Lake Champlain Alewife Impacts
February 14, 2006 Workshop Summary

Native smelt (top) and alewife from Lake Champlain

LCSG-05-06

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To Alewife Workshop Participants and Interested Parties: **August 23, 2006**

Alewives are native to the Atlantic coast and typically spawn in freshwater rivers and lakes. They are commonly used as bait and have become established in many lakes across the United States following intentional introductions and accidental bait-bucket releases. Once established in a new waterbody, alewives can cause tremendous changes to a lake ecosystem. Alewives first appeared in Lake Champlain's Missisquoi Bay in 2003; they appeared in the Northeast Arm and the Main Lake segments in 2004 and 2005. Alewives are well established in Lake St. Catherine, which drains to Lake Champlain 80+ miles south of the 2004 discovery point. Based on experiences in other states, it is believed that an alewife infestation in Lake Champlain could have substantial economic and ecological impacts. Because the specific impacts of a widespread alewife infestation on Lake Champlain are uncertain, Lake Champlain Sea Grant and the Lake Champlain Basin Program organized a workshop on February 14, 2006 to learn from resource managers and scientists with experience in the Great Lakes and Finger Lakes of New York. Invited experts provided specific information on alewife introductions, discussed the range of potential changes to expect in Lake Champlain, and explored management responses to these changes.

The workshop was envisioned as an opportunity for technical transfer of likely alewife impacts in a personal setting. Evaluation comments indicate that most attendees felt the workshop met their expectations. In addition, most of those who provided feedback indicated that their knowledge of alewife ecological and/or physiological impacts increased as a result of their attendance. Several indicated that they learned of management options that might be employed to mitigate alewife impacts in Lake Champlain. Others reported that at least some of the information presented would be useful knowledge for sportfishing, business owners (i.e., bait and tackle shops, charter captains, guides, etc.), fishing organizations, or other stakeholders.

Members of the technical audience have requested copies of the scientific presentations given at the workshop. The following "chapters" reflect a distillation of notes and computer graphic files supplied and edited by the five presenters. It is anticipated that taken collectively these papers will serve as useful references as managers seek out available options that might be employed in the face of an emerging alewife colonization of Lake Champlain.

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Lake Champlain Sea Grant

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Lake Champlain Sea Grant is a cooperative research and outreach program of the University of Vermont and Plattsburgh State University of New York and part of the National College Sea Grant Program. Funding is provided primarily by the National Oceanic and Atmospheric Administration, academic partners, and other sources.

The Lake Champlain Basin Program is a partnership among the State of Vermont, the State of New York, the Province of Québec, and several federal and local organizations working to implement *Opportunities for Action*, a restoration and management plan for the Lake Champlain Basin.

SPEAKER 1: Population Dynamics and Life History of Alewife in the Great Lakes: Implications for Lake Champlain

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I. General Alewife Characteristics

- Alewife are pelagic planktivores.
- Alewife spawn late spring and early summer, at night, near shore, and near the water surface. They spawn over rocks, sand, mud, etc.
- Alewife are very temperature sensitive. They experience both winter and spring die-offs. Their ideal temperature range is 16-19°C (61°-66°F). They become stressed at temperatures <3°C (37°F) and avoid waters ≤1°C (34°F). Mass mortalities can occur while crossing sharp temperature gradients, e.g. while migrating from very cold water to warmer, near-shore waters to spawn in spring. Prolonged exposure to cold temperatures is thought responsible, in part, for winter mortalities. Poor condition of fish at high population levels increases magnitude of temperature induced mass mortalities. Spring mortalities are more visible than winter mortalities although winter mortalities may be equally as large.
- Alewife have been successful in all the Great Lakes, except for Lake Superior, the coldest Great Lake..

II. Alewife Introduction Patterns and Responses

<u>There are four primary factors that favor alewife population expansion:</u>
- Reduced predation;
- Warm spring and early summer /warm winters;
- Nutrient enrichment; and
- A vacant niche (for example, when fishing practices remove competitors, such as lake herring, *Coregonus artedi*).

<u>Great Lakes Introductions:</u>
Alewives were first discovered in the Great Lakes in 1873 in Lake Ontario. They were subsequently found in Lake Erie in 1931, Lake Huron in 1933, Lake Michigan in 1949, and Lake Superior in 1954.

By the late 1940's, alewives had free range in Lakes Huron and Michigan, due to the elimination of native predators, lake trout and burbot, by exotic sea lamprey. Their maximum population was reached within 15 years; massive die-offs occurred in Lake Michigan. Alewives were so abundant, they jammed municipal water intakes during spawning and experienced large die-offs, which fouled beaches with rotting fish.

<u>Great Lakes Response:</u>
Two competing solutions emerged:
1. Trawling – This was attempted in Lake Michigan, but was not economically feasible on the scale needed to successfully reduce the population.
2. Replacing predators by stocking Chinook salmon, coho salmon, steelhead/rainbow trout, brown trout, and lake trout after successfully reducing sea lamprey numbers.

Chinook salmon were cheap and easy to raise, and consumed large quantities of alewife during their relatively short life. Because Chinook salmon grew to a large size, anglers loved them. Stocking Chinook salmon along with other salmon and trout generated a new industry, i.e. a recreational Great Lakes fishery which included a large charter fishery.

<u>Alewife populations in the Great Lakes since stocking:</u>

Lake Michigan – Alewife declined to 10-30% of a population peak measured by the first lake-wide survey in 1973 within 12 years after large-scale stocking began. Alewife abundance in 1973, however, was likely much lower than that in the mid to late 1960s.

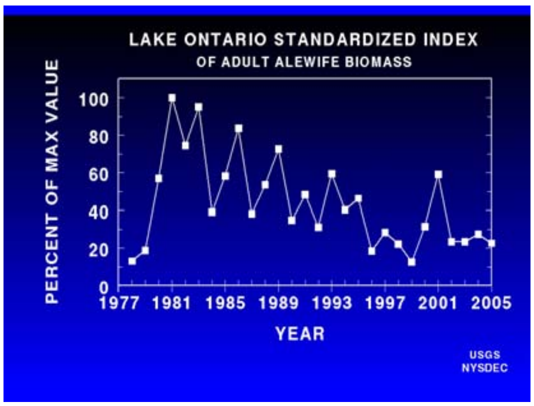

Figure 1. Lake Ontario Standardized Index of Adult Alewife Biomass

Lake Huron – Trawl surveys on the Michigan (western) side of Lake Huron showed a near absence of alewife during 2003-2005. Collapse of the alewife population was apparently due to improved suppresion of sea lamprey and Chinook salmon reproduction augmenting hatchery releases. Dreissenid mediated disappearance of *Diporeia* may have also played a role.

Lake Ontario – A very cold winter in 1976-1977 caused a major dieoff in the alewife population. The population quicky rebounded, but has been stair-stepping down since. Phosphorus levels were also very high in the late 1970's and then began decreasing, hence reducing carry capacity for planktivorous alewife. (P levels were up to 22 ug/L, and have since declined to 4-6 ug/L.) Predators were not fully controlling alewife. It appears that alewife in Lake Ontario can produce more young per egg spawned than alewife in Lake Michigan; when alewife produce large year classes, predators are overwhelmed and the population surges upward but when alewife produce small year classes predators can maintain the population at a low level.

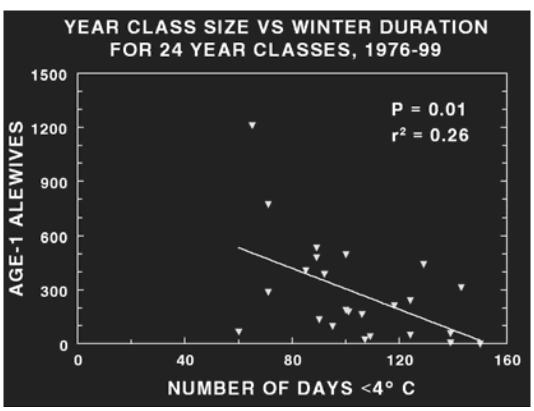

Figure 2. Year Class Size vs. Winter Duration for 24 Year Classes, 1976-1999.

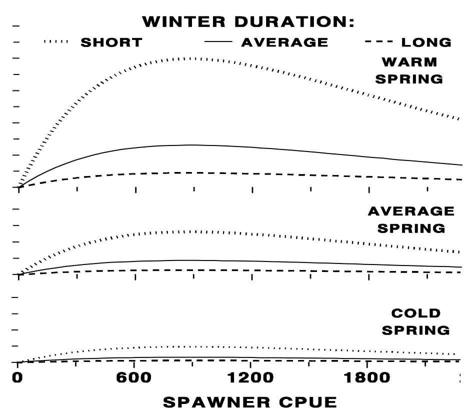

Figure 3. Generalized Spawning Success Under Various Winter/Spring Weather Patterns.

Water temperature during egg incubaton and the first months of life (generally late May through July) and winter duration influences alewife recruitment. To survive their first winter, alewife should exceed 60 mm in length.

Alewife Distribution:
Once Lake Ontario stratifies, alewives are in the epilimnion or near shore waters; they are no longer in the hypolimnion. During the summer, they are spread across the lake in the epilimnion. The Lake Ontario thermocline is sharp – they can't stay in that narrow zone. As the thermocline weakens and descends in fall, alewife follow it downward. Once the thermocline falls apart, they eventually move to the lake bottom as winter progresses.

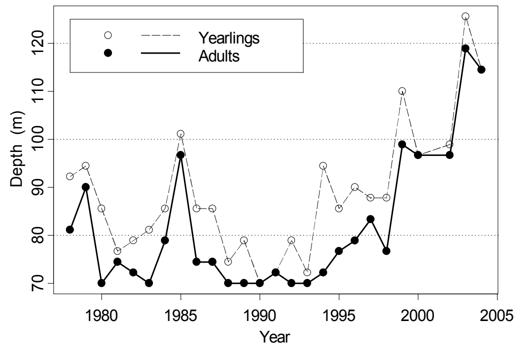

Figure 4. Mean Depth of Peak Catch at South Shore Ports (excluding Mexico Bay, Southwick, and Cape Vincent), Lake Ontario.

Prior to the zebra mussel and quagga mussel invasions, alewife depth distribution in spring was dependent on temperature. Beginning in 1994-1995, everything, including fish, moved deeper. The reason isn't clear, but it doesn't appear to be based on temperature.

Alewife Growth:
In Lake Michigan, alewife growth has slowed, due to the decline of the burrowing amphipod, *Diporeia* . Density dependency doesn't appear to be a factor. Conversely, alewife growth rates in Lake Ontario haven't changed much even though *Diporeia* have largely disappeared from the lake.

Age composition:
Once alewives survive their first winter, they have the potential to reach an age of 6 or more years.

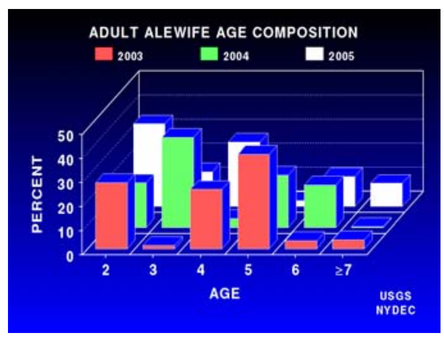

Figure 5. Adult Alewife Age Composition 2003, 2004, and 2005, Lake Ontario.

III. Discussion

Comment: There is no evidence that Lake Ontario alewife are more fecund than alewife in other Great Lakes. They apparently produce more progeny per egg spawned than alewife in Lake Michigan.

Q: How have rainbow smelt and alewife interacted? A: I've never seen data showing any impact on smelt. If you put in enough predators to reduce alewife, however, then you'll likely reduce smelt. In Lake Ontario, smelt larger than 150 mm are uncommon.

Q: Does the change in depth suggest they're going for a deeper food source? A: People have suggested this. Diporeia have disappeared in Lake Ontario, but *Diporeia* were never prominent in alewife diets.

Q: Given the longevity of lake trout and efforts toward lake trout restoration, what if we just focused on lake trout for alewife control? A: Success of this strategy depends on the magnitude of your alewife spawning stock and the conditions in the Lake for overwinter survival, particularly of juveniles. If the spawning stock stays low and juvenile alewife survival is low, then you may not have a problem. It may largely depend on the over-wintering habitat. Lake trout were apparently successful in retarding alewife expansion in the upper Great Lakes until they were reduced by sea lamprey so the key here may be to build up lake trout stocks before alewife become numerous.

Q: Why are alewife in Lake Erie not successful? A: There's no agreement on this. Lake Erie is shallow. Perhaps the summer habitat is too warm? There are lots of predators and competitors that were never driven down. Also, Lake Superior is a very cold lake – alewife can't spawn in July and grow large enough to survive the winter. There is no good index to show ups and downs in Lake Erie alewife population.

Q: Would lake trout occupy the same summer habitat as alewife? A: Lake trout living in the hypolimnion do go up through the thermocline to to feed on alewife in the epilimnion. Chinook will also go up.

SPEAKER 2: Trophic Changes Following the Introduction of the Alewife in Otsego Lake, NY

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I. Alewife Introduction to Otsego Lake

Alewives were illegally introduced to Otsego Lake, NY in 1986. Following this introduction, the water turned from blue to green as a result of the lack of algal grazing by larger zooplankton, the latter having been decimated by alewives. Average annual Secchi depth measurements decreased after alewives became established.

II. Changes in planktivores and plankton

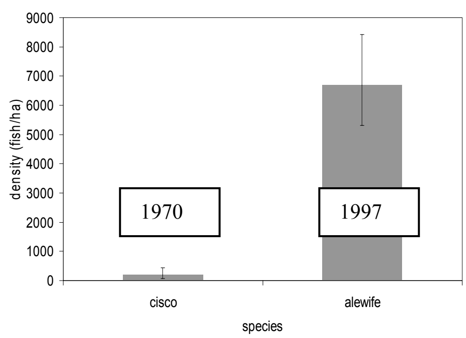

Figure 1. Piscivorous zoo-planktivore densities in Otsego Lake during July in 1970 and 1997

Rotifers comprised 14% of the Lake's zooplankton community in 1935, yet expanded to 75% by 1993; larger zooplankton were decimated.

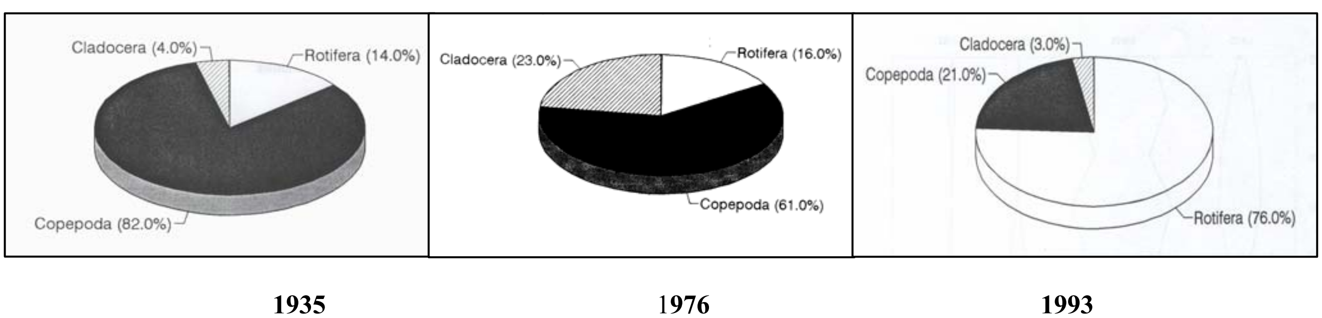

Figure 2. Proportional Abundances of Rotifera, Cladocera, and Copepoda Ostego Lake, NY; 1935, 1976, and 1993

III. Concurrently, the political framework for whole lake management developed.

"BOTTOM UP" Management Activities to date:

- Ban on high phosphorus detergents.
- Ban on surface disposal of sanitary wastewater.
- Inspection of septic systems, PHL#1100
- Land use regulations developed, including lake protection districts.
- $383,000 invested in agricultural BMP's, $1.2M in wetland reclamation.

- Water level regulation and control.
- No wake zones.

Opposing Activities:
- Increasing recreational use on and around Lake.
- Larger powerboats.
- Seasonal homes to year round.
- Subdivision of agricultural lands.
- Introduction of exotic nuisance species: Eurasian watermilfoil, alewife.

IV. End result after 35 years – NO SIGNIFICANT IMPROVEMENT IN WATER QUALITY

- Cisco, lake whitefish, and a diversity of cyprinids have been decimated
- Alewife fed lake trout; lake trout increased in size, yet showed no thiaminase problems.
- Introduced rainbow smelt disappeared following alewife expansion.
- Alewives feeding on larger bottom zooplankton.
- Whitefish declined due to lack of food (Copepods).

V. History of introduced fish:

Walleye declined after ciscoes stocking and whitefish augmentation. It's believed that ciscoes ate walleye fry. Nothing was controlling alewife.

VI. Management Response:

Beginning in 2000, 80,000 walleye were stocked annually to feed on young alewives. Now walleyes reach up to 30 inches in length. Gill net catches are comparable to best New York walleye lakes.

VII. Management Goals include:

- Reasonable walleye growth
- Successful reproduction
- Self-sustaining population
- Reduction of alewife population
- Increase in size and abundance of Cladocera
- Decrease in algae populations
- Increase in water clarity

VIII. Results:

Following the walleye stocking program, chlorophyll a declined; *Daphnia pulex* increased in abundance and size; Secchi disk transparency increased.

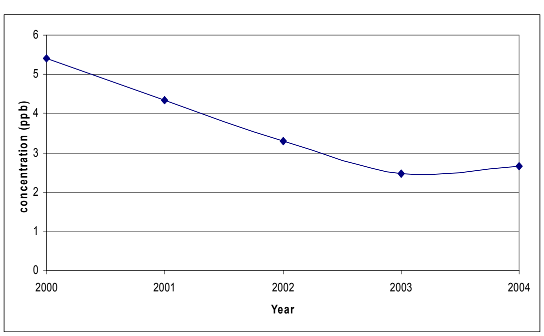

Figure 3. Otsego Lake Mean Chlorophyll a, 2000 – 2004

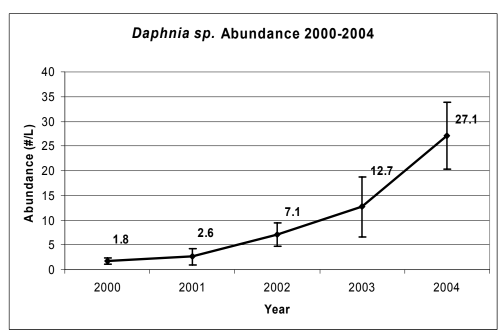

Figure 4. Abundance of *Daphnia pulex*, 2000 - 2004

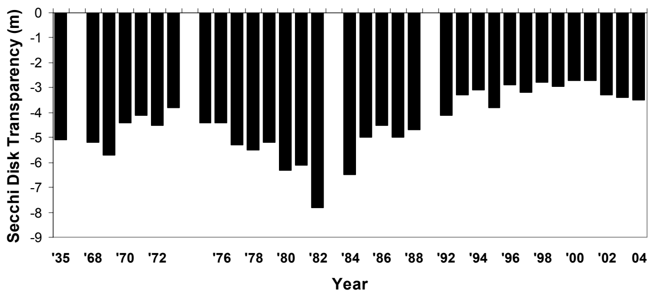

Figure 5. Secchi Disk Transparency.

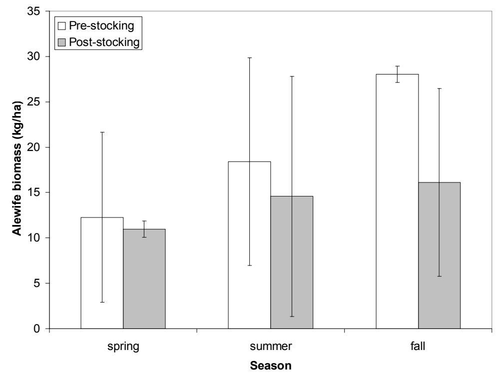

Figure 6. Alewife Biomass by Hydro-acoustics Pre- and Post- Stocking Years.

IX. Our Present Conclusions:

- To date large amounts of resources used for reduction of nutrient loading and availability have had little positive affect on water quality.
- Exotic aquatic nuisance species (ANS) have had greater negative impacts on trophic relationships and recreational use than eutrophy.
- It appears that one effort in “top down” management of an ANS, the alewife, has a reasonable potential to restore previously prevailing pelagic trophic characteristics.

X. So what have been the impacts of alewife introduction?

- Increased intensity of all the symptoms of eutrophy
- Short-term improvement of lake trout growth
- Concern about loss of oxygen in hypolimnetic waters threatening the cold water fisheries
- Added expense and real setbacks in lake and watershed management planning to restore water quality to historic conditions

XI. Discussion:

The Lake trout population is self-sustaining. Both Seneca and Adirondack strains have been stocked. Adirondack strains are no longer stocked due to lack of reproduction. There has been no evidence of thiaminase problems in lake trout.

During warmer years, alewives have experienced die-offs.

There are no mysids in Otsego Lake. Rotifer populations exploded after alewife introduction, but their populations are now decreasing.

SPEAKER 3: Food Web Effects and Population Dynamics of Alewives

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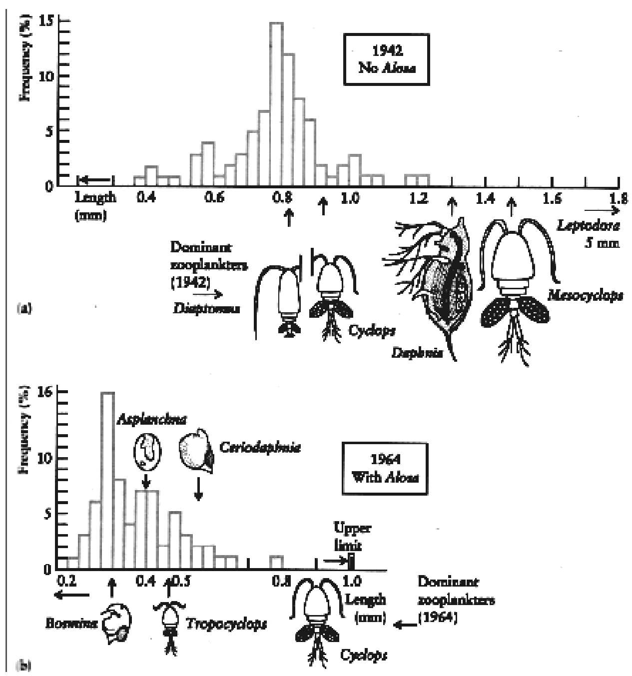
I. Food Web Effects

The effects of an alewife population on a lake food web can be described through:

A. Changes in zooplankton size distribution;
B. "Top-down" trophic cascades; and
C. Predation on early fish life stages.

<u>A. Changes in zooplankton size distribution</u>

Studies in Otsego Lake and Lake Michigan have helped to establish a predictable trajectory of alewife impacts on lake food webs. The question is: will this trajectory apply to Lake Champlain? The presence of zebra mussels is one factor that could alter this trajectory.



Several early studies examined zooplankton size distribution following alewife establishment and showed that the larger-sized zooplankton disappear.

Size structure of zooplankton could be a more useful metric than alewife biomass or population size for evaluating ecological impacts of alewives.

Figure 1. Zooplankton Size Distribution With and Without Alewife, Brooks and Dodson, 1965

<u>B. "Top-down" trophic cascades</u>

In general, the top-down impact of alewives result in:

- Fewer large cladocerans;
- More small cladocerans & copepods; and
- Greater algal abundance.

C. Predation on early fish life stages

Alewife reduce the abundance of:

- emerald shiners
- bloater chubs
- lake herring
- yellow perch
- deepwater sculpin
- spoonhead sculpin

(Crowder 1980, Kohler & Ney 1981, Crowder et al. 1987)

In Lake Michigan, emerald shiners and yellow perch declined. It is unclear whether these declines were due to predation or competition with alewife. Alewife do prey on yellow perch larvae. There are suggestions of a negative relationship between alewife and rainbow smelt.

II. Finger Lakes

The Finger Lakes could serve as good models for Lake Champlain. A prominent bait fish industry, including a heavy trade in shad-like fish, is present in the Finger Lakes. Only two Finger Lakes do not have established alewife populations. This food web model illustrates the role that alewives play in many of the interactions in the Finger Lakes.

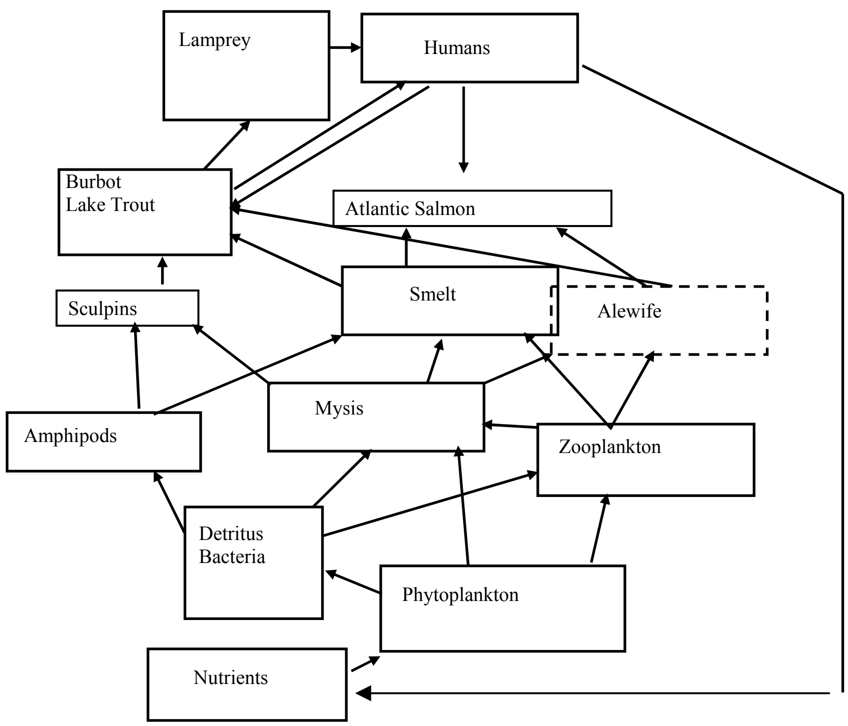


Figure 2. Food Web Model of Finger Lakes.

III. What controls alewife abundance?

Cold winter conditions

Long-term field surveys have shown a correlation between cold winter temperatures, poor condition and adult alewife mortality. However, in a pond study conducted at Cornell during winter 2004-05, alewife exposed to mild and severe winter temperatures showed no significant difference in mortality or condition. Survival of alewife held in ponds with mild winter conditions (~ 4°C) was similar to that of alewife exposed to prolonged periods (more than six weeks) of temperatures < 2°C. Although this result contrasts with previous observations indicating that alewife cannot tolerate temperatures < 3°C, immune system suppression was observed in alewife exposed to cold temperatures. The influence of winter conditions on alewife survival remains uncertain.

Predation
Pacific salmon are effective predators. They will continue to pursue alewife prey until they are very scarce.

Can you crash an alewife population?
Alewives arrived in Cayuta Lake in 1977. Cayuta Lake is 371 acres in size, with a maximum depth of 26 feet. It is eutrophic and has one small outlet. There is no temperature or seasonal refuge for alewife to avoid predation. Walleye were stocked in an attempt to limit alewives. Walleye were stocked for six years. Acoustic estimates of alewife showed that alewives haven't responded to the stocking program. These results suggest that walleye cannot be relied upon to control alewife populations.

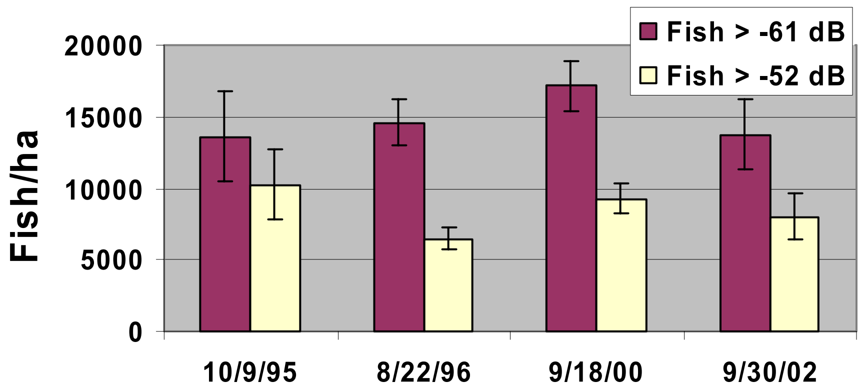


Figure 3. Adjusted Cayuta Lake alewife density including the top 2 m, 95% CI

IV. Mixed messages in the Media

Since the late 1970s, the success of the Great Lakes salmon sportfishing industry has been linked to the presence and maintenance of thriving populations of non-native alewife. Along the Atlantic coast of New England, where alewife are native, there is a long cultural history associated with spring runs of anadromous alewife. Efforts have been recently initiated to restore locally extirpated alewife runs in coastal New England. Given that the media will continue to portray these fish as both bad and good at different times and locations, it will be a challenge to convey contrasting messages that alewife are "good" in some circumstances and "bad" in others.

Chicago Tribune (1/22/06)

> "Can we ever get rid of alewives in the Great Lakes?" he (Michigan DNR biologist Claramunt) asked rhetorically. "Probably not."
>
> "I can't say what would happen, but I am confident that outcome would be undesirable," Claramunt said.

V. Discussion

Q: The St. Lawrence alewife population is 'natural'. Is it not surprising alewife got to Lake Ontario? Did the 1873 report state that alewives were not found downstream in the St. Lawrence? Why didn't they make it into Lake Champlain? Some have been found in the Richelieu River.

SPEAKER 4: Link Between Lake Trout Reproductive Failure and Thiamine

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(Credit for data used in this presentation is extended to Scott B. Brown, Environment Canada, John D. Fitzsimons, Canadian Department and Oceans, Don E. Tillitt, US Geological Survey and Ellen Marsden, University VT).

I. Relevant Historical Background of Great Lakes in General

- 1820-1870 - alewife and sea lamprey discovered;
- 1912 - rainbow smelt introduced;
- 1920-30's - lake trout stocking reduced;
- 1950-1970 - contaminants major factor (PCB and Dioxin);
- late 1960s -1970's – early mortality syndrome (EMS) reported;
- late 1980's - zebra mussels and other invasives; and
- mid 1990 - EMS/M74 significantly increased

II. Thiamine, Early Mortality Syndrome, and Thiaminase

Thiamine, or Vitamin B1, is an essential dietary vitamin.

<u>What is Early Mortality Syndrome (EMS)?</u>
A condition observed between hatch and first feeding in Great Lakes salmonids and is characterized by:

- Loss of equilibrium;
- Swimming in a spiral pattern;
- Lethargy;
- Hyperexcitability;
- Hemorrhage, etc.

<u>Species in Great Lakes Basin that Exhibit EMS include:</u>
Atlantic Salmon (*Salmo salar*)
Lake Trout (*Salvelinus namaycush)*
Brown Trout (*Salmo trutta*)
Coho Salmon (*Onchorhynchus kitsuch*)
Steelhead (*Onchorhynchus mykiss*)
Chinook Salmon (*Onchorhynchus tshawytscha*)

<u>What We Know:</u>

- If thiamine concentration is low, thiamine treatment of eggs/fry is therapeutic.
- EMS-like symptoms can be induced by anti-thiamine compounds.
- EMS impairs reproductive success.
- There's no connection with hatchery practices, genetics, or pathogens.
- There's no connection to contaminants. However, in thiamine deficient fry, there's an increased toxicity to PCB's and Dioxin.
- Thiaminase destroys thiamine. If prey have thiaminase, predators can become thiamine deficient.

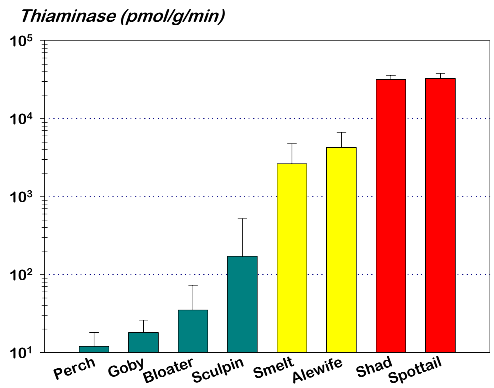


Figure 1. Thiaminase Levels in Eight Fish Species

<u>Sources of thiaminase:</u>
All alewife have thiaminase. Bacteria is a source, but other sources could be *de novo* synthesis and/or blue-green algae. It's unclear what the biological function of thiaminase might be in alewife.

<u>Experimental Reproduction of EMS</u>
Lake Trout fed low thiamine diets containing bacterial thiaminase. Mortality occurred at 1.5 nmol/g total thiamine level. (2005. J. Aquatic Animal Health 17:4-12)

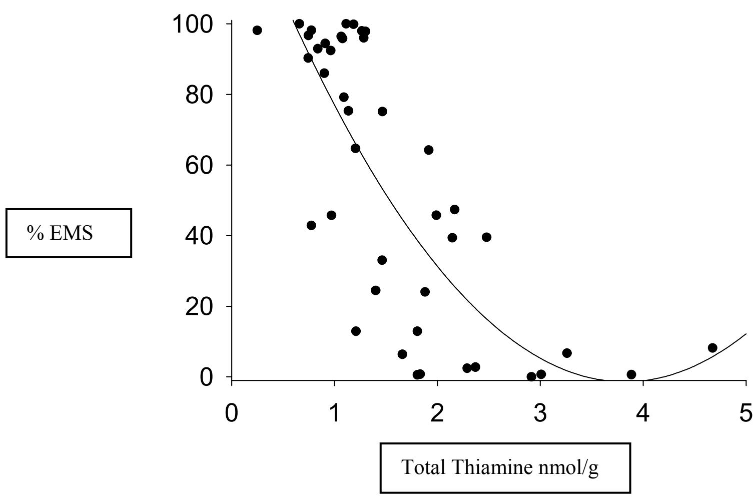
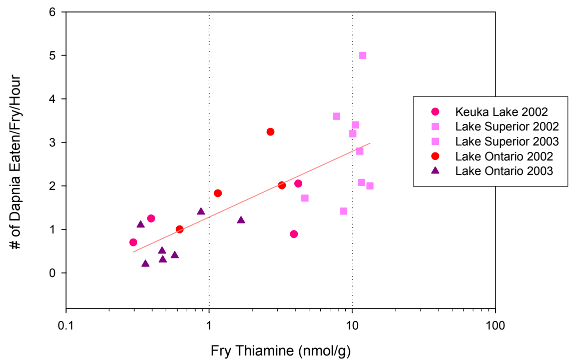


Figure 2. The Relationship between Percent of EMS and Total Thiamine

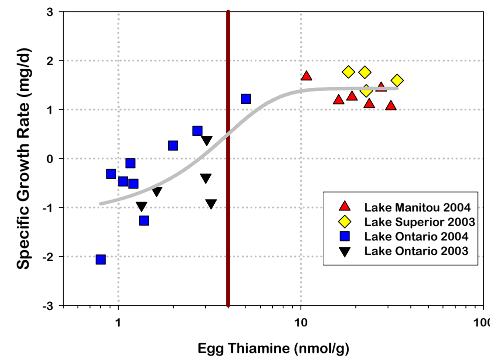
<u>Feeding study</u>
Bloater chubs and alewife were fed to lake trout for two years. It took two years to see fry with signs and symptoms of EMS. Low egg thiamine and fry mortality (EMS) were observed in fish fed 35-100 % dietary alewife.

<u>Effects other than Death Related to Thiamine Deficiency</u>
Brain lesions typical of thiamine deficiency were observed in lake trout fry that survived suggesting that neural function might be impaired. In thiamine deficient lake trout fry, visual acuity threshold was affected. Furthermore thiamine deficient fry's ability to avoid predators and capture prey was affected. Sculpins selected and consumed more thiamine deficient fry than fully repleate fry. Thiamine deficient fry captured approximately half the number of *Daphnia* compared to controls. An inflection point in fry growth was observed at 4 nmol/g. At less than 4 nmol/g thiamine growth was negatively affected. Above 10 nmol/g thiamine a plateau in growth was seen. Other biological functions observed with thiamine deficiency include immune function and gene expression.

Foraging



Growth



<u>Immune function in thiamine deficiency:</u>

- Macrophage bactericidal activity and cytotoxic cell activity did not appear to be impacted by the level of thiamine deficiency.
- Lymphocyte activity is differentially impacted with T-cell populations exhibiting reduced proliferation following mitogen stimulation.
- B-cells do not appear to be impacted.

<u>Implications</u>

- T-cells play a critical role in immunity to intracellular pathogens, such as viruses and bacteria.
- Thiamine depleted lake trout may be more susceptible to diseases caused by intracellular pathogens.

III. Lake Trout Egg Thiamine in Lake Superior and Lake Champlain

Thresholds for direct effects (mortality) and secondary effects of thiamine deficiency are suggested to be 1.5 and 4.0 nmol/g. In Lake Superior natural reproduction of lake trout is common and egg thiamine is 17-34 nmol/g. Egg thiamine in Lake Champlain lake trout are not as high as lake trout eggs collected from lake Superior, but only one Lake Champlain sample was below the threshold for secondary effects.

<u>Thiamine Concentration Categories</u>

- <1.5 nmol/g thiamine - Fry mortality, EMS
- < 4.0 nmol/g - Secondary effects:
  - * Predator avoidance
  - * Immune/disease
  - * Gene expression
  - * Prey capture
  - * Growth

<u>Lake Superior, n = 6</u>

Egg Thiamine, nmol/g	
Mean	23.01
Median	22.60
Min	17.30
Max	33.71

<u>Lake Champlain (2004), n = 31</u>

Egg Thiamine, nmol/g	
Mean	11.2
Median	11.2
Min	3.3
Max	17.8

IV. Summary

<u>Thiamine Deficiency causes EMS</u>

- Mortality (fry and adult)
- Reproductive failure
- Reduced Growth
- Impaired Vision
- Reduced Prey capture
- Predator avoidance
- Immune function (T-cells & disease)

V. Management Options

- Reduce alewife population by stocking chinook salmon.
- Encourage commercial fishing of alewife.
- Invest in daughter-less technology (inserting gene in alewife to create male-only offspring).

VI. Discussion

The graph of thiaminase levels among prey species, showed that smelt and alewife were similar. Is there a critical level? Or would we not see much difference? A: The important fact is this. Preliminary data indicates that the enzyme (thiaminase) in smelt is less active in the stomach at acid pH whereas alewife thiaminase retains its full activity at stomach pH (ie pH optimum of thiaminase activity differs between smelt and alewife). Although thiaminase activity appear similar under assay conditions, their function in real life is not the same; alewife thiaminase has a much larger negative affect than smelt thiaminase.

In this same graph, spottail and gizzard shad were super high. Shad 4-5X activity as alewife, etc. Any Comment? A: Normally these prey are not part of lake trout diets and were presented to give the full range of thiaminase observed in various prey species.

What is daughter-less technology? A: In simplified terms, all offspring are males and eventually there are no females to produce eggs. This emerging technology is being used in Australia. The gene for aromatase is over expressed in the offspring. Even though fish are born as females (XX), aromatase converts estrogen to androgens (male hormones) thus short-circuiting normal female reproductive function. If management is to consider this option, there are certain issues that need to be addressed to implement this technology. Daughter-less technology was given as a possible option but not necessarily as an immediate solution.

SPEAKER 5: Thiaminase-induced Thiamine Deficiency in Feral Landlocked Atlantic Salmon and Steelhead with Preliminary Observations of Thiamine Impacts on Walleye

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I. Introduction

Historically, over-fishing, pollution, and building of dams and barriers to spawning migration were suggested as possible causes of the decline of the Atlantic salmon in Lake Ontario and Cayuga Lake (Smith 1892). Based on findings reported here and other reports (Smith 1970), we suggest another possible contributing cause of the extirpation of landlocked Atlantic salmon in Lake Ontario and some other inland waters of New York — the entrance of alewives (*Alosa pseudoharengus*) containing thiaminase, which induced thiamine deficiency in eggs and increased mortality in fry of the predatory salmon.

II. Landlocked Atlantic salmon from Cayuga Inlet (Ithaca, New York)

Mortality in fry of Atlantic salmon (*Salmo salar*) from Cayuga Lake (New York) is associated with low levels of thiamine (vitamin B1) that can be corrected by immersing fry in water containing thiamine or by injections. Ketola et al. (2000) tested injections of thiamine in gravid female Cayuga Inlet Atlantic salmon with thiamine 14-23 days before spawning. Chemical analyses showed that injections increased thiamine content of eggs from 1.1 to 1.6 nanomoles thiamine/gram. Although injections had no effect of the percentage hatch of eggs, survival of fry was markedly increased from less than 2% to about 98%. Therefore this study showed that thiamine injections of pre-spawning female salmon from Cayuga Lake increased thiamine content of their eggs and prevented the Cayuga syndrome and subsequent mortality of fry.

Because little is known about the impact of thiamine on adult male fish, we compared fertility in eight male salmon captured in Cayuga Inlet. Immediately after determining packed cell volume and confirming motility of sperm, milt from control and injected males (nine days post-injection) was tested (pair-wise) for ability to fertilize thiamine-adequate eggs. Eggs from a common female were briefly immersed in a quantity of aerated water after adding a standardized amount of milt normalized to the same cell content. Fertility was estimated by the percentage of eggs that developed eyes. Although fertilization rates were low, our results showed that injecting males with thiamine significantly ($P<0.02$) increased the percentage of eyed eggs. While this study should be repeated to increase exposure of eggs to milt to increase percentages of eyed eggs, these results suggest that thiamine deficiency reduces fertility of male landlocked salmon from Cayuga Lake.

III. Evaluation of landlocked Atlantic salmon from Lake Champlain 2001

In 2001, we examined the thiamine status of salmon eggs from Lake Champlain where alewives had not yet become established and from Lake Huron where alewives were established. Replicated lots of eggs from thirteen Lake Champlain salmon and four Lake Huron salmon were analyzed, incubated and hatched in the laboratory. The mean thiamine content of eggs from Lake Champlain were found to be high (5.7 nmol/g) while that for Lake Huron was highly variable: The mean of two lots of eggs was low (0.7 nmol/g) and high for the other two (8.7 nmol/g). Upon hatching, each lot of fry was divided and immersed for 48 hr in either of culture water or the same water with 1,000 mg thiamine/liter. After seven weeks, Lake Champlain fry suffered no thiamine-related mortality or other signs of thiamine deficiency regardless of immersion. In contrast, fry of two lots of low-thiamine salmon from Lake Huron salmon suffered 100% mortality unless they had been immersed in thiamine. Fry of the other two lots of high-thiamine salmon from Lake Huron salmon experienced negligible mortality regardless of immersion. Therefore, we concluded that landlocked salmon sampled from Lake Champlain had adequate thiamine; whereas, some Lake Huron salmon had insufficient thiamine for reproduction.

IV. Evaluation of impact of thiamine deficiency upon spawning migration of rainbow trout in Cayuga Inlet (Ithaca, New York)

Fry of rainbow trout *(Oncorhynchus mykiss)* from Cayuga Lake suffer from a thiamine deficiency characterized by general weakness, loss of equilibrium, and increased mortality which are prevented by treatment with thiamine. The effect of thiamine deficiency on migratory ability of adult spawning salmonids was unknown. Therefore Ketola et al. (2005) captured, tagged, and released 64 and 189 pre-spawning rainbow trout in years 2000 and 2002, in Cayuga Inlet at a collection fish ladder to evaluate their thiamine status and the effect of thiamine injection (150 nmol/g) on upstream migration. Each year half of the trout were injected with thiamine and half were un-injected; all trout were released above the fish ladder to continue their upstream migration. In 2000, we recaptured, by electrofishing, seven thiamine-injected and no un-injected trout approximately 7 to 9.3 river km upstream from the fish ladder. In 2002, the concentration of thiamine in muscle of trout collected above a 1.8-m cascade was significantly higher (mean 5.47 nmol/g) than that of trout collected below the cascade (mean 1.20 nmol/g). The lowest concentration of thiamine observed in muscle of trout collected upstream of the 1.8-m cascade was 1 nmol/g, suggesting that the concentration required for trout to ascend the cascade was no more than that. Analyses of thiamine in muscle of 26 untagged rainbow trout captured in Cayuga Inlet in 2002 suggested that approximately 66% had at least 1 nmol/g, concentrations apparently sufficient to support vigorous migration.

V. Evaluation of steelhead from Salmon River, New York

Hatchery fry of several species of feral salmonid brood stocks develop thiamine deficiency that is reversed by immersing fry in water containing thiamine. Such rehabilitated fry appear normal and grow well and may be stocked, but possible long-term subtle effects on their behavior or physiology are unknown. Therefore the effect of transitory deficiency in fry of steelhead from Lake Ontario and landlocked salmon from Cayuga Lake was examined. Fry that developed signs of deficiency were immersed for 24 hr in water containing 1,000 PPM thiamine. Control fry were immersed as eggs during water hardening and when first hatched. These fry were reared and fed a standard feed containing adequate thiamine. After they became fingerlings and yearlings, we tested their avoidance responses to culture water containing added zinc sulfate. Fingerlings and yearlings were tested in special paired avoidance units each constructed with three adjacent chambers arranged in a line with passageways between adjacent chambers. The outer chambers were supplied with either laboratory culture water (control) or the same water with additions of zinc sulfate. Control water had a hardness of 240 ppm as $CaCO_3$. The level of zinc was not detectable (<0.003 ppm) by inductively coupled plasma spectrophotometry. Behavior was recorded simultaneously for 60 minutes for two sets of fish (control and rehabilitated) by use of a video camera to avoid human disturbance. From the video recordings, observations and records of location of each of five fish (control *vs* test chambers) were recorded. Tests were repeated six or more times, reversing the positions of the fish and locations of introduction of test water. Results showed that both control and rehabilitated steelhead significantly avoided 0.03 to 0.2 ppm added zinc (as zinc sulfate), while rehabilitated steelhead avoided it significantly more strongly than controls. Landlocked salmon also avoided zinc but only when added at a much higher concentration than that for steelhead, i.e., 0.1 vs 0.03 ppm. In contrast to steelhead, rehabilitated salmon were significantly less responsive to zinc than controls. In conclusion, transitory deficiency of thiamine in fry of steelhead and landlocked salmon causes long-term neurological impacts as evidenced by their significantly different responses to sub-lethal additions of zinc sulfate in water.

VI. Thiamine status of walleye in Lake Erie and several New York Lakes

Survival of fry from eggs of walleye (*Sander vitreus*) collected from several New York lakes was related to thiamine content of eggs. Some lakes have alewives, a forage fish containing an enzyme (thiaminase) known to induce thiamine deficiency and mortality in fry of salmonids. Eggs from four lakes were collected, fertilized, incubated, and hatched at approximately 9.4°C. Eggs were analyzed for total thiamine (expressed in nmol/g), most of which occurred as thiamine diphosphate. Fry were observed until 500-700 degree-days Celsius post-fertilization. Thiamine-deficiency signs were experimentally induced in normal fry by addition of a known antagonist (oxythiamine) to water. Induced signs included exophthalmia, pericardial edema, gaping, lethargy, and mortality. Mean thiamine values varied annually and between lakes. Between 1996 and 2002, mean thiamine for eastern Lake Erie and Oneida Lake ranged from 2.1 to 6.0 and 3.4 to 7.1, respectively. In contrast, mean thiamine for eggs from Otisco Lake measured in 2000-2004 were generally low (1.1 to 2.7), possibly reflecting the abundance of alewives. Mean thiamine for Conesus Lake was 2.8 in 2001 and for eastern Lake Ontario, 3.3 in 1997 and 2.2 in 2004. No consistent relationship was found between thiamine content of eggs and fry mortality.

VII. References

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