

## ANALYSIS OF IMPACTS RELATED TO THE INTRODUCTION OF ANADROMOUS ALEWIVES INTO A SMALL FRESHWATER LAKE IN CENTRAL MAINE, USA

Frederick W. Kircheis<sup>1</sup>

Maine Department of Inland Fisheries and Wildlife  
Division of Fisheries and Hatcheries  
650 State Street  
Bangor, Maine 04401-5654

Joan G. Trial<sup>2</sup>

Maine Department of Inland Fisheries and Wildlife  
Division of Fisheries and Hatcheries  
650 State Street  
Bangor, Maine 04401-5654

David P. Boucher

Maine Department of Inland Fisheries and Wildlife  
Division of Fisheries and Hatcheries  
689 Farmington Road  
Strong, Maine 04893

Barry Mower

Maine Department of Environmental Protection  
Division of Environmental Assessment  
17 State House Station  
Augusta, Maine 04333-0017

Tom Squires

Maine Department of Marine Resources  
Stock Enhancement Division  
21 State House Station  
Augusta, Maine 04333-0021

Nate Gray

Maine Department of Marine Resources  
Stock Enhancement Division  
21 State House Station  
Augusta, Maine 04333-0021

Matt O'Donnell<sup>3</sup>

Maine Department of Marine Resources  
Stock Enhancement Division  
21 State House Station  
Augusta, Maine 04333-0021

James Stahlnecker<sup>4</sup>

Maine Department of Marine Resources  
Stock Enhancement Division  
21 State House Station  
Augusta, Maine 04333-0021

**June 2002**

---

<sup>1</sup>Present address: Maine Atlantic Salmon Commission, 323 State Street, 172 State House Station, Augusta, Maine 04333-0172

<sup>2</sup>Present address: Maine Atlantic Salmon Commission, 650 State Street, Bangor, Maine 04401-5654

<sup>3</sup>Present address: S.O. Conte Anadromous Fish Research Center, P.O. Box 96, 1 Migratory Way, Turner Falls, Massachusetts 01376

<sup>4</sup>Present address: Maine Dept. of Environmental Protection, Div. Of Environmental Evaluation 17 State House Station, Augusta, Maine 04333-0017

## **ACKNOWLEDGEMENTS**

---

The following individuals contributed substantially to the successful completion of this project: from the Maine Department of Inland Fisheries and Wildlife: Phil Andrews, Clarissa Trasko, Brian Campbell, Greg Burr, Merryman Johns, and Rory Saunders; from the Maine Department of Marine Resources: Kristin Geib, Melissa Robillard, Mark Lazzari, Andrew Benner, Butch Bowie, Dan Perry, Craig Uecker, and Gail Wipplehauser; from the Maine Department of Environmental Protection: staff of the Division of Environmental Assessment; and staff from the Lake George Regional Park. This work was partly financed by the Federal Aid in Sport Fish Restoration Program.

## TABLE OF CONTENTS

---

---

Acknowledgements.....	2
Executive Summary.....	4
List of Tables and Appendices.....	6
List of Figures.....	7
Introduction.....	9
Study Area.....	14
Methods.....	15
Results and Discussion.....	21
References.....	49

## EXECUTIVE SUMMARY

---

### **Water quality:**

- Water quality, as measured by Secchi disk transparency, and chlorophyll a concentrations was not significantly different during alewives but was significantly reduced after alewives, perhaps due to increased rainfall and runoff and import of nutrients from the watershed.
- Total phosphorus concentrations were significantly lower during alewives than either before or after, perhaps reflecting sequestering by alewives.
- Dissolved oxygen concentrations were largely unaffected by alewives.

### **Zooplankton community structure:**

- The introduction of alewives at six adults/surface acre resulted in a decrease in the population density of Cladoceran micro zooplankton and an increase in population density of Rotatoria. Both populations recovered to levels similar to before alewives by the third year after alewives. There were also species shifts and changes in body size in the Cladocera and Copepoda.
- The average size of individual species of Cladocera was unaffected by alewife stocking, although the change in species composition among Cladocera was indicative of a shift to medium to smaller-sized species during alewife presence. Calanoid copepod body sizes were larger during alewife presence in the lake, while Cyclopoid body sizes were smaller.

### **Freshwater fisheries impacts:**

- The four major sport fish species in Lake George showed no change in average length or weight when comparing the period before the alewives were stocked to the period when alewives were stocked into the lake. These four species were: brown trout, smallmouth bass, chain pickerel, and white perch.
- None of the minor sport fish species present in Lake George showed any difference in average size or weight when comparing before to during alewife stocking. These minor sport fish species were: brown bullhead, burbot, pumpkinseed sunfish, redbreast sunfish, and yellow perch.
- Young-of-the-year (YOY) landlocked rainbow smelt grew significantly faster during the three years while alewives were present in the lake. Possible causes for improved YOY smelt growth included changes in YOY smelt diet, mediated by alewife restructuring of the plankton community and decreased YOY smelt densities.

## EXECUTIVE SUMMARY (CONT')

---

- Smelt population size, based on trawl catch rates, was lowest during the period when alewives were stocked in the lake. Low YOY smelt populations during alewife stocking were also suggested by higher percentages of yearling and older aged smelt in trawl catches while alewives were present in the lake. We were not able to determine what combination of factors caused the decreased density; our high trawl catches in the early years of the study, commercial harvest of adults in 1990 and 1991, competition with juvenile alewives, or some other factor.
- The percentage of YOY smelt with food in their stomachs and the number of food items per stomach were both higher when alewives were present in the lake.
- Cladocera comprised a large portion of smelt diet during the period prior to alewife introduction. During and after alewife introduction, Copepoda dominated the diet in most years. YOY smelt appeared to target prey by size more than by taxon.
- During the three years they were present in Lake George, YOY alewives selected more strongly for Cladocera than for any other prey group. There appeared to be a shift from a more balanced diet of both Cladocera and Copepoda in 1991 to a diet heaviest in Cladocera beginning in 1992 and continuing through 1993.
- Through three years of alewife introduction, over half (66%) of adult alewife stomachs contained food, although (with the exception of 1993) the number of food items in the average adult alewife stomach was lower than the average number of food items contained in either the YOY smelt or YOY alewife stomachs.
- YOY smelt and YOY alewives both fed heavily upon Copepoda and Cladocera, but Morisita's test indicated little overall dietary overlap. This was probably due to the two fish species feeding on different taxa within the major prey groups, with alewives typically feeding on the larger zooplankters.
- The most dietary overlap between smelts and YOY alewives occurred during the first year that alewives were present, and declined each year for the next two years (Morisita's test). Adult alewife and smelt diets never overlapped significantly.
- Adult alewives fed primarily on Cladocera and Diptera, but also fed upon Ephemeroptera, Copepoda, Trichoptera, Coleoptera, Odonata, fish (primarily yellow perch) and Mollusca.

## LIST OF TABLES AND APPENDICES

---

---

Table 1. Mean lengths (mm) of zooplankton Before, During, and After alewives.....	27
Table 2. Lake George trap net sampling summary.....	38
Table 3. Creel Survey Summary.....	39
Appendix 1. Fish species present in Lake George, Maine.....	52
Appendix 2. Lake George stocking history, 1987-1996.....	52
Appendix 3. Summary of fishing regulations in force at Lake George, 1988-1996.....	53

**LIST OF FIGURES**

---

---

Figure 1. Bathymetric map of Lake George.....16

Figure 2. Mean annual zooplankton densities at Lake George before, during, and after alewives.....23

Figure 3. Mean summer densities of Cladocera in Lake George before, during, and after alewives.....23

Figure 4. Mean summer densities of Copepoda at Lake George before, during, and after alewives.....24

Figure 5. Mean summer densities of Rotatoria at Lake George before, during, and after alewives.....24

Figure 6. Mean monthly densities of Cladocera at Lake George before, during, and after alewives.....25

Figure 7. Mean monthly densities of Copepoda at Lake George before, during, and after alewives.....25

Figure 8. Mean monthly densities of Rotatoria at Lake George before, during, and after alewives.....26

Figure 9. Mean summer densities of Calanoida and Cylcopoida at Lake George, 1987-1996.....28

Figure 10. Mean summer Secchi disk transparency at Lake George before, during, and after alewives.....30

Figure 11. Mean monthly secchi disk transparency at Lake George before, during, and after alewives.....31

Figure 12. Mean summer chlorophyll a concentrations at Lake George before, during, and after alewives.....31

Figure 13. Mean monthly chlorophyll a concentrations at Lake George before, during, and after alewives.....32

Figure 14. Mean summer total phosphorous concentrations at Lake George before, during, and after alewives.....33

**LIST OF FIGURES (CONT')**

---

---

Figure 15. Mean monthly epilimnetic total phosphorous concentrations at Lake George before, during, and after alewives.....34

Figure 16. Mean monthly hypolimnetic dissolved oxygen concentrations at Lake George before, during, and after alewives.....35

Figure 17. Mean monthly hypolimnetic dissolved oxygen concentrations at Lake George before, during, and after alewives.....35

Figure 18. YOY smelt von Bertalanffy predicted length at age.....40

Figures 19a and 19b. YOY smelt growth parameters for von Bertalanffy equation.....40

Figure 20. Trawl effort and catch rate summary for YOY smelt.....41

Figure 21. Trawl catch rates for smelts by month and lake area.....41

Figure 22. Trawl catch rates for smelts before, during, and after alewife introduction.....41

Figure 23. Proportions of Cladocera and Copepoda in the diet of YOY smelt and the plankton community of Lake George.....42

Figure 24. Monthly densities of Cladocera in the plankton community of Lake George.....43

Figure 25. Monthly densities of Copepoda in the plankton community of Lake George.....44

Figure 26. Proportions of Copepoda types in the diet of YOY smelt and the plankton community of Lake George.....44



## INTRODUCTION

---

### **HISTORY OF ANADROMOUS ALEWIVES IN MAINE**

Historically, diadromous fishes (anadromous and catadromous) had access to Maine's abundant freshwater resources and constituted the predominant river fisheries. The alewife (*Alosa pseudoharengus*), one of the most abundant of the ten anadromous fish species native to Maine, ascended coastal rivers and streams in May and June to spawn in freshwater lakes, ponds, and dead water sections of rivers and streams. Alewife runs probably occurred in every stream where access was not restricted by natural barriers. Commercially exploitable runs occurred in the St. Croix, Pennamaquan, Dennys, Orange, East Machias, Narraguagus, Tunk, Union, Orland, Penobscot, Ducktrap, Megunticook, St. George, Medomak, Sheepscot, Kennebec, Androscoggin, Presumpscot, Saco, Kennebunk, Mousam, York, and Salmon Falls Rivers.

The historical fisheries for alewives occurred well inland in the Kennebec River watershed. Alewives ascended the Kennebec River in immense numbers as far as Norridgewock Falls, 55 kilometers from the seas on the main stem. They ascended the Sandy River as far as Farmington and bred in Temple Pond. Alewives ascended the Sebasticook River at least as far as Stetson Pond in Stetson on the East Branch, and Great Moose Pond on the West Branch. It is likely that they ascended as far as Wassookeag Lake in Dexter on the East Branch, as Atkins (1887) stated that "*nearly every mile*" of the 124 square kilometers of lake surface area in the Sebasticook River drainage was accessible to alewives. Seven Mile Stream near Vassalboro was considered one of the "*principal breeding grounds*" in the Kennebec River. The Cobbosseecontee Stream drainage was also a "*principal breeding place*" for alewives (Atkins 1887).

The alewife was one of the first anadromous fish species to be impacted by dam construction because the smaller streams were among the first to be obstructed by dams. Provisions were made to allow passage of this valuable resource, which in many cases was under town control. Despite this, alewife runs declined dramatically very early in the last century. For example, a dam built at New Sharon in 1804 eliminated the run up the Sandy River drainage. Also, Atkins (1887) gave the following account: "*...Cobbosseecontee Stream afforded an extensive breeding ground in its 21 square miles of lakes and ponds, but it was early closed. In 1787 we find the Town of Wales (then including Monmouth) appointing a fish committee, which the next year designated a committee to see that the fishways are kept open according to law. The dams at Gardiner, however, were impassable, fishways were not maintained, and very early in the present century this brook of alewives were extinguished*". Completion of a large dam at Augusta in 1837 eliminated runs of alewives in the Sebasticook River and Seven Mile Stream drainages, as well as in the mainstem Kennebec above Augusta.

## **DESCRIPTION AND LIFE HISTORY OF ANADROMOUS ALEWIVES**

The alewife, a member of the herring family (Clupeidae), is easily distinguished by its silvery sides, deep body flattened laterally, and deeply forked tail. It has large, smooth scales that are easily lost when the fish is handled. The species is differentiated from the true sea herring by its sharp, saw-toothed scales along the midline of the belly and the fact that the dorsal fin originates just forward of the midpoint of the back. The sea herring, by comparison, has weakly saw-toothed scales along the midline of the belly and the dorsal fin originates to the rear of the midpoint of the back. In body form, the alewife is generally one-third as deep as it is long, while the sea herring is about one-fourth as deep as long. Alewives on the spawning run average 279 to 305 mm in length and weigh about 230 g.

The alewife makes its growth in the sea and returns to freshwater to spawn. The majority of adults return as first-time spawners at ages four and five. The numbers of repeat spawners vary according to adult escapement and may be as high as 25% of the total run. Adults enter Maine Rivers from early May to early June and run upstream into lakes, ponds, and dead water areas to spawn. Each female produces from 60,000 to 100,000 eggs, depending on the size of the individual fish. The majority of the surviving spent adults then make their way downstream shortly after spawning. Early spawners can be seen migrating seaward and passing later run spawners which are still migrating upriver. The spawning temperatures range from 12.8° to 15.5°C. The eggs, which are about 1.3 mm in diameter, hatch in about 3 days at 22°C and 6 days at 15.5°C. The seaward migration of young generally occurs from mid-July through early December, but young alewives have been observed moving seaward in Maine rivers as early as mid-July. The size of seaward migrating juveniles ranges from 32 mm to 152 mm long, depending on the availability of feed in the lakes, the total numbers of young produced in a particular watershed, and the length of time the fish remain in the freshwater environment.

The alewife is primarily a plankton feeder. Major food items include copepods, amphipods, and mysid shrimp. On occasion, adult alewives consume small fish and fish eggs.

Although considered an inshore species, alewives are sometimes taken 43-50 km offshore in the Gulf of Maine and on Georges Bank at water depths ranging from 46 m to 146 m. Available evidence suggests that the majority of the Maine alewives remain inshore where they congregate in schools of fish of the same size.

## **CURRENT STATUS AND MANAGEMENT OF ALEWIVES IN MAINE**

Alewives continue to be an important source of bait for the Maine lobster fishery and the halibut long line fishery. During early spring, as alewives ascend rivers to spawn, they are sought after by lobstermen as bait for the spring lobster fishery.

Their freshness, as well as the high fat content of alewives laden with spawn, makes them excellent bait for catching lobsters. From 0.45 to 1.6 million kg of alewives are harvested annually for use as lobster bait, although in recent years landings have decreased to be less than 0.2 million kg. A very limited quantity (less than 10%) is smoked for human consumption or used in the halibut long line fishery, which occurs inshore in early to late spring. The statewide alewife harvest comes from municipally operated alewife fisheries along the coast from South Berwick to Pembroke and from individual fishermen on larger rivers, such as the Kennebec and Androscoggin.

Although a recreational fishery for alewives in Maine is limited, there is a small fly fishery on the lower Kennebec and Saco Rivers. Incidental catches are also taken by fly fishermen on the Mousam, Kennebunk, and Downeast rivers. In southern New England and the Mid Atlantic states, recreational fishing for alewives is becoming well established and popular. This species has substantial potential for development as a recreational fishery resource. A major contribution of the alewife resource is its importance as a forage base for other recreational species, such as striped bass, and in riverine environments, brown trout and other salmonids.

An ambitious restoration program for American shad and alewife to the Kennebec River above Augusta was initiated in 1986. The Maine Department of Marine Resources (DMR) has just completed the final year of a 12-year interim trap and truck program for American shad and alewives on the upper Kennebec River. This program is being carried out by the DMR as part of an agreement between the State of Maine fishery agencies and hydroelectric dam owners located above the head-of-tide Augusta Dam; the owners of the Augusta Dam chose not to participate. The dam owners, known as the "Kennebec Hydro Developers Group [KHDG]," are providing funds for the implementation of the state fishery agencies' fishery management plan. The long-term goal of this plan is to restore American shad and alewives to their historical habitat above Augusta, for an annual production of six million alewives. The strategy developed to meet these objectives involves restoration planned in two phases: The first phase (January 1, 1986 through December 31, 1998) involved the initiation of restoration by means of trap and truck for alewives to selected water bodies. The lakes and ponds stocked in Phase I were generally eutrophic or mesotrophic lakes. Stocking of alewives to lakes that supported cold-water fisheries was postponed until studies could be completed to examine the interaction of alewives with landlocked smelt. Phase II, which commenced on January 1, 1999, builds on Phase I by phasing out trapping and trucking to Phase I lakes as fishways (fish ladders) are constructed. DMR began stocking brood stock alewives in Sebasticook River drainage lakes in 1985, prior to the KHDG Agreement. Stocking was expanded in 1987 with the implementation of Phase I of the KHDG Agreement. Since 1985, more than 550,000 alewives have been stocked into nine lakes in the Kennebec River system.

During the planning process for alewife restoration to the Kennebec River, biologists from the Maine Department of Inland Fisheries and Wildlife (MDIFW) expressed concern that the restoration of alewives could impact fish populations that have become established since extirpation of alewives from their historic spawning and nursery habitat. Specifically, MDIFW noted that the potential existed for competition to occur between alewives and landlocked smelts (*Osmerus mordax*), which support sport and commercial fisheries in many waters, and which provide the principal forage for sportfishes such as brown trout (*Salmo trutta*), landlocked salmon (*Salmo salar*), and lake trout (*Salvelinus fontinalis*).

While there have been no studies on the interaction of anadromous alewives and rainbow smelt, a study conducted by Gately (1978) examined interactions between landlocked alewives and smelts in Echo Lake, Mt. Desert Island, Maine. Gately documented significant diet overlap between the two species, and he concluded that growth rates of older-age rainbow smelt were depressed in Echo Lake compared to lakes that did not contain landlocked alewives. Based on slower growth rates Gately concluded that landlocked alewives compete with rainbow smelt, although he did not present data to show that food was a limiting factor, or that there had been a change in the population size of rainbow smelt following the introduction of landlocked alewives. Gately also found that diet overlap between juvenile landlocked smelts and juvenile landlocked alewives was moderate, and that the growth of juvenile smelt in Echo Lake was equal to or exceeded that found in other Maine lakes.

Hutchinson (1971) reported that the growth rate of landlocked Atlantic salmon declined in an Adirondack pond after the introduction of landlocked alewives. Landlocked Atlantic salmon in similar Adirondack ponds fed mainly on invertebrates (mainly zooplankton) and attained weights of 0.9 to 1.4 kg. He believed the reduced growth rate was the result of competition between landlocked Atlantic salmon and landlocked alewives for planktonic food.

There is little information available concerning competition between anadromous alewives and other freshwater fish species. McCaig (1980) concluded that anadromous alewives in Massachusetts suppressed the growth of age I brown trout and rainbow trout (*Oncorhynchus mykiss*) in reclaimed ponds, apparently due to competition, but age II trout grew at a faster rate because they were able to utilize juvenile alewives as forage.

Available data indicate limited predation by adult anadromous alewives on larval fish (Mink 1989; Jordan 1989). Two species of finfish have been identified as prey for adult anadromous alewives; larval yellow perch (*Perca flavescens*) and larval alewives.

Possible adverse effects on black bass (*Micropterus* spp) were identified as a concern following the collapse of a renowned smallmouth bass (*M. dolomieu*)

population at Spednik Lake in Washington County, which was coincident with a large -scale reintroduction of anadromous alewives in the St. Croix River drainage (Smith 1987).

The concern about potential interactions of alewives with smelts, salmonids, and other freshwater sportfish resulted in a cooperative decision to postpone stocking of alewives in those lakes where those species were an important component of the fish community. The decision to stock those lakes would be based on the outcome this joint study by the Maine Department of Inland Fisheries and Wildlife and the Maine Department of Marine Resources.

In 1986, the Maine Department of Environmental Protection (MDEP), the state agency with statutory responsibility for managing water quality, noted that several waters in the lower Kennebec River watershed targeted by MDMR for alewife restoration currently experience blue-green algal blooms, or have water quality near the threshold of developing algal blooms. Problems associated with algal blooms include marked reductions in water transparency, depletion or elimination of hypolimnetic oxygen, obnoxious odors, and reduced shorefront property values.

A number of ambient studies and enclosure studies have documented increased algae resulting from an abundance of planktivorous fish (Anderson et al 1978; Brooks and Dodson 1965; Ives et al 1999; Mills and Schiavone 1982; Mills and Green 1992; Pace et al 1998; Proulx et al 1996). Young alewives are obligate planktivores, and their prey generally include the large herbivorous zooplankton (*Daphnia spp*; *Ceriodaphnia spp*, *Calanoid* copepods) that typically dominate the pelagic plankton community of lakes. These large herbivorous zooplankton are efficient predators on phytoplankton and, in many cases, have a strong regulatory effect on algal biomass. Therefore, direct and immediate effects of a large-scale planktivore introduction may include 1) marked reductions in the density of large, herbivorous zooplankton; 2) a shift in the size structure of the entire zooplankton community toward small bodied forms, which are less efficient grazers on algae, and 3) increased abundance of obnoxious forms of algae.

On a longer time scale, introduction of anadromous alewives has been postulated to result in water quality improvement in lakes and ponds. Grazing of zooplankton by juvenile alewives increases the net efficiency of trophic transfer of nutrients up the trophic scale, and ultimately could increase net export from the lake via emigrating alewives. A study of Little Pond, Damariscotta, found that the annual export of total phosphorus via alewives was a small part of the annual phosphorus load (Mower 1978). This was a result of low stream flows and a poor outlet that limited emigration of adults and juveniles from the pond. To the contrary, in a study of Sabattus Pond, phosphorus export via emigrating alewives was significant, equal to that obtained by enhanced seasonal flushing during the height of an annual bloom of blue-green algae (Mower 1987, and unpublished data).

In consideration of these water quality issues, as well as the inland fisheries issues raised by MDIFW, these two agencies and MDMR entered into a nine-year cooperative study in 1987 to assess these possible impacts. Results of that study, which was completed in 1996, are the subject of this report.

The study was conducted in three temporal segments or phases. Sampling efforts during Phase I, which was conducted from 1987 to 1990, focused on collecting background data on water quality, zooplankton community structure, and resident fishes prior to the introduction of alewives. During Phase II (1991-1993), anadromous alewives were stocked annually at the rate of 2.4 sexually mature adults/surface ha. Data collection efforts on water quality, zooplankton community structure, and resident fishes continued during this phase. In addition, growth rates, food habits of juvenile and adult alewives, and emigration of adult and juvenile alewives were monitored. Alewife stocking was discontinued during Phase III (1994-1996). Objectives during this phase were to monitor the response of water quality, zooplankton community structure, and resident fishes to the cessation of alewife stocking.

## STUDY AREA

---

Lake George was selected as the study water due to its manageable size (228 ha), its species composition, and its accessibility to staff from the three cooperating agencies.

Lake George is located in southern Somerset County, Maine in the towns of Canaan and Skowhegan (Figure 1). The lake lies at an elevation of 69 m above sea level and drains to Carrabassett Stream, a small tributary to the Kennebec River. It has a surface area of 134 ha, a mean depth of 8 m, and a maximum depth of 22.6 m. There are two small tributaries that enter at the lake's north end. Much of the shoreline is rocky, with the exception of two small sandy beach areas and three shallow, muddy coves near the inlets and outlet. The shoreline is lightly developed with seasonal and permanent homes. The Lake George Regional Park, which borders about 1/3 of the southern and eastern shoreline, maintains a free public boat launching facility.

Fish species resident in Lake George are listed in Appendix 1. Eastern brook trout and brown trout are stocked annually by the Maine Department of Inland Fisheries and Wildlife and provide the principal sport fisheries (Appendix 2). Lake trout (*Salvelinus namaycush*) were stocked on three occasions in the early 1900's, but reproduction did not occur and none presently exist. Chain pickerel (*Esox niger*) and smallmouth bass are not native to the lake but became naturalized prior to the beginning of the study. Largemouth bass (*Micropterus salmoides*) are also not native to Lake George. They have become established through an illegal introduction made near the end of the study period. Anadromous fishes, including alewives, are denied access to Lake George by a

series of dams that lack fish passage on the Kennebec River. There are no natural obstructions on Carrabassett Stream that would have prevented alewives from accessing Lake George prior to construction of dams on the Kennebec River. Sport fishing is permitted during the winter and summer seasons. Fishing regulations varied slightly during the three study phases (Appendix 3). Most rules conformed to statewide General Laws. Commercial harvest of rainbow smelts was prohibited in 1991, one year after the beginning of the study.

## METHODS

---

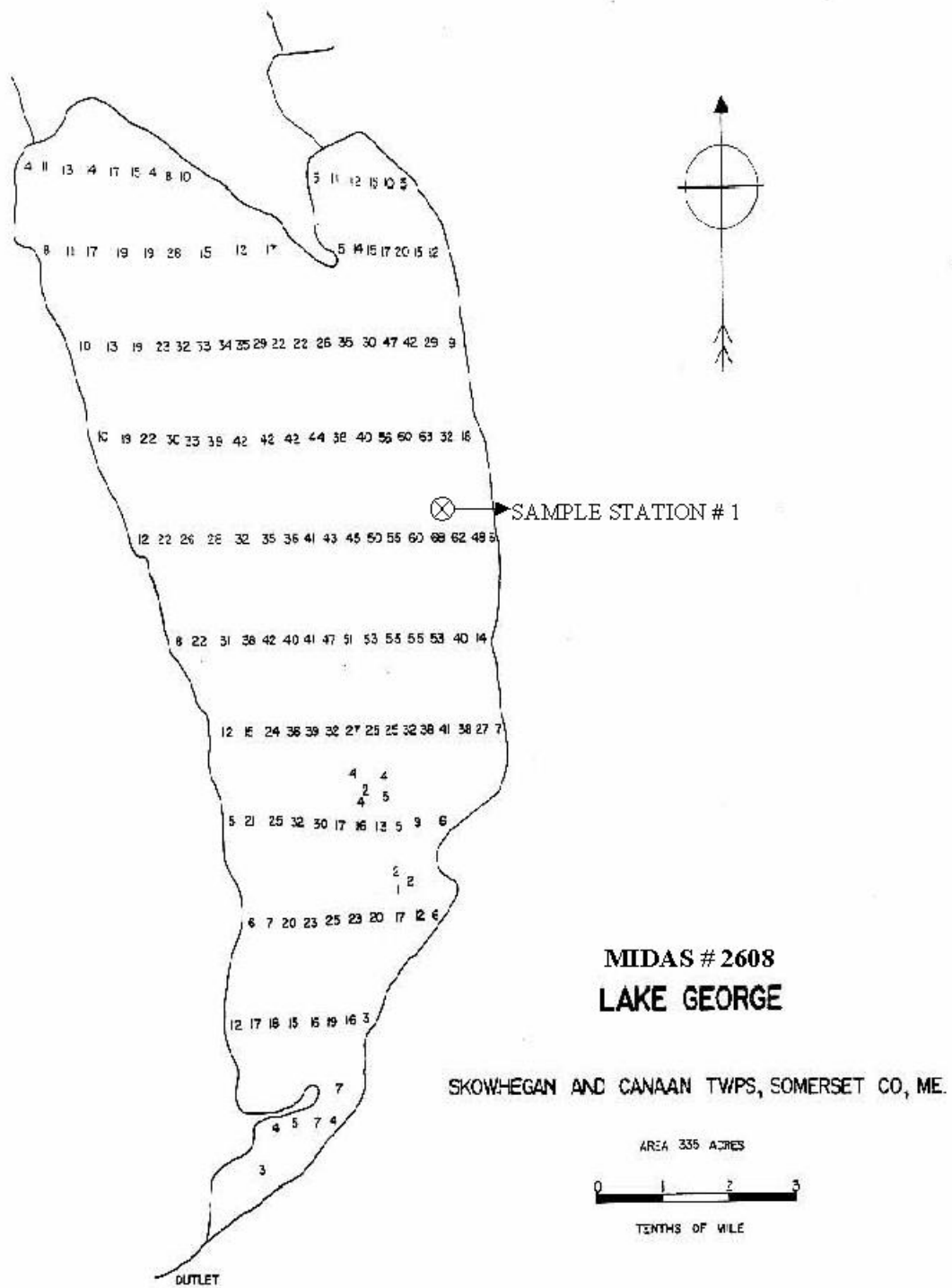
### WATER QUALITY/ZOOPLANKTON SAMPLING

Field measurements and water samples were collected annually during the open water season from May/June through September/October. Data were obtained at the deepest part of the lake (Figure 1) and generally corresponded to the dates of smelt trawls. Water temperature and dissolved oxygen profiles and Secchi disk transparency were measured in the field. Water samples were collected to analyze for chlorophyll *a*, apparent color, pH, specific conductance, total alkalinity, total phosphorous, and zooplankton community structure. Each of these is discussed below, with detailed methods available in Pearsall (1996).

Temperature and dissolved oxygen were measured every 1-2 m from the surface to the bottom of the lake using a Model 57 YSI dissolved oxygen meter. From the temperature profile, the epilimnion, metalimnion ( $\Delta T > 1^\circ\text{C}/\text{m}$ ), and hypolimnion were identified for use with other measurements.

Secchi disk transparency was measured on the shady side of the boat using a standard 20 cm black and white Secchi disk and a water scope to reduce glare. Transparency was recorded to the nearest 0.1 m.

Epilimnetic water samples were obtained to measure chlorophyll *a* and total phosphorous concentrations. A vertically integrated water core was collected by slowly lowering one end of a 1.5 cm ID clear tygon tube into the water to the depth of the epilimnion or to 10 m, whichever was less, to allow it to fill with water from each depth as it was lowered. The first core collected in this manner was a rinse and was discarded before collection of the core sample in a clean Nalgene



**FIGURE 1. BATHYMETRIC MAP OF LAKE GEORGE**



mixing jug. When epilimnetic depth was less than 8 m, two cores were collected and combined to provide a 1 l sample for analysis. An aliquot of 50 ml was poured into a pre-cleaned 125 ml Erlenmeyer flask and stored in a cooler for total phosphorous analysis. Total phosphorous concentrations were determined by the Maine Health and Environmental Testing Laboratory (HETL) using USEPA Method 365.1 (EPA 1978). The remainder of the sample was poured into a clean 1-liter cubitainer and stored on ice until it could be filtered through a 0.45  $\mu\text{m}$  membrane filter in the lab the same or next day. The filter was then stored frozen until extracted and analyzed by HETL using spectrophotometric Standard Method 10200 H (APHA 1995).

Zooplankton were collected using an 80- $\mu\text{m}$  Wisconsin-style plankton net. Five vertical tows from the bottom of the lake to the surface were composited into one container and preserved with 5% buffered formalin. Counts of several 1 ml aliquots of the sample were made in a Sedgewick-Rafter cell using a light microscope at 40x and 100x magnification. Cladocerans were identified to species, copepods to suborder, and rotifers to genus using Pennak (1978).

Once each August, during maximum thermal stratification, Baseline sampling was conducted. In addition to the samples described above, samples from the epilimnetic core were obtained for analysis of apparent color, pH, specific conductance, and total alkalinity. Apparent color was measured in platinum-cobalt units with a Nessler field color kit. An Orion Model 231 pH/mv/temperature meter with a Ross glass, liquid-filled probe was used to measure pH. Specific conductance was calculated after titration of the sample with 0.02 N sulfuric acid to the methyl orange endpoint. Samples were also collected near the top and bottom of the hypolimnion, using a Kemmerer or Van Dorn water bottle, to be analyzed for these four parameters and total phosphorous.

### **FISHERIES SAMPLING**

Lake George was stocked with hatchery-reared brook trout and brown trout throughout the study period (Appendix 2). Five hundred brook trout and 400 brown trout were stocked each spring at age I, and 300 brown trout were stocked each fall at age I+. A unique fin clip identified all stocked fish.

Lake George's fish populations were monitored using a variety of gear. Similar techniques were employed during all three phases of the study.

### **SPRING AND FALL TRAP NETTING**

Three Oneida Lake trap nets (1.3 m x 1.3 m x 2 m box; 33 m x 1.3 m leads; 8 m x 1.3 m wings; 2 cm stretch mesh throughout) were deployed annually to estimate white perch population size, and to gather basic biological information on as many fish species as possible. Nets were set within one week after ice-out in April. One net each was fished on the north, south, and east shorelines. The

west shore drops off to rapidly to sample with trap nets. Nets were tended three times each week for approximately 4 weeks.

A randomly selected sample of 30 fish of each species was measured for total length (mm) and weight (g). MS222 was used to anesthetize fish for ease in handling. Fish were recovered in fresh water prior to release. A temporary fin clip was applied to the caudal fin on all fish captured to prevent duplication of measurements, and to facilitate population estimates for white perch. All fish were released near the center of the lake after processing.

Early in the study, Floy dart tags were applied to all smallmouth bass captured in trap nets to examine movements and growth rates of individual fish. This effort was abandoned after three years due to low numbers of bass captured and unacceptably high tag loss rates.

Fall trap netting operations were conducted to examine the effects of the presence of alewives on brown trout growth rates and condition, and to estimate brown trout population size. Nets were fished at the same locations described above. Nets were deployed in early October each year, and tended thrice per week for 4 to 6 weeks until catches declined. Fish handling methods were the same as in the spring. Brown trout population size was estimated using the Schnabel method.

#### TRAWL SAMPLES

Rainbow smelts were collected to determine first-year growth rates, to determine their food habits relative to available prey, and to assess diet overlap with alewives during the years alewives were present. Samples were collected using a benthic otter trawl during each year of the study. Sampling commenced in mid-June, when young-of-the-year smelts became large enough to be captured with the trawl, and continued on a biweekly schedule until early October. All sampling was done during daylight hours. The trawl net had a 5.5 m head rope and was towed at a rate of about 1.03 m/sec. Tows continued at 5 to 20 min intervals until a 30-fish sample was obtained. Adult and young-of-the-year smelts were separated and measured to the nearest millimeter. Smelt samples were preserved whole in 10% formalin for analysis of stomach contents at a later time.

#### GILL NETTING/SEINING

Samples of adult alewives were collected with gill nets during each year that they were stocked. Green nylon and clear monofilament nets (65 mm stretch mesh) were fished biweekly beginning about one week after they were stocked (generally near the end of May), and ending when counts at the outlet weir showed that most adult alewives had left the lake. Nets were tended frequently during the day until a 30-fish sample was obtained. Alewife stomachs were

removed, identified with a paper tag, injected with a 10% formalin solution, and placed in a jar with 10% formalin.

Young-of-the-year alewives were collected each year brood alewives were stocked in the lake to determine YOY growth rates, to determine their food habits relative to available prey, and to assess diet overlap with smelt. Samples were collected using a beach seine fished in the littoral zone of the lake. Sampling commenced in mid-June, soon after young-of-the-year alewife were large enough to be vulnerable to capture by the seine, and continued on a biweekly schedule until early October. Seining for YOY alewives was conducted concurrently with trawling for YOY smelt to facilitate comparisons between species on the same sample day whenever possible. If one species was not captured in sufficient numbers that day, additional sampling commenced on subsequent days. All seining was accomplished during daylight hours.

The seine employed was 24.4 m long and 2.4 m deep and was constructed of delta nylon mesh with 6.4 mm openings. The seine was fished by pulling one end of the net off the shore into the lake while allowing the other end to remain on shore. Once the seine had been stretched to its full length perpendicular to the shore, the deep end was pulled laterally and toward shore in a radius arc until it contacted shore. If an insufficient number of alewives was caught on the first seine haul (less than 30 fish sample), subsequent hauls were conducted in new areas along the shore. Young-of-the-year alewives were separated from other non-target species and measured to the nearest millimeter. Young-of-the-year alewife samples were preserved whole in 10% formalin for analysis of stomach contents at a later time.

#### OUTLET WEIR

Prior to releasing adult alewives into Lake George, a weir was constructed on the outlet stream to trap emigrating adult and juvenile alewives. The weir was V shaped with the open portion of the V pointing upstream. A trap box was constructed at the apex of the V, with the opening in the trap pointing upstream. The wings of the weir were set at 45-60° angles to the trap box and were constructed of 1.22 m wide wood panels. The panels were covered with 1.9 cm wide vertical wood strips alternating with 1.9 cm clear spaces. Plastic aquaculture mesh with 0.32 cm openings was placed on the upstream side of the wood strips. Weir panels were bolted together and fastened to posts driven into the streambed at 1.22 m intervals. A 3.81 cm wide vertical slot in the trap box allowed out migrant fish to enter the trap. The sides of the trap box were lined with 0.32 cm aquaculture mesh.

#### CREEL SURVEYS

Clerk creel surveys were employed to monitor Lake George's sport fisheries throughout the study period. During the winter seasons (January to March),

angler counts and interviews were made on one weekend day and two weekdays during each week. Survey days were always randomly selected. Angler counts were made at about midday. Clerk interviews were supplemented with pre-addressed mail-in postcards to provide complete trip information on as many fishing trips as possible. Anglers were requested to record the time they stopped fishing and the number and species of fish they captured after the clerk departed. Estimates of winter angler use and harvest were computed using the method described by Havey (1984).

We attempted to conduct summer clerk creel surveys during the first two years of the project, but this effort was abandoned due to low angler use. A voluntary creel survey box was deployed at the boat landing to gather information on the lake's summer fisheries. This effort was abandoned after the first two years as well, because of the poor quality of data provided and vandalism to the box.

#### SMELT AND ALEWIFE FOOD HABITS

A ten smelt sub-sample was removed from each of the sampling dates when available. Each fish was measured for total length and weighed. The digestive tract of smelts was removed using forceps, placed in a petri dish, and rinsed with sterile water. Excess fat and connective tissue was removed. After this process the digestive tract was placed into a clean petri dish and rinsed again. The dissection of the digestive tract was performed under a Wild/Herbrug dissecting stereoscope set at 6X. The stomach wall, esophagus and intestine were split using a sharpened dissection pin. After splitting, the contents of the digestive tract were rinsed out using sterile water. Once the digestive tract was rinsed clean of its contents, it was removed and discarded.

Large zooplankters and insect larvae were separated from the smaller zooplankters. For the identification of zooplankters, a representative number of specimens were removed and dissected at 50X when necessary to the species level. Whenever possible, fish and cladoceran zooplankton were identified to the species level. Copepods were identified to suborder, and insects were identified to order. Identifications followed Pennak (1978) and Ward and Whipple (1945).

No specialized equipment was used for the enumeration of the zooplankters. A tally sheet was kept to one side of the scope and as a food item was enumerated a tic mark was placed in the corresponding area on the tally sheet and the zooplankter in question was carefully moved off to one side of the petri dish. Once the contents were fully enumerated the results were transposed onto standard ledger paper.

Preserved smelt and alewife stomachs were dissected, rinsed, and their contents examined under a dissecting stereoscope at 6X to 50X magnification. Prey organisms were enumerated for each stomach sample.

Diet overlap was evaluated for young-of-year smelt and young-of-year alewives, young-of-year smelt and adult alewives, and young-of-year alewives and adult alewives. Because the number of stomachs collected was not always equal within a given sample period (e.g. x smelt stomachs and x juvenile alewife stomachs were collected on xx/xx/xx), overlap was calculated using the mean number of food items per fish with Morisita's Index of Similarity (Krebs, 1989). The index was calculated as follows:

$$C_{\lambda} = \frac{2 \sum X_{ij} X_{ik}}{(\lambda_1 + \lambda_2) N_j N_k}$$

where:

- $C_{\lambda}$  = Morisita's index of similarity between sample  $j$  and  $k$
- $X_{ij}, X_{ik}$  = Number of individuals of species  $i$  in sample  $j$  and  $k$
- $N_j = \sum X_{ij}$  = Total number of individuals in sample  $j$
- $N_k = \sum X_{ik}$  = Total number of individuals in sample  $k$

$$\lambda_1 = \frac{\sum [X_{ij} (X_{ij} - 1)]}{N_j (N_j - 1)} \text{ and } \lambda_2 = \frac{\sum [X_{ik} (X_{ik} - 1)]}{N_k (N_k - 1)}$$

Scale ranges from 0 (no similarity) to about 1.0 (complete similarity). A value above 0.6 typically indicates significant overlap.

An attempt was made to compare smelt and alewife diets to available food items from the lake. However, there are two known errors in the stomach/zooplankton data. First, while rotifers are known to be utilized as food items by young-of-year smelt, they were erroneously discounted as food items while stomach samples were being analyzed. Second, some macro invertebrates (e.g. larvae of Diptera, Trichoptera, and Odonata) were identified in the stomach analysis, but were not identified in the available plankton analysis. If conventional similarity indices were used to analyze these data, the results would be erroneous. Because rotifers were not counted as food items, the food items that were counted in the YOY smelt stomachs may be assigned a higher electivity value than they would if rotifers were counted. Additionally, while macro invertebrates typically comprised a small portion of diets (with the exception of Diptera during alewife introduction which occurred in approximately 35% of stomach samples) the analysis would indicate they were strongly selected for.

## RESULTS AND DISCUSSION

---

### ZOOPLANKTON COMMUNITY STRUCTURE

Zooplankton populations are determined by complex trophic dynamics and are the integrated response to a number of different factors. Hutchinson (1967)

identifies the three most important factors as life histories, food, and predation/competition. Both occurrence and seasonal fluctuations in densities are functions primarily of these factors as influenced by environmental conditions such as temperature, light and other water quality variables. Life spans are progressively longer for Rotatoria, Cladocera, and Copepoda respectively. Brood size and reproductive response time are also important in determining reaction of populations to changes in important factors such as light, temperature, food, predation, and competition. Rotatoria have small clutch sizes but are multivoltine, having short reproductive times, which allows populations to closely follow the food supply. Cladocera have slightly longer life cycles but are also multivoltine and have brood sizes proportional to food supply. As a result Cladocera are prone to large fluctuations sometimes lagging peaks in food. Copepoda often have still longer life cycles and can be univoltine resulting in smaller fluctuations than Cladocera. During the open water season, Rotatoria typically peak in early June followed by Cladocera in early July and Copepoda in August.

Trophic relationships are also important. Within each group, each species has preferred food items and there are raptorial species within each group. In general there is a continuum of animals with different feeding strategies, ranging from small multivoltine species feeding on small particles and capable of quickly developing large populations in response to increased opportunities, to larger univoltine or even biennial and triennial species feeding on larger particles with more even and persistent populations.

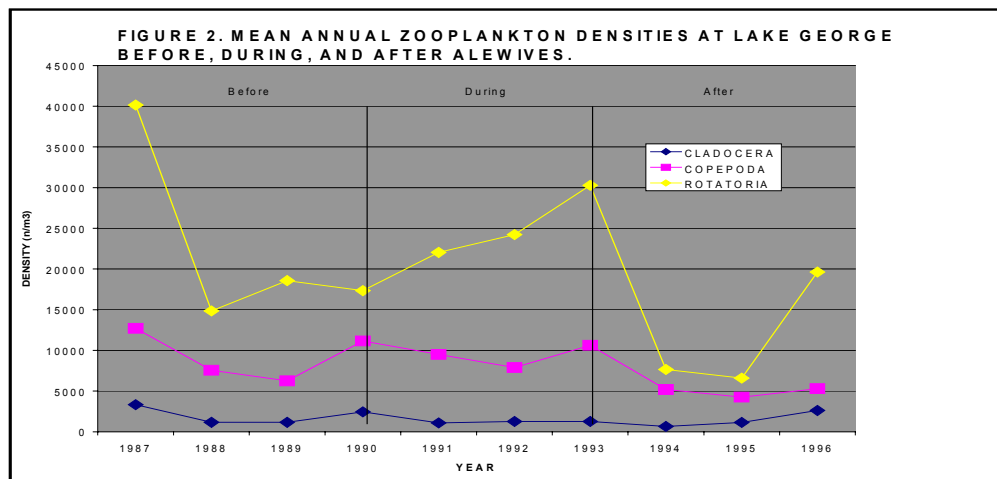
Rotatoria are primarily sedimentary suspension feeders and have varied diets. Most are omnivorous and consume periphyton, plant and animal plankton, and detritus of the appropriate size. Some consume other rotifers and other Metazoa of the right size, including small Cladocera and Copepoda. Most Cladocera filter fine suspended material including algae, protozoa, and bacteria and detritus from the water column. Only a few, like *Leptodora* and *Polyphemus* are thought to be predaceous on other Entomostraca (small freshwater Crustacea) and Rotatoria. Copepoda generally consume coarser particles or are raptorial, preying on organisms in the other groups or even they cannibalize their own nauplii. Within the Copepoda, Calanoida feed primarily on algae by filtration, but some are raptorial, feeding on animals in certain size ranges which are specific for each species and different from Cladocera. Cyclopoida have mouthparts for seizing and biting and feed on protozoa and metazoa, including their own nauplii and other crustaceans (Pennak 1978).

Predation of zooplankton is as important as food supply in determining zooplankton abundance. While larger species of algae are often avoided by zooplankton, larger species of zooplankton seem to be targeted by fish. It is well documented in the literature that small forms of zooplankton dominate in lakes with significant planktivorous fish populations (Brooks and Dodson 1965; Carpenter et al 1996; Mower 1978; Pace et al 1998; Warshaw 1972). Since

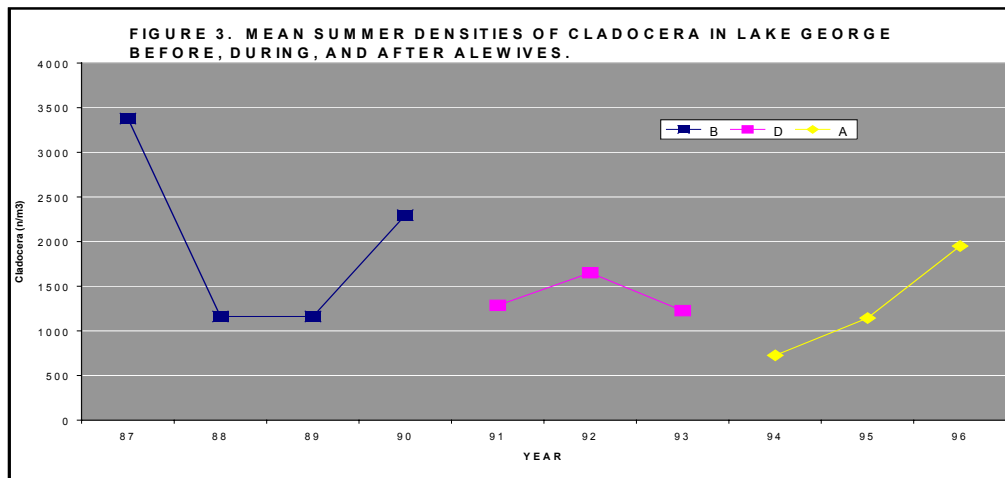
juveniles of most fish species are planktivorous, then this phenomenon occurs in lakes with significant fish populations and is used as an indicator of whether or not fish populations are balanced or not (Mills and Schiavone 1982; Mills and Green 1992). Predation of zooplankton by zooplankton may also be important. Rotatoria usually increase in presence of fish, resulting in two cycles per summer, a spring maximum followed by a fall maximum, which may be less than in the spring.

For statistical comparisons of the effect of alewives on zooplankton, data were grouped by years corresponding to periods Before (1987-90), During (1991-93), and After (1994-96) the stocking of alewives. Comparisons between periods were made sequentially using the Mann-Whitney U test (Cladocera) or t-test (Copepoda and Rotatoria, log transformed at  $p=0.05$ )

Trends within each group and comparison between groups demonstrate the complex trophic dynamics among algae, zooplankton, and planktivores. The introduction of alewives and resulting changes in zooplankton followed predictable patterns. In Lake George, Rotatoria were significantly the most abundant (numerically) zooplankton identified, followed by Copepoda and Cladocera, in decreasing abundance (Figure 2).



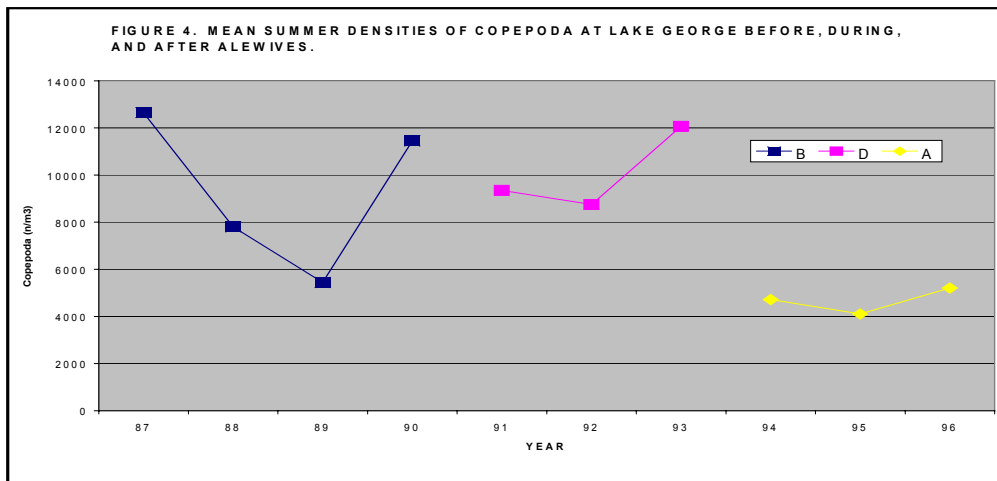
Mean annual summer densities of Cladocera were quite variable among years (Figure 3). Densities were significantly reduced during alewives from before, as a result of predation by juvenile alewives. After alewives, mean densities for the



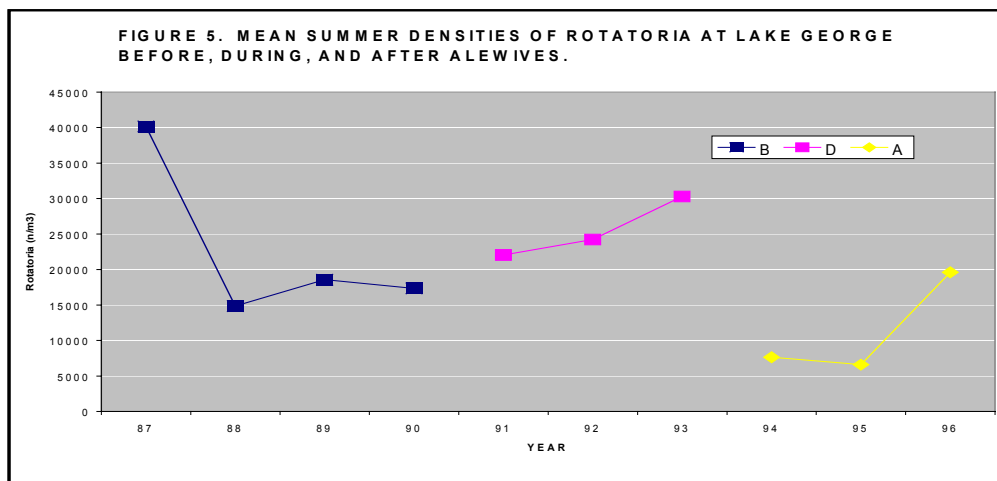
3-year period were slightly higher than during but the increase was not significant. Less variation occurred during alewives when densities were depressed.

Although the mean density was greater before than during or after, densities for 2 of 4 years before were similar to all 3 years during and to 1 of 3 years after. During the 3 years after alewives, densities steadily increased, but the increase was significant only from 1994 to 1995. By 1996 the density of Cladocera had recovered to a level before alewives, second highest, in fact, to that of 1987, the first year of the study.

The mean annual summer densities of Copepoda and Rotatoria were not significantly changed during alewives, but were significantly lower after (Figures 4 and 5). This may be a result of competition with an increasing Cladocera population, although this effect was not evident before alewives at the same densities. Furthermore, different trophic level food preferences predict minimal



competition among the 3 groups. If data for 1987, which had the highest density of all years, were ignored, the density of Rotatoria was slightly higher during than before or after alewives. This is consistent with the results of other studies where

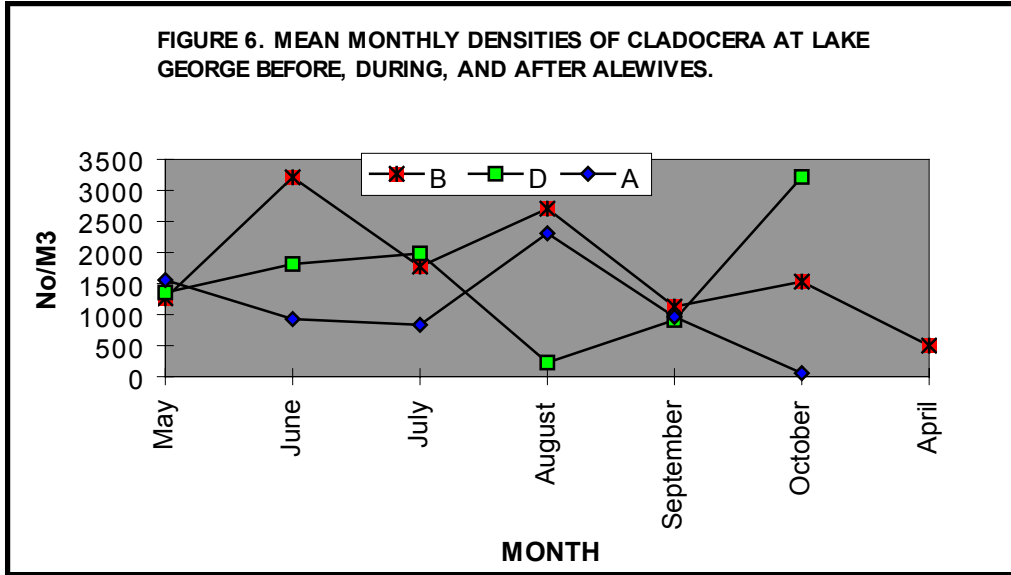


populations of fish in lakes have increased (Hutchinson, 1967). This could be

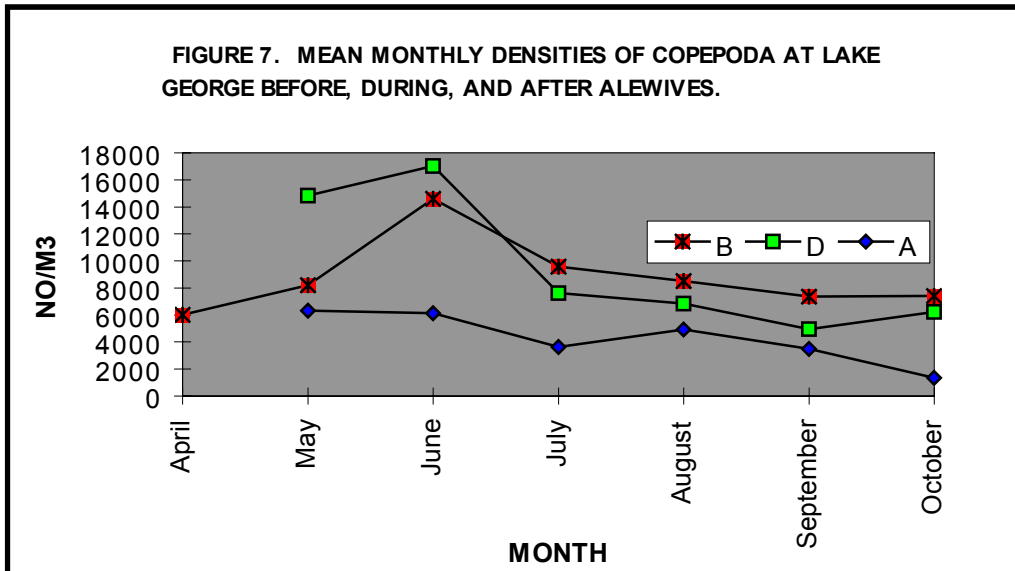


explained as an effect of decreased competition or predation from reduced populations of Cladocera.

Seasonal cycles of zooplankton may also have been affected by alewives. Mean monthly densities for each of the 3 periods for each group show that the usual late summer peak of Cladocera was delayed until fall during alewives (Figure 6). This was usually after many of the alewives had emigrated from the lake and may be a result of decreased predation. Yet in 1993, a relatively dry year in which the alewives did not emigrate until late winter, Cladocera still



increased slightly late in the summer. After alewives, the spring peak of Cladocera, that was present before alewives, was missing for all three years. Mean monthly densities of Copepoda and Rotatoria show generally similar seasonal patterns for all three periods, although the pattern after alewives, when densities were lowest of all 3 periods, was slightly different (Figures 7 and 8). During alewives, densities of Rotatoria increased in August as densities of Cladocera and Copepoda decreased, which may be simply a response to decreased competition or predation. But Rotatoria increased after alewives when densities of Cladocera and Copepoda also increased,

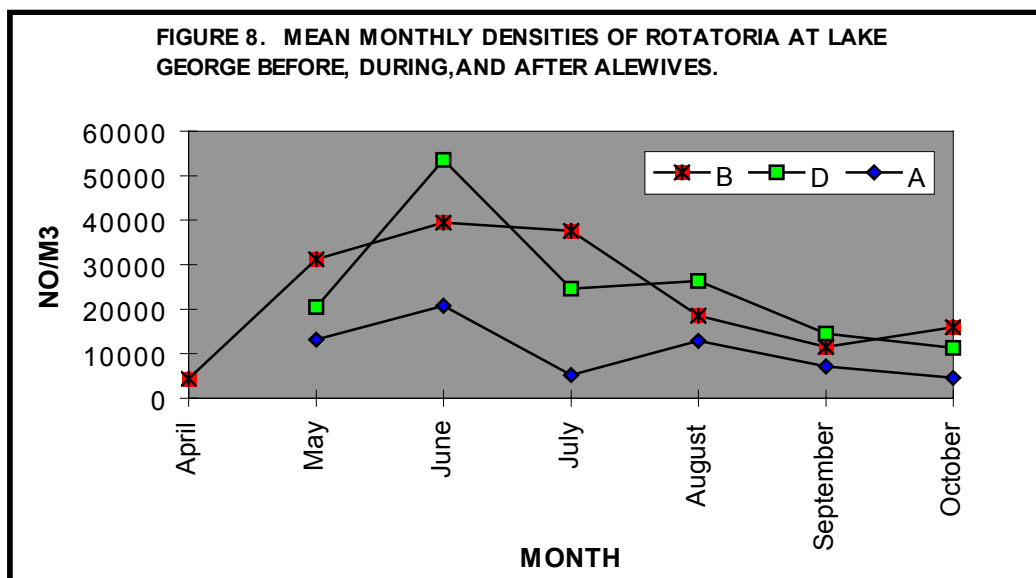


demonstrating that the trophic dynamics are more complex between groups than predicted by simple competition and predation models. These shifts in population densities of the 3 groups may be a result of shifts in species within groups, but because Copepoda and Rotatoria were not identified below order and phylum, species shifts could not be evaluated.

Within the Cladocera, several species (*Ceriodaphnia reticulata*, *Daphnia ambigua*, *Daphnia catawba*, *Daphnia dubia*, *Daphnia galeata mendota*, *Daphnia longiremis*, *Daphnia pulex*, *Diaphanosoma brachyurum*, *Holopedium gibberum*) appeared to decline during alewives. Some of these were relatively large (*Daphnia catawba*, *Daphnia galeata mendota*, *Daphnia pulex*) or medium-sized species (*Daphnia dubia*, *Holopedium gibberum*), which have been reported to be cropped to lower population densities by planktivorous fish in other studies (Brooks and Dodson, 1965; Mower, 1978; Warshaw, 1972). Some of these, however, were smaller species (*Ceriodaphnia reticulata*, *Daphnia ambigua*, *Diaphanosoma brachyurum*) which often increase in the presence of planktivorous fish, rather than decrease as occurred here. *Bosmina coregoni*, another small sized species, is the species that most often increases in density

when other Cladocera are reduced by planktivorous fish. In Lake George, however, densities of *Bosmina coregoni* did not change significantly. Furthermore, the only species of Cladocera to increase was *Daphnia retrocurva*, a medium sized species, which increased in the second year during alewives. These differences from results of other studies demonstrate the complex trophic dynamics of lake ecosystems that are not completely understood.

After-alewives densities of *Daphnia catawba* and *Daphnia dubia* recovered to densities similar to before alewives within 3 and 2 years, respectively. The density of *Daphnia ambigua* actually increased to a level greater than before



alewives within 2 years after alewives. Densities of the other species that

declined during alewives remained lower than before alewives, but the density of *Daphnia longiremis*, one of the most abundant Cladocera, steadily increased during the 3 years after alewives, although it did not reach densities similar to before alewives. *Daphnia retrocurva* densities decreased after alewives to levels below both before and during alewives. *Chydorus faviformis* was not found before or during alewives, but became the most abundant of the Cladocera by the third year after alewives making it the second most abundant for the entire three year period after alewives.

In addition to shifts to smaller species, changes in size within species also occurred. During alewives, *Bosmina coregoni* were significantly smaller than before (Table 1). After alewives, *Bosmina coregoni* were slightly larger than during, but the increase was not significant, and they did not reach the length that they were before alewives. Other cladocerans either showed no size shift or were not very numerous during or after alewives.

TABLE 1. MEAN LENGTHS (MM) OF ZOOPLANKTON BEFORE, DURING, AND AFTER ALEWIVES.

Period	Calanoida		Cyclopoida		Bosmina coregoni	
B	0.86	n=695	0.85	n=362	0.43	n=139
D	0.94*	n=529	0.83	n=164	0.36*	n= 88
A	0.90*	n= 98	0.91	n= 87	0.38*	n= 26

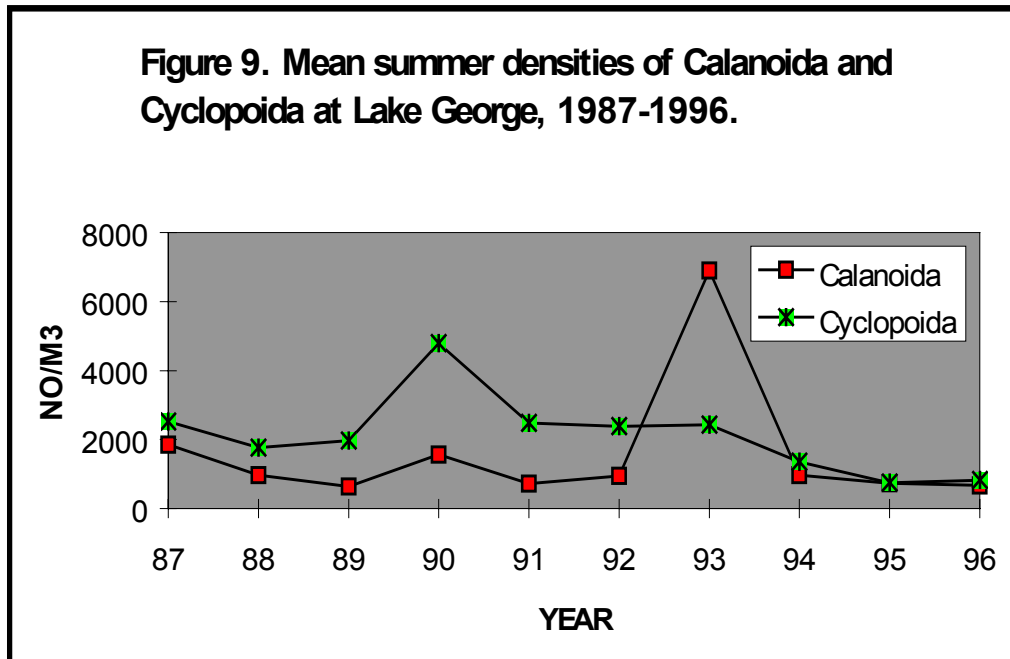
\*= significantly different than Before alewives p=0.05

Among Copepoda, Calanoida were significantly larger during alewives than before. After alewives, Calanoida were slightly smaller than during, but the decrease was not significant and they were not reduced to their length of before alewives. The opposite trends for *Bosmina coregoni* and Calanoida are not likely results of simple paired compensatory changes in competition brought about by alewife predation. Calanoida were twice the length of *Bosmia coregoni* and, consequently, feed on larger food items. Shifts in densities of other possible Cladocera competitors are as likely to have an effect on Calanoida as are *Bosmina coregoni*. To evaluate this possibility, mean length of Cladocera as a group was estimated using mean species length, weighted by species composition. The mean length of Cladocera as a group declined through all periods. Interestingly, the Cyclopoida were not significantly different before, during, and after.

Within the Copepoda, mean annual densities of Cyclopoida were greater than those of Calanoida before alewives and the first two years during alewives (Figure 9). In the third year during alewives, the mean annual density of Cyclopoida was similar to previous years, but the mean annual density of Calanoida the greatest of any year for either sub-order. After alewives, densities of both were similar and somewhat reduced from before or during alewives.

Populations of most biota in various ecosystems, are determined by both 'bottom-up' and 'top-down' trophic dynamics. The biomass of populations are

primarily function of the biomass of both predators and prey. Planktivorous fish can influence the water quality of lakes and ponds through their 'top-down' feeding strategies, changing the size structure of the zooplankton community by cropping off larger bodied forms of zooplankton, such as the Cladocera. Since small-bodied zooplankton are less efficient grazers on algae than large-bodied forms, a result is often that algal densities increase and water clarity decreases. Basic relationships between fish and zooplankton have been determined which show that the size structure of the fish community is relatively similar to the size structure of the zooplankton community. Lakes dominated by small-sized fish



are dominated by small-sized zooplankton, while for lakes where predators and prey are more balanced, fish are more evenly distributed among all sizes and zooplankton tend to be larger.

As a result of these relationships, the size structure of the zooplankton community, which is easier to measure than population densities of fish communities, can be used to determine if predators and prey are in balance. In small warm water lakes of moderate to high fertility, a mean zooplankton length >0.8 mm during spring and summer indicates that predators are balanced with planktivores, while mean lengths <0.8 mm indicate that predators and prey are out of balance. Where the system is more in balance, mean length may be greater than that during spring but less during the summer, which usually results in lower clarity during the summer (Mills and Green, 1992). In Lake George, mean length of zooplankton (Cladocera and Copepoda) during spring and summer combined was 0.90, 0.89, and 0.89 mm before, during and after alewives respectively. These results indicate that predators and prey were reasonably well balanced for all three periods despite the increase in abundance of planktivorous alewives.

Despite declines in both density and size of Cladocera during alewives, density of Copepoda, which were more abundant, did not decrease, and size increased after alewives, thereby minimizing the decline in density and size of zooplankton available for alewives. Although the stocking rate of alewives (2.4/ha) had some effects on Cladocera, compensatory mechanisms allowed Copepoda and Rotatoria to increase such that there was not a large effect on the zooplankton community as a whole.

In summary, the introduction of alewives resulted in a decrease in Cladocera, which recovered to densities similar to those before alewives by the third year after alewives. Densities of Copepoda were not changed by stocking of alewives but declined after alewives. Rotatoria appear to increase during alewives and declined after alewives, although by the third year there was a sharp recovery to before alewives densities. There were some species shifts and changes in size in the Cladocera and Copepoda. Mean length of Cladocera decreased during all three periods, while mean length of Copepoda increased after alewives due to the increased size of Cyclopoida.

#### ALGAE AND WATER QUALITY

Relative to Maine's population of glacial lakes, Lake George has moderate primary productivity. Mean total phosphorous and chlorophyll *a* concentrations approximate 7 mg/m<sup>3</sup> and 3.2 mg/m<sup>3</sup>, respectively. Total alkalinity averages 12 mg/l as CaCO<sub>3</sub>, and conductivity averages 34 µS. Mean secchi disk transparency exceeds 6 m. Lake George undergoes thermal stratification during the summer months, generally from mid-June to mid-September. Dissolved oxygen deficits (<5 mg/l) occur during the late summer period.

Like zooplankton, populations of algae are influenced by both 'bottom-up' and 'top-down' trophic dynamics. For algae, 'prey' is sunlight and nutrients rather than some other organism. Algae can be measured by a number of methods, one of the most direct being measurement of chlorophyll *a*, the photosynthetic pigment in each algal cell. A less direct, but easier measurement to make, is Secchi disk transparency, which in lakes, where there is usually little inorganic suspended solids, is a reasonably good indicator of the amount of algae in the water column. A third measurement of algae is total phosphorus, which is actually a combined measurement of the amount of phosphorus incorporated into the algal cells and the ortho-phosphorus available for new algal growth. Phosphorus is continually cycling among algae, zooplankton, water, sediments, fish, and other parts of the ecosystem such that factors that affect any of these components may also affect the total phosphorus concentration in the water.

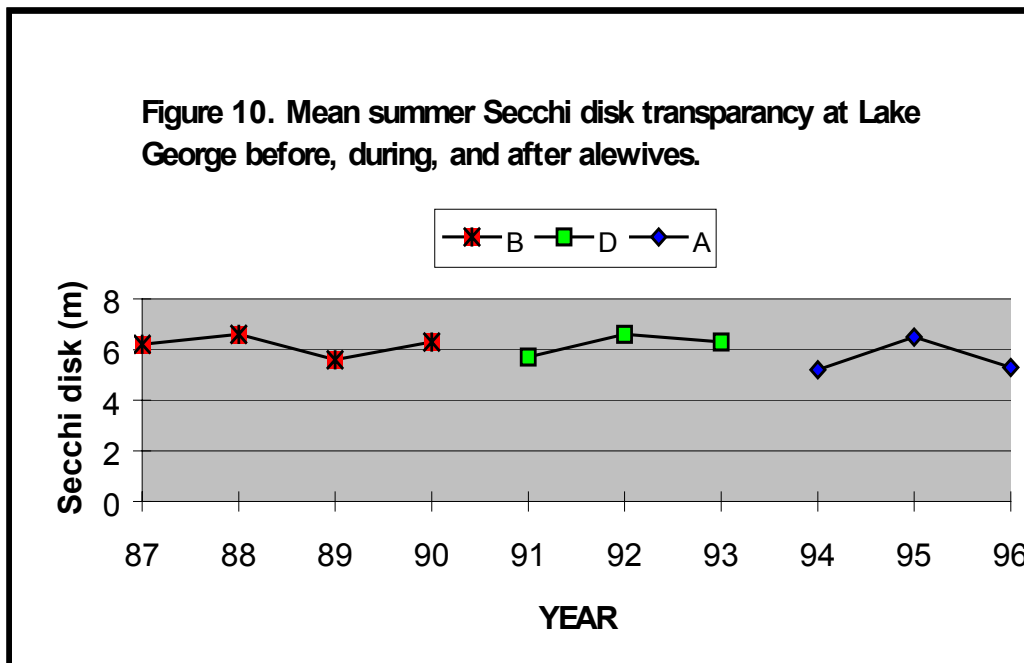
Given changes in the zooplankton community that resulted from the introduction of alewives, effects on algal populations might have been expected, resulting from shifts in top-down trophic dynamics. Reduced populations of zooplankton or shifts to less effective grazers might have resulted in an increase in algae. On

the other hand, from bottom-up considerations, increased piscivory by alewives on zooplankton could have increased the energy and nutrient transfer from the trophic level 2 to trophic level 3 for the lake ecosystem, thereby tying up nutrients that would no longer be available for algal growth. This might depend on the assimilation efficiency and rate of elimination or recycling of nutrients in alewives compared to zooplankton. It is known that rates of recycling are faster at the lower trophic levels. Resultant interactions with other fish species present in the lake also no doubt play a role in these complex relationships.

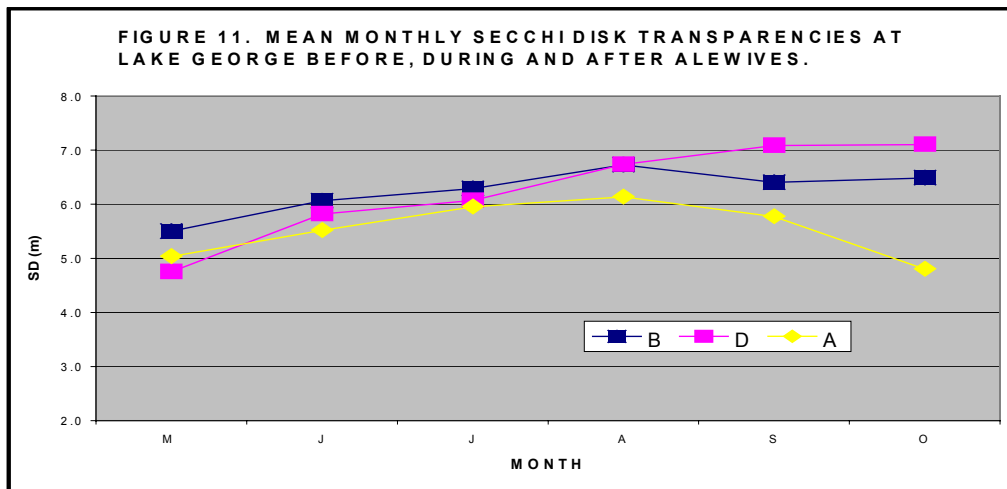
For statistical comparisons of the effect of alewives on water quality, monthly and summer mean chlorophyll *a*, total phosphorus, and dissolved oxygen concentrations, and Secchi disk transparency, were calculated for each year. These measures of algal activity were also grouped by years corresponding to periods Before (1987-90), During (1991-93), and After (1994-96) the stocking of alewives. All statistical comparisons were conducted using the non-parametric Mann-Whitney test or parametric Students t-test as required at  $p=0.05$  for determination of all significant differences.

Mean summer Secchi disk transparency varied from 5.2-6.6 m by year, but was not significantly different during compared to either before or after alewives (Figure 10). Nevertheless, mean summer Secchi disk transparency was significantly lower after (5.7 m) than before alewives (6.2 m). This was due to the fact that the two lowest Secchi disk transparencies occurred during this period, during 1994 and 1996. If not for the fact that, in 1995 Secchi disk transparencies were similar to those before and during alewives, the mean for this period would have been significantly different from during as well.

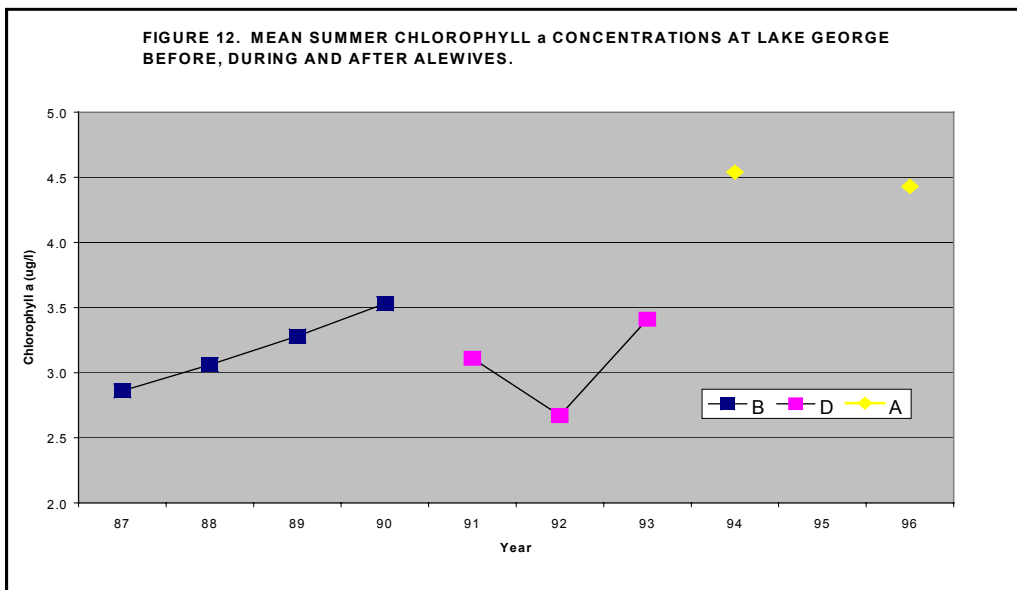
Seasonal patterns of Secchi disk transparency were similar for the three periods until August (Figure 11). During September and October, however, mean



monthly Secchi disk transparency declined considerably after alewives and to a lesser extent before alewives but continued to increase during alewives. These patterns were compared to plots of zooplankton densities to determine if transparencies could be explained by simple predator-prey interactions. There were no obvious relationships with densities of zooplankton for most of the summer, but Secchi disk transparencies generally mirrored the trends in total zooplankton densities during September and October. These trends most closely following those for Cladocera and Copepoda for all three periods during these months. The trend in Rotatoria densities followed that of Secchi disk only after alewives.



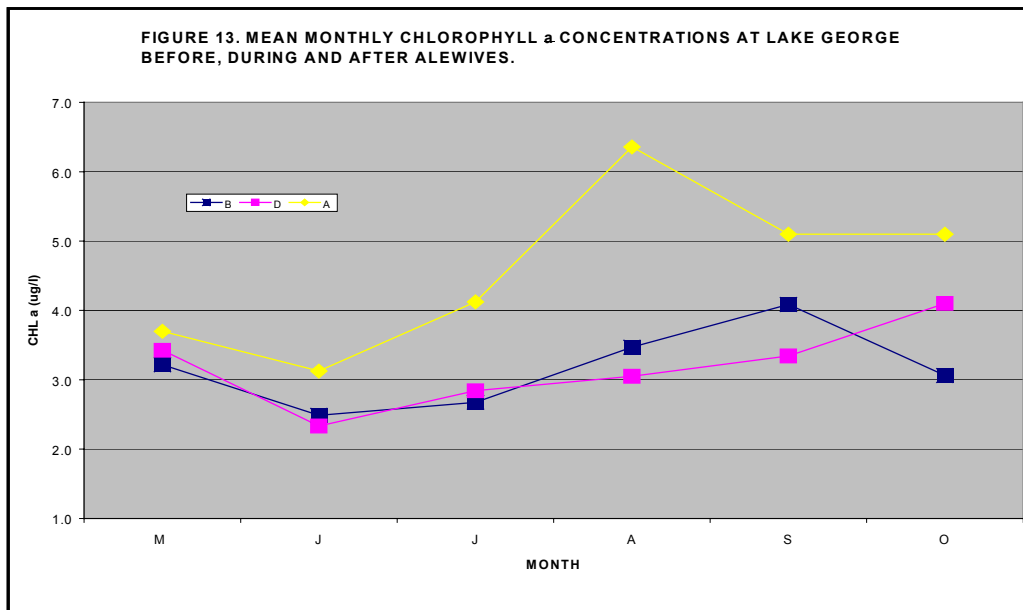
Mean summer epilimnetic chlorophyll a concentrations varied from 2.7-4.5 ug/l by year (Figure 12). There was no significant difference between chlorophyll a concentrations before and during alewives, but concentrations were significantly higher after alewives than before or during. There were no data for 1995, but



concentrations for 1994 and 1996 were the highest of the whole study. These

years correlate with those showing the lowest Secchi disk transparencies. Interestingly, there were lower densities of total zooplankton for this period as a whole which may be the reason for these chlorophyll a and Secchi disk results. But the patterns do not match perfectly. Densities of Cladocera and Rotatoria had rebounded to before alewives levels by 1996. On the other hand densities of Copepoda remained depressed during this period. Mean length of Copepoda increased after alewives, due mostly to increased size of Cyclopoida which prey more on other zooplankton than algae. From these results it may be the Copepoda were the most important predator on the algae.

Seasonal patterns of chlorophyll a concentrations were generally similar for all three periods until August, as was the case for Secchi disk transparency, and increased from a low in June (Figure 13). During September and October patterns were different for each of the three periods, and did not seem to explain the patterns in Secchi disk transparency for this period. The trend in chlorophyll a was generally inversely proportional to the trend in total zooplankton, as expected, influenced mostly by Copepoda and Rotatoria, since they were most abundant. The best relationship occurred before alewives. Trends in chlorophyll a during September and October after alewives were not explained by trends in zooplankton densities, suggesting that some other factor was more important during this period.

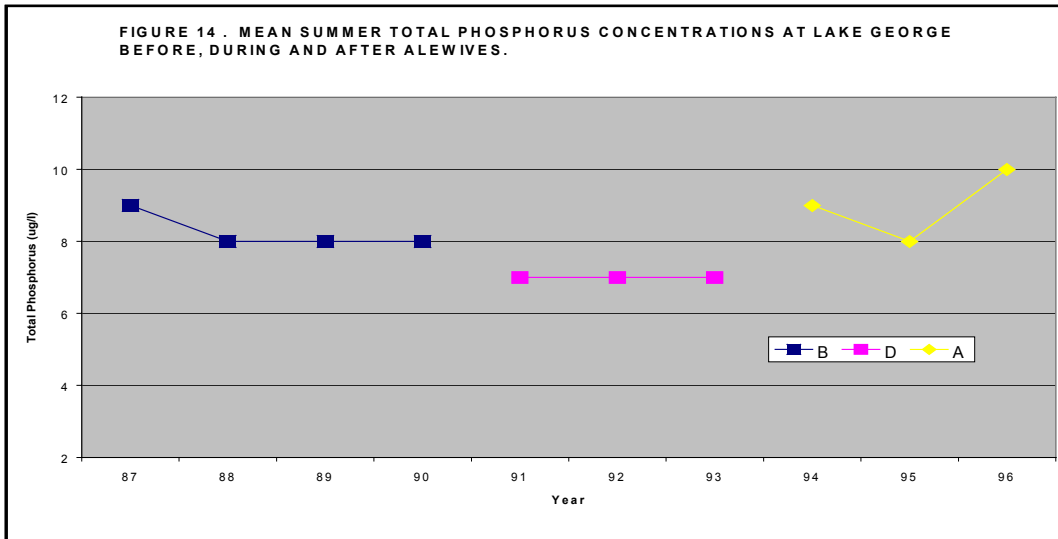


Mean summer epilimnetic total phosphorus concentrations varied from 7-10 ug/l by year and were significantly lower during alewives than either before or after, although the differences among periods (B=8 ug/l, D=7 ug/l, A=9 ug/l) were small (Figure 14). This result did not correlate well with chlorophyll a concentrations or Secchi disk transparencies during alewives, which were similar to both before and after alewives levels. Considering top-down trophic relationships, this result



was unexpected, an increase or no effect being more likely. This may be a result of sequestering of total phosphorus by the alewives.

Mean summer epilimnetic total phosphorus concentrations were highest after alewives, which is consistent with chlorophyll *a* concentrations and Secchi disk transparencies that were significantly higher and lower respectively during this period than before alewives. But mean summer epilimnetic total phosphorus concentrations were not significantly higher after alewives than before and therefore may explain part but not all of the change in chlorophyll *a* concentrations and Secchi disk transparencies. Top down effects of reduced grazing previously mentioned are probably also a factor.

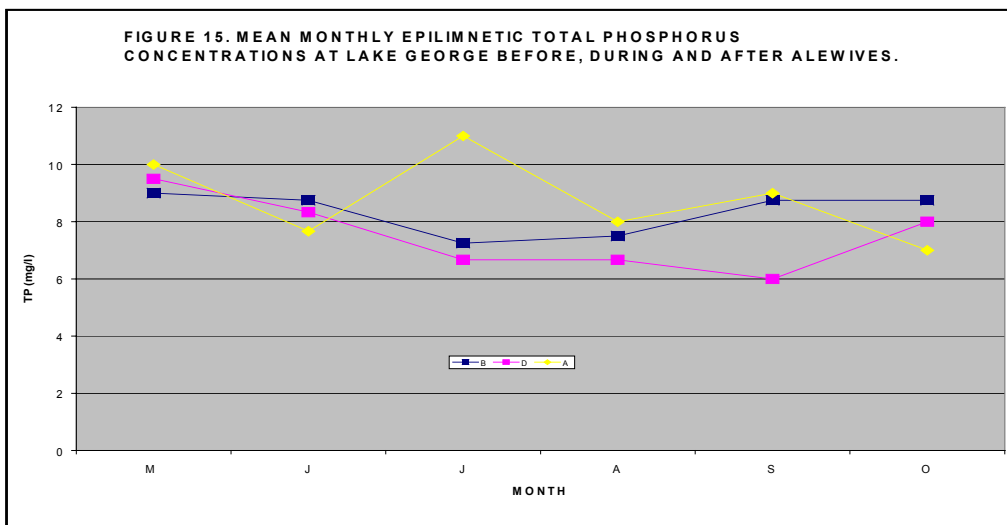


Mean summer hypolimnetic total phosphorus concentrations were also calculated for each period to determine if the phosphorus had simply changed compartments from the epilimnion to the hypolimnion through some interaction of alewives and zooplankton. From a straight averaging of epilimnetic and hypolimnetic concentrations this appeared to be the case, but when weighted by relative volumes of each compartment it was less obvious. In addition, mean summer hypolimnetic total phosphorus concentrations were similar for all three periods, unlike mean summer epilimnetic total phosphorus concentrations which were lower during alewives.

Total phosphorus concentrations are also determined by import into lakes. There were no known direct discharges into Lake George, but there were two summer camps hosting dozens of campers each on the lake until 1994 when they both closed. In order to estimate relative changes in potential runoff of phosphorus from the watershed into the lake from these and other activities in the watershed, monthly precipitation was compared for all three periods. Unlike mean summer epilimnetic total phosphorus concentrations, monthly precipitation was not significantly different before and during alewives, but it was significantly higher after than during. The significant decrease in mean summer total phosphorus concentrations during alewives could easily be the result of sequestering of

phosphorus by alewives, while increases after alewives to levels exceeding before alewives are probably a combination of lack of alewives and increased precipitation.

Seasonal patterns of epilimnetic total phosphorus were generally similar before and during until August, but the pattern after alewives was more variable (Figure 15). Concentrations during alewives tended to decline most of the summer until October, unlike before alewives, probably a result of sequestering of phosphorus by the growth of alewives during the summer until out-migration in the fall. Mean total phosphorus concentrations in July after alewives were much higher than July concentrations for other periods, due to high concentrations in 1995 and 1996. While abnormally high rainfall in May have been responsible for high total phosphorus concentrations in 1996, high concentrations in 1995 are

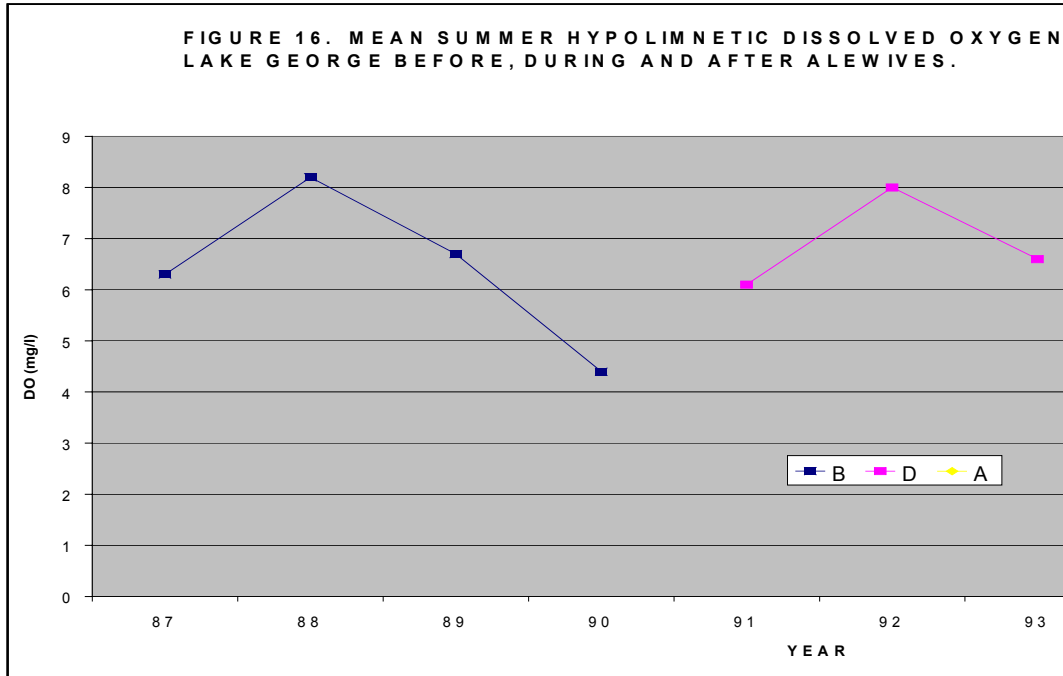


unexplained. Trends in total phosphorus for any period did not follow those of chlorophyll *a* as expected. Trends were generally inverse of those for Rotatoria before alewives, but no other relationships were obvious for other periods or zooplankton groups.

Dissolved oxygen is supplied to a lake primarily by diffusion from the atmosphere enhanced by wind driven mixing of the whole lake during periods when the lake is homothermous or mixing of the epilimnion when the lake is thermally stratified. Algae may increase dissolved oxygen concentrations during photosynthesis, which usually occurs in the epilimnion. Algae may also decrease dissolved oxygen during respiration and decay, the latter occurring mostly in the metalimnion or hypolimnion as the dead algae settle toward the bottom of the lake.

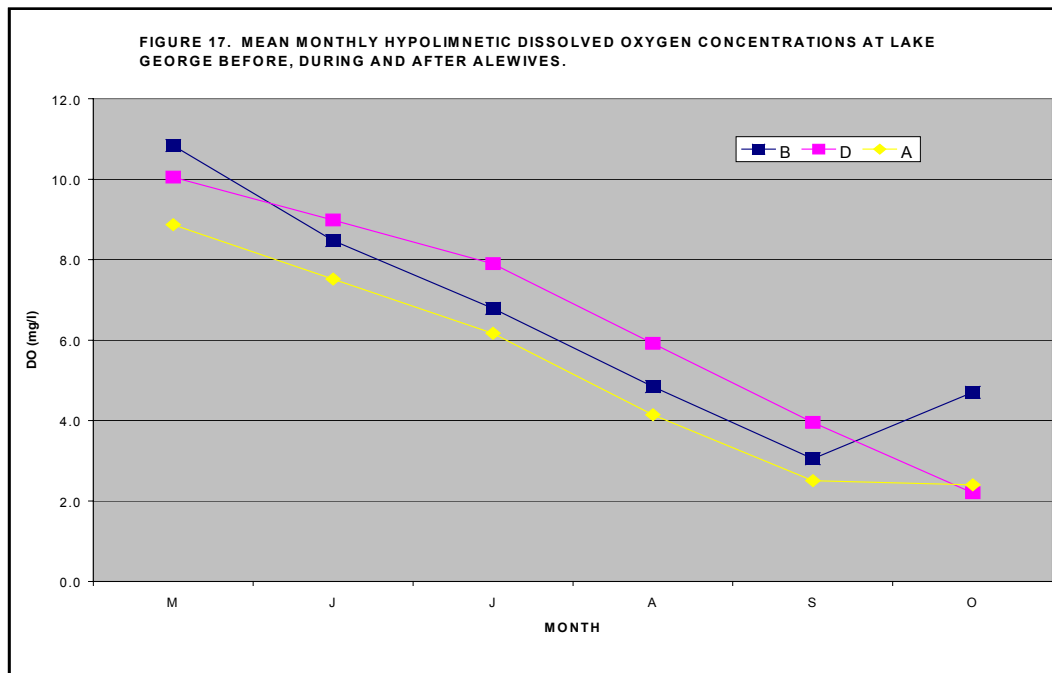
Mean summer hypolimnetic dissolved oxygen concentrations varied somewhat by year, (Figure 16). Given the observed increase in mean summer epilimnetic chlorophyll *a* concentrations after alewives, a decrease in dissolved oxygen concentrations in the hypolimnion might have been expected as a result of decay

of increased algae. The mean dissolved oxygen concentration for the period was slightly lower than before or during alewives, but the differences were not significant. Epilimnetic and metalimnetic dissolved oxygen levels would be expected to be less responsive to chlorophyll a as they are both primarily



influenced by continuous resupply from the atmosphere unlike the hypolimnion which receives no new oxygen during the summer.

Plots of mean monthly hypolimnetic dissolved oxygen for each of the three periods have slopes showing generally similar rates of depletion (Figure 17). In October mean hypolimnetic dissolved oxygen concentrations continued to decline during alewives, but actually increased or leveled off before and after alewives. Dissolved oxygen concentrations were generally lower from the



beginning of the summer after alewives than before or during, no doubt a result of higher chlorophyll a concentrations during this period, primarily from an unusually high concentration in 1994. Since maximum differences between periods occurred later in the summer for chlorophyll a concentrations than for hypolimnetic dissolved oxygen concentrations, other factors such as thermal stratification and mixing are also likely important.

To summarize, water quality, as measured by Secchi disk transparency, and chlorophyll a concentrations, was not significantly different during alewives but was significantly reduced after alewives. The trend was inversely proportional to the trend in total zooplankton. Total phosphorus concentrations were significantly lower during alewives but did not correlate well with Secchi disk transparency or chlorophyll a concentrations. This was unexpected and may reflect sequestering of total phosphorus by alewives. Total phosphorus was highest after alewives correlating with Secchi disk transparency and chlorophyll a. Another factor contributing to increased total phosphorus may be rainfall and runoff which may have resulted in more phosphorus import to the lake than the other two periods. Hypolimnetic dissolved oxygen concentrations and depletion rates were not significantly different among all three periods.

## **FISHERIES :**

### **MAJOR SPORT FISH:**

Four species of freshwater fish are targeted by the majority of Lake George anglers. They are, in order of angler preference, brown trout, smallmouth bass, white perch, and chain pickerel. Only one of these, white perch, is native to Lake George, the others having been introduced at various times since the late 1800's. The brown trout fishery is maintained by annual stocking of hatchery-reared fish (Appendix 2) because spawning habitat is not available. The smallmouth bass population is not as large as habitat potential suggests it could be, and chain pickerel abundance is limited by a paucity of both spawning and adult habitat. White perch are numerous and reach a desirable size in Lake George.

Spring and fall trap net samples, and winter angler creel surveys, found no statistical difference in mean length, mean weight, or abundance of any of the four major sport fish species (Tables 2 and 3). Data suggest that chain pickerel weights were heavier during the three years that anadromous alewives were stocked in the lake but the sample size (9) was too small to be of significance. Pickerel length, for which sufficient data was available, showed no significant difference between the four-year period prior to alewife introduction and the three years of alewife presence.

### MINOR SPORT FISH:

A small proportion of Maine anglers target five other species of fish that reside in Lake George. Brown bullhead, burbot, pumpkinseed, redbreast sunfish, and yellow perch occur in numbers sufficient to provide ample opportunity for those anglers that seek them. None of these species showed any change in size during the three years of alewife presence in Lake George (Table 2).

### FORAGE FISH:

There are three species of fish important as forage in Lake George. Rainbow smelt are particularly critical for satisfactory growth by brown trout. We assigned May 1 as the birthday for all cohorts (smelt spawn in April in Lake George) and estimated Von Bertalanffy growth equations for YOY smelt collected during all phases of the study. YOY smelt growth was significantly faster during the period when alewives were being stocked (Figure 18). The equations for smelt growth in the three periods differed both in asymptotic length ( $L_{\infty}$ ) and growth coefficient ( $K$ ) (Figures 19a and 19b). We hypothesize this was the result of changes in YOY smelt diet, mediated by alewife restructuring of the plankton community and decreased YOY smelt densities.

Our skill at collecting the target 30 YOY smelt increased throughout the study as we learned where and when to trawl. Therefore, the number of trawls, trawl duration, and catch rates varied annually (Figure 20). During the first two years we made long trawls and had several large captures of YOY smelt (> 400 in 1 haul). Catch rates were lowest in 1990 and 1991, the summers following the commercial harvests. We also found that we were more likely to capture YOY in some areas of the lake. This seemed to be related to month and proximity to spawning areas (Figure 21). Catch rates of YOY smelt were broken down into early summer (June & July) and late summer (Aug. & Sept.) because as the YOY grew they became more vulnerable to our trawl. They also moved into somewhat deeper water, but not the deepest portion of the lake. Catch rates during the period alewives were being stocked were significantly lower than the other two periods (Figure 22). While high catch rates can often be maintained as populations decline, low catch rates are good indications of decreased density. Another indicator of low YOY populations was the significantly higher proportion

**Table 2. Lake George Trap Net Sampling Summary.**

Species	Mean size	Before Alewife Introduction 1987 - 1990 combined		During Alewife Introduction 1991 - 1993 combined	
		Spring	Fall	Spring	Fall
<b>Brown bullhead</b>	length (mm)	220 (147)	217 (143)	208 (85)	216 (66)
	weight (g)	148 (17)	158 (21)	no data	145 (46)
<b>Brown trout</b>	length (mm)	367 (6)	405 (253)	350 (17)	410 (72)
	weight (g)	718 (6)	805 (253 )	407 (17)	741 (72)
<b>Burbot</b>	length (mm)	323 (3)	461 (18)	401 (1)	511 (18)
	weight (g)	300 (2)	546 (15)	no data	567 (12)
<b>Chain pickerel</b>	length (mm)	448 (45)	444 (116)	478 (25)	450 (80)
	weight (g)	659 (29)	644 (82)	906 (9)	539 (80)
<b>Fallfish</b>	length (mm)	249 (3)	230 (2)	no data	208 (4)
	weight (g)	210 (3)	160 (1)	no data	113 (3)
<b>Golden shiner</b>	length (mm)	175 (54)	191 (8)	176 (24)	174 (9)
	weight (g)	62 (13)	81 (6)	71 (6)	51 (5)
<b>Pumpkinseed</b>	length (mm)	160 (110)	137 (130)	142 (90)	140 (73)
	weight (g)	71 (57)	66 (30)	no data	62 (43)
<b>Redbreast sunfish</b>	length (mm)	171 (18)	168 (10)	171 (8)	153 (3)
	weight (g)	98 (4)	150 (3)	no data	78 (3)
<b>Smallmouth bass</b>	length (mm)	374 (78)	376 (14)	370 (31)	317 (30)
	weight (g)	804 (76)	796 (13)	856 (27)	528 (30)
<b>White perch</b>	length (mm)	228 (616)	236 (103)	239 (103)	233 (87)
	weight (g)	164 (330)	174 (81)	274 (56)	169 (87)
<b>White sucker</b>	length (mm)	422 (103)	350 (90)	553 (1)	394 (60)
	weight (g)	926 (43)	586 (45)	no data	706 (60)
<b>Yellow perch</b>	length (mm)	167 (101)	183 (55)	169 (141)	164 (60)
	weight (g)	47 (32)	71 (24)	43 (31)	48 (46)

**note: number in ( ) = sample size**

**Table 3. Creel Survey Summary.**

Water: Lake George		Town: Canaan and Skowhegan						County: Somerset		Season: Winter
Statistics	Species	Before			During			After		
		1988	1989	1990	1991	1992	1993	1994	1995	
No. anglers surveyed	all	407	364	327	361	418	328	445	383	
Anglers hrs. surveyed	all	2004	1291	1313	1495	2032	1346	2275	1714	
No. (%) legal fish in catch	BNT	66(95.7)	32(91.4)	36(100)	18(48.7)	39(97.8)	44(96)	38(100)	60(98.4)	
	PKL	68(100)	57(100)	113(100)	30(100)	69(100)	52(100)	57(100)	59(100)	
	WHP	85(100)	69(100)	21(100)	10(100)	25(100)		9(100)	45(100)	
	all	453(99.3)	322(99.1)	174(100)	401(95.4)	577(99.8)				
%succ. in catching legal fish	BNT	25.6	17.9	13.3	10.3	16.7	<i>Data not Available</i>			
	PKL	22.2	20.5	28.7	17.0	31.5				
	WHP	17.0	22.4	10.0	6.9	9.5				
	all	65.3	61.5	41.3	54.5	66.7				
No. legal fish/angler	BNT	0.16	0.09	0.11	0.05	0.09	0.13	0.08	0.16	
	PKL	0.17	0.16	0.37	0.08	0.17	0.16	0.13	0.15	
	WHP	0.21	0.19	0.09	0.03	0.06		0.02	0.12	
	all	1.11	0.88	0.58	1.11	1.38				
Hrs. to catch a legal fish	BNT	32.3	57.1	46.7	103.1	57.1	28.6	73.5	32.2	
	PKL	29.5	22.7	10.8	36.5	19.9	25.9	42.9	29.0	
	WHP	23.6	18.7	46.9	149.5	78.2		252.8	38.1	
	all	4.4	4.0	6.9	3.6	3.2				
Mean length (SE) in mm	BNT	387(9)	400(16)	414(15)	418(11)	380	361(3)	416(8)	407(8)	
	PKL	399(13)	372(15)	384(11)	442(12)	412	441(17)	405(13)	415(14)	
	WHP	279(5)	270(4)	270(6)	282(8)	285	325(0)	304(12)	307(5)	
Mean weight (SE) in g	BNT	732(70)	659(81)	807(90)	747(57)	556	479(31)	707(38)	671(36)	
	PKL	318(47)	410(51)	385(31)	541(50)	453	491(17)	464(47)	434(41)	
	WHP	313(29)	300(16)	316(23)	298(33)	358	480(0)	410(49)	470(26)	
Est. total harvest (CI)	BNT	123 (71-176)	60 (42-78)	81 (36-147)	42 (18-67)	87 (43-130)	160 (44-277)	56 (38-82)	89 (60-132)	
	PKL	98 (68-138)	74 (57-98)	254 (113-390)	69 (40-99)	153 (89-217)	129 (52-198)	84 (57-121)	144 (59-255)	
	WHP	134 (85-198)	131 (84-179)	47 (17-77)	23 (12-34)	55 (25-102)			233 (451-504)	
	YLP	498 (278-718)	573 (499-697)	392 (162-621)	960 (612-1308)	1281 (663-232)	449 (198-700)	417 (280-554)	474 (298-650)	
	all	982 (615-1348)			785 (472-1097)	963 (577-1464)				
	Est. total angler-days		882 (653-1111)	732 (602-861)	736 (487-985)	833 (575-1091)	928 (624-1232)	877 (665-1089)	805 (689-921)	681 (465-897)

Figure 18. YOY smelt von Bertalanffy predicted length at age.

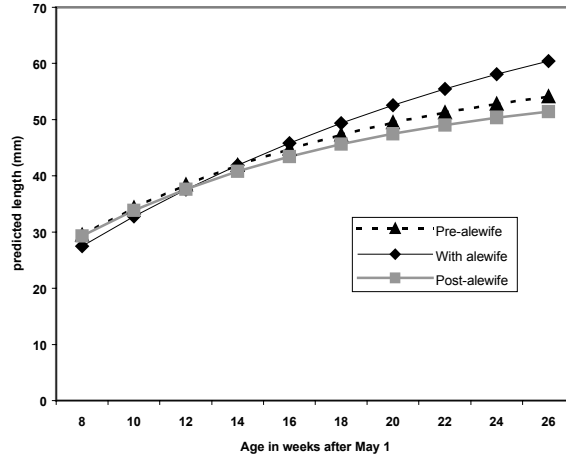


Figure 19a. YOY smelt growth parameters for von Bertalanffy equation.

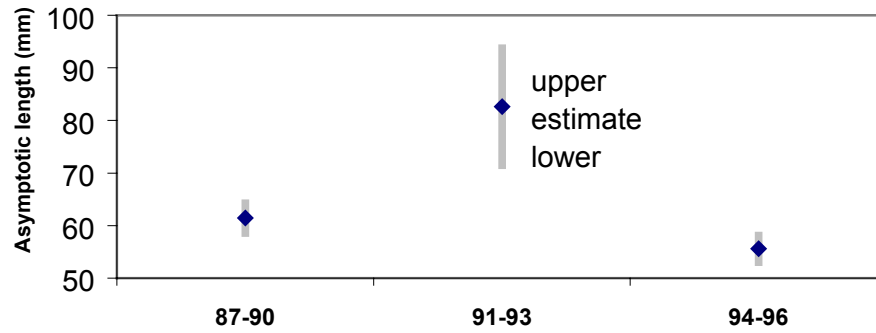
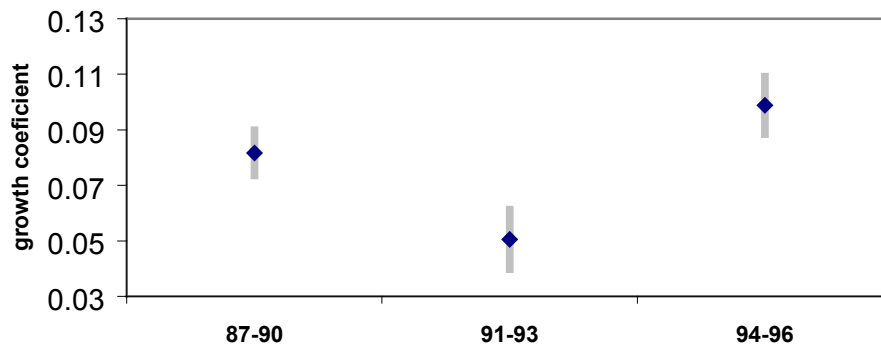
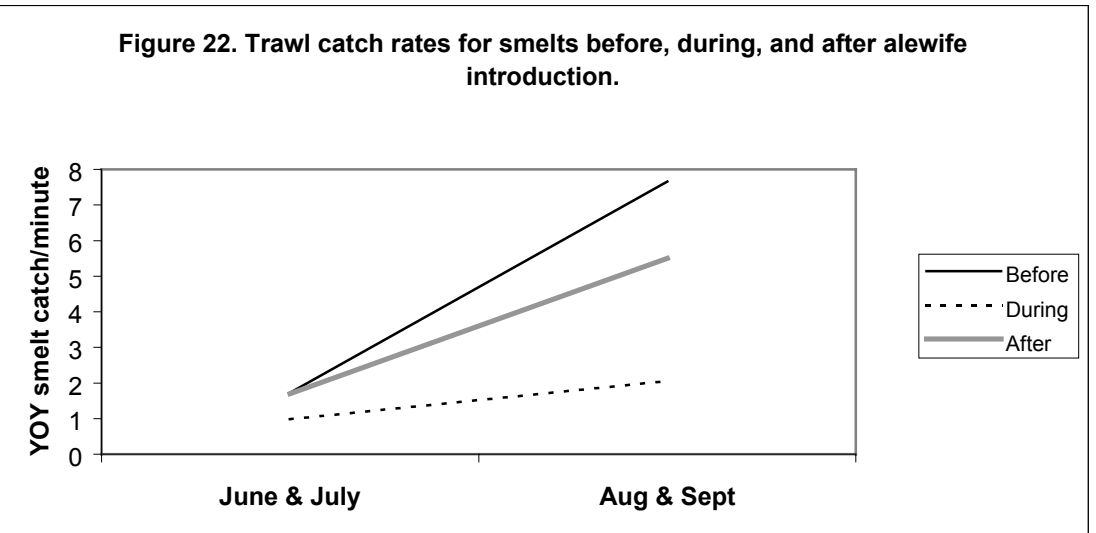
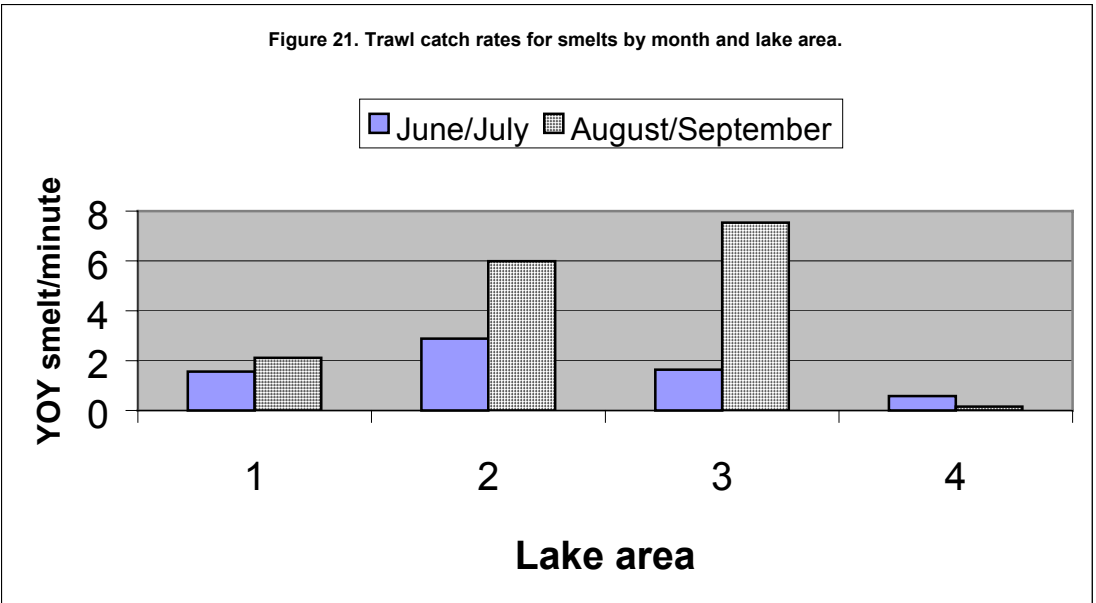
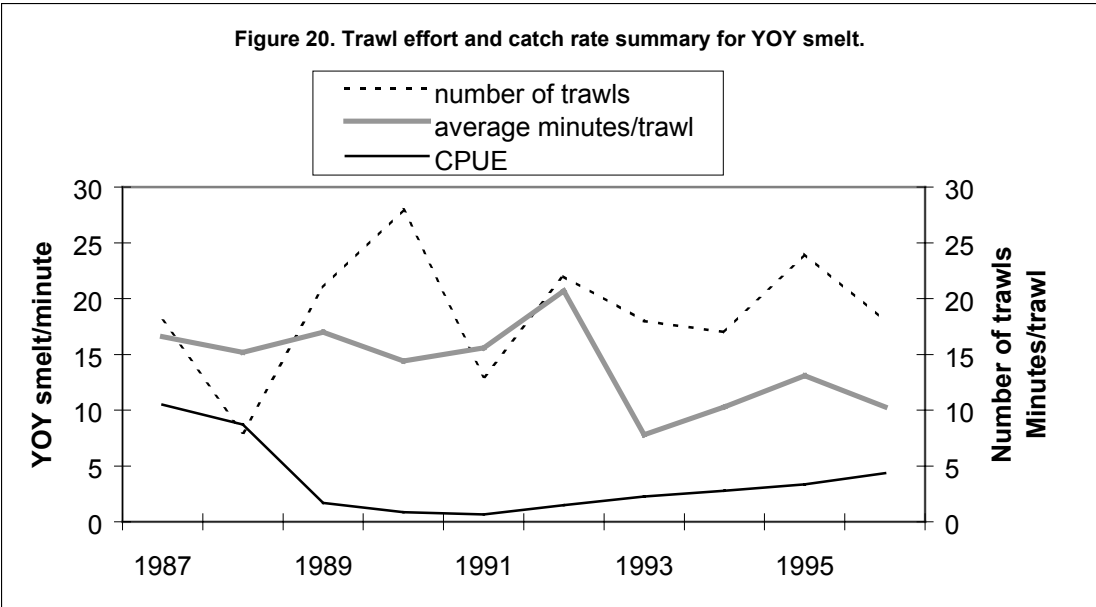


Figure 19b. YOY smelt growth parameters for von Bertalanffy equation.







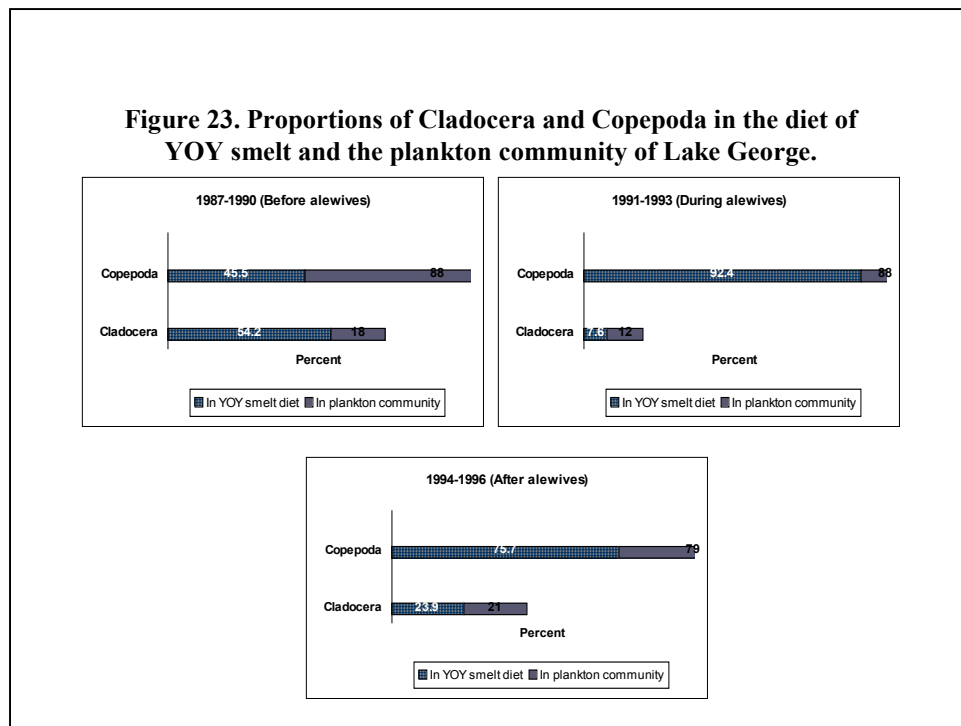
of yearling and older smelt (13.3%) in the catch during years with alewife stocking compared to before (1.25 %) and after (6.14 %).

STOMACH ANALYSIS (JUVENILE RAINBOW SMELT):

Because Rotifers were mistakenly not counted as smelt food items, the following analyses do not contain data regarding rotifers. Diet information presented as percentages, are percentages not including rotifer data.

Rotifera were dominant in the plankton community, with Copepoda next in abundance followed by Cladocera. Throughout the study 93% of the YOY had food in their stomachs with more smelt containing food in their stomachs during alewife introduction (Phase I – 90% of smelt stomachs contained food, Phase II – 95% of smelt stomachs contained food, and Phase III – 94% of smelt stomachs contained food).

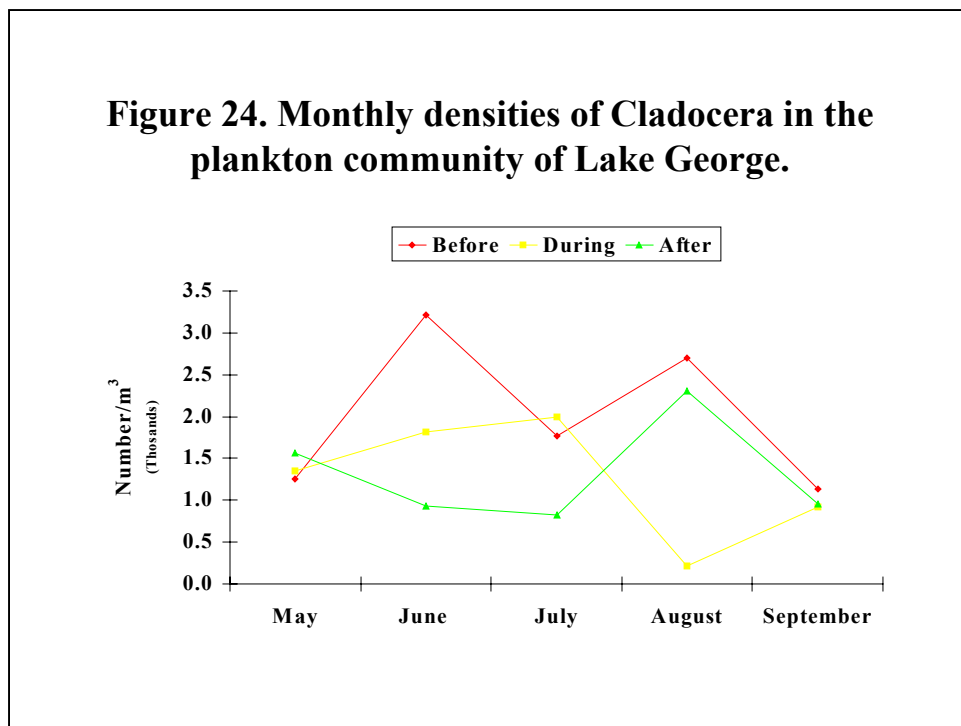
For analysis, food items were enumerated by major group. Rotifers were not enumerated in the diet, even though they are known to be important to YOY smelt especially in the first month of life. Without diet data on Rotifers, YOY smelt diet items were primarily Copepoda and Cladocera, with a small component of insects. YOY smelt contained about twice the number of food items during the period alewives were in the lake than during either other period. Additionally, the items they consumed changed.



Throughout the study, Copepoda and Cladocera were selected by YOY smelt, their occurrence in the diet disproportionate to that in the plankton (Figure 23).

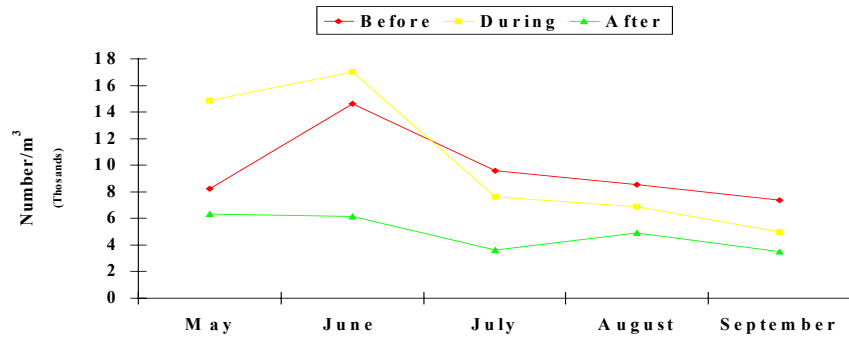
Prior to alewife introduction, Cladocera comprised a large portion of smelt diets; while in Phases II and III, Copepoda dominated the diet (except for 1995 when Cladocera comprised a large portion of smelt diets). During alewife introduction, Nauplii were also selected for on occasion (e.g. 30% of smelt diet in August 1991 and 21% of smelt diet in July 1992). Smelt ate Diptera in low numbers throughout the study, but Diptera did comprise a larger portion of the diet during alewife introduction. Trichoptera were also found in smelt stomachs, but rarely comprised more than 1% of an individual's diet.

Cladocera densities in the plankton were lower during the period that alewives were stocked compared to background data (Figure 24). The group's densities were even lower in early summer following cessation of stocking. The average size of individual species of Cladocera was unaffected by alewife predation. However, species composition changes were indicative of a shift to medium and smaller sized species.



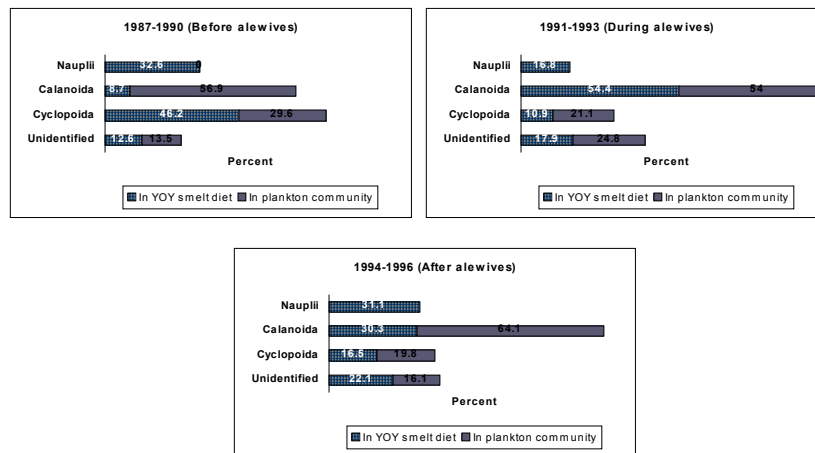
Copepoda became more important in YOY smelt diet during alewives stocking in the lake and from 1994 to 1996 (Figure 23). Copepoda density in the plankton was higher in early summer during the period alewives were in the lake, but overall were similar to those during the background period (Figure 25). Copepoda densities in the last period of the study were significantly reduced. Copepoda increased in importance in the diet during the study, although their relative abundance in the plankton was unchanged (Figure 23). There were significant changes in YOY consumption of Cyclopoid and Calanoid copepoda. From 1987 to 1990, Cyclopoids were the dominant copepod group in the diet, while after that Calanoids were consumed more often (Figure 26). This is likely

**Figure 25. Monthly densities of Copepoda in the plankton community of Lake George.**



related to the size structure of the groups, because only minor annual variations were noted in relative abundances of the two types of Copepoda (Figure 26). Calanoids were significantly larger while alewives were in the lake and Cyclopoids were significantly smaller. It seems that YOY smelt were targeting prey by size more than taxon.

**Figure 26. Proportions of Copepoda types in the diet of YOY smelt and the plankton community of Lake George.**



YOY growth was fastest during the three-year period that anadromous alewives were stocked into Lake George. Smaller sized plankton increased in abundance in the same period, with increased densities of rotifers. Smelt YOY consumed more items and the composition of their diet changed, probably related to the

influence of anadromous alewives on the size structure of the plankton community. YOY densities were also lowest during the period of alewife stocking, which also may have played a role in increased growth. However, we have no way of knowing what combination of factors caused the decreased density; our high trawl catches in the early years of the study, commercial harvest of adults in 1990 and 1991, competition with juvenile alewives, or some other factor.

#### STOMACH ANALYSIS (JUVENILE ALEWIFE):

During the three years of alewife introduction, the majority (85%) of juvenile alewife stomachs contained food. In 1992, all of the juvenile alewife stomachs contained food, while in 1991 96% of stomachs contained food and in 1993 only 59% of juvenile alewife stomachs contained food. In addition to all juvenile alewife stomachs containing food in 1992, individual juvenile alewife stomachs contained more food in 1992 than in 1991 or 1993. The average juvenile alewife contained 37 food items in 1991, 580 in 1992, and 88 in 1993. The high number of food items in 1992 was due to juvenile alewives feeding heavily upon Copepods in June and August of 1992.

Between 1991 and 1993, juvenile alewives primarily selected for Cladocera, Copepods, Nauplii and Diptera. In all three years, juvenile alewives selected more strongly for Cladocera than for any other group. In 1991, juvenile alewives selected for Cladocera and Copepods almost equally (slightly more Cladocera were eaten); Nauplii were strongly selected for in August. In June of 1992, Copepods comprised 95% of juvenile alewife diets, but then occurrence in stomachs decreased sharply. For the remainder of 1992 (July – September) and for all of 1993, Cladocera were strongly selected for.

From 1991 to 1993, juvenile alewife diets were comprised of progressively more Cladocera and less Copepoda. Additionally, Diptera were utilized as food items all three years (23% of diet in 1991, 13% of diet in 1992, and 2% of diet in 1993). In 1991, Copepoda and Cladocera were eaten in similar amounts in July (34% Copepoda, 41% Cladocera) and August (21% Copepoda, 28% Cladocera), and Nauplii were heavily utilized in August (47% of diet). In September 1991, the composition of Cladocera decreased to 15% of the diet and the amount of Diptera increased to 44% of the diet. In June of 1992, Copepoda dominated juvenile alewife diet (95% of diet). Cladocera became important in July (52% of diet), August (81% of diet), and September (77% of diet) in 1992 while the composition of Copepoda decreased. In 1993, Cladocera comprised between 85 and 100% of juvenile alewife diets while Copepods comprised less than 5% of juvenile alewife diets.

#### STOMACH ANALYSIS (ADULT ALEWIFE):

During the three years of alewife introduction, over half (66%) of adult alewife stomachs contained food. Over the three years of alewife introduction, the

percent of adult alewives with food in their stomachs increased slightly (1991 – 62%, 1992 – 65%, and 1993 – 70%). With the exception of 1993, the number of food items contained in the average adult alewife stomach was lower than the number of food items contained in either the average smelt or juvenile alewife stomach. There was a slight increase in the number of food items per stomach from 1991 (6 items per stomach) to 1992 (10 items per stomach) and a significant increase in the number of food items per stomach from 1992 to 1993 (172 items per stomach).

Adult alewives primarily selected for Cladocera and Diptera, but also fed upon Ephemeroptera, Copepoda, Trichoptera, Coleoptera, Odonata, fish (primarily yellow perch) and Mollusca. In 1991 and 1992, adult alewife diets were more diverse than either adult alewife diets in 1993, or smelt and juvenile alewife diets in general. In 1992, yellow perch comprised 35% of the diet in May, while Trichoptera and unidentified fish each comprised an additional 20% of the food items. In June Odonata was the most dominant food item and in July Trichoptera were eaten in slightly higher numbers than Odonata. Trichoptera were the most abundant food item in June of 1992, but the number of Trichoptera decreased to almost zero in July. In June and July of 1992, Diptera and Cladocera comprised roughly 28-33% of adult alewife diets. In 1993, Copepoda, Nauplii, and Cladocera were preyed upon in similar amounts in June (37%, 26%, and 32% respectively). The amount of Copepoda and Nauplii in adult alewife diets decreased to less than 10% Copepods and 0% Nauplii in August of 1993, while the amount of Cladocera in the diet increased to 85% of the total diet. Overall, only 101 fish were eaten by nine of the 17 fish sampled in May of 1991 and five fish were eaten by 20 fish sampled in June 1992; no adult alewives sampled in 1993 contained fish in their stomachs.

#### MORISITA'S INDEX OF SIMILARITY:

Morisita's index of Similarity was used to test for differences in the lake plankton community over the three phases of the study, as well as to test for differences in the diets of smelt, juvenile alewives, and adult alewives. The test returns a value from 0 to 1; the closer the value is to one, the more similar the "populations" are considered to be. When the test was employed to examine the lake plankton community, we found that the plankton community was very similar across all three phases of the study. In the test of Phase I vs. Phase II, the test returned a value of 0.999. In the test of Phase I vs. Phase III, the test returned a value of 0.992. Finally, in the test of Phase II vs. Phase III, the test returned a value of 0.995. These high values indicate that the presence of alewives did not significantly alter the zooplankton community.

While smelt and alewives fed on the same major groups (i.e. Copepoda and Cladocera), there was generally little overlap between smelt and alewife diets during Phase II of the study. When Morisita's test was used to examine overlap between smelt and adult alewife diets the test returned a value of 0.43. When

Morisita's test was employed to examine overlap between smelt and juvenile alewives, the test returned a value of 0.46. Finally, when Morisita's test was used to examine overlap between juvenile and adult alewives, the test returned a value of 0.36. In all cases the Morisita's value is well below 0.6, indicating little overlap between diets. Since smelt and juvenile alewives both feed heavily upon Copepoda and Cladocera, yet Morisita's test indicates little overlap, the two fish species are probably feeding upon different taxa within the major group (e. g. alewives typically feed on larger zooplankters).

To understand further what interactions may be occurring in smelt and alewife diets, we examined dietary overlap within years (1991-1993) for smelt and adult alewives. In all three years, smelt and adult alewives were very dissimilar; 1991 Morisita's Index=0.21, 1992 Morisita's Index=0.06, and 1993 Morisita's Index=0.23. We also examined dietary overlap indices for smelt and juvenile alewives between 1991 and 1993. Using Morisita's Index, we found that while there was overlap between smelt and juvenile alewives in 1991 (Morisita's Index=0.8), the degree of overlap decreased over time (1992 Morisita's Index=0.46 and 1993 Morisita's Index=0.13).

The decrease in diet similarity between smelt and juvenile alewife was probably due to a shift in the composition of smelt diets. When we used Morisita's Index to examine diet overlap across phases within smelt, we found that there was little overlap (Morisita's Index=0.37) between smelt diets from Phase I and Phase II. There was moderate overlap (Morisita's Index=0.64) between smelt diets from Phase I and Phase III and there was more overlap (Morisita's Index=0.83) between Phase II and Phase III. These data indicate that smelt diet changed when alewives were introduced to Lake George. In fact, there was a shift from a diet of primarily Cladocera in Phase I, to a diet composed largely of Copepoda during Phases II and III.

#### ALEWIFE EMIGRATION (ADULTS):

The number of adult alewife emigrants varied from year to year even though the number of adult alewives released into Lake George remained relatively constant. In 1991, 2,030 adult alewives were released into Lake George and 1,382 adult alewives were captured in the trap on the outlet stream. In 1992, 2,005 adult alewives were released into the lake and the trap on the outlet stream captured 858 adult alewives. In 1993, water flow out of the lake was reduced for much of the season. The reduced water flow made downstream migration difficult and only 345 adult alewives emigrated from Lake George in 1993.

In all three years of Phase II, adult emigration commenced in early June, peaked by the end of June or early July, and lasted until late fall (1991 and 1992) or winter (1993). Within each year, there were typically two or three distinct periods of adult emigration. In 1991, 1,111 adult alewives left Lake George between

June 2 and July 6. Between August 12 and September 1, a second pulse of 247 adult alewives emigrated from Lake George. Finally, between September 6 and October 5, a third pulse of 23 alewives left the lake. The peak for the year occurred on June 24 when 292 adults emigrated from Lake George. In 1992, only two distinct emigration periods occurred. Between June 1 and July 14, 737 adult alewives migrated out of Lake George. Between July 9 and July 28, a second pulse of 112 adults left Lake George. Between August 21 and October 5, another 9 adult alewives emigrated from Lake George. The peak for 1992 occurred on June 22, when 94 adult alewives left the lake. In 1993, 306 adult alewives left Lake George between June 7 and July 7. The remaining 39 emigrants left the lake in small pulses between September 1 and December 7.



## REFERENCES

---

- APHA, 1996. Standard Methods for the Examination of Water and Wastewater, 19th Edition. American Public Health Association, Washington, DC.
- Anderson, G., H. Bergorin, G. Cronenburg, and C. Gelin, 1978. Effects of planktivorous and benthivorous fish on organisms and water chemistry in eutrophic lakes. *Hydrobiologia* 59:9-15.
- Atkins, C.G., 1887. The River Fisheries Of Maine. In: Goode, G.B., 1887. The Fisheries And Fishery Industries Of The United States, Section V, Vol. 1.
- Brooks, J.L. and S.I. Dodson. 1965. Predation, body size and composition of plankton: the effect of a marine planktivore on lake plankton illustrates theory of size, competition, and predation. *Science*. 150:28-35.
- Carpenter, S.R., J.F. Kitchell, K.L. Cottingham, D.E. Schindler, D.L. Christensen, D.M. Post, and N. Voichick, 1996. Chlorophyll variability, nutrient input, and grazing, evidence from whole-lake experiments. *Ecology* 77:725-736.
- EPA, 1978.
- Gately, G.F. 1978. Competition for food between landlocked rainbow smelt (*Osmerus mordax*) and landlocked alewives (*Alosa pseudoharengus*) in Echo Lake, Maine. M.S. Thesis. University of Maine, Orono, ME. 94 pp.
- Havey, K.A. 1984. Standardization of computations involved in creel census data. Maine Department of Inland Fisheries and Wildlife, Augusta, Maine.
- Hutchinson, G.E., 1967. A Treatise on Limnology, Vol. 2 Introduction to Lake Biology and The Limnoplankton. John Wiley and Sons, New York, New York.
- Hutchinson, B.P. 1971. The effect of fish predation on the zooplankton of ten Adirondack lakes, with particular reference to the alewife, *Alosa pseudoharengus*. *Transactions of the American Fisheries Society* 100:325-335.
- Ives, A.R., S.R. Carpenter, and B. Dennis, 1999. Community interaction webs and zooplankton responses to planktivory manipulations. *Ecology* 80: 1405-1425.

- Jordan, R.M. 1989. Food habits of post-spawning adult anadromous alewives in freshwater. Interim Summary Report No. 3. Maine Department of Inland Fisheries and Wildlife, Augusta, Maine.
- McCullough, R.D. 1978. Food niche dimensions of larval rainbow smelt (*Osmerus mordax*). M.S. Thesis. University of Maine, Orono, ME. 57 pp.
- Mills, E.L. and D.M. Green, 1992. Using zooplankton to characterize the food chains of Lakes Cobbossee and Annabessacook. Report to Cobbossee Watershed District, Winthrop, Maine. Cornell University Biological Field Station, Bridgeport, NY. 20 pp.
- Mills, E.L. and A. Schiavone, Jr., 1982. Evaluation of fish communities through assessment of zooplankton populations and measures of lake productivity. *North American Journal of Fisheries Management* 2:14-27.
- Mink, L. 1989. Interactions of white perch (*Morone americana*) and anadromous alewife (*Alosa pseudoharengus*) in two coastal lakes and the potential for competition in an inland lake in Maine. M.S. Thesis, University of Maine, Orono.
- Mower, B., 1978. Utilization of juvenile alewives to control a lake water quality problem. Maine Department of Environmental Protection, Augusta, Maine. 55 pp.
- Mower, B., 1987. Sabattus Pond Restoration Project. Maine Department of Environmental Protection, Augusta, Maine. 164 pp.
- Pace, M. L., J.J. Cole, and S.R. Carpenter, 1998. Trophic cascades and compensation: differential responses of micro zooplankton in whole-lake experiments. *Ecology* 79:138-153.
- Pearsall, W., 1996. Instruction manual for baseline sampling. Maine Department of Environmental Protection, Augusta, Maine. 72 pp.
- Pennak, R.W., 1978. *Freshwater Invertebrates of the United States*, 2nd edition. John Wiley and Sons, New York, New York. 803 pp.
- Proulx, M., F.R. Pick, A. Mazumder, P.B. Hamilton, and D.R.S Lean, 1996. Effects of nutrients and planktivorous fish on the phytoplankton of shallow and deep aquatic systems. *Ecology* 77: 1556-1573.
- Siefert, R.E. 1972. First food of larval yellow perch, white sucker, bluegill, emerald shiner and rainbow smelt. *Transactions American Fisheries Society*. 101(2):219-225.

- Smith, M.R. 1987. Status of smallmouth bass populations in Spednic Lake, Maine. Summary Report No.2. Maine Department of Inland Fisheries and Wildlife, Augusta, Maine.
- Urban, T.P. and S.B. Brandt. 1993. Food and habitat partitioning between young-of-year alewives and rainbow smelt in southeastern Lake Ontario. *Environmental Biology of Fishes*. 36:359-372.
- Ward, H.B. and G.C. Whipple. 1918. *Fresh-Water Biology*. John Wiley and Sons, New York, New York. 1111 pp.
- Warshaw, S.J. 1972. Effects of alewives (*Alosa pseudoharengus*) on the zooplankton of Lake Wononskopomuc, Connecticut. *Limnology and Oceanography*. 17(6):816-825.

**Appendix 1. Fish species present in Lake George, Maine.**

<b>Common name</b>	<b>Scientific name</b>
Eastern brook trout	<i>Salvelinus fontinalis</i>
Brown trout	<i>Salmo trutta</i>
Rainbow smelt	<i>Osmerus mordax</i>
Burbot	<i>Lota lota</i>
Smallmouth bass	<i>Micropterus dolomieu</i>
Largemouth bass	<i>Micropterus salmoides</i>
Pumpkinseed sunfish	<i>Lepomis gibbosus</i>
Redbreast sunfish	<i>Lepomis auritus</i>
White perch	<i>Morone americana</i>
Yellow perch	<i>Perca flavescens</i>
Chain pickerel	<i>Esox niger</i>
Brown bullhead	<i>Ameiurus nebulosus</i>
Fallfish	<i>Semotilus corporalis</i>
Golden shiner	<i>Notemigonus chrysoleucas</i>

**Appendix 2. Lake George stocking history, 1987-1996**

	Phase I				Phase II			Phase III		
	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Brown trout										
Age I		400	400	400	400	400	400	400	400	400
Mark (see below)		RV	LP	LV	RP	BV	D	RV	LP	NONE
Age I+	500	300	300	300	300	300	300	300	300	300
Mark	LV	RV-AD	LP-AD	LV-AD	RP-AD	BV-AD	D-AD	RV-AD	LP-AD	LV-AD
Brook trout										
Age 0+	1500									
Mark	NONE									
Age I		500	500	500	500	500	500	500	500	500
Mark		RV	LP	LV	RP	BV	D	RV	LP	LV
Alewife (adult)					2,030	2,005	2,021			

Appendix 3. Summary of fishing regulations in force at Lake George, 1988-1996.

Regulation	Phase I			Phase II			Phase III		
	1988	1989	1990	1991	1992	1993	1994	1995	1996
<b>Ice Fishing:</b>									
Season	Jan. 1- Mar 30	Jan. 1- Mar 30	Jan. 1- Mar 30	Jan. 1- Mar 30	Jan. 1- Mar 30	Jan. 1- Mar 30	Jan. 1- Mar 30	Jan. 1- Mar 30	Jan. 1- Mar 30
Bag limits:									
Brown trout	3	3	2	2	2	2	2	2	2
Brook trout	5	5	5	5	5	5	5	5	2
Black bass	5	5	5	5	1	1	1	1	1
Smelt	2 qt.	2 qt.	2 qt.	2 qt.	2 qt.	2 qt.	2 qt.	2 qt.	2 qt.
Chain pickerel	10	10	10	10	10	10	10	10	10
All other species	None	None	None	None	None	None	None	None	None
Length limits (in):									
Brown trout	12	12	12	12	12	12	12	12	12
Brook trout	6	6	6	6	6	6	6	6	8
Black bass	12	12	12	12	12	12	12	12(only 1 >14)	12(only 1 >14)
All other species	None	None	None	None	None	None	None	None	None
<b>Open Water Fishing:</b>									
Season	April 1-Sept. 30	April 1-Sept. 30	April 1-Sept. 30	April 1-Sept. 30	April 1-Sept. 30	April 1-Sept. 30	April 1-Sept. 30	April 1-Sept. 30	April 1-Sept. 30
Bag limits:									
Brown trout	3	3	2	2	2	2	2	2	2
Brook trout	5	5	5	5	5	5	5	5	2
Black bass	April 1-June 20:3 June 21- Sept. 30:5	April 1-June 20:3 June 21- Sept. 30:5	April 1-June 20:3 June 21- Sept. 30:5	April 1-June 20:3 June 21- Sept. 30:5	April 1-June 20: 1 June 21- Sept. 30: 3	April 1-June 20: 1 June 21- Sept. 30: 3	April 1-June 20: 1 June 21- Sept. 30: 3	April 1-June 20: 1 June 21- Sept. 30: 3	April 1-June 20: 1 June 21- Sept. 30: 3
Smelt	2 qt.	2 qt.	2 qt.	2 qt.	2 qt.; hook & line only; trib. closed.	2 qt.; hook & line only; trib. closed.	2 qt.; hook & line only; trib. closed.	2 qt.; hook & line only; trib. closed.	2 qt.; hook & line only; trib. closed.
Chain pickerel	10	10	10	10	10	10	10	10	10
All other species	None	None	None	None	None	None	None	None	None
Length limits:									
Brown trout	12	12	12	12	12	12	12	12	12
Brook trout	6	6	6	6	6	6	6	6	8
Black bass	12	12	12	12	12(only 1 >14)	12(only 1 >14)	12(only 1 >14)	12(only 1 >14)	12(only 1 >14)
All other species	None	None	None	None	None	None	None	None	None

Total daily bag limit for brown trout and brook trout is 5 in the aggregate.

Prior to 1992, smelts could be taken by commercial anglers with any gear