COMMUNITY STRUCTURE AND POPULATION CHARACTERISTICS OF FISHES IN A RECOVERING NEW YORK LAKE.

By

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Abstract:

Onondaga Lake has been polluted by industrial and municipal waste for more than a century. Adverse conditions include low levels of dissolved oxygen, reduced density of macrophytes, high levels of ammonia, frequent algal blooms, poor substrate quality and mercury contamination. Changes in the physical condition in the lake were observed after closure of a chloro-alkali facility in 1986. A detailed study was conducted from 1989 to 1993 to examine fish community structure, and to describe growth and survivorship patterns of fish populations.

The study revealed a fish community of 48 species, of which 8 to 10 species (17% - 21%) spawned in the lake. Planktivores accounted for the majority of the total catch in all years; littoral planktivore-insectivores and benthic piscivore-insectivores were the second most abundant trophic types. Smallmouth bass (Micropterus dolomieui) in Onondaga Lake grew at rates exceeding those in several other northeastern waters, but less than in nearby Oneida Lake. Bluegill (Lepomis macrochirus), white perch (Morone americana) and pumpkinseed sunfish (Lepomis gibbosus) had growth rates comparable to fish in other northeastern lakes. Smallmouth bass

showed little change in average length at age from 1990 to 1993. White perch showed little variation in growth from 1988 to 1990, and survivorship rates were similar to those in other northeastern lakes.

Recruitment of white perch, bluegill, pumpkinseed and gizzard shad was evident, as juveniles of these species dominated inshore seine catches. Banded killifish (Fundulus diaphanus) and brook silversides (Labidesthes sicculus) were also present in significant numbers. Smaller numbers of juvenile carp (Cyprinus carpio), largemouth bass (Micropterus salmoides), smallmouth bass, yellow perch, and white sucker (Catostomus commersoni) were collected.

Biomass estimates were obtained using the Schnabel technique based on trap-caught fish in 1991 and 1993. The system appears to be dominated by white perch and bluegill. The total standing crop of white perch 100 mm or larger was 323,069 (40,383 kg) in 1991 and 291,049 (36,381 kg) in 1993. Bluegill 100 mm or larger numbered 39,919 (3,623 kg) in 1991 and 40,106 (3,640 kg) in 1993. Density estimates of smallmouth bass were 0.08 per hectare in 1991 and 1993, far lower than the 8.7 smallmouth bass/ per hectare reported by Sanders and Coble (1981) in Clear Lake, Wisconsin.

Analysis of 10,003 marked fish from 1990 to 1993 indicated that relatively little movement occurred within the lake for inshore species such as sunfish, which tended to remain near their initial capture site. However, pelagic species such as white perch were recaptured throughout the lake. Tag returns by anglers from fish

Rivers indicate substantial movement between the lake and the Seneca River.

Suggested management techniques include modification of [illegible] to increase available spawning and nursery

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Population Densities and Biomass 75
A. Black basses 75
B. Sunfishes 80
C. Catfishes 81
D. White perch 82
E. Carp 82
F. Yellow perch 83
G. Bowfin 83

Movements of Lake Fishes 84

xvi. Future Fishery and Suggested Management Plans 86

xvii. Discussion and Conclusions 92
A. Natural Reproduction 92
B. Age and Growth 93
C. Population Density and Biomass 94

xviii. Literature Cited 96

xix. Appendix 103

xx. Vita 108

LIST OF TABLES

		Page
Table 1	Total catch of trap nets, Onondaga Lake, June 6 - September 7, 1989.	14
Table 2	Total catch of trap and gill nets, Onondaga Lake, May 23 - November 12, 1990.	15
Table 3	Total catch of trap and gill nets, Onondaga Lake, April 23 - November 27, 1991.	16
Table 4	Total catch of trap and gill nets, Onondaga Lake, June 3 - October 15, 1993.	17
Table 5	Total catch of gill nets (50 hours) set in water 2 - 10 m, Onondaga Lake, October 1- 15, 1993.	27
Table 6	Levels of natural reproduction in Onondaga Lake, 1991 - 1993, based on catches in shoreline seine hauls of fish less than 100 mm.	33
Table 7	Species composition of juvenile fish captured in seine samples from Onondaga Lake, 1991	34
Table 8	Species composition of juvenile fish captured in seine samples from Onondaga Lake, 1992.	
Table 9	Species composition of juvenile fish captured in seine samples from Onondaga Lake, 1993.	
Table 10	Monthly Shannon Weiner diversity index of juvenile fish captured in seine hauls, Onondaga Lake, June - August, 1991.	40
Table 11	Monthly Shannon Weiner diversity index of juvenile fish captured in seine hauls, Onondaga Lake, June, August and November, 1992.	42

Table 12 Monthly Shannon Weiner diversity index of juvenile fish captured in seine hauls, Onondaga Lake, June - August, 1993. 44

Table 13 Mean air temperatures, recorded at the U.S Weather Bureau Station at Hancock Field, June, July and August, 1991 - 1993. 45

Table 14 Observed mean length (mm) at age for smallmouth bass from selected waters in the northeastern United States. 48

Table 15 Back-calculated lengths of smallmouth bass, walleye, bluegill, pumpkinseed and white perch captured in trap and gill nets, Onondaga Lake, 1992. 50

Table 16 Absolute growth table for smallmouth bass, bluegill, pumpkinseed and walleye captured in trap and gill nets, Onondaga Lake, 1992. 51

Table 17 Mortality and survivorship rates of adult fish captured in trap and gill nets, Onondaga Lake, 1989-1993. 57

Table 18 Estimated annual survival rates (S) of smallmouth bass populations in Onondaga Lake compared to other populations in the northeastern United States. 58

Table 19 Observed mean length (mm) at age for largemouth bass populations in Onondaga Lake compared to other populations in the northeastern United States. 61

Table 20 Estimated annual survival rates (S) of largemouth bass populations in Onondaga Lake compared to other populations in the northeastern United States. 62

Table 21 Monthly growth rates of juvenile largemouth bass collected from seine hauls, Onondaga Lake, June - August, 1991. 64

Table 22 Monthly growth rates of juvenile largemouth bass collected from seine hauls, Onondaga Lake, June - August, 1993.

Table 23 Observed mean length (mm) at age for pumpkinseed sunfish and bluegill from selected waters in the United States.

Table 24 Monthly growth rates of juvenile pumpkinseed and bluegill collected from seine hauls, Onondaga Lake, June - August, 1993. 71

Table 25 Population estimates and number per hectare of adult fish species > 100 mm captured in trap nets, Onondaga Lake, 1991.

Table 26 Population estimates and number per hectare of adult fish species > 100 mm captured in trap nets, Onondaga Lake, 1993.

Table 27 Biomass estimates of adult fish species > 100 mm captured in trap nets, Onondaga Lake, 1991. 78

Table 28 Biomass estimates of adult fish species > 100 mm captured in trap nets, Onondaga Lake, 1993 79

Table 29 Proportional stock density (PSD) and relative stock density (RSD) of fish species captured in trap and gill nets, Onondaga Lake, 1991 - 1994. 88

Figure 11 Shannon index of diversity for Onondaga Lake, from trap net catches of adult fish, June October, 1990, 1991 and 1993. 30

Figure 12 Species diversity and evenness of adult fish captured from trap nets in Onondaga Lake, June - October, 1990 - 1993. 31

Figure 13 Shannon Weiner diversity index of juvenile fish captured in seine hauls, Onondaga Lake, 1991 - 1993.

Figure 14 Shannon Weiner diversity index of juvenile fish captured in seine hauls, Onondaga Lake, 1992. 41

Figure 15 Average length (mm) at age of smallmouth bass captured in trap and gill nets, Onondaga Lake, 1990 - 1993.

Figure 16 Length frequency histogram of smallmouth bass, captured in trap and gill nets, Onondaga Lake, 1991 (April 23 - November 27), 1992 (June 10 - October 11), and 1993 (June 3 - October 15). 53

Figure 17 Average length at age of adult smallmouth bass caught in trap and gill nets from the north and south basins of Onondaga Lake, June 3 - October 15, 1993. 54

Figure 18 Length frequency histogram of smallmouth bass caught in the north and south basins of Onondaga Lake, 1991 (April 23 - November 27), 1992 (June 10 - October 11), and 1993 (June 3 - October 15). 55

Figure 19 Average length at age of largemouth bass captured in trap and gill nets, Onondaga Lake, 1992 and 1993.

Figure 20 Length frequency histogram of largemouth bass captured in trap, seine and gill nets in Onondaga Lake, 1991 and 1993. 66

Figure 21 Average length (mm) of pumpkinseed captured in trap nets, Onondaga Lake, 1988 - 1992. 68

Figure 22 Average length (mm) of bluegill, captured in trap nets, Onondaga Lake, 1990 - 1992. 68

Figure 23 Average length at age of adult white perch captured in trap and gill nets, Onondaga Lake, 1988 and 1990. 74

Figure 24 Proportional stock densities of largemouth bass compared to bluegill and pumpkinseed captured in trap and gill nets in Onondaga Lake, 1991, 1992 and 1994. 89

LIST OF APPENDICES

Appendix A	Catch curves of adult smallmouth bass captured in trap and gill nets, Onondaga Lake, 1990 - 1993.	
Appendix B	Catch curve of adult smallmouth bass captured in trap and gill nets, Onondaga Lake, 1991 - 1993.	
Appendix C	Catch curves of adult largemouth bass captured in trap and gill nets, Onondaga Lake, 1993.	
Appendix D	Catch curves of adult walleye captured in trap and gill nets, Onondaga Lake, 1991 - 1993.	
Appendix E	Catch curves of adult white perch captured in trap and gill nets, Onondaga Lake, 1990 - 1994.	
Appendix F	Catch curves of adult bluegill captured in trap nets, Onondaga Lake, 1991 - 1994.	
Appendix G	Catch curves of adult pumpkinseed sunfish captured intrap nets, Onondaga Lake, 1991 - 1994.	107

INTRODUCTION

Onondaga Lake is a highly eutrophic lake situated at the northern edge of the city of Syracuse in central New York State (Figure 1). Onondaga Lake is a remnant of ancient Lake Iroquois, a body of water that covered the northern half of Onondaga County 10,000 years ago, including present day Lake Ontario (Murphy 1978). The Lake is surrounded by commercial, industrial, and residential land use, but 80% of the shoreline is park lands owned and maintained by Onondaga County. Private owners include Conrail, Allied-Signal Corporation, Crucible Steel, and Niagara Mohawk Power Corporation (US Army Corps of Engineers 1992).

Onondaga Lake has been severely impacted by more than a century of change, including domestic and industrial waste inputs, invasion of new species via canals, stream alterations and marsh drainage. Related conditions in the lake include elevated nutrient loading resulting in frequent algal blooms, low water transparency and extended periods of anoxia within the hypolimnion (Effler 1987a). Lake sediments have been greatly altered by the precipitation and deposition of calcium carbonate from the ionic discharge of a Solvay process plant. Much of the immediate shoreline and littoral zone of the lake is covered with oncolites, which are ovoid, pebble sized structures composed primarily of calcium carbonate (Effler 1987b). The macrophyte and benthos populations are both depressed as a result of these deposits (Effler 1987b). More than 90% of the surface sediments are contaminated with mercury (Hg), resulting in elevated levels of Hg in fish tissue.

Figure 1. Location of Onondaga Lake.

Fish consumption in the Lake is prohibited. The many pollution problems in the lake are complex and not easily remedied. A warm water fish community exists in the lake, but reproductive success is limited. This paper will discuss the community structure and population characteristics of the fishes in Onondaga Lake.

Onondaga Lake has a surface area of 11.7 km^2 and a maximum depth of 20.5 m. The drainage basin of 600 km^2 holds approximately 500,000 people and most of Onondaga County's 140 industries (Murphy 1978). Major tributaries to Onondaga Lake include Ninemile Creek, Onondaga Creek, Ley Creek and Harbor Brook, which contribute 38%, 34%, 8% and 3% of the annual flow, respectively. Bloody Brook, Sawmill Creek and a small tributary together provide less than 1% of the total input (Effler 1987) (Figure 1) Water from the Metropolitan Syracuse Sewage Treatment Plant (Metro) accounts for an average 17% of the annual flow into Onondaga Lake. Water also enters the lake through intermittent bi-directional flow from the Seneca River at the outlet of the lake (Effler 1987). The lake surface level is controlled by the New York Department of Transportation at the Phoenix lock, and remains at the lock level during the canal season. The lake ultimately discharges into the Seneca River to the northwest. The confluence of the Seneca and Oneida Rivers form the Oswego River, which discharges at the southeastern shore of Lake Ontario 64 km north of Onondaga Lake (Murphy 1978) (Figure 1)

History of the lake and its basin

The fish communities and their habitats in Onondaga Lake have been radically changed over the last 100 years as a result of these cultural stresses. Some species have virtually disappeared, and new species have appeared and multiplied explosively. The present fish community bears little resemblance to the original native population (Ringler et al. 1996, Tango 1996). Atlantic salmon (Salmo salar) migrated through the lake to spawn in its tributaries, where they were harvested and shipped to the New York City market. In the late 1800s, cisco (Coregonus spp.) were relatively abundant in the deeper parts of the lake and supported a commercial fishery (Lipe et al. , 1983). However, the cisco were thought to have completely disappeared from the lake by 1897 (Lipe et al. 1983), presumably due to the deterioration of water quality and habitat. Dam construction on the Oswego River largely blocked the migration route of the Atlantic salmon (Lipe et al. 1983). Salmon, trout, bass, and yellow perch were also fished, both recreationally and commercially, but the commercial fishery declined significantly by 1895 (Lipe et al. , 1983).

Mining of salt from brine springs near the lake was the major industry of the area from 1793 to 1908 (Effler 1987b). The presence of large quantities of salt and limestone, a large body of water, and access to transportation routes made the Onondaga Lake area an ideal location for the production of soda ash (Na_2CO_3) through the Solvay process. This product was used in a variety of applications such as the manufacture of glass, soaps, detergents,

pulp and paper, textiles, and various chemicals (Kulhawy et al. 1977). In 1881, the Solvay Process Company was established in the Syracuse area, later joined by three other companies to form Allied Chemical Corporation (Kulhawy et al. 1977), which later eventually became Allied-Signal.

Other facilities operated by Allied-Signal near Onondaga Lake included two chlor-alkali plants, a chlorinated benzene plant, and a plant manufacturing benzene, toluene, and xylenes (O'Brien & Gere 1990). The two chlor-alkali plants began using mercury electrolysis cells in 1947 and 1953 to produce sodium hydroxide, potassium hydroxide, and chlorine gas. Effluent from these plants was discharged into Onondaga Lake until 1970, when the waste was combined with the Solvay process wastestream and discharged to wastebeds along Ninemile Creek. An estimated 75,000 kg of Hg were discharged to the lake from 1946 to 1970 (Effler 1987b). Other industries that developed near Onondaga Lake included the Solvay Process Company's Syracuse Works and fertilizer production plant, steel manufacturers, vehicular accessories and pottery plants (Kulhawy et al. 1977).

Untreated sewage from combined sewer systems in Syracuse was discharged into Onondaga Lake tributaries in the late1800's; sewage from the towns around the lake was discharged into tributaries or directly into the lake. In addition, Ninemile Creek carried human and animal waste into the lake from the New York State fairgrounds. In 1925, a treatment plant was constructed at the southern end of the lake to settle and chlorinate the sewage. The present Metropolitan Syracuse Sewage Treatment Plant (METRO)

was completed in 1960, including expanded settling tanks and the capability for chemical coagulation. However, this plant was still only equipped for primary treatment (Effler 1987a)

METRO was upgraded to secondary treatment in 1979 and tertiary treatment in 1981. During these upgrades (1977-1981) raw sewage was discharged directly to the lake. METRO currently has a tertiary treatment capacity of 120 million gallons per day (mgd); this effluent is discharged through the main outfall into Onondaga Lake. When combined stormwater and sewage exceeds 120 mgd, the incremental flow above 120 mgd receives only primary treatment and chlorintion and is discharged to the lake through a second outfall (Effler 1987a).

This study had five objectives:

1. To characterize the relative number and kinds of fishes currently in the lake and to examine seasonal and annual changes in community structure.

2. To determine which species spawn within Onondaga Lake and describe the distribution of juveniles.

3. To describe age distribution, population densities, growth patterns and adult mortality rates of dominant fish species within Onondaga Lake in comparison to other waters.

4. To describe patterns and timing of movement of fish species within the lake and between the lake and Seneca River.

5. To suggest future research and management options for the development of a sport fishery.

METHODS AND MATERIALS

Fish were collected at 34 sites along the margin of Onondaga Lake from May to November, 1989 - 1993 (Figure 2). Sampling in 1992 was limited to seines hauls, with minor trap and gill netting effort. Inshore sampling methods included the use of trap nets (Indiana, South Dakota, and Oneida Lake style) with 23 m leaders and 11.5 m wings equipped with 0.635 cm square mesh. The leaders of the trap nets were set perpendicular to shore in water 1 - 3 m deep; wings were set at 45° angles from the trap (Nielson and Johnson 1983). Field crews of two to three people removed fish from the traps daily from May through November 1989 - 1993. Traps were checked five days a week and left open on weekends.

Seine sweeps were conducted June - August at biweekly intervals in 1991 and 1993 at four locations and in 1992 at eight locations around the lake margin. These catches were used to examine juvenile fish assemblages in the littoral zone (Figure 2). Two continuous 30 m sweeps of the shoreline were conducted in water < 1 m in depth with a 20 m long bag seine constructed of 0.635 cm square nylon mesh.

Experimental gill nets, 50 m in length with panels of 2.54, 5.08, 7.62 and 10.16 cm stretched mesh were set June - October at biweekly intervals at 8 locations perpendicular to shore in water 1 - 4 m in depth. Gill nets were set for 2 hours during the day to mark and tag fish, and overnight to assess population characteristics, movement patterns, and community structure.

Figure 2. Net locations in Onondaga Lake, 1988 - 1994

A minimum of 50 individuals of each species larger than 100 mm was randomly selected from trap nets and gillnets to describe age distribution, growth patterns, and mortality rates of dominant fish species in Onondaga Lake. Scales were removed from the left side of the body below the lateral line, near the tip of the depressed pectoral fin. At least 25 scales were removed from each fish and placed in scale envelopes with length (mm), weight (g), date, and site of capture recorded. Scales were mounted between glass slides and projected with a 40X Ken-A-Vision microprojector. Ages were determined by counting annuli, which were verified through blind comparisons by other experienced personnel. Annual marks were validated by comparison of recaptured fish tagged in 1988 through 1993, and by examination of size-frequency histograms. Growth history was established by back-calculation of length (Nielsen and Johnson 1983), which assumed a linear relationship between scale and body growth throughout the life of the fish This assumption was tested by fitting the data using least squares regression. The following formula was employed for back-calculation (Ricker 1975).

$$Ln = C + [Sn/S\ (L - C)]$$

in which L = total length of fish at capture, S = total scale radius, Ln = length of fish when annulus "n" formed, Sn = radius to annulus "n" and C = correction factor based on the species of fish (Carlander 1981).

Mortality rates for smallmouth bass, largemouth bass and walleye fully recruited to the sampling gear were developed from catch curves, i.e., the relationship of $\log_e$ number of fish sampled versus their age (Ricker, 1975). This estimate assumes a constant

recruitment of all year classes used in the analysis and that all ages are equally vulnerable to the sampling gear. Instantaneous mortality rate (Z) was determined by taking the natural logarithm of the slope of the descending limb of the catch curve. Annual rate of total survival (S) was determined by the following formula: $S = (1-A) = e^{-Z}$. Annual rate of total mortality (A) was also calculated from this formula. Because the assumption of constant recruitment was unlikely to be met, cohort analysis based on annual catch per unit effort was also used to describe mortality rates of smallmouth bass, bluegill, pumpkinseed and white perch. Cohort analysis was not used with walleye and largemouth bass because of the small sample sizes.

Analysis of fish movements in Onondaga Lake was accomplished by tagging and recovery methods. All species of fish were tagged according to site using numbered Floy tags inserted below the dorsal fin. Fish such as brook silversides (Labidesthes sicculus) were not tagged due to their small size. Fish greater than 150 mm not fitted with Floy tags were fin clipped according to their location of capture. To encourage anglers to return tags, posters describing the study were distributed around the lake and at local tackle shops.

The proportional stock density (PSD) index proposed by Anderson (1978) was used to describe the sustainable harvest size preferred by anglers and the status of both prey and predator components of the community. The relative stock density (RSD) index was used to better assess the size distribution within the quality-length portion of the population (Anderson 1978). Species

used for this analysis included smallmouth bass, largemouth bass, pumpkinseed and bluegill.

Population density was estimated using the Schnabel method. Confidence intervals for the Schnabel method were calculated by treating the number of recaptured fish as a Poisson variable (Ricker 1975). This method assumes that fish are marked and added to the population over a considerable period, during which marked fish suffer no greater mortality than unmarked fish. Samples are taken and examined for recaptures over the entire capture period. An approximation of N is calculated from the following formula:

$$N = \sum(C_t M_t) / \sum R$$

where M_t = total marked fish at large at the start of the *t* th day (or other interval), i.e. the number previously marked less any accidentally killed at previous recaptures.

C_t = total samples taken on day *t*.

R = $\sum R_t$, total recaptures during the experiment.

N = population estimate.

Diversity estimates were based upon the Shannon - Wiener index. This index assumes that diversity in a natural system can be measured in a way similar to the information contained in a code or message (Magurran 1988). The Shannon - Wiener index assumes that individuals are randomly sampled from an "indefinitely large" population; all species should be represented in the sample (Magurran 1988). This index is calculated from the equation: $H' = -\sum pi \ln pi$, where pi is the proportion of individuals found in the ith species. Tramer's (1969) method of plotting diversity against the natural logarithm of evenness from each sample was used to provide an overall indication of change in the system. Tramer hypothesized

that collections of organisms from unstable environments will vary in diversity according to their evenness patterns, whereas collections from stable environments will vary in diversity according to species richness. A high correlation between diversity and the natural log of the number of species reflects a stable state of affairs, while a low correlation reflects an unstable state.

RESULTS

Fish Communities: 1989 to 1993

Onondaga lake contains a large variety and diversity of warm water fish species despite its highly perturbed conditions. The sampling program in 1989-1993 captured more than 100,000 fish comprised of 48 different species. A total of 33 species was collected in 1989, 36 in 1990, 48 in 1991 and 39 in 1993 (Tables 1 - 4). These data suggest an increasing trend in diversity from earlier surveys (Tango and Ringler 1996). The increased number of species recorded from the lake in the most recent studies (1989-1993) probably reflects improvements in water quality associated with reductions in material loading from METRO and the closure of the soda ash/chlor-alkali facility (Canale and Effler 1989, Effler 1987, Effler et al. 1990). The community is currently dominated by planktivorous species, including white perch, alewife (*Alosa pseudoharengus*) and gizzard shad. Sampling in 1989 to 1991 and 1993 revealed that planktivorous species represented 72%, 77%, 44% and 55% of the population, respectively (Figure 3). A study of nearby Cross Lake (Schlueter 1992) indicated a similar

Table 1. Total catch in trapnets of Onondaga Lake, June 6 - September 7, 1989.

	Trapnet days 180		Gillnet days 0		
Species	Traps	Catch per day	Gillnets	Catch per day	Total
Longnose gar (Lepisosteus osseus)	5	.03	0	0	5
Bowfin (Amia calva)	20	.11	0	0	20
Alewife (Alosa pseudoharengus)	37	.21	0	0	37
Gizzard shad (Dorosoma cepedianum)	2362	13.12	0	0	2362
Brown bullhead (Ictulurus nebulosus)	84	.47	0	0	84
Channel catfish (Ictalurus punctatus)	150	.83	0	0	150
White sucker (Catostomus commersoni)	128	.71	0	0	128
Shorthead redhorse (Moxostoma macrolepidotum)	61	.34	0	0	61
Carp (Cyprinus carpio)	101	.56	0	0	101
Golden shiner (Notemigonus crysoleucas)	11	.06	0	0	11
Emerald shiner (Notropis atherinoides)	7	.04	0	0	7
Northern pike (Esox lucius)	6	.03	0	0	6
Tiger muskellunge (Esox lucius x masquinongy)	1	.006	0	0	1
Banded killifish (Fundulus diaphanus)	50	.28	0	0	50
Brook silverside (Labidesthes sicculus)	100	.55	0	0	100
White perch (Morone americana)	3521	19.56	0	0	3521
White bass (Morone chrysops)	2	.01	0	0	2
Rock bass (Ambloplites rupestris)	1	.006	0	0	1
Bluegill (Lepomis macrochirus)	877	4.87	0	0	877
Pumpkinseed (Lepomis gibbosus)	449	2.49	0	0	449
Smallmouth bass (Micropterus dolomieui)	22	.12	0	0	22
Largemouth bass (Micropterus salmoides)	41	.23	0	0	41
Black crappie (Pomoxis nigromaculatus)	56	.31	0	0	56
White crappie (Pomoxis annularis)	2	.01	0	0	2
Yellow perch (Perca flavescens)	60	.33	0	0	60
Walleye (Stizostedion vitreum vitreum)	28	.16	0	0	28
Freshwater drum (Aplodinotus grunniens)	23	.13	0	0	23
Total	~~8207~~ 8205		0		~~8207~~ 8205

Table 2 Total catch in trap and gillnets of Onondaga Lake, May 23 - November 12, 1990.

	Trapnet days 303		Gillnet days 24		
Species	Traps	Catch per day	Gillnets	Catch per day	Total
Longnose gar (Lepisosteus osseus)	0	0	1	.04	1
Bowfin (Amia calva)	35	.12	3	.13	38
Gizzard shad (Dorosoma cepedianum)	4235	13.97	61	2.54	~~4297~~ 4296
Yellow bullhead (Ictalurus natalis)	10	.03	0	0	10
Brown bullhead (Ictalurus nebulosus)	74	.24	1	.04	75
Channel catfish (Ictalurus punctatus)	116	.38	50	2.08	166
White sucker (Catostomus commersoni)	69	.23	9	.37	78
Shorthead redhorse (Moxostoma macrolepidotum)	25	.08	30	1.25	55
Carp (Cyprinus carpio)	95	.31	26	1.08	~~123~~ 121
Golden shiner (Notemigonus crysoleucas)	34	.11	0	0	34
Brown trout (Salmo trutta)	1	.003	0	0	1
Splake (Salvelinus fontinalis x namaycush)	1	.003	0	0	1
Northern pike (Esox lucius)	7	.23	0	0	7
Tiger muskellunge (Esox lucius x masquinongy)	2	.007	0	0	2
Burbot (Lota lota)	1	.003	0	0	1
Banded killifish (Fundulus diaphanus)	2	.007	0	0	2
Brook silverside (Labidesthes sicculus)	8	.03	0	0	~~59~~ 8
Brook stickleback (Culaea inconstans)	1	.003	0	0	1
White perch (Morone americana)	4376	14.44	248	10.33	~~4626~~ 4624
White bass (Morone chrysops)	1	.003	0	0	1
Rock bass (Ambloplites rupestris)	1	.003	0	0	1
Smallmouth bass (Micropterus dolomieui)	12	.04	8	.33	~~499~~ 20
Largemouth bass (Micropterus salmoides)	27	.09	2	.08	~~1399~~ 29
Black crappie (Pomoxis nigromaculatus)	0	0	3	.12	~~20~~ 3
White crappie (Pomoxis annularis)	11	.04	0	0	~~30~~ 11
Bluegill (Lepomis macrochirus)	1321	4.36	9	.37	~~11~~ 1330
Pumpkinseed (Lepomis gibbosus)	480	1.60	5	.21	~~3~~ 485
Logperch (Percina caprodes)	1	.003	0	0	~~128~~ 1
Yellow perch (Perca flavescens)	113	.04	13	.54	~~5~~ 126
Walleye (Stizostedion vitreum vitreum)	9	.03	3	.12	12
Freshwater drum (Aplodinotus grunniens)	85	.28	0	0	85
Total	11276		472		~~11748~~ 11625

Table 4 Total catch of trap and gillnets of Onondaga Lake, June 3 - October 15, 1993.

	Trap days 165		Gillnet hours 50		
Species	Traps	Catch per day	Gillnets	Catch per hour	Total
Longnose gar (Lepisosteus osseus)	2	.01	0	0	2
Bowfin (Amia calva)	111	.67	0	0	111
American eel (Anguilla rostrata)	1	.01	0	0	1
Gizzard shad (Dorosoma cepedianum)	39	.24	127	2.54	166
Yellow bullhead (Ctalurus natalis)	3	.02	0	0	3
Brown bullhead (Ictulurus nebulosus)	185	1.12	1	.02	186
Channel catfish (Ictalurus punctatus)	171	1.04	65	1.30	236
White sucker (Catostomus commersoni)	96	.58	7	.14	103
Shorthead redhorse (Moxostoma macrolepidotum)	17	.10	24	48	41
Carp (Cyprinus carpio)	127	.77	13	.26	140
Golden shiner (Notemigonus crysoleucas)	12	.07	0	0	12
Emerald shiner (Notropis atherinoides)	15	.09	0	0	15
Redfin shiner (Notropis umbratilis)	1	.01	1	.02	2
Spottail shiner (Notropis hudsonius)	4	.02	0	0	4
Fathead minnow (Pimephales promelas)	8	.05	0	0	8
Brown trout (Salmo trutta)	1	.01	0	0	1
Northern pike (Esox lucius)	2	.01	5	.10	7
Tiger muskellunge (Esox lucius x masquinongy)	0	0	2	.04	2
Banded killifish (Fundulus diaphanus)	5	.03	0	0	5
White perch (Morone americana)	3491	21.16	86	1.72	3577
White bass (Morone chrysops)	0	0	1	.02	1
Rock bass (Ambloplites rupestris)	1	.01	0	0	1
Pumpkinseed (Lepomis gibbosus)	549	3.33	0	0	549
Bluegill (Lepomis macrochirus)	1080	6.55	0	0	1080
Smallmouth bass (Micropterus dolomieui)	56	.34	97	1.94	153
Largemouth bass (Micropterus salmoides)	39	.24	8	16	47
Black crappie (Pomoxis nigromaculatus)	32	.19	1	.02	33
Yellow perch (Perca flavescens)	63	.38	0	0	63
Walleye (Stizostedion vitreum vitreum)	13	.08	80	1.60	93
Freshwater drum (Aplodinotus grunniens)	160	.99	1	.02	161
Total	6286		583		~~6869~~ 6803

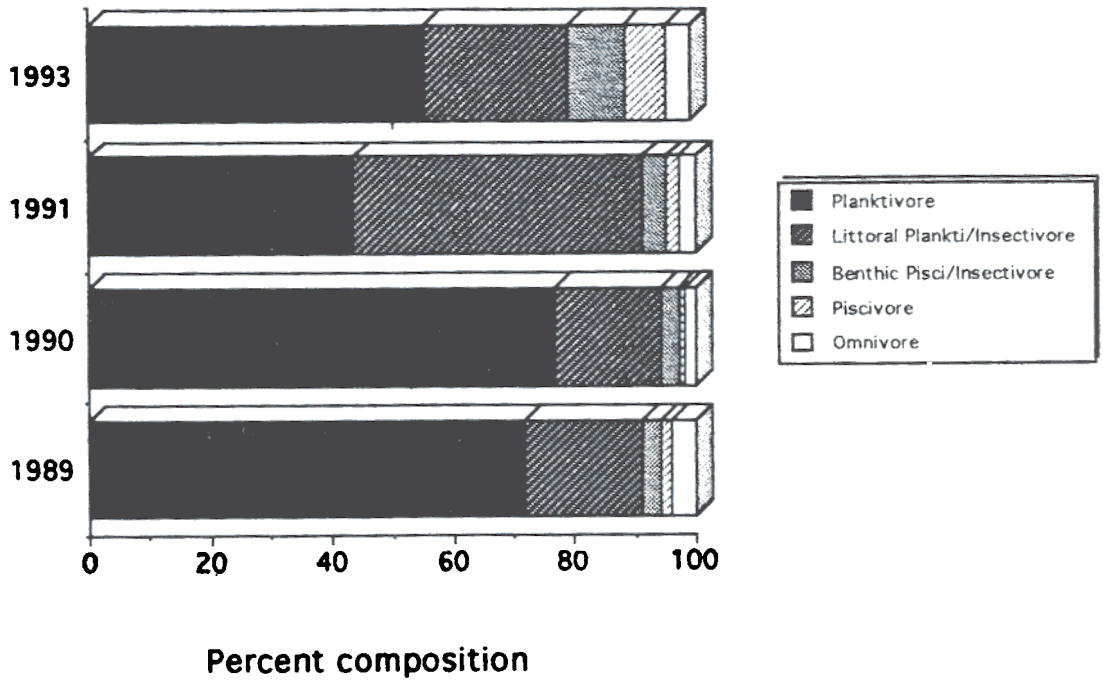


Figure 3. Trophic community categories of adult fish captured in trapnets and their percentage composition in Onondaga Lake, 1989 - 1991 and 1993.

community structure; planktivorous species including white perch and gizzard shad comprised 81% of the sample (Figure 4).

Shannon-Weiner diversity indices of Onondaga Lake trap nets was 1.69, 1.50, 2.00 and 1.62 in 1989, 1990, 1991 and 1993, respectively (Figure 5). The regression of diversity against evenness yielded a correlation of 0.89, indicating that at least since 1989 the fish community has been unstable presumably as a result of pollution inputs (Figure 6). This correlation was significant (single factor analysis of variance, $P < 0.05$). A lower correlation of 0.69 was obtained from the plot of species diversity and the natural log of the number of species as predicted by Tramer's (1969) hypotheses.

The community structure apparently underwent little change from 1989 to 1993. These collections document a fish community dominated by planktivorous species including white perch and gizzard shad. Insectivorous-planktivorous species such as pumpkinseed and bluegill dominated the littoral zone (Figure 7 & 8). Predatory species include channel catfish (Ictalurus punctatus), walleye (Stizostedion vitreum), smallmouth bass (Micropterus dolomieu) and largemouth bass (Micropterus salmoides). Other important species include brown bullhead (Ameiurus nebulosus), carp (Cyprinus carpio), bowfin (Amia calva), yellow perch (Perca flavescens) and black crappie.

The most conspicuous difference in adult species composition among the four years was the contribution of gizzard shad, which represented 29% of the total catch in 1989, 37% in 1990 and 16% in 1991 (Figure 7 & 8). Gizzard shad contributed less than 1% to the trapnet catch in 1993 (Figure 8). Catch per unit effort of gizzard

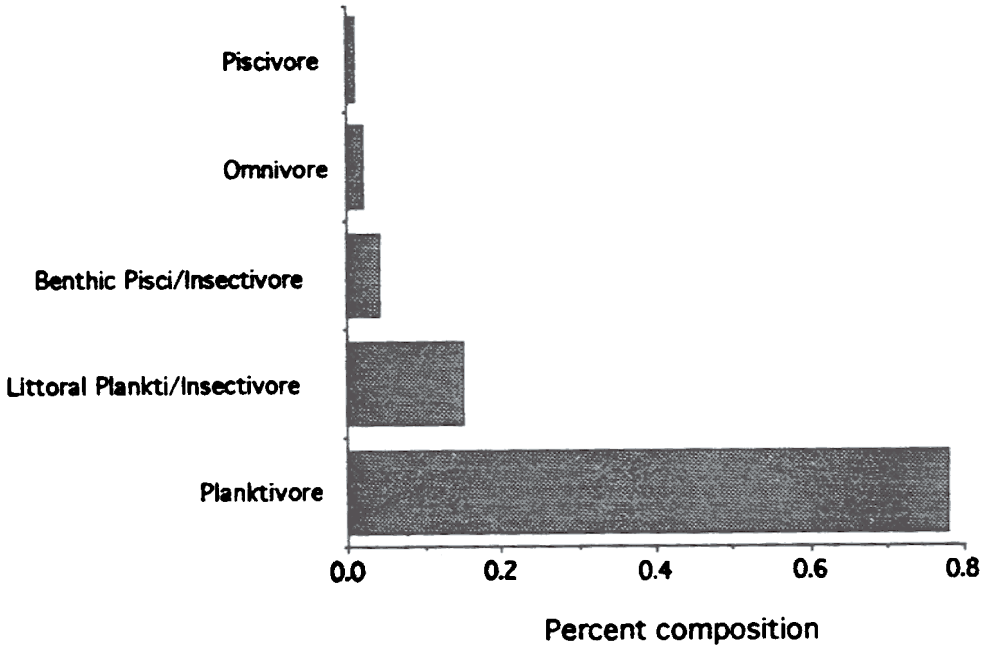


Figure 4. Trophic community categories of adult fish captured in trapnets and their percentage composition in Cross Lake, 1992.

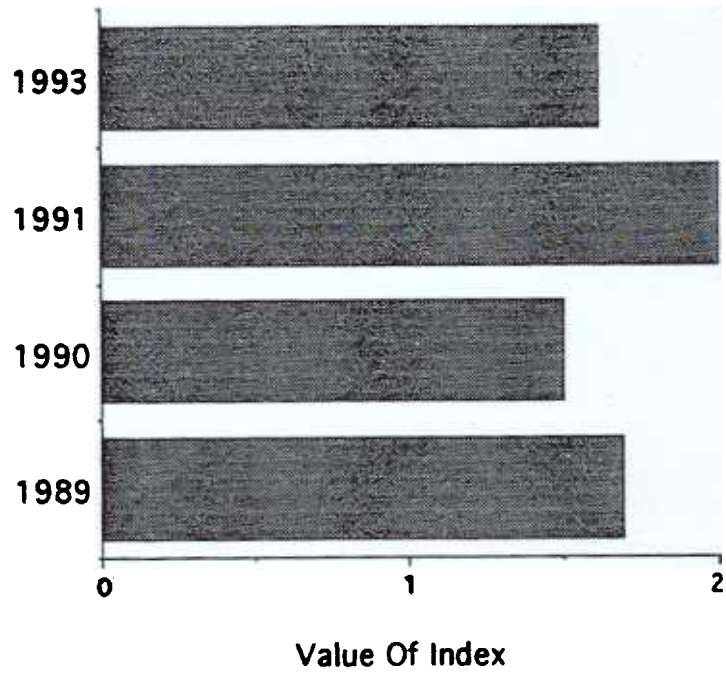


Figure 5. Shannon Index of Diversity for adult fish captured in trap nets, Onondaga Lake, 1989, 1990, 1991 and 1993.

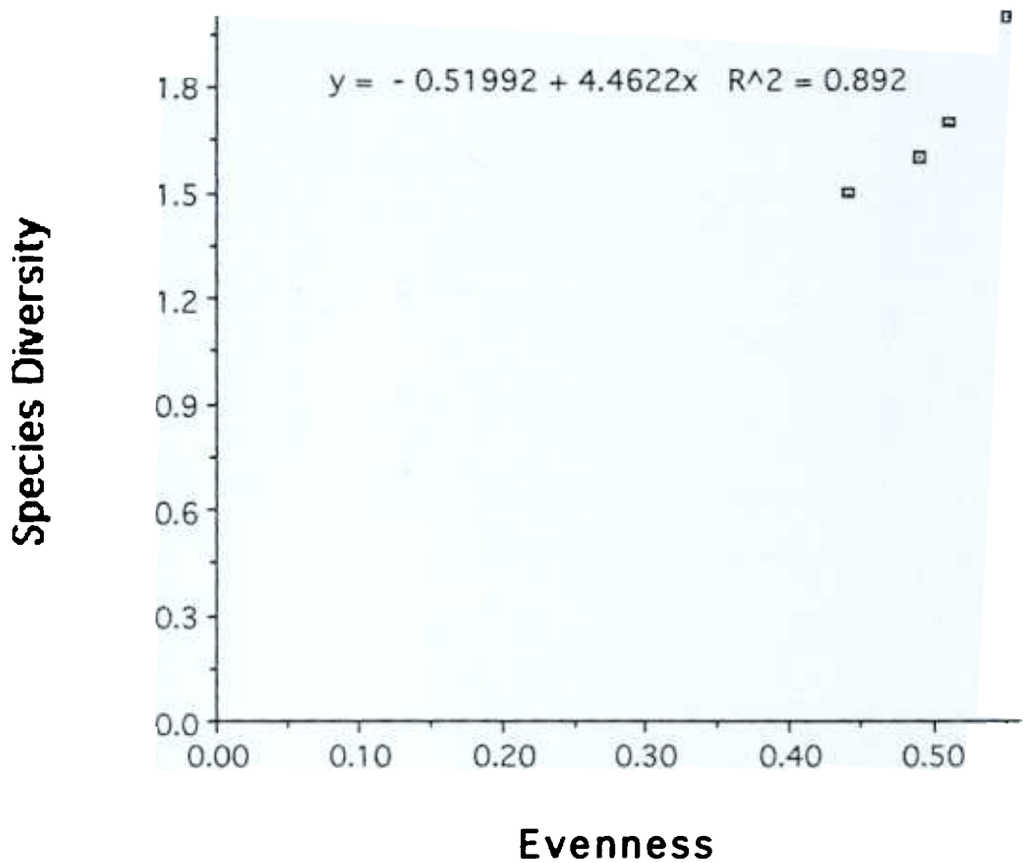
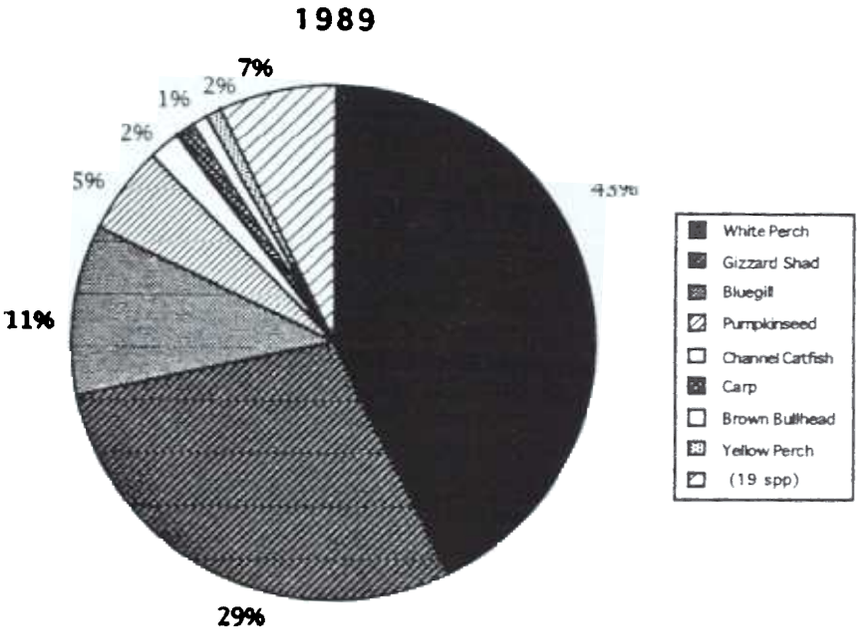


Figure 6. Species diversity of fish collections and evenness based on trapnet catches of adult fish in Onondaga Lake, 1989 - 1993.



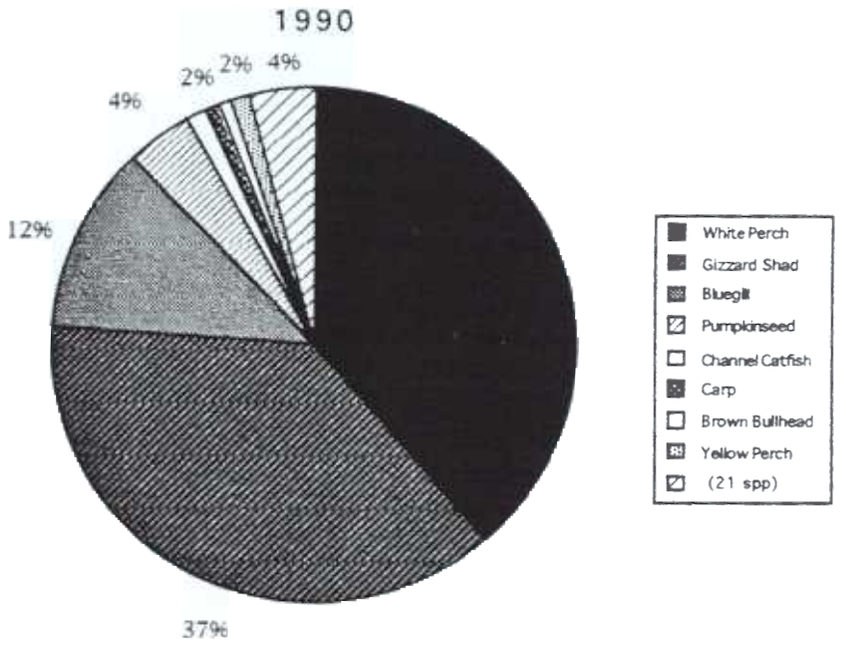
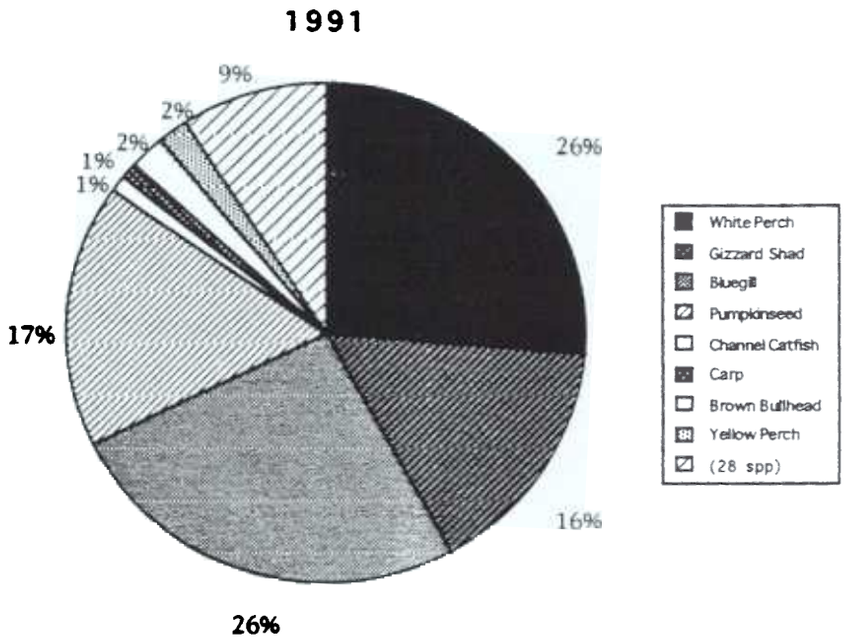


Figure 7. Species composition of adult fish captured in trapnets, set in Onondaga Lake, 1989 and 1990.



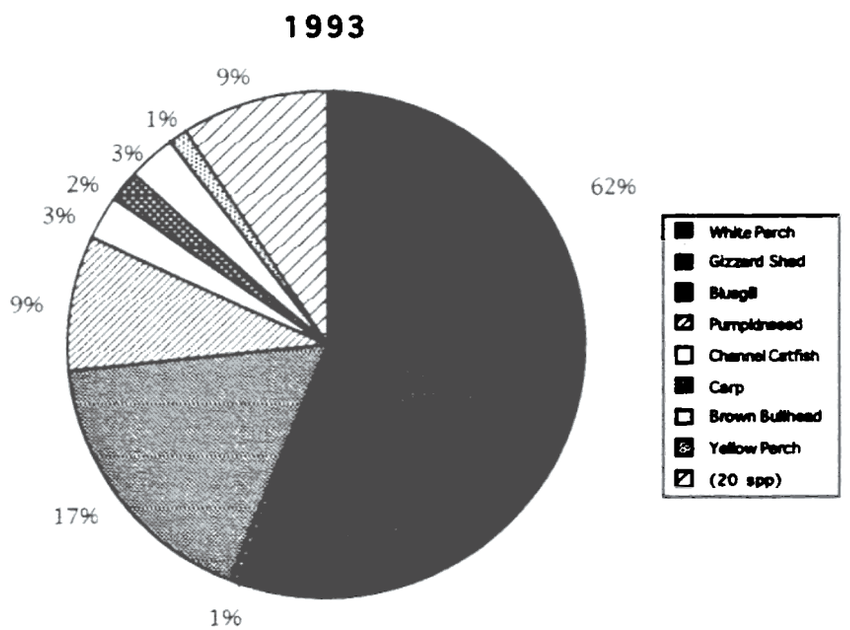


Figure 8. Species composition of adult fish captured in trapnets, set in Onondaga Lake, 1991 and 1993.

shad in 1989, 1990 and 1991 averaged 13.12, 13.97 and 11.63; the catch per unit effort decreased to 0.24 in 1993 (Tables 1 - 4). Gizzard shad are susceptible to winter mortality at the periphery of their geographic range. Massive die offs have been reported in Lake Erie (Bodola 1965), and Lake Rathbun, Iowa (Mayhew 1975). Although no such die offs have been observed in Onondaga Lake, the winter of 1993 was exceptionally cold, with record high snowfall in February and flooding conditions in the spring. Adult stocks of gizzard shad in Onondaga Lake for 1993 appear to reflect these harsh conditions.

Pumpkinseed and bluegill are major littoral inhabitants of Onondaga Lake. The numbers of bluegill and pumpkinseed increased in trapnet catches from 16% of the total fish captured in 1989 and 1990, to 43% and 26% in 1991 and 1993 (Figure 7 & 8), respectively. Annual catch per unit effort remained constant for both species except for an increase in 1991 (Tables 1-4).

Gill net catches in water 2 - 10 m deep in Onondaga Lake revealed a difference in species dominance compared to the littoral areas. The most apparent difference was the contribution of planktivorous species such as gizzard shad and white perch, which accounted for 36% of the total catch (Figure 9). Predatory species including smallmouth bass (16%), walleye (14%) and channel catfish (11%) were significantly more abundant compared to the littoral zone (Figure 9). Catch per unit effort of smallmouth bass in trap nets set in the littoral zone ranged from a low of 0.04 fish per night in 1990 to 0.40 in 1991, compared to 1.67 smallmouth bass captured per hour in water 2 - 10 m with gill nets in 1993 (Table 5). Other

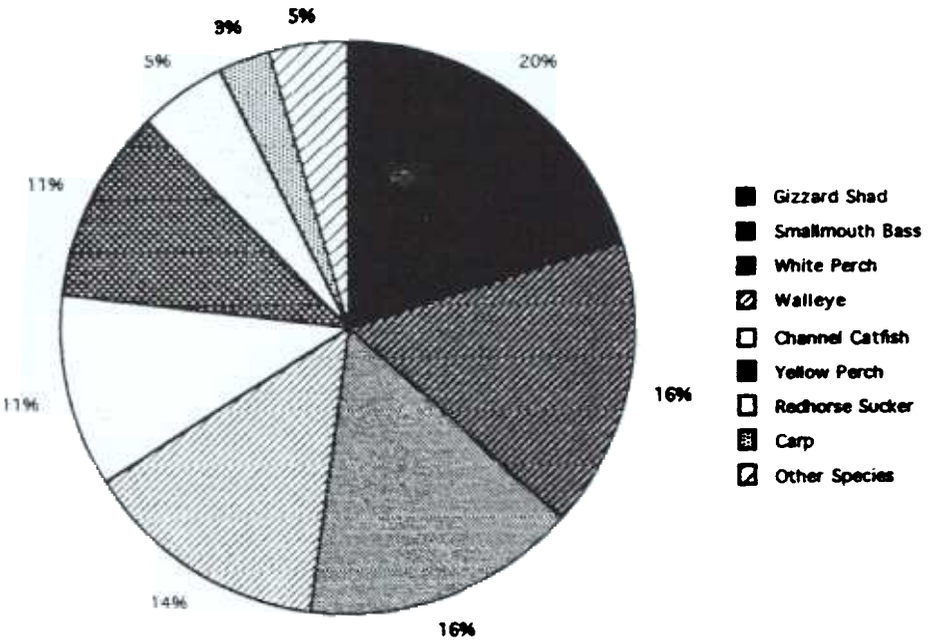


Figure 9. Species composition of adult fish captured in gill nets from depths of 2 - 10 m in Onondaga Lake, October 1 - 15, 1993 (N = 593).

Table 5. Total catch of 25 gillnets (50 hours) set in water 2 - 10 m, Onondaga Lake, October 1 - 15, 1993.

Species	Total	Catch per hour
Gizzard shad	127	2.19
Brown bullhead	1	0.02
Channel catfish	65	1.12
Redhorse sucker	24	0.41
Carp	13	0.22
Redfin shiner	1	0.02
Northern pike	5	0.08
Tiger muskellunge	2	0.04
White perch	86	1.48
White bass	1	0.02
Smallmouth bass	97	1.67
Largemouth bass	8	0.14
Black crappie	1	0.02
Walleye	80	1.38
Total	511	10.2

predatory species such as walleye and channel catfish were also more readily captured in water 2 - 10 m (Table 5). Seasonal variability in species composition was a observed in the Onondaga Lake system. White perch and gizzard shad together averaged 29%, 27% and 26% of the total catch in June to August, declining to 20% and 22% of the total catch in September and October 1990 to 1993 (Figure 10). Pumpkinseed and bluegill together comprised 32%, 26%, 21%, 33% and 23% of the total catch June to October 1990 - 1993 (Figure 10). Less abundant species such as smallmouth bass and black crappie revealed little pattern in capture rates. Channel catfish appear in trap nets later in the season (Figure 10). This reflects a typical pattern for channel catfish, which move into river systems to spawn in the spring and return to the lake after spawning (Smith 1985).

Species diversity increased in 1990 and 1991 each month from June to October. Diversity values were 0.95 and 1.3 in June of 1990 and 1991, increasing to 2.1 in October for both years (Figure 11). However, in 1993 diversity was highest in June with a value of 1.9 decreasing to 1.28 and 1.5 in July and August (Figure 11). The data show a close fit to the linear form, yielding a correlation of 0.98 in 1990, 0.85 in 1991 and 0.99 in 1993 between species diversity and evenness across all collections 1990 - 1993 (Figure 12). These correlation's are significant (single factor analysis of variance, $P < 0.05$). Significant correlations between diversity and evenness across all years suggest that Onondaga Lake has been an unpredictable and unstable envoronment for fish.

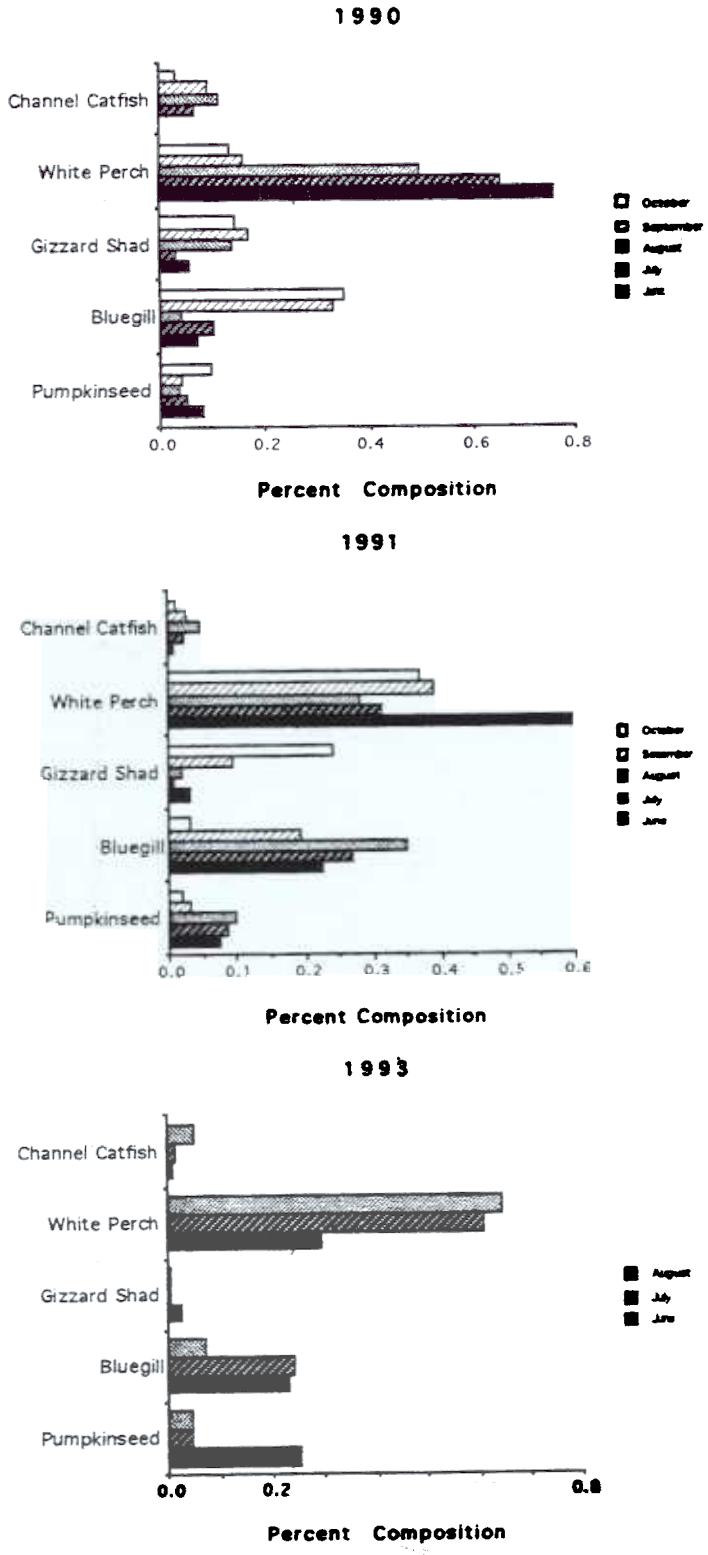


Figure 10. Monthly catches of adult channel catfish, white perch, gizzard shad, bluegill and pumpkinseed from trapnets in Onondaga Lake, 1990, 1991 and 1993.

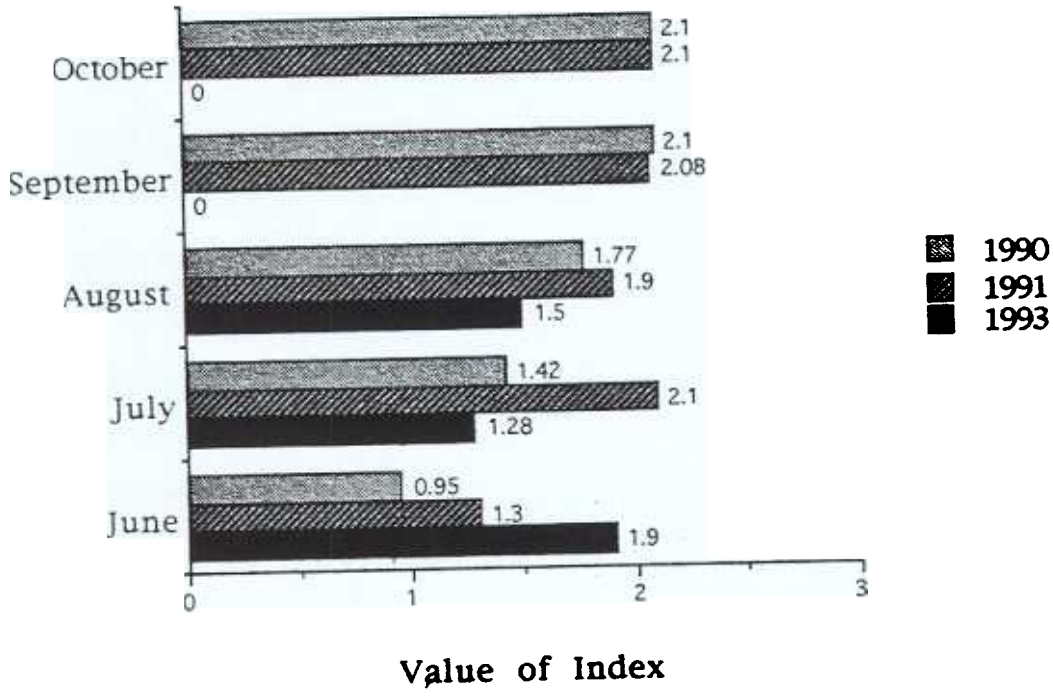


Figure 11. Shannon Index of Diversity for Onondaga Lake, based on trapnet catches of adult fish, June - October, 1990, 1991 and 1993.

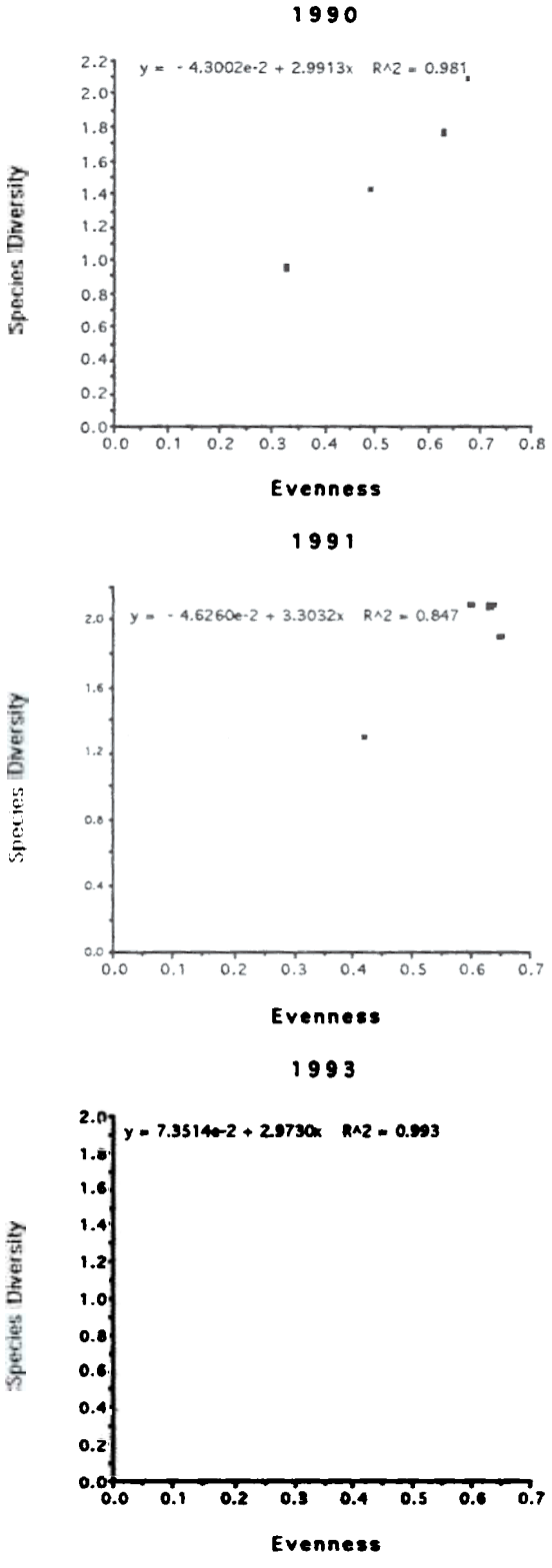


Figure 12. Species diversity of fish collections and evenness, plotted from trapnet catches of adult fish in Onondaga Lake, June - October, 1990 - 1993.

NATURAL REPRODUCTION

The distribution of juvenile fish among littoral habitat types depends on habitat characteristics and species adaptations (Meals 1987). Despite a highly modified littoral zone, some regions of Onondaga Lake are suited to nesting and rearing of juvenile fish. Ten of 48 species have been documented to reproduce successfully since 1991.

Seining during 1980 revealed few juvenile fish, suggesting to Chiotti (1981) that natural recruitment in the lake was limited or sporadic. Noble and Forney (1971) also noted that reproduction appeared to be limited in 1971. Sampling from 1991 - 1993 indicated that bluegill, pumpkinseed, white perch, and gizzard shad have been reproducing successfully at least since 1991. Other [illegible] and yellow perch reproduce within

Table 6. Levels of natural reproduction in Onondaga Lake 1991 - 1993, based on catches in shoreline seine hauls of fish less than 100 mm.

High success (average catch > 25 juveniles per 30 m seine)

White perch	Bluegill	Golden shiner
Gizzard shad	Carp	Pumpkinseed

Moderate success (average catch < 25 juveniles per 30 m seine)

Largemouth bass	Yellow perch	Brook silverside
Banded killifish		

Low success (average catch < 1 juvenile per 30 m seine)

Smallmouth bass	Northern pike	Brown bullhead
Black crappie	Freshwater drum	Emerald shiner

No success or unknown (0 juveniles per year

Longnose gar	Redfin shiner	White bass
Bowfin	Spotfin shiner	Rock bass
Yellow bullhead	Bluntnose minnow	Green sunfish
Channel catfish	Fathead minnow	White crappie
Redhorse sucker	Central mudminnow	Tesselated darter
Creek chub	Chain pickeral	Log perch
Common shiner	Brook stickleback	Walleye

Migratory spawners

White sucker	Sea lamprey	American eel
Brown trout	Brook trout	Rainbow trout
Rainbow smelt		

Hybrid - non reproductive species

Tiger trout	Tiger muskellunge

Table 7. Species composition of juvenile fish captured in seine samples from Onondaga Lake, 1991.

CPUE is based upon number of fish captured per 30 m seine haul.

Species	N	CPUE	Average L(mm)	Range (mm)
Gizzard Shad (*Dorosoma cepedianum*)	2436	30.45	65	32 - 146
White Sucker (*Catostomus commersoni*)	43	.54	54	34 - 95
Carp (*Cyprinus carpio*)	78	.98	65	15 - 113
Golden Shiner (*Notemigonus crysoleucas*)	79	.99	50	33 - 92
Creek Chub (*Semotilus atromaculatus*)	246	3.08	na	na
Emerald Shiner(*Notropis atherinoides*)	11	.14	57	31 - 86
Spotfin Shiner (*Notropis spilopterus*)	23	.29	80	65 - 98
Bluntnose Minnow (*Pimephales notatus*)	32	.40	59	55 - 74
Banded Killifish (*Fundulus diaphanus*)	648	8.10	61	26 - 97
Brook Silverside (*Labidesthes sicculus*)	227	2.84	64	19 - 98
Brook Stickleback (*Culaea inconstans*)	1	.01	na	na
White Perch (*Morone americana*)	556	6.95	45	26 - 95
Pumpkinseed (*Lepomis gibbosus*)	67	.84	77	60 - 99
Bluegill (*Lepomis macrochirus*)	62	.78	73	60 - 94
Lepomis spp. (*Lepomis spp.*)	4243	53.04	32	19 - 59
Smallmouth Bass (*Micropterus dolomieui*)	3	.04	na	na
Largemouth Bass (*Micropterus salmoides*)	165	2.06	61	31 - 185
Black Crappie (*Pomoxis nigromaculatus*)	2	.03	34	30 - 37
Tesselated Darter (*Etheostoma olmstedi*)	14	.18	60	54 - 68
Log Perch (*Percina caprodes*)	39	.49	70	54 - 85
Yellow Perch (*Perca flavescens*)	109	1.36	59	11 - 97
Total	9113			

seine catches. Juvenile and adult banded killifish (Fundulus diaphanus) and brook silversides (Labidesthes sicculus) were also present in significant numbers. Smaller numbers of juvenile carp (Cyprinus carpio), largemouth and smallmouth bass, yellow perch and white sucker (Catostomus commersoni) were also collected (Table 7).

Reproductive success in 1992 was limited compared to 1991 and 1993 (Table 8). A total of 4265 fish representing 18 species was collected in seine samples in 1992, but reproduction was documented in only 5 species: white sucker (925), largemouth bass (1), northern pike (3), Lepomis spp. (31) and freshwater drum (1) (Table 8). Most species declined in the catch from the previous year with the exception of adult banded killifish, which represented 7% of the total catch in 1991 and 52% in 1992. White suckers and adult brook silversides also increased from 1% and 3% in 1991 to 21% and 5% in 1992, respectively. The most dramatic decreases were apparent with Lepomis spp, which together represented 48% of the total catch in 1991 and 14% in 1992. Gizzard shad and white perch also sharply declined from 21% and 6% of the catch in 1991 respectively, to 0 in 1992

A marked increase in overall abundance was observed in 1993 compared to 1991 and 1992 (Tables 7-9). Catch per unit of seine effort was significantly greater in 1993 ($P < 0.05$), compared to 1991 and 1992. A total of 37,825 fish was collected in seine hauls (Table 9). The most apparent change was the increase in juvenile carp from less than 1% and 0% of the total catch in 1991 and 1992 to 22% of the total catch in 1993. Young pumpkinseed

Table 8. Species composition of juvenile fish captured in seine samples from Onondaga Lake, 1992.

CPUE is based upon number of fish captured per 30 m seine haul.

Species	N	CPUE	Average L(mm)	Range (mm)
White Sucker (*Catostomus commersoni*)	926	19.29	na	na
Carp (*Cyprinus carpio*)	2	.04	na	na
Golden Shiner (*Notemigonus crysoleucas*)	22	.46	133	127-140
Emerald Shiner(*Notropis atherinoides*)	36	.75	79	49 - 95
Spotfin Shiner (*Notropis spilopterus*)	25	.52	na	na
Bluntnose Minnow (*Pimephales notatus*)	118	2.46	na	na
Fathead Minnow (*Pimephales promelas*)	18	.38	61	51 - 71
Rainbow Smelt (*Osmerus mordax*)	1	.02	na	na
Northern Pike (*Esox lucius*)	3	.06	na	na
Banded Killifish (*Fundulus diaphanus*)	2231	46.48	44	33 - 78
Brook Silverside (*Labidesthes sicculus*)	255	5.31	57	33 - 99
Pumpkinseed (*Lepomis gibbosus*)	290	6.04	114	102-124
Bluegill (*Lepomis macrochirus*)	273	5.69	101	54-141
Lepomis spp. (*Lepomis spp.*)	31	.65	33	23 - 87
Smallmouth Bass (*Micropterus dolomieui*)	2	.04	na	na
Largemouth Bass (*Micropterus salmoides*)	2	.04	113	53-173
Yellow Perch (*Perca flavescens*)	15	.31	74	na
Freshwater Drum (*Aplodinotus grunniens*)	1	.02	na	na
Total	4265			

Table 9. Species composition of juvenile fish captured in seine samples from Onondaga Lake, 1993.

CPUE is based upon number of fish captured per 30 m seine haul.

Species	N	CPUE	Average L(mm)	Range (mm)
Gizzard Shad (Dorosoma cepedianum)	1616	44.89	70	33-104
White Sucker (Catostomus commersoni)	375	10.42	49	17 - 74
Carp (Cyprinus carpio)	8504	236.22	53	55 - 67
Golden Shiner (Notemigonus crysoleucas)	391	10.86	56	22 - 48
Emerald Shiner(Notropis atherinoides)	149	4.14	45	23 - 88
Spotfin Shiner (Notropis spilopterus)	1	.03	na	na
Bluntnose Minnow (Pimephales notatus)	3	.08	64	55 - 67
Fathead Minnow (Pimephales promelas)	65	1.81	46	45 - 47
Northern Pike (Esox lucius)	2	.06	80	na
Banded Killifish (Fundulus diaphanus)	98	2.72	58	29 - 92
White Perch (Morone americana)	2624	72.89	46	23 - 81
Pumpkinseed (Lepomis gibbosus)	6154	170.94	128	66-192
Bluegill (Lepomis macrochirus)	815	22.64	85	70 - 95
Lepomis spp. (Lepomis spp.)	14476	402.1	29	14 - 56
Smallmouth Bass (Micropterus dolomieui)	1	.03	na	na
Largemouth Bass (Micropterus salmoides)	274	7.61	55	25-111
Black Crappie (Pomoxis nigromaculatus)	2	.06	na	na
Tesselated Darter (Etheostoma olmstedi)	6	.17	na	na
Log Perch (Percina caprodes)	500	13.89	62	50 - 75
Yellow Perch (Perca flavescens)	1769	49.14	54	20 - 95
Total	37825			

and bluegill dominated the catches. A total of 21,445 juvenile pumpkinseeds and bluegill was collected (57% of the total catch: Table 9). Juvenile white perch and gizzard shad represented 11% of the total seine catch in 1993. Banded killifish, which dominated in 1992, comprised less than 1% of the catch in 1993. The numbers of juvenile yellow perch also increased from the previous two years (Table 9). Overall diversity in 1991 ranged from a low of 1.44 (Willow Bay) to a high value of 1.61 (Marina) (Figure 13). Seasonal variation in diversity of the four sampling locations did not change significantly from June to August ($P \geq 0.10$) (Table 10).

In 1992 sites located in the southern end of the lake had higher diversity values than those located in the north, Ley Creek and Metro had values of 2.37 and 1.95, compared to 1.72 and 1.66 from the Marina and Willow Bay (Figure 14). The lowest values of 0.18 and 0.57 were from samples taken at Dover Cliffs and White Sands (Figure 14). These areas are located on the west side of the lake along the waste beds, which are devoid of aquatic macrophytes and submerged structure.

Seasonal shifts in diversity were most apparent at the Metro, Maple Bay, Ninemile and White Sand sites. Sampling conducted in August revealed the absence of fish from these sites. Sampling in November however, revealed fish in all these sites with the exception of Metro, which was still devoid of fish in the seine hauls (Table 11). Diversity at other locations did not fluctuate significantly on a seasonal basis.

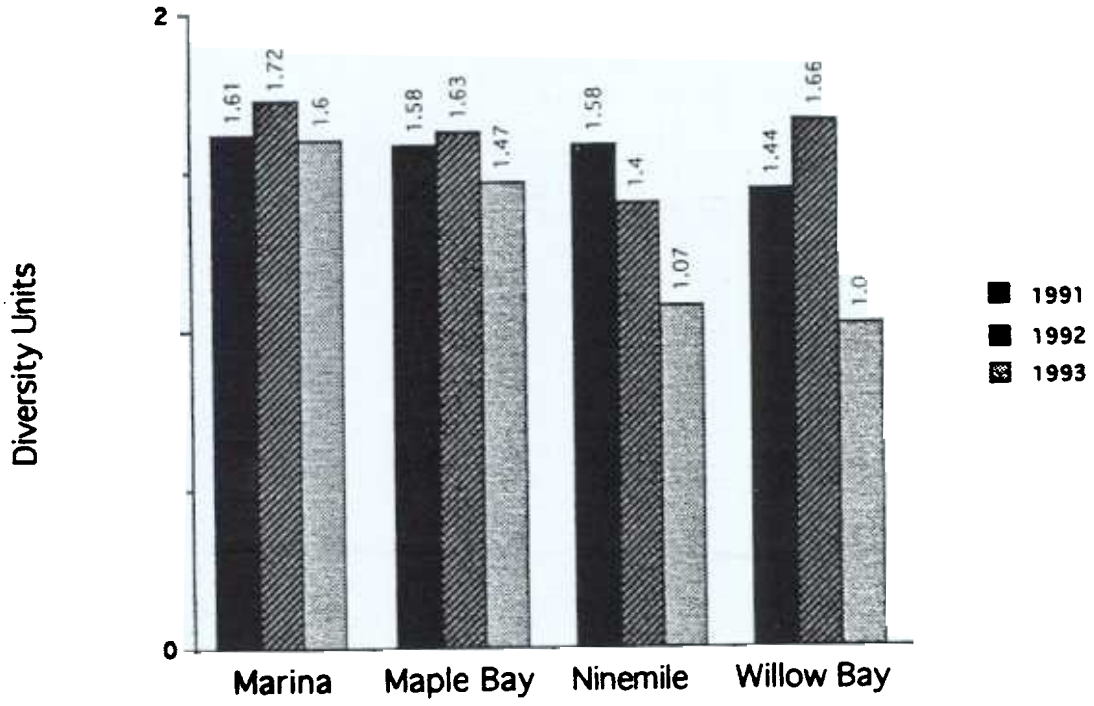


Figure 13. Shannon Weiner diversity index for juvenile fish captured in seine hauls, Onondaga Lake, 1991 - 1993.

Table 10. Monthly Shannon Weiner diversity index of juvenile fish captured in seine hauls, Onondaga Lake, June - August, 1991.

Site	Shannon Index	Evenness	Richness
Marina			
June	1.41	0.64	9
July	1.24	0.49	12
August	1.14	0.61	10
Year	1.61	0.59	15
Ninemile			
June	0.63	0.90	2
July	1.21	0.49	12
August	1.50	0.65	12
Year	1.57	0.60	14
Willow Bay			
June	1.59	0.77	8
July	1.46	0.59	12
August	1.24	0.47	14
Year	1.43	0.51	17
Maple Bay			
June	1.50	0.68	9
July	1.38	0.55	14
August	1.14	0.55	8
Year	1.57	0.60	14

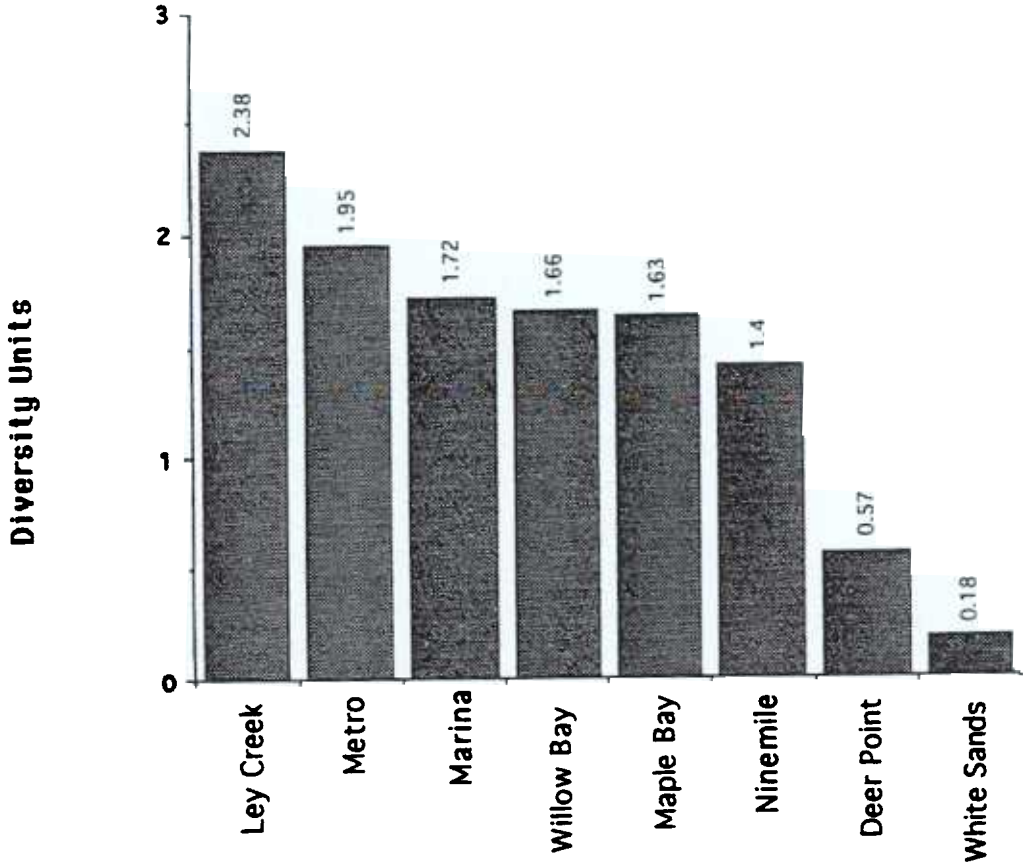


Figure 14. Shannon Wiener diversity index of juvenile fish captured in seine hauls, Onondaga Lake, 1992.

Table 11. Monthly Shannon Wiener Diversity index of junenile fish captured in seine hauls, Onondaga Lake, June, August and November, 1992.

Site	Shannon Index	Evenness	Richness
Ley Creek			
June	2.19	0.83	14
August	0.83	0.60	4
November	1.74	0.97	6
Year	2.37	0.85	6
Metro			
June	1.92	0.83	10
August	0.0	0.0	0
November	0.0	0.0	1
Year	1.95	0.81	11
Marina			
June	1.65	0.69	1
August	0.84	0.61	4
November	0.69	0.99	2
Year	1.72	0.72	1
Willow Bay			
June	1.43	0.74	7
August	1.29	0.66	7
November	1.46	0.91	5
Year	1.66	0.72	10
Maple Bay			
June	0.01	0.63	5
August	0.0	0.0	0
November	1.20	0.67	6
Year	1.63	0.74	9
Ninemile			
June	1.11	0.57	7
August	0.0	0.0	0
November	1.04	0.58	6
Year	1.39	0.63	9
Deer Point			
June	0.51	0.29	6
August	1.05	0.96	3
November	0.56	0.81	2
Year	0.57	0.25	8
White Sands			
June	0.12	0.06	7
August	0.0	0.0	0
November	0.40	0.06	2
Year	0.18	0.09	8

Species diversity tended to decrease through the 1993 sampling season in all sites except Maple Bay, which had a diversity index of 0.79 and 0.62 in June and July and increased to a value of 0.88 in August (Table 12). The Marina had the highest diversity index for the year (1.60), followed by Maple Bay, Willow Bay and Ninemile with diversity indexes of 1.47, 1.07 and 1.01, respectively (Figure 13).

The temperature regime during and following spawning has often been cited as a factor regulating early survival of fish, although supporting evidence is not conclusive (Forney 1972). The abundance of juvenile fish captured in seine hauls taken from Onondaga Lake, 1991, 1992 and 1993 was compared with air temperatures recorded at the U.S. Weather Bureau Station at Hancock Field (11.3 km east of Onondaga Lake) for evidence of climatic effects on reproduction.

Mean summer air temperatures were not significantly lower in 1992 than in 1991 or 1993 (Table 13). However, unusually cold temperatures in 1992 began on June 20 and lasted until July 7. The average temperature during this period in 1992 was 16°C, significantly lower ($p < 0.01$) compared to temperatures of the same period in 1991 (22°C) and 1993 (20°C). These temperature regimes, coupled with unusually high spring and mid-summer water levels seem to explain the limited reproductive success of many species. The average number of juvenile largemouth bass collected in seine hauls was lowest in 1992 (Table 8). Catches of other species were also low in 1992 compared to 1991 and 1993 (Table 8).

Table 12. Monthly Shannon - Weiner Diversity Index of juvenile fish captured in seine hauls, Onondaga Lake, June - August, 1993.

Site	Shannon Index	Evenness	Richness
Marina			
June	1.94	0.81	11
July	1.18	0.51	10
August	1.37	0.53	13
Year	1.60	0.56	17
Ninemile			
June	1.07	0.99	3
July	1.02	0.43	11
August	0.28	0.33	11
Year	1.01	0.39	13
Willow Bay			
June	1.10	0.99	3
July	0.84	0.38	9
August	0.71	0.31	10
Year	1.07	0.42	13
Maple Bay			
June	0.79	0.44	6
July	0.61	0.31	7
August	0.88	0.41	11
Year	1.47	0.56	14

Table 13. Mean air temperatures recorded at the U.S Weather Bureau Station at Hancock Field, June, July and August, 1991 - 1993.

Year	June	July	August
1991	68.4	72.4	71.8
1992	64.0	67.3	67.5
1993	65.2	72.5	70.7

AGE AND GROWTH

The primary objective of the age and growth analysis was to describe the size and age distribution as well as the growth and adult mortality rates of dominant fish species found within Onondaga Lake. An important goal was to compare them with other water bodies, and to Onondaga Lake before the closure of Allied Chemical Corporation. Reliable and detailed analyses of age and growth data are needed to develop of a biologically sound fisheries management plan for Onondaga Lake. Previous information on fish growth in Onondaga Lake is limited to reports by Chiotti (1981), Gandino (1988), and Ringler et al. (1996).

Smallmouth bass

A well conditioned external appearance was characteristic of Onondaga Lake smallmouth bass examined in the summer and fall. Growth was satisfactory, especially considering an active growing season of about four months and the lack of oxygen encountered during the summer and fall throughout much of the lake.

Growth rates of smallmouth bass did not change significantly ($P > .05$) annually (1990 to 1993) as shown by comparison of mean lengths at each age 1 to 10 (Figure 15). The growth of smallmouth bass in Onondaga Lake was substantially greater than that reported for several other lakes in the northeastern United States, but slower than in nearby Oneida Lake (Forney, 1961) and Cayuga Lake (Webster, 1945) (Table 14). Collections of adult smallmouth bass greater than 12 inches from Onondaga Lake were examined by the New York State Department of Environmental Conservation in 1979,

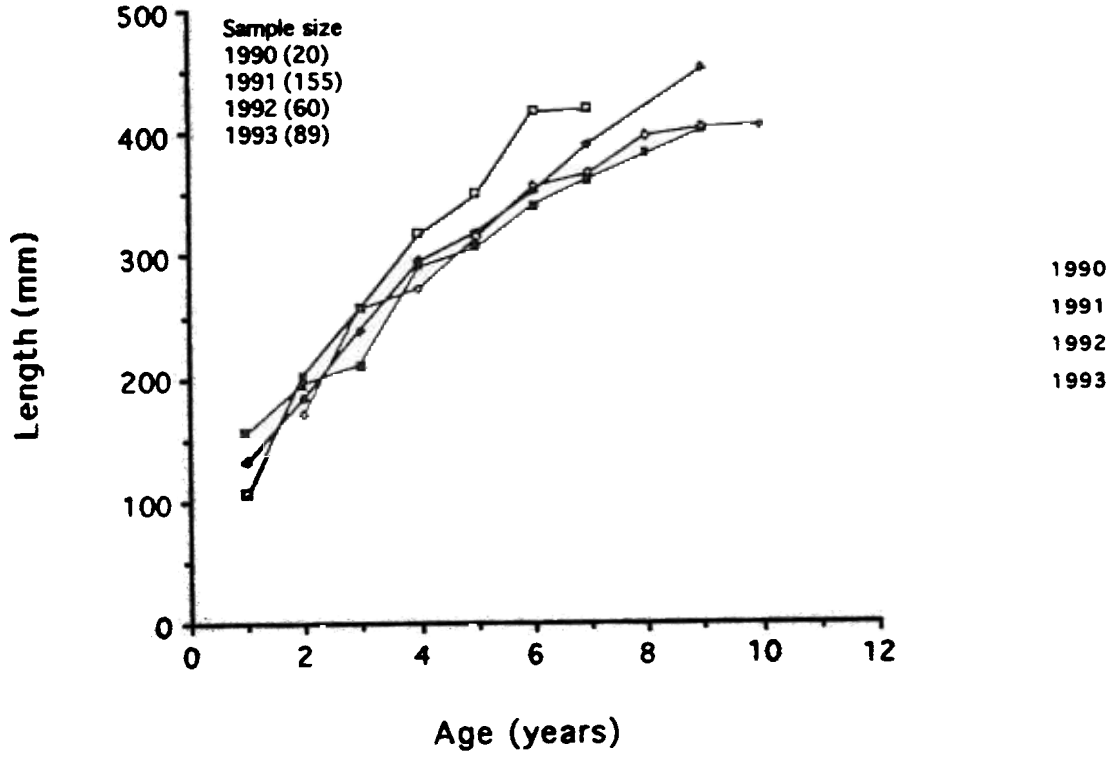


Figure 15. Average length (mm) at age of smallmouth bass captured in trap and gillnets, Onondaga Lake, 1990 - 1993.

Table 14. Observed mean length (mm) at age for smallmouth bass from selected waters in the northeastern United States.

Water	Age 9	1	2	3	4	5	6	7	8
Onondaga Lake									
1979				270	300	312	372	388	410
[a]1980			220	267	304	334	342	434	403
1984				258	286	289	310	344	361
1991	133	185	240	296	320	353	391		
1992	156	197	212	294	309	342	363	384	403
1993		171	258	275	316	358	368	399	405
[b]Canandarago Lake		165	227	276	318	352	393	414	440
[b]Cranberry Lake	88	139	182	244	264	334		372	394
[b]Jamesville Reservoir		169	241	233	269	317			437
[b]Lake Ontario		189	225	262	296	322	346	373	392
[b]Otisco Lake			203	210	270	322	370	411	409
[b]Skaneateles Lake			222	210	255	268	267	322	292
[b]St. Lawrence River		167	192	242	274	299	320	347	366
[b]Waneta Lake	102	165	234	281	314	345	390	416	418
[c]Oneida Lake									
1954			285	305	337	360	385	410	470
1958			285	317	337	370	400	418	413
[d]Cayuga Lake	160	210	258	303	343	368	390	418	425

[a] Source: Chiotti, 1981.
[b] Source: NE Division AFS Warmwater Workshop, "Managing Black Bass in Northern Waters", held October 5 - 6, 1993 in Alexandria Bay, NY.
[c] Source: Forney, 1961.
[d] Source: Webster, 1954.

1980 and 1984. These results did not significantly differ from those observed in this study (one way analysis of variance P > .05) (Table 14). Under the current 305 mm (12 inch) minimum statewide size limit, most smallmouth bass in Onondaga Lake were recruited into the fishery during their fourth and fifth growing seasons. In nearby Oneida and Cayuga lakes, most recruitment into the fishery occurred during the third and fourth growing season Table 14). Average back-calculated lengths of smallmouth bass in 1992 from the first to ninth annulus were as follows: 94; 144; 192; 239; 270; 304; 332; 356; 376 mm (Table 15). The annual increments in length and weight (Table 16) showed a decelerating pattern.

Year class strength of smallmouth bass in Onondaga Lake is probably influenced by immigration of adults from the Seneca River. This is most apparent in the length frequency histograms, which indicate an absence of juvenile smallmouth bass (Figure 16). Dominant year classes were produced in 1986 and 1987, as smallmouth bass from these years continually dominated the catch in trap and gillnets.

Previous surveys indicated that fewer fish have been collected in the southern basin compared to the northern basin, presumably reflecting the more perturbed conditions there. Although yearly growth rates of smallmouth bass in the southern basin were nearly identical to those of the northern basin (Figure 17), about 72 % of the smallmouth bass > 300 mm were captured in the northern basin of the lake (Figure 18). Similarly all smallmouth bass > 400 mm were captured in the northern basin.

Table 15. Mean back-calculated lengths of smallmouth bass, walleye, bluegill, and pumpkinseed captured in trap and gillnets, Onondaga Lake, 1992.

SMALLMOUTH BASS

Age	N	Avg L(mm) at capture	1	2	3	4	5	6	7	8	9
1+	1	156	142								
2+	1	197	94	158							
3+	2	212	74	129	180						
4+	6	294	90	159	214	265					
5+	18	309	82	134	190	246	281				
6+	13	342	92	149	195	238	280	312			
7+	7	363	91	141	192	234	271	316	340		
8+	7	384	93	140	196	233	268	302	331	359	
9+	5	403	92	141	179	217	250	284	324	352	37

WALLEYE

Age	N	Avg L(mm) at capture	1	2	3	4	5	6	7	8
3+	1	412	142	222	328					
4+	17	415	159	246	309	367				
5+	9	464	178	262	325	371	421			
6+	10	507	163	246	319	382	431	479		
7+	12	507	143	225	282	338	390	439	478	
8+	5	591	159	255	330	401	460	497	536	5

BLUEGILL

Age	N	Avg L(mm) at capture	1	2	3	4	5	6	7	8
2+	1	113	70	95						
3+	1	145	57	94	115					
4+	17	144	54	80	106	129				
5+	18	167	58	87	112	134	154			
6+	10	176	54	79	106	128	148	162		
7+	5	180	57	81	99	118	135	155	169	
8+	1	185	51	78	92	118	144	164	173	1

PUMPKINSEED

Age	N	Avg L(mm) at capture	1	2	3	4	5
2+	4	128	47	98			
3+	24	141	47	90	121		
4+	21	158	44	79	111	142	
5+	7	174	51	91	118	142	161

Table 16 Absolute growth table for smallmouth bass, bluegill, pumpkinseed and walleye captured in trap and gillnets, Onondaga Lake, 1992.

Smallmouth bass Age	n=60 Length (mm)	Length increment	Weight (g)	Weight increment
1	94		10.7	
		50		27.3
2	144		38.0	
		48		51.4
3	192		89.4	
		47		81.9
4	239		171.3	
		31		74.8
5	270		246.1	
		34		103.9
6	304		350.0	
		28		104.8
7	332		454.8	
		24		104.7
8	356		559.5	
		20		98.6
9	376		658.1	

Bluegill Age	n=53 Length (mm)	Length increment	Weight (g)	Weight increment
1	57		2.9	
		28		7.4
2	85		10.3	
		20		10.0
3	105		20.3	
		20		15.3
4	125		35.6	
		20		21.7
5	145		57.3	
		15		21.3
6	160		78.6	
		11		18.7
7	171		97.3	
		9		17.4
8	180		114.7	

Table 16. (Continued)

Pumpkinseed n=56

Age	Length (mm)	Length increment	Weight (g.)	Weight increment
1	47		2.6	
		43		14
2	90		16.6	
		27		18.5
3	117		35.1	
		25		25.9
4	142		61.0	
		19		26.4
5	161		87.4	

Walleye n=54

Age	Length (mm)	Length increment	Weight (g.)	Weight increment
1	157		25.1	
		86		84.4
2	243		109.5	
		73		155.9
3	316		265.4	
		56		194.6
4	372		460.0	
		54		266.3
5	426		726.3	
		46		299.8
6	472		1026.1	
		35		279.7
7	507		1305.8	
		65		655
8	572		1960.8	

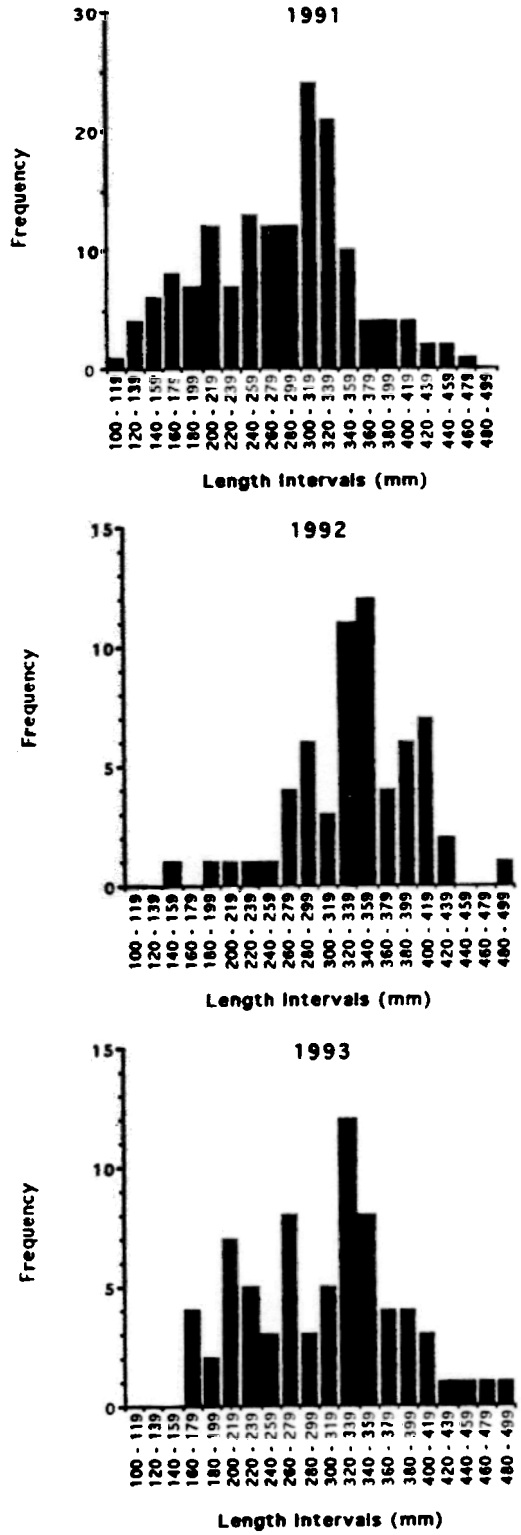


Figure 16. Length frequency histograms of smallmouth bass captured in trap and gillnets, Onondaga Lake, 1991 (April 23 - November 27), 1992 (June 10 - October 11), and 1993 (June 3 - October 15).

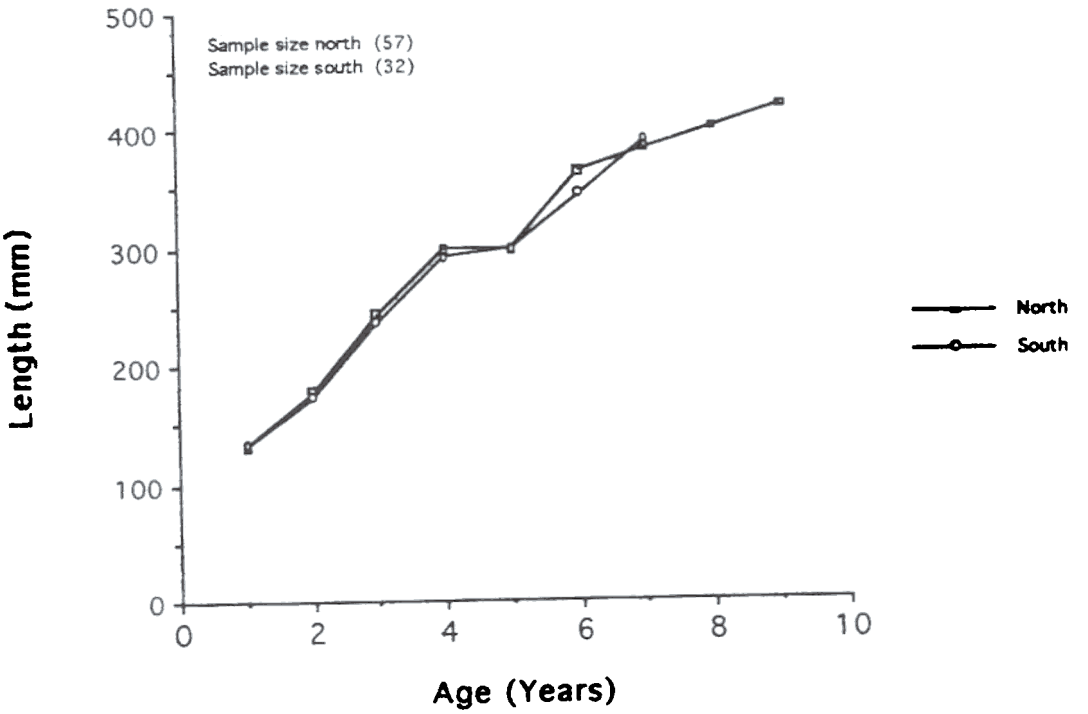


Figure 17. Average length at age of smallmouth bass caught in trap and gillnets from the north and south basins of Onondaga Lake, June 3 - October 15, 1993.

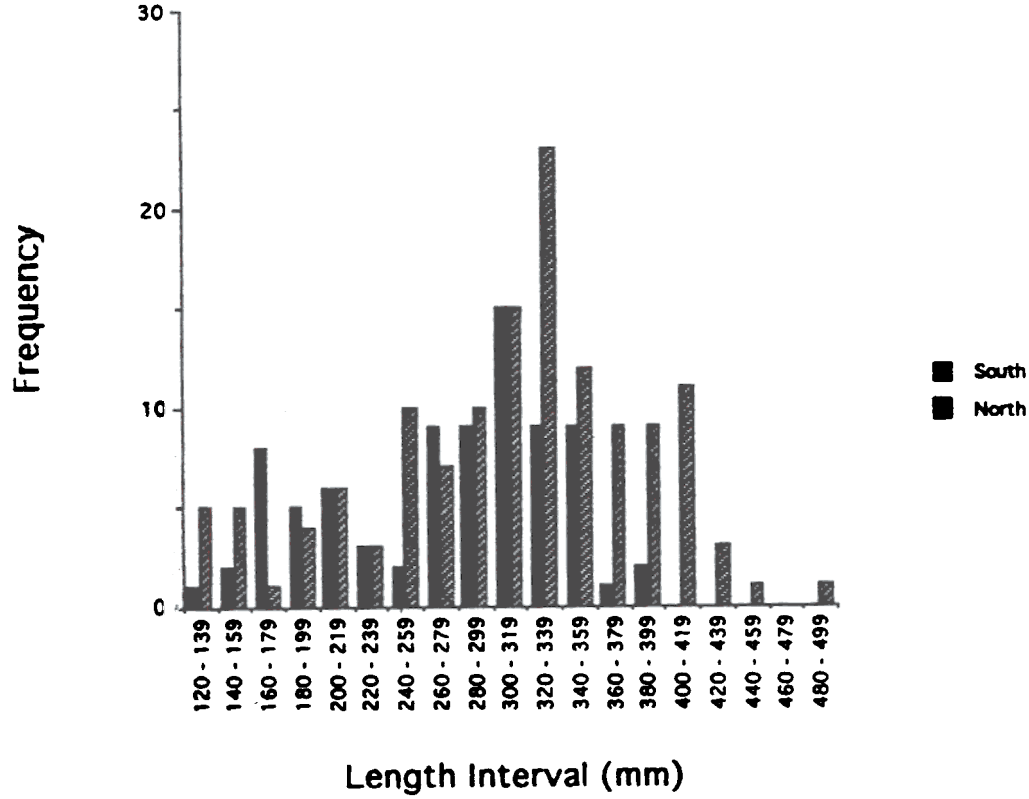


Figure 18. Length frequency histogram of smallmouth bass caught in the north and south basins of Onondaga Lake, 1991 (April 23 - November 27), 1992 (June 10 - October 11), 1993 (June 3 - October 15).

The average size of a smallmouth bass in the southern basin of the lake was 269 mm, compared to 305 mm in the northern basin. This difference in size distribution may reflect the more suitable conditions found in the northern basin of the lake as a result of the industrial and municipal wastewaters which discharge into the southern basin. Production of juvenile fish is also higher in the northern basin, which provides more forage to adult smallmouth bass.

Instantaneous rates of mortality (Z) of smallmouth bass estimated from catch curves ranged from 0.43 in 1990 to 0.61 in 1991 (Table 17). Annual survival rates ranged from 0.55 in 1991 to 0.65 in 1993 (Table 17). The instantaneous rate of mortality (Z) of smallmouth bass estimated from cohort analysis was 0.57 (Table 17). The annual survival of smallmouth bass from cohort analysis was 0.57 (Table 17). Estimated survival rates of smallmouth bass in Onondaga Lake were compared to rates in several other lakes found in the northeastern United States (Table 18).

Ricker (1975) reported that irregularities in catch curves from unstable recruitment can be reduced by combining samples from successive years. "If fishing has been steady, and the population consequently is presumed to be in a state of equilibrium except for variations in recruitment, then several years can be combined in this way without too much sacrifice of information concerning the past history of the stock in question (Ricker 1975 p 36)". Data from the four years, 1990 - 1993 for smallmouth bass were combined and each years catch was given equal weight to smooth the age frequency distribution. Survival computed from the catch curve

Table 17. Mortality and survivorship rates of adult fish captured in trap and gillnets, Onondaga Lake, 1989 - 1993.

Species	Z*	S*	A*	N*	Age Range
Smallmouth bass					
•1990	0.55	0.58	0.42	20	4 - 6
•1991	0.61	0.55	0.45	94	4 - 9
•1992	0.49	0.61	0.39	61	4 - 9
•1993	0.43	0.65	0.35	89	5-10
◊1991 - 1993	0.67	0.51	0.49	144	4 - 9
*1991 - 1993	0.57	0.57	0.43	44	4 - 6
Largemouth bass					
•1993	0.75	0.47	0.53	28	7-10
Bluegill					
*1991 - 1994	0.78	0.45	0.55	721	5 - 8
Pumpkinseed					
*1991 - 1994	0.43	0.64	0.36	283	5 - 8
White perch					
*1991 - 1994	0.55	0.57	0.43	1075	4 - 7
Walleye					
◊1989 &1992	0.42	0.66	0.34	96	4 - 8

Z = Intantaneous rate of mortality
S = Annual rate of survivorship = e^{-Z}
A = Annual rate of mortality = 1 - S
N = Sample size
*= Cohort analysis
•= Catch curve
◊=Smoothed catch curve

Table 18. Estimated annual survival rate (S) of smallmouth bass in Onondaga Lake compared to other populations in the northeastern United States.

State	Water	S	Age Range	Method
New York	Onondaga Lake			
	1990	0.58	4 - 6	catch curve
	1991	0.55	4 - 9	catch curve
	1992	0.61	4 - 9	catch curve
	1993	0.65	5 - 10	catch curve
	1991-1993	0.51	4 - 9	catch curve
	1991-1993	0.57	4 - 6	Cohort analysis
	[a]Lake Ontario	0.53		catch curve
	[a]Mohawk River	0.30	4 - 6	catch curve
	[a]Oneida Lake	0.57	5 - 10	catch curve
	[b]1955	0.51		catch curve
	[b]1956	0.73		catch curve
Maine	[a]Carlton Pond	0.63	5 - 10	•
	[a]Cobbosseecontee L.	0.50	7 - 12	•
	[a]Cathance Lake	0.62	6 - 9	•
	[a]Third Machias Lake	0.57	6 - 10	•
MA	[a]Singeltary Lake	0.67	4 - 8	Chapman-Robson
PA	[a]Large Rivers	0.24	4 - 10	catch curve
	[a]Warmwater Streams	0.14	5 - 9	catch curve

[a] Source: NE Division AFS Warmwater Workshop, "Managing Black Bass in Northern Waters", held October 5 - 6, 1993 in Alexandria Bay, NY.

[b] Source: Forney, 1961.

was 0.51 for ages 4 to 9 (Table 17)

Largemouth bass

Growth rates of largemouth bass sampled from Onondaga Lake in 1992 and 1993 were not significantly different (P > .05) (Figure 19). Growth of largemouth bass in Onondaga Lake is substantially greater than that of several other populations found in New York (i.e., Oneida River, Seneca River and Jamesville Reservoir), but less than in Cross Lake and Whitney Point Reservoir (Table 19). Under the current 305 mm (12 inch) minimum size limit most largemouth bass in Onondaga Lake are recruited into the fishery during the fourth and fifth growing seasons, compared to Whitney Point Reservoir and Cross lake, New York where most recruitment into the fishery occurred during the third and fourth growing seasons (Table 19).

The mortality estimates for largemouth bass are based on very small sample sizes. It has been difficult to get adequate samples of this species because they are not usually caught in traps. The largemouth bass is important, nevertheless, in the future management of Onondaga Lake, and the data will be presented even though they are sparse. Instantaneous rate of mortality (Z) of largemouth bass in 1993 was 0.75, annual rate of mortality (A) was 0.53 and annual survival rate (S) was 0.47. Estimated survival rates of largemouth bass in Onondaga Lake were lower than in other lakes in the northeastern United States (Table 20).

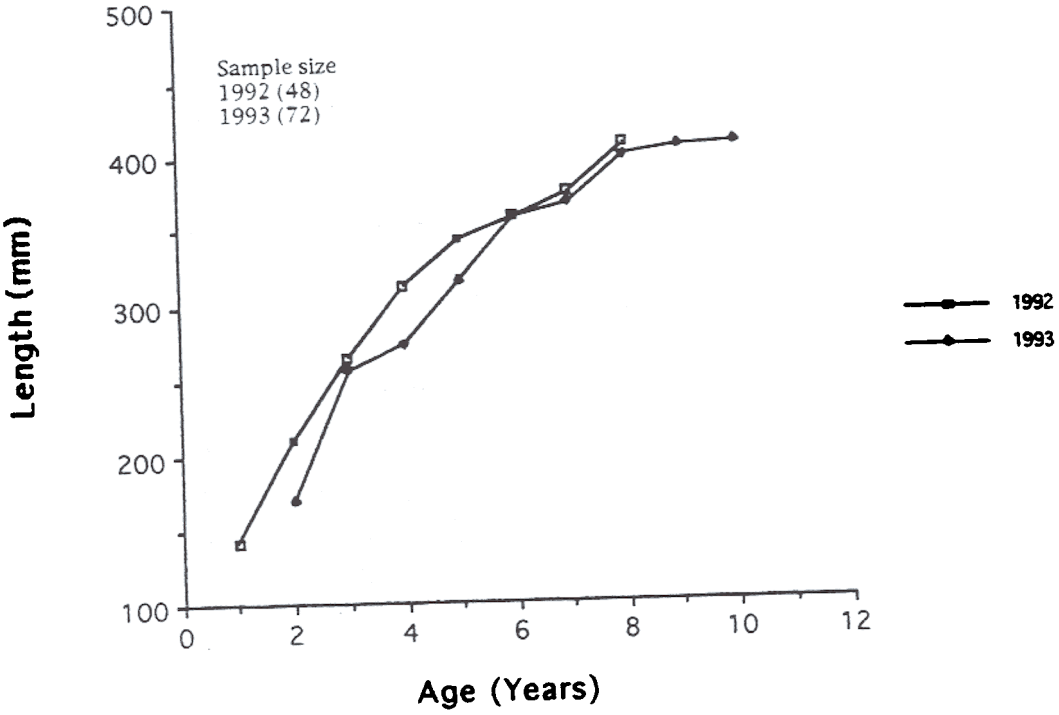


Figure 19. Average length at age of largemouth bass captured in trap and gillnets, Onondaga Lake, 1992 and 1993.

Table 19. Observed mean length (mm) at age of largemouth bass from Onondaga Lake compared to other populations in the northeastern United States.

Water	Age 1	2	3	4	5	6	7	8	9
Onondaga Lake									
1992	142	211	266	314	344	359	374	407	449
1993		171	258	275	316	358	368	399	405
[a]Oneida River				268	276	307	301	294	398
[a]Seneca River	115	170	235	273	349	289	377		417
[a]Lake Ronkonkoma1	35	212	250	281	279	362	415	474	439
[a]Whitney Point Reservior		170	267	323	330	383	399		395
[a]Tully Lake	78	189	256	298	330	357	377	406	424
[a]Cayuga Lake	106	195	250	282	311	363	403	455	
[a]Jamesville Reservoir		210	223	256	310	292	330		392
[b]Cross Lake			258	312	349	389	402		

[a] Source: NE Division AFS Warmwater Workshop, "Managing Black Bass in Northern Waters", held October 5 - 6, 1993 in Alexandria Bay, NY.

[b]Source: Schlueter, 1992.

Table 20. Estimated annual survival rate (S) for largemouth bass populations in Onondaga Lake compared to other populations in the northeastern United States .

State	Water	S	Age Range
New York	Onondaga Lake	0.47	7 - 10
	[a]Dryden Lake	0.67	5 and older
	[a]Bass Study Waters	0.65	5 and older
Massachusetts	[a]Laurel Lake	0.40	3 - 9
	[a]Manchaug Pond	0.55	3 - 7
	[a]Brimfiled Reservoir	0.47	2 - 9
	[a]John's Pond	0.57	3 - 7
Delaware	[a]Nanticoke River (1990)	0.55	2 - 9
	[a]Nanticoke River (1991)	0.58	2 - 7
	[a]Nanticoke River (1992)	0.53	2 - 7

[a] Source: NE Division AFS Warmwater Workshop, "Managing Black Bass in Northern Waters", held October 5 - 6, 1993 in Alexandria Bay, NY.

The growth rate young-of-the-year (YOY) largemouth bass was based on seine collections spaced throughout the summer of 1991 and 1993. In 1991 YOY largemouth bass first appeared in the collections on July 2 - 3. At that time the average length of 53 fish was 31 mm (Table 21) The next sample of 55 individuals, taken on July 16 - 22, averaged 61 mm. On August 11 - 13, the average length of 10 YOY largemouth bass was 82 mm. Collections on July 19 - 22, 1993 of 83 YOY largemouth bass averaged 52 mm. Lengths increased on August 1 - 5, averaging 60 mm for 117 individual YOY largemouth bass. On August 16 - 17, the average length of 42 YOY largemouth bass was 77 mm (Table 22)

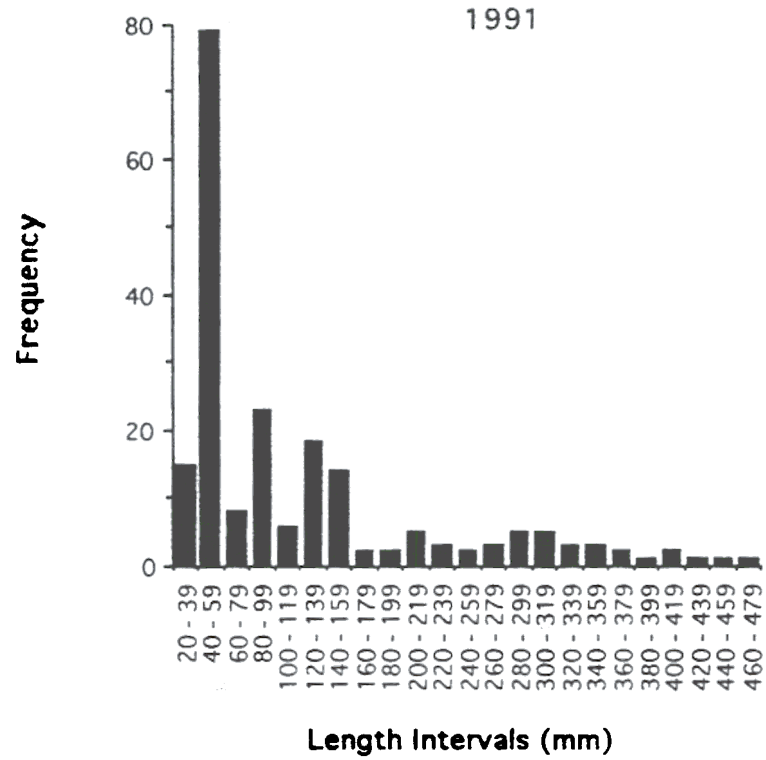
The extent to which immigration of largemouth bass from the Seneca River affects year class strength in Onondaga Lake is not known. However, unlike smallmouth bass, largemouth bass reproduce successfully within the lake. Year class failure was evident in 1992, as age 1 largemouth bass were almost totally absent from the 1993 seine sampling (Figure 20).

Table 21. Monthly length (mm) of juvenile largemouth bass collected from seine hauls, Onondaga Lake, June - August, 1991.

Site	Date	N	Average L(mm)	Range	St. Dev
Maple Bay	6/19/91	1	31	•	•
Maple Bay	7/3/91	16	44	36 - 55	
Maple Bay	7/22/91	2	66	62 - 70	
Maple Bay	8/11/91	1	84	•	•
Marina	7/2/91	20	43	33 -51	
Marina	7/16/91	8	58	50 -69	
Marina	7/31/91	3	71	64 - 80	
Marina	8/13/91	2	78	71 - 84	
Ninemile	7/3/91	2	46	45 - 47	
Ninemile	7/19/91	1	71	•	•
Ninemile	7/31/91	11	86	72 - 100	
Ninemile	8/13/91	1	90	•	•
Willow Bay	7/3/91	15	38	31 - 44	
Willow Bay	7/16/91	44	50	40 - 66	7.09
Willow Bay	8/1/91	15	72	52 - 84	7.55
Willow Bay	8/13/91	6	80	60 - 98	13.47

Table 22. Monthly length (mm) of juvenile largemouth bass collected fromseine hauls, Onondaga Lake, June - August, 1993.

Site	Date	N	Average L(mm)	Range	St. Dev
Marina	6/21/93	0	•	•	•
Marina	7//6/93	0	•	•	•
Marina	7/19/93	17	40	31 -44	
Marina	8/1/93	90	62	45 - 75	
Marina	8/16/93	0	•	•	•
Willow Bay	6/21/93	0	•	•	•
Willow Bay	7/6/93	0	•	•	•
Willow Bay	7/19/93	0	•	•	•
Willow Bay	8/5/93	20	65	50 - 72	
Willow Bay	8/16/93	40	76	55 - 91	
Maple Bay	6/22/93	0	•	•	•
Maple Bay	7/7/93	0	•	•	•
Maple Bay	7/22/93	66	37	25 - 46	
Maple Bay	8/3/93	6	57	41 - 64	
Maple Bay	8/17/93	0	•	•	•
Ninemile	6/22/93	0	•	•	•
Ninemile	7/7/93	0	•	•	•
Ninemile	7/22/93	0	•	•	•
Ninemile	8/3/93	1	54	•	•
Ninemile	8/17/93	2	78	72 - 83	7.79



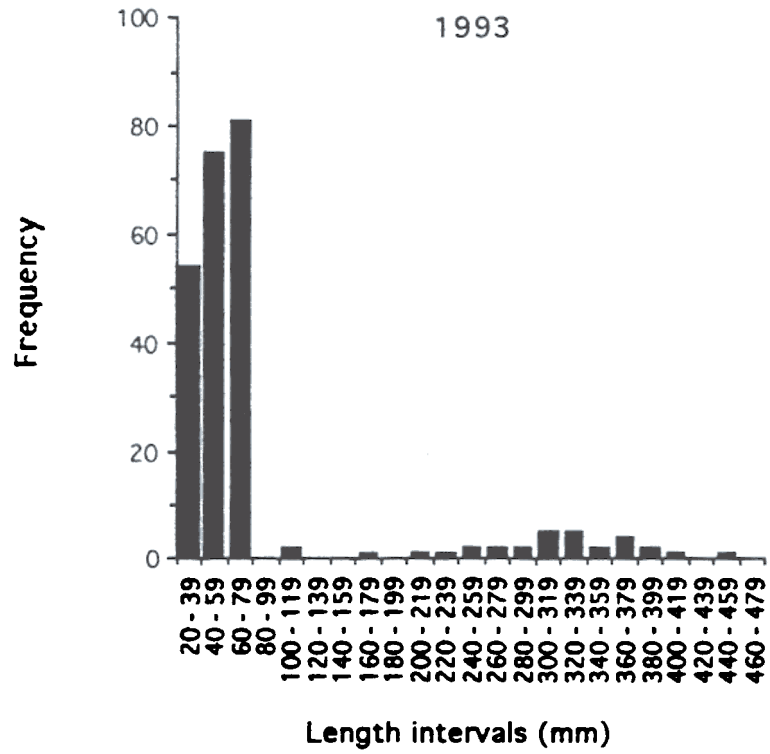


Figure 20. Length-frequency histogram of largemouth bass captured in trap, seine and gillnets in Onondaga Lake, 1991 and 1993.

Pumpkinseed and Bluegill

Pumpkinseed and bluegill are two of the most abundant sunfish in New York State (Smith 1985), and both are very common in Onondaga Lake. Although not an important game species such as the smallmouth bass and largemouth bass, they do offer much recreational fishing. Information gathered from these species is important in the future management of Onondaga lake.

Average length at age pumpkinseed sunfish from 1988 to 1992 did not change significantly ($P > .05$) (Figure 21). Growth rates of pumpkinseeds in Onondaga Lake are substantially greater than in several other populations (i.e., Rhode Island and Minnesota), but less than in Michigan (Table 23).

Back-calculated lengths of pumpkinseed in 1992 from the first to fifth annulus were as follows: 47, 90, 117, 142 and 161 mm (Table 15). The average annual increment in length was greatest in the first year of life, while the greatest increment in weight is attained in the fourth year of life (Table 16). Instantaneous rate of mortality (Z) of pumpkinseed from the 1988 cohort was 0.43 and the annual survival rate (S) was 0.64 (Table 17).

The average length at age of bluegill from 1990 to 1992 did not change significantly ($P > .05$) (Figure 22). Growth rates of bluegill were compared with fish from Oklahoma, Minnesota and Ohio (Table 23). The Onondaga Lake bluegill ages 1 - 3 grew faster than the fish from these other waters, but fish 4 - 6 grew more slowly.

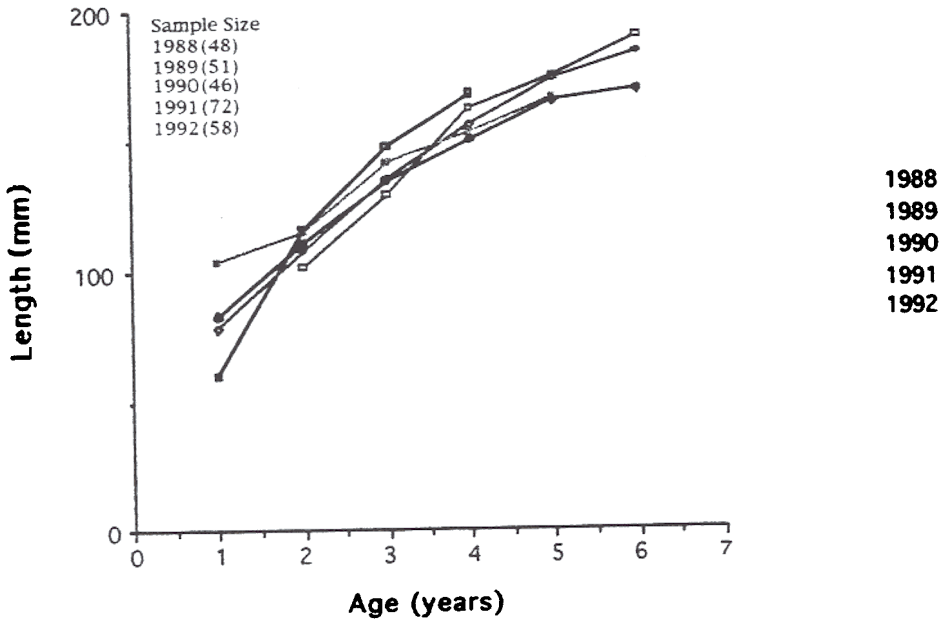


Figure 21. Average length (mm) of pumpkinseed captured in trapnets in Onondaga Lake, 1988 - 1992

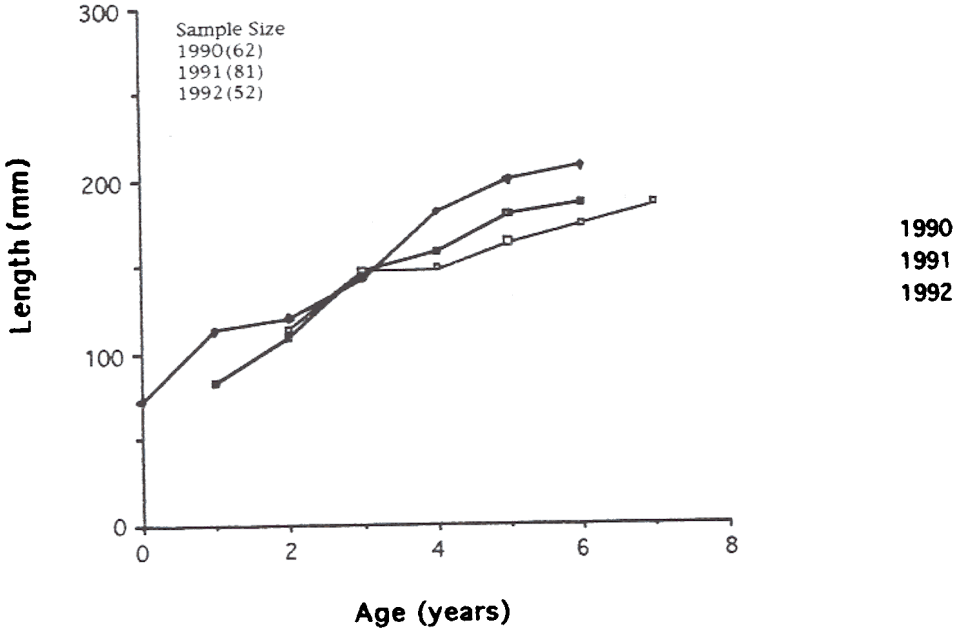


Figure 22. Average length (mm) of bluegill captured in trapnets in Onondaga Lake 1990 - 1992.

Table 23. Mean length (mm) at age for pumpkinseed and bluegill from Onondaga Lake compared to other populations in the United States.

Pumkinseed

Water	Age 1	2	3	4	5	6	7
Onondaga Lake							
1988 (n=48)	60	116	148	168			
1989 (n=51)	83	111	135	151	165	169	
1990 (n=46)		102	129	162	175	190	
1991 (n=72)	47	90	117	142	161		
1992 (n=58)	103	115	142	153	166		
[a]Rhode Island	40	78	110	138	155	168	178
[a]Minnesota	43	78	110	138	160	180	193
[a]Michigan	83	123	148	170	188	200	203

Bluegill

Water	Age 1	2	3	4	5	6	7
Onondaga Lake							
1990 (n=62)		82	108	147	158	179	186
1991 (n=81)	72	113	120	143	181	199	207
1992 (n=52)	57	85	105	125	145	160	171
[a]Oklahoma	80	123	150	170	180		
[a]Minnesota	48	85	123	153	178	195	
[a]Ohio	40	90	128	150	170	188	

[a]Source: Carlander (1977)

Possibly the available forage for the large fish is not abundant enough to allow them to maintain the relatively rapid growth that the younger fish achieve.

Observed back-calculated lengths of bluegill in 1992 from the first to eighth annulus, was 57, 85, 105, 125, 145, 160, 171 and 180 mm, respectively (Table 15). The average annual increment in length is greatest in the first year of life, while the greatest increment in weight is attained in the fourth year of life (Table 16). Instantaneous rate of mortality (Z) of the 1988 bluegill cohort was 0.78 and annual survival rate (S) was 0.45 (Table 17).

The growth rate of young-of-the-year (YOY) bluegill and pumpkinseed was determined from seine collections spaced throughout the summer of 1993. YOY bluegill and pumpkinseed first appeared in seine collections July 19 - 22; the average length of 131 YOY bluegill and pumpkinseed was 23 mm (Table 24). The next sample of 134 individuals, taken August 1 - 5, averaged 31 mm. On August 16 - 17, the average length of 138 YOY bluegill and pumpkinseed was 34 mm. These lengths are similar of those reported by Lane (1954), who found that YOY bluegill averaged 22, 33 and 43 mm on July 7, July 27 and September 17, respectively.

White Perch

The invasion of freshwater systems by exotic fish species poses a threat to native species and community stability. The white perch was one of several species to expand its range during the

Table 24. Monthly growth rates (mm) of juvenile pumpkinseed and bluegill collected from seine hauls, Onondaga Lake, June - August, 1993.

Site	Date	N	Mean Average L(mm)	Range (mm)	St. Dev
Marina	7/19/93	94	23	21 - 26	
Marina	8/1/93	3650	31	25 - 42	
Marina	8/16/93	955	28	20 - 44	
Ninemile	7/20/93	292	22	14 - 26	
Ninemile	8/3/93	3137	30	22 - 37	
Ninemile	8/17/93	2400	36	30 - 43	
Willow Bay	7/22/93	293	23	19 - 56	
Willow Bay	8/5/93	1761	32	25 - 48	4.41
Willow Bay	8/16/93	976	40	34 - 45	3.30
Maple Bay	7/22/93	4724	24	20 - 26	
Maple Bay	8/3/93	858	31	27 - 37	3.09
Maple Bay	8/17/93	547	32	18 - 42	5.70

twentieth century as canal systems were constructed (Smith 1985). Currently white perch are the most abundant species in Onondaga Lake. The effect of white perch on other species is not known, but diets of adult white perch and yellow perch are similar in Lake Ontario, which suggests some potential for competition (Danehy and Ringler 1991). Sheri and Power (1972) reported that white perch are prolific, and rapid density- dependent changes in their growth indicated intense intraspecific competition.

White perch scale samples were taken in 1988 (n=71) and 1990 (n=46) to determine growth and mortality rates. Average length at age of white perch in 1988 and 1990 was not significantly different ($P > .05$) (Figure 23). Instantaneous rate of mortality (Z) of the 1987 white perch cohort was 0.55, and annual survival rate (S) was 0.57 (Table 17). Annual survival rates of white perch in Onondaga Lake were higher than those collected in Oneida lake in 1957 and 1958, which were 0.28 and 0.34, respectively (Alsop and Forney 1962).

Walleye

The walleye is one of the most important game species in New York State (Smith 1985), and one of several species described by the Onondaga Lake Management Conference Fish and Wildlife Habitat Working Group in the long term restoration objectives. In this study 66% of walleye samples were collected in the fall with gillnets in water 2 - 10 m.

Mean total lengths of walleye sampled in 1992 from age three through eight were as follows: 412, 415, 464, 507, 507 and 591 mm (Table 15). Average back-calculated lengths in millimeters obtained from walleye in 1992 from the first to eighth annulus were: 157, 243, 316, 372, 426, 472, 507 and 572 mm (Table 15). The average annual increment in length was greatest in the first year of life, while the greatest increment in weight was attained in the seventh year of life (Table 16).

Scale samples from 1989 to 1993 were combined as described by Ricker (1975) to smooth out irregularities in catch curves from unstable recruitment and sampling. Instantaneous rate of mortality (Z) of walleye calculated from these data was 0.42, and annual survival rate (S) was 0.66 (Table 17).

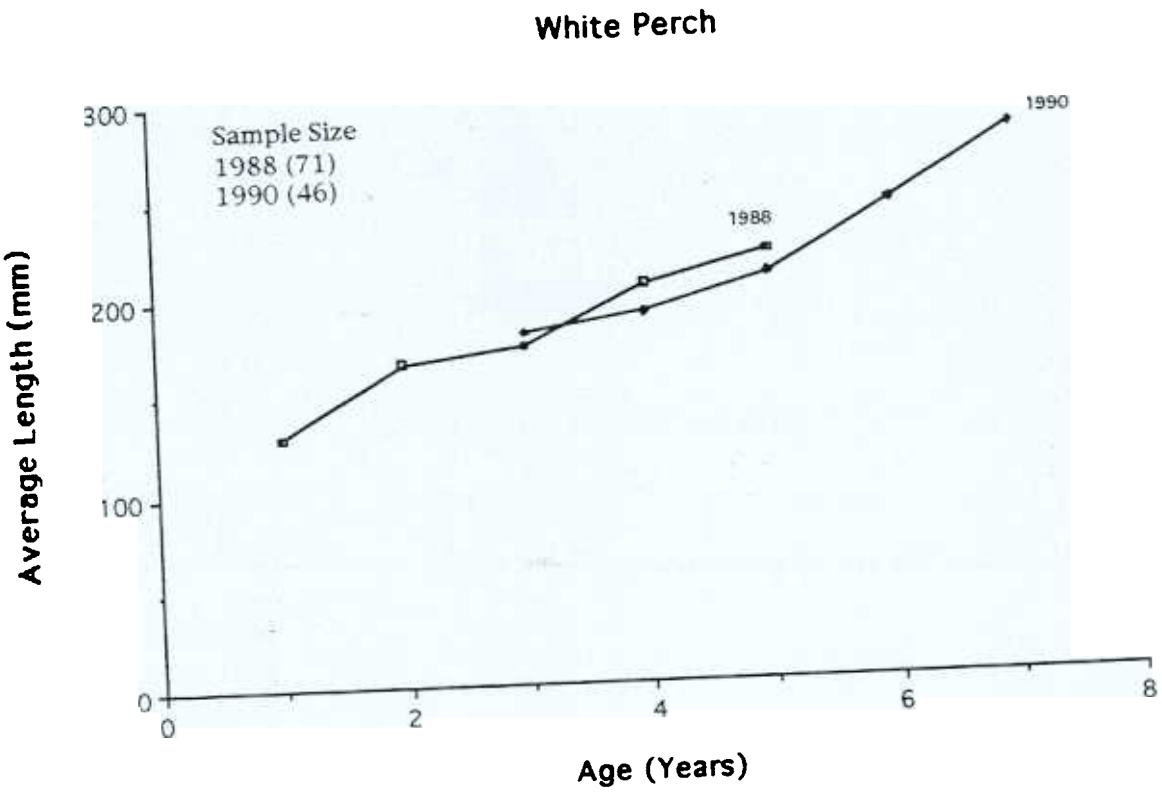


Figure 23. Average length at age of adult white perch captured in trap and gillnets, Onondaga Lake, 1988 and 1990.

POPULATION DENSITY AND BIOMASS

Schnabel population and biomass estimates were conducted in 1991 on largemouth bass, channel catfish, pumkinseed, bluegill, bowfin, smallmouth bass, carp, yellow perch and white perch This estimate was repeated in 1993 on all but two species, largemouth bass and yellow perch, which were not sampled effectively enough to provide reliable estimates. Population estimates were conducted on fish 100 mm and above. Density (number and kg/ha) was calculated on a lake wide (1201 ha) basis.

Black Basses

The 1991 population estimate for largemouth bass was 1146, with a 95% confidence interval of 382 $\leq$N $\leq$6,112 (Table 25). These estimates represent a density of only 1 largemouth per hectare (0.3 $\leq$ N $\leq$5). Biomass was calculated to be 613.46 kg (0.510 kg/hectare) Table 27).

The smallmouth bass population estimate in 1991 was 955, with a 95% confidence interval of 573 $\leq$N $\leq$2292 (Table 25). In 1993 the population estimate was 1172 with a 95% confidence interval of 209 $\leq$N $\leq$11720 (Table 26). Densities in 1991 and 1993 were 0.8 (0.5 $\leq$N $\leq$2) and 1 (0.2 $\leq$N $\leq$10) per hectare, respectively. The biomass in 1991 was 376.27 kg (.313 kg/hectare) (Table 28) and 547.32 kg (0.456 kg/hectare) in 1993 (Table 28). Sanders and Coble (1981), in a study in Clear Lake, Wisconsin 342-hectares) reported a mean population estimate for a two-year study of 2,980, or 8.7

Table 25. Population estimates and number per hectare of adult fish species > 100 mm captured in trapnets, Onondaga Lake, 1991.

Species	N	95% CI	Number per ha	95% CI
White Perch	323069	260617 - 401134	269	217-334
Bluegill	39919	31891 - 50042	33	27 -42
Pumpkinseed	6685	5157 - 8404	6	4 - 7
Carp	4393	2483 - 8595	4	2 - 7
Brown Bullhead	2674	1910 - 4011	2.23	2 - 3
Yellow Perch	2402	1201 - 4804	2	1 - 4
Channel Catfish	1528	955 - 3056	1	.8 - 3
Largemouth Bass	1146	382 - 6112	1	.3 - 5
Smallmouth Bass	955	573 - 2292	.8	.5 - 2
Bowfin	382	191 - 573	.3	.2 - .5

Table 26. Population estimates and number per hectare of adult fish species > 100 mm captured in trapnets, Onondaga Lake, 1993.

Species	N	95% CI	Number per ha	95% CI
White Perch	291049	166314 - 563322	242	138 - 469
Bluegill	40106	24258 - 71618	33	20 - 59
Pumpkinseed	8139	4284 - 18313	7	4 - 15
Channel Catfish	2708	1157 - 8462	2	1 - 7
Carp	2077	708 - 8462	2	.6 - 7
Brown Bullhead	1494	812 - 3178	1	.7 - 3
Smallmouth Bass	1172	209 - 11720	1	.2-10
Bowfin	491	265 - 1044	.4	.2 - .9

Table 27. Biomass estimates of adult fish species > 100 mm captured in trapnets, Onondaga Lake, 1991.

Species	Biomass (kg)	95% CI	kg /ha	95% CI
White Perch	40383.63	32577.13 - 50141.75	33.63	27.13-41.73
Carp	14528.66	8211.88 - 27814.12	2.10	6.84 - 23.16
Bluegill	3623.25	2894.59 - 4549.41	3.01	2.41 - 3.79
Channel Catfish	1019.18	637.0 - 2038.35	0.849	.530 - 1.70
Largemouth Bass	613.46	204.49 - 3271.75	0.510	.170 - 2.72
Brown Bullhead	641.76	458.4 - 926.64	0.534	.382 - .772
Pumpkinseed	557.93	429.65 - 695.32	0.465	.358 - .579
Bowfin	551.72	275.86 - 842.67	0.460	.230 - .702
Smallmouth Bass	376.27	225.66 - 1040.40	0.313	.188 - .866
Yellow Perch	275.39	137.69 - 550.78	0.230	.115 - .459

Table 28. Biomass estimates of adult fish species > 100 mm captured in trapnets, Onondaga Lake, 1993.

Species	Biomass (kg)	95% CI	kg /ha	95% CI
White Perch	36381.12	20789.90 - 70415.25	30.29	17 - 58.63
Carp	6869.12	2341.52 - 27985.78	5.71	1.95 - 23
Bluegill	3640.0	2200.0 - 6500.0	3.04	1.83 - 5.41
Channel Catfish	1112.98	475.52 - 3477.880	.930	.396 - 2.89
Bowfin	709.0	382.66 - 1507.540	.590	.319 - 1.26
Pumpkinseed	678.1	356.90 - 1525.650	.565	.297 - 1.27
Smallmouth bass	547.3	297.60 - 5473.24	0.456	.081 -4.56
Brown Bullhead	258.02	140.24 - 545.69	0.215	.117 - .454

smallmouth bass per hectare (1.1 kg/hectare) for fish 225 mm or longer: (95% confidence interval, 4 - 20 bass per hectare).

Sunfishes

Bluegill was the most common sunfish captured during this study. Population estimates in 1991 and 1993 differed little, with estimates of 39,919 (31,891 $\leq$N $\leq$50,042) and 40,106 (24,258 $\leq$N $\leq$ 71,618) respectively. These estimates represent densities of 33 (27 $\leq$N $\leq$42) per hectare in 1991 (Table 25); and 33 (20 $\leq$N $\leq$59) per hectare in 1993 (Table 26). Biomass was estimated to be 3,623 kg (3.01 kg/hectare) in 1991 and 3,640 kg (3.04 kg/hectare) in 1993 (Table 27 & 28). Population and biomass estimates for sunfish were not found in the literature for other northeastern lakes. Biomass estimates of bluegill from Onondaga Lake were however substantially lower than those from Beaver Lake, Arkansas, which averaged 22.8 kg/hectare (Rainwater 1982).

The pumpkinseed population estimate in 1991 was 6,685 with a 95% confidence interval of 5,157 $\leq$N $\leq$8,404. Density was estimated at 6 (4 $\leq$N $\leq$7) per hectare in 1991 (Table 25). The 1993 population estimate was 8,139 with a 95% confidence interval of 4,280 $\leq$N $\leq$18,313; density was estimated at 7 (4 $\leq$N $\leq$15) per hectare (Table 26). Biomass was estimated to be 557.93 kg (.465 kg/hectare) in 1991 (Table 28) and 678.1 kg (.565 kg/hectare) in 1993 (Table 28).

Catfishes

Brown bullhead were abundant in 1991 with an estimated population of 2,674 with a 95% confidence interval of 1,910 $\leq N \leq$ 4,011 and an estimated density of 2.2 (2 $\leq N \leq 3$) per hectare (Table 25). The population apparently decreased in 1993 to 1,494 with a 95% confidence interval of 812 $\leq N \leq 3,178$, and an estimated density of 1 (0.7 $\leq N \leq 3$) per hectare (Table 26). Brown bullhead population density estimates from Onondaga Lake are substantially lower than those reported for Muskellunge Lake, New York, 887 (664$\leq N \leq$ 1424) per hectare (Sinnott and Ringler 1987).

Channel catfish appeared in both years. Their biomass was highest in 1993 with estimates of 1,112.98 kg (0.930 kg/hectare), and lowest in 1991 with an estimated biomass of 1,019.18 kg (0.849 kg/hectare). These estimates are lower than those reported by Rainwater and Houser 1982 in Beaver Lake, Arkansas, where catfish biomass averaged 9 kg/hectare. The estimated population in 1991 was 1,528 with a 95% confidence interval of 955 $\leq N \leq 3,056$ and density estimates of 1 (.8 $\leq N \leq 3$) per hectare (Table 25). Population estimates in 1993 were 2,708 with a 95% confidence interval of 1,157 $\leq N \leq 8,462$ and a density estimate of 2 (1 $\leq N \leq 7$ per hectare (Table 26).

White perch

White perch were the most abundant fish sampled from Onondaga Lake in 1991 and 1993. The white perch population estimate in 1991 was 323,069 with a 95% confidence interval of 260,617 $\leq N \leq$ 401,134; density was estimated to be 269 (217 $\leq N \leq$ 334) per hectare (Table 25). The 1993 population estimate was 291,049 with a 95% confidence interval of 166,314 $\leq N \leq$ 563,322; density was 242 (138 $\leq N \leq$ 469) per hectare (Table 26). Biomass was estimated to be 40,383 kg (33.63 kg/hectare) in 1991 (Table 27), and 3,6381 kg (30.29 kg/hectare) in 1993 (Table 28).

Common Carp

Carp contributed 14,529 kg (12.10 kg /hectare), to the biomass of Onondaga Lake in 1991 (Table 27). Biomass dropped to 6,869 kg (5.71 kg /hectare) in 1993 (Table 28). Rainwter and Houser 1982, reported carp biomass of 77.6 kg / hectare in a study in Beaver Lake. The estimated population in 1991 was 4,393, with a 95% confidence interval of 2,483 $\leq N \leq$ 8,595 and a density estimate of 4 (0.2 $\leq N \leq$ 7) per hectare (Table 25). 1993 population estimates were 2,077 with a 95% confidence interval of 708 $\leq N \leq$ 8,462, and a density estimate of 2 (0.6 $\leq N \leq$ 7) per hectare (Table 25).

MOVEMENTS OF LAKE FISHES

Marked fish apparently moved little within the lake. Most littoral adult species such as sunfish tended to remain near their capture sites. Some pumpkinseed sunfish were captured in areas devoid of macrophytes, but most were later recaptured in areas that did contain aquatic vegetation. Recaptures of pelagic fish (e.g., white perch) also appeared most frequent in areas containing macrophytes. White perch are thought to rarely use macrophytes as cover, but often forage near plants nocturnally because of the presence of juvenile fish, a major food source (Smith 1985).

The Seneca River outlet acts as a corridor for fish movement to and from Onondaga Lake. Fish marked within Onondaga Lake have been captured in the river at various locations. Gillnets set June to October 1991 in the Seneca River caught 7 fish (4 white perch, 2 walleye, and a channel catfish) that were marked previously in the lake. Researchers from Cornell University captured 3 walleye in Oneida Lake in April 1995. These walleye were originally tagged in August of 1994 in Onondaga Lake.

An important contribution to the data base has been tag returns by anglers. A total of 33 tags have been returned by anglers since 1990. Returns of fish have been reported in the lake outlet as far up river as Baldwinsville (10 km), and as far down in the Oswego river as Fulton (25 km). Some returns have been reported even in the winter (February 21, 1991) by ice fishermen.

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A tagged bluegill was recaptured in Phoenix, approximately 10 km down river from the place of origin. This fish was tagged on September 12, 1990 at the Marina trap net location, and recaptured on June 9, 1991. A yellow perch tagged October 2, 1990 at the Maple Bay site was reported captured in Fulton May 30, 1991. To reach this destination the fish had to pass through the Phoenix lock system on the Oswego River. This suggests that limited movement of fish between Onondaga Lake and Lake Ontario is possible through the Phoenix and Oswego dams. Tagged channel catfish have been captured as far up river as Baldwinsville, and down river to Phoenix. Angler tag returns also indicated movement

SUGGESTED MANAGEMENT PLANS FOR THE FUTURE FISHERIES.

The Habitat Working Group of the Onondaga Lake Management Conference defined as one of its objectives in 1993, "The establishment of an indigenous and diversified warmwater species assemblage providing a sustainable, urban, catch and release (non-consumptive) sportfishery over the next five years". Several major game species including smallmouth bass, largemouth bass, walleye northern pike and channel catfish are currently found within the lake. The relatively low population densities suggest that existing populations probably could not withstand moderate to heavy fishing pressure without being significantly depleted. These species are growing well, but are low in relative abundance. Reproductive success is low to non-existent for all important game species except for largemouth bass. The general conditions of the lake, particularly shelter, aquatic vegetation, water quality and forage have been modified as a result of domestic and industrial inputs over the past century, thus adversely affecting the fish populations.

Although no quantitative data are available for angler use of Onondaga Lake, it is unquestionably lower than in surrounding lakes. Nevertheless, anglers should play a vital role in management decisions made with the fishery. This can be accomplished through sportsman group meetings, fishing derbies, and angler participation in studies. Volunteer anglers can provide usable information about largemouth and smallmouth bass populations. Ebbers (1987) reported that anglers provided data similar to that of electrofishing, including information on year-class strength. The ESF Chapter of the

American Fisheries Society on September 21, 1991 held an 8 hour bass fishing derby in which 22 anglers participated and caught 134 bass, many weighing three to four pounds. An angler creel census should be conducted on Onondaga Lake and the Seneca River to better understand the current fishery and help in developing a fisheries management plan for Onondaga Lake.

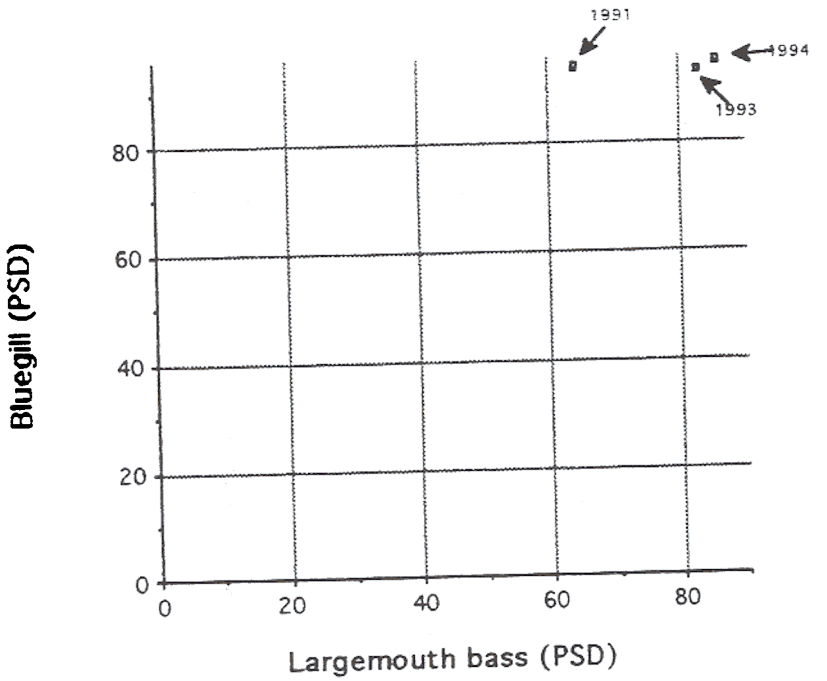
Smallmouth bass were the most frequently collected resident game species during the 1991 - 94 lake wide survey. PSD, RSD_{292}, RSD_{305}, RSD_{356}, and RSD_{432} of trap caught smallmouth bass averaged 81%, 63%, 50%, 32%, and 5%, respectively (Table 29). Smallmouth bass PSD and RSD values in Onondaga Lake were higher than those reported in the lower Mohawk River: PSD, RSD_{305}, RSD_{356}, and RSD_{406} averaged 47%, 38%, 8%, and 1%, respectively (Mcbride 1994). Largemouth bass PSD, RSD_{305}, RSD_{330}, RSD_{402}, and RSD_{488} averaged 78%, 77%, 49%, 13%, and 1%, respectively (Table 29). PSD of bluegill and pumpkinseed averaged 94% and 88%, respectively (Table 28). Largemouth bass PSD and prey species (bluegill and pumpkinseed) PSD were plotted in a tic-tac-toe graph as described by Anderson and Weithman (1978)(Figure 24). The graph helps to depict a community of largemouth bass, pumpkinseed and bluegill that is comprised of large, old specimens, as expected of an unfished population.

Management of this unique system will require habitat manipulations, supplemental stocking to restructure gamefish populations, management of undesirable fish species and the reduction of industrial and municipal waste inputs. Initial management techniques to increase the abundance of largemouth

Table 29. Proportional stock density (PSD) and relative stock density (RSD) of fish species captured in trap and gillnets, Onondaga Lake, 1991 - 1994.

	PSD	RSD305 (Quality)	RSD292 (Preferred)	RSD356 (Memorable)	RSD430 (Trophy)
Smallmouth bass					
1991	77	.47	.49	.11	.02
1992	90	.46	.80	.35	.03
1993	75	.41	.56	.24	.06
1994	80	.65	.68	.59	.08
Average	81	.50	.63	.32	.05

RSD488	PSD	RSD305 (Quality)	RSD330 (Preferred)	RSD402 (Memorable)	(Trophy)
Largemouth bass					
1991	64	.66	.33	.12	0
1993	83	.81	.52	.06	0
1994	86	.85	.63	.20	.03
Average	78	.77	.49	.13	.01
Bluegill					
1991	94				
1993	93				
1994	95				
Average	94				
Pumpkinseed					
1991	81				
1993	92				
1994	75				
Average	88				



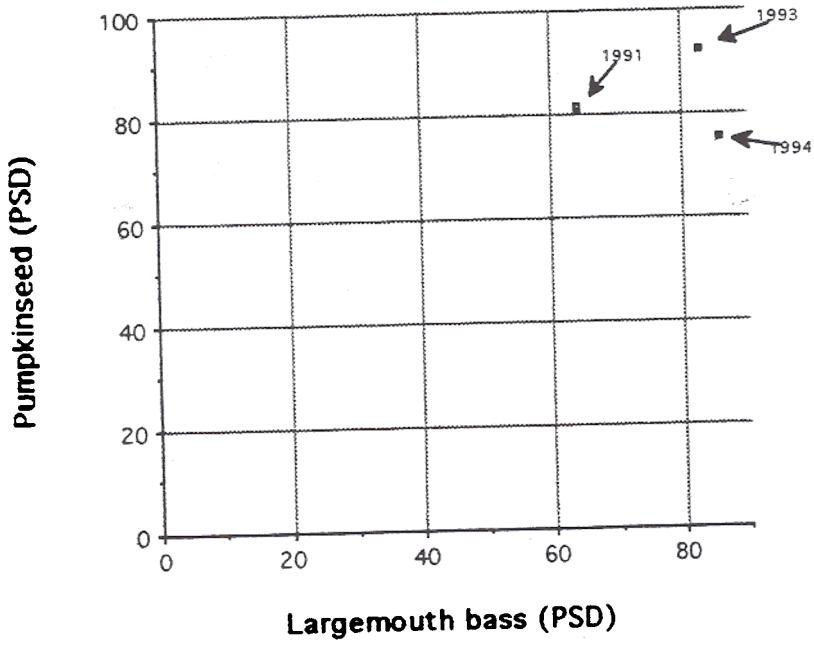


Figure 24. Proportional stock densities of largemouth bass compared to bluegill and pumpkinseed captured in trap and gillnets, Onondaga Lake, 1991, 1992 and 1994.

bass were begun in 1993 as a cooperative effort between several agencies to enhance littoral zone habitat (Arrigo and Ringler 1994). Nesting structures coupled with planted aquatic vegetation placed in the littoral zones met with encouraging results in increasing the number of spawning largemouth bass and YOY densities (Arrigo and Ringler 1994). Future plans include increasing the size of the manipulation areas and connecting an existing an wetland to the lake. This would promote spawning of northern pike and other species. The construction of spawning reefs in Brevort Lake, Michigan enhanced walleye reproduction and substantially increased walleye harvest (Prince et al. 1986). In addition to acting as spawning sites, artificial reefs may serve to concentrate diffuse fish populations, thereby increasing angler success.

Supplemental stocking was used to restructure two largemouth bass populations in Lake Bloomington and Lake Evergreen in central Illinois (Lutterbie 1993). Each lake was stocked with 11,800 largemouth bass ranging in size from 50 to 200 mm in 1990. In 1991 2500, 200 mm long largemouth bass were stocked; and 3000, 200 mm long largemouth bass were stocked in 1992. The three year stocking program achieved optimal catch per effort rates and PSD values in each lake. The largemouth bass characteristics developed due to this program represented the highest in the 20 and 30 year histories of the lakes.

The large populations of white perch and gizzard shad within Onondaga Lake may be depressing populations of more desirable species through competition for food. Manipulating forage fish populations to enhance sport fisheries is a common management

practice. Richard (1960), reported that the factor limiting abundance of game fish in Cross Lake in central New York was competition between juvenile game fish with white perch. Wills (1987) reported that high densities of gizzard shad (560 kg hectare) reduce standing crops of game fish, especially the centrarchids. However, the effects of gizzard competition have been notoriously difficult to understand (Devries and Stein 1990).

Three methods are used to control undesirable stocks of fish: chemical, biological, and mechanical. Although mechanical methods have been used successfully, they are labor intensive and often ineffective. Chemical control usually requires the removal of all species from a system, but partial treatments include treatment of spawning sites and particular sections of a lake (Lennon et al. 1970). Biological control can be grouped into three categories: (1) grazing and predation by zooplankton and fish; (2) use of pathogens; (3) biomanipulation. Biomanipulation is the most promising biological control technique for managing fish populations because it may minimize competition and help to stabilize predator-prey populations (Schuytema 1977). Tiger muskellunge have been considered for introduction into Onondaga Lake to help control gizzard shad and white perch population. As these predators are also game fish, management to regulate their harvest may need to be utilized to allow them to effectively control their prey.

Although many water quality problems exist in Onondaga Lake, the most significant limitation to fish is the lack of oxygen encountered in the hypolimnion as well as through the water column during fall turnover (Effler 1987). Turbidity resulting from material

loading from METRO, the mudboils in a tributary and calcium carbonate precipitation from the waste beds also impair macrophyte growth and fish spawning (Arrigo and Ringler 1994). These problems need to be corrected before other management techniques can be fully utilized.

DISCUSSION AND CONCLUSIONS

Natural Reproduction

Recruitment varies annually in most lakes, but such variation is particularly evident in Onondaga Lake (Ringler et al. 1996). Variation in year-class strength within geographic regions suggests that climatic conditions strongly influence survival of young-of-year (YOY) fishes (McCosh 1993). Warm temperatures and low water levels during spawning and incubation periods and during the first summer of life are often correlated with strong year classes. Habitat is generally thought to determine the presence or absence of YOY though not necessarily abundance (McCosh 1993). Water quality, predation and competition affect larval survival and growth, but these conditions have not been shown to influence year-class strength (McCosh 1993). Temperature influences food density, intensity of predation and other factors which indirectly affect early mortality in young-of-the-year fish.

Physical structures influence juvenile distribution. In this study, areas characterized by the presence of aquatic macrophytes and submerged structure (Maple Bay) produced the most fish. Variation in abundance among sites may also be affected by shelter

and turbidity during nesting. Shorelines of the most productive sites (Maple Bay, Willow Bay and the Marina) appeared to be less perturbed by wind than the less productive areas (Dover Cliffs, White Sands, and Griffin Field). Reduced perturbations by wave action and turbidity may result in increased nesting success and juvenile abundance. Krammer and Smith (1962) reported that year class strength of largemouth bass in Lake George, Minnesota was primarily determined by wind. Waves induced by the wind covered eggs with sand or dislodged eggs from nesting areas.

Age and Growth

Although Allied Chemical ceased production in 1986, resulting in major reductions in ionic inputs to the lake (Effler 1989), growth rates of smallmouth bass in this study did not significantly differ from those in 1979, 1980 and 1984 when Allied Chemical was in production.

Although growth of largemouth bass and smallmouth bass compare favorably to other water bodies, the absence of some year classes, continued pollution inputs and the low density of adults of both species suggests that management techniques need to be implemented before the lake is opened to a consumptive fishery.

The estimated annual survival rate of 0.57 for Onondaga Lake bluegill is much higher than the annual survival rate 0.19 found by Beaulieu (1979) in Lac Vert, Quebec, and Spear Lake, Indiana, with an estimated annual survival rate of 0.12 (Ricker 1955). The high survival rate probably reflects a lack of angling

pressure on pumpkinseeds, coupled with low predation rates on the adults. No adult pumpkinseed were observed in more than 100 stomach samples from smallmouth bass, walleye and northern pike, which foraged primarily on juvenile fish in 1993 and 1994. The high annual survival rate of white perch and bluegill also is likely the result of low angling pressure and low predatory mortality.

It is unlikely that either bluegill or pumpkinseed of Onondaga Lake will require specific management measures. However, it is hoped that long range analysis of growth trends for these fish will be useful in monitoring the response of the lake to restoration efforts.

The external condition of fish in Onondaga Lake system did not indicate unusually high rates of external lesions or tumors, despite the highly perturbed conditions. Less than 5% of the channel catfish had barbel deformities; 3% had skin lesions, and 1.5% had raised skin growth (Ringler et al. 1996). This rate of deformities is less than those collected for brown bullhead with more than 30% barbel deformities in the Buffalo River, N.Y. (Hirethota and Ringler 1989).

Population Density and Biomass

A major problem in any study is obtaining a representative sample of the population of interest. Largemouth bass are difficult to capture with passive sampling gear because they seldom enter trap nets, hoop nets, or wing nets in clear water (Parker 1958). Bennett (1970) described the efficiency of trap nets, wing nets, and trammel nets as poor, that of electrofishing as fair, and that of

angling as good. Only 16 largemouth bass were obtained from 107 trapnet and gill-net sets on Lake Minnetonka in central Minnesota during the summer of 1982 (Ebbers 1987). The estimates of smallmouth and largemouth bass presented here are most likely low. Carp population estimates in 1993 were less than half those calculated in 1991; this may be partially explained by flooding that occurred in 1992, resulting in the stranding of thousands of carp when the waters receded.

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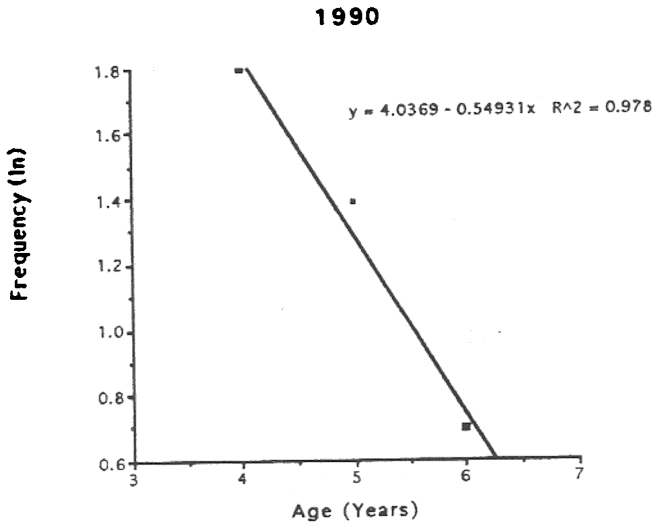
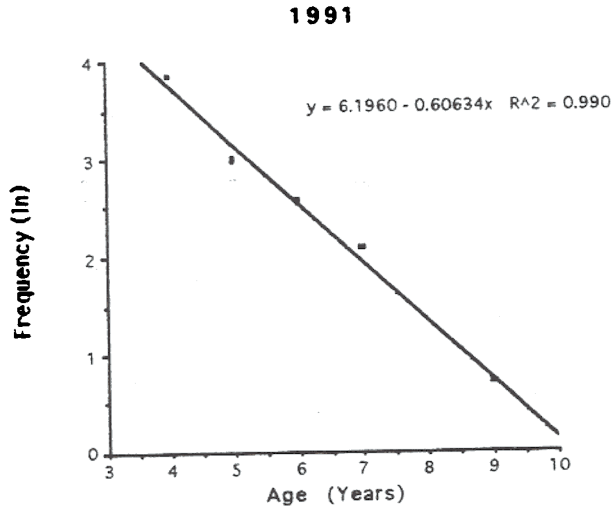
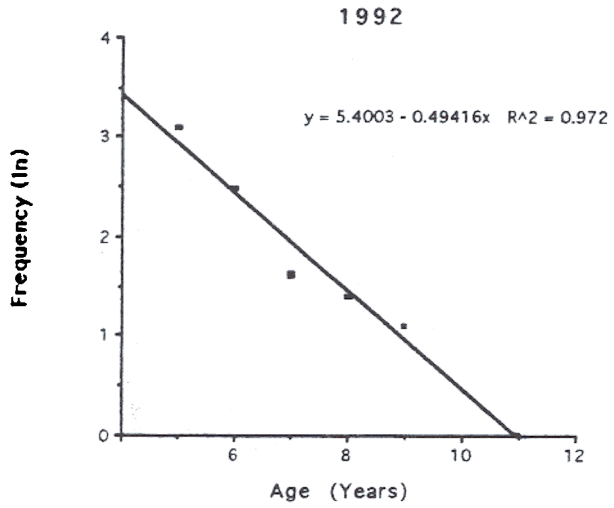
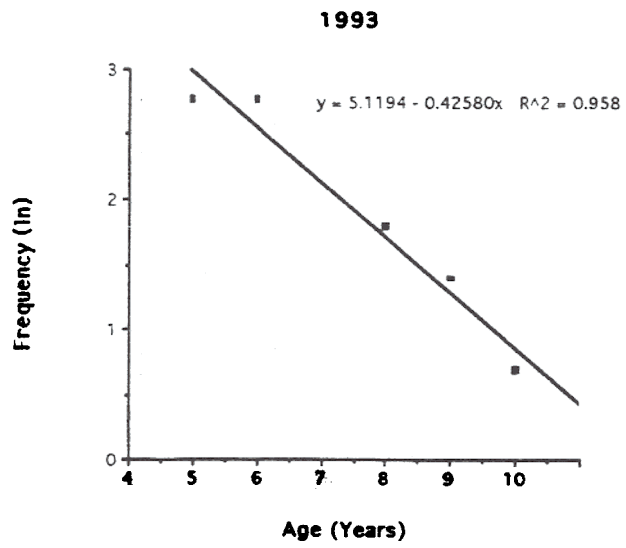
Appendix A. Catch curves of adult smallmouth bass captured in trap and gillnets, Onondaga Lake, 1990 - 1993.



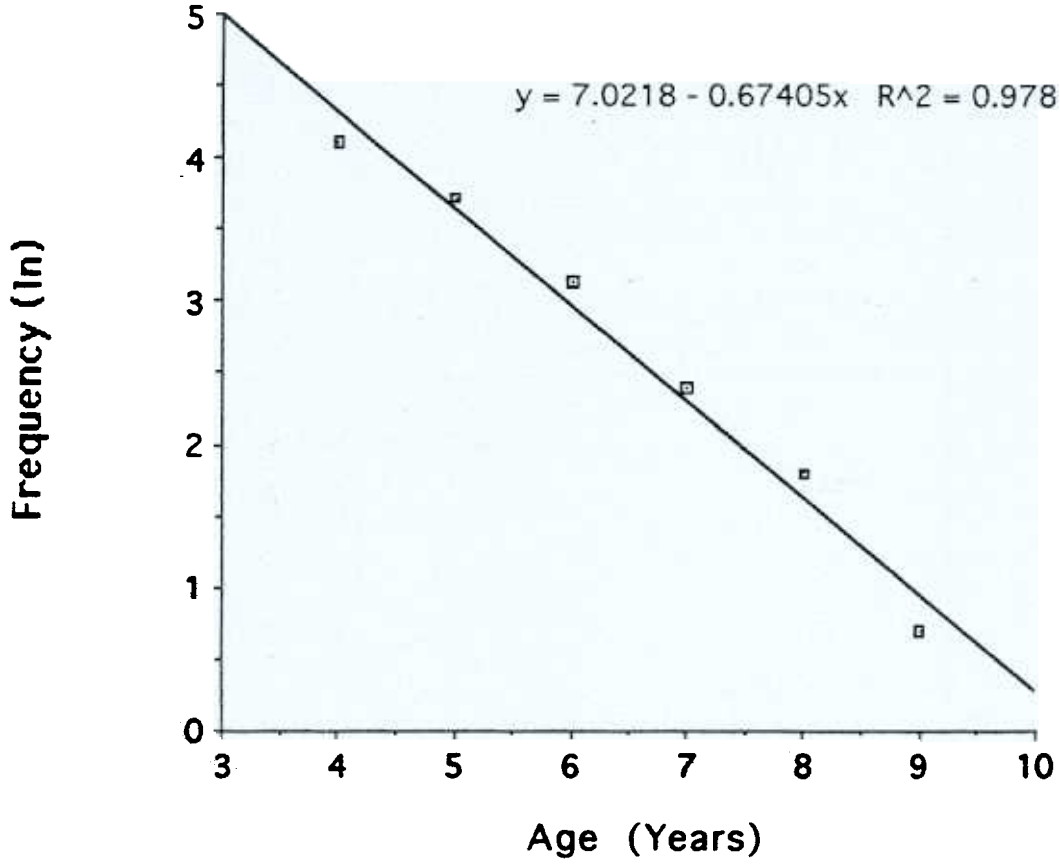


Appendix A. (Continued)

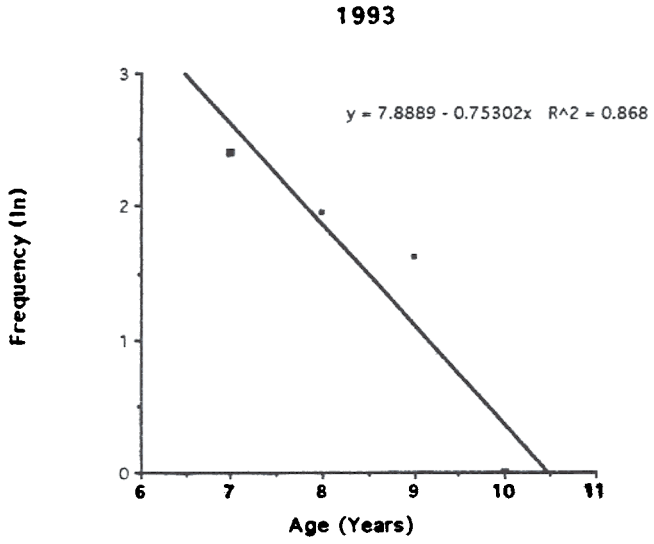




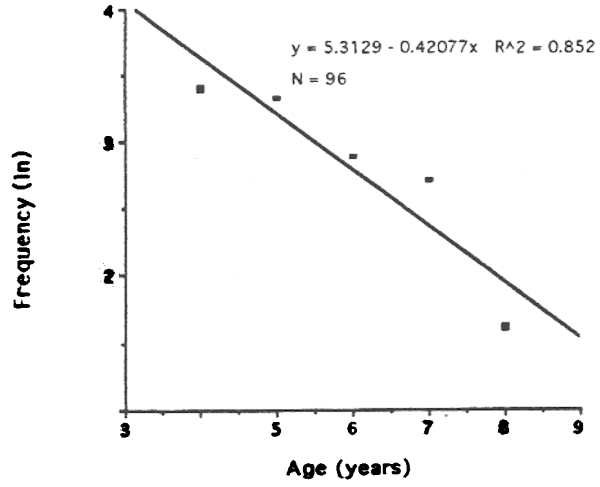
Appendix B. Catch curve of adult smallmouth bass captured in trap and gillnets, Onondaga Lake, 1991 - 1993.



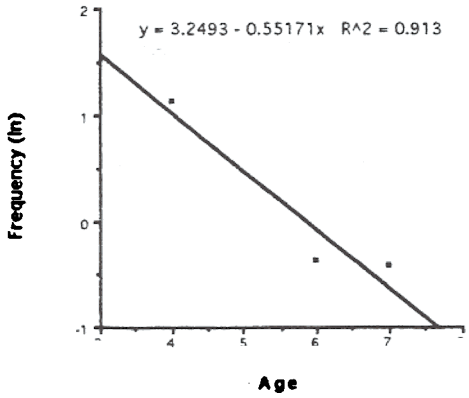
Appendix C. Catch curve for adult largemouth bass captured in trap and gillnets, Onondaga Lake, 1993.



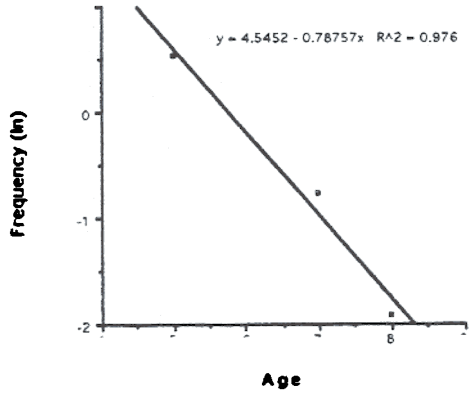
Appendix D. Catch curve for adult walleye captured in trap and gillnets, Onondaga Lake, 1989 and 1992.



Appendix E. Catch curve for adult white perch captured in trapnets Onondaga Lake, 1991-1994.



Appendix F. Catch curve for adult bluegill captured in trapnets, Onondaga Lake, 1991-1994.



Appendix G. Catch curve for adult pumpkinseed captured in trapnets, Onondaga Lake, 1991 - 1994.

VITA

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Education:

	Name and location	Dates	Degree
High school	Liverpool High School Liverpool, New York.	1980 -	
College	SUNY Agricultural and Technical College at Morrisville, New York.	1984 - 1986	A.S
	SUNY College of Environmental Science and Forestry, Syracuse, NY.	1986 - 1988	B.S

EXPERIENCE:

Employer	Dates	Type of Employment
New York State Department of Environmental Conservation	4/95 - Present	Fisheries Technician
Performance Technology Inc.	6/92 - 4/94	Fisheries Technician
SUNY College of Environmental Science and Forestry	11/89 - 5/92	Fisheries Technician
New York State Department of Environmental Conservation	9/89-12/90	Fisheries Technician
Ichthyological Associates, Inc.	10/88 - 1/89	Fisheries Technician
SUNY College of Environmental Science and Forestry	3/88 - 9/88	Fisheries Technician