Determine invasion status and ecological effects of an exotic zooplankter in several Great Lakes area parks

Project PMIS #: 105200

Strategic Plan Goal #: Ia2C, Exotic animals and insects

Date Implementation Plan Prepared: January 14, 2008

Organizations Involved in Project:
National Park Service Midwest Region
Isle Royale National Park
Pictured Rocks National Lakeshore
Sleeping Bear Dunes National Lakeshore
Voyageurs National Park
Michigan Technological University

Co-Principal Investigators:

Charles Kerfoot _____
Professor, Michigan Technological University

Brenda Moraska Lafrancois _____
NPS Aquatic Ecologist, Midwest Region

Jay Glase _____
NPS Fishery Biologist, Midwest Region

Lora Loope _____
Aquatic Ecologist, Pictured Rocks National Lakeshore

Ryan Maki _____
Aquatic Ecologist, Voyageurs National Park

Natural Resource Program Center project coordinator:

Linda Drees _____
Branch Chief, Exotic Species
NPS Biological Resources Management Division

Table of Contents

	Page
Abstract	3
Introduction	
Problem Statement	3
Background	4
Specific Objectives to be Addressed	6
Environmental Planning	6
Principal Project Managers	7
Study/Implementation Plan	
Approach and Methods	7
Tasks, Organization, and Schedule	14
Deliverables and other Reporting Requirements	
Final Completion Reports	15
Deliverables by Third Parties	15
Annual Accomplishment Reporting	16
Quality Assurance, Quality Control, and Data Quality Objectives	16
Budget-Costs	18
References	19

Abstract

The spiny water flea (*Bythotrephes longimanus*) is an invasive, predaceous zooplankter which has significantly affected Great Lakes food webs and has begun to invade inland waters of the Great Lakes states and Canada. Two lakes at Pictured Rocks National Lakeshore were invaded by the early 2000s, and *Bythotrephes* was discovered on the large lakes of Voyageurs National Park in late 2006 and 2007. It is unclear whether or not *Bythotrephes* has invaded inland lakes of other Great Lakes parks, and ecological effects of the Pictured Rocks and Voyageurs invasions have not been evaluated. The proposed study aims to 1) determine which inland lakes and parks have been invaded, 2) investigate effects of the *Bythotrephes* invasions on native zooplankton and fish at Pictured Rocks and Voyageurs, and 3) convey the implications of these findings to the public. Results of the study will establish a baseline against which to monitor future invasions of inland waters in Great Lakes parks, and will identify which aspects of aquatic resources may be most affected by such invasions.

Introduction

Problem Statement

Northern lakes, particularly those within the national park system, are highly prized for their biological resources and relatively high ecological integrity. The walleye fishery of Voyageurs National Park's (VOYA's) large lakes is rated among the top ten in the state of Minnesota, and inland lakes within VOYA and other Great Lakes area parks (i.e., Isle Royale National Park (ISRO), Pictured Rocks National Lakeshore (PIRO), and Sleeping Bear Dunes National Lakeshore (SLBE)) are popular destinations for those seeking quieter backcountry experiences. Although the national park status protects these lakes from many development pressures affecting northern lakes, they remain vulnerable to threats from climate change, atmospheric deposition, and, importantly, aquatic invasive species (Lafrancois and Glase 2005).

The spiny water flea (*Bythotrephes longimanus*) is a large, predaceous zooplankter that invaded the Great Lakes in the late 1980s and has since begun to invade inland waters. As of 1999, 42 North American watersheds were known to have *Bythotrephes* present (MacIsaac et al. 2000), including basins in Ontario, Ohio, Michigan, Minnesota, and more recently Wisconsin. Two inland lakes at PIRO were invaded in the early 2000s, and in late 2006 and 2007 *Bythotrephes* was discovered much further west, on the large lake systems of VOYA. *Bythotrephes* is known to substantially alter native zooplankton communities, and competes with ecologically important prey fish, such as yellow perch (*Perca flavescens*), for food. Although its initial Great Lakes invasion likely occurred via ballast water discharge from ocean-going ships, recreational vectors have facilitated the rapid spread of *Bythotrephes* through inland waters. In order to develop effective prevention and mitigation strategies, park managers need to know the invasion status of their inland waters and understand the ecological repercussions of current and potential future invasions.

Background

Biological invasions of the Great Lakes began during European settlement and have since accelerated as a result of development and human activities in the Great Lakes Basin. Mills et al. (1993) estimated that 139 new organisms had been introduced into the Great Lakes since the early 1800s. About 10 percent of the introduced species have had measurable impacts on Great Lakes ecosystems and economies, including 50 percent of all introduced fish species (Mills et al. 1993). Each of these introductions has contributed to reduced biological integrity in the Great Lakes, prompting some to predict an "invasional meltdown" in which interactions between introduced species facilitate the establishment of new invaders (Ricciardi 2001). Effects of species like the sea lamprey (*Petromyzon marinus*) and the zebra mussel (*Dreissena polymorpha*) are well studied in the Great Lakes region, but comparatively little is known about less conspicuous taxa like invasive zooplankton (Bollens et al. 2002).

The spiny water flea (*Bythotrephes longimanus*), discernible by its relatively large size and long, spiny caudal appendage, had invaded all of the Great Lakes by 1988 (Cullis and Johnson 1988) and has received increasing attention over the past decade. Several studies have addressed population characteristics and the spatial-temporal distribution of *Bythotrephes* in Lake Michigan (Pothoven et al. 2001, 2003). Other work has addressed Great Lakes food-web responses to the invasion (Sandgren and Lehman 1990, Lehman and Cáceres 1993, Makarewicz et al. 1998, Schulz and Yurista 1999, Vanderploeg et al. 2002), diet selection (Lehman and Branstrator 1995), and egg diapause (Yurista 1997).

Ecological effects of *Bythotrephes* in inland waters have received less attention. Most of the available inland lakes information comes from Harp Lake, Ontario (Yan and Pawson 1998) and Lake Michigamme, Upper Michigan (Jarnigan et al. 2004). In Harp Lake, the *Bythotrephes* invasion caused shifts in size and species composition toward large-bodied cladocerans and reductions in cladoceran abundance and overall species richness (Yan et al. 2001), findings corroborated by mesocosm studies in a Swedish lake (Wahlström and Westman 1999). In Long Lake, Michigan, researchers found that *Bythotrephes* consumed 1.5-5 times more zooplankton biomass than yellow perch, suggesting that the role of *Bythotrephes* as a predator in inland lakes may be substantial (Hoffman et al. 2001). Others noted that *Bythotrephes* may affect native fish by forming boluses in lake herring stomachs (Coulas et al. 1998), suppressing *Daphnia* populations and creating bottlenecks for age-0 yellow perch populations (Hoffman et al. 2001), and puncturing the stomachs of small bait fish (Compton and Kerfoot 2004).

Although *Bythotrephe*s has already invaded several inland lakes at PIRO and VOYA, recent work indicates that many more inland lakes have suitable habitat and remain vulnerable to invasion (MacIsaac et al. 2000). Likely vectors for *Bythotrephes* dispersal include fish movement and a variety of human recreational vectors, such as live bait use and the transfer of contaminated fishing lines and nets between lakes (Jarnigan et al. 2000). Several national parks in the Great Lakes area are situated in or next to *Bythotrephes*-invaded Lakes Superior and Michigan. Each of these parks features

valuable and unique inland water resources that are threatened by biological invasions from the Great Lakes.

The resources of concern, invasion threats, and known presence or absence of *Bythotrephes* varies among inland lakes in national parks of the Great Lakes area (Table 1). Isle Royale National Park, located in western Lake Superior, is home to at least 38 inland lakes, genetically unique fish species (Hubbs and Lagler 1949, Kallemeyn 2000) and notably abundant unionid mussel populations (Nichols et al. 2001). *Bythotrephes* has been collected in Lake Superior waters around ISRO (M. Romanski, ISRO biologist, personal communication), but was not found in any of the island's 38 lakes sampled a decade ago (Kallemeyn 2000) or in any of the six lakes sampled during 2005 (Reynolds 2006). Pictured Rocks National Lakeshore (PIRO) is situated along the southern shores of Lake Superior and has six inland lakes of diverse physical and ecological character. *Bythotrephes* has been documented in two of these lakes, Beaver and Grand Sable, since the early 2000s (Lora Loope, PIRO aquatic ecologist, personal communication); the invasion status of other PIRO lakes is uncertain.

Table 1. Invasion timeline and status (as currently known) for *Bythotrephes* in inland waters of national park units in the Great Lakes region.

	Number of Inland Lakes	**Number of Invaded Inland Lakes**	**Certainty of invasion status**	**Sources**
ISRO	38	0	High for 6 lakes; low for remaining 32 lakes.	Kallemeyn (2000) Reynolds (2006)
PIRO	6	2	Confirmed for 2 lakes; low for remaining 4 lakes.	L. Loope (personal communication)
SLBE	20	0	Medium for 11 lakes; low for remaining lakes.	Whitman et al. 2002
VOYA	6 large lakes	6	Confirmed for 4 lakes; high for remaining lakes.	R. Maki (personal communication)
VOYA	25 interior lakes	0	Medium-High for all 25 lakes.	B. Moraska Lafrancois (personal communication)

Sleeping Bear Dunes National Lakeshore is located along the northeastern shores of Lake Michigan and features more than 20 inland lakes. *Bythotrephes* was not documented during a zooplankton study in 11 SLBE lakes (Whitman et al. 2002), but several lakes have recently been invaded by the zebra mussel (*Dreissena polymorpha*) indicating that the invasion pathways are present and open. Voyageurs National Park is home to a system of large lakes (Rainy Lake and Namakan Reservoir, which consists of Kabetogama, Namakan, Sand Point, Crane, and Little Vermilion Lakes), as well as more than 25 smaller interior lakes. Although VOYA is not situated along a Great Lake, its six large lakes are home to a remarkable recreational fishery, which may account for the rapid westward leap of *Bythotrephes* into this system. Although *Bythotrephes* has not yet been confirmed in Sand Point and Little Vermilion Lakes, they are connected as part of

the Namakan Reservoir and the Minnesota Department of Natural Resources has officially designated all of them as infested waters. *Bythotrephes* was not detected during initial reviews of zooplankton samples from VOYA's 25 interior lakes in 2007 (B. Moraska Lafrancois, NPS Midwest Region, personal communication).

Specific Objectives to Be Addressed

Despite the presence of *Bythotrephes* in near shore waters of Lakes Superior and Michigan and the likely vulnerability of inland waters in Great Lakes area parks, it is only known to have invaded two lakes at PIRO and the large lakes at VOYA. While this may indicate actual absence of *Bythotrephes* from other inland lakes, it may also reflect the limited zooplankton sampling and monitoring efforts in those waters. In order to protect and manage vital aquatic resources, resource managers need a definitive assessment of the status and spatial distribution of *Bythotrephes* invasions in park waters.

For the two invaded lakes at PIRO and VOYA, neither *Bythotrephes* abundance nor its effects on lake ecology have been evaluated. Although ecological effects of *Bythotrephes* have been studied in other inland lakes, the available data are limited in geographic extent, variable across lakes, and in need of further study and corroboration. For these reasons, a site-specific study of *Bythotrephes* in invaded PIRO and VOYA waters is needed.

To address these critical information and resource management needs, we propose to:

1. Determine presence or probable absence of *Bythotrephes* in inland lakes of several Great Lakes area parks (i.e., ISRO, PIRO, and SLBE)
2. Assess ecological effects of the *Bythotrephes* invasion on zooplankton communities and native fish growth in invaded lakes at two parks (i.e., PIRO and VOYA).
3. Contribute to enhanced public understanding of the distribution, spread, and ecological implications of *Bythotrephes*.

Environmental Planning

Projects are subject to review under the National Environmental Policy Act (NEPA) and Section 106 of the National Historic Preservation Act (NHPA). Park Resource Management staff will ensure the compliance requirements are met. Generally, data collection, inventory, study, research and monitoring, of the kind proposed in this study plan, are considered categorical exclusions under NEPA and programmatic exclusions under Section 106, NHPA, provided there are no adverse impacts to natural or cultural resources.

Principal Project Managers (NPS)

Brenda Moraska Lafrancois
National Park Service
Aquatic Ecologist, Midwest Region
Ph: 651.433.5953 x35
Email: brenda_moraska_lafrancois@nps.gov

Jay Glase
National Park Service
Fishery Biologist, Midwest Region
Ph: 906.487.7167
Email: jay_glase@nps.gov

Study Plan

Approach and Methods

Objective 1: Determine *Bythotrephes* presence or probable absence

Because *Bythotrephes* populations vary greatly throughout a growing season and tend to be patchily distributed in lake water, we will use a lake sediment sampling technique to determine *Bythotrephes* presence (Hall and Yan 1997, Forman and Whiteside 2000). The success of this method hinges on two facts: 1) *Bythotrephes* caudal processes are spiny, readily distinguishable, and preserve well in sediments, and 2) lake sediments serve as spatial and temporal integrators, accumulating *Bythotrephes* remains throughout the water column and throughout the growing season. This method requires only one sampling trip to each lake to determine *Bythotrephes* presence/probable absence, thus enabling a greater number of lakes to be sampled.

Sediment sampling –
Inland lakes of three national parks and lakeshores (ISRO, PIRO, and SLBE) will be examined for *Bythotrephes* presence. Lakes in parks with many inland lakes (ISRO, SLBE) will be stratified into two categories according to invasion likelihood (high and medium). Placement into one of these categories will be based on accessibility, hydrologic connections, proximity to Lake Superior or Lake Michigan, degree of recreational fishing use, morphometry, and water chemistry. All lakes with high invasion likelihoods and a random subset of lakes with medium invasion likelihoods will be sampled. This should amount to approximately 15 lakes each at ISRO and SLBE and four lakes at PIRO, for a total of 34 inland lakes. A single longitudinal transect will be established along the line of maxium length in each lake, and 10 sampling points will be situated along it. One sediment sample will be collected at each sampling point with an Ekman dredge following the protocols outlined in previous studies of *Bythotrephes* caudal processes in inland lake sediments (Hall and Yan 1997, Forman and Whiteside 2000). Only the top 3 cm of the Ekman sediment sample will be retained for analysis. All sampling equipment and lines will be cleaned and dried between lakes to avoid transport of *Bythotrephes* or other non-native species via research gear (see below, quality assurance).

Sediment lab analysis –
Lab analysis of sediments will include counts of both caudal processes and diapausing (resting) eggs. Caudal processes in lake sediment provide an estimate of how many individuals died in the water column since colonization, whereas the egg counts provide

an estimate of the egg bank and the potential for continued long-term recruitment. The egg count will also specify what fraction of eggs is viable and what fraction is present as empty egg capsules. A dye will be used to help identify caudal processes.

Sediment data analysis –
Following spine identification and counting, data will be analyzed to assess the spatial distribution of *Bythotrephes*-invaded lakes within and among Great Lakes area parks, and to explore possible relationships between *Bythotrephes* distribution and geographic and lake-specific factors. Spatial distribution of the *Bythotrephes* invasion will be evaluated by creating a GIS, plotting study lakes on a map, and applying codes for *Bythotrephes* presence or probable absence. We will identify which parks are *Bythotrephes* hot-spots and which lakes or lake corridors have been invaded. We will then look at how *Bythotrephes* distribution in Great Lakes area parks relates to factors such as proximity to Lakes Superior or Michigan, degree of hydrologic connectivity (number of inlets/outlets, presence/absence of migrating Great Lakes fish), degree of recreational pressure (qualitative estimate of fishing pressure/visitation, presence/absence of boat launching sites or docks), lake morphometry (surface area, surface area:volume, maximum depth, mean depth), and basic water chemistry and food web structure (where available from previous studies). In the event that *Bythotrephes* spines are not encountered in any lakes aside from the two at PIRO, we will plot all study lakes on a map and note likely or potential invasion pathways based on the contributing factors described above. In either case, we will provide this information to parks and the Great Lakes Inventory and Monitoring Network staff for use as a monitoring baseline.

Objective Two: Assess ecological effects of *Bythotrephes* invasion on two PIRO lakes

The invaded large lakes at VOYA and the two invaded PIRO lakes will be monitored for zooplankton, water quality, and fish during the growing season (May through early-October) for two years. We propose to document seasonal, spatial and inter-annual patterns in *Bythotrephes* populations, evaluate effects of *Bythotrephes* on native zooplankton communities (by relating zooplankton composition, size structure, and abundance to seasonal population patterns of *Bythotrephes* size and abundance), and investigate effects of *Bythotrephes* on yellow perch (by examining gut contents for *Bythotrephes* remains and comparing population structure and growth rates before and after invasion, in invaded PIRO and VOYA lakes).

Zooplankton sampling –
Zooplankton vary temporally and spatially in lakes (Wetzel and Likens 2000, APHA 2005). To address temporal variation, the two invaded PIRO lakes will be sampled every other week for zooplankton during the open water season over the course of two years (FY 2009 and FY 2010), for a total of 12 sampling dates per year. This sampling regime will capture a more than typical amount of the annual variability in native zooplankton assemblages (see Arnott et al. 1998). The invaded VOYA lakes will be sampled monthly as part of an ongoing park-based monitoring effort, six times during the open water season during all project years.

Spatially intensive sampling improves estimates of zooplankton abundance, biomass, and richness in lakes, but is often constrained by logistical considerations (Blomqvist 2001). Further, zooplankton assemblages generally vary more along depth gradients than along horizontal ones (Avois et al. 2000), and whole-lake estimates of zooplankton density and biomass are rarely central to zooplankton community studies. For these reasons zooplankton monitoring programs and surveys typically collect vertically integrated samples at only one location in each lake (i.e., the deepest point). Importantly, both long-term studies and lake surveys have documented clear effects of *Bythotrephes* on native zooplankton community composition, size structure, abundance, and richness, using only a single sampling site in each lake (Yan and Pawson 1997, Strecker et al. 2006). Nonetheless, many have noted the limitations of sampling from a single location, arguing that such samples do not adequately represent zooplankton assemblages (e.g., Visman et al. 1994). We propose a less spatially intensive approach for VOYA lakes than for PIRO lakes, in order to maintain internal consistency with VOYA's longer term lake monitoring protocols.

PIRO Lakes – We will use a moderately intensive zooplankton sampling strategy for the two PIRO lakes. One sample will be collected from the deepest point in each lake, and nine additional samples will be collected from randomly selected, non-littoral sites elsewhere in the lake. This approach will increase our ability to capture rare species, allow for better estimates of zooplankton density, biomass, and richness, and improve our ability to detect changes in zooplankton communities following any future invasion by *Bythotrephes*. For example, intensive study of a Canadian Shield lake, with nine to 10 sampling locations, showed that a high proportion of the total species richness in a given sampling year was captured by collecting zooplankton from three to five sites (Arnott et al. 1998); we expect that 10 samples will capture the majority of species present in each lake.

To determine site locations, a transect of maximum lake length will be drawn for each lake such that it passes through the existing Great Lakes Network (GLKN) water quality monitoring site (i.e., the deepest point in each lake) but excludes littoral areas < 2m deep or within 100 m of the shoreline. Up to twenty possible sampling points will be randomly selected and numbered along this transect using ArcGIS. Samples will be collected at the deepest point and at the first nine randomly selected sites for a total of 10 sampling sites. If, upon field inspection, a randomly selected site is found to be less than two meters in depth or has apparent aquatic plant growth, the nearest randomly selected point along the transect will be chosen for sampling in its place.

A vertical plankton tow net will be used to ensure the entire water column is represented in the sample, and a relatively small mesh size (80 micron) will be used ensure that small crustaceans and many rotifer taxa are captured. At each sampling site, the net will be pulled up at a slow, steady rate no greater than 0.5 m per second to prevent the net from pushing water and plankton away from its mouth (APHA 2005). Each tow will integrate a column of water from 1 m above the lake bottom to the surface; tow depths will be recorded on field data sheets for later calculations of volume sampled. Tow nets will be equipped with flow meters to more quantitatively determine the volume sampled.

Once the mouth of the net has broken the surface, zooplankton will be rinsed from the sides of the net into the bucket by gently raising and lowering the mesh portion of the net into and out of the water, taking care to keep the mouth of the net from re-entering the water. When zooplankton have been rinsed into the bucket, the net will be raised completely out of the water. The bucket, still upright and with the tubing still clamped, will be unscrewed and detached from the net. With a squirt bottle of lake water, zooplankton will be rinsed from the sides of the bucket to the bottom of the bucket. This rinsing will be done from the outside of the bucket, to avoid contaminating the sample with additional plankton. Holding the bucket and tubing over an open sample container, the tubing will be gently unclamped, allowing zooplankton to wash out of the bucket. With the squirt bottle, any remaining bucket contents will be rinsed into the sample container, taking care to rinse from the outside of the bucket.

Following sample collection, samples from each lake will be placed into labeled sample containers. A small amount of carbonated water will be added to the samples to narcotize zooplankton and reduce shrinkage and distortion (APHA 2005). Once zooplankton have slowed down (usually within 30 minutes), they will be concentrated to a smaller volume by placing a small PVC tube fitted with 80 micron mesh into the sampling container, and removing water from inside the tube with a turkey baster or large pipette. Once the sample volume has been suitably reduced, 95% ethanol will be added to the sample water to achieve a concentration of ~70% ethanol (APHA 2005).

<u>VOYA Lakes</u> – Zooplankton sampling on the invaded VOYA lakes will follow established park-based protocols from previous years, and will be conducted by park personnel as an in-kind contribution to the project. Samples will be collected monthly from May through October in all project years, from 11 established sites on each of the VOYA lakes (six sites on Rainy Lake and one site each on Kabetogama, Namakan, Sand Point, Crane, and Little Vermilion). A vertical zooplankton tow net with a 30 cm mouth and a 153 um mesh size will be used, for consistency with previous years. Standard tow depths for these sites vary from 3 m to 30 m, depending on water depth. Zooplankton field processing and preservation will follow the protocols described above for PIRO lakes.

Zooplankton lab analysis –

<u>PIRO Lakes</u> – Zooplankton samples from each of the PIRO lakes will be placed in a small beaker, diluted with 70% ethanol to a stable volume, and stirred gently to re-suspend plankton. If fewer than 200 zooplankton are present in a sample, all individuals will be counted and identified; all other samples will be subjected to a subsampling procedure (APHA 2005). In most cases, many more than 200 zooplankton will be present. From these, subsamples will be removed in 1-ml aliquots using a Hensen-Stempel pipette, and placed into gridded Sedgewick-Rafter or larger counting chambers for analysis. A minimum of three aliquots (actual number to be determined based on quality assurance measures, discussed below) will be examined under dissecting and compound microscopes and identified to species, if possible, using standard and regional

zooplankton keys (e.g., Balcer et al. 1984, Thorp and Covich 1991, and Smith 2001). Crustaceans as well as rotifers will be identified, since both groups have shown responses to *Bythotrephes* elsewhere.

Abundance for each species will be estimated as individuals per cubic meter, using mean counts per 1-ml aliquot, multiplied by the total sample volume from which the aliquots were removed, multiplied by water column volume estimates derived from the area of the net's mouth, the depth of the water column sampled, and the number of tows (Wetzel and Likens 2000). Zooplankton biomass for each species will be similarly estimated, in milligrams per cubic meter, by multiplying the abundance estimate for each species by its mean biomass. The mean biomass for each species will be estimated from at least ten individuals, using existing standard length-weight regressions (for Copepoda, Cladocera, and other crustaceans) and biovolume calculations (for Rotifera), following Bottrell et al. (1976), Dumont et al. (1975), and McCauley (1984). Zooplankton species richness and Shannon-Wiener diversity will be calculated for each sample. In addition to characterizing overall zooplankton composition and biomass, detailed analysis of *Bythotrephes* populations will also be performed, including instar stage, sex, and presence and number of embryos or resting eggs.

<u>VOYA Lakes</u> – Zooplankton from the VOYA samples will be identified, counted, and measured by the Minnesota Department of Natural Resources using a video-microscope. Samples will be diluted to a known volume from which a 5 ml subsample produces 150-200 organisms. If there are less than 150 organisms in a subsample, additional subsamples will be processed until a minimum of 150-200 organisms are identified. Cladocerans will be identified to species, as will copepods, if possible. Few rotifers are expected given the large mesh size (153 um) used in the VOYA sampling protocols. Abundance and biomass will be calculated as described above for PIRO lakes.

Zooplankton data analysis –
Effects of *Bythotrephes* on zooplankton communities and biomass will be identified using two main approaches. First, changes in zooplankton composition will be evaluated by comparing species lists developed during the proposed study with those established in pre-invasion studies of Beaver and Grand Sable Lakes (Limnetics 1970, Kamke 1987). Notable changes will be compared with changes documented in Harp Lake, Ontario, following its invasion by *Bythotrephes* (e.g., shifts toward dominance by large-bodied cladocerans like *Holopedium gibberum,* reduced species richness) (Yan et al. 2001). Zooplankton size structure may be a responsive indicator of *Bythotrephes* effects, so several measures of size structure (mean zooplankton length, number or biomass of small vs. large zooplankton, etc.) will be documented and compared with the available literature for local and regional invaded and uninvaded lakes.

Secondly, effects of *Bythotrephes* on native zooplankton will be examined using seasonal patterns in both *Bythotrephes* and native zooplankton abundance and biomass. Graphical analysis and temporal coherence analysis will be conducted by calculating Pearson product-moment correlations between variables (such as abundance of *Bythotrephes* vs. abundance of select native zooplankton taxa) at various time steps throughout the

growing season. Strongly negative correlations would suggest strong species interactions and probable negative effects of *Bythotrephes* on native zooplankton taxa. Comparing coherence values between *Bythotrephes* and various zooplankton taxa would also help identify which native zooplankton are most strongly impacted by *Bythotrephes.*

Water quality sampling –
Corresponding water quality sampling will be conducted on each zooplankton sampling date at deepest water quality site in the two PIRO lakes and at each zooplankton sampling sites in the VOYA large lakes. Vertical profiles for basic water quality parameters (temperature, dissolved oxygen, pH, and conductivity) will be established using a multiparameter water quality sonde. At a single location over the deepest part of each lake, Secchi depth will be measured and integrated water samples will be collected for chlorophyll *a,* alkalinity, nutrient (total phosphorus, phosphate, total nitrogen, ammonia-nitrogen, and nitrate-nitrogen), dissolved organic carbon (DOC) analysis, and Secchi depth. The integrated water samples will be collected from the PIRO lakes using a 0-2 m tube sampler (in keeping with standard GLKN protocols (Axler et al. 2007)), and from the VOYA lakes using three pooled Van Dorn samples, from the surface, Secchi depth, and twice the Secchi depth (in keeping with standard VOYA sampling protocols). Sampling equipment and lines will be cleaned and dried prior to entering each lake to avoid transport of *Bythotrephes* or other non-native species via research gear.

Water quality lab analysis –
Immediately after each sampling date, water quality samples will be packed and shipped to the St. Croix Watershed Research Station or another water quality laboratory and analyzed for the above constituents. Standard methods for water analysis will be used (APHA 2005), and appropriate quality assurance/quality control measures (including replicates and field blanks) will be taken during sample storage, shipping and analysis.

Water quality data analysis –
Seasonal patterns in water quality parameters will be used as ancillary data to help explain variability in *Bythotrephes* populations, native zooplankton densities, and yellow perch growth rates (see below). Chlorophyll *a,* an index of algal biomass, may help account for any variation in zooplankton abundance/biomass not explained by *Bythotrephes* abundance or fish predation.

Fish sampling –
Yellow perch occur commonly in lakes of both PIRO and VOYA, and are host fish for at least one mussel species at PIRO. We will investigate effects of *Bythotrephes* on juvenile yellow perch populations to evaluate potential implications of *Bythotrephes* invasions on higher trophic levels. We will also investigate the potential for yellow perch to help control *Bythotrephes* population growth. For example, Jarnagin et al. (2004) indicate that fish predation may limit the success of *Bythotrephes* by digesting vulnerable, non-mature diapausing eggs and by prematurely curtailing autumn diapausing egg production. Fish gut analysis will allow us to infer whether predation in PIRO and VOYA lakes could have a limiting effect on *Bythotrephes.*

To determine consumption of *Bythotrephes* by young-of-year yellow perch, and to determine variability in consumption, we will sample Beaver and Grand Sable Lakes three times during the summer (May, July, and September). Investigations by Jarnagin et al. (2004) indicate that Lake Michigamme yellow perch less than 55 mm and greater than 109 mm rarely had *Bythotrephes* in gut samples. We will therefore focus on these approximate size classes (55-109 mm) for the majority of our sampling. Some sampling of fish outside of these size classes will be conducted, however, to determine if feeding behavior is similar to that reported in other investigations. During the May sampling, 30 fish <50 mm per lake will be taken for gut samples and diet analysis. July sampling will again involve taking gut samples from 30 fish <50 mm, as well as from 30 fish between 51-100 mm, and 30 fish >100 mm if available, to determine consumption by size class. September sampling will involve stomach samples from these same size classes, but there will not likely be many fish < 50 mm. To simplify diet analysis during the second year, gut samples of each size class will be pooled, greatly reducing the sample size.

To determine how *Bythotrephes* may affect growth rates of perch through competition for food resources, sampling for yellow perch juveniles will occur at the two invaded PIRO lakes and at least two of the invaded VOYA lakes, in conjunction with native zooplankton sampling. If available, several un-invaded PIRO lakes will also be sampled for comparison. Sampling in the VOYA lakes (Rainy and Kabetogama) will be accomplished in cooperation with the Minnesota Department of Natural Resources. Thirty young of year fish from each lake will be taken prior to reaching 50 mm length to compare early season growth rates. Lengths and weight (or volumetric displacement) will be measured in the field; otoliths from the same 30 fish will be taken and analyzed for growth rates and to estimate time of hatching. Length and weight measurements will be taken on an additional 30 fish per lake near the end of the growing season in late September or October to evaluate the first year's growth and to examine total growth rate differences, a) in lakes with and without *Bythotrephes,* and b) in lakes before and after the *Bythotrephes* invasion.

Fish data analysis –
Modern yellow perch growth rates in the invaded PIRO and VOYA lakes (determined in the proposed study) will be compared with pre-*Bythotrephes* yellow perch growth rates. Pre-*Bythotrephes* information will be derived from available data from the Michigan and Minnesota Departments of Natural Resources (J. Glase, personal communication). Additionally, yellow perch growth rates will be compared between invaded and un-invaded lakes at PIRO, with attention to potential confounding factors such as temperature and food availability. Finally, fish gut contents (# *Bythotrephes* spines per individual gut) will be plotted against *Bythotrephes* abundance (# *Bythotrephes* per m^3) to determine the extent to which predation by fish may affect *Bythotrephes* populations. Numbers of *Bythotrephes* spines per individual gut will also be compared with literature values, for additional context.

Interpretive Component

Though invasive species like the zebra mussel are of substantial public interest in the Great Lakes region, less conspicuous aquatic invaders such as the spiny water flea

(*Bythotrephes*) often escape attention. Because *Bythotrephes* can affect multiple aspects of inland lake ecology and because human activities represent a significant vector for *Bythotrephes* dispersal, it is important that the public be knowledgeable about current *Bythotrephes* distributions, effects of *Bythotrephes* invasions on aquatic ecosystems, and potential invasion pathways. Activities that involve the transport of water, bait or equipment between invaded and un-invaded water bodies greatly influence *Bythotrephes* translocation. Anglers, boaters, and researchers all engage in activities that could result in new lakes being colonized by *Bythotrephes.* These groups are active at all Great Lakes parks and represent our target audiences.

Traditional interpretive tools and the skills of Great Lakes area educators will be used to relay results of the proposed research to this audience. Park interpretive staff, including the PIRO educational specialist, will help develop a multi-park educational pamphlet on *Bythotrephes* for boaters and anglers and develop lesson plans for local schools. These efforts will highlight and build upon current outreach being conducted at VOYA and by the state Sea Grant agencies. A message consistent with the Stop Aquatic Hitchhikers! campaign will be stressed. The education coordinator for the Great Lakes Research and Education Center (GLREC) will provide assistance and guidance in developing educational tools and methods. GLREC will also share results of the proposed research through a posting on the Center's website, and an article in the Center's newsletter circulated to Great Lakes Network park resource managers, interpretive staff and local teachers. The GLREC will help design educational activities with teachers. Research results may, for example, be incorporated into the Great Lakes Traveling Trunk. GLREC has also volunteered in-kind monetary contributions for construction of interpretive signs. Finally, park resource management staff involved in this project will regularly share results of the project with other divisions.

Success of this communication effort may be evaluated using formal or informal visitor surveys at locations where information is provided (boat ramps, visitor centers, etc.), and informal student quizzing following educator lessons. Questions should be designed to assess public and student understanding of key issues like what *Bythotrephes* is and how human activities relate to its invasion of local waters. Numbers of teachers who become involved in projects related to the proposed research could also be used to evaluate the success of this outreach effort.

Tasks, Organization, and Schedule

This project will begin during early spring of FY 2008. Resource Managers at each park will address environmental planning requirements, and the NPS Midwest Region aquatic ecologist and fishery biologist will work with Michigan Technological University (MTU) and the Great Lakes-Northern Forests CESU to develop the necessary cooperative and task agreements. Field planning for the FY 2008 field season (i.e., the *Bythotrephes* detection surveys) will begin during spring of 2008, and will be a joint effort involving park-based resource staff at ISRO, PIRO, SLBE, and VOYA, NPS Midwest Region staff, and MTU cooperators, including Dr. Charles Kerfoot, a Ph.D. student, and an undergraduate research assistant. The 2008 survey itself will take place from May-September. During fall and winter of FY 2009, MTU cooperators will analyze samples

from the 2008 field season for presence or absence of *Bythotrephes* spines. Field sampling will be conducted for native zooplankton, fish, and water quality at VOYA during the open water seasons of FY 2008 and FY 2009, and at PIRO during the open water seasons of FY 2009 and FY 2010. MTU cooperators will lead the zooplankton collection efforts, and NPS cooperators will lead the fish and water quality sampling efforts. Laboratory analyses for these samples will be conducted during the fall and winter of FY 2009 and throughout FY 2010, and data analysis and reporting efforts will increase through the summer of FY 2010. A final project report, integrating all aspects of the study, is anticipated by December 15 of FY 2011 and will be developed jointly by MTU and NPS project leads. An MTU doctoral dissertation will follow.

Table 2. Timeline of key project tasks for each fiscal year. "Win", "Spr", and "Sum" denote seasons of Winter, Spring, and Summer.

	FY 2008				**FY 2009**				**FY 2010**				**FY 2011**
Task	Fall	Win	Spr	Sum	Fall	Win	Spr	Sum	Fall	Win	Spr	Sum	Fall
Environmental Planning		X											
CESU Task Agreement			X										
Field Season Planning			X				X				X		
Annual Research Permit Apps			X				X				X		
Invasion Status Survey				X									
PIRO Intensive Studies								X			X		
VOYA Intensive Studies				X				X					
Laboratory Analysis					X	X	X	X	X	X	X		
Data Analysis and Reporting									X	X	X	X	
Investigator Annual Report													
Draft Final Report											X	X	
Final Report												X	X

Deliverables and other Reporting Requirements

Final Completion Reports

A draft report, including detailed taxonomic data and summary analyses, will be circulated for peer review by September 31, 2010. A final project report will be submitted electronically to the Biological Resources Management Division by December 15, 2011. The report will be developed following the formatting guidelines of the Water Resources Division Technical Report Series, and, pending peer review and approval, will be published as such.

Deliverables by Third Parties

The MTU cooperators will work with NPS biologists in most aspects of the project. MTU cooperators will take the lead in the sediment and zooplankton sampling and analysis efforts, and will work with NPS staff on related analysis and reporting. They will provide electronic copies of raw data to the NPS by the final report deadline of December 15, 2011. Additionally, copies of any peer-reviewed journal articles resulting

from this work will be supplied to each Great Lakes area parks and the Water Resources Division.

Annual Accomplishment Reports

An annual accomplishment report, consisting of a stand-alone abstract less than 300 words in length, will be submitted to the Water Resources Division project coordinator by October 30th of each fiscal year. The abstract will be entered in the "Accomplishments" field of the project's PMIS record.

Quality Assurance, Quality Control, and Data Quality Objectives

Field Quality Assurance

Project managers from MTU and NPS will provide training in zooplankton collection methods and ensure (in most cases, through actual field assistance) that zooplankton are sampled safely and correctly. If needed, project managers will also provide a simple, step-by-step protocol for zooplankton sampling, detailed field datasheets, and labels for sample containers. To prevent cross-contamination or inadvertent transfer of invasive species, zooplankton sampling staff will ensure that zooplankton nets are exchanged or allowed to dry between lakes, following protocols detailed by the GLKN (Elias 2005) and in the VOYA interim spiny water flea prevention measures for interior lakes (R. Maki, personal communication). Briefly, decontamination procedures will include completely drying all nets, lines, and sampling equipment for at least 12 hours before introducing them to a new lake, and/or fully immersing them in water (140° F, 60° C) for at least one minute. In remote locations, before moving from one lake to the next, field staff will remove and rinse all visible organic material from boats/canoes, paddles/oars, boots, and all sampling equipment. Before entering the next lake, field staff will rinse the canoe/boat and all equipment with water from that lake, taking care to prevent rinse water from running directly into the lake and using a brush to clean difficult to reach surfaces.

Other Quality Assurance

Representativeness – Sediment samples from 10 sites in each lake will provide an adequate indication of whether or not *Bythotrephes* has invaded. Hall and Yan (1997) noted that "collection of just a few sediment samples at any time of the year may be adequate to establish the presence or absence of *B. cederstroemi* in lakes". Given this assertion, the positive identification of caudal processes from 10 Ekman dredge samples in an invaded Minnesota inland lake (Forman and Whiteside 2000), and the success of the method in detecting *Bythotrephes* spines in the two PIRO lakes (Loope 2007), we expect that 10 sediment samples per lake will suffice in the proposed study.

Zooplankton samples from 10 sites in each lake are assumed to adequately represent the resident zooplankton community on the sampling date. Although confirming this assumption is beyond the scope of this and most zooplankton studies (Blomqvist 2001), our approach will undoubtedly provide a more representative sample than the typical

approach (i.e., a single tow site over the deep hole), and appears more than adequate for Canadian Shield lakes (Arnott et al. 1998). However, as an additional quality assurance measure we will collect zooplankton from up to 20 sites in one of the two PIRO lakes during the mid-summer sampling. If time allows, these samples will be identified and used to evaluate the adequacy of the typical sample number per lake (10) in a manner similar to that described for Plastic Lake, Ontario (Arnott et al. 1998).

A single integrated surface water quality sample in each lake is expected to be representative of surface water quality conditions. Collection protocols for water samples will follow those outlined in the GLKN inland lakes monitoring plan (Axler et al. 2007) and the VOYA large lake monitoring methods (R. Maki, VOYA, personal communication).

Taxonomic quality assurance – The taxonomic work will be conducted by a doctoral candidate overseen by an MTU professor with many years of zooplankton experience and a solid working knowledge of the fauna of northern forest lakes. Several taxonomic quality assurance measures will be taken during the analyses. For several samples, up to 10 subsamples (aliquots) will be counted and identified, in order to ensure that three aliquots are sufficient to capture most of the species present in the VOYA samples. Counting will continue until an asymptote in species number is achieved. Additionally, the taxonomist will send samples or questionable specimens to other taxonomists for comparison, as needed, and will perform quality assurance for electronic data entry prior to submitting it to the NPS.

Budget-Cost

Table 3. Budget for FY 2008-2010, by category and item, with matching funds noted, where applicable.

Category	Item	FY 2008	FY 2009	FY 2010	Total	Matching
	MTU Graduate Student	$18,500	$12,703	$19,627	$50,830	$0
	MTU Undergraduate Student	$7,800	$8,034	$8,275	$24,109	$0
Personnel	MTU Fringe	$2,083	$1,599	$1,717	$5,399	$0
	MTU Faculty	$2,297	$2,412		$4,709	
	MTU Tuition	$12,810	$7,334	$14,146	$34,290	$0
	NPS Permanent Biologists	$0	$0	$0	$0	$43,710
Analytical	Water Quality Analysis	$0	$1,500	$1,500	$3,000	$0
Equipment	Miscellaneous	$0	$0	$0	$0	$7,250
Supplies	Supplies, publications, etc.	$5,400	$3,950	$3,450	$12,800	$7,300
Travel	MTU	$3,404	$5,771	$5,771	$14,946	$0
	NPS	$2,000	$4,500	$4,500	$11,000	$0
SubTotal		$54,294	$47,803	$58,986	$161,083	$58,260
Overhead	(CESU, 17.5%)	$9,501	$8,366	$10,323	$28,190	$9,587
Total		$63,795	$56,169	$69,309	$189,273	$67,847

The proposed project involves several parks and addresses an issue of regional concern. It draws in-kind support from individual parks as well as the Midwest Regional office and the Great Lakes Research and Education Center (GLREC). Natural Resource staff from ISRO, PIRO, SLBE, and VOYA will assist with on-site visits by researchers. Equipment, supplies, and logistical support will be provided by participating parks and Michigan Technological Univeresity as itemized as follows:

Personnel services: MWRO GS-11 Aquatic Ecologist, 3 yrs @ $4,200/yr=$12,600; MWRO GS-11 Fisheries Biologist, 3 years @ $5,100/yr=$15,300; PIRO GS-09 Aquatic Ecologist 3 yrs @ $2520/yr=$7,560, Great Lakes park unit staff GS-09, 120 hrs @ $25/hr = $3,000, GLREC Education Coordinator 5 weeks @ $1,050/week = $5,250, and VOYA aquatic ecologist (unquantified). Michigan Technological University will support one semester of the graduate student's salary and fringe ($6,352+556) and tuition ($6,138). Total personnel = $56,756.

Equipment and supplies (use provided by ISRO, PIRO, SLBE, and Michigan Technological University): water quality sonde and datalogger= $3,000; plankton net=$259; standard Ekman dredge=$299; brass sieve=$41.50; use of microscopes and digital camera = $5,000; use of boat at PIRO=$2000; use of boat at ISRO = $1,275; use of boat at VOYA = $638; use of boat at SLBE = $1,020; GLREC educational media development $1,000. Total equipment and supplies = $14,533.

In-kind support for this project thus totals over $71,000.

References

American Public Health Association. 2005. Standard Methods for the Examination of Water and Wastewater, 21st edition. Port City Press, Baltimore.

Arnott, S., J. Magnuson, and N. Yan. 1998. Crustacean zooplankton species richness: single-and multiple-year estimates. Canadian Journal of Fisheries and Aquatic Sciences 55:1573-1582.

Avois, C., P. Legendre, S. Masson, and B. Pinel-Alloul. 2000. Is the sampling strategy interfering with the study of spatial variability of zooplankton communities? Canadian Journal of Fisheries and Aquatic Sciences 57:1940-1956.

Axler, R., E. Ruzycki, and J. Elias. 2007. Field measurements and water sample collection, version 1.0. Standard Operating Procedure #6 in Inland Lakes Monitoring Plan, Great Lakes Inventory and Monitoring Network, Ashland, Wisconsin.

Balcer, M. D., N. L. Korda, and S. I. Dodson. 1984. Zooplankton of the Great Lakes: a guide to the identification and ecology of the common Crustacean species. University of Wisconsin Press, Madison, Wisconsin.

Blomqvist, P. 2001. A proposed standard method for composite sampling of water chemistry and plankton in small lakes. Environmental and Ecological Statistics 8:121-134.

Bollens, S., J. Cordell, S. Avent, and R. Hoof. 2002. Zooplankton invasions: a brief review, plus two case studies from the northeast Pacific Ocean. Hydrobiologia 480:87-110.

Bottrell, H. H., A. Duncan, Z. M. Gliwicz, E. Grygierek, A. Herzig, A. Hillbricht, H. Ilkowska, H. Kurasawa, P. Larsson, and T. Weglenska. 1976. A review of some problems in zooplankton production studies. Norwegian Journal of Zoology 24:419-456.

Compton, J., and W. Kerfoot. 2004. Colonizing inland lakes: consequences of YOY fish ingesting the spiny cladoceran (*Bythotrephes cederstroemi*). Journal of Great Lakes Research 30(Supplement 1):315-326.

Coulas, R., H. MacIsaac, and W. Dunlop. 1998. Selective predation on an introduced zooplankter (*Bythotrephes cederstroemi*) by lake herring (*Coregonus artedii*) in Harp Lake, Ontario. Freshwater Biology 40:343-355.

Cullis, K., and G. Johnson. 1988. First evidence of the cladoceran *Bythotrephes cederstroemii* Shoedler in Lake Superior. Journal of Great Lakes Research 14:524-525.

Dumont, H. J., I. Van de Velde, and S. Dumont. 1975. The dry weight estimate of biomass in a selection of Cladocera, Copepoda and Rotifera from the plankton, periphyton and benthos of continental waters. Oecologia 19:75-97.

Elias, J. 2005. Decontamination of equipment between water bodies, version 1.0. Standard Operating Procedure #5, Inland Lakes Monitoring Protocol, National Park Service Great Lakes Inventory and Monitoring Network, Ashland, Wisconsin.

Forman, M. R., and M. Whiteside. 2000. Occurrence of *Bythotrephes cederstroemi* in inland lakes in northeastern Minnesota as indicated from sediment records. Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie 27:1552-1555.

Hall, R., and N. Yan. 1997. Comparing annual population growth estimates of the exotic invader *Bythotrephes* by using sediment and plankton records. Limnology and Oceanography 42:112-120.

Hoffman, J., M. Smith, and J. Lehman. 2001. Perch or plankton: top-down control of *Daphnia* by yellow perch (*Perca flavescens*) or *Bythotrephes cederstroemi* in an inland lake? Freshwater Biology 46:759-775.

Hubbs, C., and K. Lagler. 1949. Fishes of Isle Royale, Lake Superior, Michigan. Papers of the Michigan Academy of Science, Arts, and Letters 33 (for 1947):73-133.

Jarnigan, S. 1998. Direct and indirect estimates of death rates and predator-mediated dispersal of *Bythotrephes cederstroemi*. Michigan Technological University, Houghton, Michigan.

Jarnagin, S., W. Kerfoot, and B. Swan. 2004. Zooplankton life cycles: direct documentation of pelagic births and deaths relative to diapausing egg production. Limnology and Oceanography 49:1317-1332.

Jarnagin, S., B. Swan, and W. Kerfoot. 2000. Fish as vectors in the dispersal of *Bythotrephes cederstroemi*: diapausing eggs survive passage through the gut. Freshwater Biology 43:579-589.

Kallemeyn, L. 2000. A comparison of fish communities from 32 inland lakes in Isle Royale National Park, 1929 and 1995-1997. Biological Science Report 0004, U.S. Geological Survey, Columbia Environmental Research Center and International Falls Biological Station, International Falls, Minnesota.

Kamke, K. 1987. Limnology in four lakes in Pictured Rocks National Lakeshore. Master of Science Thesis. University of Wisconsin-Stevens Point, Stevens Point, Wisconsin.

Lafrancois, B. M., and J. Glase. 2005. Aquatic studies in national parks of the upper Great Lakes states: past efforts and future directions. Water Resources Division Technical Report, NPS/NRWRD/NRTR-2005/334, Denver, CO.

Lehman, J., and D. Branstrator. 1995. A model for growth, development and diet selection by the invertebrate predator *Bythotrephes cederstroemi*. Journal of Great Lakes Research 21:610-619.

Lehman, J., and C. Cáceres. 1993. Food-web responses to species invasion by a predatory invertebrate: *Bythotrephes* in Lake Michigan. Limnology and Oceanography 38:879-891.

Limnetics, Inc. 1970. A preliminary survey of the environmental quality of the Pictured Rocks National Lakeshore and Recreational Area, Alger County, Michigan. Limnetics, Inc., Environmental Research and Engineering, Milwaukee, Wisconsin.

Loope, L., A. L. Hales, and A. Lucas. 2007. Detection of *Bythotrephes longimanus* in lake sediments. National Park Service, Pictured Rocks National Lakeshore, Munising, Michigan.

MacIsaac, H., H. Ketelaars, I. Grigorovich, C. Ramcharan, and N. Yan. 2000. Modeling *Bythotrephes longimanus* in the Great Lakes basin based on its European distribution. Archiv für Hydrobiologie 149:1-21.

Makarewicz, J., P. Bertram, and T. Lewis. 1998. Changes in phytoplankton size-class abundance and species composition coinciding with changes in water chemistry and zooplankton community structure of Lake Michigan, 1983-92. Journal of Great Lakes Research 24:637-657.

McCauley, E. 1984. The estimation of the abundance and biomass of zooplankton in samples. *In* A manual of methods for the assessment of secondary productivity in freshwaters. Blackwell Scientific Publishers, Oxford.

Mills, E., J. Leach, J. Carlton, and C. Secor. 1993. Exotic species in the Great Lakes: a history of biotic crises and anthropogenic introductions. Journal of Great Lakes Research 19:1-54.

Nichols, S., E. Crawford, J. Amberg, J. Allen, G. Black, and G. Kennedy. 2001. Status of freshwater unionid populations of Isle Royale National Park, 1999-2000. U.S. Geological Survey, Great Lakes Science Center, Ann Arbor, MI.

Pothoven, S., G. Fahnenstiel, and H. Vanderploeg. 2001. Population dynamics of *Bythotrephes cederstroemii* in south-east Lake Michigan 1995-1998. Freshwater Biology 46:1491-1501.

Pothoven, S., G. Fahnenstiel, and H. Vanderploeg. 2003. Population characteristics of *Bythotrephes* in Lake Michigan. Journal of Great Lakes Research 29:145-156.

Reynolds, W. 2006. Results of a survey for Bythotrephes longimanus at Isle Royale National Park. Undergraduate Research Opportunity Final Report, University of Minnesota-Duluth, Duluth, MN.

Ricciardi, A. 2001. Facilitative interactions among aquatic invaders: is an "invasional meltdown" occurring in the Great Lakes? Canadian Journal of Fisheries and Aquatic Sciences 58:2513-2525.

Sandgren, C., and J. Lehman. 1990. Response of chlorophyll-*a*, phytoplankton, and microzooplankton to the invasion of Lake Michigan by *Bythotrephes*. Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie 24:386-392.

Schulz, K., and P. Yurista. 1999. Implications of an invertebrate predator's (*Bythotrephes cederstroemi*) atypical effects on a pelagic zooplankton community. Hydrobiologia 380:179-193.

Smith, D. G. 2001. Pennak's Freshwater Invertebrates of the United States: Porifera to Crustacea, 4th edition. John Wiley & Sons, Inc., New York.

Strecker, A., S. Arnott, N. Yan, and R. Girard. 2006. Variation in the response of crustacean zooplankton species richness and composition to the invasive predator *Bythotrephes longimanus*. Canadian Journal of Fisheries and Aquatic Sciences 63:2126-2136.

Therriault, T., I. Grigorovich, M. Cristescu, H. Ketelaars, M. Viljanen, D. Heath, and H. MacIsaac. 2002. Taxonomic resolution of the genus *Bythotrephes* Leydig using molecular markers and re-evaluation of its global distribution, with notes on factors affecting dispersal, establishment and abundance. Diversity and Distribution 8:67-84.

Thorp, J. H., and A. P. Covich. 1991. Ecology and classification of North American freshwater invertebrates, San Diego, California.

Vanderploeg, H., T. Nalepa, D. Jude, E. Mills, K. Holeck, J. Liebig, I. Grigorovich, and H. Ojaveer. 2002. Dispersal and emerging ecological impacts of Ponto-Caspian species in the Laurentian Great Lakes. Canadian Journal of Fisheries and Aquatic Sciences 59:1209-1228.

Visman, V., D. McQueen, and E. Demers. 1994. Zooplankton spatial patterns in two lakes with contrasting fish community structure. Hydrobiologia 284:177-191.

Wahlström, E., and E. Westman. 1999. Planktivory by the predacious cladoceran *Bythotrephes longimanus*: effects on zooplankton size structure and abundance. Canadian Journal of Fisheries and Aquatic Sciences 56:1865-1872.

Wetzel, R., editor. 2001. Limnology: Lake and River Ecosystems, Third Edition. Academic Press, San Diego.

Wetzel, R., and G. Likens. 2000. Limnological Analyses, Third edition. Springer-Verlag, New York.

Whitman, R., B. Davis, and M. Goodrich. 2002. Study of the application of limnetic zooplankton as a bioassessment tool for lakes of Sleeping Bear Dunes National Lakeshore. U.S. Geological Survey, Lake Michigan Ecological Research Station, Porter, Indiana.

Yan, N., A. Blukacz, W. Sprules, P. Kindy, D. Hackett, R. Girard, and B. Clark. 2001. Changes in zooplankton and the phenology of the spiny water flea, *Bythotrephes*, following its invasion of Harp Lake, Ontario, Canada. Canadian Journal of Fisheries and Aquatic Sciences 58:2341-2350.

Yan, N., and T. Pawson. 1997. Changes in the crustacean zooplankton community of Harp Lake, Canada, following invasion by *Bythotrephes cederstromi*. Freshwater Biology 37:409-425.

Yan, N., and T. Pawson. 1998. Seasonal variation in the size and abundance of the invading *Bythotrephes* in Harp Lake, Ontario, Canada. Hydrobiologia 361:157-168.

Yurista, P. 1997. *Bythotrephes cederstroemi* diapausing egg distribution and abundance in Lake Michigan and the environmental cues for breaking diapause. Journal of Great Lakes Research 23:202-209.