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

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Water Quality:

➢ Water quality, as measured by Secchi disk transparency, and chlorophyll a concentrations were not significantly different with the presence of alewives, but were significantly reduced after their stocking ceased, perhaps because of increased rainfall and runoff and import of nutrients from the watershed.

➢ Total phosphorus concentrations were significantly lower with the presence of 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 the population density of *Rotatoria*. Both populations recovered to levels similar to those before the introduction of alewives by the third year after alewife stocking ended. 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 amongst *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 the period 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.

➢ 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(s).

➢ 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*.

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 as far as Great Moose Pond on the West Branch. It is likely that they ascended up 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;; 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 main stem 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 it is 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 that 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 three days at 22°C and six days at 15.5°C. The seaward migration of young alewives generally occurs from mid-July through early December, but juveniles 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 by lobstermen as bait for the spring lobster fishery.

Their freshness, as well as the high fat content of those alewives laden with spawn, make 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 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 down east rivers. In southern New England and the mid-Atlantic states, recreational fishing for alewives is becoming well-established and popular, indicating a 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 whose sites are located above the head-of-tide Edwards Dam in Augusta; the owners of the Augusta dam chose not to participate. The upriver 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 725,000 and six million, respectively. 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 of 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 reducing 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 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 [IFW] expressed concern that the restoration of alewives could impact fish populations that have become established since the extirpation of alewives from their historic spawning and nursery habitat. Specifically, IFW noted that the potential existed for competition to occur between alewives and landlocked smelt *(Osmerus mordax)*, which support sport and commercial fisheries in many waters and which provide the principal forage for sport fishes 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 smelt in Echo Lake, Mt. Desert Island, Maine. Gately documented significant diet overlap between the two species and 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 smelt 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 (primarily 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 1 brown trout and rainbow trout (*Oncorynchus mykiss*) in reclaimed ponds, apparently due to competition, but Age 2 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 flavesences*) 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 sport fish resulted in a cooperative decision to postpone stocking 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 of this joint study by the Maine Departments of Inland Fisheries and Wildlife and Marine Resources.

In 1986, the Maine Department of Environmental Protection [DEP], the state agency with statutory responsibility for managing water quality, noted that several waters in the lower Kennebec River watershed targeted by DMR 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,* and *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, the 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 IFW, these two agencies and DMR 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 hectare [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 period 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, with 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 one-third of the southeastern 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 this 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 on the Kennebec River that lack fish passage. 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), however, 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 ($^T>1^oC/m$), 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 mixing jug. When epilimnetic depth was less than 8 m, two cores were collected and combined to provide a one-liter 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 one-liter cubitainer and stored on ice until it could be filtered through a
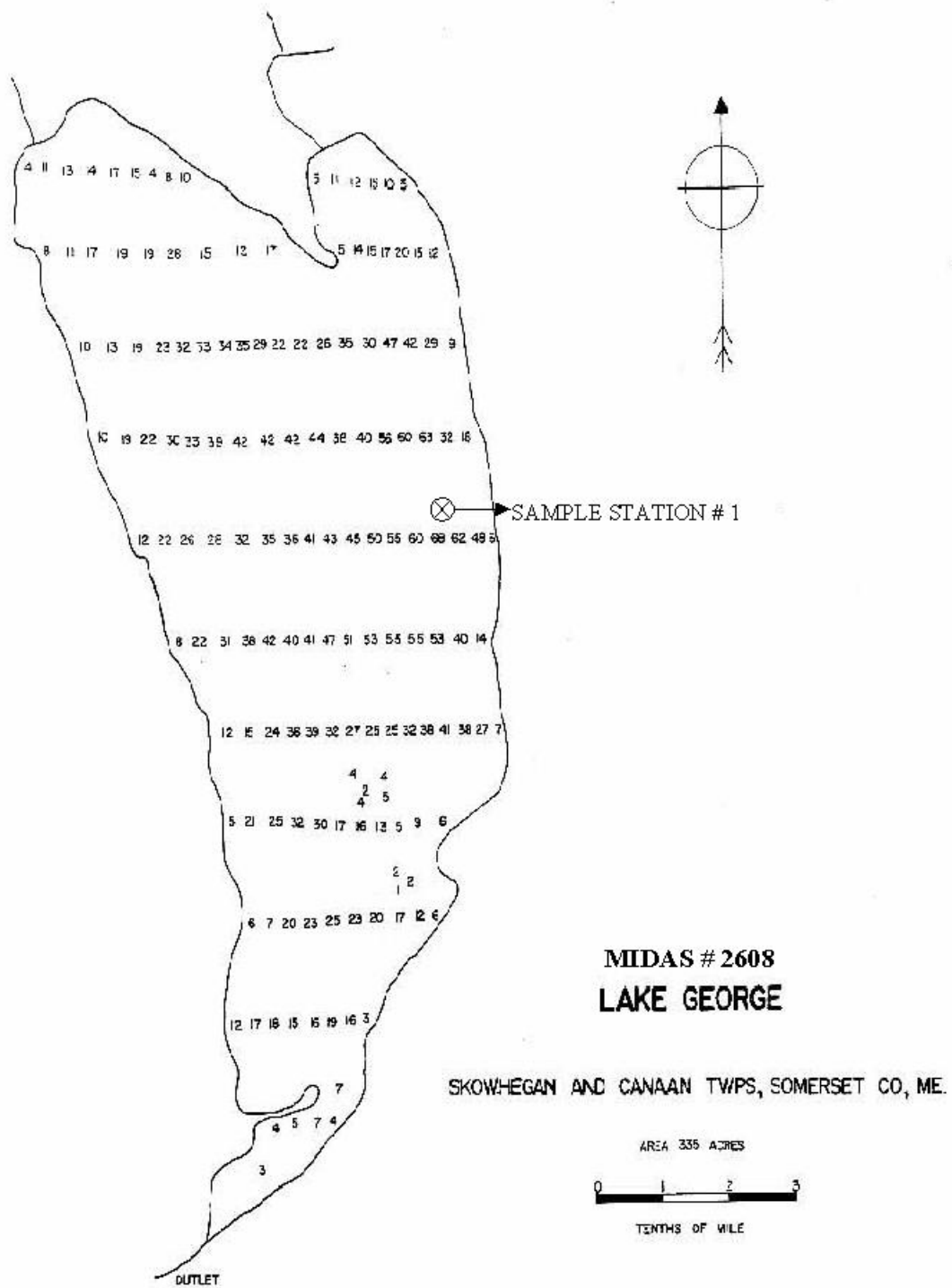
FIGURE 1. BATHYMETRIC MAP OF LAKE GEORGE

0.45- µm 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-µm 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 1 and 300 brown trout were stocked each fall at Age 1+. 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 too rapidly to sample with trap nets). Nets were tended three times each week for approximately four 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 the 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, were deployed in early October each year, and were tended three times a week for four to six 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 and 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 five to 20-minute intervals until a 30-fish sample was obtained. Adult and young-of-the-year smelts were separated and measured to the nearest millimeter, and 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 the alewives 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 and 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 alewives 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 a 30-fish sample), subsequent hauls were conducted in new areas along the shore. Young-of-the-year alewives were separated from other nontarget 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 also 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, which 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 and also lined the sides of the trap box. 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.

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).

An attempt was made 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.

<u>SMELT AND ALEWIFE FOOD HABITS</u>

A ten-smelt subsample was removed on each of the sampling dates when available; each fish was measured for total length and weighed. The digestive tract was removed with forceps and was then placed in a petri dish and rinsed with sterile water. Excess fat and connective tissue were 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 with sterile water. Once the 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 microscope 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_λ = 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

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

Scale ranged 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 macroinvertebrates (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 primarily functions 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 allow 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 bienniel and trienniel 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 cannibalizing their own nauplii. Within the *Copepoda*, *Calanoida* feed primarily on algae by filtration, but some are raptorial, feeding on animals in certain size ranges that 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 (Mills and Schiavone 1982; Mills and Green 1992). Predation of zooplankton by zooplankton may also be an important consideration. *Rotatoria* usually increase in the 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).

FIGURE 2. MEAN ANNUAL ZOOPLANKTON DENSITIES AT LAKE GEORGE BEFORE, DURING, AND AFTER ALEWIVES.
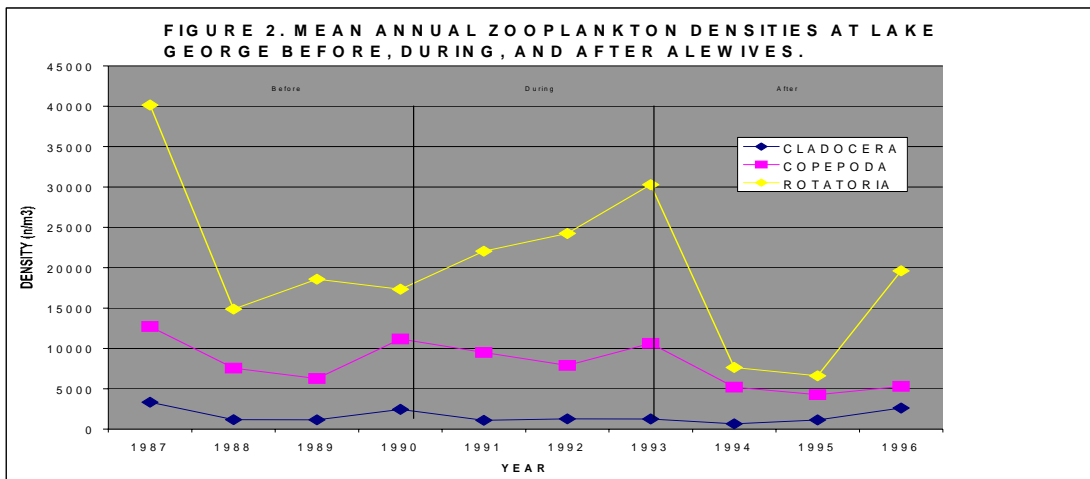
Mean annual summer densities of *Cladocera* were quite variable among years (Figure 3). Densities were significantly reduced during alewives from before, as a result of predation by juvenile alewives. After alewives, mean densities for the

FIGURE 3. MEAN SUMMER DENSITIES OF CLADOCERA IN LAKE GEORGE BEFORE, DURING, AND AFTER ALEWIVES.
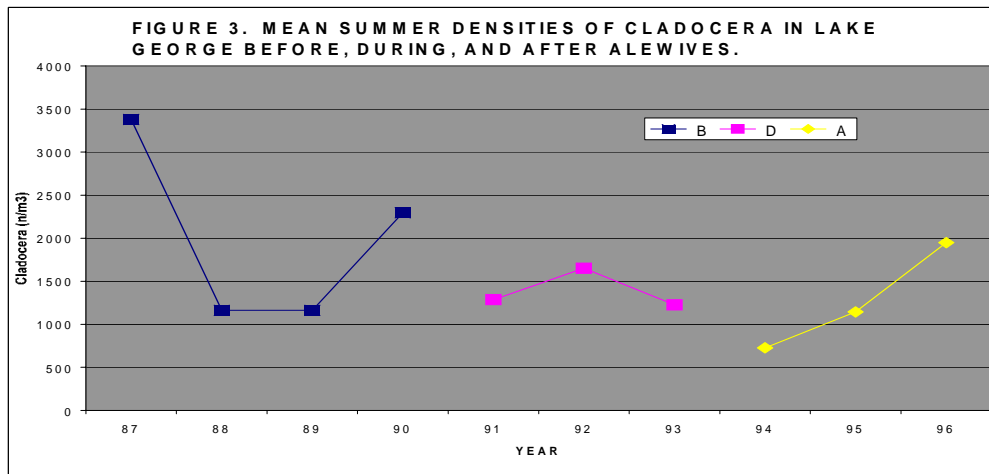
three-year period were slightly higher than during, but the increase was not significant. Less variation occurred during alewives when densities were depressed.

Although the mean density was greater before than during or after, densities for two of four years before were similar to all three years during and to one of three years after. During the three 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

FIGURE 4. MEAN SUMMER DENSITIES OF COPEPODA AT LAKE GEORGE BEFORE, DURING, AND AFTER ALEWIVES.

FIGURE 5. MEAN SUMMER DENSITIES OF ROTATORIA AT LAKE GEORGE BEFORE, DURING, AND AFTER ALEWIVES.
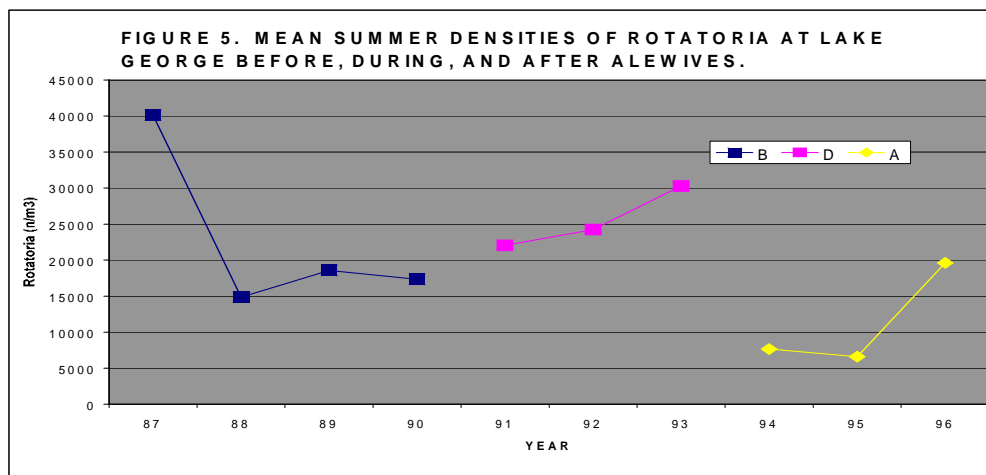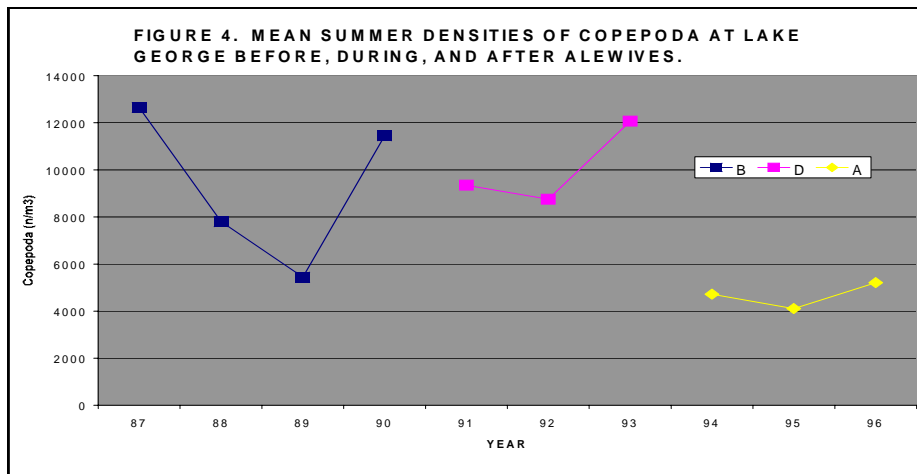
competition among the three groups. If data for 1987, which had the highest density of all years, were ignored, the density of *Rotatoria* was slightly higher during than before or after alewives. This is consistent with the results of other studies where populations of fish in lakes have increased (Hutchinson, 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 three 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

FIGURE 6. MEAN MONTHLY DENSITIES OF CLADOCERA AT LAKE GEORGE BEFORE, DURING, AND AFTER ALEWIVES.
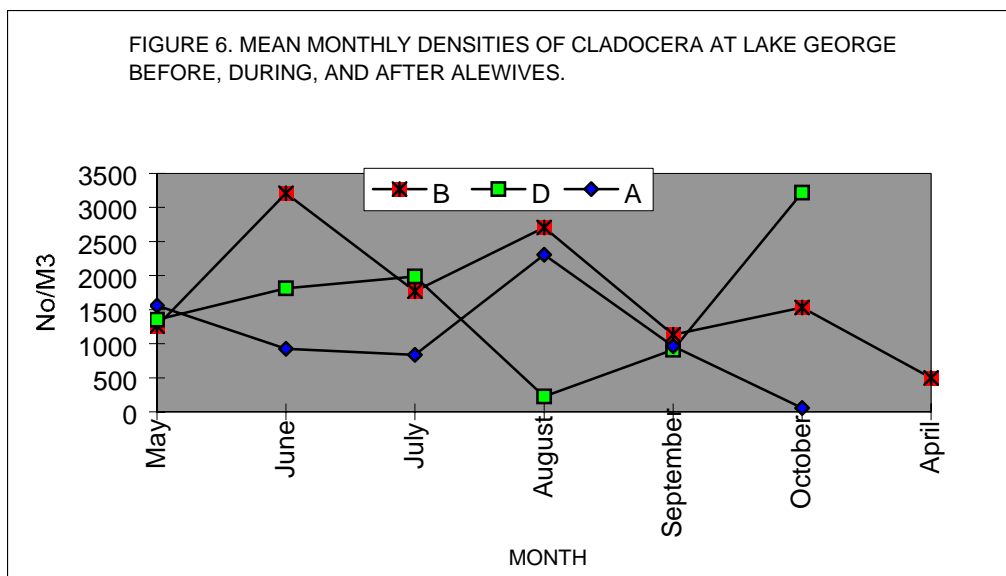
increased slightly, late in the summer. After alewives, the spring peak of *Cladocera* that was present before alewives was missing for all three years. Mean monthly densities of *Copepoda* and *Rotatoria* show generally similar seasonal patterns for all three periods, although the pattern after alewives, when densities were lowest of all three periods, was slightly different (Figures 7 and 8). During alewives, densities of *Rotatoria* increased in August as 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

FIGURE 7. MEAN MONTHLY DENSITIES OF COPEPODA AT LAKE GEORGE BEFORE, DURING, AND AFTER ALEWIVES.
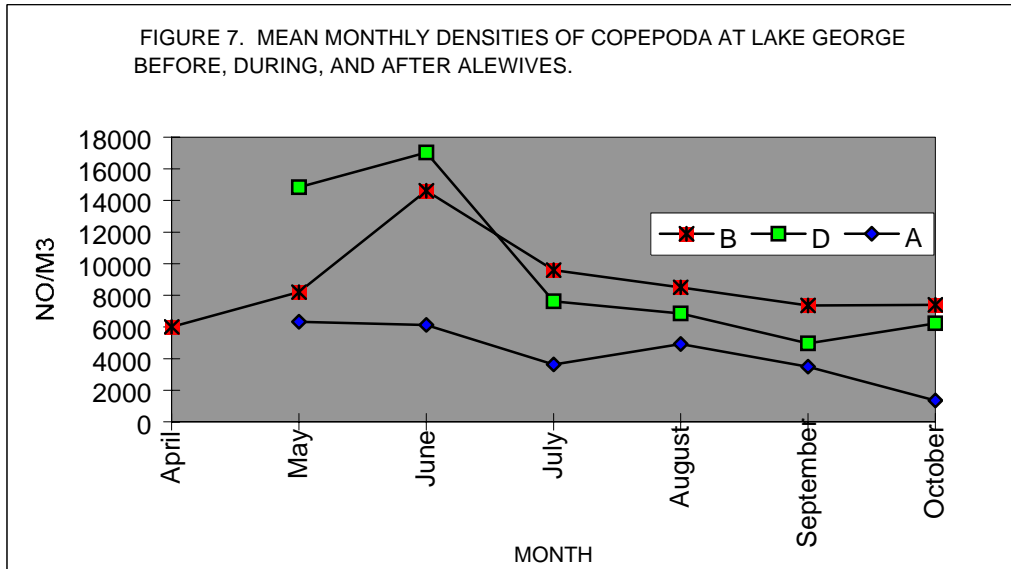
FIGURE 8. MEAN MONTHLY DENSITIES OF ROTATORIA AT LAKE GEORGE BEFORE, DURING, AND AFTER ALEWIVES.
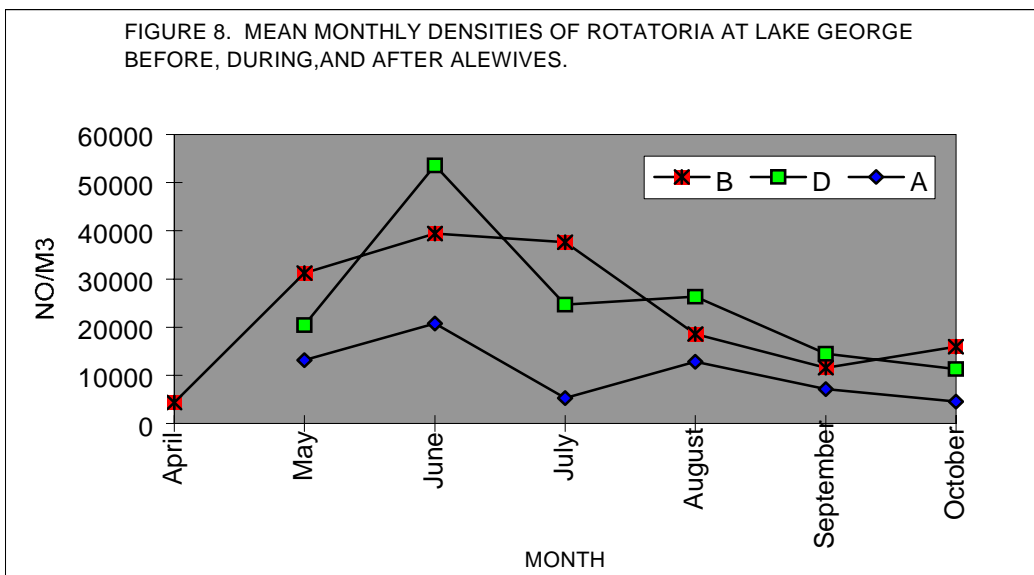
cropped to lower population densities by planktivorous fish in other studies (Brooks and Dodson, 1965; Mower, 1978; Warshaw, 1972). Some of these, however, were smaller species (*Ceriodaphnia reticulata, Daphnia ambigua, Diaphanosoma brachyurum*), which often increase in the presence of planktivorous 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 three and two years, respectively. The density of *Daphnia ambigua* actually increased to a level greater than before alewives within two years after alewives. Densities of the other species that declined during alewives remained lower than before stocking, but the density of *Daphnia longiremis,* one of the most abundant *Cladocera,* steadily increased during the three years after alewives, although not to densities similar to before alewives. *Daphnia retrocurva* densities decreased after alewives to levels below both before and during alewives. *Chydorus favivormis* 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 before alewives. The opposite trends for *Bosmina coregoni* and *Calanoida* are not likely to be the result of simple paired compensatory changes in competition brought about by alewife predation. *Calanoida* were twice the length of *Bosmia coregoni* and, consequently, fed 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 throughout all periods. Interestingly, the *Cyclopoida* were not significantly different before, during, and after.

Within the *Copepoda,* mean annual densities of *Cyclopoida* were greater that 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* was the greatest of any year for either suborder. After alewives,

densities of both were similar and somewhat reduced from before or during alewives.

FIGURE 9. MEAN SUMMER DENSITIES OF DENSITIES OF CALANOIDA AND CYCLOPOIDA AT LAKE GEORGE, 1987-1996.
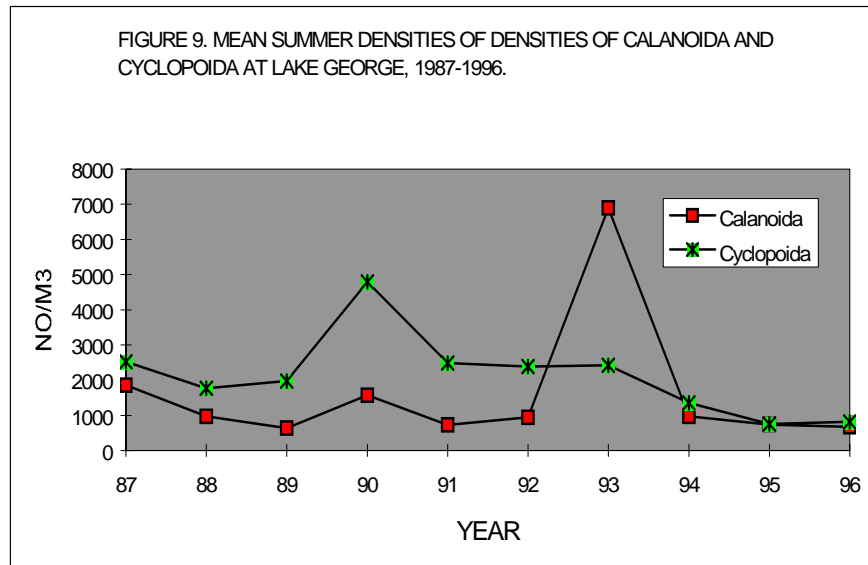
Populations of most biota in various ecosystems are determined by both 'bottom-up' and 'top-down' trophic dynamics. The biomasses of populations are primarily function of the biomass of both predators and prey. Planktivorous fish can influence the water quality of lakes and ponds through their 'top-down' 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 an increase in algal densities and a decrease in water clarity. Basic relationships between fish and zooplankton have been determined to 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 lakes in which predators and prey are more balanced, fish are more evenly distributed in size 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. When the system is more in balance, mean length may be greater than during spring, but less than in the summer, which usually results in lower water 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 the stocking of alewives, but declined after alewives. *Rotatoria* appeared 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 because of 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^3 and 3.2 mg/m^3, respectively. Total alkalinity averages 12 mg/l as CaCO$_3$, 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. Regarding 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 by 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 undoubtedly 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, 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 nonparametric 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 alewives when compared to either before or after alewives (Figure 10). Nevertheless, mean summer Secchi disk transparency was significantly lower after (5.7 m) than before (6.2 m) alewives 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

FIGURE 10. MEAN SUMMER SECCHI DISCK TRANSPARENCY AT LAKE GEORGE BEFORE, DURING, AND AFTER ALEWIVES.
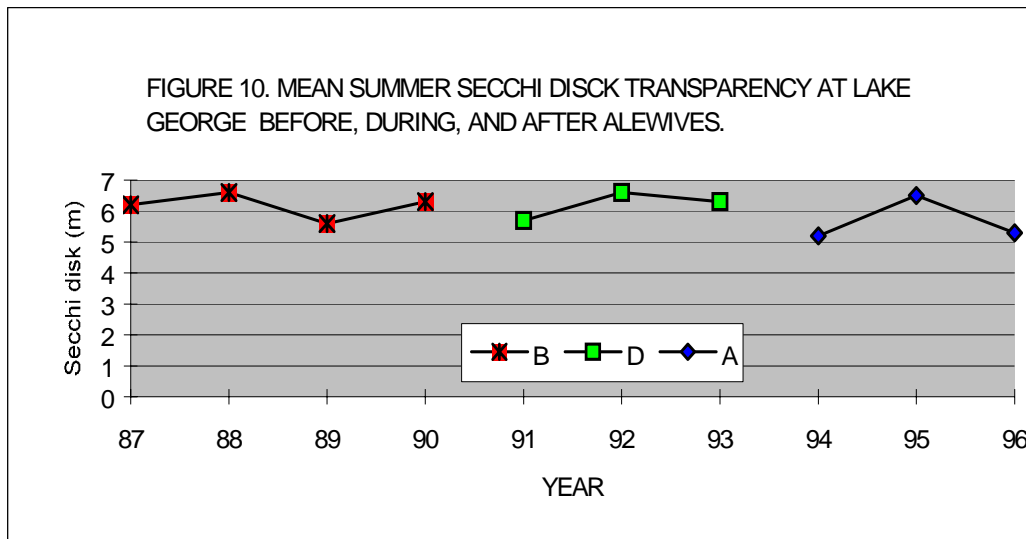
monthly Secchi disk transparency declined considerably after alewives and to a lesser extent before alewives, but continued to increase during alewives. These patterns were compared to plots of zooplankton densities to determine if transparencies could be explained by simple predator-prey interactions. 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.

FIGURE 11. MEAN MONTHLY SECCHI DISK TRANSPARENCIES AT LAKE GEORGE BEFORE, DURING AND AFTER ALEWIVES.
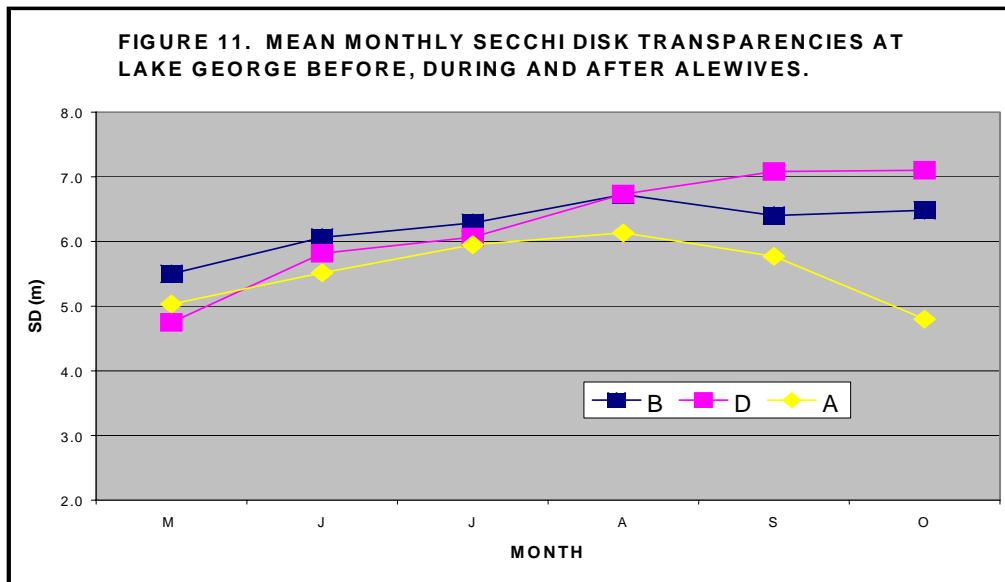
Mean summer epilimnetic chlorophyll a concentrations varied from 2.7-4.5 ug/l by year (Figure 12). There was no significant difference between chlorophyll a concentrations before and during alewives, but concentrations were significantly higher after alewives than before or during. There were no data for 1995, but

FIGURE 12. MEAN SUMMER CHLOROPHYLL a CONCENTRATIONS AT LAKE GEORGE BEFORE, DURING AND AFTER ALEWIVES.
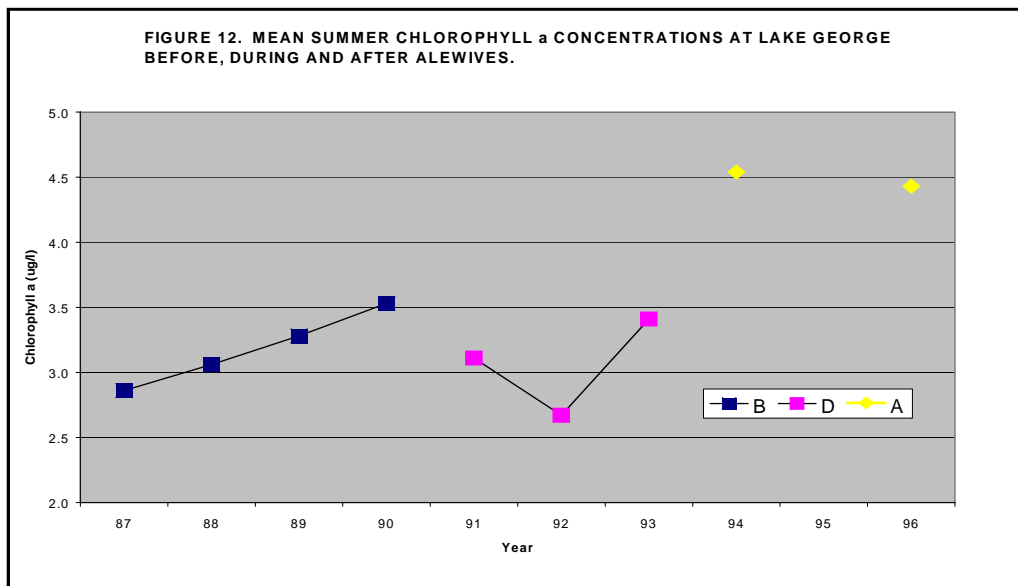
concentrations for 1994 and 1996 were the highest of the whole study. These years correlate with those showing the lowest Secchi disk transparencies. Interestingly, there were lower densities of total zooplankton for this period as a whole, which may be the reason for these chlorophyll a and Secchi disk results. However, 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.

FIGURE 13. MEAN MONTHLY CHLOROPHYLL a CONCENTRATIONS AT LAKE GEORGE BEFORE, DURING AND AFTER ALEWIVES.
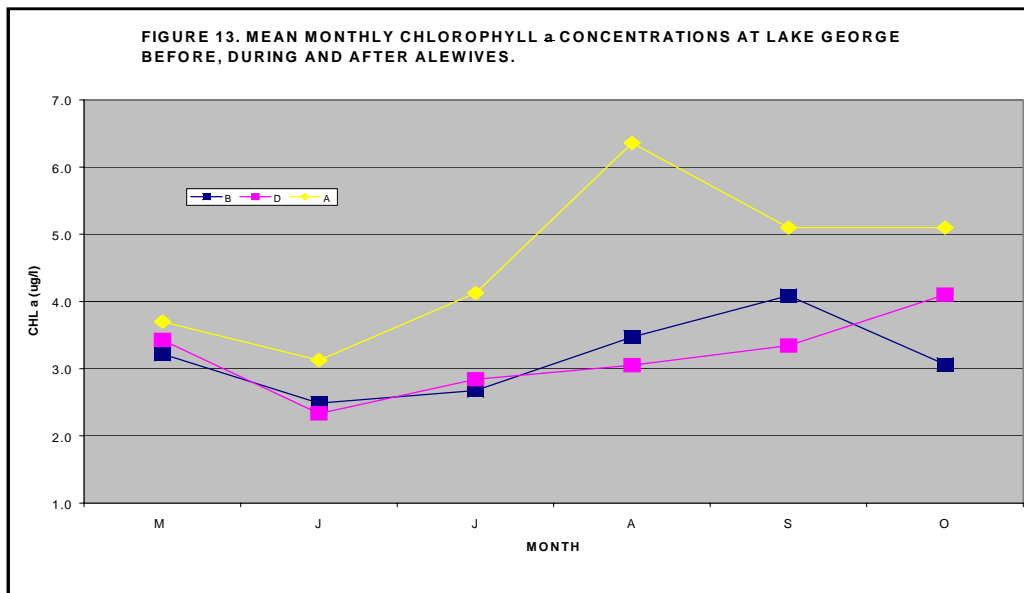
Mean summer epilimnetic total phosphorus concentrations varied from 7-10 ug/l by year and were significantly lower during alewives than either before or after, although the differences among periods (B=8 ug/l, D=7 ug/l, A=9 ug/l) were small (Figure 14). This result did not correlate well with chlorophyll 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 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. 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.

FIGURE 14. MEAN SUMMER TOTAL PHOSPHORUS CONCENTRATIONS AT LAKE GEORGE BEFORE, DURING AND AFTER ALEWIVES.
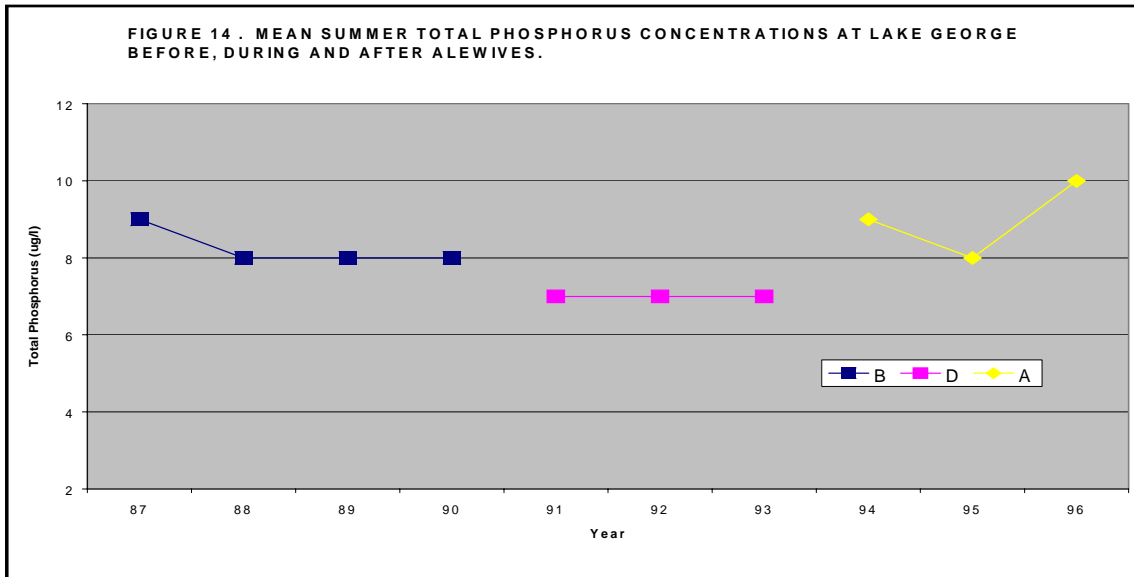
Mean summer hypolimnetic total phosphorus concentrations were also calculated for each period to determine if the phosphorus had simply changed compartments from the epilimnion to the hypolimnion through some interaction of alewives and zooplankton. From a straight averaging of epilimnetic and hypolimnetic 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, each hosting dozens of campers 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 was significantly higher after than during. The significant decrease in mean summer total phosphorus

concentrations during alewives could easily be the result of sequestering 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 sequestered 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 may have been responsible for high total phosphorus concentrations in 1996, high concentrations in 1995 are

FIGURE 15. MEAN MONTHLY EPILIMNETIC TOTAL PHOSPHORUS CONCENTRATIONS AT LAKE GEORGE BEFORE, DURING AND AFTER ALEWIVES.
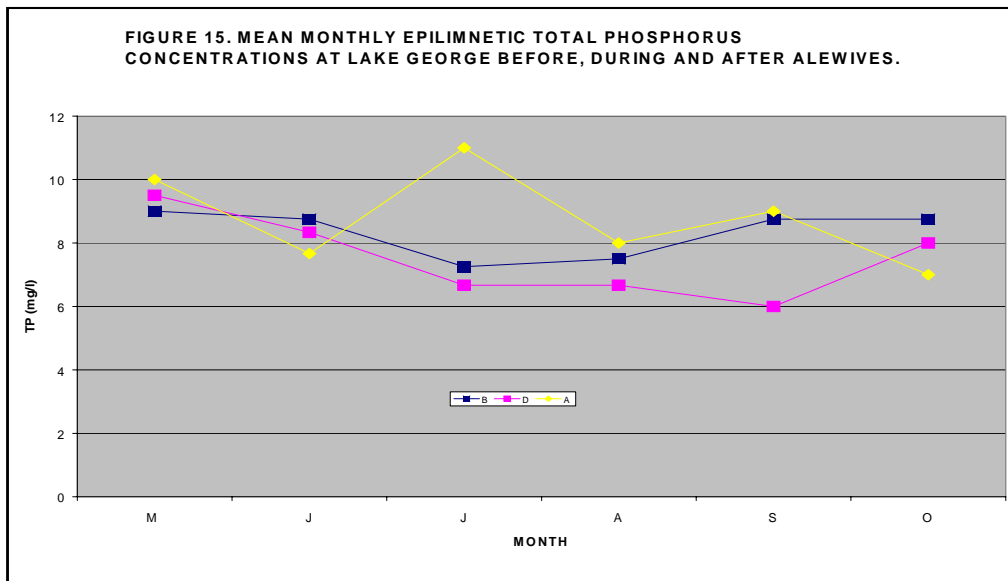
unexplained. Trends in total phosphorus for any period did not follow those of chlorophyll a as expected. Trends were generally inverse of those for *Rotatoria* before alewives, but no other relationships were obvious for other periods or zooplankton groups.

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 settles 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

FIGURE 16. MEAN SUMMER HYPOLIMNETIC DISSOLVED OXYGEN LAKE GEORGE BEFORE, DURING AND AFTER ALEWIVES.
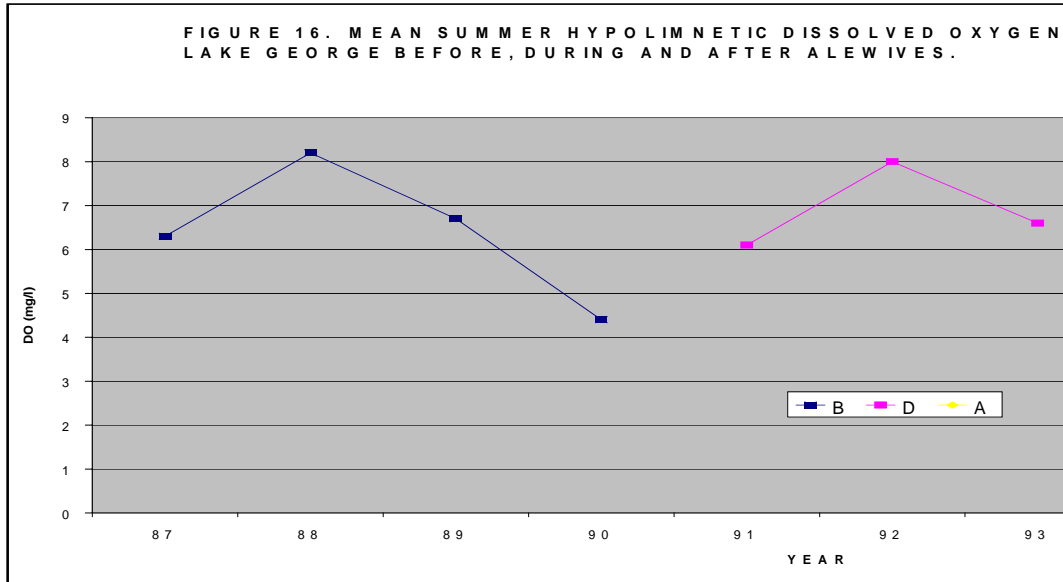
influenced by continuous resupply from the atmosphere, unlike the hypolimnion which receives no new oxygen during the summer.

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

FIGURE 17. MEAN MONTHLY HYPOLIMNETIC DISSOLVED OXYGEN CONCENTRATIONS AT LAKE GEORGE BEFORE, DURING AND AFTER ALEWIVES.
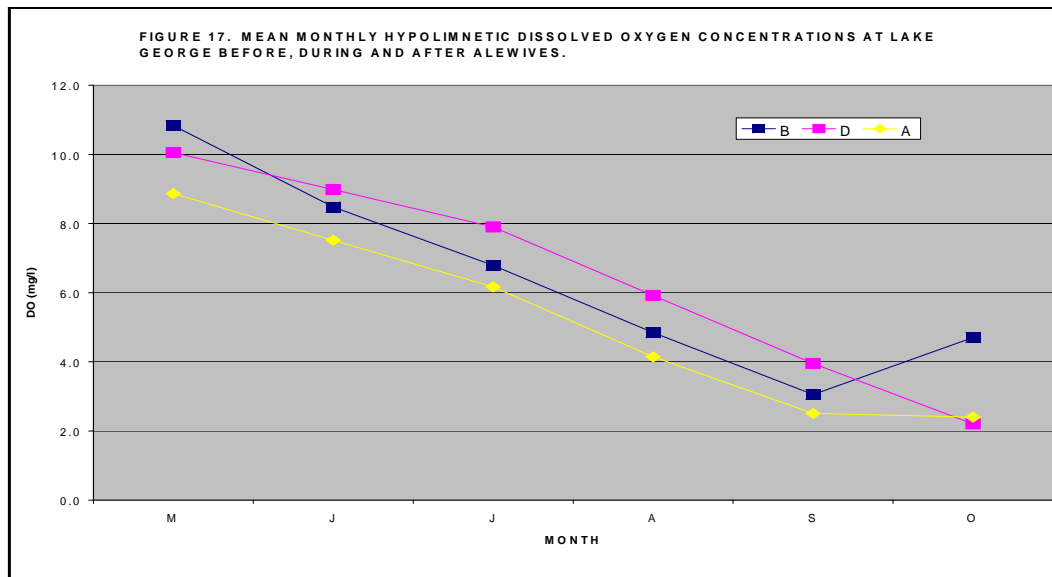
beginning of the summer after alewives than before or during, no doubt a result of higher chlorophyll a concentrations during this period, primarily from an unusually high concentration in 1994. Since maximum differences between periods occurred later in the summer for chlorophyll a concentrations than 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/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.

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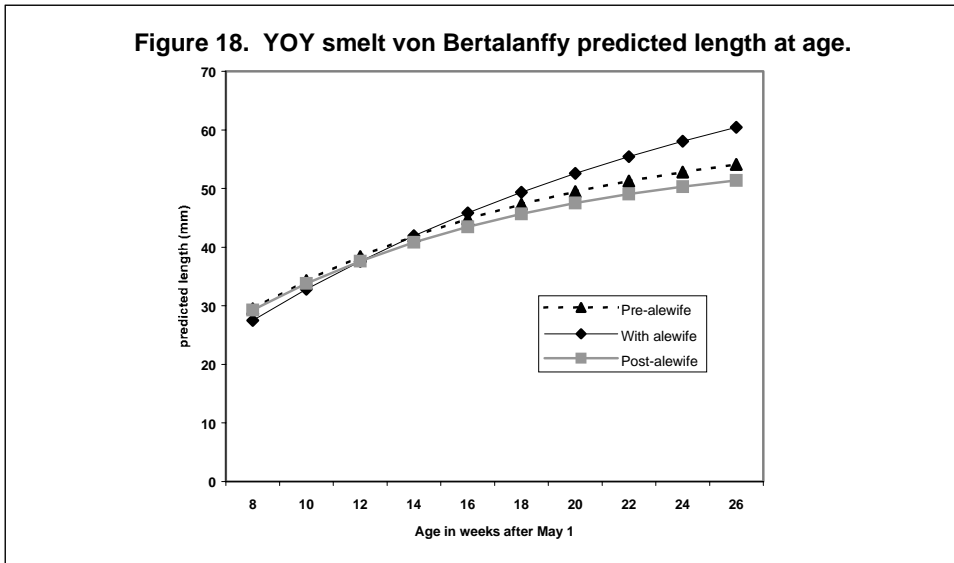
Table 3. Creel Survey Summary.

Water: Lake George Town: Canaan and Skowhegan
Season: Winter County: Somerset

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	*Data not Available*		
	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)

<u>MINOR SPORT FISH</u>

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).

<u>FORAGE FISH</u>

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-infinity) 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.

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

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

upper
estimate
lower

Asymptotic length (mm)

87-90   91-93   94-96

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

growth coeficient

87-90   91-93   94-96
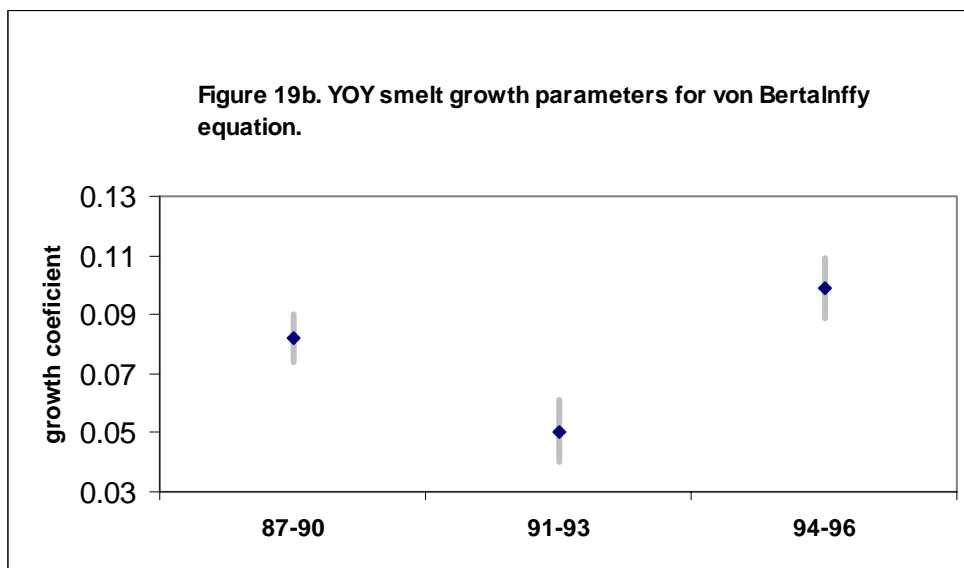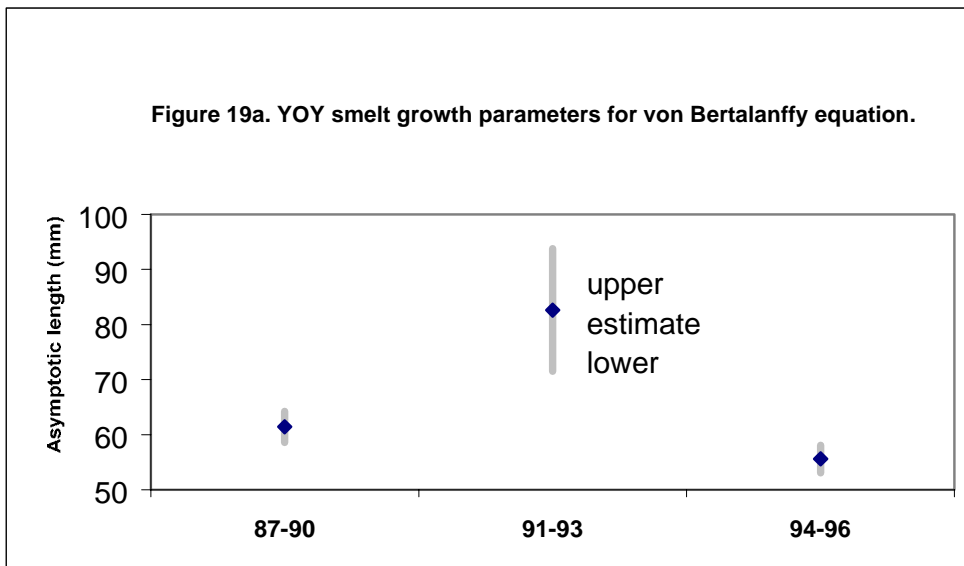
Our skill at collecting the target 30 YOY smelt increased throughout the study as we learned where and when to trawl. Therefore, the number of trawls, trawl duration, and catch rates varied annually (Figure 20). During the first two years, we made long trawls and had several large captures of YOY smelt (> 400 in one 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, apparently related to month and proximity to spawning areas (Figure 21). Catch rates of YOY smelt were broken down into early summer (June and July) and late summer (August and September) 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 of yearling and older smelt (13.3%) in the catch during years with alewife stocking compared to before (1.25 %) and after (6.14 %).

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

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

Figure 22. Trawl catch rates for smelts before, during, and after alewife introduction.
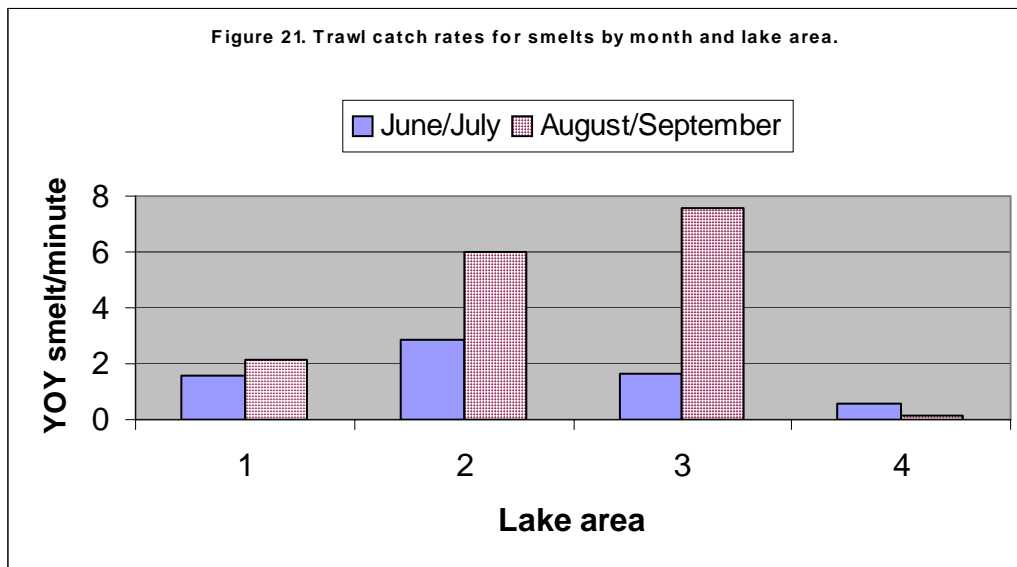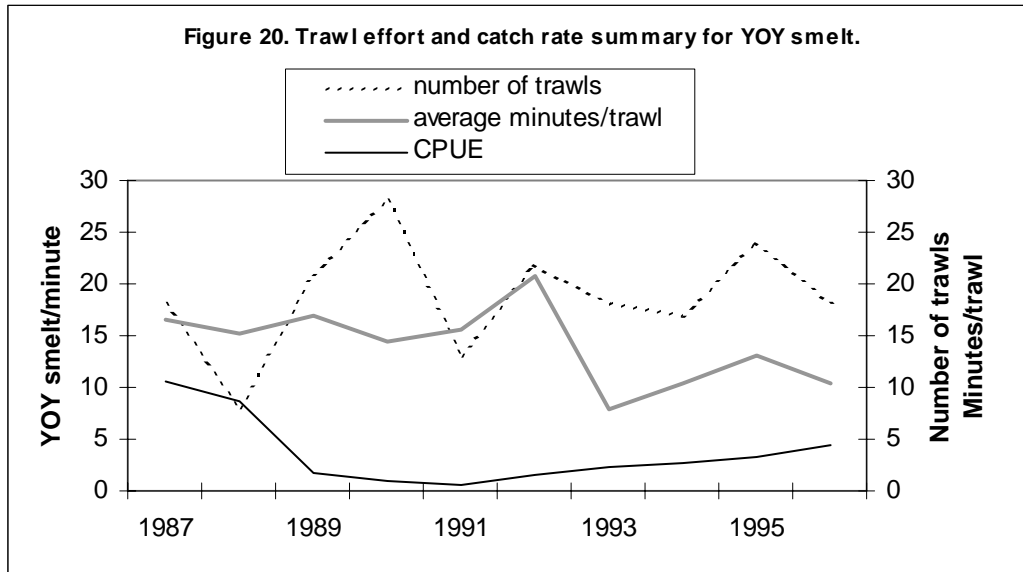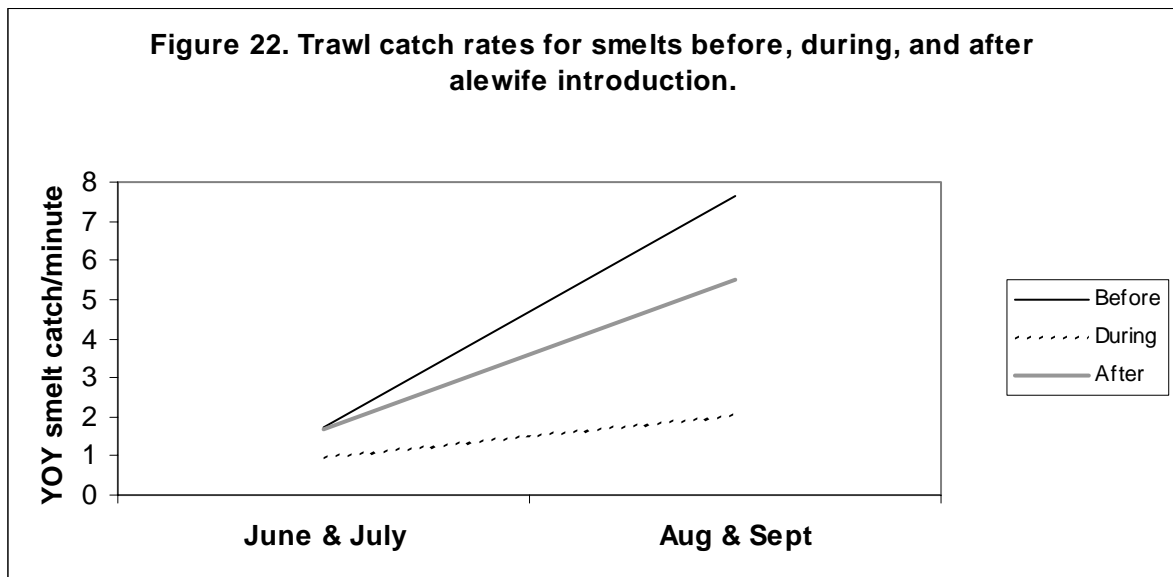
STOMACH ANALYSIS (JUVENILE RAINBOW SMELT)

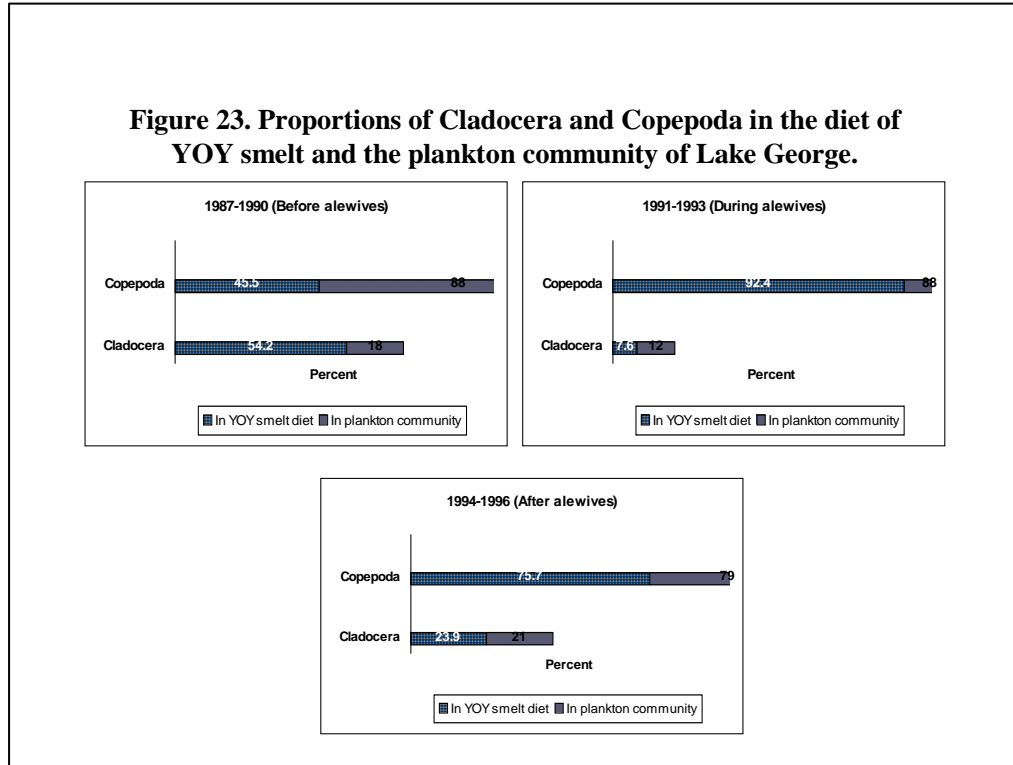Because Rotifers were mistakenly not counted as smelt food items, the following analyses do not contain data regarding rotifers. Diet information presented as percentages are percentages not including rotifer data.

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; 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 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.

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

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.

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

43
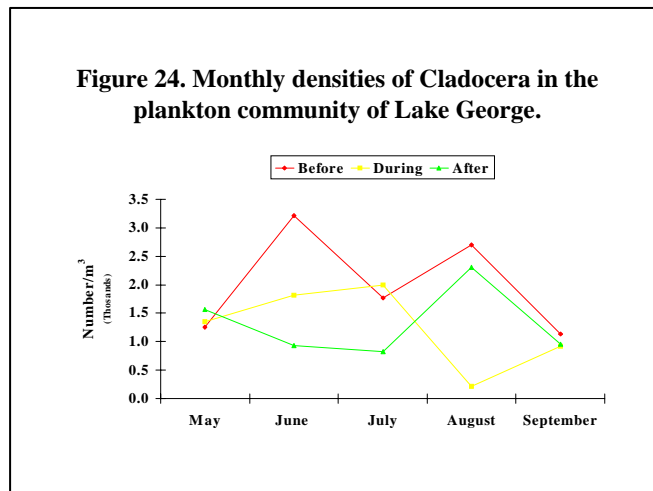
Copepoda became more important in YOY smelt diet during alewife stocking in the lake and from 1994 to 1996 (Figure 23). *Copepoda* density in the plankton was higher in early summer during the period alewives were in the lake, but overall were similar to those during the background period (Figure 25). *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 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 25. Monthly densities of Copepoda in the plankton community of Lake George.
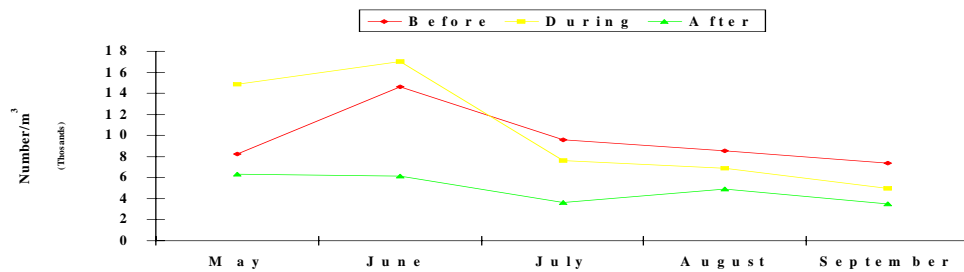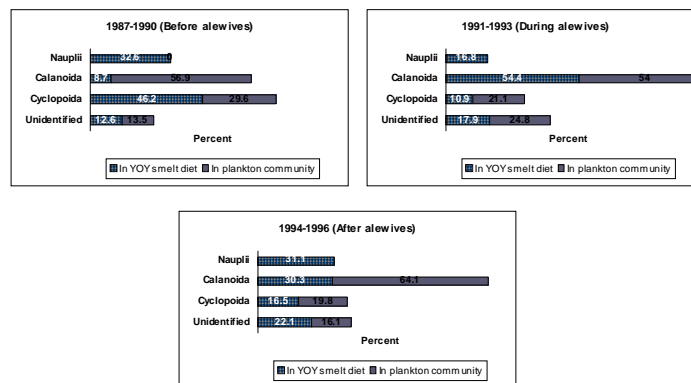

Figure 26. Proportions of Copepoda types in the diet of YOY smelt and the plankton community of Lake George.

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 1983. 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 *Cladocera*, *Copepods*, *Nauplii* and *Diptera*. In all three years, juvenile alewives selected *Cladocera* more strongly than for any other group. In 1991, juvenile alewives selected *Cladocera* and *Copepods* almost equally (slightly more *Cladocera* were eaten); *Nauplii* were strongly selected 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.

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 the diet in 1991, 13% in 1992, and 2% in 1993). In 1991, *Copepoda* and *Cladocera* were eaten in similar amounts in July (34% and 41%, respectively) and August (21% and 28%, respectively), and *Nauplii* were heavily utilized in August (47% of the 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 the juvenile alewife diet (95%). *Cladocera* became important in July (52%), August (81%), and September (77%) 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%.

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 (six) to 1992 (10) and a significant increase in the number of food items per stomach from 1992 to 1993 (172).

Adult alewives primarily selected *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 their number 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 differences in the lake plankton community over the three phases of the study, as well as to test 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, although 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, making downstream migration difficult; 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; and between July 9 and July 28, a second pulse of 112 adults left Lake George. Between August 21 and October 5, another nine 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.

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Appendix 1. Fish species present in Lake George, Maine.	
Common name	**Scientific name**
Eastern brook trout	*Salvelinus fontinalis*
Brown trout	*Salmo trutta*
Rainbow smelt	*Osmerus mordax*
Burbot	*Lota lota*
Smallmouth bass	*Micropterus dolomieu*
Largemouth bass	*Micropterus salmoides*
Pumpkinseed sunfish	*Lepomis gibbosus*
Redbreast sunfish	*Lepomis auritus*
White perch	*Morone americana*
Yellow perch	*Perca flavescens*
Chain pickerel	*Esox niger*
Brown bullhead	*Ameiurus nebulosus*
Fallfish	*Semotilus corporalis*
Golden shiner	*Notemigonus chrysoleucas*

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			

Regulation	Phase I			Phase II			Phase III		
	1988	1989	1990	1991	1992	1993	1994	1995	1996
Ice Fishing:									
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
Open Water Fishing:									
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	April 1-June 20:3	April 1-June 20:3	April 1-June 20:3	April 1-June 20: 1	April 1-June 20: 1	April 1-June 20: 1	April 1-June 20: 1	April 1-June 20: 1
	June 21- Sept. 30:5	June 21- Sept. 30:5	June 21- Sept. 30:5	June 21- Sept. 30:5	June 21- Sept. 30: 3	June 21- Sept. 30: 3	June 21- Sept. 30: 3	June 21- Sept. 30: 3	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

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

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