Feasibility of Champlain Canal Aquatic Nuisance Species Barrier Options

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Executive Summary

The present-day Champlain Canal is 60 miles long and runs between the Erie Canal at Waterford in the south and the southernmost point of Lake Champlain at Whitehall to the north. With its inception in 1823 the canal connected previously unconnected drainages – including the Hudson-Mohawk and the Champlain. Organisms thought to have invaded Lake Champlain via this route include sea lamprey, water chestnut, zebra mussel, and white perch. Control efforts associated with 3 of these species in the lake are expected to exceed $16 million for the period 1982-2008.

Current knowledge of aquatic nuisance species (ANS) confirms that new species will continue to invade Lake Champlain via the Champlain Canal, by boat trailers, aquarium trade, bait usage, and aquatic plant nursery operations. A diversity of opinions among the many stake holders and opinion leaders exists about the importance of these vectors and the degree of the ANS problem in the Champlain Basin. While many stakeholders expressed concerns over the invasive species issues, some people didn't feel that the canal posed a significant risk as an invasives pathway. Still others didn't feel the canal was the most important pathway relative to boat trailers, bait trade, aquaria/pet trade, and other vectors.

Despite these opinions, the available literature argues that the canal represents the single largest known vector of Lake Champlain ANS. While an optimal barrier would be 100% effective at preventing transport through the canal, this should not be the criterion for success. Even an 80% reduction in the probability that a species could enter Lake Champlain via the Champlain Canal represents significant progress in protecting the ecology of the Champlain basin.

Six canal barrier ideas were proposed and examined from the standpoint of feasibility. Preliminary costs and benefits were also described. The six ANS barrier ideas were:

- Alternative One: Do Nothing (i.e. no change in canal engineering or operations)
- Alternative Two: Close the Champlain Canal
- Alternative Three: Physical/mechanical modification of canal and or locks. Modifications would consist of limited hydrologic separation with provisions for overland transport of recreational vessels, and use of graving dock or seasonal lockage restrictions for commercial vessels.
- Alternative Four: Behavioral fish barriers (electrical, bubble, sound, strobe light - alone and in combinations)
- Alternative Five: Chemical/Water Quality Barrier
- Alternative Six: Biological Barrier

Alternative Three is seen as the most effective at stemming the flow of canal-borne invasives. This alternative offers the best protection against all types of ANS. Behavioral barriers (sound, bubble, electrical, light – alone or in combination) represent a good second choice, though no protection against plants and invertebrates will be realized.

Sound decisions as to the fate of any Champlain Canal ANS barrier will require further analysis. Well designed socio-economic surveys are needed to better understand current canal usage and importance. Surveys of this type should also enable decision makers to formulate "what-if" scenarios relative to boat traffic impacts caused by ANS barriers and/or canal operational changes. Engineering studies are needed to predict the physical viability and costs associated with physical and behavior barriers. The construction of graving docks, boat hoists, behavior barriers, feeder canal diversions, etc. would require significant new investment in the

NYS Canal System. The costs associated with such new infrastructure need to be detailed before any serious deliberation on the problem of canal/ANS could begin.

By their very nature, canals serve as unnatural watershed connections. Global trade and 21st century travel and tourism will combine to deliver many new invasive species across several watersheds to Lake Champlain in future decades. If no action is taken, the future will see new invasive fish, plant, and invertebrate colonizations in Lake Champlain.

Introduction

Interest in the issue of the Champlain Canal as a vector of aquatic nuisance species (ANS) dates to at least 1989 (Smith-Root, Inc. 1993). In 1998, the U.S. Fish and Wildlife Service (USFWS) sponsored a workshop summarizing the role that the NYS Canal System plays in the role of ANS invasion. Despite these efforts, no engineering efforts or operational changes in the canal have been implemented to minimize the threat of ANS invasions via the canal to Lake Champlain. It has been argued that ….*"canals facilitate the conveyance of bulk goods and commodities and inadvertently facilitate the spread of aquatic invasive species (AIS) within a watershed and allow cross-basin transfer of AIS between formerly independent watersheds. Prevention of AIS spread via canals may be one of the more tractable scenarios for AIS management"* (http://www.aisstrategyteam.org/).

Interest in addressing this "tractable scenario" led to a proposal and subsequent funding of a project to outline the nature of the problem by describing the types of organisms that have or are able to traverse the canal into Lake Champlain. We also sought to assemble a team of experts to propose solutions to the barrier problem, and then conduct an analysis of the leading two or three ideas, taking into consideration a wide range of human and ecological factors. The following represents findings and recommendations stemming from this work. This information should be of value to decision makers involved with management Lake Champlain and Champlain Canal aquatic resources.

Background

Aquatic nuisance species are increasingly cited as causes for loss of biodiversity, and change of ecosystem structure and function. Costs associated with invasive species control and prevention have been reported in the millions or billions at the national level (Office of Technology Assessment, 1993; Pimentel et al., 2000)

At the local level, Lake Champlain's aquatic ecosystem continues to be shaped by the arrival and establishment of aquatic nuisance species. Like other lakes and ponds in the U.S., aquatic nuisance species arrive through a variety of pathways, causing economic and environmental problems in unexpected ways (i.e. selective zebra mussel filtering altering phytoplankton species dominance). Invasive invertebrates, fish, and plant species enter through canals, escape from aquaculture/aquarium systems, transport by recreational boat trailers, baitfish transport, and gardening (particular residential water gardens).

This study was undertaken to 1) better understand how aquatic nuisance species have impacted the lake, 2) what vectors or pathways enable ANS colonizations of the lake, and 3) what solutions might be offered to protect Lake Champlain aquatic resource in years to come.

Champlain Canal Characteristics

The major branch of the New York State Canal System known as the Erie Canal provides connection between Lake Erie and the tidal Hudson River. Other components of the NYS canal system include: 1) the Oswego, connecting the Erie Canal to Lake Ontario; 2) the Cayuga-Seneca which connects the Erie to the two largest Finger Lakes; and 3) the Champlain, c connecting the Erie to southern Lake Champlain. Outside of New York, this system connects to the Chambly Canal in Quebec providing recreational vessel access between northern Lake Champlain and the St. Lawrence River at Sorel-Tracy (Figure 1).

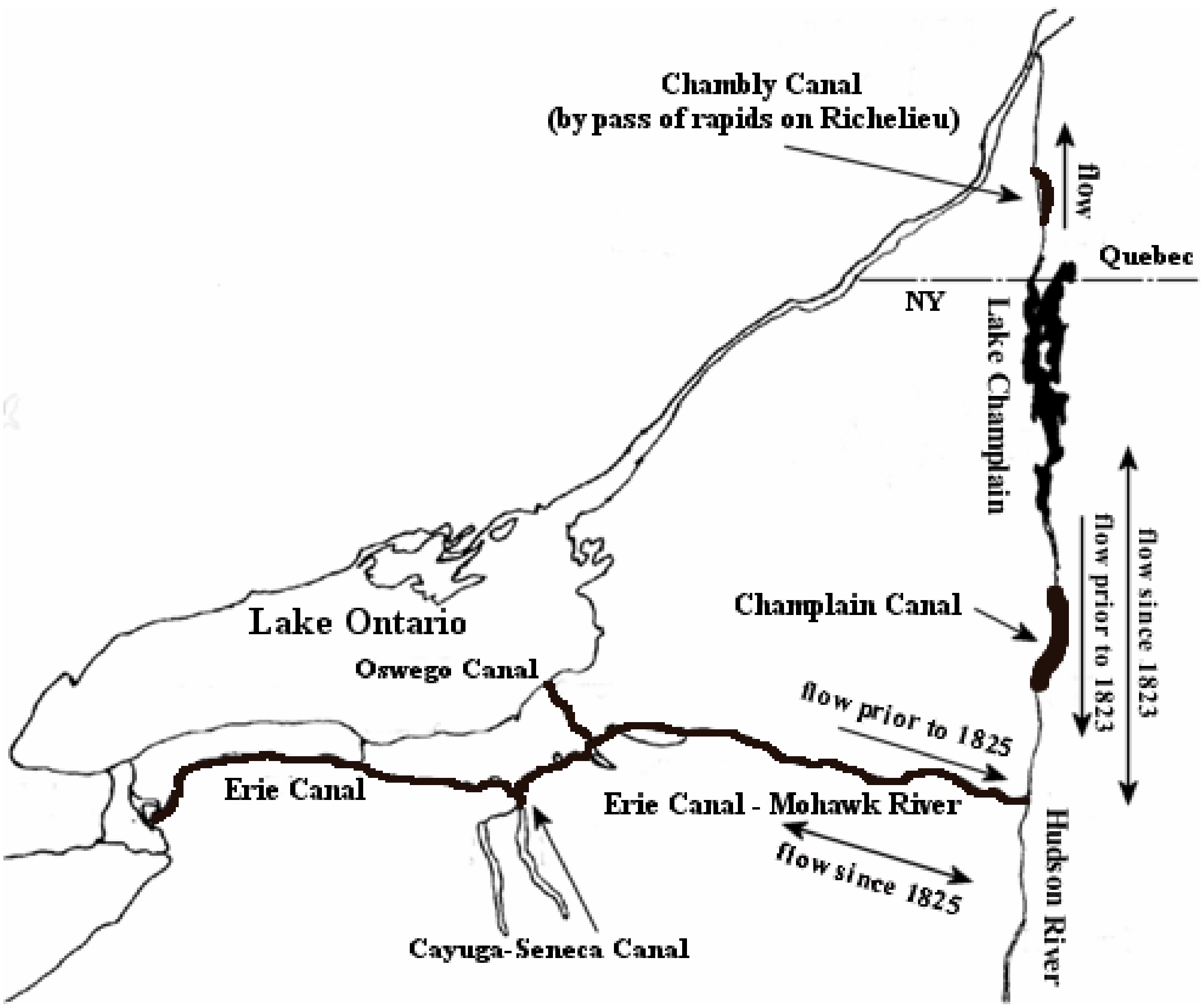

Figure 1 . Erie, Champlain and Chambly Canals

The focus of this report is aimed at the Champlain Canal, first opened in 1823. The original canal ran from Whitehall to Troy, NY; it was 40 ft wide, 4 ft deep, and had 24 locks.

Canal boats were specifically designed to have a shallow draft and masts that could be readily stepped and un-stepped from the deck. Modifications between 1860 and 1962 deepened and widened the canal, and reduced the number of locks. The present-day Champlain Canal is 60 miles long and runs between the Erie Canal at Waterford in the south and the southernmost point of Lake Champlain at Whitehall to the north There are 11 locks on the canal, which has a minimum depth of 12 feet, a twelfth lock is situated at Troy and joins the Hudson River to both the Champlain and Erie canals. The canal passes over a height of land near Fort Edwards, so that the canal flow downwards from lock 8 to the Hudson river (a drop of 134'), and downward from lock 9 toward Lake Champlain, a drop of 54' northbound (Figure 2). Between locks 8 and 9, the canal is filled by a 12-mile feeder canal linking Glens Falls with the canal, opened in 1837. The canal closes each winter in late November and is drained; the canal reopens in early May. Transits through the canal take from one to one-and-a-half days due to the 10 mph speed limit.

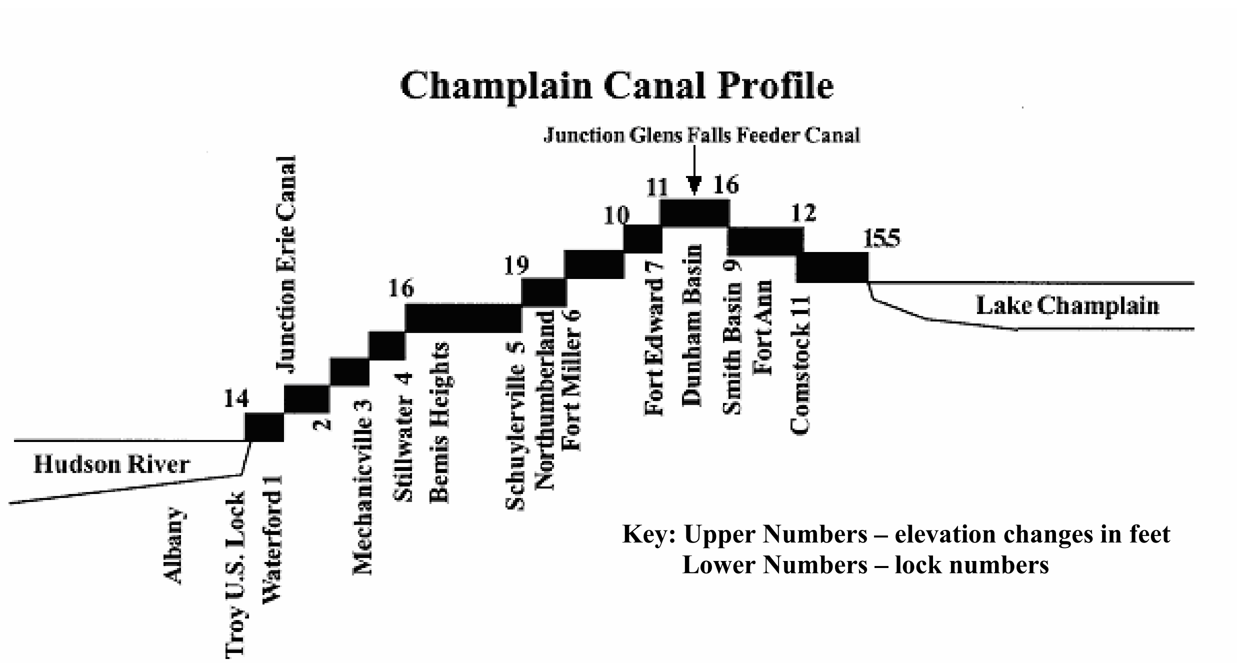

Figure 2. Champlain Canal Profile redrawn from McKibben et al.

As with the rest of the NYS Canal System, the Champlain Canal has transitioned largely to a recreational and historic resource http://www.canals.state.ny.us/cculture/history/index.html). Alternative freight transportation systems (interstate highways, railroads, etc.) and increased tourism opportunities are largely responsible for this shift. The closure of the Plattsburgh Air Force Base in 1995 also reinforced this trend (specifically in the Champlain Canal segment) as the need for barges hauling jet fuel disappeared.

The Canal System opens the first Monday in May and closes in mid-to-late November. Locks operate daily for recreational vessels and on a 24 hour schedule by request for commercial (New York State Canal System Traffic report 1997). The income from the charged fee on vessels passing through Champlain Canal in 1996 and 1997 was $17,390 and $22,625 respectively. Cumulative Vessel Lockings in the Champlain Canal in 2004 were broken down as follows: Recreational 22,315; Cargo 495; Tour 715; Hire 129; State 1,322; Total 24,976 (New

York State Canal System Annual Traffic Report, 2004, NYS Canal Corporation, Office of Maintenance and Operations)

Commercial shipping (as defined by commercial tonnage) on the Champlain Canal has declined to negligible levels in recent years (Figure 3). However, some 770 tons of cargo moved through the canal in 2004, suggesting that commercial interests are still aware of the system's capabilities to move heavy awkward cargo between the Hudson River/Erie Canal and Lake Champlain. Cumulative vessel lockings for commercial traffic still numbers in the thousands, however, suggesting significant amounts of intra-canal traffic between Waterford and Whitehall (Figure 4). Vessel lockings data also underscore the transition from a cargo transportation system to that of a recreational or tourism based system. During the period 1996 to 2004, recreational lockings exceeded commercial lockings by 8 – 10 fold (Figure 3).

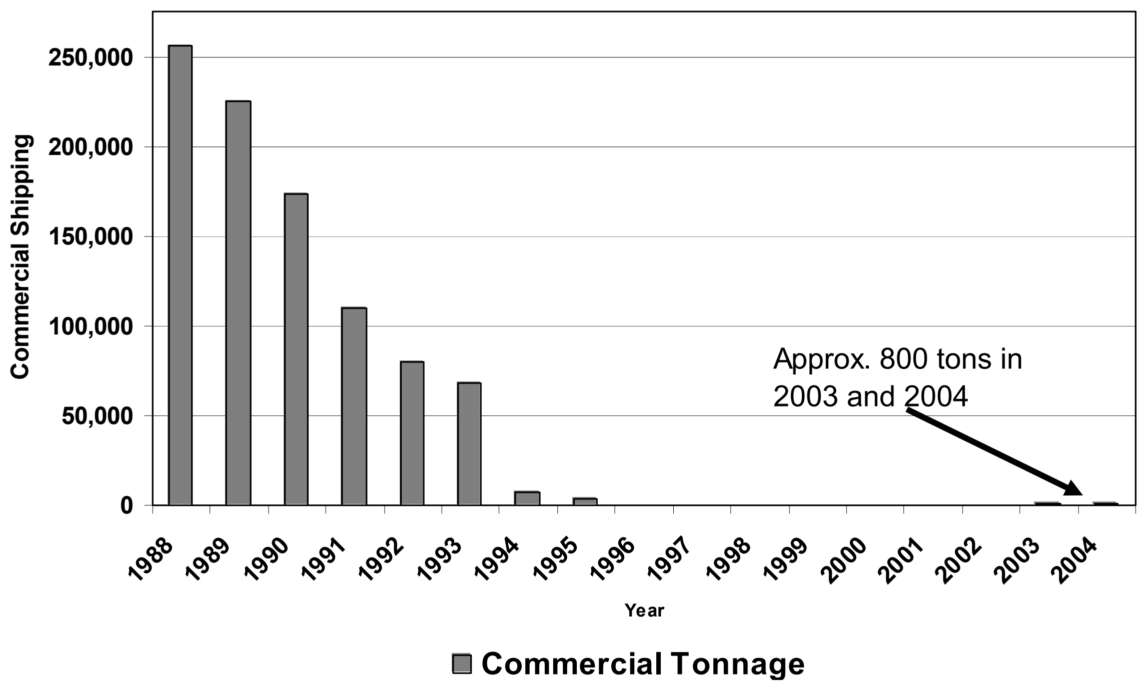

Figure 3. Tonnage of commercial vessels transiting the Champlain Canal from 1988 to 2004.

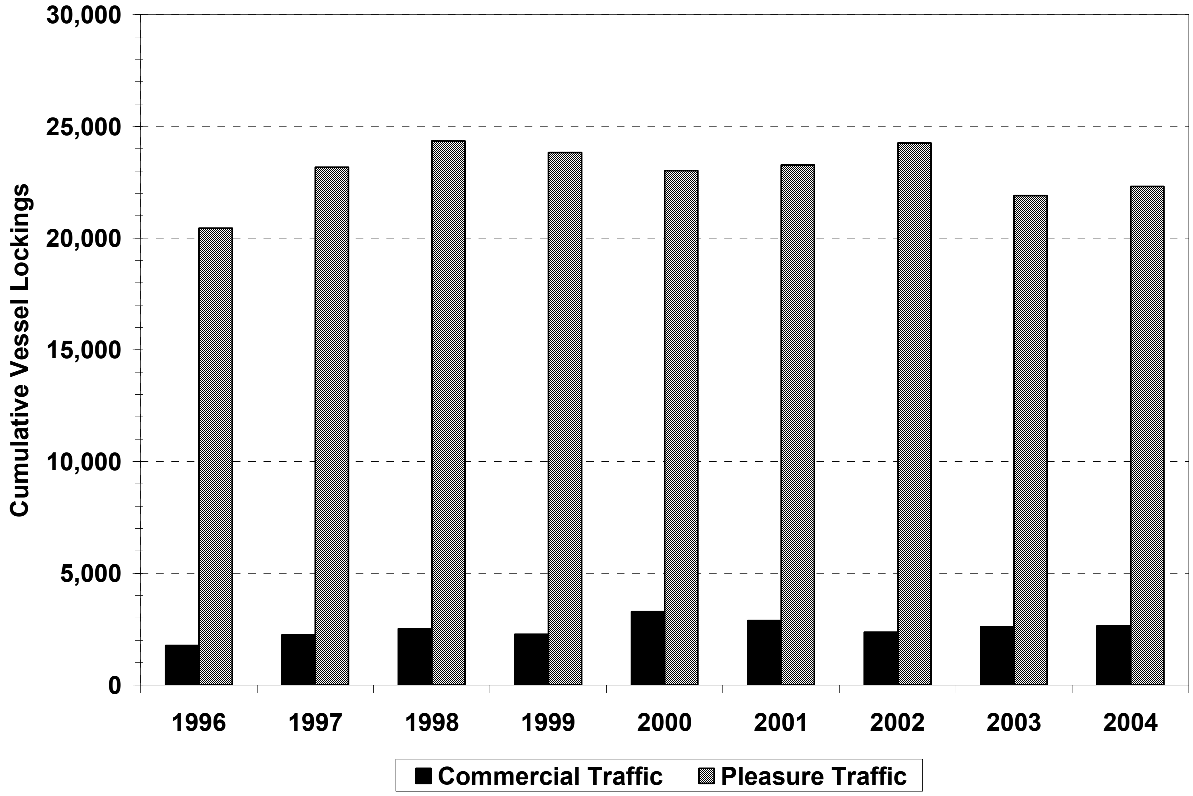

Figure 4. Cumulative commercial and recreational vessel lockings in the Champlain Canal from 1996 through 2004.

Proposed Task/Objective 1a:

Document the impact of ANS (via Champlain Canal) introductions in Lake Champlain to date.

ANS in Lake Champlain

Species exotic to, but now established in Lake Champlain, now total approximately 47 fish, molluscs, crustaceans, plants, and other organisms. We will briefly discuss a subset of this group identified as priority in the Lake Champlain Basin Aquatic Nuisance Species Management Plan. The priority fish-mollusc-crustacean species are: zebra mussel, (*Dreissena polymorpha*) sea lamprey (*Petromyzon marinus*), alewife (*Alosa pseudoharengus*). We will also include brief discussion of white perch (*Morone americana*), and tench (*Tinca tinca),* though these later species are not identified as priority species in the management plan. The priority plant species are: purple loosestrife (*Lythrum salicaria*), Eurasian watermilfoil (*Myriophyllum spicatum),* and water chestnut (*Trapa natans*). Information about known ecological (and to a lesser degree) economic impacts of these priority species are given below.

This suite of organisms was chosen for inclusion here because: (1) all likely came through the canal or Richelieu River (2) they represent perhaps the most significant current threats to Lake Champlain aquatic resources; (3) they are the only ones from the list of 47 for which at least some economic data (primarily control expenditures) are known to exist. The known control expenditure data associated with several of these species in Lake Champlain is summarized in Table 1. As can be seen, public and private sector control efforts for 3 species is expected to exceed $16 million for the period 1982-2008.

Table 1. Known Lake Champlain Invasive Species Costs

	Control Period	Expenditures	Annual Costs
Sea Lamprey[a]	1990-1997	$6,903,700	$862,963
Sea Lamprey[b]	L.T. Program 2005-2008	$1,684,473	$421,118
Water Chestnut[c]	1982 - 2004	$5,802,082	$480,000
Zebra Mussel[d]	2000 - 2002	$91,501	$30,500
Zebra Mussel[e]	1992 to current	$1,635,000	$35,000
Total		$16,116,756	

a) Gillbert, 1999; includes treatment and assessment costs. **b**) Projected TFM and other lamprey mgmt. costs 2005-2008 inclusive, LC Fish. Tech. Committee. **c**) Hunt and Marangelo, 2005. **d**) Marinas, rec. facilities, drinking water systems, commercial firms – this study. **e**) Edward Weed Fish Hatchery, VTFW, K. Kelsey, pers. comm.

Zebra Mussel

Zebra mussels (*Dreissena polymorpha*) are D-shaped mollusks with a brown and white zebra-like pattern. Since their arrival in Lake Champlain during the early 1990s, zebra mussels have colonized the entire lake, though their densities are still extremely low in the north-east portions of the lake. This species is well adapted to spread rapidly into new areas. Adult mussels release millions of eggs and sperm throughout the summer. Newly hatched larvae (or veligers) are tiny and drift near the surface of the water. As the larvae grow into juveniles they settle to the bottom and attach to anything hard: rocks, native mussels, plants and man-made objects. Under certain conditions, juvenile zebra mussels will also colonize soft sediments. This mollusk clings tightly to various objects by producing a mass of tiny fibers called byssal threads. These fibers attach at the mussel's hinge and adhere to nearby hard objects. Zebra mussels usually settle in depths less than 25 feet, but have been found in up to 225 feet of water.

Zebra mussel invaders are often adults brought to new lakes mostly attached to boats or to vegetation caught on boat trailers. Sometimes the microscopic larvae can be carried in the water of engine cooling systems, boat bilges, live wells, bait buckets, scuba equipment, and possibly kayak flotation compartments. Zebra mussels were first sighted as adults in the south end of the lake in 1993, having apparently entered the lake via boats traversing the Champlain Canal; it is also possible that they were introduced on a trailered boat.

Pimentel et al. (2000) reported that zebra mussel fouling caused $100 million per year in damages to electrical generating plants in the U.S. We surveyed marinas, recreational facilities, institutions, municipal drinking water systems, and commercial firms and found direct expenditures associated with Lake Champlain zebra mussel maintenance costs equal to $91,501 for the period 2000 to 2002. Costs associated with the prevention of zebra mussel colonization of the Ed Weed Fish Hatchery infrastructure in Grand Isle, VT have been estimated at about $35,000 per annum or a total of 1.6 million since the discovery of zebra mussels in Lake Champlain in 1992 (K. Kelsey,
VTDFW, pers. comm.).

Sea Lamprey

Though the status of sea lamprey as a non-native has recently come into dispute, it remains classified as a nuisance species with an enormous impact on lake trout, landlocked salmon, and other native fish. If it is non-native to Lake Champlain, it probably entered the lake via one or both of the canals. Its parasitic life style at the sub-adult stage results in extremely high wounding rates for its targeted species – primarily salmon and trout. The economic damage attributable to this species has not been calculated to date, though some costs have been tallied. At current sea lamprey population levels, fisheries managers have conceded that restoration of native Atlantic landlocked salmon and lake trout fisheries are impossible (though the recreational fishery for both species can be sustained by stocking). Expenditures by New York and Vermont anglers who targeted Lake Champlain trout and Atlantic landlocked salmon was valued at $37,398,827 and $24,501,250, respectively, in 1997 (Gilbert, 2000). These expenditure data and the threat posed to trout and salmon restoration were key justifications for adoption of the *Long Term Program of Sea Lamprey Control in Lake Champlain* (Fisheries Technical Committee, 2001). The estimated annual cost of current sea lamprey management is $612,000 per year (USFWS/Fisheries Technical Committee, 2001).

Alewife

This marine invader arrived in Lake St. Catherine in 1997, and has now disrupted the food web in that lake. Lake St. Catherine is in the Lake Champlain drainage and this non-native invasive species could reach Lake Champlain via the following downstream route: Mill Brook to the Mettawee River to the Champlain Canal in the vicinity of Locks 11 and 12.

> ……*The implications of alewives becoming established in Lake Champlain are serious. The multi-million dollar Salmonid Restoration Program run by Vermont, New York, and the U.S. Fish & Wildlife Service could be in jeopardy. Direct competition from alewives could negatively impact native fish communities including smelt, yellow perch, and other important forage fish which game fish populations such as trout, salmon, and bass depend on.* (VTDEC Alewife pamphlet, undated)

The USFWS Lake Champlain Resource Office recently commissioned an investigation of the feasibility of Lake St. Catherine alewife eradication. It has been estimated that the cost of this eradication (via complete destruction of the entire Lake St. Catherine fish community) would be approximately $665,162 (Spateholts, 2004). The eradication effort is being considered by the Lake Champlain Fish and Wildlife Management Cooperative. While expensive, it may represent the best option for preventing a likely colonization of Lake Champlain by alewives moving downstream from Lake St. Catherine.

Early in 2005, biologists confirmed the identity of several clupeid fish collected in Missisquoi Bay by Québec Wildlife staff in 2003. It now appears that alewife are reproducing in Lake Champlain.

White perch

White perch apparently colonized Lake Champlain via the Champlain Canal with a first reported occurrence in the lake in 1984 (Plosila and Nashett, 1990). Its absence in Lake Champlain between completion of the canal in 1837 and first occurrence in 1984 is puzzling. However, water pollution control efforts in New York were greatly spurred following enactment of the Federal Water Pollution Control Act Amendments of 1972, and adoption of the Clean Water Act in 1977. Evidence suggests that declining pollution levels in the early 1980's eliminated a *de facto* fisheries barrier (or at least filter) that was likely present in various portions of the NY State Canal system, including the Champlain segment (Daniels, 2001).

The ecological impact of the white perch invasion of Lake Champlain has not been researched. However, white perch were shown to prey heavily on the eggs of walleye *(Stizostedion vitreum vitreum*), subsequent to white perch invading Lake Erie via the Welland Canal in 1953 (Schaeffer and Margraf 1987). Some researchers have also documented white perch interactions with forage fishes that could serve to reduce available food supplies for walleye (Parrish and Margraf, 1994). White perch may also compete indirectly with yellow perch under certain conditions (Parrish and Margraf, 1994). While no direct evidence exist for these impacts in Lake Champlain, it should be noted that fisheries based upon the native walleye and yellow perch are important. Some sportsmen groups have argued that Lake Champlain walleyes in the southern portion of the lake have recently declined (relative to the 1980's), concurrent with increases in white perch populations. Recently trap net samplings (2004) by USFWS personnel have lent some support to this argument, though thorough creel survey and population analysis are lacking (D. Nettles, pers. comm.). Expenditures by New York, Vermont and non-resident anglers who targeted Lake Champlain walleye and yellow perch was valued at $6,741,697 and $5,427,056 respectively, in 1997 (Gilbert, 2000).

Tench

In October 1999, biologists with Quebec Parks and Wildlife, confirmed the presence of a new, non-native fish in the South River - a slow flowing creek that joins the Richelieu River about 12 miles northeast of Rouses Point, NY. This carp-like fish is known as the tench (a member of the cyprinid or "minnow" family) and is native to Europe. It became established following release from an aquaculture facility near Saint-Alexandre. Tench are commonly cultured in Europe for human consumption. The Saint-Alexandre fish farmer envisioned additional markets in Canada, prompting the establishment of tench pond culture sometime after 1990 (Dumont et al, 2003).

Interviews with Quebec commercial fishermen suggest that these fish were established and reproducing by 1994. Adult specimens measuring up to 18 inches and nearly 3 pounds have since been examined by biologists with Quebec Parks and Wildlife agency. In 2002, an angler caught a single specimen while angling in the Great Chazy River, NY - the first known occurrence in the NY portion of the Lake Champlain watershed (Marsden, pers. comm.). Tench have yet to appear in routine fisheries monitoring efforts by NYS.

The ecological impacts of tench are not well known, though it is considered a pest in Maryland and Idaho (Fuller et al. 1999). Its diet overlaps with that of native cyprinids and suggests potential impact to minnow populations (Moyle, 1976).

Dumont et al. (2003) suggest that tench: 1) have the ability to expand their population in the Laurentian- Great Lakes system as a function of their feeding ecology and tolerance to low oxygen environments; 2) could be poised for range expansions via the Richelieu River and the Lake Champlain–Hudson River–Erie Canal system.

Eurasian watermilfoil (*from LCBP ANS Management Plan)*

Eurasian watermilfoil, a perennial, submersed aquatic plant native to Europe, Asia, and parts of Africa, was first discovered in New England in 1962 when it was reported in St. Albans Bay of Lake Champlain (Countryman, 1975) and is now widely distributed throughout North America. The aquarium trade likely played a role in its initial introduction and spread (Couch and Nelson 1985). A 1976 survey of Lake Champlain showed Eurasian watermilfoil present in all areas of the lake and estimated that several thousand acres of the lake were infested (Countryman, 1978). Eurasian watermilfoil continues to occupy an extensive range throughout the lake and it infests at least 40 other bodies of water throughout the Lake Champlain Basin. New infestations of Eurasian watermilfoil are discovered nearly every year. Fragments attached to trailered boats are the likely cause of these overland introductions. Eurasian watermilfoil can proliferate in high densities in lakes causing impairments to water recreation such as boating, fishing and swimming and a reduction in native species. The establishment of Eurasian watermilfoil in Lake George, New York significantly reduced the number of native plant species in just two years (Madsen et al, 1991).

Numerous Eurasian watermilfoil control technologies have been employed within the Lake Champlain basin including bottom barriers, suction harvesting, mechanical harvesting, hand-pulling, lake drawdowns, hydroraking, and biological controls. Several chemicals have been used to control Eurasian watermilfoil in bodies of water within New York.

The expense of Eurasian watermilfoil control programs can reach millions of dollars to implement successfully. For example, since 1982, more than $4.1 million of federal, state, and local funds (excluding salaries and administrative costs) and thousands of volunteer hours have been spent to control Eurasian watermilfoil populations in the State of Vermont. In one lake alone, the Upper Saranac Lake of New York, the cost of a three-year Eurasian watermilfoil control program initiated in 2004 will total $1.5 million.

Purple Loosestrife

An erect, perennial herb that grows up to 8 feet tall, purple loosestrife was introduced to the United States from Europe in the early 1800s in ship ballast and as a medicinal herb and ornamental plant. The magenta flowers have five to seven petals and are arranged in long racemes. Since 1880, the distribution of purple loosestrife in the United States has been increasing rapidly (Thompson et al. 1987). From 1940 to 1980, the rate of spread was approximately 1.5 latitude-longitude blocks per year. The plant now grows wild in at least 42 of the 50 states, with greatest concentrations in New England, Mid-Atlantic, and Great Lakes states. In the eastern and central United States, purple loosestrife grows best in freshwater marshes, open stream margins, and alluvial floodplains. Loosestrife often grows in association with cattails, reed canarygrass, and other moist-soil plants.

Wetlands infested with purple loosestrife often lose 50% of native plant biomass. It is not uncommon to find affected wetlands that have been 100% infested. In such densely infested areas, predator/prey relationships change due to changes in food and cover, resulting in a reduction of vertebrate and invertebrate populations. This highly competitive plant especially threatens endangered, threatened, or declining plant and animal species (Thompson et al. 1987). Nurseries across the country still sell purple loosestrife as an ornamental despite its well-known impacts on wetlands. Loosestrife is promoted for use as a landscape plant and as a nectar plant in honey production. About 24 states have listed purple loosestrife as a noxious weed and prohibit its sale and distribution. Since purple loosestrife is very difficult to control once established, the best defense is to prevent its spread and to eradicate new populations as soon as possible (Stein and Flack 1996).

Water Chestnut

Water Chestnut is native to Eurasia and is naturalized in North America. It is frequently cultivated in Asia and elsewhere where the fruit is eaten. Water chestnut was introduced into North America about 1874 and was cultivated in the botanical garden at Harvard University in the late 1870's and later escaped to nearby ponds and lakes. It ranges from Massachusetts, to western Vermont, eastern New York, Maryland, and Virginia (Crow & Hellquist 1983). Water-chestnut is an annual with elongate, mostly simple stems which grows submersed, rooted in the substrate.

Plants grow rooted in soft mud in lakes, ponds, canals and slow backwaters and bays of rivers, in up to 5 m of water. Mature nuts sink to the bottom and may germinate for up to10 years. These edible nuts are dispersed by animals and by water. Water chestnut can grow in any freshwater setting, from waters to 12 feet deep, although it prefers nutrient-rich lakes and rivers. Water chestnut can form dense floating mats, severely limiting light -- a critical element of aquatic ecosystems. This plant can also reduce oxygen levels, which may impact juvenile fish habitat (Caraco and Cole, 2002). It competes with native vegetation and is of little value to waterfowl. Water chestnut infestations limit boating, fishing, swimming and other recreational activities. Further, its sharp fruits, if stepped on, can cause painful wounds.

Management of water chestnut in Lake Champlain consists of mechanical harvest and hand pulling (both contracted and volunteer). Costs associated with the harvesting and control program on Lake Champlain have recently averaged about $480,000 per year. Total costs for the period 1982-2004 total of $5.8 million (Hunt and Marangelo, 2005). Biological controls are being investigated, but no species have been approved for release.

Proposed Task/Objective 1b:

Conduct a threats assessment of future introductions likely to occur absent any physical/procedural changes in the canal structures and/or operations.

To accomplish this task we conducted a literature review and initiated contacts with other aquatic invasive species specialist in the Great Lakes and Hudson River drainages. Additional information was collected from various Internet web sites, including the *National Aquatic Nuisance Species Clearinghouse* (http://www.aquaticinvaders.org/nan_ld.cfm), along with other Sea Grant and federal agency (i.e. U.S.G.S.) sites. From these sources, we established the following list. All of these organisms are seen as potential invaders of Lake Champlain via the Champlain Canal.

Threats from Lake Ontario

- fish-hook waterflea (*Cercopagis pengoi*)
- spiny waterflea (*Bythotrephes cederstromi*)
- *Daphnia lumholtzi*
- round goby
- *Echinogammarus*
- *Eurytemora affinis*
- *Skistodiaptomus pallidus*

from the Hudson River and Estuary

- European stream valvata
- liver elimia
- Wabash pigtoe
- paper pondshell
- Atlantic rangia
- *Procambarus acutus*
- *Gammarus daiberi*
- *Ripistes parasita*
- *Cordylophora caspia*

from the Erie Canal portion of the NYS Canal System

- quagga mussel
- Piedmont elimia snail

Proposed Task/Objective 2:

Develop recommendations relating to possible canal barrier solutions using a process of key informant interviews, cost-benefit analyses, Delphi process, and final small group workshop techniques.

Lake Champlain and Champlain Canal Stakeholder Input

Two major stakeholder participation efforts were undertaken to gather stakeholder input relative to the problem of ANS vectors for Lake Champlain.

Workshop

On May 9, 2002 Lake Champlain Sea Grant convened a workshop to: 1) inform stakeholders of the current state of knowledge of aquatic nuisance species in Lake Champlain; 2) initiate a dialog with stakeholders; 3) gather opinions, knowledge, and ideas from stakeholders that might help formulate possible solution to the problem of invasive species migration through the canal. Participants included marina operators, natural resource agency staff, tourism representatives, boaters, shoreline property owners, and others. Approximately 40 attendees learned about canal history, design, invasives problems, and possible solutions. Speakers also presented information about the Chicago Sanitary Ship Canal and its role as an invasive species vector between the Mississippi and Great Lakes watersheds. Much of the day was aimed at gathering stakeholder's views about the canal attributes and liabilities relative to tourism, commerce, public policy, and invasive species. The collective list of concerns given by workshop participants is given in Appendix C.

Champlain Canal Barrier Options Delphi Survey Report

Following the workshop, we surveyed knowledgeable opinion leaders on issues similar to those explored at the workshop. A full report on the survey is given in Appendix D. The following is a portion of the summary authored by Bryan R. Higgins, Department of Geography and Planning, Center for Earth and Environmental Science SUNY Plattsburgh.

> *This Delphi Survey identified a number of pivotal public policy issues in regard to Champlain Canal barrier options. Since Lake Champlain has two access canals, the Champlain Canal in New York State and the Chambly Canal in Quebec, it is important to consider this overall geographical context. It should be noted that the grant which funded this research project was directed only toward the Champlain Canal in New York. Yet, to evaluate the feasibility of a barrier in only the Champlain Canal would be shortsighted, since aquatic plants and animals may also enter Lake Champlain from the Chambly Canal. It is therefore recommended that any public policy assessment of a canal barrier explicitly consider both canals. Second, a variety of notions have been offered to justify a canal barrier including the potential threat of "non-indigenous", "invasive", "nuisance", and "exotic" species. Each of these terms has a distinct definition and social context for public policy analysis within the Lake Champlain basin. For example, if "non-indigenous species" are defined as the threat, why are "non-indigenous fish" currently stocked in Lake Champlain? Thus, attention should be given to systematically define the key notions and public policy framework for assessing a canal barrier. Third, given the diversity of frameworks for understanding nature and perceived importance of a wide range of values, policy analysis of potential canal barriers should establish a systematic framework that includes and assess direct, indirect, option and existence values. Fourth, given the multiple paths by which plants and animals may enter Lake Champlain, public*

policy studies should simultaneously assess the potential of all key alternatives such as release of live bait, home aquarium fish, and boats entering the basin by trailer. Finally, even though fish species are clearly important, assessment of canal barrier options should systematically evaluate the potential for all species.

Stakeholder Summary

These efforts confirmed a diversity of opinions among the many stake holders and opinion leaders. While many expressed concerns over the invasive species issues, some people didn't feel that the canal posed a significant risk as an invasives pathway. Others felt that any modifications done to the Champlain Canal must simultaneously address another canal pathway at the outlet to Lake Champlain in Quebec – namely the Chambly Canal that bypasses two non-navigable sections of the Richelieu River. Still others didn't feel the canal was the most important pathway relative to boat trailers, bait trade, aquaria/pet trade, and other vectors.

Project Findings

Subsequent (and ongoing) extensive literature reviews by two of us (Marsden and Hauser) indicate that exotic species introduction via one or both of the canals represent at least 40% of the introductions for which the vector is known or can be reasonably guessed at (Figure 5). While a project to reduce future invasions via the Champlain Canal would certainly not eliminate the risk of invasions, other pathways of invasion are or have been addressed separately. Despite the historic introduction of rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) to the lake, management agencies no longer perceive stocking of exotic species as a desirable management strategy; future introductions through deliberate stocking are unlikely. Legislation to control the introduction of non-native bait fish species in Vermont was passed in 2002, effectively reducing the risk of new introductions via this route (Note: this issue remains largely intractable in New York). In response to the problems caused by zebra mussels, water milfoil, and other exotics in the Lake Champlain basin and throughout the Great Lakes region, public education campaigns and signage at boat launches have addressed the risk of invasions via boat trailers and aquarium dumping.

Once appropriate technology is in place in the Champlain Canal to restrict future introductions of exotic species, similar methods can be applied to the Chambly Canal. However, this project was initiated in the U.S., and the researchers have no jurisdiction to work in Canada. Moreover, the Chambly Canal, unlike the Champlain Canal, does not link Lake Champlain to any new ecosystems; it is only a more navigable stretch of an existing aquatic conduit, the Richelieu River. Thus, the risk of novel introductions occurring via this pathway is lower than from the Champlain Canal.

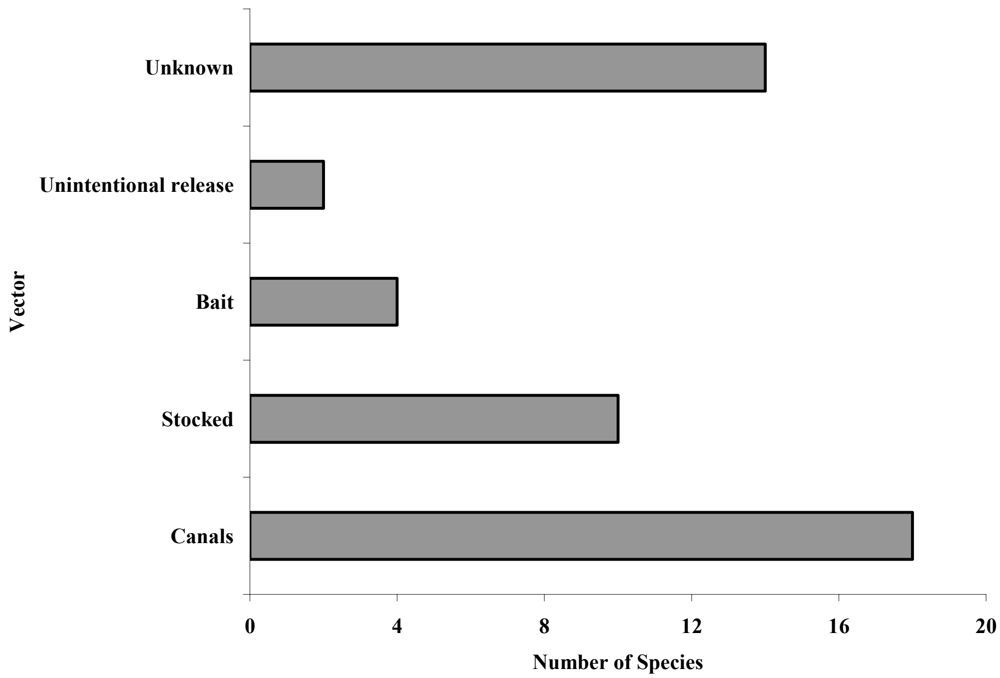

Figure 5. Number of exotic species that have entered Lake Champlain, categorized by vector of arrival.

Potential ANS Canal Barrier Solutions

Review of the alternatives that would stop exotic species transfer through the Champlain Canal points out several principles:

1. A barrier to exotics must address multiple taxa. While considerable attention is generally placed on the more obvious and damaging taxa – fish and plants – many organisms are microscopic (plankton, bacteria, fish diseases), and many exotics have small to microscopic life stages (e.g., zebra mussels). Thus, a barrier must address transport of organisms by vessels through the canal, <u>and</u> transport in the water itself.
2. While an optimal barrier would be 100% effective at preventing transport through the canal, this should not be the criterion for success. Even an 80% reduction in the probability that a species could enter Lake Champlain via the Champlain Canal represent significant progress in protecting the ecology of the Champlain basin.
3. An effective solution to exotic species transport via the Champlain Canal will likely involve several options used simultaneously. Public education and outreach will be a critical component of any solution, to enable the public to understand why the barrier is in place, and avoid making accidental introductions via other pathways such as bait buckets and aquaria. Many of the technological barriers work best in concert with one another; for example, one method may be used to block vertebrates, while another might be used simultaneously to prevent the spread of plants.

We also note that any method that reduces the passage of exotic species through the Champlain Canal also benefits the Hudson, St. Lawrence, and Great Lakes ecosystems, as Lake Champlain has historically served as a conduit for species between these ecosystems (Daniels 2001).

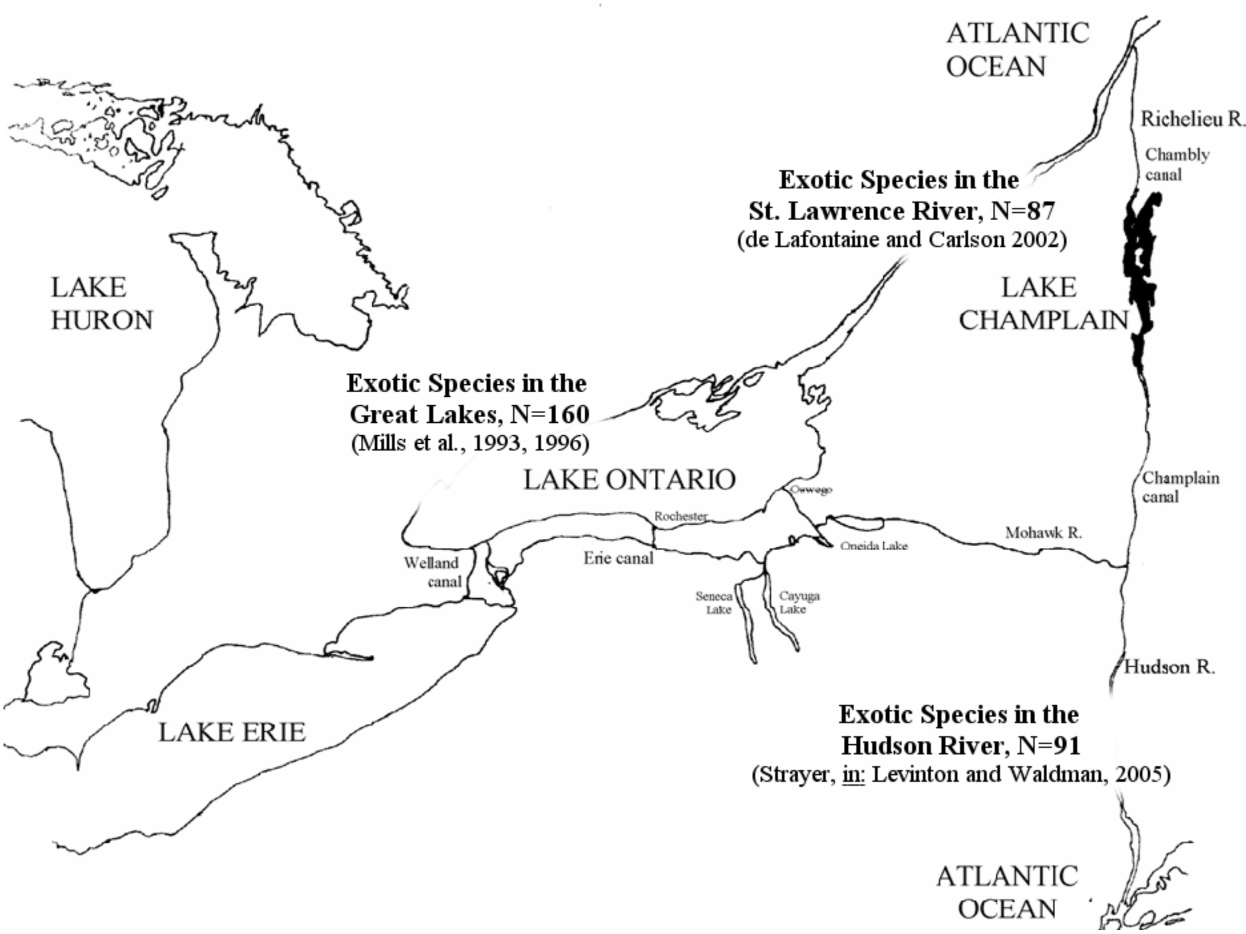

Figure 6. Relative magnitude of aquatic invasive species threats in nearby watersheds

Alternative One: Do Nothing

(i.e. No change in canal engineering or operations)

This alternative implies an acceptance of the consequences of additional exotic species entering Lake Champlain. It may be considered that the expense of a barrier is too high, the risk of new species entering the lake through the canal is low, and the probability of any new invaders becoming nuisances is too low to warrant action. These ideas and opinions were recorded at the May 2002 Champlain Canal Stakeholders (LCSG workshop summary, 2005), and in a related Delphi Process exercise that solicited opinions of stakeholder experts (Higgins, 2003).

Lake Champlain currently has on record 47 exotic species. Though not insignificant, this number is low relative to the number non-native species that have invaded nearby watersheds (Figure 6). Alternative One does not address the threat of new exotic species reaching Lake Champlain from the Great Lakes and Hudson River via the canal system. Several species have the potential to invade Lake Champlain via the Champlain Canal including round gobies, fishhook waterfleas, ruffe, quagga mussel, Asian carp, and alewife.

Benefits:

Benefits include no monetary costs for prevention or treatment of invasive species to Vermont or New York, to taxpayers, or to recreational users. Current economic contributions from tourism associated with canal travel and commerce would continue.

Costs:

Experience in other parts of the country shows that allowing continued entrance of new exotic species may result in destruction and extinction of native plants and animal species and their habitats. Additional exotic species (i.e. round goby, fishhook waterflea, ruffe) over time could disrupt the Lake Champlain Basin ecosystem, thereby lowering its value to recreational users, anglers, and the adjacent economy. Despite the view of stakeholders and experts surveyed in the Delphi process, a very thorough literature review conducted here strongly argues that the canal represents the single largest known vectors of Lake Champlain ANS (Figure 5).

Several challenges make it difficult to estimate of dollar value costs associated with potential new invasions of the lake via the Champlain Canal. Indeed, evaluation of regional or site-specific economic impact of ANS is often problematic, and few studies exist even at the national level (Lovell and Stone, 2005). The ecosystem and economic costs of these new invaders are unknown, and unlikely to be known prior to invasion, but likely will be enormous if current impacts of lamprey, zebra mussels and water chestnut are any indication. As an example, Pimentel (2005), estimates the total annual cost of invasions linked to the New York State Canal and Hudson River systems to be nearly $500 million per year. Impacts associated with losses to sport and commercial fishing were responsible for 80% ($400 million) of the total.

Alternative Two: Close the Champlain Canal

This solution is drastic, and the only one that has a 100% probability of preventing further transport of exotic aquatic species into Lake Champlain via the Champlain Canal. Closure would produce a loss of more than 20,000 recreational boat passages through the system (Figure 4).

The closure of the canal would also have a significant influence on other tourism activities that link to the economy of the region. It would also eliminate a unique cultural heritage resource from the region. Boater options for accessing the Great Lakes and Hudson River from Lake Champlain, and vice versa, would be severely curtailed. Impacts on commercial canal and lake traffic in the region would be significant, despite changing uses of the canal in recent years. If the canal was neither filled nor otherwise managed, closure might create artificial wetlands and ponds with both societal and ecological benefits and costs. A more apt description of this option might be “dewatering” of the Champlain Canal system. Since water depth for navigation is maintained via a system of locks and “make up water” (i.e. feeder canals), it may be fairly easy to dewater the system. However, flow into the canal bed via feeder canals (primarily Glens Fall feeder canal) would need to be addressed.

Benefits:

The closed canal could be converted to a variety of uses. Water could potentially be stored in newly ponded sections of the canal. Canal beds might be used for sport activities, or completely filled and the land recovered for alternate uses. Though not estimated, there could presumably be some small economic benefits associated with minor recreational uses (bike paths, fishing sites, etc.) Ecological benefits associated with dewatering could be major, given the role of the canal as a major ANS conduit.

Cost:

The Champlain Canal supports very few commercial vessels and evidence suggests that at least some of this traffic is not time-sensitive. Lock transits in the late 1990s varied from 195 to 390 transits per lock. Total tonnage of commercial goods traversing the canal has steadily decreased in the last decade, to less than 10% of total transits in 1997. Recreational transits at each lock during the same period ranged from approximately 1,700 to 2,420 vessels. Cumulative Vessel Lockings in the Champlain Canal in 2004 were broken down as follows: Recreational 22,315; Cargo 495; Tour 715; Hire 129; State 1,322; Total 24,976 (Canal System Annual Traffic Report, 2004).

Use of the canal requires permits for lock use and opening of bridges. Passes vary from a 2-day pass for small boats at $5, to a seasonal permit for large vessels, which can be as much as $100. Total income from the permits and passes in 1997 was $22,625. Newer income data for the Champlain Canal are unavailable, though the New York state canal system as a whole is thought to contribute $384 million dollars annually in economic benefits (Canal System Annual Traffic Report, 2004). If the canal is closed, the revenues are definitely influenced. Allowing for the small scale of commercial uses by the canal, we expect that the opportunity cost in closing the canal would be limited. However, in terms of individual stakeholders (i.e. Lake Champlain Transportation Company) the strategy would push them into the margin of business risk (W. Dumbleton, LC Trans. Co., pers. comm.).

Alternative Three: Physical/Mechanical Modifications to the Canal

Physical barrier

It may be possible to fill or dewater a very short stretch of the canal to serve as an ANS barrier. Existing locks could be made to open only for commercial transits, and only by permit for emergency/priority use. Recreational vessel passage would be enabled by short-distance transport vehicles/systems. Obviously, significant engineering or operational solutions would be needed to allow for both recreational and commercial vessel passage under this scenario.

At least three applicable methods have been developed to transport pleasure boats short distances overland. These methods could readily be adapted to boats needing to circumvent a physical canal barrier. The simplest approach is the forklift system used at many dry-stack boat storage yards and marinas. A second technology is the sling-type lift in which a boat is lifted, transported a short distance overland via a lift vehicle, and subsequently lowered back into the water. This boat hoist system is used to annually remove boats from the water for winter storage. Sling-type lifts have been designed for 600 ton capacity, though units above 150 tons capacity are relatively uncommon. A third system is the marine railway such as the Big Chute railway used on the Trent-Severn Waterway (see: http://collections.ic.gc.ca/waterway/ov_eng_i/bigchute.htm). This technology was first incorporated during construction of the canal in 1917. A "new" railway was opened in 1978 with a capacity of 90 tons and 100' long and 24' wide, able to accommodate up to 6' draft.

Passage of commercial/state barges, tugs, tour boats etc. around any physical barrier is much more problematic. Travel lift technology would not enable passage of large vessels (i.e. barges, ferries). Vessels in this class would have to be accommodated by marine railway systems, or perhaps via highly regulated rare instance uses of specialized new locks (e.g. graving docks), built adjacent to/around the separation barrier. Marine railways continue to exist in old shipyards (Shelburne, VT; Greenport, NY) and may have broader application as boat transportation devices around invasive species barriers. Graving docks (also known as dry docks) which are normally used for major hull maintenance could also be used to block ANS. This technology dates to at least 1746, when a new graving dock was built in Liverpool, England for ship maintenance and removal of barnacles (http://www.diduknow.info/docks/access/gl_graving.asp and http://www.diduknow.info/docks/access/dock_history7.html).

In the case of the Champlain Canal, commercial (and similar vessels) could theoretically be locked into a dry dock which could serve as a physical ANS barrier when the lock area is dewatered. The Lake Champlain Transportation Company has suggested this technology could be used in the transport of new ferries to Burlington, VT – a scenario repeated about once per 3 to 5 years since 1971. (W. Dumbleton, LCTC, pers. comm.). Similarly, existing locks could be used but could remain closed except by permit. Such transits might be limited to spring-fall periods when low water temperatures and ANS life-history patterns (i.e. few eggs, larvae) combine to minimize the risk of unwanted ANS passage.

A physical barrier in the Champlain Canal would ideally be located at the high point of the system, between locks 8 and 9. In this manner both northerly and southerly bound ANS would be blocked before "crossing the divide." Currently, ANS passing this region are transported down slope, effectively reaching a new watershed. Since makeup water is introduced at this point via the Glens Falls Feeder Canal, some provision would need to be made for supply of ANS-free water to either side of a physical barrier.

This method would be effective at blocking movements of all taxa. Assuming some degree of boat hull inspection and cleaning takes place during transit over the barrier, and that live wells, bait buckets, etc. are emptied; the effectiveness approaches 100%.

Benefits

Hydrologic separation is documented in the Chicago Sanitary Ship Canal Barrier II discussion as offering THE best insurance against invasive species expansion via canal (Wisconsin Sea Grant, 2001). While it cannot address the problem of other pathways (e.g. use of trailered boats, bait and aquaria release), it does address nearly all taxa and life history stages of the most threatening invasive species.

The delay imposed on recreational boaters while their boat is being transferred across a barrier provides educational and economic opportunities. Boaters will be forced to realize that exotic species are having an impact on their lives, and may be more willing, in consequence, to learn why the barrier has been constructed and how their activities can help to reduce exotic species transfer. The importance of the exotic species problem is dramatically highlighted by the presence of the barrier.

During the transfer of boats, boaters may find the time useful to engage in a variety of activities, perhaps restocking supplies at a local chandlery, sampling locally produced foods and beverages, pumping out the head, inspecting the hull, effecting minor repairs, or shopping at local businesses. While the transfer itself may take less than 15 minutes, the break in passage (which will be anticipated, as boaters become aware of the change in the canal operation) may lead to longer-term stay-overs while boaters attend to various needs. Construction of a small slip area near the barrier would facilitate boaters taking time to engage in these activities, which may lead to increased economic health of the region. A variety of tourism opportunities may be developed, or may grow in the region of the barrier. Indeed, the Big Chute Marine Railway in Ontario, Canada is managed by Parks Canada and provides both positive ecosystem protection benefit and economic tourism benefit.

Additionally, pumping, collection, and treatment of dirty bilge water at the barrier site would contribute to improved water quality. Water treatment could be effected by sending the water to a municipal water treatment plant instead of having on-site water treatment.

Costs:

Total costs for installation of a sling-type lift are unknown. Some cost and other data provided by the dominant manufacturer (Marine Travel Lift, Inc) are given in Table 2. Other costs (site preparation, dredging, etc.) are yet to be estimated. The cost of building a graving/dry dock is also yet to enumerated, and likely represents a significant investment in new canal infrastructure. Transporting boats across a barrier will carry a per-boat cost. This cost can be paid by the boater, as a tax for use of the canal system, by the state(s) that are protected by the presence of the barrier, by the businesses that benefit from the barrier to slow boat traffic and provide commerce opportunities, or a combination of the three. Vessels transiting the Trent-Severn Lockage in Ontario, Canada are charged per foot length of vessel. Some examples are: single lock and return – $0.85; single day – $1.50; transit one-way – $4.25; six-day – $4.60 and seasonal – $8.10.

The primary limitation of this strategy is the inability to lift very large vessels. The travel lift may pose a limitation on the size of ships that pass through the canal. As shown in Table 2, typical sling-type lifts are best suited for recreational vessels (i.e. beam <26 ft).

Additional methods would be needed to pass ferries and other large vessels as reviewed above. Each of these methods has an associated cost to be considered in greater detail; a fee could be charged for these larger vessels to offset the added cost of exotic species prevention. In addition, the strategies of canal closure or travel lift bypass would influence some private companies' (for example, the Lake Champlain Transportation Company) operations and may consequently contribute to business losses.

Table 2: Product Information for Travel Lifts by Marine Lift, Inc.

Model	100BFM	150BFM
Maximum lifting capacity(lbs.)	220,000	330,000
Recommended maximum boat length	95'	105'
Recommended maximum boat beam for std.width	25'	26'
Inside turning radius(wheel at 90 degrees)	0"	0"
Outside turning radius	50'0"	52'0"
Overall height	30'11"	33'0"
Inside clear height(under front beam)	28'0"	30'0"
Overall width	33'6"	38'0"
Inside clear width	26'0"	28'0"
4-wheel drive option	No	No
Base Price (from phone call)	$350,000	$400,000
Radio Control Option	$10,000	$10,000

Alternative Four: Behavioral Barriers

Sound/bubble/electrical barriers

It is theoretically possible to address free-swimming ANS invasions through the installation of various behavioral barriers (Patrick et al., 1985; Sager et al., 1987; Bullen and Carlson; 2003). Such barriers include electrical, sound, bubble curtain, strobe-light and various combinations of the above. These technologies (alone and in combination) have been used successfully to deter some fish from power plant intakes, irrigation canals, and other engineered conduits and waterways. The concept of an electrical barrier for the Champlain Canal was first investigated by Smith-Root, Inc. at the request of NYSDEC in 1989 (Smith-Root, Inc., 1993). The primary concern at that time was the potential invasion of alewife into Lake Champlain from the Hudson River. The plan was not pursued due to concerns about safety and liability by the NYS Canal Corporation. In April, 2002, an electrical barrier (Barrier I) was put into operation on the Chicago Canal to prevent fish movement between the Mississippi River drainage and the Great Lakes drainage. A more permanent barrier (Barrier II) has been funded and is scheduled for completion in 2005 (http://www.seagrant.wisc.edu/ais/Default.aspx?tabid=393). An electrical barrier is only effective against vertebrate aquatic species (fishes) and, to some extent, macroinvertebrates (crayfish) and large insect larvae; the field would not affect plants or bacteria, and would have a negligible effect, if any, on plankton or mollusks.

Benefits:

Boating traffic would be unimpeded, and the effect of the installation on the canal scenery could be relatively minor. Historical architectural impairment to existing canal infrastructure could likely be mitigated through use of period facade on new buildings, etc.

Costs:

Installation costs may be comparable to the cost of the Chicago Canal electrical barrier, as there is little economy of scale. The cost of installing the long-term electrical barrier is estimated at $6.7 million, with an additional $1.7 million in design costs (P. Moy, Wisconsin Sea Grant, pers. comm.). Annual costs would include maintenance and power use. Opportunities for public education at the site would be limited since boaters would not need to stop at the barrier. However, a docking area and public outreach/education center could be planned at the site. Public concerns about safety would have to be addressed. The cost involved in the method includes:

1. site investigation
2. construction
3. electrodes
4. annual operation and maintenance
5. annual electricity
6. monitoring
7. hydro-acoustic array

Alternative Five: Chemical/Water Quality Barriers

Water entering specialized locks in the vicinity of the Glens Falls feeder canal could theoretically be treated using a variety of methods to make it inhospitable to most aquatic life. Treatment methods include chemical reduction of dissolved oxygen (e.g., by addition of sodium thiosulfate), addition of nitrogen (NO_2?) by bubbling to purge O_2 from the water, increase of decrease in pH, heating of the water, or addition of a toxin. Rotenone, a common piscicide, works by interfering with oxygen take-up across gill membranes (Bettoli and Maceina 1996). The primary concerns with any of these methods are human health hazards, cost, implementation, liability, and impacts to non-target organisms.

Options

- Change in pH: Elevated or reduced pH is lethal to most organisms, although plant seeds and resting eggs of some plankton may be resistant for prolonged periods. A change in pH is reversible, for example, acidic water could be elevated (though not necessarily returned to neutral) by bubbling CO_2. However, drastic changes in pH will also have corrosive effects on boat hulls and fittings, which is unacceptable in a canal.
- Heating: heating water in dedicated locks to a lethal level could be used to kill most taxa except seeds and some resting eggs of planktonic animals. The energy required to heat the volume of water entering the canal for each lockage event, and make up for the loss to the atmosphere between lockage events, is likely to be prohibitive. Water would need to be cooled before leaving the canal to prevent mortality or entrainment of native species in Lake Champlain or the rivers connected to the canal, and to meet EPA regulations.
- Toxins: few toxins that are registered by EPA for use in open waters affect more than one taxon. For example, there are herbicides and pesticides available for use in aquatic systems; a combination would need to be used in the canals. Costs of chemical use are likely to be prohibitive, and detoxification of water before leaving the canal is not feasible. Several toxins are not registered for human consumption, so that issues of human safety would also arise.
- De-oxygenation. A drop in dissolved oxygen is likely the most acceptable method because it does not affect human health, and is readily reversed by aerating water with a bubbler or other devices. The cost of a deoxygenating agent such as sodium thiosulfate may be prohibitive. Alternatively, nitrogen could be bubbled into the canal to purge O_2; this method is currently being researched as a method of killing organisms in ballast tanks.

Anticipated effectiveness

Low dissolved oxygen will kill most aerobic organisms. The critical factor is the duration of exposure to deoxygenated water. Some fish species, such as catfishes and eels, and many bivalves, including dreissenids, can survive prolonged periods (hours to days) with little or no oxygen in the water

Some chemical treatments have been found to be highly effective with acceptable (though not insignificant) non-target effects. For example, application of lampricides, such as the most commonly used 3-trifluoromethy1-4-nitrophenol, or TFM, is the principal method of sea lamprey control. The chemical is successful at killing an estimated 95 to 98 percent of lamprey larvae. Another effective method is the application of chlorine in treating zebra mussels at water intake locations.

Some have argued that chemicals are not recommended for regular or initial use due to current public perceptions, permit requirements, and effects on non-target organisms (Keppner and Theriot, 1997). Using chlorine for controlling the zebra mussel has been instituted with varying degrees of success in the Great Lakes. However, chlorine can result in the formation of trihalomethanes in drinking water and contradicts the efforts of some environmental activities to reduce chlorine in the ecosystem.

It remains open to question whether any of these methods could be used to establish and maintain an ANS barrier throughout the canal operating season.

Benefits

Chemical control is still deemed as a very effective method in preventing invasive species. Keppner and Theriot (1997) compared chemical and physical methods of preventing ANS in the Illinois Waterway system in terms of effectiveness, cost and regulatory restriction. They conclude that the applications of rotenone, antimycin and chlorine are more desirable than electrical barriers while the costs of chemical alternatives are higher. They ranked each factor with a 1-3 point scale with three being the most desirable. In the effectiveness ranking, the electrical barrier scored 2 while the chemical applications scored 3. But when considering cost, the electrical method was give 3 points while rotenone and chlorine scored 2 and antimycin only scored 1.

Costs

There are at least three costs that we need to include in the cost-benefit analysis when considering the chemical control option. First are the resource requirements of the chemical control method such as the chemical product, labor and equipment for application. Due to the relatively small market for many invasive species control products, market forces serve to elevate product costs. As an example, *the Long-Term Program of Sea Lamprey Control in Lake Champlain* is expected to incur about $1 million in chemical lampricide purchases during the period 2005-2009 (W. Schoch, Lake Champlain Fisheries Tech. Committee, pers. comm).

The second cost is related to permit requirements and maintaining or supervising the application. Experience with permitting and public policy issues suggest that these costs would be difficult to forecast. In any case, this process requires careful review of scientific and legal records, and involves a substantial investment in time, state personnel, and fees.

The third cost is environmental costs transformed into economical costs. Non-target and unanticipated ecological impacts may result in additional costs (i.e., remediation). As soon as the application of the chemical produces a negative effect, the environmental impact will immediately turn into real costs by computing economic loss.

Technical application costs associated with chemical/water quality reductions are difficult to estimate for an as-yet-to-be-specified barrier. However, dosing equipment, boilers, heat exchangers, ozone production systems and/or chemicals can be expected to cost from tens to hundreds of thousands of dollars.

Alternative Six: Biological Barriers

Biological control of invasive species has historically involved use of a predator to limit the numbers of an already established exotic. Mosquitofish (*Gambusia* spp.), have been stocked throughout the U.S. to control disease-bearing mosquitoes, and Pacific salmon (*Oncorhynchus kisutch* and *O. tshawytscha*) were stocked in the Great Lakes to control invasive alewife (*Alosa psuedoharengus*) (Fuller et al.1999). Increasing the densities of natural and exotic predators was also considered as a potential method to limit the expansion of ruffe (*Gymnocephalus cernuus*) in Lake Superior. In Vermont, stocking of predators was considered as an option to control alewife in Lake St.Catherine (Vermont Department of Fish and Wildlife, 2003).

In the context of herbivory, grass carp (*Ctenopharyngodon idella*) have been stocked to reduce beds of unwanted aquatic vegetation. Aquatic weevils (*Euhrychiopsis lecontei*) and moths (*Acentria ephemerella)* have been used to control Eurasian watermilfoil in smaller waterbodies (Creed, 1998; Johnson et al., 1997). Recent research with the moth *Acentria ephemerella* has had promising results in Lincoln Pond – a small waterbody within the NY portion of the Lake Champlain watershed (R. Johnson, pers. comm.). These grazing species can be introduced into the target area to control specific invasive species.

However, stocking of predators and grazers can have significant drawbacks for limiting movement of exotic species through a canal. First, the 'target' species for which predators will be introduced are 1) often unknown, 2) not predictable in the timing of their arrival, 3) may involve several taxa, and 4) may present a mis-match with available predators. Second, exotic species moving through the canal are likely to be in small numbers and fairly dispersed - conditions limiting predator efficiency. Third, the stocking effort must be focused on species that are native (or at least non-invasive) to all of the connected ecosystems, as any organism introduced into the canal system is likely to disperse. Predators used to control unwanted species may also reduce non-target, desirable species. Finally, the predator may not be effective at controlling the target species.

Other examples of biological control include the use of sterilization techniques and pheromones. Sterilization involves swamping the species population with sterile males that mate with the females; thus, producing no offspring for the next generation. This sterile-male-release technique has been used to reduce sea lamprey production in the St. Marys River, Michigan (Twohey et al. 2003). Chemical pheromone traps have been used by entomologists to disrupt mating by target species (Trimble, et al., 2004). This approach also holds promise for sea lamprey control, though research to-date has yet to produce demonstrable results in the field (Li et al. 2003). These methods are targeted toward exotic species that are already established; given that they take considerable time to research and develop and are species-specific, they offer little advantage in prevention of invasions.

In analyzing the benefits/costs of biological control, values for the following variables would be necessary:

a. The damage in terms of quantity and quality resulting from varying levels of invasive species;
b. The efficacy of biological control agents at different levels of invasion;
c. The resource requirements of the biological control method (augmentation or conservation) such as labor and equipment for application, the quantity of biological control agents, and the labor required to determine the need for conservation or augmentation (field monitoring);
d. The effects in subsequent time periods on infestation, yield and other pest controls needed;
e. The interactive relationships among biological control agents and factors such as water quality, fish species and weather.

In summary, the risks of introducing another species into a new environment must be carefully studied. Some may debate the safety of the method, particularly with regard to the potential of introduced biological control agents to have adverse effects on non-target organism. However, with the improvement of the safety standards of biological control, managers of control projects are often able to make an informed decision by taking into account the potential for any effects on non-target organism. Nevertheless, biological control is "biological" and therefore subject to great variability in impact, effectiveness, and non-target impacts.

As an ANS management approach, biological control will: (1) create less physical disturbance to habitat and wildlife compared with mechanical removal; (2) could be a feasible option absent other management alternatives; (3) be potentially cheaper than other management methods, <u>assuming</u> any newly introduced predators/grazers have received "clearance" for release into the Champlain Basin ecosystem. Unfortunately there has been limited information to weigh the effectiveness of biological control methods when native species are also exposed to the biological treatment, especially in aquatic systems. There is always a chance that the biological control method will disturb non-ANS and change the ecosystem unintentionally. More research is essential to identify side-effects of biological control before it is applied.

Conclusions

The analysis presented here suggests that decision makers should seriously consider threats to the Lake Champlain ecosystem posed by the primary ANS vector – namely the Champlain Canal. Potential ANS barrier solutions for the canal are likely to be controversial, expensive, and less than perfect in design and operation. These concerns, however, are <u>not</u> justifiable reasons for inaction. Available information indicates that the ideas associated with Alternatives 3 (physical barrier) or 4 (behavioral barrier) might well result in a viable ANS deterrent. Such technology and/or operational changes would offer enormous protection for Lake Champlain - a valuable ecosystem and tourism engine.

Alternative 3 is seen as "preferred" from an ecological perspective. It clearly would offer the most protection against further ANS invasion of Lake Champlain. Alternative 4 would be less effective (relative to a physical barrier) in terms of protection against most taxa. It would, however, have the potential to stem many invasions (particularly invasive fish), while not significantly impeding commercial and recreational boat traffic.

Further analysis is clearly warranted. Sound decisions as to the fate of any Champlain Canal ANS barrier will require at least two types of information. First, well designed socio-economic surveys are needed to better understand current canal usage and importance. Surveys of this type should also enable decision makers to formulate "what-if" scenarios relative to boat traffic impacts caused by ANS barriers and/or canal operational changes. Such studies are routinely conducted to help answer resource economics questions similar to this. Many universities have this capability, but these data will go lacking absent any directed research toward user attitudes and canal transit expenditures. Similar information from other regions (even if it exists) is simply not transferable to the problem at hand.

Secondly, engineering studies are needed to predict the physical viability and costs associated with Alternatives 3 and 4. The construction of graving docks, boat hoists, behavior barriers, feeder canal diversions, etc. would require significant new investment in the NYS Canal System. The costs associated with such new infrastructure need to be detailed before any serious deliberation on the problem of canal/ANS could begin.

As a final conclusion, it should be stressed that Alternative 1 (no change/no action) represents an important *de facto* decision for Lake Champlain aquatic resource stakeholders. Aquatic nuisance species will continue their "march" toward Lake Champlain aboard boat trailers, in bait buckets, aquarium trade, aquatic plant trade, but most likely through the Champlain Canal. This and other canals were of vital commercial importance in the 19th century and continue to have enormous tourism benefit today. By their very nature, however, canals serve as unnatural watershed connections. Global trade and 21st century travel and tourism will combine to deliver many new invasive species across several watersheds to Lake Champlain in future decades. If no action is taken, the future will see new fish, plant, and invertebrate ANS colonizations in Lake Champlain.

Addendum

On May 16, 2005 two of us (Malchoff and Marsden) met with eight New York State Canal Corporation staff at New York State Thruway Authority/Canal Corporation Headquarters in Albany, New York to review the above project findings. The meeting with the key stakeholder group provided an opportunity to offer ideas and receive constructive criticism. The following e-mail excerpt was received by Malchoff following the meeting. It concisely summarizes the view points expressed by the Canal Corporation staff on May 16.

> *The Canal Corporation is interested in learning more about barriers to aquatic nuisance species. However, before any decisions can be made with regard to installing mechanical barriers, an engineering review and analysis will have to be conducted to determine feasibility for an installation. As discussed, funding will be required to pursue this analysis and any possible alternatives.*
>
> *In addition, there were some questions and concerns raised regarding the assessment of impacts of the alternatives. We recommend the severity of the impacts both fiscally and operationally be more fully analyzed. If possible, before this report is finalized and used to generate support, these issues should be fully addressed and the Canal Corporation should have the opportunity to review and comment.*

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Appendix A. (from LCBP ANS Management Plan)

Non-native Lake Champlain Basin Species of Potential Concern

Within the Lake Champlain Basin

Other nonnative plant and animal species that have the potential to become problematic are found throughout the Lake Champlain Basin. Many of these species have not been well documented and the full extent of their distribution and impacts within the Basin is not known. As new information from survey or research work becomes available a species' status will be re-evaluated and elevated to a priority for management, if warranted. The following list of all currently known non-native species of concern within the Basin was taken from a paper in progress by Dr. J. Ellen Marsden of the University of Vermont and Michael Hauser of Vermont Department of Environmental Conservation:
(*denotes a priority species)

Plants

*purple loosestrife	(*Lythrum salicaria*)
*Eurasian watermilfoil	(*Myriophyllum spicatum)*
*water chestnut	(*Trapa natans*)
*Japanese knotweed	(*Fallopia japonica*)
flowering rush	(*Butomus umbellatus*)
European frog's bit	(*Hydrocharis morsus-ranae*)
common reed	(*Phragmites australis*)
yellow floating heart	(*Nymphoides peltata*)
curly leaf pondweed	(*Potamogeton crispus*)
slender-leaved naiad	(*Najas minor*)
yellow flag iris	(*Iris pseudacorus)*
water plantain	(*Alisma gramineum)*
great water cress	(*Rorippa amphibia)*

Fish

*sea lamprey	(*Petromyzon marinus*)
*alewife	(*Alosa pseudoharengus*)
gizzard shad	(*Dorosoma cepedianum*)
white perch	(*Morone americana*)
European rudd	(*Scardinius erythrophthalmus*)
blueback herring	(*Alosa aestivalis*)
common carp	(*Cyprinus carpio*)
goldfish	(*Carassius auratus*)
tench	(*Tinca tinca)*
rainbow trout	(*Oncorhynchus mykiss)*
brown trout	(*Salmo trutta)*
brook silverside	(*Labidesthes sicculus)*
white crappie	(*Pomoxis annularis)*
black crappie	(*Pomoxis nigromaculatus)*

(Black crappie is native to Lake Champlain, but is spreading to other lakes within the Basin.)

Mollusks

*zebra mussel	(*Dreissena polymorpha*)
mud bithynia	(*Bithynia tentaculata)*

big-ear radix (*Radix auricularia)*
banded mystery snail (*Viviparus georgianus)*
buffalo pebblesnail (*Gillia altilis)*
chinese mysterysnail (*Cipangopaludina chinensis*)
globe siltsnail (*Birgella subglobosa)*
woodland pondsnail (*Stagnicola catascopium)*
sharp hornsnail (*Pleurocera acuta)*
European fingernail clam (*Sphaerium corneum)*
greater European pea clam (*Pisidium amnicum)*
European stream valvata (*Valvata piscinalis)*

Crustaceans
rusty crayfish (*Orconectes rusticus)*
Allegheny crayfish (*Orconectes obscurus)*
big river crayfish (*Cambarus robustus)*
water flea (*Eubosmina coregoni)*
gammarid amphipod (*Gammarus fasciatus)*
cyclopoid copepod (*Thermocyclops crassus)*

Other
freshwater jellyfish (*Craspedacusta sowerbyi)*
flatworm (*Schmidtea polychroa*)
water veneer moth (*Acentria ephemerella*)

<u>Outside the Lake Champlain Basin</u>
Other aquatic or wetland species have the potential to be introduced to the Lake Champlain Basin. These species exist in nearby waters or are potentially available through the bait or aquarium trades. They currently are not known to be established in the wild within the Basin, but it is possible that some are established and have not been detected. The potential for their impact if introduced is not clear; as new information becomes available, a species' status will be re-evaluated and elevated to a priority for spread prevention or management if warranted. The following list of species currently outside of the Basin, but with significant potential to enter the Basin was taken from a paper in progress by Dr. J. Ellen Marsden of the University of Vermont and Michael Hauser of Vermont Department of Environmental Conservation: (*denotes a priority species)

Plants
*hydrilla (*Hydrilla verticillata*)
fanwort (*Cabomba caroliniana*)
Brazilian elodea (*Egeria densa*)
parrot's feather (*Myriophyllum aquaticum*)
variable-leaved watermilfoil (*Myriophyllum heterophyllum*)

Fish
*round goby (*Neogobius melanostomus*)
*Eurasian ruffe (*Gynocephalus cernuus*)
tubenose goby (*Proterorhinus marmoratus*)
northern snakehead (*Channa argus*)
bighead carp (*Hypophthalmichthys nobilis*)
silver carp (*Hypophthalmichthys molitrix*)

Mollusks

*quagga mussel	(*Dreissena bugensis*)
Asian clam	(*Corbicula fluminea*)
Chinese mystery snail	(*Cipangopaludina chinensis*)
Piedmont elimia snail	(*Elimia virginica*)
liver elimia	(*Elimia livescens*)
sharp hornsnail	(*Pleurocera acuta*)
Wabash pigtoe	(*Fusconaia flava*)
paper pondshell	(*Anodonta imbecilis*)
Atlantic rangia	(*Rangia cuneata*)
ridged lioplax	(*Lioplax subcarinata*)
green floater	(*Lasmigona subviridis*)
New Zealand mudsnail	(*Potamopyrgus antipodarum*)

Crustaceans

*spiny waterflea	(*Bythotrephes cederstroemi*)
waterflea	*(Daphnia lumholtzi)*
*fishhook waterflea	*(Cercopagis pengoi)*
amphipod	(*Echinogammarus ischnus*)
calanoid copepod	(*Eurytemora affinis*)
calanoid copepod	(*Skistodiaptomus pallidus*)
parasitic copepod	(*Argulus japonicus*)
Chinese mitten crab	(*Eriocheir sinensis*)
white river crawfish	(*Procambarus acutus acutus*)
gammarid amphipod	(*Gammarus daiberi*)

Oligochaetes

oligochaete	(*Ripistes parasita)*

Other Invertebrates

freshwater hydroid	(*Cordylophora caspia)*

Other

bacterium	(*Thioploca ingrica)*
cynobacterium	(*Cylindrospermops*is *raciborskii*)
whirling disease (protozoan)	(*Myxobolus cerebralis*)

Appendix C.

Summary of "mind map" from May 9, 2002
Champlain Canal Stakeholder Conference.

List represents the total catalog of issues related to management of aquatic nuisance species invasions through the Champlain Canal, as captured by workshop participants and professional facilitator. Asterisks denote the labeling of given issue as "important." Triangles denote the labeling of a given issues as "urgent." Count of symbols indicates level of group agreement on a particular issue (i.e. more symbols = more agreement).

1. **Increase pressure on sports fisheries - prevent NIS ******
2. **How to value non-market resources ****
3. **Voluntary action Programs; increase communication re: voluntary needs**
4. **Imposing Costs ΔΔΔ**
5. **Increase classroom learning about NIS**
6. **Education**
7. **Provide Curriculum**
8. **Put on Regents Exam**
9. **Biological migration – Barrier Δ**
10. **Modify canal use ***ΔΔ**
11. **Commercial traffic decreasing *******
12. **Local impacts of global changes**
13. **Importance of connections to river/lake systems ΔΔ**
14. **Native species displacement – more measures for prevention**
15. **Lack of funds – educate legislators ***Δ**
16. **Clarification of terminology Δ**
17. **Improving/changing fishing opportunities ***
18. **links to global warming**
19. **Changing water user behavior ***
20. **Habitat changes – prevent NIS *********
21. **Disconnect between public awareness : increase outreach and behavior ******

22. **Impacts to cultural heritage resources – prevent additional introductions *******
23. **Increasing importance of "political will"**
24. **Increased competition for limited resources – collaborative products – increase resources**
25. **Uncertain future ***
26. **It's not over – continuing problem – ballast water ****
27. **Nineteenth century technology – 22nd century issues**
28. **Sonication, electric barrier ΔΔΔΔΔΔ****
29. **Ecological Imbalance – change ***
30. **Regional vs. Local tension**
31. **Burdensome permitting process ***
32. **Change in basin population – smart growth policies**
33. **Increased uncertainty in ecosystem management**
34. **Changing social/economic character of population**
35. **Local water front revitalization**
36. **Conflict between status quo : change *****Δ**
37. **Costs to taxpayers – business community ******
38. **Data Needs ΔΔΔΔΔΔ***
39. **Fund monitoring and research ****
40. **Improving water quality**
41. **impacts on shoreline/ private property use/values *****
42. **Changing recreational opportunities ΔΔ**
43. **Recreational boating ΔΔΔ**
44. **Communication and cooperation across the border ΔΔ**
45. **User surveys ****
46. **Education / behavior changes ΔΔ**
47. **Increase funding to address issues ****
48. **Gene attached species introduction ***
49. **Increasing need for regional / national / international perspective ******
50. **public awareness ****
51. **increased funding for outreach/ media ***

52. heightened public concern **

53. water shed development *

54. Develop watershed management plans and assessments

Appendix D.

Champlain Canal Barrier Options
Delphi Survey Report (abbreviated version)

February 14, 2003

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This report is one component of a
National Oceanic and Atmospheric Administration grant entitled:

Multidisiplinary Analyses of the Feasibility of Champlain Canal Barrier Options: A Proposal to National Sea Grant

This report summarizes the results of a Delphi Survey about potential Champlain Canal barrier options which was part of a National Sea Grant project. This study included two distinct survey instruments that are presented in the appendix of this report. This survey was based upon a review of the literature on public and stakeholder opinions of Lake Champlain and a Champlain Canal workshop that was held in Glen Falls, New York during April of 2002 that had over 40 participants. The Delphi Survey process was approved by the Human Subjects review committee at SUNY Plattsburgh at the start of July in 2002. The two Delphi survey instruments were developed by Dr. Higgins in conjunction with professional review and comments from Dr. Ellen Fitzpatrick and Mark Malchoff of SUNY-Plattsburgh. The first round of the survey was mailed in July and the second in August of 2002. This report summarizes the results of this survey and identifies key issues to evaluate in regard to potential Champlain Canal barriers.

Previous research has identified a broad range of views about Lake Champlain that include direct values which involve market valuation, indirect values such as nutrient recycling, option values implying future tangible values and existence values such as aesthetic appreciation, cultural protection and ecological stewardship (Higgins et al 1994). In addition, previous research has also identified a lack of consensus among stakeholders on an appropriate conceptual framework to understand and evaluate nature (Higgins et al 1994). Furthermore, in 2001, a public opinion survey of residents in the Lake Champlain Basin also identified important differences between New York and Vermont residents in regard to concern with Lake Champlain water quality, pollution issues, and awareness of Lake Champlain Program initiatives as well as significant opinion differences among other stakeholder segments within the basin (LCBP 2001). Given this dissensus among Lake Champlain stakeholders, this survey assessed a series of preliminary issues and questions that relate to the feasibility of Champlain Canal barrier options. This Delphi Survey should not be considered a definitive assessment of feasibility issues. It does provide a systematic evaluation of what issues these key informants think are important on this topic. The respondents for this survey are listed in the appendix of this report. They were selected to offer voices from a diversity of public and private perspectives as well as views from both New York and Vermont. It is especially noteworthy that, despite the diversity of values, all of the issues in this survey were considered either very or somewhat important in regard to assessing Champlain Canal barrier options by a majority of the respondents. In fact, the issue that received the very lowest rating, question number 16 in the survey on "option value," was still considered very or somewhat important by 11 out of 19 or 58% of the respondents. Thus, all these specific issues should be systematically assessed with regard to potential barriers in the Champlain Canal.

This Delphi Survey identified a number of pivotal public policy issues in regard to Champlain Canal barrier options. Since Lake Champlain has two access canals, the Champlain Canal in New York State and the Chambly Canal in Quebec, it is important to consider this overall geographical context. It should be noted that the grant which funded this research project was directed only toward the Champlain Canal in New York. Yet, to evaluate the feasibility of a barrier in only the Champlain Canal would be shortsighted, since aquatic plants and animals may also enter Lake Champlain from the Chambly Canal. It is therefore recommended that any public policy assessment of a canal barrier explicitly consider both canals. Second, a variety of notions have been offered to justify a canal barrier including the potential threat of "non-indigenous", "invasive", "nuisance", and "exotic" species. Each of these terms has a distinct definition and social context for public policy analysis within the Lake Champlain basin. For example, if "non-indigenous species" are defined as the threat, why are "non-indigenous fish" currently stocked in Lake Champlain? Thus, attention should be given to systematically define the key notions and public policy framework for assessing a canal barrier. Third, given the diversity of frameworks for understanding nature and perceived importance of a wide range of values, policy analysis of potential canal barriers should establish a systematic framework that includes and assess direct, indirect, option and existence values. Fourth, given the multiple paths by which plants and animals may enter Lake Champlain, public policy studies should simultaneously assess the potential of all key alternatives such as release of live bait, home aquarium fish, and boats entering the basin by trailer. Finally, even though fish species are clearly important, assessment of canal barrier options should systematically evaluate the potential for all species.

Results of the Second Round of the Delphi Survey

Average of
<u>Responses</u>

1.2 The impact on sport fishing in Lake Champlain. New fish species may directly displace a current species or new plants and microorganisms may alter the niche of current sport fish populations.

1. Very important - 16
2. Somewhat important - 3
3. Not important - 0
4. Undecided - 0

1.3 The impact of aquatic nuisance species entry to Lake Champlain through the Chambly Canal or Richelieu River in Quebec.

1. Very important - 14
2. Somewhat important - 5
3. Not important - 0
4. Undecided - 0

1.3 The impact on tourism businesses.

1. Very important - 14
2. Somewhat important - 5
3. Not important - 0
4. Undecided - 0

1.4 The impact of live bait for fishing and/or release of home aquarium fish as alternative entry routes for nuisance species that would circumvent a Champlain Canal barrier.

1. Very important - 12
2. Somewhat important - 7
3. Not important - 0
4. Undecided - 0

1.4 The impact on public health with potential beach closings due to nuisance species.

1. Very important - 12

2. Somewhat important - 6
3. Not important - 1
4. Undecided - 0

1.5 The impact on Lake Champlain water systems for drinking, fish hatchery production, etc.. This includes the costs of research, preventative measures and modifications of current systems.

1. Very important - 10
2. Somewhat important - 9
3. Not important - 0
4. Undecided - 0

1.6 The impact on market value such as commercial sales of lake resources (e.g. perch), tourism receipts, etc..

1. Very important - 8
2. Somewhat important - 11
3. Not important - 0
4. Undecided - 0

1.6 The impact on shoreline maintenance costs (e.g. weed removal) and reduced access for canal and shoreline property owners.

1. Very important - 8
2. Somewhat important - 10
3. Not important - 1
4. Undecided - 0

1.6 The impact on existence value such as bio-diversity, aesthetic appreciation and heritage preservation.

1. Very important - 10
2. Somewhat important - 6
3. Not important - 3
4. Undecided - 0

1.7 The impact of disagreement among stakeholders about whether or not a species is a "nuisance" as well as the acceptable consequences of control options (e.g. ecological damage with lamprey poison).

1. Very important - 9
2. Somewhat important - 5
3. Not important - 4
4. Undecided - 1

1.7 The impact on historical and cultural resources of the Champlain Canal & Lake Champlain.

1. Very important - 7
2. Somewhat important - 10
3. Not important - 2
4. Undecided - 0

1.8 The impact on non-market consumptive value such as fish caught and eaten by a household.

1. Very important - 5
2. Somewhat important - 12
3. Not important - 2
4. Undecided - 0

1.9 The impact on option value of future uses of lake resources that have not yet been identified.

1. Very important - 2
2. Somewhat important - 11
3. Not important - 1
4. Undecided - 5

1.9 The uneven impact on residents in New York, Vermont and Quebec, Canada.

1. Very important - 4
2. Somewhat important - 11
3. Not important - 3
4. Undecided - 1

1.9 The impact on non-consumptive value such as nutrient recycling and scientific research.

1. Very important - 4
2. Somewhat important - 12
3. Not important - 3
4. Undecided - 0

1.9 The impact on waterfront development for municipalities along the Champlain Canal. Modifications in the operation of the canal may impact future development potential.

1. Very important - 6
2. Somewhat important - 8
3. Not important - 5
4. Undecided - 0

2.0 The impact on boaters who utilize the Champlain Canal and Lake Champlain. Depending on the option, this may include increased risk with an electrical barrier or more time for passage with a boat lift.

1. Very important - 4
2. Somewhat important - 11
3. Not important - 4
4. Undecided - 0

2.0 The impact of new economic opportunities that respond to the entry of aquatic nuisance species (e.g. zebra mussel protection systems).

1. Very important - 7
2. Somewhat important - 4
3. Not important - 8
4. Undecided - 0

References

Higgins, Kujawa, Dietz, Kalof and Holmes, 1994 *Lake Champlain's Future: A Community Based Strategy for Environmental Policy Development*, Lake Champlain Basin Program, Education Report No. 3.

Lake Champlain Basin Program, 2001, Public Opinion Survey: Lake Champlain Basin 2001.