atlas of North American Freshwater Fishes. North Carolina State Museum of Natural History, Raleigh.

Mitsch, W.J. and J.G. Gosselink. 1993. Wetlands, 2nd Ed. New York: Van Nostrand-Reinhold. 722 pp.

Morin, P.J. 1999. Community Ecology. Blackwell Science, Inc. Malden, MA.

Murphy, B.R. and D.W. Willis, (Eds.) 1996. Fisheries Techniques. 2nd Ed. Bethesda. 732 pp.

New York State Department of Environmental Conservation (NYSDEC). 2014. http://www.dec.ny.gov/docs/lands_forests_pdf/isprohibitedanimals.pdf Accessed 20 January 2017.

Nichols, S.A., and B.H. Shaw. 1986. Ecological life histories of the three aquatic nuisance plants, *Myriophyllum spicatum*, *Potamogeton crispus*, and *Elodea canadensis*. Hydrobiologia 131:3-21.

Page, L.M. and B.M. Burr. 1991. A Field Guide to Freshwater Fishes. Houghton Mifflin. Boston.

Siemann, D. 1999. The Great Swamp: A Watershed Conservation Strategy. The Nature Conservancy, Lower Hudson Chapter. 68pp.

Smith, C.L. 1985. The Inland Fishes of New York State. Department of Environmental Conservation. Albany.

Sokal, R.R. and J. Rohlf. 1981. Biometry. 2nd Ed. W.H. Freeman and Co. New York.

U.S. Army Corps of Engineers (USACE) in cooperation with FEMA's National Dam Safety Program. 2005. National Inventory of Dams, Water Control Infrastructure. <http://www.tec.army.mil/nid> Accessed January 23rd, 2007.

USDA (United States Department of Agriculture). 2017. Plants Database. www.plants.usda.gov Accessed 20 January 2017.

van Holt, T., D. Murphy, and L. Chapman. 2006. Local and landscape predictors of fish-assemblage characteristics in the Great Swamp, New York. Northeastern Naturalist 13: 353-374.

Washington State Department of Ecology (WSDE). 2001. An Aquatic Plant Identification Manual for Washington's Freshwater Plants. Publication 01-10-032. Washington State Department of Ecology, Olympia WA.

Weldy, T., D. Werier, and A. Nelson. 2017 New York Flora Atlas. http://newyork.plantatlas.usf.edu/ Accessed 20 January 2017.

Williams, M.O. 1967. The Neascus (Posthodiplostomulum) stage of *Posthodiplostomutn nanum Dubois* and an experimental determination of part of the life cycle. Journal of Helminthology 41: 269-276.

Yochum, Steven E. 2018. Guidance for Stream Restoration. U.S. Department of Agriculture, Forest Service, National Stream & Aquatic Ecology Center, Technical Note TN-102.4. Fort Collins, CO.

Yozzo, D.J. 2008. Fish Restoration and Passage Projects in the Northeast and Mid-Atlantic U.S. Unpublished white paper, HDR, Inc., Pearl River, NY.