GREAT LAKES FISHERY COMMISSION

2004 Project Completion Report[1]

Status and Assessment, Research, and Restoration Needs for Lake Herring in the Great Lakes

by:

John Fitzsimons[2], and Robert O'Gorman[3]

[2]Department of Fisheries and Oceans
Bayfield Institute
867 Lakeshore Road
Burlington, Ontario

[3]United States Geological Survey
Biological Resources Division
Great Lakes Science Center
Lake Ontario Biological Station
17 Lake Street
Oswego, New York
13126

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Abstract: The Great Lakes Restoration Act sponsored a workshop to summarize the status of remnant lake herring stocks, review impediments, and develop recommendations for assessment, research and restoration in the Great Lakes. The report and framework resulting from the workshop held July 9-10 2003 will help managers and interested researchers develop actions to assess stocks and develop research. This research needs to assess and develop corrective actions as appropriate to limit the impacts of impediments and foster the recovery of remnant stocks. Given that most remnant stocks are small, spatially isolated, and genetically depleted it is expected that restoration stocking will be a necessary part of restoring lake herring populations in many parts of the Great Lakes.

The workshop process was initiated by plenary summary presentations on the status of lake herring in all five of the Great Lakes and a number of inland lakes in Ontario. Presentations were also made on phylogeography, life history requirements, and dietary and rearing requirements. The thirty workshop participants then reviewed and assessed the importance of eight classes of impediments (e.g. habitat degradation, contaminants, exploitation, non-native biota, native biota, genetics, stock structure, spawning stocks and climate) rating them as to their potential to affect lake herring stocks on a lake by lake basis. The loss of stocks was considered the most important impediment now facing restoration of lake herring in the Great Lakes. This was followed by non-native biota with threats at almost all trophic levels but overall, alewives being perceived as the greatest threat in this class of impediments. Relative to the impacts of non-native biota, habitat degradation, contaminants, exploitation, native biota, stock structure and climate were considered of less importance.

As part of the impediment rating process, research approaches to assess the most important impediments were developed with emphasis on Lake Ontario. Approaches incorporating a combination of laboratory and field studies were advocated as they can provide data on actual mechanisms but applied to open lake stocks avoiding the largely circumstantial approach of the last century. Of the impediments in most need of research are those related to exotic species particularly those posed by alewives, a species suspected of impacting lake herring but where evidence to date has been of an anecdotal, speculative, and circumstantial nature.

Restoration stocking should be applied where it will not affect an existing remnant stock or stocks using an experimentally determined most appropriate life stage. Numbers to stock are problematic due to lack of information on early life stage mortality rates and knowledge of factors that affect recruitment success.

Management can play an important role in lake herring restoration by limiting exploitation, whether targeted or not, to the extent possible so as to preserve the few remaining remnant stocks. In addition there is a need to describe these remnant stocks in terms of population size, age composition, and genetic profile. Protecting remnant stocks is made all the more urgent by their low abundance and the steadily increasing influx of exotic species into the Great Lakes that may further elevate the risk of localized extirpations of lake herring. Despite best efforts, remnant stocks may still become irretrievably lost such that restoration becomes the only course of action to restore stocks and this will need to be supported by sufficient hatchery infrastructure.

Status and Assessment, Research, and Restoration Needs for Lake Herring in the Great Lakes

Results of a Workshop Sponsored by The Fish and Wildlife Restoration Act

Reported by:

John Fitzsimons
Department of Fisheries and Oceans
Bayfield Institute
867 Lakeshore Road
Burlington, Ontario

Robert O'Gorman
United States Geological Survey
Biological Resources Division
Great Lakes Science Center
Lake Ontario Biological Station
17 Lake Street
Oswego, New York
13126

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Table of Contents

Executive Summary

The Great Lakes Restoration Act sponsored a workshop to summarize the status of remnant lake herring stocks, review impediments, and develop recommendations for assessment, research and restoration in the Great Lakes. The report and framework (Fig. 1), resulting from the workshop held July 9-10 2003, will help managers and interested researchers develop actions to assess stocks and develop research. This research needs to assess and develop corrective actions as appropriate to limit the impacts of impediments and foster the recovery of remnant stocks. Given that most remnant stocks are small, spatially isolated, and genetically depleted it is expected that restoration stocking will be a necessary part of restoring lake herring populations in many parts of the Great Lakes.

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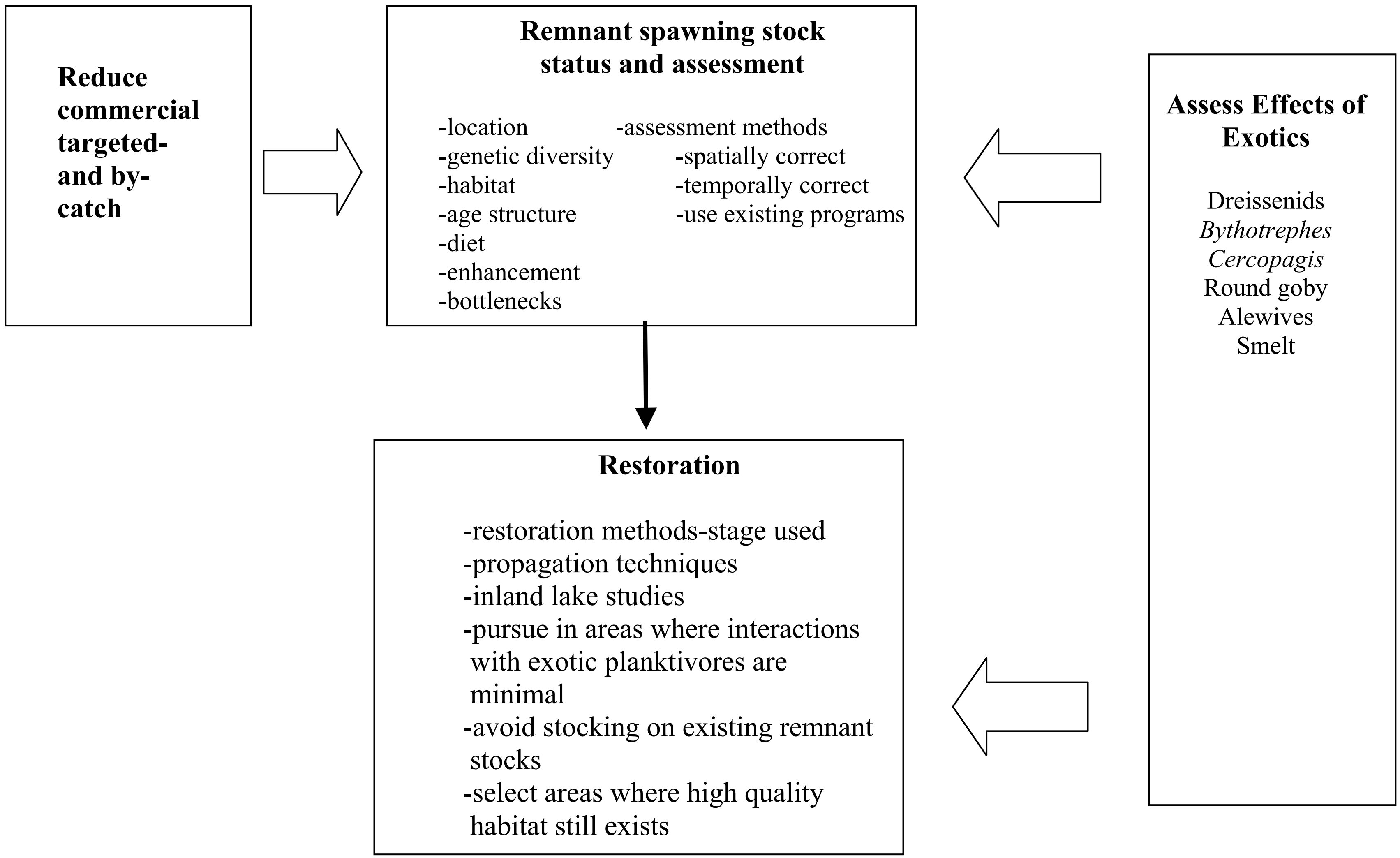
Integrated Assessment, Restoration and Research Framework



Introduction

The lake herring (*Coregonus artedii*) was one of seven species of ciscoes that were found historically in the Great Lakes (Todd and Smith 1992). Ciscoes were the major link between invertebrates and top piscivores in the Great Lakes food web and they also supported important commercial fisheries. During the early 1900s, most populations of ciscoes were decimated from overfishing and interactions with exotic planktivores such that by the end of the century, the bloater (*C. hoyi*) was only found in lakes Huron, Michigan, and Superior; *C. kiyi* was only found in lakes Huron and Superior; *C. reighardi* was only found in Lake Huron; and *C. zenithicus* was only found in Lake Superior (Smith 1972). Two other cisco species, *C. nigripinnis* and *C. johannae*, had been eliminated from the Great Lakes (Todd and Smith 1992). Lake herring were greatly reduced outside of Lake Superior and were extremely rare in Lake Erie. The continuing presence of lake herring throughout its historic range after regional and basin wide extirpations of other ciscoes suggests that it is the most resilient of the seven cisco species that originally inhabited the Great Lakes and therefore it is an excellent candidate for restoration.

Re-establishing vigorous populations of ciscoes in the Great Lakes would repair a food web compromised by exotic species and facilitate restoration of native piscivores, lake trout (*Salvelinus namaycush*) and, in Lake Ontario, Atlantic salmon (*Salmo salar*) whose decline paralleled those of the cisco complex. Relaxation of predation allowed two exotic planktivores, alewife (*Alosa pseudoharengus*) and rainbow smelt (*Osmerus mordax*) to flourish (Smith 1972) and replace ciscoes as the key link between invertebrates and piscivores (Brown et al. 1999). To control the large numbers of low-value exotic planktivores, fishery agencies introduced coho salmon (*Oncorhynchus kisutch*) and Chinook salmon (*O. tshawytscha*) to the Great Lakes in the 1960s (Tanner and Tody 2002). Annual introductions of salmon successfully reduced exotic planktivores (Madenjian et al. 2002; Mills et al. 2003) and the salmon became the basis of an economically valuable sport fishery (Bence and Smith 1999). However, attempts to re-establish self reproducing populations of lake trout failed in all lakes save Superior, due, in part, to high mortality of fry from early mortality syndrome (EMS), a syndrome linked to thiamine deficiency (Fitzsimons et al. 1999; Ketola et al. 2000). Alewives and rainbow smelt in the Great Lakes are rich in thiaminase and native piscivores that eat them produce thiamine deficient eggs from which emerge thiamine deficient fry (Fitzsimons et al. 1998, Tillitt et al. 2004). Alewife predation on larval lake trout has also been suggested as a bottleneck to lake trout restoration (Krueger et al 1995) although its basin-wide impacts are less clear than are the effects of the thiamine deficiency.

Increasing the proportion of lake herring in the planktivore community would be desirable for the reasons, including: 1) to stabilize prey fish abundance – native lake herring are not subject to die-offs and are long-lived whereas alewives, and to a lesser extent rainbow smelt, are subject to die-offs and both are short-lived, 2) to reduce incidence of EMS, because lake herring are not high in thiaminase, and thereby facilitate restoration of self-reproducing populations of native piscivores , 3) to increase food web efficiency since lake herring eat native invertebrates, *Mysis relicta* and *Diporeia* spp. all year whereas alewives use these prey only seasonally , and 4) to provide a large bodied prey for piscivores – small size of exotic planktivores likely limits asymptotic size of piscivores. Restoration of lake herring should be easier when competition with alewives and rainbow smelt is relaxed and currently, populations of these exotic planktivores are reduced or declining throughout the Great Lakes (Madenjian et al. 2002; Mills et al. 2003, Bronte et al. 2003).

In conclusion, the persistence of lake herring in all the Great Lakes when closely related species were extirpated, the accumulation of a large body of scientific evidence demonstrating the need for an alternative to exotic planktivores for prey fish, and the waning of competitive pressures from exotic planktivores all suggest that it was an appropriate time to examine the status of lake herring and outline research needs for a restoration program. Current fish community objectives support the protection and rehabilitation of lake herring stocks throughout the basin (Appendix C).

Workshop Organization, Goals and Objective

The workshop was organized by Robert O'Gorman of the US Geological Survey and John Fitzsimons of the Department of Fisheries and Oceans with funding from the Great Lake Restoration Act. The goal of the workshop was to identify the research and information gaps limiting our ability to restore lake herring and develop specific restoration measures for the Great Lakes with an emphasis on Lake Ontario. To accomplish this goal individuals working with or interested in the species in the Great Lakes Basin and elsewhere were brought together with the intent of addressing five objectives:

1. To review population trends and status of lake herring in the Great Lakes and selected inland lakes.
2. To assess the role of exploitation, species interactions, habitat deterioration, climate and genetics in explaining trends in lake herring abundance. .
3. Develop a list of current and future major impediments to recovery of lake herring for each of the Great Lakes.
4. To develop a list of first and second order research priorities to address impediments for each of the Great Lakes.
5. To develop a list of restoration activities and management actions to facilitate lake herring restoration in the Great Lakes.

To accomplish the first two objectives, presentations were given in a plenary session for each of the Great Lakes providing all participants with the same background information as to current and historic stock status and the suspected impediments. Facilitated discussion groups were used as the primary tool to accomplish the next four objectives. Three individual groups were used and the demographics of each group included representatives from state, federal and provincial natural resource agencies, and universities. An effort was made to have individuals familiar with lake herring stocks on each of the five Great lakes in each of the three discussion groups. To develop a list of impediments, groups worked from a list that was developed in consultation with speakers (Table 1) that could be used to compare and contrast impediments among the five Great Lakes. This was organized by seven different types of impediments, each ranked on a five point scale. For some impediments where there was insufficient information on which to determine their potential significance discussion groups were asked to identify these as well. Discussion groups were then asked to describe research projects that could evaluate suspected impediments with emphasis on Lake Ontario. Finally given the state of the lake herring populations in each of the lakes and impediments, each group was asked to develop plans and management actions to facilitate restoration.

Table 1: Potential Impediments to Lake Herring Restoration in the Great Lakes

- a. Habitat degradation
  - a. spawning
  - b. egg incubation
  - c. juvenile
  - d. adult
- b. Contaminants
- c. Exploitation
  - a. commercial
    - i. direct
    - ii. by-catch
  - b. recreational
- d. Non-native biota
  - a. Fish
    - i. piscivores (coho, Chinook, and pink salmon; brown and rainbow trout)
    - ii. planktivores (alewife and rainbow smelt)
    - iii. benthivores (round goby)
    - iv. parasites (sea lamprey)
  - b. Invertebrates
    - i. zooplankton (*Cercopagis, Bythotrephes*)
    - ii. Dreissenids
  - ~~b.~~c. Birds
    - i. cormorants
- e. Native biota
  - a. Fish
    - i. piscivores (lake trout, burbot, yellow perch)
    - ii. planktivores (other ciscoes)
    - iii. benthivores (whitefish)
  - b. Invertebrates
    - i. Zooplankton
      - *1. Diporeia*
      - 2. *Mysis*
- f. Genetics
- g. Stock structure
  - a. Age distribution
  - b. Sex-ratio
- h. Spawning stock(s)
  - a. Size and number
  - b. Spawning site fidelity

i. Climate

Summary of Status of Lake Herring Stocks in the Great Lakes

Lake Ontario

After reaching a peak commercial harvest of approximately 360 metric tons (MT) in 1917 the commercial catch of lake herring in the Bay of Quinte declined but stabilized at 136 MT for the period 1923 to 1937. It then began a precipitous decline to very low harvest levels by the mid 1950's. The commercial catch for the Canadian waters of the entire lake declined from about 50 MT in 1953 to 2 MT in the early 1980's. There was a brief resurgence in commercial catch to 9 MT by the mid 1990's followed by a decline to near zero by the end of the century.

Index netting by the Ontario Ministry of Natural Resources in the northeast portion of the lake during the period 1986 to 2002 indicated that catch per gillnet (CPGE) in the Kingston Basin increased from 3 in 1986 to 8 in 1991 but then slowly declined to 0 by 2002. A similar pattern with lower catches was noted for west-central Lake Ontario as well. In the Bay of Quinte, CPGE increased from near 0 in 1995 to 37 by 1998 but then declined to approximately 3 by 2002.

In US waters, index trawling indicated an increase in lake herring abundance from 10 per trawl in 1978 to over 40 by 1990 but then a slow decline to near 0 by the end of the century. Although lake herring are collected in US waters all along the south shore of the lake the greatest abundance has occurred in the eastern basin and near Sodus Bay.

Lake Erie

Between 1870 and 1920 lake herring supported an annual commercial harvest of approximately 13,600 MT. During the 1920's, the harvest fluctuated and declined from 9000 MT at the start of the decade to 200 MT by the end of the decade where it remained albeit with considerable year to year variation until the late 1950's. By this time the lake was severely affected by eutrophication and harvest declined to near 0. Since 1995 a few lake herring have been collected regularly in commercial gear from all parts of the lake that indicate that the species is still present and reproducing but that abundance is extremely low.

Lake Huron

During the relatively stable period of the first half of the last century annual catches of lake herring remained relatively high but were highly variable ranging from 930 to 3630 MT prior to 1940. After comprising a fairly constant proportion of the commercial harvest in Lake Huron during the first half of the last century, the species between 1950 and 1960 went into a precipitous decline. After 1960, lake herring became commercially insignificant for the remainder of the century. During the period 1950 to 1960 deepwater ciscoes almost totally replaced the former catch of lake herring but then also went into a period of decline but still comprised about 10% of the coregonid harvest by the end of the century.

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During the second half of the last century, commercial harvest was maintained at about 20 MT but shifted from US waters in the first two decades, to mostly Canadian waters in the next two decades, and a mixture for the last decade.

Based on index netting, lake herring made a brief resurgence increasing five-fold in abundance in Canadian waters during the last quarter of the last century but this was mostly restricted to waters of the North Channel, northwestern Georgina Bay and northern Michigan waters. In the area of the Drummond Island Refuge of northern Lake Huron, catches peaked in 1994 and declined thereafter but are still more abundant than before 1994.

Lake Michigan

Commercial catch of lake herring during the last century fluctuated widely but averaged about 2700 MT until the late 1950's. Then over a three to five year period, abundance underwent a precipitous decline such that commercial catch remained close to zero until the end of the century.

Bottom index trawling by the U.S. Geological Survey during the period 1960 to 2002 also showed a precipitous decline during the early 1960s, with no indications of a recovery until 1994 when numbers approached those of the 1960s before the crash. This short resurgence seems real as a similar increase was noted by Michigan Department of Natural Resources at the same time with highest catches occurring in Little Traverse Bay. After 1994 numbers dropped to zero where they remained until 2002.

Lake Superior

Commercial yield of lake herring in Lake Superior peaked at 8600 MT in 1941 and only once fell below 4500 MT during 1942-1963. In the mid 1960s, yields declined sharply and never recovered and in most political jurisdictions commercial fishery regulations were expanded to protect declining lake herring stocks. During 1980-1999, commercial yields ranged from 450 to 700 MT.

Despite markedly smaller commercial extractions in the last two decades of the 20th century, lake herring remained a dominant part of the Lake Superior fish community. Bottom trawl assessments conducted by the U.S. Geological Survey around the periphery of the lake during 1978-2002 found that the catch of lake herring, by weight, was greater than that of any other species. Lake herring made up about 25% of the catch, ranging from a low of 0.5% in 1978 to a high of 40% in 1990. Year class strength varied by a factor of about 4,000 and trends in biomass were driven by strong year classes that were produced in 1984, 1988-1990, and 1998 (Bronte et al. 2003). Currently, most of the lake herring biomass is Lake Superior is composed of fish from the 1998 year class.

In Canadian waters, surveyed during 1989-2002, lake herring population trends generally followed that in U.S. waters. After the mid-1990s, however, lake herring declined to historic low levels in Canadian waters of eastern Lake Superior.

Summary of Impediments for Lake Herring in the Great Lakes

Overall the loss of stocks in the Great Lakes was considered the biggest impediment (Table 1, Fig. 2). This would strongly argue for protection of the existing stocks through reduction of targeted fisheries and by-catch by commercial and sport fisheries until the size and amount of genetic diversity in existing populations can be determined. In the event that existing stocks are too small and genetically depleted relative to historic stocks consideration should be given to restoration.

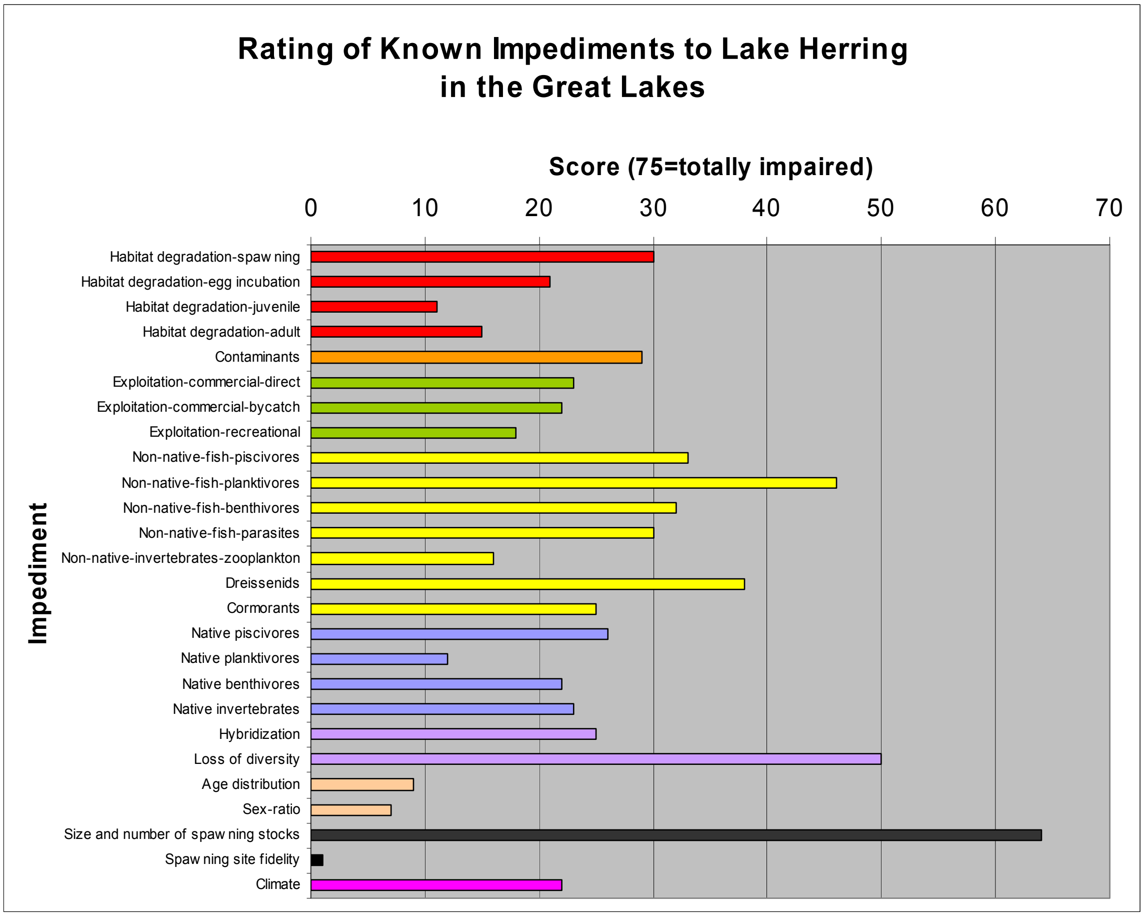
The impact of non-native biota on lake herring stocks in the Great Lakes represents a large and poorly understood group of impediments. now facing lake herring stocks in the Great Lakes. The list includes alewives, rainbow smelt, sea lamprey (*Petromyzon marinus*), cormorants (*Phalacrocorax auritus*), dreissenids (*Dreissena polymorpha*), round gobies (*Neogobius melanostomus*), *Bythotrephes longimanus*, and *Cercopagis pengoi*. Although alewives have been in the lakes since the late 1800s, much of the evidence linking them to declines in lake herring abundance is anecdotal, speculative, and circumstantial. Negative statistical correlations between the abundance of lake herring and alewives are lacking as are mechanisms that would explain such correlations. The inability to secure robust qualitative and quantitative data linking the impacts of non-native species on lake herring will become only more daunting and complex with the increasing pace of invasions in the Great Lakes. Nevertheless we can neither anticipate nor expect controls on existing or future invasive species without first producing more tangible evidence of effect than has characterized the record to date.

Table 1: Summary of impediment ranking across all groups by lake. The total possible score for each individual lake is 390 points. For individual criteria the total possible score for all lakes is 75 points, based on a total of 5 points for each of the five lakes for each of the three groups.

Impediments:	**Superior**	**Huron**	**Michigan**	**Erie**	**Ontario**	**All**
a. Habitat Degradation						
a.a. spawning	3	6	5	6	10	**30**
a.a. egg incubation	2	5	4	5	5	**21**
a.b. juvenile	3	2	2	2	2	**11**
a.c. adult	3	4	4	4	4	**15**
b. Contaminants	4	5	7	6	7	**29**
c. Exploitation						
a. commercial-i. direct	8	8	3	2	2	**23**
a. commercial-ii. Bycatch	3	3	5	6	5	**22**
b. recreational-	3	5	4	3	3	**18**
d. Non-native biota						
a. fish, i. piscivores	4	6	7	10	6	**33**
a. fish, ii. Planktivores	3	11	13	6	13	**46**
a. fish, iii. Benthivores	3	8	7	5	9	**32**
a. fish, iv. Parasites	4	8	8	3	7	**30**
b. invert., i. zooplankton	4	3	3	1	5	**16**
b. invert., ii. Dreissenids	3	8	7	9	11	**38**
c. birds cormorants	3	5	5	6	6	**25**
e. Native biota						
i. piscivores	3	5	5	7	6	**26**
ii. planktivores	3	3	3	3	3	**12**
iii. benthivores	3	4	4	2	3	**22**
iv. invertebrates	3	4	4	5	7	**23**
f. Genetics						
a. hybridization	4	3	6	7	5	**25**
b. diversity	4	7	13	13	13	**50**
g. Stock structure						
a. age	3	3	1	1	1	**9**
b. sex-ratio	3	1	1	1	1	**7**
h. Spawning stock						
a. magnitude/size	6	14	15	15	14	**64**
b. spawning site fidelity	1	0	0	0	0	**1**
i. Climate	2	4	4	6	6	**22**
TOTAL	**88**	**135**	**140**	**134**	**149**	

One group with insufficient information
Two groups with insufficient information
Three groups with insufficient information

Figure 2: Summary of known impediments to lake herring in the Great Lakes.



Summary of Knowledge Gaps for Lake Herring in the Great Lakes

Knowledge gaps tended to be impediment specific and at times lake specific (Fig. 3). Lack of knowledge on specifics of early life history and adult habitat needs was prominent and made any measure of evaluation of habitat degradation uncertain. This was further confounded by a general lack of information on habitat requirements of most life stages throughout the basin. In contrast there appeared to be little doubt as to the effects of habitat degradation on spawning with many examples available of extensive losses throughout the basin (e.g. Hamilton Harbour, Sandusky Bay, Saginaw Bay, Green Bay) with the exception of Lake Superior.

Spawning site fidelity also represented a significant knowledge gap for all lakes. This will determine the potential of extant stocks to colonize new areas once barriers to expansion are reduced and determine what reliance there will be on stocking to restore populations especially for lakes where remnant stocks are small spatially isolated, and of unknown genetic constitution.

The effect of the invasion by the exotic zooplankters *Bythotrephes longimanus* and *Cercopagis pengoi* and gradual dominance of the zooplankton community of all lakes with the exception of Lake Superior, posed a significant knowledge gap. Of greatest concern was the effect of these exotic zooplankters on native communities that were historically important in the diet of lake herring which is an obligate zooplanktivore. In the event that these new species replace or seriously reduce native zooplankter abundance it is unknown whether these species can be consumed by lake herring and the nutritional adequacy of these zooplankters relative to native zooplankters.

There is practically no information available on an appropriate age structure for stable lake herring stocks. This has been confounded by an early reliance on scales for aging that underestimate true ages for older fish. This is slowly being resolved with the use of sagittal otoliths for aging but will not be useful for comparisons to historic age data derived solely from scales. Unbalanced sex ratios are also of concern as it is not known what causes them, what they may signify, or if they represent a departure from normality.

Concerns about the effects of climate change were the result of not knowing the effects of individual environmental variables in influencing year class strength. As a result it will be very difficult to estimate what impacts the predicted change in climate will have on stocks in future. It appears that climate variation plays a more important role than parental stock size in lake herring recruitment as suggested by data from Lake Superior (Bronte et al. 2003). Concurrent increases and declines of lake herring abundance during the 1980s and 1990s in other Great Lakes also suggest density-independent factors may be operating basin wide.

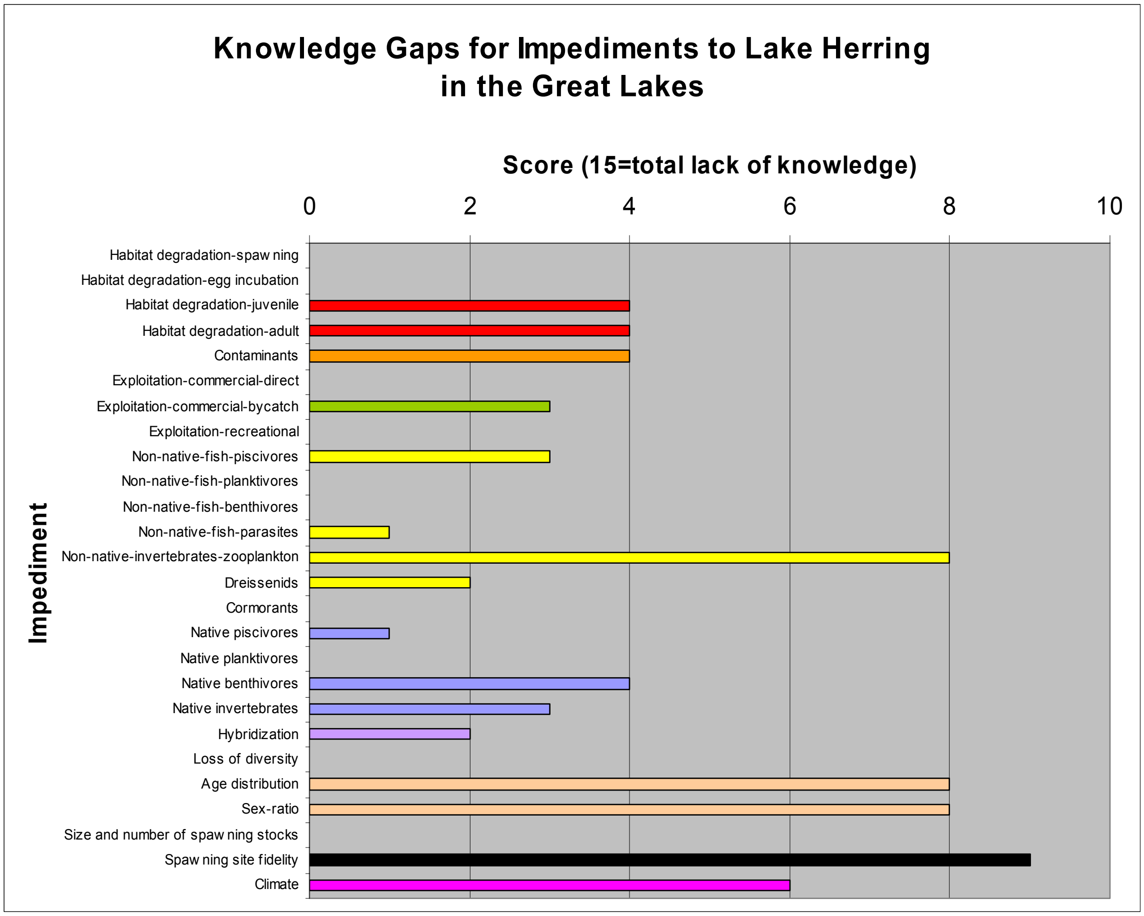
Because of the potential importance of *Diporeia* to the diet of adult lake herring particularly in open lake environments, there is concern that the decline of *Diporeia* may have impacts on lake herring stocks. These may either be direct from the loss of *Diporeia* or indirect because of increased competition for *Mysis* the only other deepwater benthic macroinvertebrate, with other species such as sculpins, lake whitefish, and other deepwater coscoes.

Considered of less immediate concern to the other knowledge gaps were questions about the importance of hybridization with other coregonids particularly by remnant lake herring stocks with bloater, predation by an expanding and recovered lake trout stock in Lake Superior, and a commercial fishery impacting remnant stocks of unknown but potentially irretrievable genetic material.

Table 2: Summary of knowledge gaps from discussion groups. Numbers represent the number of groups reporting that there was insufficient information available to make a judgement for a particular impediment

Impediments:	**Superior**	**Huron**	**Michigan**	**Erie**	**Ontario**
a. Habitat Degradation					
a.a. spawning					
a.a. egg incubation	1		1	1	1
a.b. juvenile		1	1	1	1
a.c. adult		1	1	1	1
b. Contaminants					
c. Exploitation					
a. commercial-i. direct			1	1	1
a. commercial-ii. Bycatch					
b. recreational-					
d. Non-native biota					
a. fish, i. piscivores	1	1			1
a. fish, ii. Planktivores					
a. fish, iii. Benthivores					
a. fish, iv. Parasites	1				
b. invert., i. zooplankton		2	2	2	2
b. invert., ii. Dreissenids		1	1		
c. birds cormorants					
e. Native biota					
i. piscivores	1				
ii. planktivores					
iii. benthivores	1	1	1	1	
iv. invertebrates		1	1	1	
f. Genetics					
a. hybridization		1	1		
b. diversity					
g. Stock structure					
a. age	1	1	2	2	2
b. sex-ratio	1	1	2	2	2
h. Spawning stock					
a. magnitude/size					
b. spawning site fidelity	1	2	2	2	2
i. Climate	2	1	1	1	1

Figure 3: Summary of knowledge gaps for lake herring in the Great Lakes.



Summary of Workshop Research and Assessment Needs

Habitat requirements especially as relates to basic biology and accompanying habitat needs, was perceived to be a major research need. This need is most pressing for early life history stages where it is important to know where spawning is occurring, what habitat factors determine success, and how changes due to sedimentation, eutrophication and colonization by dreissenids may affect embryonic survival. Of somewhat less importance was the need to evaluate juvenile habitat.

At present the lack of information on critical habitat makes it difficult to qualitatively and quantitatively sample and assess the remaining stocks and identify potential bottlenecks. In addition it will also be impossible to assess the nature of habitat overlaps with other native and exotic species, some of which may have negative impacts on lake herring. Moreover without this information it will be difficult to determine what impact either an increase or decrease in habitat will have on stocks or the effects of other potentially important habitat factors such as ice cover, wind fetch, siltation, or algal blooms. Information on temperature preference is important for assessing the potential impacts of climate change. It follows that if the temperature requirement for spawning and egg incubation is unknown so too will be the impacts of climate change that is suspected to result in an increase in water temperature of as much as 4-6ºC.

For lake herring, contaminant research issues were considered minimal and revolved primarily around the potential impacts of contaminant burdens in altering the nutritional status of lower trophic levels organisms. Concerns about the impacts of egg burdens were only expressed for methyl mercury.

Determining the impacts of exotic organisms on lake herring posed the most significant and widest array of research questions. These included all trophic levels from the bottom of the food chain up to impacts of piscivorous exotics. The invasion of the Great Lakes by the invasive zooplankters *Bythotrephes longimanus* and *Cercopagis pengoi* have changed the composition and size spectra of plankton communities. Accordingly controlled laboratory studies are needed to determine what effect the loss of native zooplankters may have on lake herring, particularly at early life stages. Similarly as the invasive zooplankters may make up an increasing proportion of the diet of lake herring, there is a need to know to what extent they can replace the loss of native zooplankton, and if so what are the nutritional consequences if any at all life stages.

Extensive colonization of almost all of the Great Lakes by dreissenids presented concerns for effects on primary and secondary productivity and how these might affect larval and older lake herring. It was recommended this be approached through controlled mesocosm/experimental lake studies as well as comparative lake studies. With mesocosms or experimental lakes, dreissenids would be introduced and their consequences to lake herring would be monitored. Comparative lake studies could address the effects of the trophic changes expected with dreissenids by sampling lake herring from lakes having a range in trophic status.

Alewives and to a lesser extent smelt, of all potential impediments considered evoked the greatest concern and as a result the greatest number and variety of research studies to assess their impacts on lake herring. One approach advocated was the retrospective analysis of the stock recruitment relationship of stocks with and without alewives present. Retrospective analysis should not only assess potential interactions between lake herring and alewives but account for the effect of density of alewives and lake herring as well. Abundance of contemporary lake herring stocks are extremely low such that they may be more vulnerable to the effects of alewives than their historic counterparts, whose abundance was much higher. Such information may help to direct restoration efforts. Specifically there may be opportunities for restoration of lake herring where alewife abundance is significantly reduced as a result of die offs, limitation of planktonic food resources, or a high stocking rate of salmonine predators.

In order to confirm information of a correlative nature from retrospective analysis there is a need to conduct manipulation experiments aimed at artificially reducing or increasing alewife and assessing their consequences to lake herring. In addition there is a need to undertake abundance detailed meso- and micro-cosm studies to look at the nature of the interaction between alewives and lake herring to assess the relative importance of competition and predation.

Of less concern regarding the impacts of alewives on lake herring, was the potential of alewives to cause a thiamine deficiency in lake herring by eating alewives. This is similar to a situation in salmonine predators where low egg thiamine concentration has been associated with a high proportion of alewives in the diet. Whether current levels of alewife consumption are of concern could readily be assessed by thiamine analysis of eggs of lake herring having a high proportion of alewives in their diet and comparing it to a stock where alewives are absent from the diet.

Because of the demonstrated ability of round gobies to feed on the demersal eggs of other species (e.g. lake trout, lake whitefish, smallmouth bass) there is a concern that this may occur with lake herring as well. Their eggs are deposited on the bottom with no particular protection from predators so could be readily preyed upon by gobies. Egg predation by gobies may be affected by temperature given the low spawning temperature of lake herring although gobies continued to feed on lake trout eggs at temperatures as low as 1-2ºC.

A secondary concern with gobies was their potential competition with lake herring for benthic food resources such as *Diporeia* and *Mysis*. This may be limited to the winter months when gobies move offshore although feeding activity during this time may be reduced by the colder temperatures. Currently there are no data available on diet overlap between gobies and lake herring but the amount of overlap is likely to change. Throughout the Great Lakes, *Diporeia* are in decline and their loss may shift greater importance to *Mysis* such that their numbers may decline as well. This decline may be enhanced if the factor or factors responsible for the *Diporeia* decline begins to affect *Mysis* as well.

At present there is insufficient information available to define a stock-recruitment relationship for lake herring. In Lake Superior, periodicity of recruitment appears to be spatially synchronous suggesting that climatic or environmental factors are involved but the actual factors involved and the mechanism by which they affect recruitment is not known. Understanding why recruitment is so cyclical and determining what annual mortality rate is consistent with sustainable harvest were considered important research questions.

Summary of Restoration Needs for Lake Herring in the Great Lakes

Restoration of lake herring should be carried out in areas of the Great Lakes where historic spawning sites still have high quality substrate but with low densities of alewives and rainbow smelt which are perceived impediments for restoration. In addition there should be no remnant lake herring populations present to prevent erosion of unique and irretrievable genetic characteristics. The lack of a remnant stock would also facilitate assessing the success of a particular restoration activity.

Donor stocks for use in restoration plans should come from locations with similar limnological conditions and where lake herring are self-sustaining. Consideration of donor stocks should not necessarily be restricted to the Great Lakes as many inland lakes within the Great Lakes drainage could potentially contain donor populations.

Experimental stocking of a combination of different life stages should be done in an inland lake where evaluations are logistically feasible. To determine the most appropriate strategy this would include paired stocking of eggs in astro-turf and fingerlings to assess what stage was most appropriate. Adult transfers, while logistically difficult, should also be considered.

Determining the number of lake herring to stock is for restoration is problematic and will likely ultimately be determined by the availability of gametes and financial resources. Consideration should be given of the need to compensate for potential losses to resident smelt and alewives. Such impacts may be revealed by data analysis of historic records for South Bay and eastern Lake Ontario-Bay of Quinte where smelt and lake herring co-existed.

Accompanying restoration studies should be a limited number of detailed studies to assess possible bottlenecks to early survival. Given the concern with the potential negative effects of alewives such studies should include areas with and without alewives.

Summary of Management Actions Required To Facilitate Lake Herring Restoration in the Great Lakes

Remnant lake herring stocks in the lower four Great Lakes are at very low levels and hence all exploitation whether targeted or not should be reduced to the extent possible to aid in recovery. There was also concern with extraction due to the recreational fishery. Although generally less intensive, there is a need to undertake creel surveys to assess its current significance. Existing remnant stocks likely represent unique irretrievable genetic resources that could be lost with continued exploitation. This is made all the more urgent by the escalating number of exotic species entering the Great Lakes with essentially unknown effects on remnant stocks. Along with limitations on lake herring fisheries should be efforts to reduce or eliminate alewives and rainbow smelt that are perceived as one of the most significant impediments to a lake herring recovery. Options to accomplish this include increased stocking of salmonine predators and targeted trawl fisheries for alewives and rainbow smelt. This may however have undesired effects on other prey fish, impede lake herring restoration, or interfere with restoration programs for lake trout.

All remnant stocks should be described in terms of population size or density, age composition, and genetic profile. Along with genetic evaluation of contemporary stocks should be comparisons with historic populations perhaps with the use of scales to determine changes in genetic diversity. Assessments of the adult stocks in the open lake should be spatially and temporally scaled to determine how many stocks there are and their potential contribution to the open lake populations.

Given the changes in trophic structure with the invasion of dreissenids and other invasive species it is important to assess the diet of contemporary stocks. This should also be compared on a seasonal basis with historic populations to look at the degree of overlap and competition with other planktivores, and assess how non-native zooplankters may be used in the diet. Studies should include multiple levels of non-native planktivores to look at the effects of competition on diet.

Since stocks in many areas have been lost, recovery is not possible and in such areas restoration through stocking is the required management action. To support such an action there is a need for dedicated lake herring hatchery of sufficient size to effectively support a restoration program.

References

Bence, J. R. and K. D. Smith. 1999. An overview of recreational fisheries of the Great Lakes. Pages 259-306 in Taylor, W. W. and C. P. Ferreri, editors. Great Lakes fishery policy and management: A binational perspective. Michigan State University Press, East Lansing, MI.

Bronte, C. R., M. P. Ebener, D. R. Schreiner, D. S DeVault, M. M. Petzold, D. A. Jensen, C. Richards, and S. J. Lozano. 2003. Fish community change in Lake Superior, 1970-2000. Can. J. Fish. Aquat. Sci. 60: 1552-1574

Brown, E. H. Jr., Busiahn, T.R., Jones, M.L., and Argyle, R.L. 1999. Allocating Great Lakes forage bases in response to multiple demand. Pages 355-394 in Taylor, W. W. and C. P. Ferreri, editors. Great Lakes fishery policy and management: A binational perspective. Michigan State University Press, East Lansing, MI.

DesJardine, R.L., Gorenflo, T.K., Payne, R.N., and Schrouder, J.D. 1995. Fish-community objectives for Lake Huron. GLFC Spec. Pub. 95-1, 38 pp.

Eshenroder, R.L., Holey, M.E., Gorenflo, T.K., and Clark, R.D., Jr. Fish-community objectives for Lake Michigan. GLFC Spec. Pub. 95-3, 56 pp.

Fitzsimons, J. D., and S. B. Brown. 1998. Reduced egg thiamine levels in inland and Great Lakes lake trout and their relationship with diet. Pages 160-171 *in* G. McDonald, J. Fitzsimons and D. C. Honeyfield, editors. Early life stage mortality syndrome in fishes of the Great Lakes and the Baltic Sea. American Fisheries Society, Symposium 21, Bethesda, Maryland.

Fitzsimons, J.D., S.B. Brown, D.C. Honeyfield and J.G. Hnath. 1999. A review of early mortality syndrome in Great Lakes salmonids and its relationship with thiamine. Ambio 28:9-15.

Horns, W., Bronte, C.R., Busiahn, T.R., Ebener, M.P., Eshenroder, R.L., Gorenflo, T., Kmiecik, N., Mattes, W, Peck, J.W., Petrzold, M., and Schreiner, D.R. 2003. Fish-community objectives for Lake Superior. GLFC Spec. Pub. 03-01, 78 pp.

Ketola, H. G., P. R. Bowser, G. A. Wooster, L. R. Wedge, and S. S. Hurst. 2000. Effects of thiamine on reproduction of Atlantic salmon and a new hypothesis for their extirpation in Lake Ontario. Transactions of the American Fisheries Society 129(2): 607-612.

Krueger, C.C., Perkins, D.L, and Mills, E.L., and Marsden, J.E. 1995. Predation by alewives on lake trout fry in Lake Ontario: Role of an exotic species in preventing restoration of a native species. J. Great Lakes Res. 21(Supplement 1):458-469.

Madenjian, C. P. and 14 others. 2002. Dynamics of the Lake Michigan food web, 1970 – 2000. Canadian Journal of Fisheries and Aquatic Sciences 59:736-753.

Mills, E.L. and 17 others. 2003. Lake Ontario: food web dynamics in a changing ecosystem (1970-2000). Canadian Journal of Fisheries and Aquatic Sciences 60:471-490.

Ryan, P.A, Knight, R., MacGregor, R., Towns, G., Hoopes, R., and Culligan, W. 2003. Fish-community objectives for Lake Erie. GLFC Spec. Pub. 03-02, 56 pp.

Smith, S. H. 1972. Factors of ecologic succession in oligotrophic fish communities of the Laurentian Great Lakes. Journal of the Fisheries Research Board of Canada 29(6): 717-730.

Stewart, T.J., Lange, R.E., Orsatti, S.D., Schneider, C.P., Mathers, A., and Daniels, M.E. 1999. Fish-community objectives for Lake Ontario. GLFC Spec. Pub. 99-1, 56 pp.

Tanner, H. T. and W. H. Tody. 2002. History of the Great Lakes Salmon Fishery: A Michigan Perspective. Pages 139-154 in Lynch, K. D., M. L. Jones, and W. W. Taylor, editors. Maintaining North American salmon: Perspectives across regions and disciplines. American Fisheries Society.

Tillitt, D. E., J. Zajicek, S. B. Brown, J. Fitzsimons, D. Honeyfield, M. Holey, and G. Wright. 2004 Thiamine, thiamine vitamers, and thiaminolytic activity in forage fish of salmonids from Lake Michigan (submitted to JAAH).

Todd, T. N. and G. R. Smith. 1992. A review of differentiation in Great Lakes ciscoes. Polskie Archiwum Hydrobiologii 39(3-4): 261-267.

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Appendix A

Agenda
Lake Herring Workshop
A Workshop Sponsored by The Fish and Wildlife Restoration Act

July 9-10, 2003
Weber's Inn, Ann Arbor, Michigan

Agenda

Wednesday, July 09, 2003

8:10	Welcome/Introduction	Fitzsimons/O'Gorman
8:20	Lake herring life history	Ron Kinnunen
8:40	Comparative phylogeography of Great Lakes coregonids	Kim Scribner
9:00	Development of an optimal feeding regime for rearing lake herring early life stages	Trent Sutton
9:20	Lake herring studies in Algonquin Park lakes	Kris Vascotto
9:40	Status of lake herring in Lake Simcoe	Frank Amtstaetter
10:00	Break	
10:20	Status of Lake Superior lake herring	Owen Gorman
10:30	The commercial herring fishery in the Ontario waters of Lake Superior	Jeff Black
10:40	Status and management of lake herring in Minnesota waters of Lake Superior	Don Schreiner
10:50	Status and management of lake herring in Wisconsin waters of Lake Superior	Steve Schram
11:00	Status of lake herring in Lake Michigan	Randy Claramunt
11:15	Status of lake herring in Lake Huron	Lloyd Mohr
11:30	Status of lake herring in Lake Erie	Phil Ryan

11:45	Status of lake herring in Lake Ontario	Jim Hoyle
12:00	Lunch	
1:15	Charge to break-out groups	
1:30	Convene break-out groups	
3:00	Break	
3:20	Reconvene break-out groups	
5:00	Adjourn	

Thursday, July 10, 2003

8:30	Reconvene Break-out Groups	
9:30	Report of Group 1	
10:00	Break	
10:20	Report of Group 2	
10:50	Report of Group 3	
11:20	Summary	Fitzsimons/O'Gorman
11:45	Adjourn	

Appendix B

Participant List

Frank Amtstaetter
Ontario Ministry of Natural Resources
Lake Simcoe Fisheries Assessment Unit,
RR #2, Sutton West
frank.amtstaetter@mnr.gov.on.ca
905-722-0252

Jeff Black
Ontario Ministry of Natural Resources
435 James St. S, Suite 221E,
Thunder Bay P7E 6S8
jeff.black@mnr.gov.on.ca
807-475-1268

Chuck Bronte
U.S. Fish and Wildlife Service
Green Bay FRO, 2661 Scott Tower Drive,
New Franken, WI 54229
Charles_Bronte@fws.gov
920-866-3650

Randy Claramunt
Michigan Department of Natural Resources
96 Grant Street, Charlevoix,
MI 49720
claramur@michigan.gov
231-547-2914 ext 224

Mark P. Ebener
Inter-Tribal Fisheries and Assessment Program
Chippewa/Ottawa Resource Authority
179 W. Three Mile Road
Sault Ste. Marie, Michigan 49783
906-632-0072
FAX: 906-632-1141
mebener@nmo.net

Dave Fielder
Michigan Department of Natural Resources
160 E. Fletcher,
Alpena, MI 49707
fielderd@michigan.gov
989-356-3232

John Fitzsimons
Dept. of Fisheries and Oceans
Bayfield Institute
867 Lakeshore Rd.
Burlington, Ontario
L6L5R9
Phone: 905-336-4865
E-mail: fitzsimonsj@dfo-mpo.gc.ca

Tom Goniea
Michigan Department of Natural Resources
gonieat@michigan.gov

Dale Honeyfield
Northern Appalachian Research Laboratory
176 Straight Run Road
Wellsboro, PA 16901
570-724-3322 ext 233
honeyfie@usgs.gov

Jim Hoyle
Ontario Ministry of Natural Resources
Glenora Fisheries Station, RR #4, Picton, Ontario K0K 2T0
jim.hoyle@mnr.gov.on.ca
613-476-2400

Chuck Madenjian
U.S. Geological Survey
1451 Green Rd, Ann Arbor, MI 48105
chuck_madenjian@U.S. Geological Survey.gov
734-214-7259

Lloyd Mohr
Ontario Ministry of Natural Resources
1450 Seventh Ave. East,
Owen Sound, Ontario N4K 2Z1
lloyd.mohr@mnr.gov.on.ca
519-371-5924

Owen Gorman
U.S. Geological Survey
2800 E. Lake Shore Dr,
Ashland, WI 54806
owen_gorman@U.S. Geological Survey.gov
715-682-6163 ext 16

Robert O'Gorman
U.S. Geological Survey
17 Lake Street,
Oswego, NY 13126
robert_o'gorman@U.S. Geological Survey.gov
315-343-3951 ext 22

Jim Peck
104 Veda St.,
Marquette, MI 49855
jpeck@lushen.com
906-249-4514

Randy Eshenroder
Great Lakes Fishery Commission
2101 Commonwealth Blvd., Suite 100,
Ann Arbor MI 48105-1563
randye@glfc.org
734-662-3210

Kim Scribener
Michigan State University
Department of Fisheries and Wildlife,
13 Natural Resources Bldg,
East Lansing MI 48824-1222
scribne3@msu.edu
517-353-3288

Tom Todd
U.S. Geological Survey
1451 Green Rd,
Ann Arbor, MI 48105
tom.todd@u.s. geological survey.gov
734-214-7227

Ron Kinnunen
Michigan State University Extension
702 Chippewa Square,
Marquette, MI 49855-4811
kinnunen@msue.msu.edu
906 228-4830

Ali Shakoor
1451 Green Rd, Ann Arbor, MI 48105
Ali A Shakoor @U.S. Geological Survey.gov
734-214-7259

Betsy Trometer
U.S. Fish and Wildlife Service
Lower Lakes Fisheries Resources Office,
405 North French Road, Suite 120A,
Amherst, NY 14228
Betsy_Trometer@fws.gov
716-691-5456 ext. 22

Phil Ryan
Ontario Ministry of Natural Resources
PO Box 429, 1 Passmore St.,
Port Dover, N0A 1N0
phil.ryan@mnr.gov.on.ca
519-583-0981

Shawn Sitar
Michigan Department of Natural Resources
484 Cherry Creek Rd., Marquette, MI 49855
sitars@michigan.gov
906-249-1611 ext 310

Kris Vascotto
University of Toronto
kris.vascotto@utoronto.ca'

Jeff Schaeffer
U.S. Geological Survey
1451 Green Rd, Ann Arbor, MI 48105
jeff_schaeffer@U.S. Geological Survey.gov
734-214-7250

Marty Stapanian
martin_stapanian@u.s. geological survey.gov

Steven Schram
Wisconsin Department of Natural Resources
PO Box 589, Bayfield, WI 54814
steven.schram@dnr.state.wi.us
715-779-4035 ext 12

Trent M. Sutton
Purdue University
195 Marsteller Street,
West Lafayette, IN 47907-1159
tsutton@fnr.purdue.edu
765-496-6266

Don Schreiner
Minnesota Department of Natural Resources
5351 North Shore, Duluth, MN 55804
don.schreiner@dnr.state.mn.us
218-525-0853

WendyLee Stott
1451 Green Rd, Ann Arbor, MI 48105
wstott@U.S. Geological Survey.gov
734-214-7259

Appendix C

Summary of Status of Lake Herring in Fish Community Objectives for the Great Lakes

Lake Ontario (Stewart et al. 1999)

Offshore benthic community objective: Rehabilitate native prey species (pg. 5)

Lake Erie (Ryan et al. 2003)

Rare, threatened and endangered species: Prevent extinction by protecting rare, threatened, and endangered fish species (for example, lake sturgeon and **lake herring**) and their habitats (p. 41).

Lake Huron (DesJardine et al. 1995)

Coregonine (Lake whitefish and ciscoes) objective: Restore lake herring to a significant level and protect, where possible, rarer deepwater ciscoes (p. 19)

Lake Michigan (Eshenroder et al. 1995)

Planktivore objective: … rehabilitation of native planktivores is desirable…. (p. 34)

Lake Superior (Horns et al. 2003)

Prey species objective: A self-sustaining assemblage of prey dominated by indigenous species at population levels capable of supporting desired populations of predators and a managed commercial fishery (p. 31).

Appendix D

Summary of Discussion Group I

Participants: Mark Ebener (group leader), Betsy Trometer (rapporteur), Jeff Black, Randy Eshenroder, Owen Gorman, Ron Kinnunen, Chuck Madenjian, Robert O'Gorman, Jeff Schaeffer, Kris Vascotto.

Impediment Matrix

Category	Superior	Huron	Michigan	Erie	Ontario
a. Habitat					
a.a. spawning	1	3	2	2	4
a.b. egg incubation	1	3	2	2	4
a.c. juvenile	1	1	1	1	1
a.d. adult	1	1	1	1	1
b. Contaminants	1	1	1	1	1
c. Exploitation					
a. commercial-i. direct	2	2	I	I	I
a. commercial-ii. by-catch	1	1	1	1	1
b. recreational	1	1	1	1	1
d. Non-native biota					
a. fish, i. piscivores	I	I	1	4	I
a. fish ii. Planktivores	1	3	3	1	4
a. fish, iii. Benthivores	1	1	I	I	I
a. fish, iv parasites	I	1	1	1	1
b. invert., i. zooplankton	1	I	I	I	I
b. invert., ii dreissenids	1	I	I	1	1
c. birds cormorants	1	1	1	1	1
e. Native biota					
i. piscivores	I	1	1	1	1
ii. planktivores	1	1	1	1	1
iii. benthivores	I	I	I	I	1
iv. invertebrates	1	I	I	I	2
f. Genetics					
a. hybridization	1	1	1	1	1
b. diversity	2	3	5	5	5
g. Stock Structure					
a. age	I	I	I	I	I
b. sex ratio	I	I	I	I	I
h. Spawning Stock					
a. magnitude/Size	2	5	5	5	5
b. spawning site fidelity	1	I	I	I	I
i. Climate	1	1	1	1	1

Explanatory notes for impediment matrix for Group I

a. Habitat degradation
Superior-no impediments at any life stage
Michigan-the lower part of Green Bay was considered impaired
Huron: Saginaw Bay considered to be degraded for spawning and juveniles although full effects were unknown; major problems considered to be sediments and contaminants
Erie-the loss of marshland in the southwestern part of the lake considered an impediment to spawning; the destruction of spawning areas in the Detroit River and Lake St. Clair was considered an impediment but with unknown effects
Ontario-destruction of spawning areas in Hamilton Harbour, Irondequoit Bay, Sodus Bay, and other bays were considered impediments; the eastern end of the lake was considered relatively unaffected

b. Contaminants
there were no concerns for any of the lakes

c. Exploitation
Superior –there were considered to be local problems resulting from the commercial fishery; the roe fishery may be impacting recruitment but data not available; the population in the lake is considered to be at about 50% of the desired population size
Michigan-the commercial fishery through by-catch may be imposing negative effects
Huron- the roe fishery may be impacting recruitment but data not available
Huron, Erie, Ontario-effects of commercial fishery largely unknown
There was a general basin-wide concern that there was insufficient information available on exploitation rates

d. Non-native biota
- Piscivores-smelt are a concern in Michigan, Huron, Erie and Ontario; salmon are a concern in Black Bay (Superior)
- Planktivores-alewives are a concern in Michigan, Huron, and Ontario
- Parasites- sea lamprey not considered an impediment in any of the lakes except Superior
- Benthivores- the round goby is a concern in Michigan, Erie, and Ontario
- Invertebrates-zooplankton- *Bythotrephes longimanus* are a concern in Michigan and Huron; *Cercopagis pengoi* are a concern in Erie and Ontario
- Invertebrates-dreissenids-a concern in Michigan, Huron, Erie and Ontraio

e. Native biota
- Piscivores-lake trout may have impacts in Superior whereas in all other lakes native piscivores did not seem to represent an impediment
- Planktivores-there were no impediments for any of the lakes
- Benthivores- there are possible interactions between whitefish and herring in Superior; interactions in other lakes were unknown

- Invertebrates-only considered an impediment in Ontario because of declines in *Mysis* and *Diporeia*; in Huron there were concerns for these *Mysis* and *Diporeia* but no data and in Erie and Michigan the situation is unknown
-

f. Genetics

- Hybridization-no concerns for any of the lakes
- Diversity-there were concerns for loss of diversity, loss of local stocks some of which may be locally adapted; there was a concern for deep-water and/or deep-bodied forms in Erie and Ontario; the loss of diversity may represent a bottleneck to restoration in all lakes

g. Stock Structure

- Age structure-it was not known what an appropriate age structure should be; there was no data to evaluate its importance in any of the lakes
- Sex ratio- there was no data to evaluate in any of the lakes

h. Spawning Stock

- Magnitude/size: the loss of spawning stocks was seen as an impairment to restoration; in Michigan there were concerns for loss of spawning stocks in the main lake and Grand Traverse Bay; in Huron there were concerns for loss of spawning stocks in Saginaw Bay and the main basin although stocks were considered adequate in Georgian Bay and the North Channel; as a general observation herring were considered to do well in bays
- Site fidelity: no information was available for this except for Superior where it was not a concern

i. Climate**-**

-this was not considered to be a concern for any of the lakes although it appears to have substantial effects on cycles of recruitment across the basin but it's not known know by what mechanism(s); it was not considered to be within normal bounds for lake herring and there have been favourable years for recruitment in recent years (ie 1998)

Research Questions for Group I

1. Can extirpated populations be rehabilitated (ie overcome genetic bottlenecks through stocking?
   1. Find historic spawning sites with good substrate, low invasive species and no spawning fish.
   2. Stock fish from a similar site having natural reproduction but not necessarily the same lake.

2. What life stage should be used for rehabilitating populations?
   1. Contrast the effectiveness of astro-turf bundles with eggs with fingerlings.
   2. Assess the utility of adult transfers.
   3. Use inland lakes to assess the effects of different stages.

3. Assess whether alewives and smelt affect recruitment
   1. Conduct retrospective analysis of data from Lake Ontario (Glenora) and Georgian Bay (Spangler data) to determine if the level of recruitment when alewives or smelt abundant differs from when abundance of alewives or smelt was depressed.
   2. Conduct manipulation experiments where alewives are either included or excluded and assess effects on herring.

4. Determine the characteristics of areas where herring currently spawn in Lake Ontario
   1. Conduct population surveys where herring spawn
   2. Quantify egg deposition of herring
   3. Assess and quantify spawning habitat of herring

5. Determine the relationship between spawning and successful reproduction
   1. Find areas of egg deposition.
   2. Measure hatching success of herring in different areas of deposition.
   3. Determine ecology and habitat of larval herring once they leave the spawning site.

6. Determine if herring populations in northern Lake Huron have expanded their range in the past 25 years and whether this expansion extends to the main basin.
   1. Conduct retrospective analysis of Michigan DNR survey data
   2. Determine sites where spawning herring occurred and didn't occur historically and compare with where spawning herring are now caught.
   3. Monitor spawning stocks of herring in the fall.

Management Considerations for Group I

1. Reduce or eliminate exploitation on depressed and /or very small populations in Lake Huron and Ontario and institute monitoring of age and size structure.
2. Implement surveys of known spawning populations including development of strategies for monitoring spawning populations. Surveys should be spatially broad, temporally correct and account for gear saturation.
3. If alewives are viewed as detrimental to herring restoration, a strategy to eliminate alewives through increased stocking of salmonines or fishery harvest should be considered. Such actions would benefit herring, reduce a known cause of a thiamine deficiency and associated effects, and reduce a species implicated in the demise of many indigenous species. Moreover alewives may not persist through time.

Appendix E

Summary of Discussion Group II

Participants: Tom Todd (group leader), Jim Peck (rapporteur), Dave Fielder, Dale Honeyfield, Jim Hoyle, Lloyd Mohr, Kevin Pangle, Phil Ryan, Don Schreiner, Kim Scribener

Impediment Matrix

Impediments:	Superior	Huron	Michigan	Erie	Ontario
a. Habitat Degradation					
a.a. spawning	1	2	2	3	1
a.a. egg incubation	1	2	2	3	1
a.b. juvenile	1	I	I	I	I
a.c. adult	1	I	I	I	I
b. Contaminants	2	3	5	4	5
c. Exploitation					
a. commercial-i. direct	3	3	2	1	1
a. commercial-ii. bycatch	1	1	1	2	2
b. recreational	1	2	1	1	1
d. Non-native biota					
a. fish, i. piscivores	3	5	5	5	5
a. fish, ii. planktivores	1	5	5	1	5
a. fish, iii. benthivores	1	5	5	1	5
a. fish, iv parasites	3	5	5	1	5
b. invert., i. zooplankton	2	3	3	1	5
b. invert., ii. dreissenids	1	3	3	3	5
c. birds i. cormorants	1	3	3	4	4
e. Native biota					
i. piscivores	2	3	3	4	4
ii. plantivores	1	1	1	1	1
iii. benthivores	2	3	3	1	1
iv. invertebrates	1	3	3	4	4
f. Genetics					
a. hybridization	1	2	5	5	3
b. diversity	1	2	5	5	5
g. Stock structure					
a. age	2	2	I	I	I
b. sex-ratio	2	1	I	I	I
h. Spawning stock					
a. magnitude/size	2	4	5	5	4
b. spawning site fidelity	I	I	I	I	I
i. Climate	1	3	3	5	5

Explanatory notes for impediment matrix for Group II

a. Habitat degradation
Superior-not considered to have impediments for any life stage
Huron-there has been a loss of spawning habitat in Saginaw Bay but area unknown; Saginaw Bay fish show good growth in first 3-4 years suggesting they remain inshore whereas other populations go to colder offshore waters after the first year
Michigan-Green Bay suspected to have similar habitat degradation to Saginaw Bay but not to the same extent
Erie-Sandusky Bay, Maumee and the whole western basin are considered degraded; anoxia affects the west-central basin; Long Point considered near pristine
Ontario-no real concerns here; Bay of Quinte considered recovered

b. Contaminants
Superior-there are contaminants in the lake but levels appear to be below biological thresholds
Huron-there are traditional contaminants in the system but they are largely tied up in sediments
There are many 'new' contaminants that may pose impediments but no information on levels; effects if they exist may be greatest in Michigan and Ontario, followed by Erie, Huron, and Superior.

c. Exploitation
Superior -there was concern for excessive harvest and a lack of adequate control on harvest for some parts of the lake; the recreational fishery was considered minor
Huron- there was concern for excessive harvest and a lack of adequate control on harvest for some parts of the lake; the recreational fishery in the St. Mary's River was considered significant
Michigan-at present there is no commercial fishery
Erie and Ontario-herring are strictly taken as by-catch although significance unknown; no recreational fishery

d. Non-native biota

- Piscivores—salmon were considered potentially important in all lakes except Superior; smelt were considered important in Superior, Huron, Michigan and Ontario;white perch were considered significant in Erie
- Planktivores—alewives were considered potentially important in all lakes with the exception of Superior and Erie
- Benthivores-gobies were considered potentially important in Huron, Michigan and Ontario
- Parasites: sea lamprey are considered important in all lakes but less so in Erie
- Invertebrates-zooplankton. *Bythotrephes* and *Cercopagis* are important in Huron, Michigan; *Cercopagis* very important in Ontario; *Bythotrephes* may replace native plankton in Superior;
- Invertebrates-dreissenids: considered important in Huron, Michigan, Erie and Ontario

e. Native biota

- Piscivores—lake trout are a concern in Superior, Michigan and Huron
- Planktivores-no concerns
- Benthivores—there are concerns for interactions with whitefish particularly at larval stages and other deepwater coregonids in Superior, Huron and Michigan that are also likely dependent on the 'health' of lower trophic levels
- Invertebrates—the loss of *Diporeia* is a concern in Huron, Michigan, Erie and Ontario and the pressure that this may put on *Mysis* is a concern in Erie and Ontario
- Birds—growing populations of cormorants are of concern in Huron, Michigan, Erie and Ontario

f. Genetics

- Hybridization-consensus is that it is a problem especially with other ciscoes where it readily occurs
- Diversity-there is a need to identify stocks; it's not known what the potential diversity of phenotypes now available is such that in the event of further population declines it's not known what could be lost; critical mass of numbers may be absent for Ontario, Erie and Michigan; there are questions about the origin and traits of donor stocks to use to rehabilitate stocks in Huron, Erie and Michigan; one effect of rehabilitation efforts on these lakes may be to be overwhelm remnant stocks
- Phenotype identification is an issue for data collection

g. Stock Structure

- Age structure—.the variation in year class strength in Superior is of concern but may be within the bounds of natural variation; little information for other lakes
- Sex ratio--- the sex ratio in Superior that is skewed to females appears anomalous; little informationm for other lakes

h. Spawning Stock

- Magnitude/size: in Superior where the most information is available the variation in year class strength is a concern
- Site fidelity: there is relatively no information on this but what is available for Huron suggests fidelity
-

i. Climate-there is interest as to what climate is now relative to what it was when herring were abundant; herring are at the southern end of their range so could be impacted by climate change particularly for Ontario and Erie; as ice cover benefits egg incubation of some coregonines it was of interest to know if the reduced ice coverage of recent years was affecting herring reproductive success

Final Charge 1: Research Issues for Group II

Habitat

Issue: What is habitat and ecology of juvenile herring?

Issue: Do herring have a thiamine deficiency?

Issue: Are there effects of current contaminant burdens at lower trophic levels such that the nutritional value may be altered and so affect status of herring ?

Issue: Do methyl mercury levels in eggs affect incubation success?

Issue: How do herring stocks respond to different environmental characteristics

Non-native species

Issue: Does periodicity of alewife abundance create a window for successful herring recruitment and can alewife stocks be experimentally reduced?

Issue: What conditions are necessary to maximize and assess the efficiency of stocking herring fry as a restoration technique?

Spawning stock

Issue: What annual mortality rate is consistent with sustainable harvest?

Issue: What factors influence the stock-recruitment relationship in herring and is the cyclical nature of herring recruitment natural?

Issue: What are the climatic conditions associated with successful recruitment?

Issue: What factors cause the skewed sex ratio of stocks and are such stocks of concern?

Issue: What is the critical stock size for successful egg fertilization?

Genetics

Issue: What was the genetic makeup and diversity of historic stocks and how does it compare with contemporary stocks?

Final Charge 2 for Group II. Describe research projects and methods to restore lake herring to areas of the GL such as Lake Ontario where they have been extirpated or reduced to a remnant stock.

1. Determine the number of extant herring stocks in Lake Ontario and determine their adequacy for use in restoring Lake Ontario.
2. Initiate an enhancement program in a portion of Lake Ontario having suitable habitat along with reduced numbers of predators and/or competitors.
3. Assess the presence of bottlenecks at early life stages.
4. Assess the relationship between alewife abundance and herring recruitment

Priority Issues and Research

Losses

Issue: What are the effects of native and non-native biota on the loss of stocks?
Issue: How has habitat influenced the loss of stocks?

Research: 1. Determine juvenile ecology and habitat and look at overlap with native and non-native biota for evidence of bottlenecks.

Restoration

Issue: What is the importance of genetic diversity?
Issue: What is the importance of stock size?
Issue: What role should fish-culture play in restoration?

Research: 1. Determine the genetic diversity from scales of historic and contemporary stocks.
2. Determine the minimum stock size necessary for successful reproduction from the stock-recruitment relationship.
3. Determine the optimum stocking size or life stage to use for restoration.

Appendix F

Summary of Discussion Group III

Participants: Charles Bronte (Group Leader), Shawn Sitar (rapporteur), Frank Amtstaetter, Randall Claramunt, John Fitzsimons, Tom Goniea, Steven Schram, Marty Stapanian, Wendylee Stott, Trent Sutton.

Impediment matrix

Impediments:	Superior	Huron	Michigan	Erie	Ontario
a. Habitat Degradation					
a.a. spawning	1	1	1	1	5
a.a. egg incubation	I	I	I	I	I
a.b. juvenile	1	1	1	1	1
a.c. adult	1	3	3	3	3
b. Contaminants	1	1	1	1	1
c. Exploitation					
a. commercial-i. direct	3	3	1	1	1
a. commercial-ii. Bycatch	1	1	3	3	2
b. recreational-	1	2	2	1	1
d. Non-native biota					
a. fish, i. piscivores	1	1	1	1	1
a. fish, ii. Planktivores	1	3	5	4	4
a. fish, iii. Benthivores	1	2	2	4	4
a. fish, iv. Parasites	1	2	2	1	1
b. invert., i. zooplankton	1	I	I	I	I
b. invert., ii. dreissenids	1	5	4	5	5
c. birds cormorants	1	1	1	1	1
e. Native biota					
i. piscivores	1	1	1	2	1
ii. plantivores	1	1	1	1	1
iii. benthivores	1	1	1	1	1
iv. invertebrates	1	1	1	1	1
f. Genetics					
a. hybridization	2	I	I	1	1
b. diversity	1	2	3	3	3
g. Stock structure					
a. age	1	1	1	1	1
b. sex-ratio	1	1	1	1	1
h. Spawning stock					
a. Magnitude/size	2	5	5	5	5
b. spawning site fidelity	I	I	I	I	I
i. Climate	I	I	I	I	I

Explanatory notes for Group III

a. Habitat degradation:
Thermal effects on lake herring populations was discussed, in terms of recent warming trends (global). In Lake Superior recruitment is synchronized across jurisdictions suggesting that density independent factors (abiotic) may be responsible. It was interest to know if recruitment events are modulated by strong environmental variations. At present the data used to look at such correlations may not have been the right data for assessing environmental effects. Better alignment between data type and availability and hypotheses about environmental factors influencing recruitment is needed. It was of interest to know if there was global synchrony with temperature and lake herring recruitment. This was discussed for lake whitefish also a corgeonin but found to be inconclusive.

Physical habitat for spawning has likely not been affected except in some localized embayments. In Ontario egg incubation is likely impacted by anthropogenic effects—especially in embayments. At present the data available on egg incubation was considered insufficient. Juvenile habitat is likely not impeded. Adult habitat other than spawning is likely a potential impediment in the lower lakes. Adults may be affected by the effects zebra mussels on water clarity potentially shifting distribution to offshore areas thus impacting the potential access for spawning.

b. Contaminants
This was not considered an issue. There has been some monitoring in Superior by Wisconsin. The presence of contaminants in roe and effects was considered but it seemed unlikely there would be effects.

c. Exploitation
Superior has the highest levels of harvest followed by Huron however the degree of exploitation is unknown. In Superior the highest levels of exploitation occur in Ontario bays but data was considered insufficient. In Wisconsin the harvest levels appear appropriate. ON—information gap? In Michigan and Huron lake herring are taken as bycatch and due to low stock size exploitation may be impediments. It seemed unlikle that recreational fisheries are affecting lake herring re-establishment.

d. Non-native biota

- Piscivores--not likely an issue given a lack of habitat overlap and the abundance of alternate prey for non-native piscivores
- Planktivores—Superior-inconclusive ; Ontario—Christie inferred negative relationship; Michigan—alewife and smelt can have effect; Erie—has high smelt population; Huron—similar negative relationship for smelt and alewives
- Benthivores- Superior-none; Ontario—goby may act as egg predator on offshore waters ; Michigan—gobies may concentrate only on rocky areas offshore; Erie—has many gobies, so they may respond to lake herring egg deposition zones
- Parasites: Superior—not likely a problem—some marking, but not considered an impediments. Stable isotope analysis shows some corgeonine predation by

lampreys; Huron—maybe chubs were a buffer for lampreys when lake trout declined and lamprey abundance is still high; Michigan—lamprey could be an impediment here; Erie and Ontario—wounding rates low on lake trout lamprey are not likely an impediment to lake herring.

- Invertebrates-zooplankton: *Bythotrephes* predation on intermediate zooplankton may inhibit larval herring growth even though *Bythotrephe* serve as food for larger herring; effects on herring may indirect such as competition; there is insufficient information specifically on direct effects on herring; some studies are necessary as the potential is there for some impediments.
- Invertebrates-dreissenids: Superior—dreissenids rare so likely not a problem; Ontario, Erie, Michigan, Huron—high densities of zebra/quagga may have food chain effects on plankton and amphipods decreasing phytoplankton and zooplankton such that there is reduced food for larval lake herring

<u>e. Native biota</u>

- Piscivores—Superior, Huron—not an issue; Erie—burbot may eat herring; Ontario—unknown
- Planktivores—introgression/hybridization an issue on all lakes with bloaters and lake herring overlap butprobably not an impediment
- Benthivores—not likely an issue
- Invertebrates—native invertebrates not a impediments in the predatory or competitive sense; though may be an impediment if they serve as forage for herring

<u>f. Genetics</u>

- Hybridization--- between lake herring and hoyi has been observed although the negative effects, if any, are unknown. Erie, Ontario—not an issue. Michigan, Huron—possibly an issue. Superior—does occur and may pose an issue, but effects unknown.
- Diversity—where diversity has declined or collapsed it can be a problem especially where locally adapted stocks have been lost.
- Phenotype identification is an issue for data collection

<u>g. Stock Structure</u>

- Age structure—Superior—fine, old age compositions; need fish to have issues with age structure. Although age distributions extends out to older ages, age structure of lake herring has been characterized by intermittent reflecting a high contrast in recruitment.
- Sex ratio---Superior—fine; other lakes—unknown

<u>h. Spawning Stock</u>

- Magnitude/size: definitely a limiting factor for rebuilding stocks; other than SU, a major impediment to rehabilitation.
- Site fidelity: knowledge on spawning site fidelity poor

<u>i. Climate</u>

- It is unknown whether large scale climate changes can affect lake herring dynamics. Recruitment patterns in Lake Superior suggest abiotic factors at work likely related to the effects of thermal conditions on hatching/larval success.

Final Charge 1 for Group III: Research projects addressing impediments

<u>Dreissenids:</u>

Issue: Does dressenid feeding reduce primary and secondary production that result in deficient zooplankton densities that effect larval or older life stage survival?

Study: Use mesocosm/experimental lakes with stable herring population and recruitment. Introduce zebra mussels and monitor lake herring response.

Study: Look at recruitment (year class strength and survival) dynamics in unexploited lake herring lakes with similar trophic status with various stages of zebra mussel colonization which may represent various stages of reduced primary and secondary production.

<u>Alewife/Smelt:</u>

Issue: Do exotic alewife and smelt populations reduce lake herring recruitment through predation and/or competition? Most evidence is circumstantial hence research should be directed to determine potential impact. If negative interaction potential is present then determine the level of reduction needed to release predation/competition pressure on herring.

Study: Predation experiments on lake herring early life stages

- Meso- or microcosm experiments
- Vary densities of predators and prey to determine levels at which predation effects are significant
- Extrapolation to real world may be difficult because of other interactions such as alternate prey or movement of prey outside the predation arena
- Experimental designs should be robust to allow for alternative hypotheses

Study: In situ approach—remove potential predators and competitors

- Assess response in lake herring recruitment dynamics in selected areas where all three species exist or in inland experimental lakes.

Study: competitive exclusion, competitive release

- Study single species that describe feeding dynamics of competitors (smelt, alewife, lake herring)
- Look at deviations in feeding dynamics when one or more species are introduced at different densities
- Experimental lakes or laboratory type study

Issue: Is EMS a factor in limiting herring recruitment due to thiamine deficiency because of herring predation on alewife and smelt.

Study: look at thiamine levels in lake herring across stocks

<u>Gobies:</u>

Issue: Does goby predation on lake herring eggs reduce recruitment potential where these two species exist together.

Study: Determine goby density and distributions in areas of herring egg deposition, and assess predation on eggs. Determine nature of overlap and describe habitat and thermal conditions where overlap occurs.

Study: In mesocosms look at predation on known eggs/fry with varying densities of gobies.

Issue: Do gobies potentially compete with herring for crustacean forage where goby and herring distribution overlap?

Study: Determine habitat and diet overlap and estimate consumption.

<u>Non-native zooplankton:</u>

Issue: Do changes in size spectra of native zooplankton caused by non-native zooplankton affect herring foraging and survival? Can lake herring feed on non-native zooplankton and what are the nutritional/survival effects?

Study: In controlled lab settings compare herring growth and survival with perturbed and unperturbed native zooplankton communities with and without non-native zooplankton.

<u>Climate change:</u>

Issue: Temporal correlation among recruitment events across Lake Superior suggests abiotic factors (environmental conditions) may be important in contemporary recruitment dynamics. If abiotic factors were also important historically, has global warming cause subtle changes in environmental conditions that effect recruitment success especially in other Great Lakes? Resolution of this issue requires explicit information on the early life history requirements of herring, which is now incomplete.

Issue: What is the timing of plankton blooms and herring hatching, and has the latter changed over time?

Field studies in Lake Superior that describe timing of plankton blooms and hatching of lake herring.

Issue: What are the early life history requirements of lake herring?

Study: Need to review and describe early life history of lake herrring. Need to develop survey designs that can effectively sample and describe early life history dynamics and this is most likely accomplished in Lake Superior.

Issue: How do changes in thermal conditions due to climate change affect early life survival; What is the effect of climate change on thermal habitat volume for all life stages of lake herring, especially in Lake Erie?

Study: Run experiment to assess thermal regime effects on early life survival both in terms of absolute change and variation of temperatures. This can be conducted in the laboratory.

Issue: What is the relative importance of other environmental factors such a wind events, siltation, ice-cover on herring recruitment?

Study: Re-evaluate the importance of factors from historical data for Lake Superior.

Final Charge 2. Describe research projects and methods to restore lake herring to areas of the GL such as Lake Ontario where they have been extirpated or reduced to a remnant stock.

1. Describe and inventory remnant populations. This would include stock size, age structure, genetic profile, spawning locations, diet, and effective population size (genetic).
2. Genetic inventory of historical and contemporary populations and compare.
3. In areas where remnant stocks exist such as Lake Huron close all targeted fisheries, and monitor responses. Set F=0.
4. Assess lake herring response to large-scale removal of exotics (alewife, smelt, gobies) either through fishing or predation**.**

Appendix G

List of presentations given at lake herring workshop

Amtaetter, F. The Status of lake herring in Lake Simcoe.

Black, J. Status of lake herring in the Ontario waters of Lake Superior.

Claramunt, R. and Madenjian, C. Status of lake herring in Lake Michigan.

Gorman, O. ??????

Hoyle, J.H. The status of lake herring in Lake Ontario.

Kinnunen, R. Lake herring life history.

Mohr, L. Status of lake herring in Lake Huron.

Pangle, K.L. and Sutton, T.M. Evaluation of practical and natural diets for juvenile lake herring.

Ryan, P. Status of lake herring in Lake Erie.

Schram, S. Population dynamics of lake herring in the Wisconsin waters of Lake Superior.

Schreiner, D. Status of lake herring.

Scribener, K.T. Comparative phylogeography of Great Lakes coregonids

Vascotto, K. Patterns and processes in life history variation in Ontario cisco populations.