State of Michigan's

Status and Strategy for Spiny Waterflea Management

Scope

The invasive spiny waterflea (*Bythotrephes longimanus*), native to Northern Europe and Asia has impacted lakes throughout the Great Lakes Basin. The goals of this document are to:

- Summarize current level of understanding on the biology and ecology of the spiny waterflea.
- Summarize current management options for the spiny waterflea in Michigan.
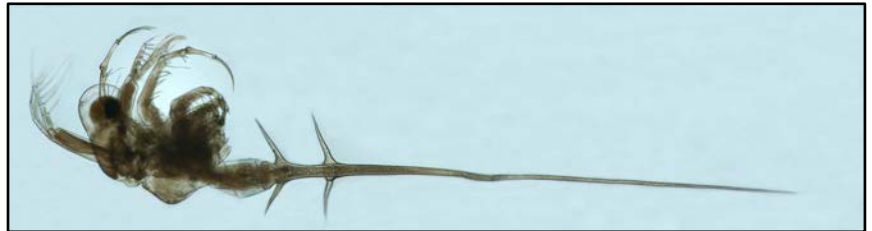- Identify possible future directions of spiny waterflea management in Michigan.

Biology and Ecology

I. Identification

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The spiny waterflea, formerly known as *Bythotrephes cederstroemii*, is a large planktivore of the suborder Cladocera and can have dramatic effects on zooplankton communities by altering the trophic structure in invaded waters (Yan et al. 2002). They can grow to lengths of 15 mm with females growing larger than males. The spiny waterflea has a large compound eye and well-developed abdomen with an extremely long tail twice the length of the body (Branstartor 2005, Kelly 2013); the tail has three to four spines and lacks a terminal loop. Lack of a terminal loop distinguishes the spiny waterflea from *Cercopagis pengoi*, another invasive species in the Great Lakes basin. Fully developed parthenogenetic individuals have three barbs while fully developed sexually reproducing individuals have four barbs. Adult females also have a distinctive brood pouch on their back (Liebig 2014).

II. Life History

Spiny waterfleas go through three instar phases and can reproduce both parthenogenetically and sexually, switching from parthenogenesis during the summer to gametogenesis during the fall. The resting eggs produced during sexual reproduction are thought to be essential for the species' survival since the presence of its planktonic stage has never been reported during the winter months (Rivier 1998, Brown 2008). Resting eggs are released from the mother's brood pouch in autumn where they settle into the sediment and hatch the following spring. Hatching is triggered by water temperature, pH, and salinity; eggs can remain dormant for several months. Some summer production and hatching of previously established resting eggs has been reported (Brown 2008). Spiny waterflea populations peak in

late summer or fall before disappearing during the winter months (Pothoven *et al.* 2012). Individual size and fitness is typically positively correlated with population densities, but can be altered if conditions are unfavorable or predation is high. The spiny waterflea requires high quantities of food due to constant swimming and inefficient feeding, losing 38% of its prey (Yurista and Schulz 1995, Yurista et al. 2010, Kim 2012). As a result, prey densities play a crucial role in spiny waterflea abundance and fitness and spring prey abundances may be a prime determinant of population size (Young et al. 2011).

III. Diet

The spiny waterflea feeds on zooplankton such as Daphnia and copepods, along with cladocerans, rotifers, and phytoplankton. The spiny waterflea targets herbivorous members of the zooplankton and can cause zooplankton composition shifts in favor of predatory or omnivorous zooplankton (Rennie 2011). However, Cladocerans have been found to be the preferred prey items with copepods and rotifers being used as an alternative or secondary source of prey (Schultz and Yurista 1999).

IV. Habitat

The spiny waterflea prefers large, deep, cold, oligotrophic to mesotrophic lakes where they occupy the epilimnion, but have also been documented to occupy brackish waters. Egg carrying individuals will seek shelter from predators in the epilimnetic strata between the bottom of the photic zone and the top of the hypolimnion during the day (Kerfoot et al. 2011). The spiny waterflea has a narrow temperature range (14-26 C°) in comparison to native Cladocerans and is poorly equipped to accommodate temperature fluctuations above its maximum water temperature. Consequently, high summer water temperatures can lead to a late summer population crash (Garton et al. 1990, McMahon 2002). The spiny waterflea favors near neutral pH, negative correlations were seen under basic or acidic conditions with effects starting at approximately pH 9 and 5 respectively (Brown 2008). Salinity tolerance ranges from 0.4% to 4%. Temperature is the main determinant of the spiny waterflea's range (Garton et al. 1990).

V. Effects from the Spiny Waterflea

The spiny waterflea was first documented in North America in the Laurentian Great Lakes in the early 1800's and has since spread to over 130 lakes within North America (Weisz and Yan 2010, Brown et al. 2012). This demonstrates the ability to exploit a number of habitats as well as overcome land barriers. Following the introduction of the spiny waterflea, dramatic reductions in the populations of many zooplankton species were observed along with a reduction in overall species richness (Barbiero and Tuchman 2005). The largest reduction of species richness is observed within the Cladocerans, the preferred prey of the spiny waterflea (Strecker et al. 2006). The effects on overall species richness can be attributed to both direct

and indirect effects. Competitive release may allow other plankton species populations to increase (Wahlstrom and Westman 1999) while other studies have found that feeding activities of the spiny waterflea may be directly correlated with a reduction in zooplankton populations (Yan et al. 2002). Consumption rates of the spiny waterflea often equal or exceed the productivity of its planktonic prey (Lehman and Caceres 1993, Kelly et al. 2013). The spiny waterflea can also alter trophic status by competing for food and replacing other species as a food source. These effects often cascade through multiple trophic levels, affecting a wide range of organisms. In some systems it has become the preferred prey for zooplanktivorous species such as the lake herring (*Coregonus artedi*) and yellow perch (*Perca flavescens*) (Manca et al. 2007). The full trophic effects of the spiny waterflea varie between systems and long-term effects are unclear, but the overall zooplankton biomass is generally decreased. This limits food for planktivorous fish, especially younger fish, which may not feed on spiny waterfleas due to their large caudal spine. As a result, spiny waterflea populations remain high while their planktonic prey continue to decline.

Current Status and distribution in Michigan

The spiny waterflea was first found in Lake Ontario in 1982 and by 1987 had become established in all five Great Lakes. Today it inhabits all 5 Great Lakes and ~ 100 inland waterbodies. Densities are low in Lake Ontario and Lake Michigan, moderate in Lakes Huron and Superior and high in Lake Erie, especially in the central basin (Berg and Garton 1986, Branstrator and Lehman 1996, Figure 1). Lakes with high levels of recreational use have been affected the most, experiencing the most exposure to boats and equipment that may serve as a transport vector. The spiny waterflea has had trouble becoming established in small or shallow lakes throughout southern Michigan due to warmer water temperature but these areas should still be considered at risk when assessing future invasion sites. The spiny waterflea has been reported in Arenac, Allegan, Benzie, Berrien, Gogebic, Huron, Keweenaw, Mackinac, Mason, Presque Isle, Schoolcraft, St. Clair, Oceana, and Ottawa counties since 2012 (MISIN 2014, Figure 2). According to the United States Geological Survey (USGS), spiny waterfleas have also been found in Long Lake, Beaver Lake, Little Trout Bay, Dead River Storage Basin, Forestville Basin, Lac La Belle, Michigamme Reservoir, and Peavy Pond (Figure 2).

Management of the Spiny Waterflea

Past experience with aquatic invasive species such as sea lamprey and zebra mussel have shown that once a reproducing population becomes established, management becomes difficult, lengthy, and expensive. With this in mind, Michigan's main focus should be preventing the introduction and spread of aquatic invasive species. This is especially true with species such as the spiny waterflea for which effective management has not yet been developed. Given the spiny waterflea's ability to effectively overcome land barriers (Brown et al. 2012) and past success invading inland bodies of water, developing and implementing an effective prevention plan should be a top priority.

I. Prevention

Once a spiny waterflea population becomes established, there is currently no way to effectively remove them therefore prevention should be the number one priority. The best time of year to detect spiny fleas would be the end of June. Simple 30-cm plankton nets will work for detection. At typical summer densities, multiple hauls will likely be required for detection. Unfortunately, until there are several million organisms in a water body, they cannot be caught with plankton nets making this a poor method for early detection. Research is under way to develop molecular (eDNA) methods for early detection, but results are currently unavailable.

The spiny waterflea was likely introduced to the Great Lakes through repeated ballast water exchange from commercial shipping (Ricciardi and Rasmussen 1998). Recreational lake users have also played a role in spreading the spiny waterflea, which can become entangled in fishing gear and transported on or in recreational watercrafts. The baitfish used by anglers can also spread spiny waterfleas, whose resting eggs remain viable after passing through the digestive tract of most fish (Kerfoot et al. 2011). Targeting commercial shipping and recreational lake users in combination with public education could prevent the spread of the spiny waterflea. To accomplish this, the following guildelines should be promoted:

- Wash boats with hot (>60 C$^\circ$) water and drain bilges, live wells, etc. before transporting between locations.

- Quarantine baitfish in live wells for 24 hours (defecation period) before use.

- Encourage on site dumping of live well and baitfish water.

- Increase public awareness and education about harmful effects and spread of the spiny waterflea.

- Develop a predictive model for spiny waterflea spread to identify high-risk areas.

II. Management

Because it is so difficult to control or remove the spiny waterflea once established, it is important to prevent initial establishment. However, long-term establishment is not guaranteed even when initial colonization is great. Due to the temperature sensitivity of the species, control of propagule pressure is imperative for the prevention of re-establishment, especially when summer water temperatures in shallow, warm lakes are capable of decimating a population (Yan et al. 2011). Therefore, by preventing

repeated exposure, it may be possible to stop initial populations from reaching sustainable levels. Some biological and chemical controls have been suggested, but the efficacy and side effects of these methods can be called into question. Predation (bio-control) is a common biological control of some invasive species, but studies have shown that predation levels are too low to control spiny waterfleas, even when predator densities are high. Chemical controls could eliminate spiny waterfleas, but the chemicals required to kill them would also kill native and non-target species without a guarantee that the system would not be invaded again. Physical controls such as skimming are unlikely to have success due to the size and distribution of the spiny waterflea.

A. Biological

The spiny waterflea has been incorporated into the diet of several Michigan fish species and predation by these fish may be able to limit their populations. Fish consumption exceeded waterflea production in many surveys, but after high waterflea consumption, a decline in spiny waterflea population did not occur; demonstrating little control (Keeler 2014). An increase in predator densities could be attempted and quickly accomplished through strategic stocking of affected lakes, but with the lack of results thus far and the possible side effects of altering these fish communities, spiny waterflea control via fish predation merits more research and does not appear to be a viable management option at this time.

B. Chemical

Past efforts in managing aquatic invasive species have proven that chemical controls are effective, but chemical methods are yet to be developed for the spiny waterflea. Treatment with chlorine is one suggested chemical control. Chlorine is highly toxic to aquatic organisms; just 0.29-ppm is capable of killing trout and 0.82-ppm killing sunfish (Lindgren 2014). Unfortunately, chlorine treatments would almost certainly kill non-target organisms and could do more harm than good if administered prematurely. Methods to effectively administer chemicals while reducing non-target kill or alternative chemicals need to be developed and evaluated before chemical treatment can become a reliable method for control.

Future Directions for Michigan and Spiny Flea Management

Safe and effective treatments to remove existing spiny waterflea populations need to be developed, but, as with any invasive species management plan, prevention is the most cost effective method and should be top priority. Considering the current lack of treatment options, prevention becomes even more important for the spiny waterflea. A predictive model must be developed using distribution data from both the native and invaded range. This model would then be used to identify high, moderate, and low-risk areas as well as potential invasion corridors to ensure resources are distributed as effectively as possible. Increasing watercraft inspections and decontaminations, bait

trade regulations, and public education also have the potential to significantly slow or eliminate the spread of both new and established invasive species and should be viewed as a crucial component when developing future management programs. If an effective plan can be developed for the spiny waterflea it would provide Michigan with invaluable experience and data when attempting to deal with future and existing planktonic invaders.
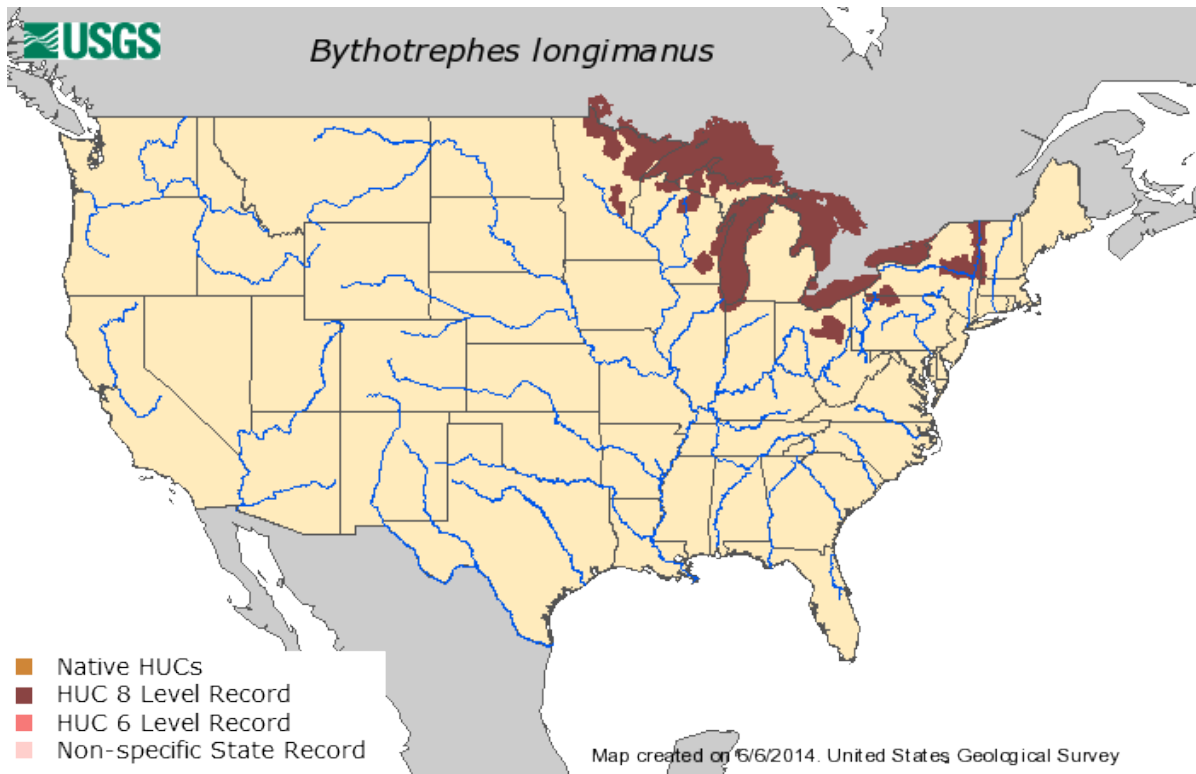
Figure 1. Distribution of the spiny waterflea (Bythotrephes longimanus) in the United States (Liebig et al. 2014). Accessed June 11, 2014.
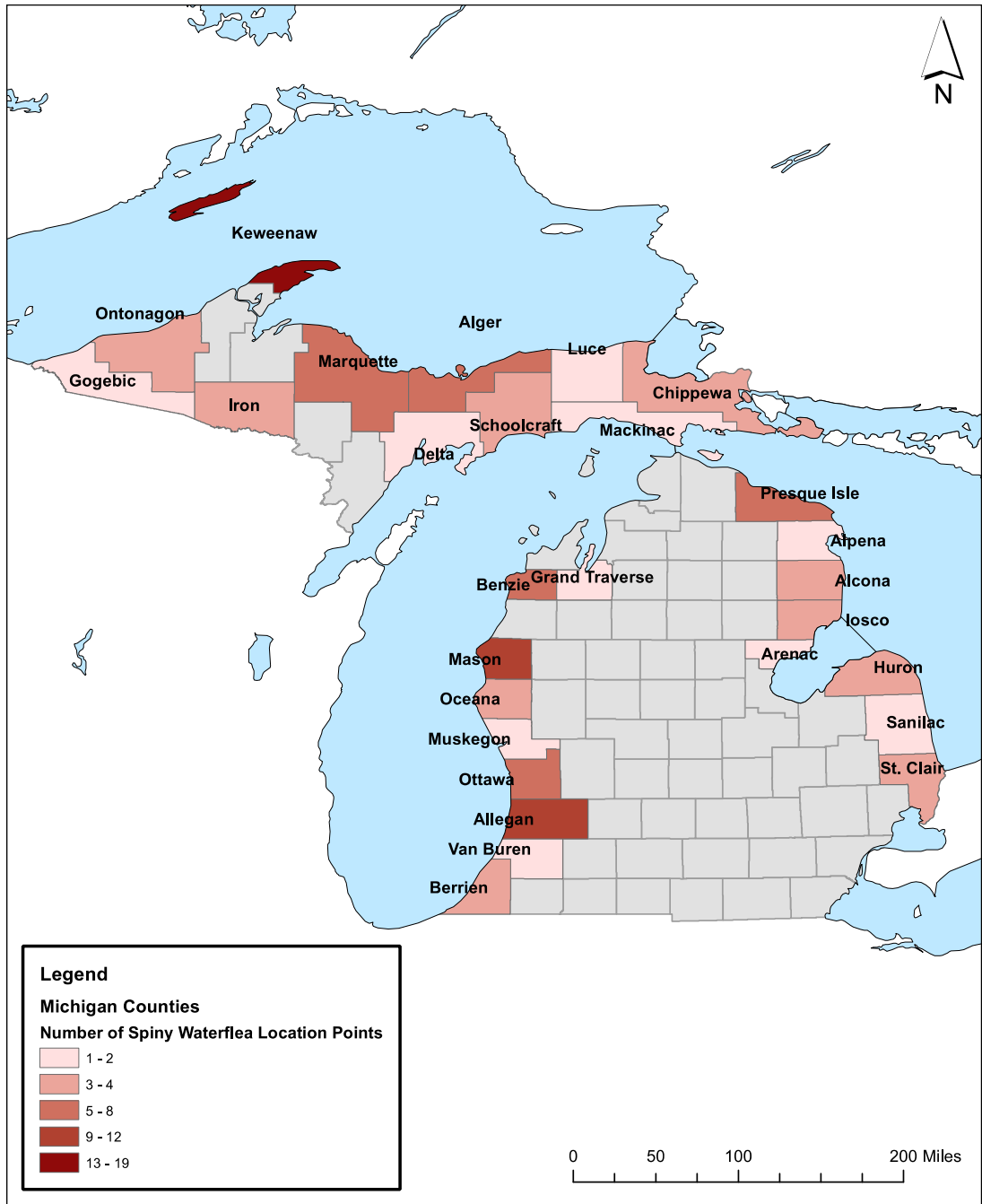
Figure 2. Number of unique coordinate location points within Michigan counties at which grass carp were detected. This data is according to the United States Geological Survey (USGS), Midwest Invasive Species Information Network (MISIN) and Biodiversity Information Serving Our Nation (BISON).

Literature Cited

Barbiero, R.P. and M.L. Tuchman. 2005. Changes in the crustacean communities of Lake Michigan, Huron, and Erie following the invasion of the predatory cladoceran *Bythotrephes longimanus*. Canadian Journal of Fisheries and Aquatic Sciences. 61:2111-2125.

Berg, D.J., and D.W. Garton. 1988. Seasonal abundance of the exotic predatory cladoceran, *Bythotrephes cederstroemi*, in western Lake Erie. Journal of Great Lakes Research. 14(4):479-488.

Branstrator, D.K., and J.T. Lehman. 1996. Evidence for predation by young-of-the-year alewife and bloater chub on *Bythotrephes cederstroemi* in Lake Michigan. Journal of Great Lakes Research. 22:917-924.

Brown, M.E. 2008. Nature and nuture in dormancy: dissolved oxygen, pH, and maternal investment impact *Bythotrephes longimanus* resting egg emergence and neonate condition. Canadian Journal of Fisheries and Aquatic Sciences. 65(8):1692-1703.

Brown, M.E., D.K. Branstrator, and L.J. Shannon. 2012. Population regulation of the spiny water flea (*Bythotrephes longimanus*) in a reservoir: Implications for invasion. Limnology and Oceanography. 57(1):251-271.

Foster, S.E. and G.W. Sprules. 2010. Effects of *Bythotrephes* on the trophic position of native macroinvertebrates. Canadian Journal of Fisheries and Aquatic Sciences. 67(1):58-68.

Garton, D.W., D.J. Berg, and R.J. Fletcher. 1990. Thermal Tolerances of the Predatory Cladocerans *Bythotrephes cederstroemi* and *Leptodora kindti*: Relationship to Seasonal Abundance in Western Lake Erie. Canadian Journal of Fisheries and Aquatic Sciences. 47(4): 731-738.

Keeler, K. 2014. Determining the role of fish planktivory on spiny water flea (*Bythotrephes longimanus*) production in the upper great lakes. University of Michigan. 1:1-21.

Kerfoot, C.W., F. Yousef, M.M. Hobmeier, R.P. Maki, S.T. Jarnagin, and J.H. Churchill. 2011. Temperature, recreational fishing and diapause egg connections: dispersal of spiny water fleas (*Bythotrephes longimanus*). Biology Invasions. 13:2513-2531.

Kim, N. and D.N. Yan. 2013. Food limitation impacts life history of the predatory cladoceran *Bythrtrephes longimanus*, an invader to North America. Hydrobiologia. 715:213-224.

Lehman, J.T. and C.E. Caceres. 1993. Food-web response to species invasion by a predatory invertebrate: *Bythotrephes* in Lake Michigan. Limnology and Oceanography. 38(4):879-891.

Lehman, J.T., D.M. Bilkovic, and C. Sullivan. 1997. Predicting development, metabolism and secondary production for the invertebrate predator *Bythotrephes*. Freshwater Biology. 38(1):343-352.

Liebig, J., A. Benson, J. Larson, and A. Fusaro. 2014. *Bythotrephes longimanus*. USGS Nonindigenous Aquatic Species Database, Gainesville, FL. http://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=162 Revision Date: 3/20/2012. June 11 2014.

Lindgren, J. 2014. Spiny water flea (Bythotrephes cederstroemi). Illinois Indiana Sea Grant database. June 10 2014.

Manca, M.M., M. Portogallo, M.E. Brown. 2007. Shifts in phenology of *Bythotrephes longimanus*. and its modern success in Lake Maggiore as a result of changes in climate and trophy. Journal of Plankton Research. 29(6):515-525.

McMahon, R.F. 2002. Evolutionary and physiological adaptations of aquatic invasive animals: *r* selection versus resistance. Canadian Journal of Fisheries and Aquatic Sciences. 59(7): 1235-1244.

Noreen, E.K., J.D. Young, J.G. Winter, N.D. Yan. 2013. Dynamics of the invasive spiny waterflea, *Bythotrephes longimanus*, in Lake Simcoe, Ontario, Canada. Inland Waters. 3:75-92.

Pothoven, S.A., H.A. Vanderploeg, D.M. Warner, J.S. Schaeffer, S.A. Ludsin, R.M. Claramunt, and T.F. Nalepa. 2012. Influences on *Bythotrephes longimanus* life history characteristics in the Great Lakes. Journal of Great Lake Research. 38(1):134-141.

Rennie, M.D., A.L. Strecker, and M.E. Palmer. 2011. *Bythotrephes* invasion elevates trophic position of zooplankton and fish: implication for contaminant biomagnification. Biology Invasions. 13:2621-2634.

Ricciardi, A. and J.B. Rasmussen. 1998. Predicting the identity and impact of future biological invaders: a priority for aquatic resource management. Canadian Journal of Fisheries and Aquatic Sciences. 55:1759-1765.

Strecker, A.L., S.E. Arnott, N.D. 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.

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

Yan, N.D., A. Blukacz, W.G. Sprules, P.K. Kindy, D. Hackett, R.E. Girard, and B.J. Clark. 2001. Changes in the zooplankton and 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.D., B. Leung, M.A. Lewis, and S.D. Peacor. 2011. The spread, establishment and impacts of the spiny water flea, *Bythotrephes longimanus*, in temperate North America: a synopsis of a special issue. Biology invasions. 13:2423-2432.

Yan, N.D., R.E. Girard, and S. Boudreau. 2002. An introduced invertebrate predator (*Bythotrephes*) reduces zooplankton species richness. Ecology Letters. 5:481-485.

Young, J.D., A.L. Strecker, and N.D. Yan. 2011. Increased abundance of the non-indigenous zooplanktivore, *Bythotrephes longimanus,* is strongly correlated with greater spring prey availability in Canadian Shield lakes. Biology Invasions. 13:2605-2619.

Yurista, P.M. 1999. A model for temperature correction of size specific respiration in *Bythothrephes cederstroemi* and *Daphnia middendorffiana.* Journal of Plankton Research 21:721-734.

Vander Zanden, M.J., and J.D. Olden. 2008. A management framework for preventing the secondary spread of aquatic invasive species. Canadian Journal of Fisheries and Aquatic Sciences. 65:1512-1522.