Alternative Strategies for the Management of Non-Indigenous Alewives in Lake St. Catherine, Vermont

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EXECUTIVE SUMMARY

Alewives were first discovered in Lake St. Catherine, Rutland County, Vermont in July 1997. This was the first recorded occurrence of alewives in Vermont waters. Alewives are primarily an ocean fish species that spawns in freshwater rivers and lakes. Although they are native to the Atlantic coast of North America, they are also capable of inhabiting freshwater lakes, and they have become established in lakes across the U.S. It is thought that the Lake St. Catherine population was established through a purposeful, illegal stocking, as opposed to an accidental bait-bucket release.

In many cases, the establishment of alewives in lake environments has resulted in serious ecological impacts to native aquatic ecosystems. Through selective predation, alewives can decrease zooplankton abundance in a lake, resulting in reduced water clarity and inferior food resources for planktivorous fish. Alewives will also compete with native fish for food as well as feed directly on the eggs and larval stages of native fish species. Alewives have been implicated in the decline and extinction of several fish species in the Great Lakes as well as other inland lakes in the U.S.

The existence of alewives in Lake St. Catherine is of great concern to Vermont's fisheries managers because of their potential to spread and impact other native aquatic ecosystems in the State, and in particular, Lake Champlain. Alewives could be spread to other Vermont waters through use as bait or illegal stocking. In addition, alewives may spread unassisted to Lake Champlain via Lake St. Catherine's outlet. Water from the lake spills over a small dam into Mill Brook, then the Mettawee River, and the Champlain Barge Canal, and finally enters southern Lake Champlain at Whitehall, NY – a total distance of 47 km (29 miles). It is possible that drifting larval alewives as well as actively swimming juveniles and adults could successfully enter Lake Champlain by means of this route.

As a result of this threat, various alternatives to manage alewives in Lake St. Catherine were investigated: 1) Public Education & Outreach, 2) Population Reduction, 3) Containment, and 4) Eradication/Reclamation. While drawbacks are present in all alternatives, some are more problematic than others and reduce the viability of those alternatives. To summarize each alternative and their respective disadvantages:

1) Public Education & Outreach: Direct monetary costs associated with this alternative vary depending on the type of education and outreach efforts implemented. While it important to have an educated public, it is often difficult to change public opinion, attitude, and practices. Though public education and outreach efforts may prevent the further spread of alewives to other lakes, it does not address the risk the population in Lake St. Catherine poses to Lake Champlain through fish escapement and outmigration.

2) Population Reduction: Approximate costs associated with this alternative total $13,400 annually. Major drawbacks to this alternative are; a) alewives remain in Lake St. Catherine and continue to threaten other waters; b) labor-intensive; c) it is unlikely that alewife numbers would be sufficiently reduced to decrease the risk of escapement.

3) Containment: Approximate costs associated with acoustic, electric, or physical barriers range from $50,000 to $250,000 for initial construction and $2,000 to $20,000 annually for operation and maintenance. The major drawback to all three barriers is that none can prevent the outmigration of all life stages of alewives year-round.

4) Elimination/Reclamation: Approximate costs associated with a rotenone reclamation of Lake St. Catherine are close to $350,000. This alternative is truly the only one that has any chance of eliminating alewives from Vermont waters. However, there are several major drawbacks to this alternative: a) a 100% kill would be required for success, which is almost never achieved in a reclamation (average is 90 to 95 %). Alewives reproduce quickly and just a few hundred survivors could re-establish a population; b) there is always the chance that there could be another illegal re-introduction in the future, requiring subsequent reclamations; c) a rotenone reclamation would be an expensive proposition, and may not solve the problem in the long run.

The status of Lake St. Catherine's alewife population has been monitored annually since 1997. Additionally, downstream waters have been sampled frequently for presence/absence of larval, juvenile, and adult alewives. To date, larval alewives have been collected immediately below the Lake St. Catherine dam in Mill Brook, but not further downstream. No juvenile or adult alewives have been found at any sampling sites outside of Lake St. Catherine.

Unfortunately, there is no straightforward answer to the current alewife problem. It is very rare when an invasive exotic species can be eradicated. More often than not, managers must find ways to cope with the invasive species. Alewives could be re-introduced illegally to Lake St. Catherine or any other lake in Vermont in the future. In addition, it is quite possible that alewives may eventually migrate to Lake Champlain via the Hudson River and Champlain Barge Canal, as have blueback herring, gizzard shad, and a host of other recent Lake Champlain fish invaders.

The Vermont Department of Fish and Wildlife will continue to search for new alternatives to control or eradicate alewives. We will also continue our efforts to prevent the further movement of alewives through public education, and the adoption of pertinent regulations, such as the new baitfish regulation.

Approved by: [signature] Date: 06/03/03
Wayne Laroche, Commissioner

SECTION I

INTRODUCTION

This report provides detailed information on the known ecological impacts of exotic alewives based on an extensive review of the published literature. This information is used to assess the impacts that alewives will likely have in Lake St. Catherine and Lake Champlain. Alternative management schemes to prevent the spread of alewives from Lake St. Catherine are evaluated and a preferred alternative is presented.

This report was partially funded by a grant to the Vermont Department of Fish and Wildlife from the United States Environmental Protection Agency through the Lake Champlain Basin Program. The funds were administered by the New England Interstate Water Pollution Control Commission.

SECTION II

NEED FOR ACTION

In July 1997, a large population of alewives, an anadromous fish species native to the Atlantic coast of North America, was discovered in Lake St. Catherine, a small inland lake in Rutland County, Vermont. This is the first record of the species in the state of Vermont ; alewives were not detected in Lake St. Catherine prior to 1997 and have not previously been reported in other Vermont lakes. The alewife has a long history of establishing landlocked populations which negatively impact native ecosystems. The presence of alewives in Lake St. Catherine therefore poses a major threat to the native fish community within the lake, as well as the native fishes of other Vermont waters, including Lake Champlain.

The discovery of alewives in Lake St. Catherine was made during routine bass surveys conducted by State of Vermont fisheries biologists. The origin of the alewives is uncertain. It is unlikely that alewives migrated naturally into Lake St. Catherine. While there is a direct water connection to the Hudson River (into which anadromous alewives make yearly spring spawning migrations) there are several factors which would make it improbable that alewives migrated to Lake St. Catherine from the Hudson River via the Champlain Canal, the Mettawee River, Wells Brook, and Mill Brook (see Figure 1). Firstly, alewives have not been reported anywhere along this hypothesized migration route, and furthermore, alewives would not have been able to navigate Lake St. Catherine's outflow dam (see section III and Figure 3a) to get into the lake, nor the multiple natural barriers (waterfalls) along the Mettawee River. It is more plausible that alewives were introduced to the lake by human activity, either as accidental bait bucket releases or as a purposeful introduction to the lake. Since alewives are not readily available as bait in the region, the belief is that they were transported from out-of-state and purposely released into Lake St. Catherine.

Alewives are known to impact native fish communities in a variety of ways. They out-compete other planktivorous fish for food and cause shifts in zooplankton species composition and size structure. They are known to feed directly on the eggs and larvae of native fish species, they undergo massive fluctuations in abundance, and they have recently been identified as the cause of major mortality syndromes in salmon and trout fry. The detrimental effects of alewives on many native fish stocks in the Great Lakes, the Finger Lakes, and numerous other small inland lakes and reservoirs have been well documented. Similar impacts are expected in Lake St. Catherine, but perhaps the greatest impacts would occur if alewives were to spread to Lake Champlain.

The spread of exotic species, referred to as bioinvasion, is quickly becoming one of the greatest threats to the earth's biological diversity, and as a global threat of extinction, is now believed to rank just behind habitat loss (Bight 1998). Approximately 42% of threatened and endangered species in the United States are at risk primarily because of non-indigenous species (Pimentel et al. 1998), and during the past century, exotic species have been a factor in 68% of fish extinctions in the United States (Bight 1998). As well as a major ecological problem resulting in loss of native species, reduced biodiversity, and altered habitat, bioinvasions carry major public health and economic impacts. Invading non-indigenous species in the United States cost the nation more than $122 billion per year (Pimentel et al. 1999). Pimental et al. (1999) conservatively estimated the economic costs of non-indigenous fish species in the United States to be more than $1 billion per year.

SECTION III

SCOPE OF ACTION

The geographic area covered by the alternatives reviewed in this report is Lake St. Catherine in Rutland County, Vermont. The impacts of alewives could, however, extend beyond the lake to Lake Champlain and other Vermont, New York and Canadian waters.

Lake St. Catherine

Lake St. Catherine ($43^{o}25'$, $73^{o}10'$) is a mesotrophic lake with a surface area of 852 acres (345 hectares). The main lake is connected by short channels to two small ponds, Lilly Pond to the north with a surface area of 20 acres (8 hectares) and Little Pond to the south with a surface area of 180 acres (73 hectares). The lake has an average depth of 32 ft (10 m), a maximum depth of 64 ft (19 m) and is heavily vegetated with Eurasian watermilfoil and native aquatic plant species, including pondweeds and coontail, in the littoral zone. It supports a large and diverse fish community composed of rainbow smelt, yellow perch, bluegill and pumpkinseed sunfish, black crappie, rock bass, smallmouth bass, largemouth bass, northern pike, brown bullhead, common white sucker, and various cyprinids, including golden and emerald shiners. Lake trout, rainbow trout, and brown trout are stocked annually on a put, grow and take basis.

Lake St. Catherine has one year-round inflow, Parker Brook, which enters the main body of the lake on the northeast shore in the State Park. A single outflow runs over a small dam at the southern end of Little Pond. Water spills over the dam into Mill Brook, which flows for 1.7 miles (2.8 km) into Wells Brook, which in turn flows for 1.2 miles (1.9 km) into the Mettawee River. From that point, the Mettawee flows northwest for approximately 24 miles (39 km) into the Champlain Barge Canal which flows north for 1.7 miles (2.7 km) into the southern end of Lake Champlain (Figure 1).

The Mill Brook dam is a stone and concrete spillway dam approximately 4.75 ft (1.5 m) high and 87 ft (26.5 m) wide (Figure 2). Water spills over the entire width of the dam during high flow periods, but only over a 4 foot (1.2 m) wide notch during low flow (Figure 3). Water depth directly upstream of the dam is approximately 1.25 m and increases to as deep as 2 m several hundred feet up the outflow channel (Figure 4). Water depths in the remainder of the channel connecting Little Pond to the outflow dam range from approximately 0.5 to 1.5 m. Water spilling over the dam flows through two culverts passing beneath Lake Hill Road.

Lake Champlain

Lake Champlain, the sixth largest natural lake in the United States, has a surface area of 278,000 acres (112,500 ha) and an average depth of 19.4 m. It ranges in characteristics from riverine and eutrophic in the south to deep and oligotrophic in the main lake (Hawes 1997). It is approximately 200 km long, extending from Whitehall, NY, where it connects to the Champlain Canal, north to Quebec, where it empties into the Richelieu River. It supports more than 80 species of fish, including warm, cool and cold-water species.

The Champlain Canal connects the Hudson River to Lake Champlain. It runs from Fort Edward, NY on the Hudson River to Whitehall, NY on the southern tip of Lake Champlain. It is operational only during the summer, and de-watered during the winter and early spring. Although blueback herring have successfully reached Lake Champlain via the canal, alewives migrate up the Hudson earlier than do bluebacks and have never reached the lake (NY DEC 1996). This is likely due to two reasons : 1) until recently, a "pollution barrier" has existed in portions of the Hudson River and the high susceptibility of alewives to poor water quality conditions prevented their migration into the upper reaches of the River, 2) alewives spawn earlier than blueback herring (Scott and Crossman 1973), and the timing of the opening of navigation locks along the canal system has generally prevented migrating alewives from traveling far up the system during their spawning runs. However, considering the fact that blueback herring have colonized Lake Champlain via this route, and alewives typically journey much further upstream than do blueback herring during their annual spawning migrations (Scott and Crossman 1973), it would seem possible that alewives may indeed colonize Lake Champlain eventually via this route if water quality continues to improve and the operation of navigational locks more closely correlate with alewife spawning migrations, or the timing of alewife spawning migrations changes due to shifting weather patterns.

The Richelieu River is Lake Champlain's outlet to the St. Lawrence River, flowing out of the northern end of the lake. Alewives do not typically migrate up the St. Lawrence as far as the Richelieu, although historical records from the late 70's and mid-80's show small ($n<10$) groups of alewives being collected in both the Richelieu and Pike rivers (Dumas 1999). While alewives found in the Richelieu would likely be prevented from moving into Lake Champlain by several large rapids (NY DEC 1996), the collection of alewives in 1987 in the Pike River is troubling, as it is a direct tributary to Missisquoi Bay on Lake Champlain.

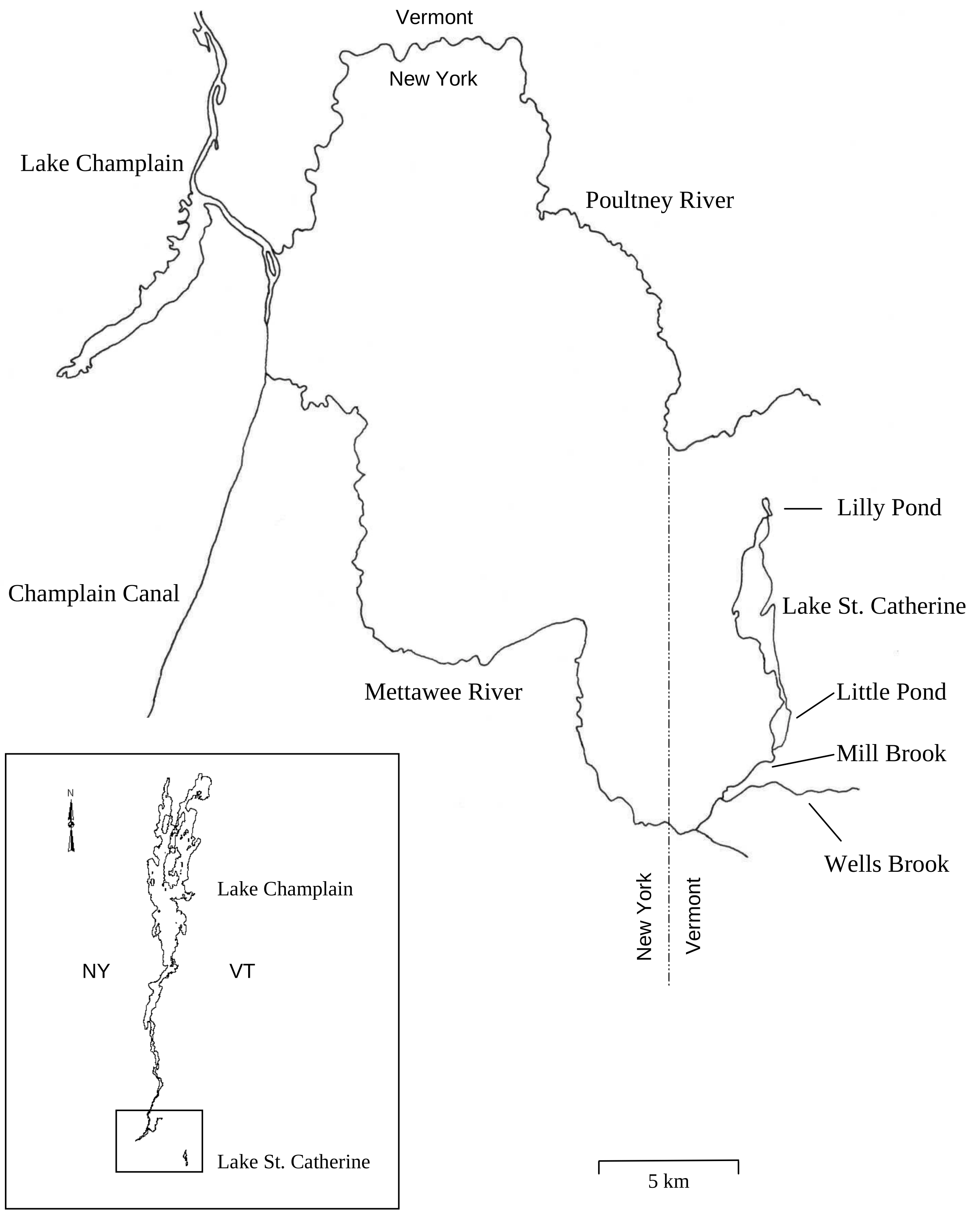


Figure 1. Map illustrating the relative locations and sizes of Lake St. Catherine and Lake Champlain (inset), and the water connection between them.

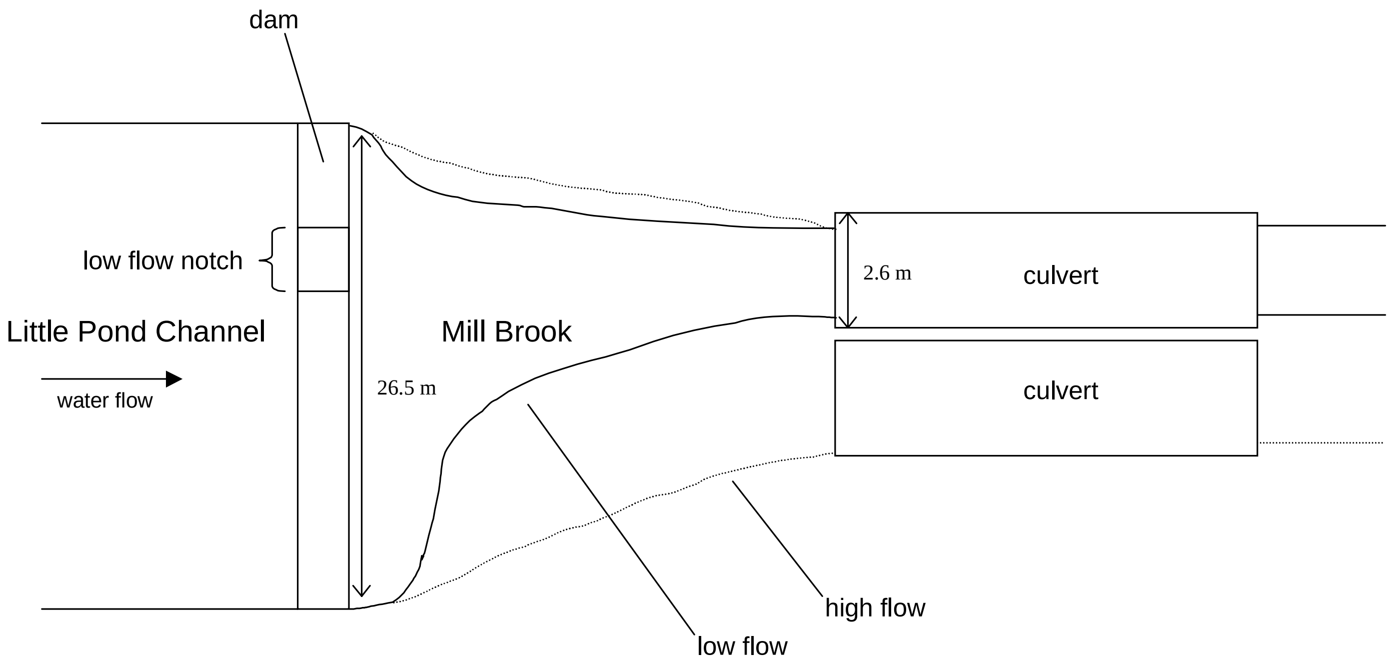


Figure 2. Schematic of the Lake St. Catherine outflow showing the location of the dam, the low flow notch, the culverts which pass under Lake Hill Road, and the high and low flow widths of Mill Brook (not to scale).

(a)

(b)

Figure 3. Photographs of the Lake St. Catherine outflow. (a) View of the dam and the start of Mill Brook, taken from across Lake Hill Road. (b) View of the culverts where Mill Brook passes under Lake Hill Road, looking upstream. Both photos taken during high flow, March 19, 1998.

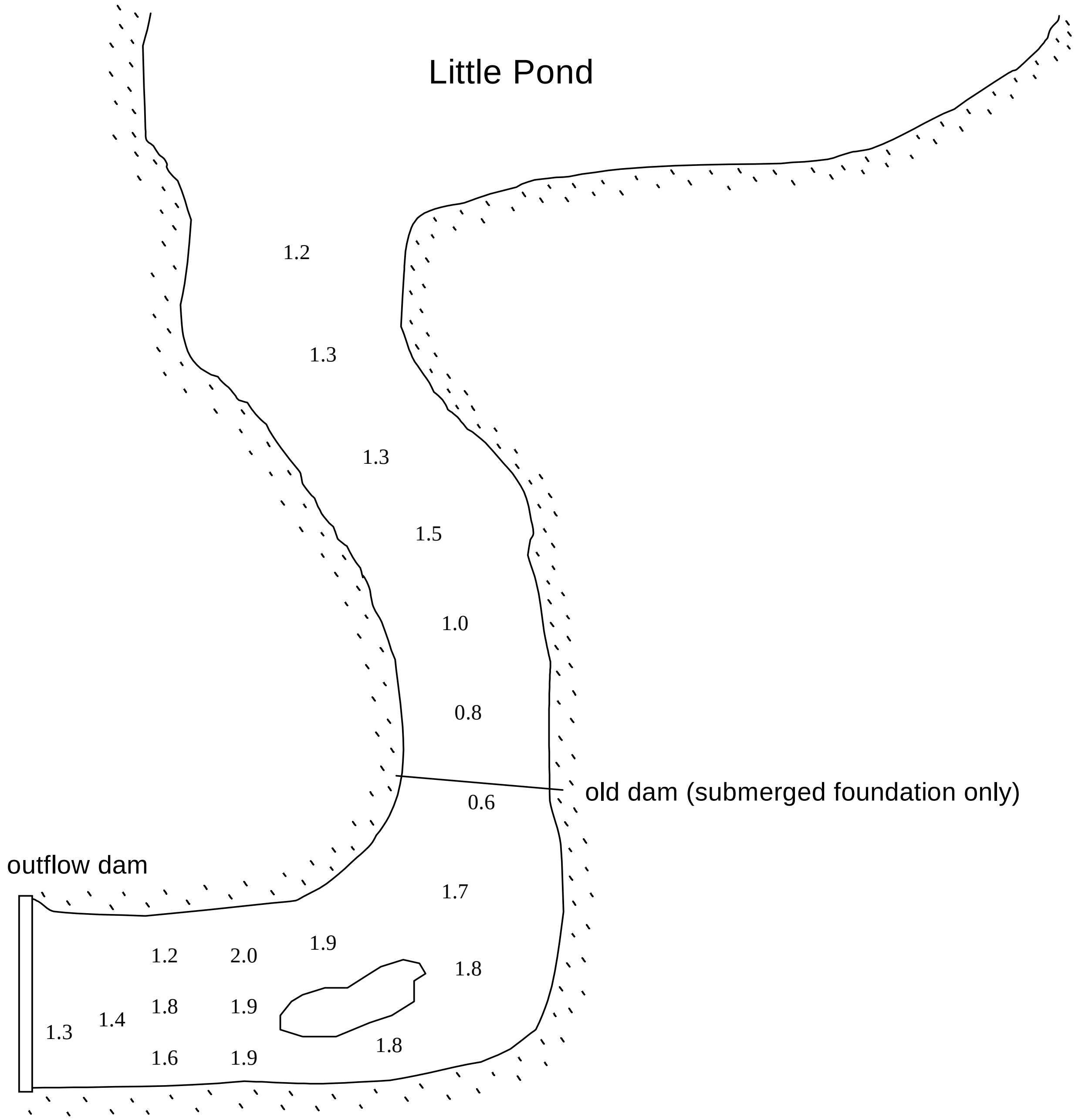


Figure 4. Schematic showing the general shape and depth (metres) of the channel flowing from Little Pond to the outflow dam at Mill Brook (not to scale).

SECTION IV

LIFE HISTORY, POPULATION STATUS, AND IMPACTS OF ALEWIVES

LIFE HISTORY

The alewife is a member of the herring family (Clupeidae) that is native to the eastern coast of North America. An anadromous species, the alewife undergoes spawning migrations into freshwater rivers and lakes of the Atlantic coastal drainage from Newfoundland to South Carolina (Leim and Scott 1966, Mullen et al. 1986, Scott and Scott 1988). Spawning generally occurs from late March through early July and is linked to temperature, occurring progressively later with increasing latitude (Scott and Crossman 1973, Mullen et al. 1986). Spawning occurs in rivers, streams, ponds, and lakes (Mullen et al. 1986, Scott and Scott 1988) over gravel, sand, detritus, or submerged vegetation, in sluggish water 0.15-3 m in depth (Pardue 1983). Adults leave freshwater immediately after spawning, but the young remain on the spawning grounds until the late larval stage (Scott and Crossman 1973).

Numerous self-sustaining, landlocked populations of alewives that spend their entire life in freshwater, have formed. In the United States alone, freshwater alewife populations have become established in at least 18 states (Fuller 1999). Adult landlocked alewives generally average about 6 inches (152 mm) in length, considerably smaller than the 10-12 inches (254-305 mm) averaged by anadromous alewives (Scott and Crossman 1973, Scott and Scott 1988).

Landlocked alewives inhabit open lake waters during most of the year, moving inshore in the spring and early summer to spawn (Rothschild 1966, Scott and Crossman 1973). Inshore movements begin in April and continue to mid-July in Lake Ontario (Scott and Crossman 1973) ; by late August, most adults have returned to deep water (Graham 1956). During the spring and summer inshore period, alewives undergo short inshore-offshore migrations, moving into shallow waters at night and returning to deeper waters (2-3 m) during the day (Rothschild 1966, Scott and Crossman 1973). During the fall and winter offshore period, they are concentrated on or near the bottom during the day and migrate upward to the base of the thermocline at night (Janssen and Brandt 1980). These diel vertical migrations have been linked to feeding. In Lake Michigan the timing of vertical movement by alewives coincides with the movement of *Mysis*, a major food source (Janssen and Brandt 1980).

Inshore migrations and spawning generally take place from April to August, although the exact timing varies among geographical locations (Odell 1934, Graham 1956, Rothschild 1966, Norden 1967, Lackey 1970, Scott and Crossman 1973). Spawning takes place at night over sand or gravel bottom (Scott and Crossman 1973) and adults retreat to deeper waters immediately following spawning (Graham 1956, Rothschild 1966). Fecundity of landlocked female alewives is highly variable, ranging from 8,190-10,011 eggs in Cayuga Lake, NY (Rothschild 1966), 10,000-12,000 eggs in Seneca Lake, NY (Odell 1934), 11,147-22,407 eggs in Lake Michigan (Norden 1967), to 29,894-159,366 eggs in Lake Superior (Bronte et al. 1991). This is considerably lower than the 48,000-360,000 eggs estimated for anadromous females (Kissil 1974).

The eggs of landlocked alewives average 0.23 mm (0.07-0.46 mm) in diameter in Lake Superior (Bronte et al. 1991) ; the eggs of anadromous alewives are much larger, averaging 0.8-1.3 mm (Mullen et al. 1986). They are broadcast at random and are demersal, developing on the substrate (Scott and

Crossman 1973). Hatching takes place in 15 days at 7°C, 6 days at 15.6°C, 3.7 days at 21°C, and 3 days at 22.2°C (Edsall 1970, Scott and Crossman 1973). Larvae from Lake Michigan averaged 4.3 mm at hatch, and the yolk sac was absorbed at an average length of 5.1 mm (Norden 1967). The young remain on the spawning ground until at least the late larval stage and then move slowly to deeper waters. Age at maturity in Lake Ontario is 2 for males and 3 for females (Graham 1956) while in Cayuga Lake both males and females mature at 2 years (Rothschild 1966). Anadromous alewives mature about 1 year later than landlocked Lake Ontario alewives (Scott and Crossman 1973).

Alewives are planktivores, feeding predominantly on zooplankton as both young and adult. In freshwater, the principal food items tend to be copepods, cladocerans, mysids and ostracods (Scott and Crossman 1973), but this varies by location (see Lackey 1970, Hutchinson 1971, Mills et al. 1992, Laux et al. 1996, Wells 1980). Large landlocked alewives also feed on the larvae of other fish species, such as yellow perch (Brandt et al. 1987, Mason and Brandt 1996) and lake trout (Krueger et al. 1995), as well as larvae of their own species (Rothschild 1966). Hoagman (1974) reported that Lake Michigan alewives readily ate larval lake whitefish in the laboratory. However whitefish are probably not a common prey of alewives in the wild. Larval predation occurs primarily at night in the littoral zone (Kohler and Ney 1980, Brandt et al. 1987).

Alewife are preyed upon by just about all larger piscivorous fish, including northern pike, smallmouth bass, largemouth bass, walleye, burbot, bowfin (Wagner 1972), lake trout (Stewart et al. 1981, Jude et al. 1987, Elrod and O'Gorman 1991), brown trout, rainbow trout (Jude et al. 1987), and Great Lakes Pacific salmon (Stewart et al. 1981, Brandt 1986, Jude et al. 1987, Jones et al. 1993). As well, adult rainbow smelt (O'Gorman 1974) and yellow perch (Wells 1980) prey on larval and young-of-the-year alewives.

POPULATION STATUS OF LAKE ST. CATHERINE ALEWIVES

Juvenile/Adult Monitoring – Lake St. Catherine

1997

Alewives were first discovered in Lake St. Catherine on July 7, 1997 during routine, night-time bass electrofishing surveys. They were the most numerically abundant species taken at all standardized sampling stations and several size classes were present. Alewives had not been documented during May 1997 bass sampling on the lake ; however, they were likely present but overlooked. No whole lake abundance estimates were made.

1998

No whole-lake abundance estimates were made ; however, the alewife was again the most numerically abundant species taken during 1998 bass electrofishing surveys on the lake. Lake St. Catherine alewives taken within the littoral zone during May and June 1998 ranged in size from 65 to 162 mm total length (TL) and 2 to 28 g wet weight. Several size classes were collected during the spring (Figure 5), and there were at least 4 age classes (determined from scale samples) - young-of-the-year (YOY), 1, 2, and 3 - within the population.

The size of alewives taken during May and June 1998 decreased steadily with date. The average length of alewives decreased from 120.8 mm on May 5, to 94.4 mm on May 20, 93.6 mm on June 8, and 85.6 mm on June 20. This trend is likely due to the timing of inshore movement by alewives being size-dependent, with larger alewives entering shallow waters to spawn earlier than smaller individuals. Early in the spawning season, the length-frequency distribution of alewives was dominated by the larger size class, but fewer and fewer large individuals were taken on subsequent sampling dates (Figure 5).

Lake St. Catherine alewives show sexual dimorphism for body size. Females were significantly longer and heavier than males (mean total length: 145.3 mm vs. 134.9 mm, $t = 6.10$, $p < 0.001$; mean wet weight: 21.1 g vs. 17.3 g; $t = 6.40$, $p < 0.001$). All alewives less than 90 cm TL were immature and all alewives greater than 125 mm TL were sexually mature; 18-50% of individuals 91-110 mm TL were mature. In terms of age, all individuals are mature by 2 years of age, and some mature as early as 1 year.

Ripe alewives, with flowing milt and eggs, were taken during each sampling date in 1998. Thus, the duration of 1998 spawning season was at least from May 5-June 20. The timing of ripening seems to be size-dependent, with larger alewives ripening earlier than smaller alewives. On May 5 and 20, the smallest fish with mature gonads were 130 mm and 129 mm, respectively, but by June 10 fish as small as 91 mm were developing gonads. The sex ratios of mature alewives varied with date, with fewer and fewer females taken as the spring progressed. In 1998, the proportion of males captured steadily increased from 48% on May 5, to 58% on May 20, 69% on June 10, and 87% on June 16. This trend could be a result of females spawning a single time then returning offshore and males remaining inshore to spawn again. Alternatively, it could result from an overall sex ratio biased toward males.

1999

A major alewife die-off occurred on April 5, 1999, around the time of ice-out on Lake St. Catherine. This was the first reported alewife mortality event in Lake St. Catherine. Mortality tended to occur among the larger individuals in the population (Figure 6). The cause of the die-off is not known, however, the dead alewives had significantly lower condition factors ($K = W/L^3$) (mean ± standard deviation: 0.439 ± 0.061) than alewives taken two months later on June 8 (0.814 ± 0.101) and those collected during May and June 1998 (0.681 ± 0.087) (ANOVA: $F = 972.5$, $p << 0.001$). The impact of this size-selective mortality on the size-structure of the population is difficult to infer, however the largest alewife captured in June 1999 was only 146 mm TL and only six individuals were over 140 mm TL (Figure 7).

Ripe alewives, with flowing milt and eggs, were taken during each sampling date in 1999 (June 8, June 30, and July 15). No whole lake abundance estimates of the Lake St. Catherine alewives were made; however, the alewife was once again the most numerically abundant species taken during 1999 bass electrofishing surveys on the lake.

2000

In the summer of 2000, standard electrofishing efforts were continued from June through September to determine relative abundance of alewives throughout the Lake St. Catherine system. Both male and female alewives were found to be ripe during the June through August sampling period. Adult alewives were found to be present in all 3 basins of the Lake St. Catherine system, although the numbers found in Lilly Pond and Little Pond were very low (n<5 individuals). Alewives were found to be more numerous than all other fish species sampled.

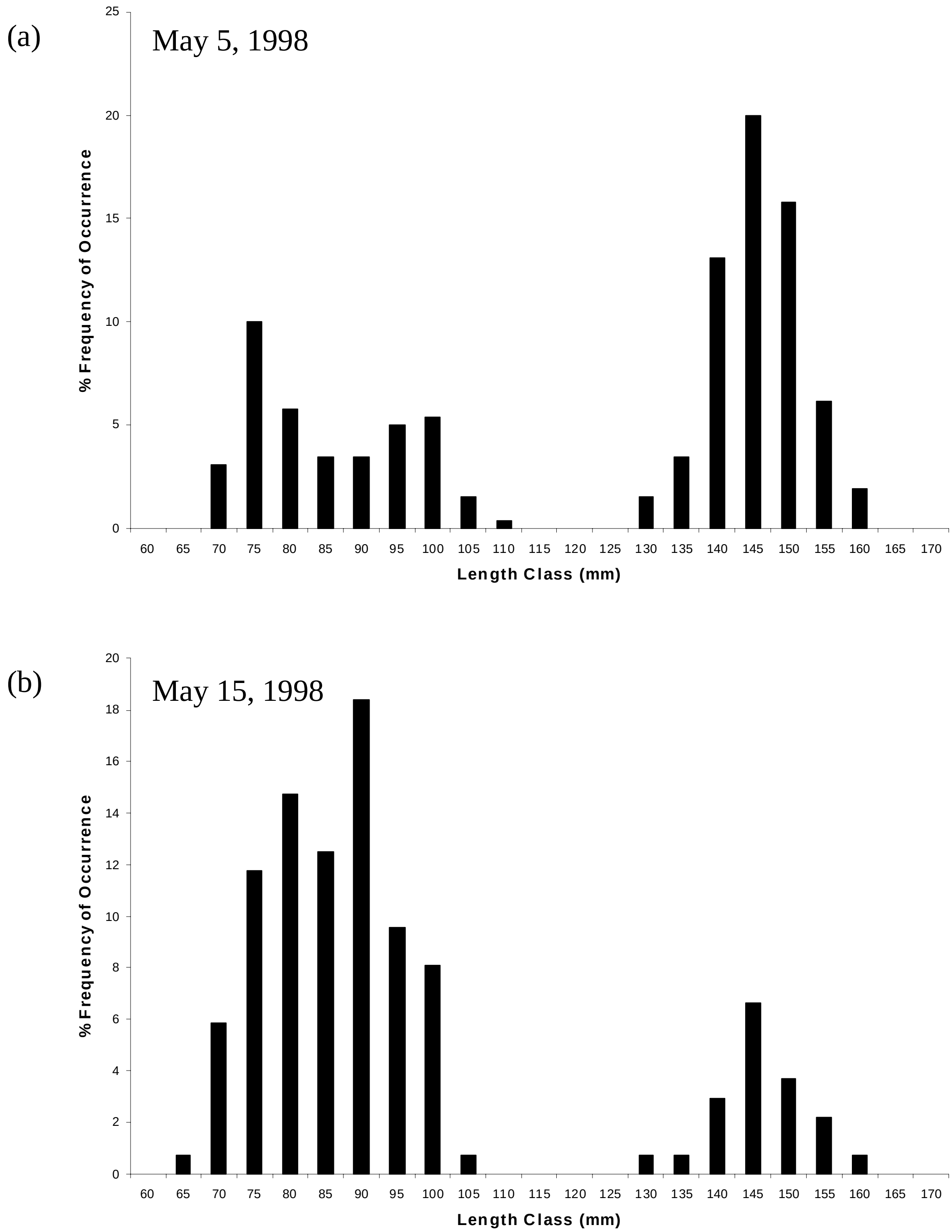
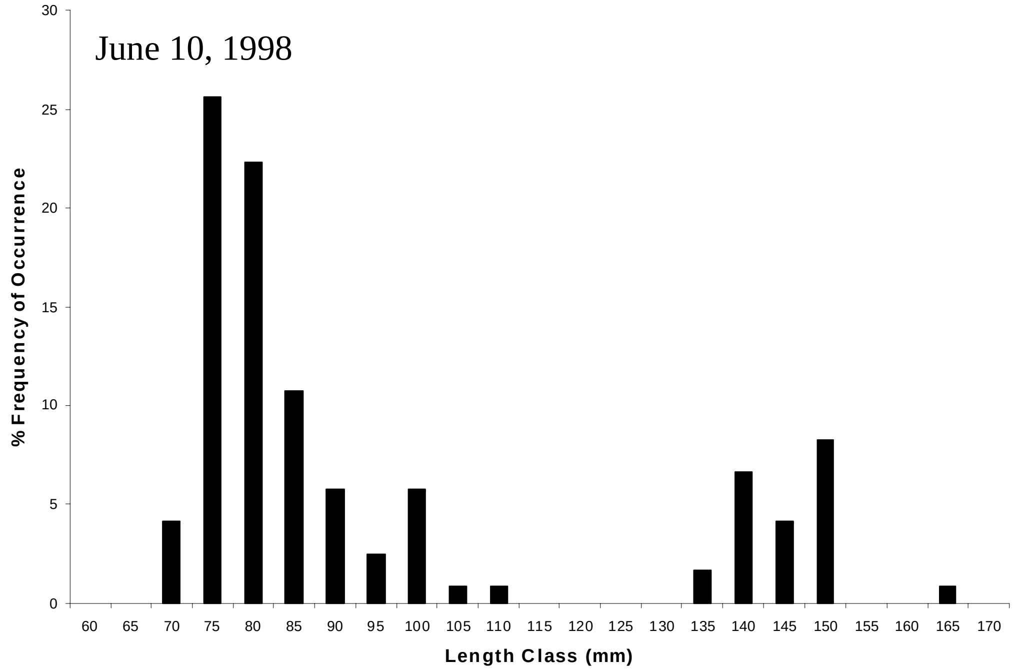


Figure 5. Length frequency distributions of alewives captured during May and June 1998. (a) May 5 (n=260), (b) May 20 (n=136), (c) June 10 (n=121), and (d) June 16 (n=52).

(c)



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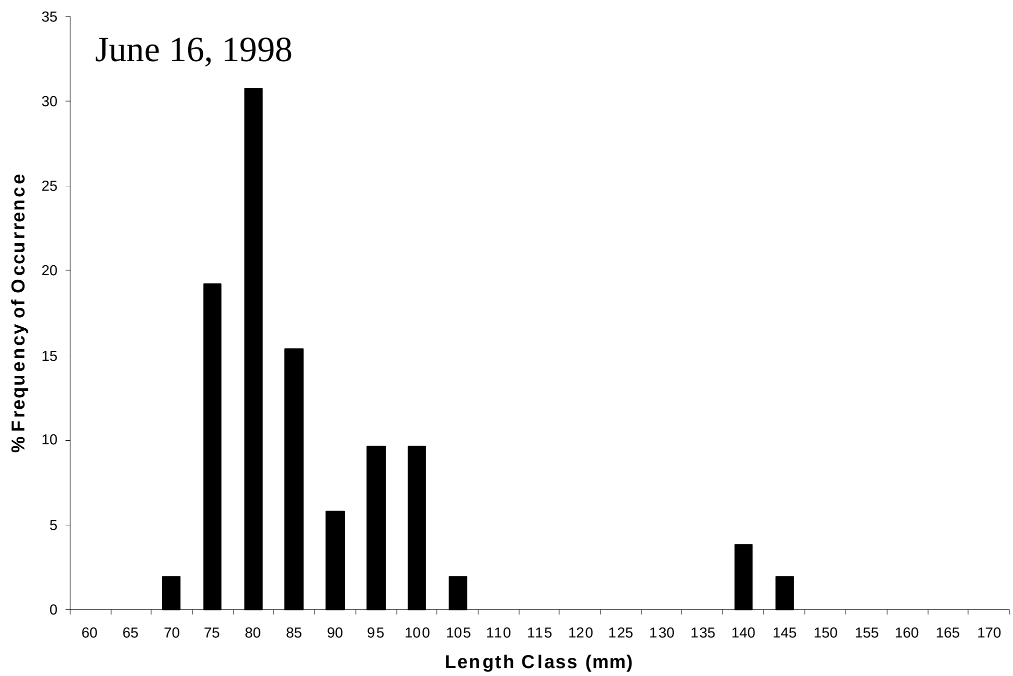

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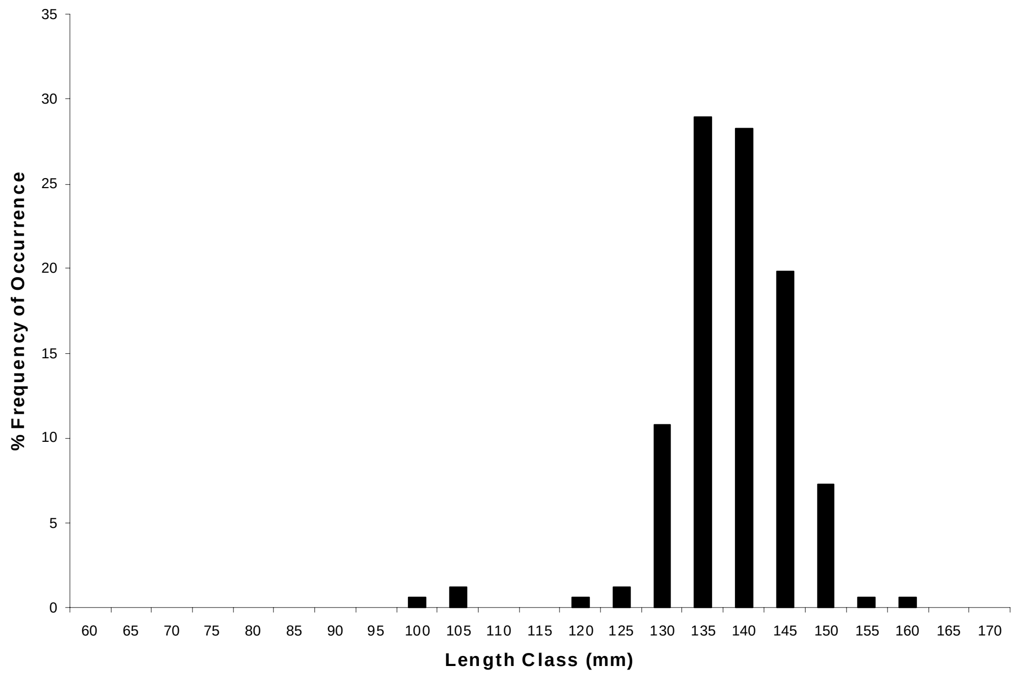

Figure 6. Length-frequency distribution of dead alewives collected following the April 5, 1999 alewife die-off (n=166).

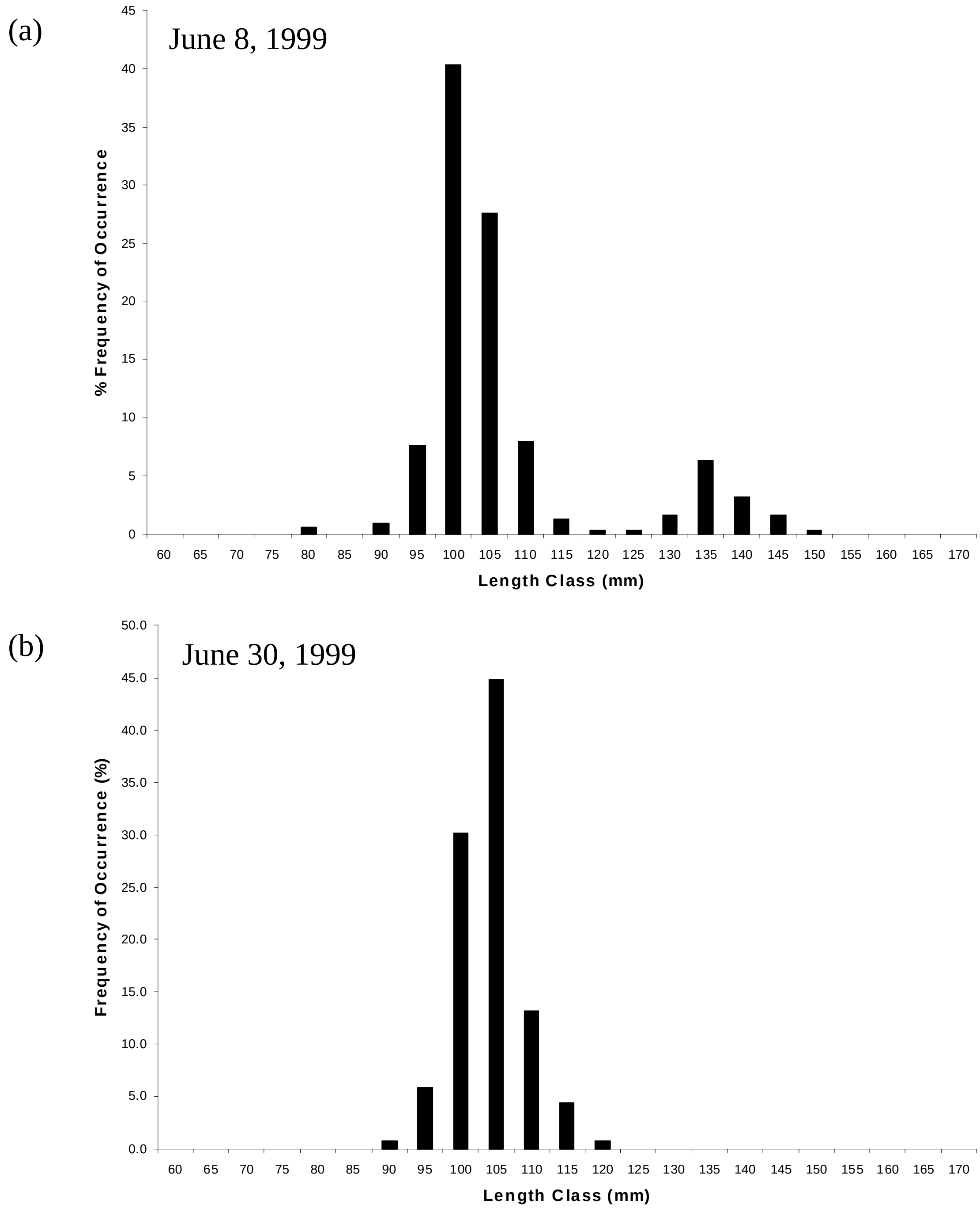

Figure 7. Length-frequency distributions of alewives captured during June and July 1999. (a) June 8 (n=315), (b) June 30 (n=136), and (c) July 15 (n=305).

(c)

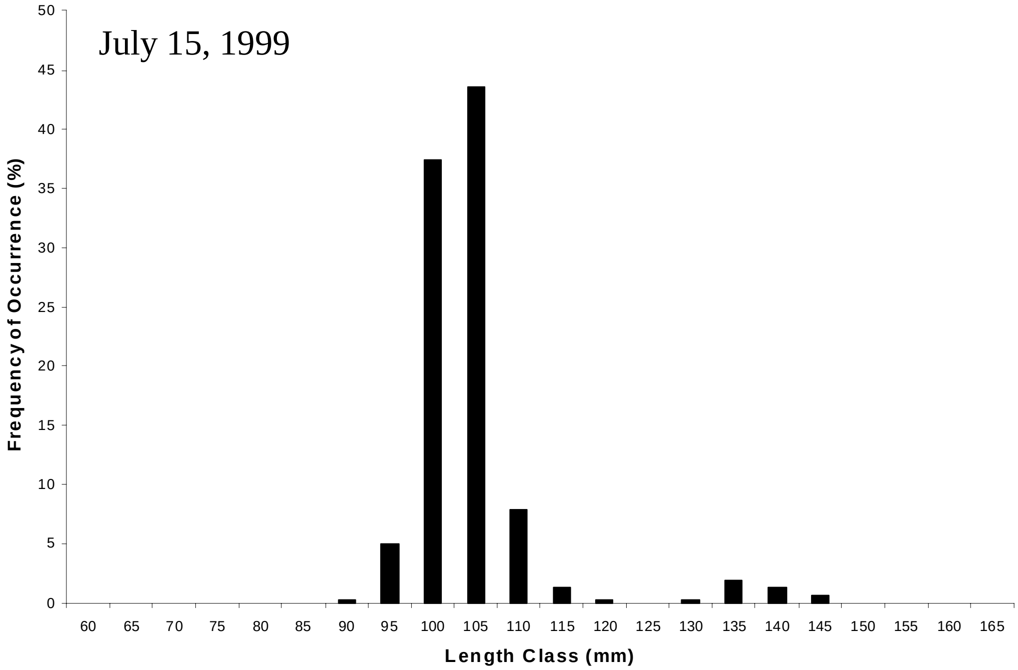

Figure 7. Cont'd.

Due to the morphometry of the Lake St. Catherine system, the presence of dense stands of Eurasian watermilfoil in the littoral zone, and the habitat preferences of alewives in the Lake and their response behaviour to electroshocking, it was determined that adequately estimating alewife numbers would be very difficult, if not impossible. Moreover, it is not important to know exactly how many alewives are in the Lake ; it is more important to use available resources to monitor their reproduction and movement within the system, and to monitor downstream waters for evidence of alewife escapement and/or establishment. Consequently, 2000 was the last year adult alewife sampling was conducted in Lake St. Catherine, Lilly Pond, and Little Pond.

Larval Monitoring – Lake St. Catherine

In addition to adult alewife electrofishing, larval alewife trawling was conducted to determine spawning and larval dispersal patterns. In both 2000 and 2001, nine trawling transects, one located in Little Pond at the mouth of the outflow channel, and eight in the main body of Lake St. Catherine, were sampled once every two weeks from late May through early September. Larval trawling stations incorporated a variety of habitats, including deep open water, shallow sandy and gravel bottoms, and shallow, heavily vegetated areas. Within each sampling station, an array of depths were trawled, from the surface down to approximately four meters. All trawling was conducted during the day.

Results were remarkably similar in both years. No larval alewives were collected from any sampling stations in May. Larval alewives were first collected early June in the Little Pond sample, while the other sampling sites revealed no larval alewives until the late June sampling period. This is likely due to the fact that Little Pond warms earlier than the rest of the lake, and therefore the water temperature reaches the appropriate level there first. By the end of June, however, alewife larvae were widely distributed throughout the lake, and were found at all sites sampled through mid-August. Throughout the entire sampling season in both 2000 and 2001, the sampling station located in Little Pond, at the mouth of the outflow channel, continued to have the highest abundance of larval alewives compared to the other eight sampling sites in the main lake. In mid-August, larval alewives ceased appearing in samples from the main lake, but continued to be collected at the mouth of the outflow in Little Pond until early September (Meriel Brooks, Green Mountain College, personal communication).

These results indicate two things : 1) alewives begin reproducing in early June and continue to successfully reproduce through August, and 2) as indicated by the high abundance of larvae collected in Little Pond at the mouth of the outflow, larval alewives drift with water currents through the system and accumulate in Little Pond, very near the outflow.

Alewife Monitoring – Downstream Waters

The possibility of alewives escaping Lake St. Catherine, moving downstream, and becoming established in southern Lake Champlain is very real. However, it was unclear as to which life stage of alewives, larval or juvenile/adult, posed the greatest risk of escapement. To answer this, various monitoring and sampling regimes have been implemented since 1998.

Larval Escapement

Lake St. Catherine's outflow and downstream waters have been periodically monitored for drifting alewife larvae from May through September of 1998 through 2001. Waters downstream of Lake St. Catherine's damn were sampled for drifting alewife larvae by use of 363 µm ichthyoplankton drift nets.

In 1998 and 1999, no larval alewives were collected in the samples taken periodically over the known reproductive season in Lake St. Catherine. In 2000, a drift sample taken June 27th approximately 50 metres downstream of the dam contained 3 post-yolk-sac alewife larvae. Two larvae were 4.5mm and the other was 10mm in length. On August 4th, a drift sample from the same location contained 1 post-yolk-sac alewife larvae 4mm in length. Other samples taken in July and September contained no larval alewives.

Due to the fact that several larval alewives were found in 2000 downstream of Lake St. Catherine's dam, sampling efforts were increased in 2001 through cooperation with Dr. Meriel Brooks of Green Mountain College in Poultney, Vermont. Sampling was repeated at the site 50 metres downstream of the dam, and 2 other sites in Mill Brook were sampled – one halfway between the dam and where Mill Brook enters the Mettawee, and one just above the confluence of Mill Brook and the Mettowee. Additionally, 4 sites were added on the Mettawee River, beginning just downstream of it's confluence with Mill Brook and continuing downstream to Granville, NY. Sites were generally sampled once per week from late May through early August. Larval alewives were captured only at the site closest to Lake St. Catherine's outflow. No samples from the other 2 sites on Mill Brook or the 4 sites on the Mettawee River contained larval alewives. The first collection at Site 1 in Mill Brook was on June 3rd, when 103 drifting larvae were collected in a 25-minute sample. The last larval alewife collected at this site was on July 2rd, when one was captured in a 20-minute sample. Samples taken from July 5th through early August contained no alewife larvae. A total of 161 larval alewives were collected between June 3rd and July 5th at this site. It should be noted that water flow over the dam on Lake St. Catherine ceased due to low lake levels in early July.

Adult/Juvenile Escapement

It is known that juvenile and adult fish of all species from Lake St. Catherine occasionally escape over the dam, particularly during high water events. These fish congregate in a plunge pool directly below the dam, and remain there until winter, when they most likely suffer high levels of mortality in this small shallow stream. Electroshocking in this plunge pool, and Mill Brook some distance downstream has turned up extremely high densities of mainly juvenile fish - bluegill and pumpkinseed sunfish, largemouth and smallmouth bass, northern pike, brown bullhead, rock bass, golden shiner, emerald shiner, yellow perch, and white sucker have all been captured. Considering this, regular electrofishing surveys of the plunge pool, Mill Brook, and the upper portions of Wells Brook have been regularly conducted from May through September 1998 through 2003 to determine if juvenile or adult alewives had escaped over the dam. Similarly, sections of southern Lake Champlain, the Champlain Barge Canal from Lock 12 in Whitehall New York to the mouth of the Mettawee River, and the lower 2 miles (3.2 km) of the Mettawee River have also been surveyed by boat electrofisher to determine the presence/absence of juvenile and/or adult alewives.

Electrofishing conducted from 1998 through 2003 in waters downstream of Lake St. Catherine turned up no juvenile or adult alewives, although an abundance of blueback herring have been noted annually in the lower Mettawee River, the Champlain Barge Canal south of Lock 12 in Whitehall, New York, and southern Lake Champlain, north of the lock.

Probability of Out-Migration

This data demonstrates what biologists have predicted : alewives can and will passively drift out of Lake St. Catherine under the right circumstances. Results from larval alewife trawling in Lake St. Catherine are particularly troubling, as it appears that the highest density is found at the entrance to the outflow canal on Little Pond (see Figure 4 for reference). If high water events occur during or immediately following spawning it is likely that large numbers of larval alewives may be washed over the dam. However, it is still unclear as to their likelihood of survival during downstream drift in Mill Brook and the Mettawee River. Significant numbers of larval alewives (n=161) were captured at the sampling site closest to the dam in 2001 yet none were captured at sites further downstream (the next closest sampling site is approximately 400 metres downstream). Interestingly, larval alewives have not shown the ability to survive in a stream environment once outside of Lake St. Catherine. This could be due to a variety of reasons, including insufficient food resources (zooplankton) for larval alewives, high water temperatures, and low flow conditions. There are still many unknowns with respect to understanding the risk posed to Lake Champlain by larval alewife escapement from Lake St. Catherine. For example, we have no precise measurement of probability of survival of an alewife larvae traveling downstream to Lake Champlain, nor do we do know how many individuals would need to survive to maturity (1 year) in southern Champlain before reproducing and establishing a population. However, to date, it does not appear that larval alewives are capable of surviving a 47 km (29 mile) journey downstream to southern Lake Champlain. The risk of establishment via larval alewife escapement from Lake St. Catherine seems to be low at this time.

While no juvenile or adult alewives have been collected during stream and boat electroshocking efforts in Mill Brook, the Mettawee River, the Champlain Barge Canal, and lower Lake Champlain, it could be said that these life stages most likely pose the greatest risk of spread from Lake St. Catherine. If juvenile and adult alewives were to escape over the dam, it is conceivable that they could survive the downstream journey to Lake Champlain. As with larval alewives, however, sufficient numbers would have to do so in order to ultimately reproduce and become established. In the six years since they were first discovered in Lake St. Catherine, no juvenile or adult alewives have knowingly made it to Lake Champlain and survived.

Alewives in Other Waters of the State

On June 13, 2003, a vigilant angler fishing on Lake Bomoseen spotted 4 dead fish floating in a side channel on the eastern shoreline of Lake Bomoseen. Thinking they might be alewives, the angler collected the fish and brought them to the local bait and tackle shop. The owner of the shop then contacted Shawn Good, Fisheries Biologist at the VTDFW, who verified the anglers' identification. Later that same day, a quick survey on Lake Bomoseen in the vicinity of the original discovery found 18 more dead alewives. The origin of this introduction is unknown at this time. The alewives may have been captured in Lake St. Catherine or they could have been transported from out-of-state. The location of the discovery in Lake Bomoseen is worthy of note in speculating the alewives origin. All dead fish were collected in what is known as the "Neshobe Canal", a short, dredged canal that is very shallow (avg. depth less than 2 feet) with abundant aquatic vegetation. The canal does not open directly to the lake ; the mouth is "S"-shaped with a breakwall-type point. Considering this, it is unlikely the dead alewives drifted into this canal on their own. Similarly, because of the habitat type, it is unlikely the fish swam into or inhabited the canal prior to dying. The location and concentration of the discovery leads to the belief that they were brought to Lake Bomoseen, used as bait, and the remaining dead alewives were discarded at the end of the day, likely by someone living in or renting a camp on the canal. At this time, it appears as if this was an isolated incident since alewives were not collected in July of 2003 during VTDFW annual bass electrofishing index surveys conducted at 16 standard stations throughout Lake Bomoseen. Alewives were first discovered in 1997 in Lake St. Catherine during these same annual bass electrofishing index surveys, and it stands to reason that if alewives were already established in Lake Bomoseen, they would be found during these same surveys. Biologists will monitor the situation closely on Lake Bomoseen during future bass electrofishing surveys.

In August of 2003, biologists with the Société de la Faune et des Parcs du Québec collected seven (7) clupeids in the Quebec portion of Missisquoi Bay during index netting activities. The Quebec biologists initially identified the specimens as alewives, strictly on external features. The primary internal feature which differentiates alewives from blueback herring – the colour of the peritoneum (silver in alewives, black in blueback herring) – was not verified. Blueback herring are recent invaders to Lake Champlain, but have become relatively abundant in the southern portion of the lake ; their occurrence has not previously been recorded north of Converse Bay, VT or Essex, NY. Without suitable verification, it is impossible to say which fish species was collected in Missisquoi Bay. During the winter of 2004, the Quebec biologists submitted tissue samples from five of the seven clupeid specimens collected to a DNA laboratory at the University of Maine for genetic species identification. The samples have not yet been processed.

KNOWN IMPACTS OF EXOTIC ALEWIFE

Landlocked populations of alewives have been studied extensively, especially in the Great Lakes. A wide range of impacts of exotic alewives have been documented, and it is clear that alewives impact all levels of aquatic ecosystems. The alewife has directly and indirectly restructured both fish and zooplankton communities (Hewett and Stewart 1989). Alewife impacts that have been documented in the published literature are detailed here.

Alteration of the Zooplankton Community

Alewives are very efficient, size-selective feeders. They feed selectively on larger zooplankton species and the larger individuals within a species (Brooks and Dobson 1965, Wells 1970, Hutchinson 1971). They have been shown to drastically alter zooplankton size, abundance and community structure through intense size-selective predation (Wells 1970, Hutchinson 1971, Kohler and Ney 1981, Evans 1986, O'Gorman et al. 1991). The result is a less abundant zooplankton community that is dominated by small species (Brooks and Dobson 1965, Wells 1970). This phenomenon has been reported in a number of lakes, including Lake Michigan (Wells 1970, Evans 1986, Crowder et al. 1987), Lake Ontario (Johannsson and O'Gorman 1991), Claytor Lake, Virginia (Kohler and Ney 1981, Kohler 1984), Black Pond, New York (Hutchinson 1971), and seven lakes in eastern Connecticut (Brooks and Dobson 1965).

In Lake Michigan, as alewife abundance increased tremendously during the early 1960s, the largest cladocerans, the largest calanoid copepods, and the largest cyclopoid copepods declined sharply, while certain small- or medium-sized species increased in number (Wells 1970). The alewife population crashed in 1967, and the composition of the zooplankton community in 1968 shifted back toward that of 1954, when alewives were still uncommon in the lake (Wells 1970). Alewife declines in the late 1970s and early 1980s resulted in a similar response in the offshore zooplankton community structure as larger species increased in abundance (Evans 1986). There was no response in the inshore zooplankton community, however, since predation pressure remained high as a result of increased yellow perch abundance that accompanied the alewife decline.

Similar changes occurred in Claytor Lake, a hydroelectric impoundment of the New River in Virginia. Kohler and Ney (1981) noted a shift in the summer zooplankton community following a severe alewife mortality event during the winter of 1977-78. In the relative absence of alewives during the summer of 1978, the zooplankton community was dominated by larger species. Due to very successful reproduction in 1978, the alewife population rebounded dramatically, and in the summer of 1979 the zooplankton community shifted back to smaller forms (Kohler and Ney 1981).

The zooplankton community of Black Pond, New York changed dramatically from 1958 to 1966 after alewives were introduced as forage for landlocked Atlantic salmon. Large species of zooplankton, which were abundant in 1958, had been replaced by small forms by 1966 (Hutchinson 1971). A comparison of alewife stomach contents and limnetic plankton samples in Black Pond indicated that alewives were feeding both species- and size-selectively (Hutchinson 1971). Alewives eliminated most large zooplankton species from the pond by selectively feeding on the larger zooplankton.

Brooks and Dobson (1965) reported that large zooplankters were absent while small zooplankters were abundant in several Connecticut lakes containing natural, landlocked alewife populations. They hypothesized that this was due to size-selective predation by alewives. They based this hypothesis on Crystal Lake, a lake in northern Connecticut in which blueback herring had been introduced. The plankton community of Crystal Lake in 1964, when blueback herring were abundant, resembled the plankton of the lakes containing alewives, and was very different than the plankton community in the lake in 1942, before blueback herring were abundant (Brooks and Dobson 1965). In 1942, zooplankton up to 1.8 mm in length were found in the lake, but in 1964 no zooplankton over 1 mm were found.

The efficient size-selective zooplanktivory of alewives may also indirectly impact nutrient dynamics and water clarity. In the Bay of Quinte, Lake Ontario, a 50% decrease in phytoplankton biomass during 1978-1981 coincided with decreased phosphorus loading and major winter kills of alewife and white perch. Nicholls and Hurley (1989) concluded that levels of zooplankton and benthic macroinvertebrate predation by alewives and white perch had a significant effect on the phytoplankton biomass in the Bay. Scavia et al. (1988) modeled the summer plankton community in Lake Michigan and concluded that it is largely controlled by predation. They found that alterations in the phytoplankton and zooplankton species composition were explained more by reduced predation on large zooplankton due to declining alewife abundance than reduced phosphorus loading. However, the link between alewives and phytoplankton may not be as straightforward as these studies suggest (Evans 1992). In any case, in Lake St. Catherine it seems that declines in zooplankton abundance may already be contributing to increased algal growth (decreased grazing on algae by zooplankton) and decreased water clarity. Data obtained through Vermont's Water Quality Lay Monitoring Program, administered by the Water Quality Division of the Vermont Department of Environmental Conservation, shows that secchi disc readings have declined remarkably since the introduction of alewives (Table 1). From 1993 through 1996, the year prior to the discovery of alewives in Lake St. Catherine, the average secchi disc reading was 6.2m (20.3 feet). In the six years following their discovery, the average secchi disc reading was 4.0m (13.0 feet). The decrease in water clarity in Lake St. Catherine is quite significant.

Table 1. Average secchi disc readings from Lake St. Catherine. Data provided by the Vermont Water Quality Lay Monitoring Program, Vermont DEC.

Average Secchi Disc Readings **(min. of 8 readings taken through June, July, August each year)**		
Year	Secchi Reading Depth (meters)	Secchi Reading Depth (feet)
1993	6.6	21.7
1994	5.5	18.0
1995	6.5	21.3
1996	6.3	20.7
1997 *	5.9 *	19.4 *
1998	4.3	14.1
1999	3.8	12.5
2000	3.7	12.1
2001	4.5	14.8
2002	3.9	12.8
2003	3.8	12.5

* 1997 was the year alewives were first discovered in Lake St. Catherine

Competition for Food

Alewives are potentially very serious competitors with other planktivorous fish (Kohler 1984). Alewives compete directly for zooplankton with other planktivorous fish, including yellow perch, bloater, cisco, and rainbow smelt (Crowder et al. 1987). They also compete directly with the young of piscivorous species which are dependent on zooplankton during the early parts of their lives (Wells and McLain 1972, Crowder 1980). Competition with alewives for zooplankton has been hypothesized as a major cause of the declines of many native fish species in the Great Lakes (Smith 1970, Crowder 1980, Hewett and Stewart 1989).

Alewives in Lake Michigan are much more efficient than native species such as bloater at feeding on small zooplankton in the water column (Crowder and Binkowski 1983, Crowder et al. 1987). This is due at least in part to their ability to switch from particulate feeding to filtering (Janssen 1976, Crowder and Binkowski 1983). In response to feeding competition with alewives, bloaters in southeastern Lake Michigan underwent an alteration in gill raker morphology (fewer, smaller gill rakers) and a habitat shift (they now shift to bottom feeding as much as two years earlier than before alewives became abundant) due to selection for benthic foraging efficiency as a result of intense competition with alewives (Crowder 1984).

Alewife-induced shifts in zooplankton composition represent a potentially significant negative impact on cohabiting planktivores (Kohler 1984). Reduced food availability, by way of fewer or smaller zooplankton, results in reduced growth rates and increased mortality of native fishes, particularly the larval and juvenile stages that are susceptible to size-dependent mortality (Brown 1972, Crowder et al. 1987). Slow growth could lead to increased vulnerability to predation due to an increase in the amount of time spent at smaller, vulnerable sizes (Werner and Gilliam 1984) and would most likely result in increased winter mortality as a result of smaller sizes being attained prior to winter (Crowder et al. 1987). In Lake Ogallala, Nebraska, for example, alewives shifted dominance of the zooplankton community from the large *Daphnia* spp. to the smaller *Bosmina* sp. and rotifers. Reduction in this food resource has caused, in part, a reduction in growth and survival of rainbow trout in the lake (Laux et al. 1996).

<u>Egg and Larval Predation</u>

Predation by adult planktivorous fish on eggs, embryos or larvae has been suggested as an important source of mortality (Crowder 1980). Alewives are know to feed on both the eggs and larvae of a number of fish species, and alewife predation on larval fish can be quite intense (Kohler and Ney 1981). As a result, egg and larval predation by alewives is now considered a major mechanism by which alewives affect native species, potentially more important than competition for food (Crowder 1980, Eck and Wells 1987).

Alewives feed on yellow perch larvae (Kohler and Ney 1980, Brandt et al. 1987, Mason and Brandt 1996), and this predation appears to be a significant source of yellow perch mortality. Mason and Brandt (1996) suggested that alewife predation could have a major impact on recruitment of yellow perch in Lake Ontario. Krueger et al. (1995) found that alewife predation on lake trout larvae in Lake Ontario caused substantial mortality. Alewife predation on lake trout larvae may have caused nearly 100% mortality of emergent fry from near-shore spawning areas where alewives were abundant. They also suggested that alewife predation could be an important source of mortality in lakes Michigan and Huron as well. Kohler and Ney (1980) found that alewives fed on the larvae of largemouth bass, smallmouth bass, white bass, sunfish, yellow perch, and golden shiner in Claytor Lake, Virginia. Peak larval predation coincided with a sharp decline in zooplankton density, suggesting that predation by alewives on larvae may intensify once they have depleted their zooplankton food base.

<u>Thiamin Deficiency</u>

Alewives have recently been implicated as the cause of major reproductive failures that have plagued landlocked Atlantic salmon and lake trout populations. The Cayuga syndrome is a maternally transmitted, non-infectious disease that causes up to 100% mortality in the larval offspring of landlocked Atlantic salmon from several of New York's Finger Lakes (Fisher et al. 1995, 1996, 1998). The swim-up or early mortality syndrome (EMS, identical in all but name to the Cayuga syndrome) impairs the survival of lake trout in Lakes Ontario and Erie; mortality ranges from 25.2-57.9% (Fitzsimons et al. 1995, Fisher et al. 1996).

Several lines of evidence suggest that both syndromes are the result of thiamin or vitamin B_1 deficiencies. First, whole body analysis of landlocked Atlantic salmon larvae from Cayuga and Seneca lakes revealed very low thiamin levels. Second, there is a significant negative correlation between thiamin concentration of both Lake Ontario and Lake Erie lake trout eggs and the mortality of resultant fry (Fisher et al. 1996). Third, treatment of afflicted fry with thiamin reduces the mortality associated with EMS in Lake Ontario lake trout (Fitzsimons 1995) and completely eliminates the mortality associated with the Cayuga syndrome (Fisher et al. 1996). Finally, the progeny of landlocked Atlantic salmon fed thiamin-deficient diets for six months prior to spawning were afflicted with the Cayuga syndrome while the progeny of landlocked Atlantic salmon fed thiamin-sufficient diets were not (Fynn-Aikin et al. 1998).

The thiamin deficiencies appear to be dietary in nature - the result of diets consisting principally of alewives. Alewives contain very high levels of thiaminase (Neilands 1947), a group of enzymes that diminish the ability to store thiamin in tissues and that may cause thiamin deficiencies in fish (Fynn-Aikins et al. 1998). Alewives are the principal food of lake trout in both Lake Ontario (Jones et al. 1993) and Lake Michigan (Jude et al. 1987) where EMS has been reported. In Lakes Huron and Superior, where alewives are much less abundant and therefore only a minor part of the salmonid diet, mortality syndromes have not been reported (Fisher et al. 1996). In fact, the average thiamin level in lake trout eggs from Lake Ontario is less than half of that in eggs from Lake Huron (Fitzsimons and Brown 1998). Cayuga syndrome only occurs in those Finger Lakes containing alewives. All progeny derived from Cayuga, Seneca and Keuka lake broodstocks, that feed principally on alewives, are afflicted with the syndrome, but those from Skaneateles Lake, which does not contain alewives, are not (Fisher et al. 1995, 1996).

Decline/Extinction of Native Species

The alewife has had detrimental impacts on many native fish stocks (Wells and McLain 1972) and the establishment of alewives in the Great Lakes was associated with the population collapse of several native planktivorous and minor piscivorous fishes (Kohler and Ney 1981). Blackfin cisco, shortnose cisco, longnose cisco, shortjaw cisco, longjaw cisco and kiyi became extremely rare or locally extinct in Lake Michigan after the appearance of alewives and rainbow smelt (Crowder 1980). Bloater, yellow perch, and deepwater sculpin in Lake Michigan have all shown large-scale declines during alewife increases and subsequent increases during alewife declines (Crowder 1980, Eck and Wells 1987). Lake herring and emerald shiner in Lake Michigan have also been adversely affected by alewives (Eck and Wells 1987). The disappearance of native Lake Ontario planktivores such as lake whitefish and lake herring has been attributed at least in part to the introduction of alewives which reduced zooplankton populations (Smith 1970). In Cayuga Lake, the alewife appears to have replaced the cisco as the major forage species (Youngs and Oglesby 1972). In Lake Ogallala, Nebraska, reduction of the zooplankton food resource by alewives has resulted in decreased survival of rainbow trout (Laux et al. 1996).

Die-Offs

Landlocked alewife populations undergo periodic mass mortalities. Catastrophic midwinter, early spring and summer mortalities have been common in the Great Lakes since the alewife first established itself (Colby 1973). In Lake Michigan, a major lake-wide die-off occurred in June and July 1967 (Brown 1972), and die-offs have occurred quite regularly ever since (Eck and Brown 1985). In general, alewife populations recover rapidly after such catastrophic mortality events. Following the massive winter 1976-77 die-off in Lake Ontario, adult alewife abundance increased nearly sevenfold during 1978 to 1981 (O'Gorman and Schneider 1986). In Claytor Lake, a successful reproduction followed the major winter 1977-78 die-off, and the population rebounded sharply in 1979 (Kohler and Ney 1981). The causes of these mortality events are unclear, but density-dependent effects, such as food limitation, and temperature extremes and fluctuations are likely involved.

Die-offs are sometimes massive when alewives are extremely abundant (Smith 1970). Brown (1972) hypothesized that over-abundance decreased the food supply, depressed growth, and caused the poor condition that made Lake Michigan alewives vulnerable to the excessive mortality of 1967. Graham (1956) suggested that early spring mortality of alewives is related to exposure to low temperatures. Alewives in the Great Lakes may be exposed to lower water temperatures than anadromous alewives in the ocean (Colby 1973). In the Great Lakes they may experience temperatures of $3^{o}C$ or less for prolonged periods, while ocean temperatures do not drop below $4^{o}C$. Eck and Brown (1985) attributed declines in Lake Michigan alewife abundance in the late 1970s and early 1980s more to a string of cold winters than to increased predation by salmonids. Bronte et al. (1991) concluded that adverse environmental conditions (e.g., cold winter temperatures) are the reason that alewives have never become abundant in Lake Superior. Alewife year-class strength is negatively correlated with the average temperature of the growing season (Eck and Wells 1987). These factors most likely work in combination; for example, food scarcity resulting in poor condition may result in increased susceptibility to low temperature stress (Colby 1973).

Alewife die-offs result in fouled beaches (Brown 1972, Scott and Crossman 1973), affect tourism, and raise public health concerns. Losses to industry, municipalities, and recreational interests as a result of the 1967 mass mortality in Lake Michigan were estimated to be in excess of $100 million (Colby 1973). From an ecological perspective, alewives provide an unstable forage base. The effects of extreme fluctuations in abundance on the suitability of alewives as a forage base have not been assessed (Kohler and Ney 1981).

Expansion of Existing Forage Base

Alewives are the major prey of salmon and trout in Lakes Michigan and Ontario (Stewart et al. 1981, Eck and Brown 1985, Brandt 1986, Jude et al. 1987, Jones et al. 1993). Eck and Brown (1985) reported that the alewife-dominated forage base in Lake Michigan produces more potential forage for predators and could therefore support more lake trout than the original cisco-based system ever did. Stocking of trout and Pacific salmon to take advantage of the abundant alewife populations in the Great lakes since the 1960s has created a multimillion dollar sport fishery (Brandt 1986). The success of salmonid stocking in the Great Lakes was the impetus for the stocking of alewives as a pelagic forage species into many small lakes and reservoirs throughout the United States (Kohler 1984).

EXPECTED IMPACTS IN VERMONT WATERS

Based on the impacts that exotic alewives have had in the past, we are able to make predictions about the specific impacts they are likely to have in Lake St. Catherine. The main impacts would result from competition for zooplankton and from predation. We would expect declines in rainbow smelt and yellow perch since all life stages are in direct competition with the alewife, and decreased growth rates and survival of rainbow trout due to competition for food. Although initial impacts on bass could be positive (e.g., increased growth due to increased food supply), long-term impacts due to alewife competition with the early life stages and larval predation during spring and summer could be severe. We also expect declines in emerald shiner, which have been adversely affected by alewives in Lake Michigan. Furthermore, we expect periodic alewife die-offs to occur, such as the one which occurred in April 1999.

The direct water connection between Lake St. Catherine and southern Lake Champlain makes the migration of alewives to Lake Champlain possible. If alewives were to invade Lake Champlain, we might expect a huge impact due to thiaminase and serious setbacks for efforts to re-establish self-reproducing populations of lake trout and landlocked Atlantic salmon into the lake. Recent evidence that Lake Champlain lake trout are successfully reproducing (Ellrott and Marsden, 2004) makes this potential impact even greater. Additionally, if the Vermont Department of Fish and Wildlife begins utilizing adult trout and salmon from Lake Champlain as a source of eggs and milt for culture, mass mortalities of fry in the hatchery could be encountered, if these salmonids have an alewife-dominated diet. We would also expect impacts due to competition and predation, including declines in yellow perch, rainbow smelt, lake whitefish, and lake herring, as well as impacts on bass and walleye due to predation on their early life stages. The mooneye, a threatened fish species, is also likely to be impacted by alewives. Finally, due to the size of Lake Champlain, there is potential for alewife abundance to skyrocket and for massive die-offs similar to those seen in the Great Lakes.

In contrast, the establishment of alewives in Lake Champlain could be viewed as a benefit to the fisheries community. If alewives were to become established in Lake Champlain, the most likely event would be their replacement of rainbow smelt as the primary forage base. Although accompanying this potential impact could be decreases or even losses of other native fish species, the potential is there for alewives to provide a much larger forage base in terms of sheer biomass. Alewives are far more fecund than rainbow smelt and their reproductive potential is great. Consequently, the food availability to the major predators of Lake Champlain could be significantly increased, which in turn could support a sport fish community much larger than the current one in both numbers and economic value, similar to that of the Great Lakes. However, a major drawback to the supposed "benefit" of alewives becoming the dominant forage base is that alewife populations are almost never stable. In the Great Lakes, alewife populations fluctuate wildly year-to-year, making it very difficult for fisheries managers to correctly stock the appropriate number of salmonids, based on the forage base status. Since management requests for cultured fish are made 2 years in advance, it would be too late to modify stocking numbers, if an alewife crash were to occur between the time the request for cultured fish is made and when they are stocked. This would result in significant decreases in efficiency of hatchery operations, and losses of time and money, since large numbers of cultured fish would not survive due to the lack of food in the lake.

SECTION V

PROPOSED ACTION

PROPOSED ACTION

The goal of this report is to assess the threat posed by the alewife population in Lake St. Catherine to other Vermont waters, particularly Lake Champlain, and to evaluate the need to deal with this potential threat. Options could include 1) Public education and outreach, without direct fisheries management actions – if the threat is not perceived large enough, or other factors outweigh the threat, such as the current status of alewives in the State, time and cost involved for various alternatives, or probability of success of listed alternatives, 2) preventing the spread of alewives beyond Lake St. Catherine, 3) eliminating their presence in Vermont altogether.

Spread may occur through movement of alewives as baitfish or through illegal stocking of alewives as forage. This mechanism of spread poses an immediate threat to lakes in the vicinity of Lake St. Catherine (e.g., Lake Bomoseen), but over time also threatens more distant lakes, including Lake Champlain. The spread of alewives as baitfish has already been addressed through a revision to Regulation 106 of Vermont's Fishing and Hunting Regulations that prohibits their transportation, possession, and use as bait in Vermont (VT DFW 2002). The state of New York has similar baitfish restrictions in place within the Lake Champlain watershed. The use, or possession for use, of alewife as baitfish is prohibited in Clinton, Essex, Franklin, Warren, and Washington counties (NY DEC 1998). Human-induced spread of alewives is also currently being addressed through a public education campaign that includes press releases, newspaper and magazine articles, information pamphlets, posters in bait shops, seminars, and direct contact with anglers at fishing derbies.

Alewife spread is also possible through the natural migration of alewives out of Lake St. Catherine (see section III and Figure 1). This possible route of natural out-migration of alewives poses a direct threat to Lake Champlain. Furthermore, if alewives were to become established in Lake Champlain, other water bodies in both Vermont and New York that are accessible from Lake Champlain would become susceptible to invasion by alewives.

RATIONALE FOR THE PROPOSED ACTION

The negative impacts of alewives in landlocked, freshwater lakes have been well documented in the past (see section IV). At the present time in Vermont, impacts are restricted to Lake St. Catherine, although small numbers of larval alewives have been found immediately downstream of the dam on Lake St. Catherine. If alewives were to spread beyond the lake and become established, however, there is potential for major ecological damage to Lake Champlain and other Vermont and New York waters. Furthermore, while a variety of options currently exist to address the threat posed by alewives, management options will be much more limited if they spread further and become established (e.g., eradication would no longer be an option).

Actions to mitigate the threat posed by alewives are supported at both the state and federal levels:

State

- The 1999 Strategic Plan of the Vermont Agency of Natural Resources identifies the control and prevention of exotic nuisance species as integral to the maintenance of healthy aquatic ecosystems within the state. The plan states that programs to control and prevent nuisance exotic plants and animals should be expanded. Actions to mitigate the impact of alewives in Vermont waters are, therefore, in line with the goals laid out by the Strategic Plan for the fiscal years 1997-2000.

- The state of New York has, in the past, has attempted to take action towards removing alewives from waters within the Lake Champlain basin (e.g., Green Pond, Franklin County, NY). The New York Department of Environmental Conservation supports actions to eradicate the threat posed by Lake St. Catherine alewives (L. Nashett, New York DEC, Region 5, Ray Brook, NY, personal communication).

Federal

- The Lake Champlain Management Conference, convened in 1991 by the United States Environmental Protection Agency to develop a comprehensive long-term management plan for Lake Champlain, identifies the introduction of nuisance exotic species as an issue of high priority for lake managers (LCMC 1996). A major objective of the *Opportunities for Action* plan is to “prevent the introduction of, slow the spread of, and control, where possible and appropriate, nuisance nonnative aquatic species which currently **or potentially** may cause damage to the social or biological benefits of the Lake Champlain Basin.” Actions to mitigate the threat that alewives pose to Lake Champlain are therefore supported by the Lake Champlain management plan.

- The U.S. Fish and Wildlife Service has long been involved in the prevention, detection and monitoring of exotic fish and could be expected to provide technical assistance in controlling alewives in Lake St. Catherine in order to help prevent their spread into Lake Champlain.

    - The control of exotic invasive species has recently been made a national priority. An executive order signed by President Clinton on February 3, 1999 directs federal agencies to increase efforts to control invasive species.

SECTION VI

ALTERNATIVES

ALTERNATIVE #1 – PUBLIC EDUCATION & OUTREACH

Under this alternative, no direct fisheries management activities would be undertaken to reduce or eliminate the alewife population in Lake St. Catherine. Instead, various education and outreach measures would be implemented. These activities would take various forms including media contact through local and State newspapers and television (i.e. Champlain 2000 series), pamphlets and brochures disseminated through bait and tackle shops, VTDFW offices and fish culture stations, posters and signs at access area and boat launch kiosks, and direct contact with the public such as angler creel surveys, and public presentations (State Parks, angler clubs and groups etc).

Direct monetary costs associated with this alternative will vary depending on the type of outreach. However, considering that this alternative does not result in the immediate control, reduction, or eradication of alewives in Lake St. Catherine, there may be indirect costs associated with changes to recreational fisheries in the lake. These costs could be further exacerbated if alewives escaped to Lake Champlain.

Alternatively, some facets of the sport fishery in both Lake St. Catherine and Lake Champlain may in fact improve if alewives come to replace rainbow smelt as the primary forage species. Economic values of the sport fishery may increase due to possibly more and larger sport fish supported by an increased forage base.

Drawbacks : This alternative addresses neither the threat posed by alewives to Lake Champlain nor the impacts that alewives are expected to have in Lake St. Catherine. If alewives were to escape Lake St. Catherine and become established in Lake Champlain, the ecological impacts could be serious. Social and economic costs could be incurred as well through decreases in certain species such as rainbow smelt and the loss of their traditional fisheries. However, this loss could be overshadowed by an increase in the value of the trout and salmon fishery.

ALTERNATIVE #2 – POPULATION REDUCTION

Under this alternative, fisheries biologists would attempt to reduce the abundance of alewives in Lake St. Catherine in order to (a) reduce the impacts they will have within Lake St. Catherine, and (b) possibly reduce the risk that alewives escape the lake in large numbers. Furthermore, even if alewives manage to escape the lake, reducing the population of alewives in Lake St. Catherine may decrease the number escaping, and as a result, reduce the probability that a critical mass reaches Lake Champlain. Under this alternative, the impacts to Lake St. Catherine and the threat to Lake Champlain remain, but should theoretically be reduced. Physical (netting, water level manipulation) and biological (predation) methods for reducing the alewife population in Lake St. Catherine exist.

i. Netting Program

An aggressive netting program could be used to reduce and control the Lake St. Catherine alewife population. Netting would be carried out during the spring and summer, times when alewives inhabit inshore areas (Scott and Crossman 1973). Netting must occur regularly (i.e., every year) to be effective (Wiley and Wydoski 1993).

A number of potential capture methods are available. While seining would be difficult due to the heavy vegetation in Lake St. Catherine's littoral zone, gillnetting would be useful in capturing a schooling species such as the alewife ; however, this would probably have major impacts on non-target species. Trapping (trap nets, funnel traps) with specialized (small mesh) equipment would probably capture significant numbers of alewives, although considerable time and energy would be required to separate alewives from non-target species that would also be captured. Vermont fisheries biologists have also found electrofishing the littoral zone in spring and summer to be a successful method of capturing large numbers of alewives in Lake St. Catherine.

During the spring and summer, alewives undergo inshore movements at night (Scott and Crossman 1973). A combination of day-time trap netting and night-time electrofishing in the littoral zone for two weeks each spring (May or June) could therefore be an effective way of reducing alewife abundance in Lake St. Catherine. Two electrofishing boats, each manned by a crew of three individuals, should allow the lake to be intensively sampled during the two week period. This could be combined with netting to maximize the catch. Arrangements for the disposal of large numbers of captured alewives may be required. Disposal options include composting at a compost facility or in pits on state lands, or disposing of the fish in a landfill. If necessary arrangements for disposal containers and transport could be made with a local waste disposal company.

The annual cost of a netting program would be roughly $13,400 per year (see Section VIII for details). This does not include disposal costs that will depend on the amount of fish that is being disposed of.

Drawbacks : (1) The impacts to Lake St. Catherine remain, and the threat to Lake Champlain and other Vermont waters is not eliminated; (2) This option is labor intensive; (3) This is an ongoing, continuing alternative that would have to be carried out each year as long as alewives remain in the lake; (4) The likelihood of succesfully depressing alewife populations below a threshold level required to forestall escapement is next to zero.

ii. Biological Control (increased predation)

Fast growing populations of forage fish can be controlled by stocking sport-fish predators (Wiley and Wydoski 1993). Almost all U.S. states and Canadian provinces use predators for biological control of forage fish (Wiley and Wydoski 1993). For example, coho and chinook salmon were introduced into the Great Lakes in the mid-1960s at least in part to control alewife numbers (Mills et al. 1995).

Not all predator introductions for biological control are successful, however. Problems that may be encountered include: 1) the predator is not stocked at adequate densities, 2) the predator reduces desirable, non-target forage fish, 3) the predator becomes overpopulated and stunted, 4) the predator causes declines in other sportfish species, 5) the predator is so exploited as a sport species that it never becomes abundant or larger enough to control the targeted forage fish, and 6) the predator is ineffective as a control agent. Introduced fish can eliminate native species, reduce survival and growth rates of established species, or change the structure of the fish community (Wiley and Wydoski 1993). The ideal species therefore is one that is effective as a biological control agent and that has minimal impacts on the native fish community.

Stocking a predatory fish species into Lake St. Catherine that will consistently feed on alewives may reduce and control the alewife population. The brown trout is a salmonid species currently found in Vermont waters that consistently does well feeding on alewives (F. Brautigam and F. Kircheis, Maine Department of Inland Fisheries, Bangor, Maine, personal communication). A long-term, annual saturation stocking effort of broodstock and yearling brown trout may successfully reduce and control the alewife population in Lake St. Catherine. Chinook and coho salmon have been effectively utilized to control alewives in other waters, but these species are not currently found in Vermont and are not recommended for stocking at this time.

Brown trout were first stocked into Lake St. Catherine in 1998. This has continued annually through 2002. In addition, lake trout and rainbow trout stocking has also continued in the lake (Table 2). It is anticipated that the larger brown trout will immediately begin foraging on alewives and the smaller 1-year olds will soon attain a size conducive to preying on them as well. Although the effectiveness of this biological control has not yet been evaluated, a similar stocking regime could be continued or increased in the future to control alewife abundance.

A biological control program using brown trout will likely not have any costs associated with it on top of the costs of the current state of Vermont stocking program. It is achieved by simply shifting the existing stocking regime, for example, to more brown trout and less rainbow trout (as was done in 1999). If a decision is made to increase the stocking effort over 1999 levels, this will likely be done by reallocating fish destined for other water bodies and therefore should not represent increased costs.

Drawbacks : (1) The impacts to Lake St. Catherine remain, and the threat to Lake Champlain and other Vermont waters is not eliminated ; (2) The impact that increased predation will have on native, non-target species is unknown ; (3) Stocking will have to be continued as along as alewives remain. If predation pressure is once again decreased, alewives will likely quickly rebound to high levels ; (4) It is unlikely that the addition of brown trout to Lake St. Catherine will significantly increase predation on alewives to the point where their abundance is appreciably reduced ; (5) A good fishery for brown trout may develop in Lake St. Catherine, possibly resulting in public pressure to stock alewives for forage in other Vermont lakes. At the very least, anglers may consider alewives to be a good addition to a lake because of their prolific numbers.

Table 2. Lake St. Catherine stocking history.

Year	Brown Trout		Rainbow Trout		Lake Trout	
	No.	Avg. Length	No.	Avg. Length	No.	Avg. Length
1998	2,000	8.9”	2,000	10.2”	485	8.5”
	500	13.0”				
1999	3,100	8.8”	2,200	10.4”	800	7.3”
	500	12.1”	240	20”		
	500	20”				
2000	2,000	9.6”	1,000	10.75”	800	9.0”
	1,000	20.0”				
2001	4,000	7.8”	1,000	10.2”	800	8.3”
	1,000	20”				
2002	2,000	9.0”	1,000	11.2”	800	7.9”
2003	2,000	8.0”	1,000	10.0”	0	n/a
	5,738	5.0”				
	92	15.0”				

iii. Water Level Manipulation (forced winter-kill)

Alewives are known to be particularly sensitive to extreme cold water conditions in winter and massive die-offs in the Great Lakes have been linked to abnormally cold winter conditions (Graham 1956, Colby 1973, Eck and Brown 1985). Lowering the water level of a lake in late summer or fall may provide conditions for winterkill (Wiley and Wydoski 1993). Decreasing the water level in Lake St. Catherine prior to winter so that there is no reverse stratification and hence no warm water refugia, could result in increased overwinter mortality and depress the alewife population in the lake.

Drawbacks : (1) The dam structure on Little Pond is not suitable for drawing down the main basin of Lake St. Catherine sufficiently enough to force a winter kill. Other methods would be required such as pumping water out of the lake ; (2) Massive drawdowns such as this would have significant impacts on other species in the lake. The Vermont Department of Fish and Wildlife has previously spoken out against winter draw downs as a means of controlling Eurasian watermilfoil, since non-target fish species and other littoral zone organisms (plants, amphibians, crustaceans) may be negatively impacted in a draw-down.

ALTERNATIVE #3 - CONTAINMENT

This alternative involves measures to prevent alewives from migrating out of Lake St. Catherine via the Little Pond outflow. Possible containment methods include the use of acoustic, electrical, or physical barriers at the outflow. This alternative diminishes the threat which alewives pose to Lake Champlain, but does not address the impacts to Lake St. Catherine.

The Vermont Department of Fish and Wildlife has attempted to address the issue of overland transport of alewives (e.g., bait bucket, illegal stocking) through baitfish restrictions and public education (see Section V). The success of this campaign will depend on the public's knowledge and understanding of the issue, and compliance with the law.

i. Acoustic Barrier (High Frequency Sound)

The members of the herring family, including alewives, are capable of perceiving acoustic stimuli (Haymes and Patrick 1986) and have the ability to detect high-frequency sound and determine its direction (Nestler et al. 1992). There is evidence that alewives can detect and will avoid low- and high-frequency sound (Haymes and Patrick 1986, Dunning et al. 1992, Ross et al. 1993). The reasons why alewives are deterred by acoustic signals is not clear, but Richard (1968) suggested that pulsed low-frequency sounds mimicked hydrodynamic disturbances associated with active predation. Ross et al. (1993) suggested that the response to high frequency sound probably did not involve hearing, but rather was due to cavitation or resonance.

Several studies have examined the utility of low- and high-frequency acoustic systems in keeping alewives away from water intake pipes. In one study, high frequency broadband sound decreased the number of alewives impinged on water intake screens by as much as 87% and the density of alewives near the intakes by as much as 96% (Ross et al. 1993). Another study demonstrated that low frequency, high amplitude sound produced by pneumatic poppers effectively repelled alewives from the intake of a power generating facility (Haymes and Patrick 1986). The number of alewives entering an experimental structure was reduced by 71-99% when the poppers were operating.

An acoustic deterrent system could be used at Lake St. Catherine's outflow to keep alewives away, thereby decreasing the chance that they enter the outflow stream. High frequency sound may be most effective as clupeids may not respond consistently to low frequency sound (Dunning et al. 1992). As well, the system used to produce high frequency sound is much smaller and cheaper than that used to produce low frequency sound (Ross et al. 1993). The entire width of the outflow dam (87 feet) would have to be covered by the system, which consists of transducers in the water (which transmit the sound) connected by surface cables to amplifiers on land (which produce and amplify the sound). The transducers would ideally be situated every 10-15 feet along the face of the dam. The cost of installing a high frequency sound deterrent system would be approximately $52,000 and annual operating costs (electricity) would be roughly $3,500 per year (see Section VIII for details).

Drawbacks : (1) This alternative does nothing to address the impacts to Lake St. Catherine ; (2) High frequency sound does not deter all alewives (none of the studies achieved 100% exclusion) ; (3) Passively drifting eggs or larvae are not repelled ; (4) Alewives of all life stages may be swept past the acoustic array during high water events ; (5) Fish eventually habituate to high frequency sound and are no longer deterred (Dunning et al. 1992, Nestler et al. 1992). Acoustic systems are most effective in situations where contact with the system is short, for example, as a guidance system for migrating fish (D. Smith, Smith-Root Inc., Vancouver, WA, personal communication); and (6) The water depths in Little Pond and the channel leading up to the dam appear to be too shallow for effective deployment of high frequency sound transducers. Sufficient depth (approximately 20 feet) is required to prevent the transducers from cavitating (B. Janda, Sonalysts Inc., Waterford, CT, personal communication) ; (7) The construction of such a barrier would require the annexing of land and homes along the canal from Little Pond to the dam in order to erect generating buildings and 15-foot high fences for public safety.

ii. Electrical Barrier

Electrical barriers have been used to block fish movements in a wide variety of circumstances and have been used since the 1950s to reduce entrainment at hydropower projects (Barwick and Miller 1996). Barwick and Miller (1996) tested a graduated field electrical barrier, in which the voltage increases from one end of the barrier to the other. They found that the barrier restricted the movement of a number of fish species (including gizzard shad, a close relative of the alewife) in a test channel, and that the effectiveness compared favorably to results of studies using low and high-frequency sound. Effectiveness of electrical barriers tends to be 90% or better, and in some situations 100% repulsion may be achieved (D. Smith, Smith-Root Inc., Vancouver, WA, personal communication).

The electrical barrier consists of an electric current passing between submersed electrodes, producing an electric field in the water. Fish swimming into the field become part of the electrical circuit with some of the current flowing through their body, evoking reactions ranging from a slight twitch to full paralysis, depending on the current level and shock duration. An electrical barrier with a field of at least 1.5 volts/cm is needed to provide effective blockage of fish (Barwick and Miller 1996).

An electrical field could be placed upstream of the Mill Brook outflow dam to affect fish before they enter the flow of water spilling over the dam and out of the lake. The electrical array is effective to depths of approximately 12 feet and would consist of about 6 electrodes across the bottom, spaced 3 feet apart, each with an accompanying pulse generator on land. The electrodes are fixed into an insulating medium on the stream bottom and the electrical field which is generated is graduated, becoming increasingly intense further into the field. As fish advance into the graduated field, they feel an increasingly unpleasant sensation. When the sensation is too great, they are unable to advance any further and swim in the opposite direction from the increasing electrical current. The cost of an electrical barrier system would range from approximately $50,000-$100,000 and annual operating costs (electricity) would be roughly $2,250 per year (see Section VIII for details).

A barrier design incorporating two electrical zones is currently being used to block the movement of Lake Michigan round gobies through the Illinois-Michigan canal to the Mississippi River drainage basin. The system consists of a ‘repulse’ zone followed by a ‘kill’ zone to take care of fish that manage to get through the first zone (E. Marsden, University of Vermont, Burlington, VT, personal communication). A similar system could be quite successful at the Lake St. Catherine outflow. However, the numerous residences located on the outflow channel in the vicinity of the outflow dam raises public safety issues.

Drawbacks : (1) The electrical barrier does nothing to address the impacts to Lake St. Catherine itself ; (2) Passively drifting eggs or larvae will not be repelled ; (3) Alewives of all life stages may be swept quickly through the electrical field during high water events, and therefore may not be exposed to the electricity long enough for an effective kill ; (4) There are public safety concerns due to the presence of residences along the outflow channel. Humans are also at risk of injury and even death with exposure to such electrical currents ; (5) The construction of such a barrier would require the annexing of land and homes along the canal from Little Pond to the dam in order to erect generating buildings and 15-foot high fences for public safety. This would greatly increase the monetary and human impact costs of this alternative.

iii. Physical Barrier

This option entails the use of a physical barrier to impede the movement of alewives over the Mill Brook outflow dam. Fish screens are used to keep fish out of particular reaches of streams, but little is known about the fundamental design needs to make them perform efficiently (Wiley and Wydoski 1993). In August 1999, a molecular polyethylene screen was installed across the spillway of Highline Lake to keep non-native largemouth from migrating downstream to the Colorado River (P. Martinez, Colorado Department of Natural Resources, Division of Wildlife, personal communication). A barrier could be situated directly upstream of the outflow dam or, alternatively, downstream of the dam at the opening of the culverts that direct Mill Brook under Lake Hill Road (see Figure 2).

A major requirement of a potential alewife barrier is the ability to block the passage of passively drifting eggs and larvae, which may present the greatest threat of escape. Barrier technologies exist that can theoretically meet this requirement, including steel mesh screens, vertical bar screens, and permeable dyke structures. However, high maintenance costs and decreased water flow are associated with the narrowly spaced openings required to do this, and it may, therefore, not be feasible to use these barriers to block eggs and larvae. A detailed analysis to determine the appropriate barrier technology is beyond the scope of this report, but a brief description of potential barrier types is provided here. A more detailed investigation will most likely be required if a physical barrier is the chosen alternative.

Vertical Bar Screen - Composed of parallel, vertical bars spaced at equal distances from each other. The distance between bars determines the size of fish that is blocked. This type of screen is generally more useful for larger fish because the close spacing of bars required to block smaller fish (and life stages) leads to problems of fouling by debris and unacceptable flow restrictions (US COE 1998). For example, 0.5-inch diameter bars spaced 0.5-inches apart would block fish 3.5-inches and longer (US COE 1998). This screen is therefore not feasible for blocking eggs and larvae.

Mesh Screen - Woven mesh screens are constructed of wire with square openings between the meshes. Various designs exist and the size of the mesh and the mesh material can be adapted for the types of fish to be excluded. For example a 0.1-inch opening can exclude 1-inch salmon fry (US COE 1998). In Tasmania, Australia, inclined screens constructed of 1.1 mm stainless steel mesh supported by load bearing gates are currently being used to contain European carp (J. Diggle, Tasmania Inland Fisheries Commission, personal communication). This screen requires daily cleaning and would not be able to screen out alewife eggs (which are < 1 mm diameter) and larvae. The U.S. Bureau of Reclamation has developed a downstream fish screen which is able to screen out all fish, eggs, and larvae. It was designed with emphasis on Utah chub, rainbow smelt, carp, and gizzard shad (whose eggs are similar in size to those of the alewife). However, the screen is extremely expensive to construct and maintain (G. Gould, U.S. Bureau of Reclamation, Lower Colorado Region, personal communication).

Permeable Dyke Structure – A permeable dyke is currently being designed and tested by the U.S. Bureau of Reclamation for use on the lower Colorado River (G. Gould, U.S. Bureau of Reclamation, Lower Colorado Region, personal communication). It allows water to flow through it, while blocking the movement of fish, including eggs and larvae. The barrier is composed of a layer of random riprap through which water flows on the bottom and a non-permeable compacted fill layer on top. Initial results of testing have been positive. A major drawback, however, is that this barrier does not easily accommodate high water flows.

The cost of installing and maintaining a physical barrier at the outflow varies considerably, depending on the barrier type. Design and installation of a physical barrier could easily cost as much as $250,000 and maintenance would run approximately $18,000 per year (see Section VIII for details).

Drawbacks : (1) This alternative does nothing to address the impacts to Lake St. Catherine itself; (2) Physical barriers with the ability to block eggs and larvae are very expensive to construct and are labor intensive as continual cleaning (of entrained fish, leaves, woody debris, etc.) and maintenance are required. Additional full-time positions would be required who's for barrier maintenance. This would be required 24 hours per day during high water events ; (3) Blockage of these fine-mesh screens would result in severe upstream flooding, which could be serious since both banks of the canal leading from Little Pond to the dam are lined with year-round camps and homes ; (4) The construction of such a barrier would require the annexing of land and homes along the canal from Little Pond to the dam to accommodate periodic flooding during certain times of the year. This would greatly increase the monetary and human impact costs of this alternative.

ALTERNATIVE #4 – RECLAMATION

Reclamation involves chemically treating Lake St. Catherine to remove 100% of the alewives in the lake. Two chemicals, rotenone and antimycin, are currently approved for general fishery uses by the United States Environmental Protection Agency (Sousa et al. 1987b, Wiley and Widoski 1993).

Rotenone is the most commonly used fish toxicant in the United States (Wiley and Wydoski 1993). It is a natural plant substance found in the roots of several tropical plants, including jewel vine or flame tree, lancepod, and hoard pea (Sousa et al. 1987). It has been used for thousands of years by South American natives to catch fish and has been used in the United States for fish management purposes since 1934 (Sousa et al. 1987, Wiley and Wydoski 1993). It is a fully registered fish toxicant (although not currently in Vermont) that can be applied to non-food fish ; the applicator must consult with state and federal fish and wildlife agencies and obtain a suitable permit (Marking 1992).

Rotenone disrupts the process of cellular respiration, which results in physiological suffocation (Bradbury 1986, Wiley and Wydoski 1993). It is therefore toxic to all oxygen breathing organisms. All organisms possess natural enzymes that detoxify sub-lethal amounts of rotenone (Bradbury 1986). Organisms differ greatly in how easily they absorb or degrade rotenone, which results in major differences in susceptibility (Bradbury 1986). Fish tend to be much more sensitive to rotenone than other organisms because they absorb rotenone efficiently through the gills (Bradbury 1986). Thus, at the dosages generally used for fishery purposes (typically 0.5-1.5 ppm), rotenone does not affect most non-target organisms, although some organisms, namely zooplankton and benthic invertebrates, will be mildly impacted (Bettoli and Maceina 1996). Sensitivity to rotenone also varies considerably among fish species, with gar, catfish, bullhead, and bowfin being most resistant while gizzard shad (a close relative of the alewife), walleye, pike, and trout are more sensitive (Sousa et al. 1987b, Bettoli and Maceina 1996).

Rotenone is relatively non-toxic to birds and mammals, does not kill fertilized fish eggs (Wiley and Wydoski 1993), and has no effect on phytoplankton (Bradbury 1986, Harig and Bain 1995). Insects, molluscs and crayfish are generally less sensitive to rotenone than fish (Chandler and Marking 1982). Zooplankton are often eliminated immediately after a rotenone treatment, but populations usually rebound quickly (Harig and Bain 1995, Bettoli and Maceina 1996) ; 95-100% of zooplankton are killed in open water areas, but in shallow, weedy areas where rotenone is quickly detoxified zooplankton may show survival up to 30% and undergo quick recovery to pre-rotenone levels within 10 weeks (Bradbury 1986). Most adult amphibians and reptiles should not be killed when rotenone is applied at normal concentrations (Farringer 1972), however some turtle species may succumb to rotenone (Fontenot et al. 1994) and tadpoles and metamorphosing amphibians are vulnerable to concentrations as low as 0.1 mg/L (Hamilton 1941).

Bradbury (1986) claims that impacts on benthic invertebrates are mild ; rotenone concentrations of 0.5-1.0 ppm appeared to have little effect on oligochetes, dipterans, caddisflies, damselflies, and midge larvae, but leeches and snails showed high mortalities. Harig and Bain (1995) reported that benthic invertebrates were virtually exterminated from rotenone treated Adirondack lakes and required an entire year to re-establish themselves. Benthic mortalities are mitigated somewhat, however, by the presence of submerged aquatic vegetation and by extensive bottom sediments which provide shelter for benthic organisms (Melville 1989).

Rotenone is most toxic in warm, acidic, clear waters with little vegetation. In Lake St. Catherine, where a large portion of the system is infested with dense stands of Eurasian watermilfoil, a 100% successful rotenone reclamation would be difficult, if not impossible (AFS Rotenone Working Group,

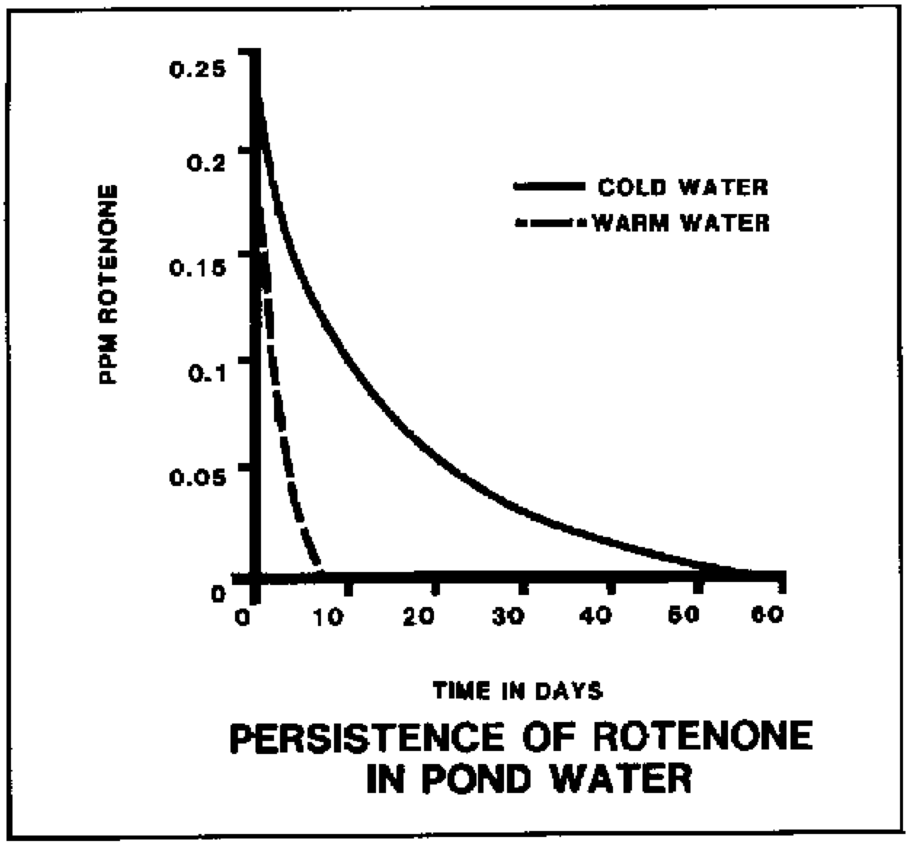

Figure 8. Persistence of rotenone in cold and warm pond water (from Sousa et. al 1987b).

AFS National Meeting, St. Louis, MO, August 2000, personal communication). Dense stands of aquatic vegetation interferes with rotenone's ability to properly mix top-to-bottom and cause a 100% kill. Dense stands of aquatic vegetation would serve as a refuge for fish, since those areas would not contain the appropriate concentrations of rotenone required for a successful reclamation (Rowe 2003). In most instances, rotenone is relatively unstable and persistence varies mainly with temperature (see Figure 8), but also with light, dissolved oxygen, turbidity and alkalinity (Wiley and Wydoski 1993). Detoxification takes longer in colder, acidic, low light, low oxygen, clear, deep, stratified waters. Above 23^{o}C, the half-life of rotenone in water is less than 1 day and concentrations in sediments normally fall to below detectable limits within 24 hours (Gilderhus et al. 1988). At 7^{o}C toxicity may last for 33 days (Sousa et al. 1987b).

Antimycin is an antibiotic produced by a mold (Bettoli and Maceina 1996) and was first used as a piscicide in 1963 (Wiley and Wydoski 1993). As with rotenone, antimycin works by interfering with cellular respiration. Sensitivity varies considerably among organisms ; fish are generally more sensitive to antimycin than most other organisms because they absorb it through the gills (Wiley and Wydoski 1993). Sensitivity also varies among fish species, with yellow perch, gizzard shad, and white sucker being most sensitive (Marking 1992). Antimycin is more toxic to fish than rotenone (Bettoli and Maceina 1996) and will kill fertilized fish eggs (Wiley and Wydoski 1993). Toxicity does not vary much with temperature, but it is much less toxic and persistent in alkaline (pH > 8) and turbid waters (Lee et al. 1971). The half life of antimycin in water is 310 hours at pH 6.5, 120 hours at pH 7.5, 46 hours at pH 8.5, and 4.6 hours at pH 9.5 (Marking 1992). As with rotenone, antimycin generally exhibits low toxicity to mammals (Bettoli and Maceina 1996).

The costs of the two toxicants are comparable (Bettoli and Maceina 1996) and the degradation products of both are non-toxic. However, antimycin is less commonly used than rotenone because of limited availability (Wiley and Wydoski 1993). Fish are able to detect and possibly avoid rotenone, whereas antimycin does not elicit an avoidance response. Antimycin is therefore preferred in some situations, for example, stream treatments (Bettoli and Maceina 1996). As well, antimycin oxidizes faster than rotenone (Bettoli and Maceina 1996) and detoxification is not affected by temperature, potentially making it preferable for fall (i.e., colder water) treatments.

Ideally, if a reclamation of Lake St. Catherine is conducted, it would be carried out during the fall. Treating the lake during fall turnover, when lake waters are mixing, ensures that deeper areas of the lake are fully exposed to the treatment. As well, an early fall treatment ensures that waters will completely detoxify before fall turnover is complete, due to high oxygen levels, whereas a late fall treatment could result in water toxic to fish until spring turnover (NY DEC 1996). Furthermore, a fall treatment is ideal since at that time usage of the lake is minimal and many seasonal residents are absent. Due to the special and difficult circumstances in Lake St. Catherine (multiple basins, dense stands of Eurasian watermilfoil, marshy shorelines, spring upwelling), the AFS Rotenone Working Group recommended that if a rotenone reclamation was pursued, a late fall treatment just before ice-up would give the best chance of success (AFS National Meeting, August 2000, personal communication). Treating just before ice-up would essentially "lock-in" the rotenone for the entire winter, causing the water to remain toxic for several months, ensuring rotenone-exposure of all fish. Rotenone would break down rapidly in the spring when the water is exposed to sunlight and warm temperatures. Although having the lake remain toxic for the length of the winter would increase the chances of successfully eliminating all fish, there are a couple of obstacles to this strategy. First, year-round residents would need alternative water sources for domestic use for a long period of time which could be expensive and logistically difficult to arrange. Additionally, the outflow of Lake St. Catherine would have to be continuously monitoring for flow and a potassium permangenate drip would have to be adjusted and administered continuously for detoxify downstream waters. Again, this would be expensive and logistically difficult to manage.

The treatment of Lake St. Catherine would require approximately 130,000 pounds of powdered rotenone to achieve a 1.5 ppm treatment (see Section VIII for calculations – these are rough estimates ; more accurate and detailed information about lake volume, tributary sizes, expected water temperatures, and outflow velocities would be required in making final calculations ; as well, a detailed survey of Lake St. Catherine's watershed would have to be performed to identify all tributaries and springs feeding the lake).

The rotenone powder would be mixed with water into a slurry by mixing crews on shore. The slurry would then be loaded onto boats and applied to the lake with aspirators (sprayers). Each boat would be able to apply up to 10,000 pounds of rotenone each day (B. Spateholts, Utah Department of Natural Resources, Division of Wildlife Resources, personal communication). As well, tributaries would need to be treated using hand-held sprayers, and the heavily vegetated, marshy areas in Little and Lilly Ponds would most likely have to be treated with liquid rotenone which contains an emulsifying carrier that helps it dissolve into thick vegetation. To ensure that waters downstream of the lake are not affected by toxic outflow, the outflow of the lake would have to be detoxified using potassium permangenate drip stations for approximately 2 weeks after treatment (or as long as the lake is toxic).

The lake would be replenished with fish the spring following the rotenone treatment. Warmwater species (bass, pike, sunfish, minnows, etc.) would likely be captured from nearby lakes which are physically and biologically similar to Lake St. Catherine ; coldwater species (brown, rainbow, and lake trout) would be stocked via the existing spring trout stocking regime ; and rainbow smelt would likely be re-introduced to the lake by transferring eggs from another lake. Fishing on the lake would likely need to be closed (or at least restricted, e.g., catch and release only) for a period of time after re-stocking. The duration of such restrictions would have to be determined, but would likely last for at least one season. Other measures may need to be taken in order to mitigate the impact of the reclamation on landowners, including the removal and disposal of dead fish during the toxic period and supply of alternate water sources or charcoal filters for water lines.

If maintaining genetic diversity of the Lake St. Catherine fish community is a concern, extensive netting of the native fish species in the lake could be conducted for several weeks prior to the treatment and these fish restocked into the lake. As many fish as possible of each species would be captured in an attempt to maintain the natural genetic diversity within the lake. Fish would be captured by any of a number of methods, including electrofishing, gillnetting, seining, and trap netting. Holding these fish during the lake's toxic period is an issue that would need to be worked out ; the use of state or federal hatchery facilities is complicated due to disease issues.

The cost of reclaiming and restocking Lake St. Catherine would be approximately $347,000 (see Section VIII for details).

Drawbacks : (1) Reclamation impacts non-target fish and invertebrate species ; (2) Reclamation is a very expensive and technically-demanding procedure ; (3) Success rates for reclamations are rarely 100% (Sousa et al. 1987b) and unless a 99%+ kill is achieved, treatment would be required again in just a few years ; (4) There is no guarantee that alewives will not be re-introduced again to Lake St. Catherine or other waters of Vermont, or migrate naturally via the Champlain Barge Canal and become established in Lake Champlain at some point in the future, making a long and expensive rotenone reclamation of Lake St. Catherine ultimately ineffectual.

Cumulative Effects of Multiple Approaches

There is the possibility that while the alternatives reviewed here may not be feasible as stand-alone options, a combination of multiple approaches may increase the probability of success in the management of alewives in Lake St. Catherine. Additionally, technology is constantly and rapidly changing, and at some point in the future, the technology may exist to implement an alternative that would be considered successful - particularly in the case of Alternative #3 – Containment.

However, in the interest of time, and for the purposes of this report, additive or cumulative effects of multiple action implementation, or prospective future technological advancements were not reviewed or considered.

Other Pertinent Research Activities

A group of researchers are currently investigating the Hudson and Champlain Barge Canal system as a potential vector of aquatic nuisance species. The group's Principal Investigators are : Mark Malchoff (Lake Champlain Sea Grant), J. Ellen Marsden (University of Vermont), Michael Hauser (Vermont Dept. Environmental Conservation), Ellen Fitzpatrick (SUNY Plattsburg), and William Howland (Lake Champlain Basin Program).

The goal of the group is to provide decision makers with a sound analysis of the benefits and risks associated with various aquatic nuisance species barriers and/or procedures that could be retrofitted to/implemented in the Champlain Barge Canal. Specifically, the objectives are as follows:

1. Document the impact of ANS (via Champlain Canal) introductions in Lake Champlain to date, and conduct a threat assessment of future introductions likely to occur in the absence of any physical/procedural changes in the canal structures and/or operations.

2. Develop recommendations relating to possible canal barrier solutions integrating community and technical expertise through interviews, economic and financial analyses, and a modified Delphi decision making process.

The groups' efforts are focused the Champlain Barge Canal between locks 8 and 9, which is the height of land on the canal and therefore would be the easiest place to install a barrier. Unfortunately, a barrier constructed at this location would not prevent alewives escaping Lake St. Catherine via the Mettawee River from entering Lake Champlain, as the Mettawee enters the Champlain Barge Canal close to Lock 12, in Whitehall, NY. However, this project could potentially prevent other alewife populations from invading Lake Champlain via the Hudson canal. This is the suspected source of blueback herring, which have become established in Lake Champlain in recent years.

Table 3. Comparison of the impacts of the alternatives considered in this report.

Impact	Alternative 1 Public Education/Outreach	Alternative 2 Population Reduction	Alternative 3 Containment	Alternative 4 Reclamation
BIOLOGICAL				
On the abundance of alewives in Lake St. Catherine	*Alewife abundance may continue to increase or at least will likely remain at current high levels. The risk of spread will always be present.*	*Alewife abundance may be reduced, although the level of reduction may be insignificant or insufficient to lower the risk of spread.*	*Alewife abundance may continue to increase or at least will likely remain at current high levels. The risk of spread is not eliminated.*	*Alewives may be completely eradicated; if the reclamation is not 100% successful, alewife abundance will be reduced considerably, but will likely recover in a few years.*
On native species in Lake St. Catherine	*Native fish and plankton species will continue to be impacted by the presence of alewives.*	*Alewife impacts on native fish and plankton species may be reduced, but not eliminated.*	*Native fish and plankton species may continue to be impacted by the presence of alewives.*	*Alewife impacts on native fish and plankton species may be eliminated; if the reclamation is not 100% successful, impacts will be reduced. The reclamation may temporarily impact non-target fish, zooplankton and benthic invertebrate species, but these will be expected to recover on their own.*
On biodiversity in Lake St. Catherine	*The introduction of exotic species to a system generally results in decreased biodiversity. Biodiversity in Lake St. Catherine is therefore expected to decrease through the loss of native fish and plankton species, since alewife abundance will remain high.*	*Since alewife abundance will be decreased, biodiversity should be impacted less than under alternatives 1 and 3.*	*Biodiversity in Lake St. Catherine is expected to decrease through the loss of native fish and plankton species, since alewife abundance will remain high.*	*Successful reclamation followed by restocking of native fish species and natural re-colonization by benthic invertebrates, amphibians, reptiles, birds, and mammals will re-establish biodiversity.*

Table 3. Cont'd.

Impact	Alternative 1 Public Education/Outreach	Alternative 2 Population Reduction	Alternative 3 Containment	Alternative 4 Reclamation
BIOLOGICAL (cont'd)				
On native species in Lake Champlain	*The risk of Lake St. Catherine alewives spreading is not addressed and the threat they pose to Lake Champlain's native fish and plankton species remains. Large Lake Champlain predators may initially benefit from the abundance of forage provided by alewives if they became established.*	*The risk of Lake St. Catherine alewives spreading and the threat they pose to Lake Champlain's native fish and plankton species remain, but should be reduced. Large Lake Champlain predators may initially benefit from the abundance of forage provided by alewives if they became established.*	*No containment method will sufficiently block all life stages and the threat of angler-induced spread remains. Thus, the risk of spread and the threat posed by Lake St. Catherine alewives to Lake Champlain's native fish and plankton species remains, but should be reduced.*	*The risk of spread and the threat posed by Lake St. Catherine alewives to Lake Champlain's native fish and plankton species would be eliminated; if the reclamation is not 100% successful, the threat remains, but should be reduced for a few years ; Alewives would re-build their populations quickly.*
ECONOMIC				
On the recreational fishery in Lake St. Catherine	*Alewife impacts to the lake's fish populations are not addressed and a depression of the lake's recreational fisheries may be expected to eventually occur. Initially, large predators will enjoy increased growth through the abundance of forage, and as a result, anglers will enjoy larger game fish. Impacts to larval and juvenile fish reducing recruitment will eventually detrimentally impact the recreational fishery.*	*Alewife impacts to the lake's fish populations are reduced and impacts to the lake's recreational fishery should therefore be lessened. Additionally, the addition of brown trout as an alewife-control predator will provide a new and mostly likely, abundant fishery for anglers in Lake St. Catherine.*	*Alewife impacts to the lake's fish populations are not addressed and a depression of the lake's recreational fisheries may be expected over time.*	*The reclamation itself will temporarily eliminate the lake's recreational fishery. However, after the eradication of the alewife, native fish will be restocked and the recreational fishery is expected to recover with time. If the reclamation is not 100% successful, alewife populations will be reduced and impacts on the recreational fisheries should be lessened after the lake's ecosystem recovers from the reclamation.*

Table 3. Cont'd.

Impact	**Alternative 1 Public Education/Outreach**	**Alternative 2 Population Reduction**	**Alternative 3 Containment**	**Alternative 4 Reclamation**
ECONOMIC (cont'd)				
On the recreational fishery in Lake Champlain	*The risk of spread is not addressed and the threat of alewives invading Lake Champlain remains. There is a potential for major impacts to the multi-million dollar recreational fishery of Lake Champlain, impacting past investment in the salmon and lake trout restoration program. Conversely, alewives may provide a more abundant forage base than currently provided by rainbow smelt, and the recreational fishery may actually improve for some species.*	*The risk of spread is decreased and the threat to Lake Champlain's recreational fishery is reduced, but remains.*	*The risk of spread is decreased and the threat to Lake Champlain's recreational fishery is reduced, but remains.*	*The threat to Lake Champlain's recreational fishery is eliminated; if the reclamation is not 100% successful, the risk of spread is decreased and the threat to Lake Champlain's recreational fishery is reduced, but remains.*

Table 3. Cont'd.

Impact	Alternative 1 Public Education/Outreach	Alternative 2 Population Reduction	Alternative 3 Containment	Alternative 4 Reclamation
ECONOMIC (cont'd)				
Health risks and clean-up costs	*Alewife abundance remains high and periodic mass mortality events are expected. There may be public health concerns and clean-up costs as a result of large numbers of decaying fish following spring and summer mortality events. The spread of alewives to Lake Champlain would tremendously elevate associated clean-up costs and health risks.*	*Alewife abundance is controlled, lessening the probability and severity of mortality events and resulting in decreased human health risks and clean-up costs.*	*Alewife abundance remains high and periodic mass mortality events are expected. There may be public health concerns and clean-up costs as a result of large numbers of decomposing fish washing up on shore following spring and summer mortality events.*	*Alewives may be eradicated from the lake, eliminating health risks and costs from with die-offs. If reclamation is not 100% successful, alewife numbers will be reduced, lessening the probability and severity of mortality events, resulting in decreased health risks and clean-up costs. While the reclamation uses toxic chemicals, water use restrictions, water quality monitoring and outflow detoxification will assure public safety. At the concentrations used, a 132 lb human would have to consume over 15,850 gallons of treated water in one sitting to receive a lethal dose.*

Table 3. Cont'd.

Impact	Alternative 1 Public Education/Outreach	Alternative 2 Population Reduction	Alternative 3 Containment	Alternative 4 Reclamation
SOCIO-CULTURAL				
Angler groups	*Angler groups and others would become more aware of the risks associated with Aquatic Nuisance Species. Some anglers oppose this single approach alternative because it does not address the problem at hand.*	*Some anglers support this alternative in combination with some means of containment.*	*Anglers support this alternative, but would more strongly support this alternative in combination with a form of population reduction.*	*Most anglers support this alternative, but some oppose it, calling it an extreme measure with too much of an impact on other humans and other species.*
Lake St. Catherine riparian landowners and recreational users	*Most landowners are not concerned about the alewife presence in Lake St. Catherine and it's potential problems there and elsewhere, calling it a "non-issue".*	*Would likely support this alternative since it does not directly impact their "way of life" and may even provide a strong brown trout fishery.*	*Would likely not support this alternative on its own since the construction of any kind of barrier system will result in the purchasing of land and the eviction of people from homes near the dam. Electric barriers may pose a risk to human health ; physical barriers may pose a risk of flooding.*	*Some landowners have supported this alternative while others have not supported it because of the associated temporary restrictions on lake usage and human health concerns.*
Lake Champlain riparian landowners and recreational users	*Would likely not support this alternative as a stand-alone option because it does nothing to address the risk of Lake St. Catherine alewives invading Lake Champlain.*	*Would likely not support this alternative on its own as it does not directly address the risk of Lake St. Catherine alewives invading Lake Champlain, but would likely support it in combination with alternative 3.*	*Would likely support this alternative as it reduced the threat which Lake St. Catherine alewives pose to Lake Champlain.*	*Would likely strongly support this alternative because it eliminates, or at least reduces, the threat posed by Lake St. Catherine alewives to Lake Champlain.*
General public	*Very little input from the general public has been received. Oureach efforts could be targeted to non-angling groups.*	*Very little input from the general public has been received.*	*Very little input from the general public has been received.*	*Very little input from the general public has been received.*

Table 3. Cont'd.

Impact	Alternative 1 Public Education/Outreach	Alternative 2 Population Reduction	Alternative 3 Containment	Alternative 4 Reclamation
PHYSICAL				
On air	*Alewife abundance will likely remain high in Lake St. Catherine and potentially Lake Champlain ; air quality may be impacted by odors following periodic spring and summer mortality events.*	*Alewife abundance may be controlled, lessening the probability and severity of mortality events, and reducing impacts to air quality through undesirable odors..*	*Alewife abundance will likely remain high in Lake St. Catherine and air quality may be impacted by airborne odors following periodic spring and summer mortality events.*	*Although it is possible for powdered rotenone to become airborne during mixing, proper handling and application procedures will ensure no impact of the reclamation on air quality, and will eliminate the potential alewife die-offs, removing any odor impacts.*
On water	*Alewife abundance will remain high and water quality of Lake St. Catherine and Lake Champlain (if alewives spread) may be impacted periodically during spring and summer mortality events. As well, increased algal blooms due to alewife-induced reductions in zooplankton size and abundance may be expected.*	*Alewife abundance would be controlled, lessening the chance and severity of mortality events, lessening the impact of alewives on plankton, and therefore reducing impacts on water quality.*	*Alewife abundance will remain high in Lake St. Catherine and water quality may be impacted by periodic spring and summer mortality events. As well, increased algal blooms due to alewife-induced reductions in zooplankton size and abundance may be expected.*	*The reclamation itself will temporarily result in lake water toxic to all dissolved-oxygen breathing organisms. However, rotenone breaks down rapidly (at warm water temperatures and sunlight) to non-toxic products and proper detoxification of the outflow will ensure that downstream waters are not affected by toxic lake waters. It is unlikely that rotenone would enter groundwater because it strongly binds to organic matter in the soil.*
On soil	*N/A*	*N/A*	*N/A*	*Rotenone will leach into most soils to a depth of only 2 cm and a maximum of 8 cm in sandy soils. It breaks down rapidly to non-toxic products, leaving no traces in the soil.*

SECTION VII

CASE STUDIES

Numerous landlocked alewife populations have formed in the United States either through purposeful stocking, accidental introductions, or natural invasion by anadromous populations (Fuller 1999). Several cases are well documented and provide valuable insights and lessons into the various ways of dealing with non-indigenous alewives.

Green Pond, Franklin County, New York

-similar to the Lake St. Catherine situation in that it is a proposed reclamation to remove an alewife population located within the Lake Champlain watershed and in that there are landowner issues complicating the situation

Green Pond is a 26 hectare (64 acres) lake located in the town of Santa Clara in Franklin County, New York. The lake is spring fed and has no outlet (NYDEC 1996). Approximately half of the lake's shoreline is publicly owned, while the other half is privately owned by 22 landowners. Alewives were intentionally introduced into the pond in 1957 and 1959 to serve as forage for splake, which are stocked on an annual basis. This is the only population of alewives known to exist within the Lake Champlain watershed in the state of New York. The New York Department of Environmental Conservation (NY DEC), therefore, decided to reclaim Green Pond using rotenone in order to eliminate alewives from the Lake Champlain watershed. In August 1994, the first of a series of letters proposing the reclamation of Green Pond were sent to riparian users. Public meetings were held in September 1994 and August 1996, and an official 21 day public comment period was held during February and March 1996. A number of issues and concerns were raised by landowners.

In October 1996, a responsiveness summary was prepared as an official response to the issues raised by riparian users. The main issue raised by riparian users was regarding water use restrictions - drinking water, irrigation, swimming, septic systems, exposure to pets – during the treatment. This issue was addressed by a plan to provide alternate water sources and charcoal filters for water lines. Other issues included the visual and odor impacts of dead fish (addressed by a plan to collect dead fish during the treatment), loss of angling opportunities in the lake (addressed by a plan to stock brook trout and other salmonids during the spring following the treatment), the persistence of rotenone toxicity (addressed by a plan to do the treatment in the early fall, when mixing of the lake will speed up detoxification), long-term eutrophication impacts, and impacts to non-target organisms. Several landowners also challenged both the NY DEC's legal authority to conduct the reclamation and their claims that alewives would have serious ecological impacts on Lake Champlain. As of February 2001, the reclamation has yet to proceed due to public objection.

[Information from NY DEC (1996) and L. Strait, Fisheries Manager, New York Department of Environmental Conservation, Inland Fisheries, Region 5]

Lake Ogallala, Nebraska
-a good example of how quickly alewives can come to dominate a lake ; reclamation followed by biological control using brown trout and chinook salmon

Alewives were introduced above Kingsley Dam into Lake McConaughy in 1986 to provide a diverse forage base for walleye and white bass. The relative weights of both species improved. Within several years, however, alewives had migrated over the dam and into Lake Ogallala, a 239 hectare (590 acre) reservoir. By 1990 alewives were the dominant fish species in Lake Ogallala, comprising 47% of the fish biomass. The zooplankton community shifted from large to small species and as a result, stocked rainbow trout suffered huge declines in survival and growth rates.

The Nebraska Parks and Game Commission concluded that a reclamation of the lake to remove alewives was the best solution. An Environmental Impact Statement was completed and the reclamation quickly approved by the Nebraska Department of Environmental Quality. Lake Ogallala was reclaimed, but since Lake McConaughy could not be reclaimed, alewives continued to enter Lake Ogallala over the dam. However, the reclamation allowed the establishment of a predator base that could keep up with the constant production of alewives coming from upstream. Biologists have found that brown trout and chinook salmon do very well feeding on alewives. Thus, alewives are under control, but Lake Ogallala is an artificial system with non-native species and no natural reproduction of the predator species.

[Information from Laux et al. (1996) and D. Gablehouse, Fisheries Director, Nebraska Game and Parks Commission]

Lake George and Keeser Lake, Maine

The State of Maine intentionally introduced alewives into many lakes. In most cases they did not thrive ; however, in several lakes alewives flourished and have had major impacts.

In Lake George, a 1,017-acre lake, 2,500 anadromous alewives were introduced, and by the following year their estimated production was 1,000,000 individuals. A noticeable shift in zooplankton composition occurred after the introduction as large zooplankton disappeared and smaller zooplankton increased. As a result, young-of-the-year rainbow smelt realized a growth spurt, although recruitment into the adult stock was depressed.

In Keeser Lake, there was a significant reduction in the yellow perch population, due to adult alewives feeding on juvenile yellow perch. Rainbow smelt also declined but have not disappeared completely. There is no longer any natural lake trout and landlocked Atlantic salmon spawning, presumably due to the consumption of alewives and thiaminase-caused Early Mortality Syndrome. Landlocked salmon growth rates have been severely depressed. However, brown trout have done well on alewives, and some of Maine’s largest brown trout now come from lakes containing alewives.

[Information from F. Brautigam and F. Kircheis, Maine Department of Inland Fisheries]

East Twin Lake, Connecticut
-an example of baitbucket introduction of alewives, salmon population crash, and unsuccessful biological control

Alewives were inadvertently introduced into East Twin Lake (228 hectares, 563 acres), most likely through bait releases. Alewives were discovered in the lake when a large winter kill occurred and dead alewives were littering the shoreline of the lake. The die-off included at least 3 year classes and alewives up to 11 inches (28 cm) total length. Alewives significantly altered the lake's zooplankton community and as a result, the lake's Kokanee salmon population crashed. Brown trout were over-stocked into the lake in an attempt to reduce the alewife numbers. This attempt at biological control had little effect on the alewife population ; however, the best brown trout fishery in the state was created. Brown trout were stocked at 12 inches to quickly recruit into the slot protection limit of 14-22 inches. Within two years the stocked trout were over the slot limit - five inches of growth per year. The lake's zooplankton never recovered, and in 1997 the Connecticut Department of Environmental Protection abandoned any attempts to control the alewives.

[Information from B. Gerrish, Connecticut Department of Environmental Protection and Schluntz (1999)]

Skehany Reservoir, New York
-an example of alewives flourishing, having major impacts on natives fishes, and then crashing and disappearing

Alewives were introduced into Skehany Reservoir through bait bucket releases about 10 years ago and quickly became the most dominant fish in the lake. All walleye under 4 years of age disappeared, most cyprinids were decimated, and for several years there was no visible walleye recruitment. However, alewives crashed in 1997 and since have not been observed during electrofishing surveys. The causes of the sudden disappearance are unknown.

[Information provided by T. Bandanza, Fisheries Manager New York City Department of Environmental Protection, Shokan, New York]

Lake Davis, California
-an example of a reclamation to eradicate an exotic species, stressing the importance of good public relations and following proper procedures

Northern pike were discovered in Lake Davis, a 4,025-acre water body, in 1994. They were most likely illegally stocked several years earlier from nearby Frenchman Reservoir (which itself had been reclaimed to eradicate pike in 1991). In order to prevent the spread of pike into the Sacramento-San Joaquin Delta where they would likely negatively impact native trout and salmon species, the California Department of Fish and Game (CA DFG) decided to reclaim Lake Davis using Nusyn-Noxfish, a liquid rotenone solution.

Public opposition to the reclamation initially centered on the loss of the trout fishery and the resulting economic impact to the Lake Davis area. However, concerns later shifted to public health, and in particular to trichloroethylene (TCE), a known carcinogen that is found in Nusyn-Noxfish. Although TCE concentrations in the lake immediately following the treatment (0.001 ppm) were to be far below the level permissible in the state (0.005 ppm), the CA DFG arranged temporary alternate drinking supplies.

The CA DFG also planned to heavily restock the lake in spring 1998 in time for the spring fishing season. Public opposition remained, but the state proceeded with the reclamation and the lake was treated with Nusyn-Noxfish on October 15 and 16, 1997.

A number of problems occurred. First, although rotenone in the lake dissipated within two weeks, piperonyl butoxide, a chemical in Nusyn-Noxfish used to increase the toxicity of rotenone, remained in the water six months later. As a result, the city of Portola faced a water shortage and restocking of the lake did not occur in the spring as planned. The CA DFG paid a $4.5 million settlement to Pumas County and the city of Portola for impacts to the area's tourist industry and drinking waters. Second, miscalculations about the expected outflow volume resulted in inadequate detoxification and impacts from discharges of treated waters extended further than the 0.5 miles downstream that had been stipulated. As a result the CA DFG was fined $250,000 by the state for allowing toxic water to seep out of the lake into other waterways. Third, over 80 health complaints were filed following the treatment, although the California Department of Pesticide Regulation determined that it is unlikely that the levels of airborne rotenone that people were exposed to would result in illnesses. Finally, in May of 1999, northern pike were rediscovered in Lake Davis and subsequent monitoring efforts have shown that there now exists an established, reproducing population. This indicates that either the reclamation had not been 100% successful or that pike had once again been illegally stocked into the lake.

Summary of Reclamation Case Studies

A detailed review of case studies found no examples of chemical control or eradication projects for unwanted fish species that closely resembled the Lake St. Catherine situation. There were numerous examples found for waterbodies much smaller than Lake St. Catherine, and there were a small number found for waterbodies much larger ; however these were reservoirs or man-made impoundments which were significantly drawn down prior to reclamation efforts. Finlayson et. al. (2000) summarized 4,833 rotenone treatments in North America from 1988-1997 and reported that attempts to eradicate exotics as the primary objective comprised only 6% (n=126) of the treatments. Beyond that, this treatment type was considered to be the least successful. Other surveys have reported the same basic results. In most cases, eradication of an exotic is considered “successful” when something less than a 98% reduction in the exotic population is achieved (Moyle et. al. 1983, Meronek et. al. 1996). Often, the undesirable fish species have repopulated the waterbody within a few years, making repetitive reclamations necessary (Moyle et. al. 1983). In a review of 250 fish control projects, Meronek et. al. (1996) found that 145 (58%) utilized chemical treatments. For the 69 treatments employing rotenone, 48% were considered successful, 20% were failures, and 32% had insufficient data to make a determination. Antimycin treatments (n=67) were 45% successful, while 14% were failures, and 42% had insufficient data. Most success criteria were described as reductions – but not elimination - of standing stock of target species, with only 2 cases (brook trout removal from small alpine lakes) described as successful “elimination”. Combination treatments (multiple chemicals, or chemical treatment followed by physical removal through netting, or increased predator stocking) increased combined “success” rates to 66%.

Finlayson et. al. (2000) found that the majority (42%) of rotenone reclamations targeted fish communities that were unbalanced, over-populated, and stunted. In such treatments, the objectives are not total fish eradication, but instead, reductions in fish abundance to improve growth rates, fish condition and size, recreational angling value, and to decrease rough fish populations. For these projects, often referred to as “fisheries renovations”, rotenone treatments are generally considered effective and successful. However, success seemed to vary with the size of waterbodies treated. Meronek et. al (1996) found success rates to decline as waterbody surface area increased. They reported chemical treatment success rates of 94% for waters of 0.5-5 acres, 75% (12.5-50 acres), 40% (50-100 acres), 63% (100-1,000 acres), and 80% for waters greater than 1,000 acres.

It is difficult to offer specific examples of fish control or eradication projects as comparison to the Lake St. Catherine situation. Chemical control or eradication efforts on large, natural lakes with minimal drawdown potential are not frequently attempted. In cases that have attempted such treatments, primary objectives are generally “reductions” in fish abundance, with the understanding that complete eradication was difficult (Meronek et. al. 1996).

SECTION VIII

COSTS

SUMMARY

Population Reduction – Netting		**$13,400 per year**
Population Reduction - Biological Control		**$0**
Containment - Acoustic Barrier	Installation:	**$52,000**
	Operation:	**$3,500 per year**
Containment - Electrical Barrier	Installation:	**$48,000 - $102,000**
	Operation:	**$2,250 per year**
Containment - Physical Barrier	Installation:	**$250,000**
	Maintenance:	**$18,576 per year**
Reclamation		
Rotenone:	$272,160	
Outflow Detoxification:	$4,536	
Application Equipment:	$29,250	
Application Manpower:	$31,200	
Post-Treatment Stocking:	$10,400	**$347,546**

POPULATION REDUCTION

(1) Netting Program

Electrofishing the littoral zone plus netting (gillnets, traps) in spring (late May)

Manpower - 10 days/year, 2 teams of 3* (2 x 10 x [$200/day + $200/day + $120/day])	$10,400.00	*2 biologists, 1 technician
Equipment*	$2,500.00	*nets, net repair, batteries, motor repairs, etc.
Gas	$500.00	
Total Cost of Netting	**$13,400.00 per year**	

(2) Biological Control

There should be no additional costs associated with increased stocking of brown trout – already budgeted.

CONTAINMENT

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(1) Acoustic Barrier

High frequency transducers set every 10-15 feet across the face of the dam

High frequency transducer: pinger+amplifier every 10' = 8 x $5000/set	$40,000	
Equipment Building (houses amplifiers)	$6,000	*houses amplifiers, etc.
Installation*	$6,000	*rough estimate
Total Cost	**$52,000**	
Operating Cost (Electricity)*	**$3,500.00 per year**	* rough estimate – about 50% more electricity to run than the electric barrier

Source: Smith-Root, Inc., 360-573-0202

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(2) Electrical Barrier

Graduated pulse electrical barrier with 6 electrodes

Pulse generators: 6 x $6000	$36,000	*very rough estimate as cost depends on how much work is needed to install the electrodes; at the dam, the bottom is silty so more work may be required, base may have to be put in place
Equipment building	$6,000	
Installation of electrodes*	$6000-$60000	
Total Cost	**$48,000-$102,000**	
Operating Cost (Electricity)	**$2,250.00 per year**	

(estimated 2850 KWH / month, CVPS commercial rate 2 service, 9 months / year)

Source: Smith-Root, Inc., 360-573-0202

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(3) Physical Barrier

Barrier*	**$250,000****	*ranges widely, depending on the type of barrier
Maintenance (1 technician) 9 ice-free months per year		
high flow, high debris* - 5 days / week		*Mar. - May, Sep. - Nov.
($120/day x 5) x (4.3 wks/mon x 6 mon)	$15,480.00	
low flow, low debris* - 2 days / week		*June, July, August
($120/day x 2) x (4.3 wks/mon x 3 mon)	$3,096.00	
Total Maintenance	**$18,576.00 per year**	

**the net installed by the Colorado DOW cost $250,000 including engineering costs in the design and contractor costs in its installation

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RECLAMATION

(a) Rotenone

Powdered rotenone	$2.10	per pound	
(5% active ingredient assay)			
To achieve a 1.5 ppm equivalent treatment	4.05	pounds/acre	
(20.25 / % active ingredient)			
Estimated volume of Lake St. Catherine	32000	acre feet	
(area ~1000 acres x avg. depth 32 feet)			
Amount of rotenone needed	129600	pounds	
(32,000 acre feet x 4.05 pounds/acre foot)			
Cost of rotenone	**$272,160.00**		
(129,600 pounds x $2.10/pound)			

Sources: AGREVO (Ruth Fisher, 800-438-5837); Prentiss (www.prentiss.com)

(b) Detoxification of the Outflow

Flow rate over dam*	10	cfs	*actual flow rate needs to
Rotenone load	1.5	ppm	be measured
Organic load (2-4 times rotenone)	1.5	ppm	
Duration of rotenone toxicity	14	days	
(rotenone toxic for 2 weeks @ 50F)			
Amount needed per ppm per day per cfs	5.4	pounds	
Amount of Potassium permanganate needed*	2268	pounds	*rough estimate
(10 cfs x 3.0 ppm x 14 days x 5.4 pounds)			
Cost of Potassium permangenate	**$4,536.00**		
(2268 pounds x $2.00/pound)			

Sources: Van Waters and Rogers (518-861-5181)

(c) Application Equipment

Jon or pontoon boats applying a maximum of 10,000 pounds of rotenone per day
(5 boats x 10,000 pounds/day = 50,000 pounds/day)

(129,600 pounds / 50,000 pounds/day)	2.6	days	
Application time	**3-4**	**days**	
(allow for less than max. application, delays)			
Boats (jon boats or pontoons)*	$0.00		*should be able to borrow
Mixing and application equipment			
Pressure pumps $1,200 each x 7*	$8,400.00		*1 per boat + 2 backup
aspirators $150 - $200 x 7	$1,400.00		
Hoses, etc. $100 per setup x 7	$700.00		
Personal safety gear	$18,750.00		
(power respirator, tyvex suit, gloves etc.)			
$750 / person x 25 people (see 4 below)			
Total equipment cost	**$29,250.00**		

(d) Application Manpower

2 crew members per boat x 5 boats	*10*	
10-15 shoreline support (mixing, etc.)	*15*	
Total Manpower	*25*	
Rotenone Manpower Cost (25 x $200/day x 4 days)	$20,000.00	
Detoxification & Clean-up* Manpower Cost (4 x $200/day x 14 days)	$11,200.00	*collection of dead fish
Total Manpower Cost	**$31,200.00**	

(e) Post-Treatment Stocking

Warmwater fish will be captured from nearby lakes and transferred immediately to Lake St. Catherine; trout species will be stocked during regularly scheduled spring stocking

10 days x 2 crews of 3* (2 x 10 x [$200/day + $200/day + $120/day])		*2 biologists, 1 technician
Total Stocking Cost	**$10,400.00**	

Observations on Cost Estimates Presented

The cost estimates indicated in the above section may well be inaccurate due to out-of-date information. Many of these estimates were made early on in the drafting of this report and it is foreseeable that actual costs may have increased for the various alternatives discussed.

It has been suggested that the costs of alewife management, be it control or eradication, would likely be far less than the ecological and economic costs associated with an alewife infestation of Lake Champlain. However, that statement is very difficult, if not impossible, to prove or disprove, and a firm declaration either way would simply be speculation at this point. Recent studies indicate that the total economic value of Lake Champlain's sport fishery is approximately $204 million (Gilbert, 2000). Compared to that value, it is clear that a complete fisheries reclamation of Lake St. Catherine to eradicate alewives would cost substantially less. However, a prediction of the true economic losses to Lake Champlain's sport and recreation fishery following the establishment of alewives is difficult to estimate. It is reasonable to predict potential changes to Lake Champlain's fish community ; it could be said with a degree of confidence that change is a certainty. However, the magnitude of fish community changes, and how those changes will impact the economic value of the lake's fishery cannot be projected. Furthermore, the form of Lake Champlain's sport fishery will have a bearing on the economic impact of an alewife infestation. For example, if a high value was to be placed on a natural, self-sustaining sport fishery of salmonids and other game fish, then that fishery may have a low economic value in the face of alewife establishment. On the other hand, as was indicated earlier in this report, if the lake's sport fishery was to become similar to the Great Lake's (little or no reproduction, heavily supported by hatchery stocking), then the economic (as well as social) value of the fishery could actually increase with alewife as the primary forage base.

For these reasons, estimates of the economic benefit of alewife control or eradication would be questionable at best.

SECTION IX

PUBLIC COMMENTS AND RESPONSIVENESS SUMMARY

On August 8, 2000, a public meeting was held at Castleton State College to solicit public input and comment on the various management alternatives being investigated to deal with alewives in Lake St. Catherine. The meeting was advertised 2 weeks in advance through local media in both Vermont and New York State. Over 35 newspapers in the 2 states ran the announcement. Additionally, WPTZ News Channel 5 in Burlington announced the meeting the previous night at the end of an alewife segment as part of their Champlain 2000 series. A personal phone call was also made to the President of the Lake St. Catherine Association, inviting all riparian landowners to the meeting. In spite of being well-publicized, only 15 citizens attended the meeting.

What follows is a summary of oral and written comments received from the public and the Department's response (in *italics*) to each comment.

1. All exotic species come in through boat launches – VTDFW needs to better monitor launches.

   While it is true that many exotic species are introduced to new waters through human activity, not all exotic species are introduced through public boat access areas. Many people that use and access waterbodies do so through private property. As a result, to best address the issue of exotic species movement, rules and regulations are passed that address the movement and introduction itself, not the avenues of movement and introduction. It is the public's responsibility to adhere to these rules and regulations, regardless of where and how they access the lake.

2. Control out-of-state tournament anglers (to prevent introduction of exotic species).

   See response for comment (1) above. Additionally, there would not be any difference in the activities of resident or non-resident tournament anglers with respect to the risk of introducing exotic species to new waters. Furthermore, most open-water tournaments prohibit participants from using any form of live bait. Movement of exotic species in boats and plant materials attached to trailers is addressed by several Vermont rules and regulations.

3. Try to sterilize alewives.

   The technology does not exist to successfully sterilize alewives, or any other wild fish population. The time and money required to conduct such research and to design a working program would exceed resources available. In the meantime, alewives would have more time to increase in numbers and escape Lake St. Catherine. Other alternatives available would require less time and money and have an equal or greater chance of succeeding.

4. Move aggressively to control alewife populations – support rotenone.

   The Vermont Department of Fish and Wildlife (VTDFW) is taking steps to quickly address the issue of the alewives in Lake St. Catherine. The support of this reclamation alternative is noted.

5. Should try to combine more than one alternative (multiple barriers).

    While a combination of alternatives, instead of one specific alternative, may actually be the final choice, the construction of multiple barriers most likely would not be selected as an option. Each barrier type has both shared and different shortcomings. No combination of barriers would address all the potential chances of failure much more than a single type of barrier.

6. The system is one lake – shouldn't try to separate Lily Pond, Lake St. Catherine, Little Pond.

    Water and boat traffic moves unrestricted between Lily Pond, Lake St. Catherine and Little Pond. Therefore, the VTDFW is treating all 3 basins as one entity. Any remediation efforts will be directed towards the health and well-being of all three waterbodies, and not one specifically.

7. Build barrier on the Mettawee River (to prevent downstream migration of alewives).

    Constructing any kind of barrier on the Mettawee River would not serve the purpose any better than a barrier constructed on the outlet of Lake St. Catherine. The same drawbacks to acoustic, electric and physical barriers discussed in this report would apply to a barrier built on the Mettawee River. Additionally, a barrier on the Mettawee River could have large environmental impacts of its own and could detrimentally impact the healthy wild trout fishery of the river.

8. Shouldn't be considering rotenone with low populations (of alewives) in Little Lake.

    If a reclamation with rotenone is chosen as the preferred alternative, all waters of the Lake St. Catherine "system" will be treated as one waterbody. Alewives have the ability to move unimpeded between all 3 basins, and a reclamation effort must attempt to eliminate every single alewife in the system, including Little Pond, regardless of the numbers of fish that exist there.

9. Change creel limit for brown trout (lower) so that there are more trout to eat alewives.

    This could be a possible management action and will be considered. However, for the most part, the same result could be achieved by increasing stocking efforts, which the VTDFW has done. In any case, since it is doubtful that brown trout would significantly impact the alewife population through predation, increasing the number of brown trout either through increased stocking or reduced harvest will not likely have a significant impact on alewife numbers.

10. Commercial harvest for alewife population reduction.

    A similar option has been suggested as part of Management Alternative #2. In this case, the VTDFW would harvest, by an assortment of means, as many alewives as would be possible each year. The disposal of alewives, whether for commercial sale or not, would have to be worked out if this option was chosen. On a related note, in July 2000 the Oregon Department of Fish and Game contracted a commercial fisherman to remove an exotic fish species, the Tui Chub, from the 3,000-acre Diamond Lake, in order to decrease potential impacts on the trout fishery. Of the estimated 25 to 30 million chub in the lake, only a few thousand were captured in 4 days.

11. Serious enforcement of laws needed (fish transportation, exotics laws etc).

    Vermont Game Wardens receive annual training on new rules and regulations. This past year, all wardens were trained on all current Vermont regulations that deal with fish importation, transportation, and the introduction of exotic species. These laws are enforced by Game Wardens.

12. More homework needed by the VTDFW before we really are sure alewives are a problem in VT.

    An extensive review of the relevant literature and direct interviews with out-of-state fisheries biologists has been conducted. This report outlines in detail all known impacts, both detrimental and positive, of landlocked alewives on freshwater ecosystems. While direct impacts in Vermont have not yet been measured, there is no reason to believe that impacts in Vermont waters would differ from those seen elsewhere. It has been determined that the potential for loss outweighs any potential good alewives provide to the waters of Vermont and as a result, some type of control effort may be justified.

13. Affects of rotenone treatment on non-target wildlife (loons etc that eat fish) is a concern.

    A brief outline of known impacts to non-target wildlife has been provided in the rotenone section of this report. If rotenone is chosen as the preferred alternative, a more detailed investigation will be required.

14. Need a catch and release law on Lake St. Catherine so more predator fish will eat alewives.

    This could be a possible management action and will be considered. Also, see response to comment #9.

15. VTDFW needs to be proactive with respect to other nuisance species.

    See responses to comment #'s 1, 2, and 11.

16. Better public education efforts are needed with respect to ANS.

    The VTDFW and the Vermont Department of Environmental Conservation (VTDEC) both have active programs educating the general public on the perils of Aquatic Nuisance Species. Both Departments continuously strive for greater effectiveness.

17. Need boat inspections.

    See response to comment #'s 1 and 2.

18. As much effort as is directed towards Lake Champlain (i.e. zebra mussels) needs to made elsewhere to keep exotics out of other waters.

    Rules and regulations enforced by the VTDFW and the VTDEC, and public education campaigns established by these Departments are directed towards all waters of the State, and not just Lake Champlain.

19. Need to do mailing to all Lake Association members for public comment.

The public meeting on the alewife issue was held in August of 2000, a time of the year chosen specifically because it was when most resident and non-resident riparian owners would be able to attend. The President of the Lake St. Catherine Association attended the meeting and was provided with copies of a written summary of the presentation made that night to pass out to members not able to attend. Written comments were accepted for several months after the public meeting. None were received.

20. Post info on web site for comment solicitation.

This has been done on the VTDEC Aquatic Nuisance Species web page. The address is :

http://www.anr.state.vt.us/dec/waterq/lakes/htm/ans/lp_alewife.htm

SECTION X

ALTERNATIVES SUMMARY & FUTURE ACTIONS

Four separate categories of alternatives have been discussed in this report. These are : 1) Public Education & Outreach, 2) Population Reduction, 3) Containment, and 4) Reclamation. While drawbacks are prevalent in all alternatives, some are more problematic than others, reducing the viability of those alternatives. To summarize each alternative and their respective disadvantages :

1) Public Education & Outreach : Direct monetary costs associated with this alternative vary depending on the type of education and outreach efforts implemented. While it important to have an educated public, it is often difficult to change public opinion, attitude, and practices. Though public education and outreach efforts may prevent the further spread of alewives to other lakes, it does not address the risk the population in Lake St. Catherine poses to Lake Champlain through fish escapement and outmigration. Having said this, despite the substantial public outreach efforts already undertaken by the VTDFW (see Appendix II), the public is still largely unaware of the alewife issue, or they remain unconcerned as to the threats posed by introducing these fish to Vermont waters – as is evidenced by the recent discovery of dead alewives in Lake Bomoseen (page 21 of this report).

2) Population Reduction : Approximate costs associated with this alternative total $13,400 annually, mostly for staff labour required to physically remove alewives from Lake St. Catherine. Major drawbacks to this alternative are ; a) alewives remain in Lake St. Catherine and continue to threaten other waters ; b) labour-intensive ; c) netting and predation would most likely not reduce alewife numbers sufficiently enough to decrease the risk of them escaping Lake St. Catherine.

3) Containment : Approximate costs associated with acoustic, electric, or physical barriers range from $50,000 to $250,000 for initial construction and $2,000 to $20,000 annually for operation and maintenance costs. The major drawback to all three barriers is that none can prevent the outmigration of all life stages of alewives year-round. Drifting eggs and larvae are not repelled by acoustic sound. Eggs, larvae, and adults can get swept through an electrical barrier during high water events without being affected. Physical barriers that are capable of filtering out eggs and larvae are extremely expensive to design and construct, and require dedicated employees for full-time, year-round maintenance. Moreover, the construction of any kind of barrier at the outlet of Lake St. Catherine would almost surely require the purchase of land and homes for construction and safety reasons, and require Environmental Assessments and permits – which would delay implementation.

4) Reclamation : Approximate costs associated with a rotenone reclamation of Lake St. Catherine are close to $350,000. These costs would be a one-time expenditure. This alternative is the only one that has any likelihood of eliminating alewives from Vermont waters. However, there are several major drawbacks to this alternative : a) A 100% kill, which is almost never achieved in a reclamation (average is 90 to 95 %) would be required to be considered a success. Alewives have incredibly high fecundity and just a few survivors could re-establish a population very quickly ; b) there is always the chance that there will be an illegal re-introduced again in the future, requiring subsequent reclamations ; c) a rotenone reclamation would be an expensive proposition, and may not ultimately solve the problem in the long run.

Considering the above summary, it is understandable that there is no straightforward answer and a decision is very challenging. It is very rare when an exotic species that has invaded an ecosystem can be eradicated. More often than not, managers must find ways to cope with the invasive species. Sometimes control efforts are possible, although eradication is almost always impractical and unachievable. This is certainly the case with alewives in Lake St. Catherine. Moreover, even if alewife control or eradication was plausible, the fact remains that alewives could be re-introduced illegally to Lake St. Catherine or any other lake in Vermont in the same manner. In addition, it is quite foreseeable that alewives may eventually migrate naturally to Lake Champlain via the Hudson River and Champlain Barge Canal, as have blueback herring, gizzard shad, and a host of other recent Lake Champlain fish invaders.

The Vermont Department of Fish and Wildlife will continue a regular monitoring program of the outflow of Lake St. Catherine and southern Lake Champlain to determine if and when alewives escape and become established in Lake Champlain. Also, Lake St. Catherine's fish community will continue to be evaluated on an annual basis. Stocking of brown trout into Lake St. Catherine will also be continued in the future to take advantage of the plentiful forage base and provide a fishery to the anglers of Vermont. The Vermont Department of Fish and Wildlife will also continue its efforts to prevent the further movement of alewives through angler education, and the adoption of pertinent regulations, such as the new baitfish regulation.

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APPENDIX I

COMMON AND LATIN NAMES

Fish

Alewife	*Alosa pseudoharengus*	Golden shiner	*Netemigonus crysoleucas*
Atlantic salmon	*Salmo salar*	Kiyi	*Coregonus kiyi*
Black crappie	*Promoxis nigromaculatus*	Lake herring	*Coregonus artedii*
Blackfin cisco	*Coregonus nigripinnis*	Lake trout	*Salvelinus namaycush*
Bloater	*Coregonus hoyi*	Lake whitefish	*Coregonus clupeaformis*
Blueback herring	*Alosa aestivalis*	Largemouth bass	*Micropterus salmoides*
Bluegill sunfish	*Lepomis macrochirus*	Longjaw cisco	*Coregonus alpenae*
Bowfin	*Amia calva*	Mooneye	*Hiodon tergisus*
Brown trout	*Salmo trutta*	Northern pike	*Esox lucius*
Brown bullhead	*Ictalurus nebulosus*	Pumpkinseed sunfish	*Lepomis gibbosus*
Burbot	*Lota lota*	Rainbow smelt	*Osmerus mordax*
Catfish	*Ictalurus* spp.	Rainbow trout	*Oncorhynchus mykiss*
Cisco	*Coregonus artedii*	Rock bass	*Ambloplites rupestris*
Chinook salmon	*Oncorynchus tshawytscha*	Round goby	*Neogobius melanostomus*
Coho salmon	*Oncorhynchus kisutch*	Shortjaw cisco	*Coregonus zenithicus*
Common white sucker	*Catostomus commersoni*	Shortnose cisco	*Coregonus reighardi*
Deepwater sculpin	*Myoxocephalus quadricornis*	Smallmouth bass	*Micropterus dolomieui*
Emerald shiner	*Notropis atherinoides*	Yellow perch	*Perca flavens*
European carp	*Cyprinus carpio*	Walleye	*Stizostedion vitreum*
Gar	*Lepisosteus* spp.	White bass	*Morone chrysops*
Gizzard shad	*Dorosoma cepedianum*		

Plants

Coontail	*Ceratophyllum demersum*	Hoard pea	*Tephrosia* spp.
Curly Leaf Pondweed	*Potomogeton* spp.	Jewel vine	*Derris* spp.
Eurasian watermilfoil	*Myriophyllum spicatum*	Lancepod	*Lonchocarpus* spp.
Flame tree	*Derris* spp.		

APPENDIX II

List of Public Outreach Efforts by the VTDFW

The Principal Investigator has been interviewed by the media numerous times since the discovery of alewives in Lake St. Catherine. Articles have been printed in Vermont newspapers across the state, as well as New York state newspapers.

Print Media

Date	Article	Publication
July 25, 1997	Alewives Invade Area Lake	Rutland Herald
August 10, 1997	Discovery has big ramifications	The Post-Star, Glens Falls, NY
October 10, 1997	Looming fish invasion threatens native species	Press Republican
December 1997	Alewives: A New Threat to the Lake ?	Boquet River Association Newsletter Bulletin
December 28, 1997	Alewives Harm Vermont Waters	Rutland Herald
June 1998	Alewife Introduction Threaten's Vermont's Native Fish	Vermont Outdoors Magazine
July 1998	Anglers Can Help Stop Alewives' Invasion	Vermont Woodlands Magazine
July 15, 1998	Vermont Fish & Wildlife bans use of alewives in all but one lake	Boston Globe
July 15, 1998	State bans alewives as bait – Alien fish poses threat to lakes	Burlington Free Press
January 1999	Alewives Threaten Lake Champlain	Investments for the Next Century – VT ANR Annual Report
March 26, 1999	Unnatural born killer: Non-native fish species threatens Lake St. Catherine ecosystem	Lakes Region Free Press & Granville (NY) Sentinel
April 16, 1999	Fish kill is called natural	Rutland Herald
April 16, 1999	Officials: Alewife die-off a natural phenomenon	Brattleboro Reformer
April 17, 1999	Fish Kill May Cause Big Stink	White River Junction Daily
June 1999	Alewives in Vermont Waters: Another Threat to Lake Champlain?	L. Champlain International Gazette
August 13, 2000	The alewife threat: Invasive baitfish has potential to cripple trout, salmon populations in Lake Champlain	Burlington Free Press
January 2001	Is Lake Champlain headed for a "Smelt-Down" ?	Burlington Free Press
August 11, 2002	Cutting bait : VT restricts bait fish	Rutland Herald
June 19, 2003	Dead nuisance fish found in Bomoseen	Rutland Herald
June 22, 2003	Dead alewives found in Lake Bomoseen	Burlington Free Press
June 29, 2003	F&W goes after alewives – with brown trout	Rutland Herald

Television

News Channel 5 and Champlain 2000's news anchor Thom Hallock has taken a strong interest in the alewife situation. The news crew has accompanied the Principal Investigator several times in the field during alewife sampling efforts and the alewife project has been Champlain 2000's premier story 3 separate times since 1997. In addition, the story appeared on the general news on both Channel 3 (Plattsburg) and Channel 5 (Burlington) several times over the years.

Presentations

The Principal Investigator has presented the alewife issue multiple times in both scientific and public forums. The following is a list of presentations :

- Poultney-Granville Lions Club Meeting, March 1999.
- Fish Invaders conference, SUNY-Plattsburg, NY, Nov. 1999. Invited Speaker. Audience was comprised of SUNY-Plattsburg Students, Professors, members of the public, and media. Following this conference, News Channel 5 conducted an interview with the Principal Investigator and aired a segment on the 6 o'clock news on the alewife issue.
- Vermont Dept. Fish & Wildlife annual Department Meeting, March 2000
- Alewife Public Meeting, Castleton State College, August, 2000.
- Lake Champlain Citizen's Advisory Group, Nov. 2000, Westport, NY
- Atlantic International Chapter of the American Fisheries Society, Annual Meeting, Jay Peak, VT, Sept. 1998 and Geneva Point, NH, Sept. 2001.
- Half Moon State Park, Public Presentation, July 2002
- Castleton State College, Biology Dept. Guest Lecturer, March, 2002 & March, 2004

Other Outreach

- Brochure "The alewife in Lake St. Catherine. A threat to Vermont's native fish populations ?" Currently available at bait and tackle shops throughout the Lake Champlain Basin, VTDFW information kiosks at District and Head Offices and Fish Culture Stations, and on the VT Dept. Environmental Conservation's website (PDF format).
- Direct person-to-person angler contact, primarily during winter ice fishing derbies on Lake St. Catherine and Lake Bomoseen. The above-mentioned brochure has been distributed during these times.
- Posters – "Attention – Have you seen this fish ?". Metal signs are currently posted at all F&W Access Area kiosks and boat launches throughout southwestern Vermont and along southern Lake Champlain.
- Direct mailing of "Issues Statements" in 1999 to various interest groups such as Trout Unlimited (Vermont Chapter), Bass Anglers Sportsmen's Society (Vermont Chapter), New Haven River Angler's Association, and other such groups.