Discussion Paper

NATIVE PREY FISH RE-INTRODUCTION INTO LAKE ONTARIO:

BLOATER (*Coregonus hoyi*)

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Table of Contents

Executive Summary
NATIVE PREY FISH RE-INTRODUCTION INTO LAKE ONTARIO: BLOATER (*Coregonus hoyi*)

This Discussion paper is the result of the Lake Ontario Committee of the Great Lakes Fishery Commission charging the Lake Ontario Technical Committee to address several questions regarding the proposed re-introduction of the bloater to Lake Ontario. Re-introducing bloaters to Lake Ontario is consistent with the bi-national fisheries management objectives.

The bloater was the smallest of four deepwater ciscoes native to Lake Ontario, all now extirpated. With other coregonines, they made up the greatest fish biomass in the lake. The loss of the bloater by the 1960s left the exotic alewife and smelt as the predominant pelagic forage fishes. Reasons suggested for the ciscoes' disappearances are over-fishing, increasing alewife and smelt populations, lamprey predation, and water quality.

The Discussion paper considers ecological benefits, risks, and uncertainties of re-introducing bloaters; positive and negative technical considerations and technical uncertainties of re-introducing bloaters; ecological circumstances favourable to the re-introduction of bloaters; and, briefly, the possibility of re-introductions of other deepwater ciscoes.

Ecological benefits of re-introducing bloaters include:

- filling an empty niche. The deep waters, about 50% of the volume of Lake Ontario, are almost empty of fish. Large *Mysis* populations are considered part of a dysfunctional food web.

- increasing stability of the offshore pelagic forage fish community. A large number of predators now rely on alewife and smelt, both known for great population fluctuations.

- providing an alternative prey species for offshore piscivores. A variety of predators, but especially lake trout, would benefit. All salmonines would benefit from a reduction of thiaminase in their diets. Alewife and smelt have high levels of thiaminase; it is thought to impair reproduction in their predators.

- reducing impacts of alewife and smelt on other fish species. Alewife and smelt prey on larvae of native fish species. Declines in alewife and smelt, if they occur, may reduce predation and increase the abundance of native fish species.

Ecological risks of re-introducing bloaters include:

- decreasing alewife and smelt populations. This may be viewed as a risk or a benefit. Interactions among alewife, smelt, and bloater would depend on habitat overlap. Adult bloaters may overlap most with smelt, which occur deeper than the surface-dwelling alewife. Young bloaters live near the surface, overlapping with both other species. There is strong evidence from other Great Lakes that smelt and especially alewife may prey on bloater young, and some evidence that larger fish of all three species may compete for food or space.

- reducing prey for salmonines other than lake trout. Other salmonines may be slow to include bloaters in their diets, and thus they may be impacted if populations of their favoured prey species, alewife and smelt, are reduced.

- providing prey for lamprey. This risk is very small.

- having inadequate food available for bloaters. There is some concern about adequate *Diporeia* (amphipod) and zooplankton populations, at least partly because of the effects of exotic invertebrates in the lake.

- bloaters competing or hybridizing with recently-found deepwater forms of lake herring. Population status of these forms is uncertain. A pattern of hybridization among coregonines makes their loss possible.

Ecological uncertainties of re-introducing bloaters include:

- introducing a coregonine that may behave differently in Lake Ontario than in other Great Lakes; coregonines are known for their variability.

- being impeded by the effects of unknown water quality problems. Bloaters may tend to accumulate contaminants, but not enough is known to predict whether contaminant burdens in predators might be affected by preying on bloaters.

- affecting populations of other species. As well as the species considered above, bloaters could interact with all other native and exotic invertebrate and fish species in the offshore community, as a predator or competitor.

- the difficulty of predicting the outcome because of a general lack of ecological knowledge of this unstable ecosystem.

Positive technical considerations of re-introducing bloaters include:

- acquiring new knowledge of bloater biology, fish culture techniques, and lake ecology.

- possibly re-establishing a commercial fishery for bloaters in the future.

Negative technical considerations of re-introducing bloaters include:

- failure. There are few examples of successful current or past coregonine stocking programs based on hatchery rearing.

- bringing disease from another lake to Lake Ontario. This is probably a small risk, given that there are natural connections between the Great Lakes that allow disease dispersal now. Lakes Huron, Michigan, and Superior are the possible sources of bloaters.

- producing inappropriate characters in bloaters through hatchery rearing. Bloaters are too fragile for direct adult transfer but can be raised in hatcheries, though hatchery space is limited. Direct egg transfer or pen rearing might also be possible.

The technical uncertainty of re-introducing bloaters is not knowing how many fish would be needed. Estimates went from 100,000s to millions of larvae or juveniles per year, depending partly on size at release, but these numbers are considered very uncertain.

There are several ecological circumstances that would be favourable to re-introducing bloaters. Populations of smelt and especially alewife should be low. Current low alewife populations, and a high risk of a catastrophic decline, are viewed by some as a window of opportunity that needs to be used quickly.

Piscivore populations should not be too high or low (the latter to control alewife numbers). The status of deepwater lake herring forms and possibly deepwater sculpins should be better understood. Other fish species may be useful as indicators of favourable conditions. Populations of bloaters' invertebrate food species should be adequate, in general and at specific times of release of bloaters. Monitoring of a re-introduction, to measure its success, is considered important.

Of the former deepwater ciscoes in Lake Ontario, only the kiyi exists in adequate numbers (in Lake Superior) to consider re-introduction. There are arguments for re-introducing the two species, but practically it is probably only reasonable to consider the bloater now.

Discussion Paper
NATIVE PREY FISH RE-INTRODUCTION INTO LAKE ONTARIO: BLOATER (*Coregonus hoyi*)

1 INTRODUCTION

1.1 BACKGROUND TO THE DISCUSSION PAPER

This Discussion paper is the result of the Lake Ontario Committee (LOC) of the Great Lakes Fishery Commission (GLFC) charging the Lake Ontario Technical Committee to address several questions regarding the proposed re-introduction of the bloater (*Coregonus hoyi*) to Lake Ontario (Appendix A, Terms of Reference). The bloater was native to Lake Ontario (Scott and Crossman, 1973), one of a number of native fishes to decline or be extirpated in Lake Ontario in this century, leaving the non-indigenous alewife (*Alosa pseudoharengus*) and rainbow smelt (*Osmerus mordax*) as the predominant forage fishes in the open waters of the lake (Christie, 1973; U.S. Fish and Wildlife Service (USFWS), 1995).

Re-introducing bloaters to Lake Ontario is consistent with bi-national fisheries management objectives. One of the guiding principles of the draft Fish Community Objectives for Lake Ontario (GLFC – LOC, 1998) is: "The protection and rehabilitation of native and naturalized species and genetic stocks is an important element in securing biodiversity". Specifically, fish community objectives for the offshore benthic food web include "rehabilitating the native prey fish community". Because these goals are considered social, rather than ecological, they are not discussed further in this report, but they clearly form the very important underpinning of any bloater re-introduction.

1.2 THE BLOATER IN LAKE ONTARIO

The bloater was one of four, out of seven Great Lakes deepwater ciscoes, that occurred in Lake Ontario, with the kiyi (*Coregonus kiyi*), the blackfin cisco (*C. nigripinnis*), and the shortnose cisco (*C. reighardi*) (Scott and Crossman, 1973). Bloaters, traditionally the smallest and slowest growing of the deepwater ciscoes, were also found in Lakes Huron, Michigan, Superior, and Nipigon (Scott and Crossman, 1973). Historically, the planktivorous coregonines – the lake whitefish (*C. clupeaformis*), the lake herring (*C. artedii*), and the deepwater ciscoes – made up the greatest biomass of fish groups in all of the Great Lakes, with the ciscoes accounting for the greatest biomass in the deep regions of the lakes (Smith, 1995).

Christie (1973) described population trends for Lake Ontario ciscoes, based on fishery statistics. Catch statistics for ciscoes were usually combined with lake herring. As a group they were very important in the Lake Ontario fishery, particularly in the western part of the lake, making up 30 – 40% of total Lake Ontario catches in all decades from 1890 to 1949 except the 1920s. The largest deepwater cisco, the blackfin, was probably extinct by 1900. However, Christie described the remaining cisco populations as plentiful around 1900, probably decreasing into the 1920s, increasing in the 1930s and early 1940s, but failing during the 1940s. The three species disappeared at different times, the shortnose cisco and the kiyi between 1927 and 1942, leaving only the bloater. The bloater fishery collapsed in western Lake Ontario in the mid-1940s but persisted in eastern Lake Ontario until 1950.

A fishery survey in the U.S. waters of Lake Ontario in 1942 found bloaters still common (Stone, 1947) but by 1964 Wells (1969) found deepwater ciscoes very scarce in U.S. waters, capturing only 10 bloaters, 2 shortnose ciscoes, and 1 kiyi. Since then, there are apparently only two records of bloaters, both adults, caught in Lake Ontario, one captured off Port Credit, Ontario on 4 May 1972 and one captured off Smoky Point, New York on 28 April 1983 (RO; see section 1.3 regarding personal communications). Parker (1989) refers to two specimens from 1972 and 1982, but these are likely the same fish. There is a single specimen in Ontario Ministry of Natural Resources (OMNR) collections from 1978, but several checks of the data showed that it was almost certainly misidentified (JB).

The last two bloaters caught in Lake Ontario were recently aged by R. O'Gorman and R. Owens (ROG). R. O'Gorman provided the following discussion of their possible origins. The bloater caught in 1972 was 297 mm total length (TL) and eight years old (1964 year class). Because Wells (1969) found bloaters in Lake Ontario in 1964, the 1972 fish may have been the progeny of a remnant Lake Ontario population. Brown et al. (1987) reported that the 1964 year class of bloaters was strong in Lake Michigan; perhaps environmental conditions favoured bloater reproduction across the Great Lakes in 1964. Alternatively, the 1972 bloater may have drifted down (section 3.2.2) from the upper lakes where recruitment was strong. The bloater caught in 1983 was 272 mm (TL) and 5 (or perhaps 6) years old (1978 or 1977 year class). Origin of this specimen was most likely Lake Huron where strong year classes were produced in the late 1970s (Brown et al., 1987).

The lack of records between 1972 and 1982 comes in spite of considerable fishing effort from 1978 to 1982 (RO), and generally adequate sampling over the last 40 years, although more consistent deep trawling has been done in American than in Canadian waters (JC). Stanley Rankin, a retired Ontario fisher, described the sudden disappearance of cisco from his nets in the early 1960s, with hundreds of pounds per lift one fall, and no ciscoes the next year.

The bloater has been extirpated from Lake Nipigon (McAllister et al., 1985), but was considered common in Lakes Huron and Superior, and abundant in Lake Michigan in 1995 (USFWS, 1995).

The reasons for the disappearances of deepwater cisco populations, and of bloaters in particular, have been discussed by several authors. Christie (1973) thought that Lake Ontario deepwater ciscoes were very vulnerable to fishing pressure, and that their final elimination could have been caused by the loss of competitive position or changes in predator/prey ratios caused by fishing. He noted that the bloater collapse coincided with the expansion of smelt populations, but was doubtful about attributing cisco declines to the proliferation of smelt or alewife populations. Smith (1972) also discussed the great sensitivity of individual Great Lakes cisco species to exploitation, although as a group he considered them very resistant. However, he also thought that expanding alewife populations and sea lamprey (*Petromyzon marinus*) predation, and in Lake Ontario water quality, played a role in the declines of deepwater ciscoes. Brown et al. (1987) felt that, along with heavy fishing pressure, alewife were strongly implicated in cisco population declines or disappearances in Lakes Michigan and Huron, especially the former. Smelt, especially in Lake Huron, and lamprey were also factors. Crowder (1980) and Eck and Wells (1987) placed great emphasis on the influence of alewives on bloater population fluctuations in Lake Michigan. In Lake Huron, Ebener (1995) attributed deepwater cisco declines and extinctions primarily to overexploitation, but also to interactions with smelt and alewife. A long-term decline in deepwater cisco populations in Lake Superior is thought to be related to predation by deepwater lake trout (*Salvelinus namaycusch*) populations (Hansen, 1994).

All of these factors could play a role in the proposed re-introduction of bloaters into Lake Ontario, and will be discussed in this Discussion paper.

1.3 STUDY METHODS AND ACKNOWLEDGEMENTS

The primary data source for this report was interviews. Appendix B is a list of the people with whom I spoke, on the telephone or at the Lower Lakes Lake Trout Coordination Meeting (February 17, 1999 at Amherst, New York). I am very grateful to them for their generosity with their time, and, in many cases, for directing me to others and to many of the references which formed the other data source for the report. Personal communications are written simply as initials (in alphabetical order); peoples' initials are listed in Appendix B.

This report generally follows the Terms of Reference (Appendix A) in its outline: ecological benefits, risks, and uncertainties of re-introducing bloaters; positive and negative technical considerations and technical uncertainties of re-introducing bloaters; ecological circumstances for the re-introduction of bloaters; and a brief consideration of the possibility of re-introductions of other deepwater ciscoes.

2 ECOLOGICAL CONSEQUENCES OF RE-INTRODUCING BLOATERS

2.1 ECOLOGICAL BENEFITS OF RE-INTRODUCING BLOATERS

2.1.1 Filling an Empty Niche

One of the greatest benefits of re-introducing bloaters to Lake Ontario, pointed out by almost every fishery scientist I interviewed, was filling a long-standing empty deepwater niche in the lake. Christie (1973) described the abyss of Lake Ontario as "strangely devoid of fish." R. Eshenroder calculated that approximately 50% of the volume of the lake has no planktivores, and virtually no fish at all because bottom-dwelling sculpin populations are low. Alewives do overwinter in deep water; Bergstedt and O'Gorman (1989) found adults concentrated between 35 and 75 m in samples from October to March in Lake Ontario. However, they eat little – their energy demands are probably at least halved from summer levels (TS).

The deepwater food web is now viewed as dysfunctional, or a "dead end" (i.e. lacking in top fish predators) (JH, BL, TJS): there are large populations of *Mysis relicta* (opossum shrimp) that are currently largely uneaten by fish, resulting in a very large potential energy loss to food webs. *Mysis* is a preferred food of adult bloaters (Scott and Crossman, 1973), although as bloaters grow Wells and Beeton (1963) found that the amphipod *Diporeia hoyi* formed a larger part of their diet (section 2.2.4). In fact R. Eshenroder has suggested that deepwater ciscoes have evolved to feed on *Mysis*, following their daily vertical migrations.

The limited fish predation on *Mysis* has been primarily by smelt, feeding on *Mysis* when they migrate into the metalimnion, and alewife, feeding on *Mysis* only in late spring and early fall (RE, EM) when they are in deep water. Alewives and smelt appear to have more thermal and/or depth limitations in the lake than in the marine environment; alewives, for example, do not have daily vertical migrations in Lake Ontario (RE). Seasonal migrations of alewife and smelt in the lake (GLFC – LOC, 1998), do provide some transfer of energy from the benthic to the pelagic food web. However, as alewife, smelt, and juvenile lake trout shift to deeper water (section 2.2.4), fish predation on *Mysis* is increasing (ROG). It has been suggested that lake trout, burbot (*Lota lota*), rainbow trout (*Oncorhynchus mykiss*), and brown trout (*Salmo trutta*) all probably rely on *Mysis* as a food source to some degree (BL), but Lake Ontario Management Unit (LOMU) unpublished data suggest that it is minor.

Some concerns were expressed that *Mysis* populations were smaller than in the past (ROG), following the general decrease in lake productivity (USFWS, 1995; JB, JC, ROG). However, several sources indicated that there were still large numbers of *Mysis* in the lake: E. Mills; B. Lantry, based on hydroacoustic data; and O. E. Johannsson, whose most recent data (1997) showed large *Mysis* populations at both 129 m and 240 m stations. A bloater re-introduction would be expected to reduce *Mysis* populations, but they should be able to support the predation if other conditions remained about the same (OEJ).

Thus re-introducing a native offshore planktivore could use untapped available energy and increase the energy transfer between trophic levels (USFWS, 1995). Perhaps some of the tremendous historical fish production from the deep waters of the lake could be restored (JH).

2.1.2 Increased Stability of the Offshore Forage Fish Community

A second major benefit of re-introducing bloaters would be the stabilizing influence on the offshore forage fish community, because the current pelagic forage fishes, alewife and smelt, are well-known for their population fluctuations (JB, JC, BL, ROG, RO, TJS). Smelt went through tremendous population fluctuations after the disappearance of lake trout from Lake Ontario (JC). Alewife is known for its extreme fluctuations. Major die-offs occurred in Lake Ontario in the winters of 1976 – 77 and 1983 -- 84 (O'Gorman et al., 1987). Decreasing alewife and smelt populations necessitated major reductions in stocking of salmonine predators in 1993 and 1994 (LOMU, 1998), and may not be capable of supporting current predator populations (USFWS, 1995). Relying on a single potentially unstable prey species like the alewife as a "lynchpin" for a large number of predator species is questionable (TJS).

A more diverse forage fish community may increase stablility. Predation can accentuate population fluctuations in a prey species: declining prey populations subjected to a constant consumption rate by predators will experience proportionately larger losses in a positive feedback loop situation (RE). With alternative prey species available, the loop can be broken or its effects reduced. With more prey species, changing conditions year-to-year would tend to favour different prey species, with less likelihood of one species always dominating (TJS). Historically, the lake's food webs would have had more linkages, between shallow- and deepwater communities, and between near- and offshore communities; bloaters, through their depth changes with age and daily vertical migration patterns, might re-establish some of these linkages again (TJS).

The Lake Ontario ecosystem is changing quickly from year to year (BL). In general the history of Great Lakes ecosystems is one of major disruptions, such as the introductions of exotic species, followed by major changes in ecological communities (ROG). The re-introduction of a native open water prey fish such as the bloater might bring some stability (but see section 2.3.1), and is considered essential to any further re-establishment of an historical native fish community in the lake (BL, ROG). Of course, even if bloaters become successfully re-established, the historical fish community cannot be expected to be re-established as it was (TS, WBS, BT). According to W. B. Scott, a more reasonable goal would be stable, self-sustaining fish populations that provide useful human products.

2.1.3 An Alternative Prey for Offshore Piscivores

Again, almost all the fishery scientists with whom I talked, cited the addition of another prey fish as an important benefit to Lake Ontario piscivores, especially lake trout. The overall need for more food for predators was discussed in section 2.1.2. The slimy sculpin (*Cottus cognatus*) is considered an important link in the offshore benthic food web (GLFC – LOC, 1998), where it is prey primarily for lake trout, but its populations are low (section 2.1.1).

However, there is some doubt about how much, in fact, lake trout would eat bloaters. Ciscoes were the preferred natural food of most lake trout populations, although the alewife was of primary importance to adult lake trout in Lake Ontario earlier this century (Scott and Crossman, 1973), and Christie (1973) referred to lake trout eating many ciscoes after alewife moved inshore in spring. Lake trout still apparently prefer alewife but do eat bloater in other Great Lakes (JB, RE, BL). Lake Ontario lake trout do not appear to prey on other coregonines, lake whitefish or lake herring, in spite of the former having population levels in the late 1980s and early 1990s as high as any this century (JC). Alewife and smelt, though, were much more abundant than lake whitefish or lake herring during this period (BL). Lake whitefish and lake herring probably only reach the upper depths of the lake trout distribution in Lake Ontario, whereas adult bloaters may overlap the entire depth range, and bloaters are smaller and might not outgrow predator gape sizes to same degree as the other coregonines (BL).

Brown et al. (1987) reported that stocked lake trout were slow to switch from preying on exotic species to bloater, but these reports are probably related to the fact that the trout were stocked rather than indigenous (RO), possibly from source lakes without cisco populations, and to years of low bloater recruitment (RE). Lake trout are considered more adaptable than other salmonine predators, eating a wider variety of prey (including invertebrates) and using a greater depth range, and it is therefore believed that they would eat bloater in Lake Ontario (BL, ROG, RO, TJS). As noted above (section 1.2) lake trout predation on deepwater ciscoes may be high enough at times to reduce their populations.

Re-introducing bloaters would greatly extend the sizes of prey available to lake trout and other salmonines (ROG, RE), allowing a more normal progression to larger prey as the predators grow (ROG). At about 160 mm (TL) juvenile bloater in Lake Michigan are already larger than adult alewife and smelt in Lake Ontario, and as they are still in the epilimnion (section 2.2.1) available to all salmonines (RE). Large lake trout in particular might benefit from larger adult prey: trout now preying on 20 – 30 g alewives would be expected to have increased growth with 200 – 300 g bloaters as prey (ROG).

In other lakes containing large lake trout, they often feed on smaller conspecifics (BL). With the recent declines in survivorship of newly stocked lake trout in Lake Ontario and the build-up of a population of large adults coupled with declines in prey fish numbers it is possible that lake trout cannibalism is occurring (BL). There would thus be an indirect benefit of reduced mortality to the lake trout population from having bloaters available as an alternate prey. The possibility of bloater predation on lake trout fry is discussed in section 2.3.3.

Whether bloaters would be eaten by other salmonines is more uncertain; this is discussed in section 2.2.2.

There is a potential benefit to salmonines feeding on bloaters through the reduction of thiaminase in their diets (RE, BL, ROG, RO, BT). Thiaminase is present in much higher levels in alewife and smelt than in native species (JB, BT). In Lake Michigan, levels in alewives 100 times greater than those in bloaters have been found (JF). It occurs in both gut bacteria and the tissues of alewives (JF), and can cause many reproductive problems: early shedding of eggs, early mortality syndrome (EMS), sublethal effects in fish that do hatch and survive (JB, RE), and sometimes neural effects in fish apart from reproduction (RE). It can affect all salmonines, although species sensitivities vary (RE). The importance of the problem is somewhat controversial: it may have caused the near-collapse of the coho salmon (*Oncorhynchus kisutch*) stocking program in Lake Michigan (RE) but temperature effects on fish development may be a complicating factor in understanding the thiamine problem (JC).

Reduced thiaminase in lake trout diets might help their currently low rates of natural reproduction in Lake Ontario (ROG, RO), although some recent data for Lake Huron suggest that natural reproduction is increasing there despite relatively stable EMS levels (JF). There could be a particular benefit for the relatively new Atlantic salmon (*Salmo salar*) stocking program in Lake Ontario (LOMU, 1998) because Atlantic salmon appear to be very sensitive to thiaminase (RE, ROG, RO). In fact, it is now thought that thiaminase may have played a role in the original extirpation of Atlantic salmon from Lake Ontario in the late 1800s (RE).

Burbot might also benefit as predators from the re-introduction of bloaters (JH, RO, TS, TJS). Burbot over 500 mm eat a wide variety of fishes, including ciscoes, but also cisco eggs (Scott and Crossman, 1973). Deepwater sculpins (*Myoxocephalus thompsoni*) and to some extent slimy sculpins are also predators on bloater eggs and larvae in the hypolimnion (Rice, Crowder, and Holey, 1987; Lueke et al., 1990; section 2.2.1). Lake herring are also potential predators on bloater eggs and larvae (JC).

Burbot and lake trout might also benefit from bloater re-introduction, if the addition of another prey species reduced the competition between them that is believed to be occurring now (JH). There could be a third benefit to burbot of reduced smelt and alewife predation on their young (section 2.1.4).

2.1.4 Reduced Impacts of Alewife and Smelt on Other Species

Predicting the interactions of alewife, smelt and re-introduced bloater populations is complex; potential predation and competition are discussed in section 2.2.1. If alewife and smelt populations were reduced by a successful bloater re-introduction, benefits might occur for other species that are also subject to predation by alewife and smelt on pelagic larval forms (USFWS, 1995). There is evidence from both Lake Ontario and Lake Superior that alewives are implicated in decreases of all stocks with pelagic larvae (BL). These species could include whitefish, burbot, emerald shiner (*Notropis atherinoides*), deepwater sculpin, yellow perch (*Perca flavescens*), and walleye (*Stizostedion vitreum*) (RE, JH, BL, RO). In fact, populations of several of these species, as well as threespine sticklebacks (*Gasterosteus aculeatus*), have increased in recent years, and this is generally attributed to lower alewife or alewife and smelt populations (JH, RO; LOMU, 1998; Bowlby et al., 1991). Lake herring might also benefit from lower alewife and smelt populations (LOMU, 1998; JH).

However, it may also be possible for a bloater re-introduction to have the opposite effect. It the introduction of an alternate prey species reduced predation pressure on alewife and smelt, so that their populations increased, then their impacts on other species might be increased rather than decreased (JC).

2.2 ECOLOGICAL RISKS OF RE-INTRODUCING BLOATERS

2.2.1 Impacts on Alewife and Smelt Populations

Re-introduced bloaters would interact with alewife and smelt populations, according to almost all the fishery scientists I interviewed, but exactly how is less clear. The consensus is that the three species could co-exist, based on the fact that they do in Lakes Michigan and Huron. Whether decreases in alewife and smelt populations are viewed as benefits or risks depends on one's point of view – there are clearly potential benefits to some other species besides bloaters (section 2.1.4), but major decreases in alewives could cause public concern because of their importance to the stocked salmon fishery (DB, BL, TJS; section 2.2.2). I have included these impacts as risks because they involve possible reductions in existing fish populations.

The opportunity for interactions among alewife, smelt, and bloaters would depend on habitat overlap, and this can vary with season, time of day, and life stages of fish. The greatest potential for habitat overlap of bloater adults was generally thought to be with smelt (JB, RE, BL, TS, TJS), except in winter when alewives move to deep waters (section 2.1.1). This is reflected by adult summer temperature preferences, based Wismer and Christie (1987), Crowder and Crawford (1984), and LOMU unpublished data: 16 – 28°C (mean 16.8°C) for alewife, 7 – 16°C (mean 11.3°C) for smelt, and 5 – 16°C (mean 10.5°C) for bloater.

Crowder (1980) plotted seasonal depth distributions from the literature for alewife and smelt in Lake Michigan. Alewives occupied relatively shallow but variable depths in summer, from a few m to about 50 m, and from about 40 m to well below 90 m in winter. Smelt were usually below 10 – 20 m, in summer to about 40 m, and in winter 60 m. Catch records for the three species, for 1977 to 1991 in Lake Michigan, were summarized in USFWS (1995). Alewives were captured at a range of depths, but concentrations varied more in shallower (5 – 30 m) water. Smelt and bloater distributions were similar, with abundance higher at intermediate depths of 18 – 55 m.

In Lake Ontario, hydroacoustic data from the N.Y. Department of Conservation (NYDEC) and the OMNR show that the alewife is an epilimnetic fish in summer (BL). Smelt would be expected to be higher in the water column than bloaters in Lake Ontario (TS), although the similarities in temperature preferences suggest that there might be considerable overlap of the two species. Smelt generally occupy deeper water as they grow, but then return to shallower water when they become piscivorous; thus maximum overlap with bloater adults might occur with smelt of medium age (RE). Predictions of smelt/bloater overlap are further complicated by current changes in smelt distributions in Lake Ontario since the invasions of exotic zebra and quagga mussels (*Dreissena polymorpha* and *D. bugensis*), described by R. O'Gorman. Mean spring (June) capture depths have gone from 18 -- 35 m to 39 -- 54 m. In July and August most smelt are now captured deep in the hypolimnion (feeding exclusively on *Mysis*). Historically, Koelz (1927) reported that bloater occupied greater depths in Lake Ontario (50 – 60 fathoms, 91 – 110 m) than in other lakes (30 fathoms, 55 m). However, Scott and Crossman (1973) give a depth range (38 – 121 m) similar to that for the other lakes, with maximum abundance at 76 – 91 m.

There is more potential for overlap of young bloaters in the epilimnion with one or both species (JB, JC, RE, BL, TS). Rice, Crowder, and Binkowski (1987) summarize early bloater life history in Lake Michigan. Bloaters spawn primarily in January to March, in deep water, usually 70 – 100 m. After hatching in late spring and early summer, the larvae stay in the hypolimnion for about 10 days after first feeding and then migrate to the epilimnion. In the day they are near the surface but move down as far as the metalimnion at night. Because they are concentrated offshore (outside the 25 m contour), their most likely predators are pelagic alewife and smelt. In the 1960s in Lake Michigan, this pelagic zooplanktivore stage may have lasted until age 3+, ending with a switch to deeper waters and benthic prey (Crowder and Crawford, 1984), and still lasts at least until the end of the second year (RE).

Varying opinions in the literature on the role of alewife and smelt in bloater and other deepwater cisco declines were summarized in section 1.2. Generally, even where alewife or smelt were considered important factors, mechanisms were unknown, at least in earlier studies. In Lake Michigan bloater and alewife populations have shown a strong relationship, one increasing when the other decreased, and vice versa (Crowder, 1980, Brown et al, 1987; BL, BT).

A series of studies on Lake Michigan bloater, alewife and smelt interactions provide some insights, first on predation by alewife and smelt. Changes in bloater reproduction between the early 1970s and 1984 were closely linked to alewife population levels, suggesting predation by alewife on early life stages of bloater as the cause (Eck and Wells, 1987). Crowder (1980) also showed that the near-extinction of the bloater in Lake Michigan in the late 1960s was consistent with heavy predation on its early stages, and that predation by alewife, but to a lesser degree by smelt, could have occurred on very early stages due to habitat overlap with bloater spawning habitat in the hypolimnion. Rice, Crowder, and Holey (1987) thought that predation in the hypolimnion, probably from sculpins and adult bloaters, was higher than predation pressure from juvenile alewife and smelt in the epilimnion. However, in laboratory studies of predation on bloater eggs and sac-fry, in hypolimnetic (dark and cold) conditions, Lueke et al. (1990) showed that only sculpins, and not alewives or adult bloater, were important predators. In epilimnetic conditions, yearling alewives, smelt, and bloater all ate bloater larvae. Smelt ate relatively few, and smelt and bloater ate less when zooplankton were present; alewife selected larvae even in the presence of zooplankton, making it the "prime suspect" in larval predation. Smelt have been found feeding on young-of-the-year (yoy) bloater in the fall (RO), but their reputation for consuming eggs and larvae may be worse than the reality (RE). They do not usually become piscivorous until they are relatively large (RE, JH). Nevertheless, predation by yearling smelt (less than 100 mm) on yoy smelt is considered the most likely cause of alternating strong and weak year classes in Lake Ontario (O'Gorman et al., 1987). Larger smelt are currently in relatively low numbers in Lake Ontario (JC, JH), although overall smelt numbers are relatively high (JH). Alewives at the surface of Lake Ontario now are believed to prey heavily on fish larvae (TS).

Lake Michigan studies also appear to document competition among alewife, smelt, and bloater, with no one species dominating, although the evidence is less clear than that for predation. Crowder and Magnuson (1982) sampled fish in 1977 and 1979 where the thermocline intersected the bottom. Bloaters (small probable yearlings and older fish) constituted less than 1% of fish captured in 1977, but 42% in 1979. Over that time, adult alewives shifted into cooler water (away from their laboratory preferred temperatures), and smelt into slightly warmer water; no native species shifted their habitats thermally. The authors thought that exploitation competition may have explained the shift. Laboratory work by Crowder and Binkowski (1983) showed that, while alewives could use small prey more effectively, bloaters were much better at capturing prey on the bottom. Crowder and Crawford (1984) found yoy bloaters at the surface, feeding on zooplankton, but juvenile bloaters (probably age 1+), although they were in somewhat warmer water than adults (age 2+ and up), had switched to a 99% benthic (by weight) diet. This move to the benthos, up to two years earlier than occurred in the 1950s and 1960s, they thought could be explained by competition with alewives. However, R. Eshenroder believes that problems with age assumptions by Crowder and Crawford make it wrong to interpret these data as showing bloater recruitment to the hypolimnion this soon. Eck and Wells (1987) questioned the importance of competition between alewife and bloater.

Brown et al. (1987) concluded that there was convincing evidence that alewife and smelt can limit bloater populations in Lakes Michigan and Huron. The varying results of Lake Michigan studies suggest, however, that predicting the net results in Lake Ontario is impossible. Brown et al. (1987) also suggested that salmonine predators may modify alewife and smelt impacts on bloaters, and Crowder and Binkowski (1983) believed that the presence of salmonines was important to alewife/bloater co-existence.

2.2.2 Reduction in Prey for Salmonines other than Lake Trout

Bloater as an alternative prey for salmonines, especially lake trout, was considered as a benefit (section 2.1.3). However, if bloaters were to cause reduced alewife populations in Lake Ontario, and non-lake trout salmonine piscivores did not switch to preying on bloaters, piscivore populations could be negatively affected.

In general, stocked Pacific salmon are not expected to eat bloaters as readily as lake trout because of different depth or food preferences (JB, BL, ROG, RO, TS, TJS). Salmon apparently select primarily alewife in Lakes Ontario and Michigan, alewife and smelt in Lake Huron (USFWS, 1995) and smelt in Lake Superior (Hansen, 1994), even when they are less abundant than other prey. It was suggested that the large numbers of chinook salmon (*Onchorynchus tshawytsha*) dying in Lake Michigan in the late 1980s from bacterial kidney disease (BKD) were weakened by poor nutrition during a period of low alewife (but high bloater) numbers (USFWS, 1995; JB). However, chinook salmon are beginning to include bloaters in their diet now in Lake Michigan, though they are not favoured (BL, RO) and when they were recruiting well in Lake Michigan in the 1980s, young bloaters were important in salmon diets (RE). It was also pointed out that if lake trout switched substantially from feeding on alewife to bloater, more of the alewife population would be available to salmon (JC). High salmonine populations might actually impede a bloater re-introduction (BT) if it were a favoured prey. Although it is more of a social than ecological risk, there could be a perception that the alewife/chinook salmon food web, which is more valuable economically to the sports fishery, was being reduced by managers in favour of the bloater/lake trout food web (BL, TJS).

Brown and rainbow trout are considered more adaptable than salmon, and therefore more likely to prey on bloaters (RO).

The risk to salmonines of a reduction in preferred prey may be somewhat offset by the benefit of less thiaminase in non-preferred prey (section 2.1.3).

2.2.3 Interactions with Sea Lamprey

The potential risks related to lampreys are that they would benefit from the introduction of an alternative host species, and that the bloater re-introduction could be harmed by lamprey parasitism. Both risks appear very small, however. Lamprey can feed on adult bloater (Brown et al, 1987) and did in Lake Ontario (Smith, 1972). Currently lampreys are quite well controlled in Lake Ontario (GLFC – LOC, 1998). Their preferred prey in the lake is lake trout, and few wounds are found on whitefish (JB).

2.2.4 Inadequate Food Availability

The large populations of *Mysis relicta*, one of adult bloaters' preferred foods, in Lake Ontario were discussed in section 2.1.1. However, there is some concern about the availability of other foods. Bloater diets were summarized by Scott and Crossman (1973), and reported for Lake Michigan by Wells and Beeton (1963). Adult bloaters ate primarily *Mysis* and *Diporeia hoyi* (formerly *Pontoporeia affinis*). Wells and Beeton (1963) found that as bloaters grew in length, *Diporeia* was incorporated into their diet to a greater extent than *Mysis*, although both of these macroinvertebrates contributed heavily. They found that relative proportions of *Mysis* and *Diporeia* also varied with depth and season; and fingernail clams and a group of other items (including fish eggs and insects) each made up about 2% of food by weight. Smaller bloaters ate mainly zooplankton, with the proportions of *Mysis* and *Diporeia* increasing with size (Scott and Crossman, 1973). Yoy bloaters in Lake Michigan selected two types of zooplankton in particular, *Cyclops* and, when they were larger, *Daphnia* (Warren and Lehman, 1988). Crowder and Crawford (1984) found results in Lake Michigan similar to those above: yoy bloaters ate zooplankton; juveniles (probably age 1+) ate 66 – 70% zooplankton by number, but about 99% benthos (almost all *Mysis* and *Diporeia*) by weight; adult bloaters ate 29 – 38% zooplankton by number, but over 99.8% benthos by weight. Although *Mysis* and *Diporeia* are usually reported as benthic prey, *Mysis* have extensive and rapid daily vertical migrations, and *Diporeia* is considered both benthic and planktonic, with both species active at night (Pennak, 1953). Bloater diets can, however, be more diverse than these data might suggest: their (former) position as the shallowest of the deepwater ciscoes is evident in their more generalist food habits (RE).

For example, adults have been shown at times to feed almost exclusively on deepwater *Daphnia* (RE).

Most of the fisheries scientists with whom I spoke were concerned that recent large decreases in *Diporeia* populations in Lake Ontario could mean inadequate food for bloaters. The most recent data (1996) on *Diporeia* in the lake showed that it had become very rare in the east, at depths over 60 m, but that at 120 m in the central basin numbers were higher than those in the 1980s (RD). *Diporeia* populations tend to go through an approximate 7-year cycle, so that low 1996 levels may have been partly the result of a long-term trend, but it is uncertain without more recent sampling (RD). Low *Diporeia* are also thought to be related to competition with zebra and quagga mussels, which remove plankton from the water (RD).

Quagga mussels are now more abundant in Lake Ontario than zebra mussels: 1995 data showed depths less than 25 m dominated by zebra mussels, but from 25 m to approximately 90 m dominated by quagga mussels (EM). The latter are considered more of a problem because they can inhabit not only deeper areas, but a greater variety of habitats (RD), and would clearly overlap more with bloaters. It is too soon to know all the impacts quagga mussels will have (OEJ, BL) but they could compete with *Mysis* and *Diporeia* for diatoms (OEJ).

General concerns about zooplankton availability for young bloaters are related to the poorer condition of Lake Ontario fish in recent years (JC, BT), although, with declines in condition mostly in benthivores, benthic prey availability may be a more important issue (BL). R. Eshenroder thought the problem of food availability was overemphasized, but E. Mills thought the concerns might be justified by lower zooplankton populations in the lake. Overall reductions in lake productivity and removal of zooplankton by mussels have reduced zooplankton populations (LOMU, 1998; EM). Predation by alewives may have contributed, so that lower alewife populations may account for some rebounding recently, but zooplankton populations are not up to the levels of 10 – 15 years ago (EM). The spiny water flea, *Bythotrephes cederstroemi*, significantly reduced *Daphnia* populations in Lake Michigan (Warren and Lehman, 1988; section 2.3.3). A large new exotic zooplankter, the "spinier" water flea, *Cercopagis*, first seen but very abundant in Lake Ontario in 1998, may also be reducing zooplankton populations (EM).

Rice, Crowder, and Binkowski (1987) found that bloater larvae were very resistant to starvation. Half of unfed larvae lived 25 days, some up to 40 days, and they did not show a "point of no return" with first feeding delayed as much as 16 days. While increased mortality from predation was considered a probable consequence of lack of food, these results suggest that bloater larvae could survive temporary food shortages.

There is evidence that with decreasing productivity in the lake, many species are shifting to greater depths (ROG). Some of these shifts may also be related to the changes in water clarity that accompany decreasing productivity, and the inshore *Diporeia* losses (BL). Recent captures of lake herring (JC), lake whitefish, slimy, and deepwater sculpins (JH) in deep water may be evidence of a good deepwater food base in the depths.

2.2.5 Impacts on Deepwater Forms of Lake Herring

Almost all the fishery scientists I interviewed thought that re-introducing bloaters could have negative impacts on the relatively recently-found deepwater forms of lake herring in Lake Ontario. It may be considered a very serious risk (JC). There might be some risk to the bloater re-introduction as well.

The deepwater forms of lake herring were described by J. Casselman, from OMNR unpublished data. There are two deepwater forms, one shallow- and one deep-bodied, but both differing in a number of characters from the more typical shallow-water lake herring. Estimates of numbers are not possible now, but each deepwater (approximately 80 – 90 m or more) sampling finds more; sampling in search of deepwater sculpin has actually produced 2 – 3 times more lake herring. The specimens examined have been young, fast-growing, and with gonadal development different from that of shallow-water lake herring at the same time of year, suggesting that they may be reproducing. Scott and Crossman (1973) discuss how, following the disappearances of the familiar species, new ciscoes have appeared in deep waters of the Great Lakes that differ from any species previously there. Koelz (1927) described two different subspecies of lake herring, shallow- and deepwater forms, but these are not believed to be the same as the newer forms (JC).

Bloaters might affect deepwater lake herring through competition (JC, RO, TS) or hybridization (JC, RE, BL, ROG, RO). The result could be complete loss of one or the other (TS) but on the other hand, different ciscoes did co-exist and evolve together in the past (TJS). The two coregonines in Lake Ontario now, lake whitefish and lake herring, are believed to have negative effects on each other through competition (JC).

Hybridization or introgression (the exchange of genes or blocks of genes between populations through frequent hybridization) is a characteristic of coregonines (Svärdson, 1970). According to Scott and Crossman (1973), some biologists believe that the new forms of deepwater ciscoes are the result of hybridization between species that are becoming increasingly rare, and the more common lake herring and bloater. A remnant lake herring population in northern Lake Michigan was apparently lost through hybridization when bloater populations were increasing (ROG). Clarke and Todd (1978) wrote that bloaters apparently hybridize frequently with lake herring, especially when populations are under stress.

J. Casselman believes that the new deepwater lake herring forms may increase to use more of the available deepwater niche in Lake Ontario (section 2.1.1). However, others are skeptical because of the low numbers that have been caught (JH, BL, TT). It is possible that very small deepwater lake herring populations are "bottlenecked" by genetic drift driving their evolution rather than selection (RE). Whether to re-introduce bloaters to populate the available niche, or wait to see whether coregonines will fill it without intervention, becomes a philosophical as well as an ecological issue (DB, JH, BL, RO, TJS) but both options represent ways of trying to achieve a more natural fish community in Lake Ontario. Complicating the situation more is the possibility that some other exotic species might arise to fill the niche (section 2.3.3), if deepwater lake herring cannot form a population quickly enough, or the population formed is not resilient enough to fill it (BL).

There is a need to be concerned, from a biodiversity perspective, about protecting deepwater lake herring forms (DB, RE, JH). The draft Fish Community Objectives for Lake Ontario (GLFC – LOC, 1998) has a guiding principle of "The protection and enhancement of rare and endangered species, in particular, is an important element in securing biodiversity", and a healthy fish communities objective of "protecting and enhancing rare and endangered fish species". It may be possible to raise more deepwater lake herring in a culture situation (JC, RO) as is proposed for the bloater re-introduction (section 3.2.3). More information is clearly needed to assess this risk: genetic work is underway (JB, JC, RE), and more information about numbers and the chance of population recovery or expansion is also needed (TS).

2.3 ECOLOGICAL UNCERTAINTIES OF RE-INTRODUCING BLOATERS

2.3.1 Introduction of a Coregonine

W. B. Scott believes that introducing a coregonine species from one lake to another would be a very unfortunate idea, particularly under the currently unstable conditions in Lake Ontario. He believes that introducing bloaters into Lake Ontario would not be restoring a species, since the genetic material is irretrievably lost (also JC) and the bloater in other lakes is not the same fish genetically that was in Lake Ontario. However, it has been pointed out that bloaters from other lakes would be much closer to what was in Lake Ontario than the exotic alewife and smelt of today (JB). Also, connections among the Great Lakes mean that bloaters from all the upper Great Lakes had the opportunity to reach Lake Ontario; because young bloaters are epilimnetic, Lake Erie would not have been a barrier to larval drift (ROG; section 3.2.2).

Coregonines of the subgenus *Leucichthys* (ciscoes) vary tremendously from lake to lake and Great Lake to Great Lake, and can be completely different fish in different Great Lakes (WBS). Svärdson (1970), summarizing the results of many studies in Sweden, found that most coregonine characters, including growth rate, spawning habits, body proportions, and meristic characters, varied with environmental conditions. Todd et al. (1981) raised four types of deepwater ciscoes in hatchery conditions, and found that the hatchery fish differed more from their parents than from each other.

The problem then becomes unpredictability: bloaters might be successfully introduced, but the results might be very different from what was expected and from bloater populations in other lakes (WBS). With the loss of clear dividing lines among ciscoes (WBS) existing bloater populations may also be quite different from what they were historically. In contrast, T. Todd would not expect large changes in bloaters if they were moved into Lake Ontario, based on historic populations in the lake.

2.3.2 General Water Quality Problems and Persistent Toxic Chemicals

Smith (1972) thought that degraded water quality may have played a role in the decline of deepwater ciscoes in Lake Ontario (alone of the Great Lakes). Although the deep waters of Lake Ontario still appeared to be suitable habitat, Christie (1973) wondered if some unidentified water quality characteristics were responsible for the lack of fish. This possibility was also raised by J. Casselman and J. Hoyle. If an attempted bloater re-introduction were to fail, it might actually provide some information on problems in the lake (JH, TS).

Persistent toxic chemicals could play a role in a bloater re-introduction (JC, JH, BL, RO, TJS, BT) but how is uncertain. Because contaminant levels in fish vary with growth rate and condition (affecting lipid levels; JC, RE) predictions become even more uncertain.

It has been suggested that contaminants have contributed to low sculpin populations; if this is true, it would likely be through diet, and bloaters might also suffer reproductive impacts (JH). Such an impact would likely take some time to appear (MW). However, natural lake trout reproduction (giving measurable year classes) in Lake Ontario since 1993 coincided with lower contaminant levels in the lake (JH), although these lake trout reproduction levels have also been linked to population demographics and the decline in alewives (BL).

Increased levels of contaminants in piscivores could occur if bloaters had elevated levels (BL, TJS, BT). Studies of toxic chemical levels in the four Canadian Great Lakes have shown a sequence of fishes, from most to least contaminated: lake herring, lake trout, sculpins, smelt, alewife (MW). These studies have shown that the coregonines, lake herring and lake whitefish, seem to have a propensity for contaminant accumulation. In Lake Michigan, bloaters are used to monitor contaminant levels in fish because their relatively high lipid content leads to an appreciable accumulation of contaminants (Hesselberg et al., 1990). But their PCB levels for bloater in Lake Michigan – 5.7 μg/g wet weight in 1972 and 1.64 μg/g in 1986 – were lower than those reported for lake trout in Lake Michigan – 10.59 μg/g – by Rasmussen et al. (1990).

Rasmussen et al. (1990) found that the length of the food chain had important effects on PCB levels in lake trout: those from lakes with no *Mysis* or pelagic forage fish had the lowest levels, those from lakes with forage fish but no *Mysis* had intermediate levels, and those from lakes with both, and the Great Lakes, had the highest levels. In Lake Ontario, where lake trout and other piscivores are already eating forage fish, introducing bloaters may not make a difference, but any switching by lake trout from invertebrates to bloaters could increase their contaminant levels. Changes in predator contaminant levels could also depend on whether bloaters replaced alewife or smelt in current diets: because smelt consume *Mysis* but alewives usually do not, smaller contaminant increases would be expected with a switch from smelt to bloaters, than a switch from alewives to bloaters (JB).

If a commercial bloater fishery were ever re-established, toxic chemical levels would, of course, become a direct concern (RO).

2.3.3 Interactions with Other Species

Theoretically, bloaters could interact with all other species in the Lake Ontario offshore community. Benefits or risks to the major fish species, potential predators and competitors of bloaters, have been discussed (sections 2.1.3, 2.2.1, 2.2.2), but the probable nature of interactions with species considered here are uncertain. Because bloaters can use all levels of a lake at different life stages, they could interact with pelagic and benthic species. Species interactions could occur in the fall, when cold- and warm-water communities mix, that do not occur at other times (JB).

Alewife predation has probably reduced zooplankton populations in the past in Lake Ontario (EM) and reduced the average size of zooplankton in Lake Michigan, with important effects on bloaters (Crowder and Binkowski, 1983). It is reasonable to assume that young bloaters would also affect the zooplankton, and larger bloaters the benthic invertebrate, populations they preyed on. Yoy bloaters probably affected both abundance and daily vertical migration patterns of *Daphnia* in Lake Michigan (Warren and Lehman, 1988). In Lake Ontario, patterns of *Mysis* distribution, with lower numbers in shallower and nearshore waters, were probably related to predation by alewife, smelt, and slimy sculpins (Johannsson, 1995). By consuming *Mysis*, itself a planktivore, bloaters might also indirectly affect zooplankton populations (JB). *Mysis*, in turn, can consume enough of the daily zooplankton production in Lake Ontario (and Lake Michigan) to be a potentially serious competitor for planktivorous fish (Johannsson et al., 1994).

Changes in invertebrate populations caused by bloaters could also impact planktivores other than alewife and smelt. Threespine sticklebacks and emerald shiners have become increasingly common in Lake Ontario midwater trawls through the 1990s (LOMU, 1998). The potential exists for competition with slimy and deepwater sculpins for benthic invertebrates; they both also prey on *Diporeia* and *Mysis* (ROG, RO; Scott and Crossman, 1973; GLFC -- LOC, 1998). However, bloaters and sculpins have obviously co-existed in the past and elsewhere, and no effect of high bloater populations on deepwater sculpins has been observed in Lake Michigan (ROG). Sculpin may also benefit from predation on bloater eggs and larvae (section 2.1.3).

A concern that adult bloaters might prey on lake trout fry has been expressed (WBS, JC). When the two species are together in the epilimnion, bloaters are too small to feed on lake trout fry (BL, RO). However, lake trout fry move into deepwater nursery refugia (probably at 40 – 60 m) (JC) and there the possibility of bloater predation would depend on the relative sizes of the fish (JB).

Interactions with newly arrived exotic species, or those yet to come, present an even greater degree of uncertainty and risk to a bloater re-introduction. As planktivores, the spiny water fleas (*Bythotrephes* and *Cercopagis*) may affect zooplankton food availability for bloater. Warren and Lehman (1988) found that *Bythotrephes* appeared to be a serious competitor for *Daphnia* with yoy bloaters in Lake Michigan. In 1987, a year after *Bythotrephes* became established, no bloater yoy were captured at their research station. But *Bythotrephes* could also be food for bloaters: Branstrator and Lehman (1996) found *Bythotrephes* remains in 40% of yoy bloaters (all over 30 mm) they examined in Lake Michigan, and considered it an important diet item for them.

Round gobies (*Neogobius melanostomus*), which were very abundant in Lake Erie in 1998 (LLLTCM), have now been found in Lake Ontario (BL, ROG, RO). They are bottom-dwelling, in shallow warm water in summer and deeper in winter, and will probably behave ecologically like a large sculpin (ROG) but would probably interact little with bloaters (BL). The more pelagic ruffe (*Gymnocephalus cernuus*) is now in Lake Huron (LLLTCM). The blueback herring (*Alosa aestivalis*) has been found in the Oswego River; it has a life cycle similar to that of alewives and might compete with them (BL, BT). The latter two species might be possible competitors of bloaters.

2.3.4 Lack of Ecological Knowledge

There is a general lack of knowledge about the Lake Ontario ecosystem, particularly the deep waters of the lake (JC), that adds uncertainty to a bloater re-introduction and, added to the lake's ecological instability (section 2.1.2), makes predictions difficult (RO). Lake Ontario is unique among the Great Lakes because of its historical geological connection to the sea (WBS), so that predictions based on knowledge of the other lakes become less certain. The apparent window of opportunity for a bloater re-introduction provided by low alewife populations (section 4.1) may not be real (WBS).

A recent example of this lack of knowledge was the finding of deepwater sculpins in 1996 when they had been considered extinct in Lake Ontario (JC). This argument assumes that deepwater sculpins were present but undetected by surveys (ROG). If there was no remnant population, finding deepwater sculpins in 1996 could show instead the lake's environmental suitability for the survival of fish larvae drifting down from the upper lakes (section 3.2.2).

As a more general example of the lack of knowledge, a number of native species were showing positive signs of recovery in the early 1990s that were thought to be associated with low alewife numbers and improving conditions: lake trout reproduction increased and lake herring numbers increased; also the deepwater sculpin and more deepwater lake herring forms were found (JH). However, in the last two years, despite continued low alewife numbers, there appears to be less lake trout reproduction, and lake whitefish numbers have decreased (JH), although changes in trawl gear are likely responsible for declines in index catches of lake trout in the last two years (BL).

Opinions differ as to whether this lack of knowledge, together with the other risks and uncertainties, are enough to decide not to re-introduce bloaters, but there is some general agreement that the outcome is uncertain.

3 TECHNICAL CONSIDERATIONS AND CONSEQUENCES OF RE-INTRODUCING BLOATERS

3.1 POSITIVE TECHNICAL CONSIDERATIONS OF RE-INTRODUCING BLOATERS

3.1.1 New Knowledge

Attempting to re-introduce bloaters to Lake Ontario would produce new knowledge, whether or not the re-introduction was successful – knowledge of the biology of bloaters, knowledge of fish culture techniques, and increased knowledge of the lake ecosystem (section 2.3.2).

3.1.2 Restoration of a Commercial Fishery for Bloater

This is perhaps more of a social than a technical benefit, but re-introduction of bloaters to Lake Ontario might at some time in the future lead to the resumption of a commercial fishery (JH, RO). The commercial fishery ended in Lake Ontario about 1950 (section 1.2), but "chub" fisheries now exist in Lakes Michigan and Huron (Brown et al., 1987; Ebener, 1995). In both lakes, however, low bloater populations in the 1970s resulted in temporary closures of all or part of the fishery (Brown et al., 1987). Traditionally, bloaters were considered too small to catch commercially (Smith, 1968), but as other deepwater ciscoes or chubs disappeared they became the only species available. Bloater growth rates also increased following the loss of the lake trout (Scott and Crossman, 1973; Smith, 1968), although increases in average age may have contributed to increased bloater size in fishery statistics (Smith, 1968).

Brown et al. (1987) caution that the degree of resilience to fishery pressure in bloaters depends partly on the history and condition of stocks. A stock that has developed a highly unbalanced sex ratio, as occurred in Lake Michigan in the 1960s (Brown, 1969), may fail at apparently low exploitation rates. The presence of non-endemic species may also destabilize bloater populations. Brown et al. emphasize the difficulty of maintaining bloater yields within safe limits to avoid very high as well as low population densities.

3.2 NEGATIVE TECHNICAL CONSIDERATIONS OF RE-INTRODUCING BLOATERS

3.2.1 Lack of Success

The most basic negative technical consequence is that the re-introduction will fail with the resulting loss of possibly large amounts (section 3.3) of time and money (JB, JC, JH, WBS, TJS). The example of low returns from lake trout stocking in general (TT) and in Lake Ontario was cited: after 25 years and 32 million trout stocked (JB), recruitment is still low (JC). Some of the lake trout problems may be due to the use of non-endemic fish that did not evolve in the Great Lakes and had inappropriate spawning behaviour (RE), and to sea lamprey predation, an intensive sport fishery, aging of the population (lake trout females do not seem to become effective spawners in terms of egg production until about age 7), and high dietary thiaminase levels (BL).

There were widespread whitefish hatchery-based stocking programs in the Great Lakes from the 1880s into the 1920s, with a few continuing until the 1950s and 1960s, but they were considered failures (TT; USFWS, 1995). In general whitefish stocking into lakes with existing populations has been unsuccessful, but this situation, with bloaters absent, holds more promise (TT).

Various coregonine species have been transplanted successfully in Europe, and coregonine fisheries, especially in Finland, are maintained by stocking (RE). Svärdson (1970) writes of hundreds of years of coregonine transfers among Swedish lakes. According to T. Todd though, there are few examples of successful hatchery-based whitefish stocking, and there is very little experience with deepwater coregonine stocking. He knows of successful whitefish stocking programs by OMNR in Lake Simcoe (also SW; section 3.2.3), the Minnesota Department of Natural Resources/aboriginal program, as well as programs in the Bodensee in Germany and Lake Baikal in Russia. The latter two programs are very large in scale (30 -- 50 million fish per year in the Bodensee), and raise offspring from the lake fish themselves in hatcheries. Only the Lake Baikal program deals with a deepwater species.

3.2.2 Considerations Associated with the Source of Bloater Stock

There are only three possible sources of bloaters – Lakes Huron, Michigan, or Superior (section 1.2). With no bloaters in Lake Ontario now, the common genetic risk of mixing genes from outside populations with the existing one does not exist (TJS, BT), and whatever stock is used will have different genetics from historical Lake Ontario bloater populations (JC, WBS; section 2.3.1).

Any of the stocks may be suitable for Lake Ontario (TS), but there may be some merit in examining differences in behaviour that may make one stock more suitable (DB, JH). Looking at genetic differences would then be needed (DB). Characterizing genetics should be done in any case for later monitoring (SW; section 4.3). Getting bloaters from more than one location, in one or more lakes, may be useful to get enough fish (ROG) and to reduce reliance on a single source (JB).

There is a preference for using the Lake Huron bloater stock because it is the closest to Lake Ontario, and if any dispersal happened naturally by larval drift, this is where it would come from (ROG, RO). There are a number of examples of fish in Lake Ontario that are believed to have come from upstream lakes. The former blue pike (*Stizostedion vitreum* subspecies) and white bass (*Morone chrysops*) populations of Lake Ontario are thought to have been maintained by Lake Erie populations (Christie, 1973; RE, RO), although Bowlby et al. (1991) re-examined the same data for blue pike and showed otherwise. The deepwater sculpin recently found in Lake Ontario might have come from Lake Huron (BT); probable movement of their larvae from Lake Huron to Lake Erie has been documented (RO) by captures of larvae in the St. Clair River and western Lake Erie (Roseman et al., 1998). The gobies now in Lake Ontario are also probably from Lake Erie (RO). When a population explosion of pink salmon (*Oncorhynchus gorbuscha*) occurred in Lake Huron a few years ago, several were caught in Lake Ontario and may have come from Lake Huron (ROG); all Great Lakes pink salmon populations result from dispersal from a single release in Lake Superior in the 1950s (JB).

With any re-introduction comes the risk of introducing disease. R. Eshenroder felt that the Lake Huron stock should not be used because of the presence of BKD, but that the Lake Michigan and Lake Superior stocks would be acceptable. However, others felt that the risk of disease from Lake Huron fish was small or acceptable because diseases already have a natural opportunity to reach Lake Ontario from Lake Huron (JH, ROG, TS, TJS). Disease analyses of deepwater sculpins from Lake Huron have not found any diseases different from those already in Lake Ontario (WK, BL, BT). S. Watson thought that the risk of BKD was of equal concern for all the lakes, and that all adult bloaters collected for spawn should be checked for health. Adult transfers (as opposed to culture) carries a greater risk of disease introduction (TJS, BT) but in this case adult transfer is probably impossible (section 3.2.3).

3.2.3 Considerations Associated with Culturing Bloaters

There are definite risks associated with culturing fish. Hatchery conditions, so different from natural conditions, impose artificial selection pressures on fish that may not select for appropriate traits for the lake environment (JC, JH). Hatchery-related genetic problems are summarized in Ebener (1995). On the other hand, hatcheries can remove some selection pressures and enhance survivorship (BL). Hatchery-raised bloaters and other deepwater ciscoes were very different phenotypically from their wild-caught parents (Todd et al, 1981). For bloaters, not enough is known about bloater biology, and the importance of light and pressure for egg development and especially hatching (SW), to be able to predict what might happen if hatchery fish were moved to the lake (TT). Because bloater young do live near the surface (section 2.2.1) and there is probably a genetic propensity to move to deeper water later, hatchery fish may well do so (TT).

Direct adult transfers of fish can avoid the risks of hatcheries, but bloater adults are simply too fragile to move (RE, ROG, WK). Most adults are killed by being brought to the surface (they do bloat), and if they survive are delicate and do poorly in confinement (RE). Interestingly, Crowder and Binkowski's (1983) work on feeding behaviour used about a dozen wild-caught bloaters (maximum TL 234 mm) in the laboratory; however, these captures were made during an upwelling, and certainly do not make adult transfers practical for a re-introduction (RE). It would be worthwhile though to investigate the possibility of direct transfers of young bloaters from the epilimnion (JB).

Culturing bloaters is possible. There is considerable experience in Europe with raising coregonines (ROG, RO). The knowledge gained over several years of developing methods to raise whitefish to fall fingerling size in OMNR's White Lake hatchery could be applied to bloaters (SW). Several of the references cited in this report are based on research on laboratory- or hatchery-raised bloaters (eg. Todd et al, 1981; Rice, Crowder, and Binkowski, 1987).

W. Krise has done several experimental tests on culturing bloaters with F. P. Binkowski (pers.

comm. and unpublished data). They tested laboratory stocking densities for rearing larvae (30 days old) and juveniles (mean 83 mm) over 30 days and 8 weeks respectively. They recommended less than 30 fish/l for larvae, to give 85 – 90% survival and better growth than at higher densities. For juveniles (which were considered larger than might be used in a re-introduction program) the maximum recommended density was 20 kg/m^2. This is similar to the densities needed by other coregonines but lower than those for salmonines. Handling stress tests were conducted on juveniles (mean length 91 mm). They returned to approximately normal metabolism in about five hours. This is similar to responses in other species, so bloaters can be handled, but only with care because scales are easily lost. Transport tests on juvenile bloaters (mean length 82 mm) showed that they were very sensitive to being in 7.6 *l* bags in shipping boxes for 36 hours; only a density of 20 kg/m^2 gave no mortality. This is 4 – 5 times lower than that needed for whitefish. Such actively swimming fish may need larger containers, and recovery time before release.

All of the programs and experiments referred to above have reared eggs taken from wild-caught adults. The logistics of collecting enough ripe adults for eggs could be one of the bigger technical problems in rearing bloaters (ROG, SW), especially with bloaters' winter spawning (section 2.2.1). Possibly eggs could be collected directly from the lake bottom (BL).

The question of how long to rear bloaters before release also needs consideration. Incubation and yolk absorption take about two months (WK). Ideally the fish should be stocked as small as possible (RE), to save time and money and to prevent "domestication" of the fish (WK). But ecological risks, such as food availability and predation pressure, may be more important (section 4.2). Stocking several sizes in the same location would allow assessment of which works best (RE).

Two alternatives to standard hatchery rearing have been suggested. Direct egg transfer (BL) would be possible (WK, SW). However, there are health risks; by the time adults could be checked for disease the eggs would be in the lake (SW). In Pennsylvania both egg transfer and hatchery rearing have been tried with American shad (*Alosa sapidissima*), but hatchery rearing has given much better results (WK).

Aquaculture methods for rearing bloaters was suggested by R. O'Gorman and would be feasible (WK, LLLTCM). It should be cheaper than hatchery rearing and would avoid acclimation and transfer problems (TS). The southern shore of Lake Ontario has suitable embayments (ROG), and the Bay of Quinte could be used for some time in spring (before temperatures become too warm) (JB). To avoid "domestication", which occurs in salmonines after 5 – 7 months, pen rearing should only continue for a few months at fairly low densities, although not too low for this schooling species (WK).

The best way to reduce risks may be to combine several methods (JB, SW) – egg transfer, hatchery and pen rearing.

The lack of available culturing facilities is the last technical (or perhaps social, as money is the limiting factor) consideration. OMNR at White Lake has some experimental laboratory space that could be used for bloaters (SW), but it is unlikely to be adequate for the numbers of fish needed (section 3.3). Hatchery facilities are not available now elsewhere in Ontario (TJS) or in the U.S., so that other uses would have to be displaced (WK, ROG). Bloaters would need warm water conditions, more like those used for walleye than for trout (ROG).

3.3 TECHNICAL UNCERTAINTIES OF RE-INTRODUCING BLOATERS: NUMBERS REQUIRED

How many bloaters would be required for a successful re-introduction is very uncertain. Put simply, enough are needed so that they can find each other to spawn (JC). That would depend on the degree of dispersal – with more dispersal more fish would be needed; with less, a colonizing population could be formed more easily in one place (RE).

Numbers would be limited not only by hatchery capacity but the ability to catch enough adults (section 3.2.3; SW). The White Lake whitefish program aims for 140,000 fall fingerlings per year (starting from about double the number of eggs; SW). Estimates of numbers of bloaters needed per year – with everyone emphasizing the uncertainty of their estimates – ranged from at least 100,000s (RE, JH, TT) to several million (ROG, TS, TJS) based on experience with lake trout and other salmonine stocking, and the expectation that survival rates might be lower for bloaters than for salmonines. Size at stocking would also affect numbers needed, with more needed the smaller the fish; for larvae even millions might be inadequate (ROG). There are no guidelines and only the experiment of actual stocking would show what is needed (BL, TJS, TT).

4 ECOLOGICAL CIRCUMSTANCES FOR THE RE-INTRODUCTION OF BLOATERS

4.1 ALEWIFE AND SMELT POPULATIONS

The Terms of Reference (Appendix A) specifically ask questions about the timing of bloater re-introduction relative to the potential for further catastrophic declines in alewife. Further declines are possible based on poor alewife recruitment since 1995, and low numbers of alewife yoy in 1996 and 1997, combined with high piscivore populations that result from increased stocking and increased natural reproduction of chinook salmon (GLFC -- LOC, 1998). But not everyone agrees that the decline will be catastrophic: the alewife population now consists of the strongest individuals and is therefore less susceptible to winterkill, and they may respond differently to changes in predator levels in the eastern basin where there are fewer salmon (JH).

Almost all the fishery scientists agreed that bloaters should be re-introduced when alewife populations were low, and most thought that now is a good time without waiting for further declines in alewife should they occur. Alewife numbers are very low, especially in the offshore areas where bloaters would be introduced, and whether or not the population declines further, it does not seem to be recovering (BL, BT). Smelt population levels should also be considered (JH); the larger smelt that are the potential predators on young bloaters are in relatively low numbers, so that again now could be a good time for re-introduction. For some there is a sense of urgency, that a large year class of alewives or a new invasion by an exotic species could soon fill the available niche (section 2.1.1) and eliminate the opportunity afforded by low alewife numbers (BL, ROG). However, low alewife numbers now may not be relevant to a stocking program that could take perhaps 10 years to establish a bloater population (RE).

4.2 OTHER SPECIES AND INDICATORS

For a successful bloater re-introduction, low alewife and low piscivore populations might be ideal, but this would be undesirable from the sports fishery community's point of view (TJS). However, very low piscivore populations could put a bloater re-introduction at risk because alewife populations might increase (RE). That combination of high alewife populations and low piscivore populations may be what caused bloaters to finally disappear from Lake Ontario when they survived low population levels in other lakes (JB, RO).

There is an argument for delay in order to learn more about the deepwater sculpin population, in particular whether it is reproducing or represents individuals from Lake Huron (BL), although if the population is increasing its origin may not be important (JC), and impacts of bloaters on deepwater sculpins would likely be small (section 2.3.3). Similarly, the situation of deepwater lake herring populations could be better understood, especially their potential for expansion (RE; section 2.2.5).

Several other fish species might be used as ecological indicators for the timing of bloater re-introduction. Populations of other species with pelagic larvae, eg. burbot, emerald shiner, and yellow perch would be good indicators: good recruitment would show favourable conditions for bloaters (RE; section 2.1.4). Threespine sticklebacks and lake whitefish populations might also be a good indicator of Lake Ontario conditions favourable to bloater re-introduction (DB, RE).

Population levels of food species should also be considered – low levels of *Diporeia* or *Mysis* might jeopardize a bloater re-introduction (ROG, RO, TS). Food availability could be assessed not only on a year-to-year basis, but for the timing of actual releases of bloaters. Monitoring could be done for pulses of zooplankton, and an analysis of sizes of available prey could help determine the size(s) at which to release bloaters (RE). Larger size at release could also reduce or possibly eliminate alewife and smelt predation (RE, JH, TS).

At a more general level, the lower productivity of the lake is making it more favourable for coregonines (BL). However, it has been suggested that more improvement is needed, and that a more normal, stabilized ecological community should be present before bloater re-introduction (JC, WBS).

4.3 MONITORING

Monitoring any bloater re-introduction is very important (TJS, TT). It is usually very difficult to assess the results of stocking programs, but with no bloaters present now, and bloaters and lake herring different enough to distinguish, it should be easier in this situation (TT).

Marking some fish would allow comparisons to be made with bloaters in other lakes (RE). However, at the scale needed for a successful stocking program (section 3.3) all fish may not be able to be marked, and it is possible that with such fragile fish, traditional marking may not be possible (TT). Mass marking may be possible by altering hatchery temperatures to produce patterns of thermal marks or "bar codes" on otoliths, as is done now for salmonine fry (ROG, JB). In the U.S., mass marking with tetracycline may also be possible (ROG). Characterizing the genetics of stocked fish is normally important in order to separate them from the existing populations (SW) but in this case it could be used to identify bloaters from different sources if more than one was used.

Bloater information should be included in the existing fish community indexing program (TJS). Some modifications to these programs may be required to adequately sample deep water (JB). The re-introduction should be done with a plan that includes benchmarks, targets, and assessment (TJS).

5 RE-INTRODUCING OTHER DEEPWATER CISCOES

Of the three other deepwater cisco species that inhabited Lake Ontario (section 1.2), only the kiyi could be considered for re-introduction. The blackfin cisco has been extirpated from all the major Great Lakes, although a population still existed in Lake Nipigon in the 1980s (McAllister et al., 1985). The shortnose cisco has been listed as rare in Lake Huron (USFWS, 1995), but it is probably extinct. None have been captured for 14 years (TT) in spite of an exhaustive survey in 1992 (TT; Ebener, 1995). It has been suggested that the shortjaw cisco (*Coregonus zenethicus*) may have occurred in Lake Ontario historically (RE), but a search of old Lake Ontario specimens has not found any (TT). The kiyi is probably extirpated from Lake Huron (Ebener, 1995) and was considered rare in Lake Superior (USFWS, 1995). However, its populations there are healthy enough to support an attempted re-introduction (RE, TT).

There is some appeal in the idea of re-introducing more than one deepwater cisco, to approach more closely the lake's historical native fish community (JH, BL, TJS, BT). Bloaters can be viewed as improving the empty niche situation in Lake Ontario, but together with kiyi, with the kiyi's specialization for greater depths, they would fully use the available niche space (RE; section 2.1.1).

Having the bloater established in Lake Ontario might possibly impede any later attempt to re-introduce kiyi (JB, RO). It is also possible that kiyi might have some features that would make it more suitable ecologically for Lake Ontario, or technically easier to stock (JH, TJS), but such predictions are probably very uncertain (TS). The ecological differences among species are not very clear (TT), and Todd et al. (1981) found that, while bloaters and kiyi had different genotypes adapted to different ecological conditions, their genetic differences were slightly less than are generally accepted for separating "morphospecies". Technically, collecting eggs from the winter-spawning kiyi in Lake Superior may (TT) or may not (RE) be difficult. Monitoring a kiyi introduction may be affected by the difficulty of distinguishing kiyi from deepwater forms of lake herring (JC).

From a practical point of view, it is probably only reasonable to consider re-introducing the bloater now (DB, ROG, TJS, TT). As the last deepwater cisco in Lake Ontario, bloaters may be more resistant to any water quality problems (section 2.3.2) in the lake (JH) and better able to co-exist with alewife (ROG). If bloater re-introduction was successful, then a later attempt to re-introduce the kiyi to Lake Ontario might be possible (ROG).

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APPENDIX A

Terms of Reference: Native Prey Fish Re-Introductions White Paper - Bloaters *(Coregonus hoyi)*

"New York State is interested in diversifying the prey fish community through the re-introduction of native species, prior to reaching a decision about proceeding with this approach, the Lake Ontario Committee (LOC) charges the Lake Ontario Technical Committee to address the following questions and report at the 1999 LOC Annual Meeting (minutes from LOC meeting, fall 1998):

a) What are the ecological and technical risks, uncertainties and benefits associated with the re-introduction of bloaters to Lake Ontario?

b) Under what ecological circumstances, would the re-introduction of bloaters be implemented?"

Some of the ecological considerations are:

- limitations and impacts related to smelt and alewife,
- limitations and impacts related salmonines and other piscivores (e.g. burbot),
- impacts on deepwater morphs of lake herring, (*C. artedii)*.

Some of the technical considerations are:

- source of stock
- numbers required
- adult transfer *vs*. culture
- availability of culturing facilities

The ecological circumstances for bloater reintroduction would consider the population levels of competitors (smelt and alewife) and predators (salmonine). The chances of a crash in the alewife populations are considered to be quite high. We need to consider reduced competition and predation (of bloater fry) with reductions of alewife and smelt, and increased predation by salmonines at the initial stages of the alewife crash. As well, would the reintroduction of bloaters reduce the impact on salmonines, if an alewife crash occurred? Therefore:

1) Should we go ahead before the crash?
2) wait for the crash?
3) wait longer until salmonines crash due to lack of prey?

Although bloaters are the primary interest we are also interested in similar analyses for kiyi (*C. kiyi*) and shortnose cisco (*C. reighardi*), if time permits.

Much of the needed information is known by people who have been connected with Lake

Ontario fish community rehabilitation. Most of these people are with the Great Lakes Fishery Commission (GLFC), New York Department of Environmental Conservation, US Fish and Wildlife Service, US National Biological Survey, and OMNR. A list of these people and their phone numbers have been provided and your responsibility is to contact them to get the appropriate information.

A draft report, as outlined above, the will be sent (electronically) to Jim Bowlby on, or before March 8, 1999. A final copy will be sent (electronically)) to Jim Bowlby on, or before March 15, 1999, followed by a paper copy.

APPENDIX B: PEOPLE PROVIDING PERSONAL COMMUNICATIONS

The initials after each name are those used in the report to refer to personal communications.

J. Bowlby – JB
Ontario Ministry of Natural Resources, Picton, Ontario

D. Busch – DB
U.S. Fish and Wildlife Service, Amherst, New York

J. Casselman – JC
Ontario Ministry of Natural Resources, Picton, Ontario

R. Dermott – RD
Canada Centre for Inland Waters, Burlington, Ontario

R. Eshenroder – RE
Great Lakes Fishery Commission, Ann Arbor, Michigan

J. Fitzsimons – JF
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J. Hoyle – JH
Ontario Ministry of Natural Resources, Picton, Ontario

O. E. Johannsson – OEJ
Canada Centre for Inland Waters, Burlington, Ontario

W. Krise – WK
U.S.G.S. -- Biological Resources Division, Wellsboro Laboratory, Pennsylvania

B. Lantry – BL
N.Y. Department of Environmental Conservation, Cape Vincent Fisheries Station, New York

Lower Lakes Lake Trout Coordination Meeting – LLLTCM
February 17, 1999, Amherst, New York
– there were several general discussions that could not be attributed to one person

E. Mills – EM
Cornell Field Station, New York

R. O'Gorman – ROG
U.S.G.S. – Biological Resources Division, Lake Ontario Biological Station, Oswego, New York

R. Owens – RO
U.S.G.S. – Biological Resources Division, Lake Ontario Biological Station, Oswego, New York

S. Rankin
retired fisher, Prince Edward County, Ontario

T. Schaner – TS
Ontario Ministry of Natural Resources, Picton, Ontario

W. B. Scott – WBS
Ontario Ministry of Natural Resources, Picton, Ontario
formerly Royal Ontario Museum

T. J. Stewart – TJS
Ontario Ministry of Natural Resources, Picton, Ontario

T. Todd – TT
U.S. Fish and Wildlife Service, Ann Arbor, Michigan

B. Trometer – BT
U.S. Fish and Wildlife Service, Amherst, New York

S. Watson – SW
Ontario Ministry of Natural Resources – Fish Culture, Peterborough, Ontario

M. Whittle – MW
Canada Centre for Inland Waters, Burlington, Ontario