Science and Information Branch
Northwest Science and Information
Technical Workshop Report TWR-005

Threats to Lake of the Woods and the Winnipeg River by the rusty crayfish (*Orconectes rusticus*), an aquatic invader

Ministry of Natural Resources

Science and Information Branch
Northwest Science and Information

Technical Workshop Report TWR-005

Threats to Lake of the Woods and the Winnipeg River by the rusty crayfish (*Orconectes rusticus*), an aquatic invader

D.M. Rosenberg[1], M.A. Turner[1], Wolfgang Jansen[2] , Thomas Mosindy[3] and Douglas A. Watkinson[4]

[1,4] Fisheries and Oceans Canada
Freshwater Institute
501 University Crescent
Winnipeg, MB R3T 2N6

[2] North/South Consultants Inc.
83 Scurfield Boulevard
Winnipeg, MB R3Y 1G4

[3] Ontario Ministry of Natural Resources
Lake of the Woods FAU
808 Robertson Street
Kenora, ON P9N 3X9

Ministry of Natural Resources

Ontario

Front cover photo: Rusty crayfish (*Orconectes rusticus*)
Courtesy of Michael Turner, Fisheries and Oceans Canada

52627
ISBN 978-1-4435-2303-5 (Print)
ISBN 978-1-4435-2304-2 (PDF)

Single copies of this publication are available from:

Ontario Ministry of Natural Resources
Northwest Science & Information
RR 1, 25th Side Road
Thunder Bay, Ontario
P7C 4T9

Phone: 807 939-2501
Fax: 807 939-1841
E-mail: nwst@Ontario.ca

Cette publication spécialisée
n'est disponible qu'en anglais

This publication should be cited as:

Rosenberg, D.M., M.A. Turner, W. Jansen, T. Mosindy and D.A. Watkinson. 2010. Threats to Lake of the Woods and the Winnipeg River by the rusty crayfish (*Orconectes rusticus*), an aquatic invader. Ont. Min. Natur. Resour., Northwest Sci. & Info., NWSI Tech. Workshop Rpt. TWR-005. 54 pp. + append.

Abstract

This workshop, which brought together experts, stakeholders and potential partners, provided background information and insights on the state of aquatic invasive species (AIS) monitoring at both provincial and federal levels, crayfish biology, and sampling techniques to support the development of programs to monitor the spread of rusty crayfish (*Orconectes rusticus*) in Ontario and Manitoba waters. Workshop participants recommended a stratified survey design and protocol currently used to monitor crayfish populations in south-central Ontario lakes for Lake of the Woods and a modified sampling protocol that could adapt to initial survey results from the Winnipeg River, in order to effectively detect an invasion front downstream. Workshop participants also identified impacts and risks posed by a rusty crayfish invasion of these ecosystems, possible partners and their roles in monitoring, research and management, and key research needs for inclusion in current and future proposals. Preliminary results from the 2006 sampling season are presented.

Acknowledgements

Funding for this workshop was provided by Fisheries and Oceans Canada's Aquatic Invasive Species Program. We thank S. McLeod for facilitating the Workshop, and S. Ryland for her logistical assistance. S. Cosens, F. MacDonald, W. Momot, and K. Somers presented background material and co-operated in revisions requested for this publication. B. Hann, K. Somers, and R. Vinebrooke acted as reporters for the small group sessions. N. Geard and J. Stewart took notes throughout the workshop, and J. Stewart collated the material on impacts/risks of rusty crayfish invasions. We thank the people who attended and participated in the small and large group discussions. A. McColm prepared the report for publication.

Disclaimer

The views, conclusions, and recommendations are those of the authors and should not be construed as either policy or endorsement by the Ontario Ministry of Natural Resources.

Contents

Contents (cont.)

List of Tables

List of Figures

List of Figures (cont.)

List of Appendices

1.0 Introduction

1.1 Invasive Species

Organisms that are transported from areas of their natural distribution usually into distant areas where they previously did not occur often create ecological problems in their new habitats. Invasive species frequently do not encounter the normal complement of predators and diseases in their new habitat, so the usual checks and balances to population growth are reduced and populations of the transplanted invader often proliferate with disastrous consequences to the native biota.

Perhaps the best known contemporary examples of invasive species are the zebra (*Dreissera polymorpha*) and quagga (*D. bugensis*) mussels introduced into the Great Lakes, and numerous species of alien beetles all across Canada. Among their many deleterious effects, zebra and quagga mussels have contributed to the extirpation of many species of native mussels and have also blocked municipal water-intake pipes. Introduced beetles such as the European elm bark beetle (*Scolytus multistriatus*), the emerald ash borer (*Agrilus planipennis*), the Asian longhorn beetle (*Anoplophora glubripennis*), and the brown spruce longhorn beetle (*Tetropium fuscum*) have affected urban and natural forests. The best known of these species is the European elm bark beetle, purveyor of the fungus that causes Dutch elm disease.

The rusty crayfish (*Orconectes rusticus*) is another invasive species that is threatening Canadian freshwater ecosystems. It has moved or been transported into Ontario and Manitoba waters from the northern limits of its natural range in the Ohio River in the U.S. (see Momot's presentation in Section 3.2) and currently is found in several locations in Ontario, including Lake of the Woods (see Figure 11 in section 6.2.1) and the upper Winnipeg River (see Figure 12 in section 6.2.2), and Falcon Lake in Manitoba. The rusty crayfish can cause dramatic changes in the ecosystems into which it spreads: it outcompetes native species of crayfish, can cause extensive disruption to macrophyte habitat in lakes, and has been linked to changes in fish populations.

This workshop, held in Winnipeg, Manitoba, 2–3 May 2006, was organized because of the potential threats posed by the spread of rusty crayfish in Ontario and Manitoba waters. Immediate areas of concern include Lake of the Woods and the Winnipeg River, but the ultimate repository of the rusty crayfish may be Lake Winnipeg.

1.2 Workshop Goals and Objectives

The workshop intended to inform individuals and agencies (government, academic, NGOs [non-governmental organizations])[1] about the threats posed by rusty crayfish to freshwater ecosystems in Ontario and Manitoba, and to offer the best available information to monitoring programs being planned for Lake of the Woods and the Winnipeg River. The goal of the workshop was to bring together experts, stakeholders and potential partners to do the following:

- learn about aquatic invasive species (AIS) in general and the rusty crayfish in particular
- assess the potential risks of invasion of the rusty crayfish in Lake of the Woods and the Winnipeg River
- develop monitoring plans to address the rusty crayfish invasion of Lake of the Woods and the Winnipeg River in 2006, and set the stage for future monitoring
- identify research needs for inclusion in future proposals.

The workshop also had a number of subsidiary goals:

- learn about the design of successful crayfish monitoring programs
- develop monitoring partnerships and a possible monitoring team
- identify links to the AIS program of Fisheries and Oceans Canada (DFO)
- identify potential funding sources for monitoring and research
- identify strategies for mitigating future invasions.

Workshop organizers also hoped to provide answers to the following detailed questions:

- Are rusty crayfish a risk to Ontario aquatic ecosystems? If so, can we begin to quantify the economic cost of disruption to the Lake of the Woods and other Ontario ecosystems?
- Has the rusty crayfish been designated a "prohibited species" by Manitoba?
- Is it probable that the rusty crayfish will eventually invade Lake Winnipeg? What are the effects of barriers such as dams along the Winnipeg River? Does Lake Winnipeg contain natural biological barriers such as crayfish-eating fish? Are native crayfish important to the Lake Winnipeg ecosystem? Are the fish habitat and fisheries of Lake Winnipeg likely to be at risk?

[1] Acronyms used in this report are listed in Appendix A

- Are mitigation strategies such as commercial harvesting of rusty crayfish feasible?

1.3 Workshop Deliverables

Workshop organizers hoped to deliver the following items:

- a workshop proceedings report
- suggestions for monitoring Lake of the Woods and the Winnipeg River for 2006 and beyond
- a monitoring team
- identification of research issues concerning risk assessment pathways of rusty crayfish invasions, and potential mitigation measures for the rusty crayfish invasion.

2.0 Methods

2.1 Background Presentations

Workshop organizers felt that the best way to inform participants about invasive species in general and the rusty crayfish in particular was to invite four speakers to explore different aspects of the subject. Francine MacDonald (see Appendix A for contact information for invited speakers) provided a general background on the problem of invasive species, especially in Ontario. (Her presentation was rewritten by Wolfgang Jansen for this report.) Walter Momot provided information on the thermodynamics and energy transfer in ecosystems, and on crayfish biology and distribution, especially the rusty crayfish. Keith Somers (with Ron Reid) presented the details of the crayfish monitoring program in the Dorset, Ontario area. Last, Susan Cosens presented the DFO AIS action plan. This background material was presented near the outset of the workshop (see agenda, Appendix B).

2.2 Impacts and Risks Posed by the Rusty Crayfish

Workshop participants then identified both negative and positive impacts of rusty crayfish activity, the probability of occurrence, and the severity, extent, and duration of these impacts (see impacts template, Appendix C). Workshop organizers felt this exercise was important as a way for workshop participants to both design monitoring programs and to think ahead: Did an impact warrant further attention? Could something be done about negative impacts in already invaded systems or systems about to be invaded? Who would be ideal partners to deal with these problems?

2.3 Format for Days 1 and 2 of the Workshop

The two days of the workshop had similar formats. Tom Mosindy presented background information and his draft monitoring plan for Lake of the Woods (day 1) and Doug Watkinson presented background information and his draft monitoring plan for the Winnipeg River (day 2). Workshop participants then broke into three smaller groups (see Appendix D for assignments of participants to each group) to critique the draft monitoring plans using a standard set of questions and guidelines (Appendix E). The four questions included:

1. What are the strengths and weaknesses of the draft monitoring plan? How would you address the identified weaknesses given the limitation of resources already noted?
2. What suggestions can you make regarding the sampling plan? (The details of this question differed between Lake of the Woods and the Winnipeg River.)

3. What are the key research needs for Lake of the Woods/Winnipeg River and how would meeting these needs affect short- and long-term monitoring plans?
4. Who are the likely key supporters or partners in monitoring, research, and management processes for the rusty crayfish, and what role would each of these supporters/partners play? (See Appendix E for details of these questions.) Answers to the questions were summarized at the end of each breakout session, and posted on the walls. Workshop participants then circulated through these three separate presentations, in preparation to reconvene in plenary. The large group then discussed common points and differences among the three small groups, and recommended alterations to the draft monitoring plans presented by Mosindy and Watkinson. Mosindy and Watkinson then summarized the take-home messages from each of the day 1 and 2 deliberations on their monitoring plans for Lake of the Woods and the Winnipeg River, respectively.

2.4 Final Considerations

Three important topics were discussed after the plenary session on day 2: 1) possibilities of collaboration with other research programs, 2) possible partnerships to address the rusty crayfish invasion, and 3) ideas on how to go forward from the workshop (i.e., next steps).

3.0 Background Presentations

3.1 Aquatic Invasive Species—Spreading the Word, not the Species

W. Jansen, based on F. MacDonald's presentation

Introduction. Alien species are non-native (non-indigenous) animals or plants that occur in areas outside their natural, past, or present distribution. If the establishment and spread of an alien species threatens ecosystems, habitats, or other species with economic or environmental harm, this species is commonly referred to as an invasive. Invasive species possess certain common biological traits that enable them to establish and rapidly spread within newly settled ecosystems. Such traits include a general adaptability to changing environmental conditions that often lets the organism thrive in disturbed systems, a lack of natural predators, rapid reproduction, a strong competitive ability, and taxonomic distinctiveness (Lozon and MacIsaac 1997, Ricciardi and Atkinson 2004). Invasive alien species have been identified as the most important threat to native species biodiversity next to habitat destruction (Mack *et al.* 2000). The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has estimated that 25% of Canada's endangered species, 31% of threatened species, and 16% of vulnerable species are in some way at risk because of non-native species. Similar data for the US are even more alarming in that they suggest that 42% of the species listed as threatened or endangered under the US Endangered Species Act are considered to be at risk primarily because of competition with, and predation by, introduced species (Pimentel 2002). It has been predicted that AIS will contribute to the extinction of native freshwater species in North America at a rate of 4% per decade, suggesting freshwater organisms will go extinct five times faster than terrestrial organisms and three times faster than coastal species (Ricciardi and Rasmussen 1998). Approximately 175 AIS have been recorded in the Great Lakes alone (Bailey 2005b, Munawar *et al.* 2005), and the list is growing. Several of these species had and continue to have significant ecological and economic impact (e.g., zebra mussel, sea lamprey [*Petromyzon marinus*]; Coulatti *et al.* 2006).

Ontario's Federation of Anglers and Hunters, the province's largest conservation organization, has co-ordinated an Invading Species Awareness Program (ISAP) in partnership with the Ontario Ministry of Natural Resources (OMNR) since 1992. The focus of this program is on prevention, monitoring, and control of aquatic invaders. A similar concept has recently been implemented at the national level as the Operational Plan for Aquatic Invasive Species (OPAIS). This paper describes some of the approaches and challenges for both the ISAP and the OPAIS, and provides several case studies of AIS in Ontario lakes and wetlands.

OPAIS. The OPAIS was released in February 2004 for public consultation. The Plan was developed in association with the Canadian Council of Fisheries and Aquaculture Ministers Aquatic Invasive Species Task Group. The OMNR and DFO co-chaired the group. The Plan takes a pathways approach to dealing with invasive species, focusing on the many pathways of AIS introduction: ship ballast, aquarium trade, baitfish, water gardens, recreational watercraft, and live food fish. Specific actions have been identified to deal with each of these pathways.

A recent review of AIS introductions into Ontario concluded that eight different pathways are responsible for the establishment of >160 species in Ontario waters (Kerr *et al.* 2005). One major concern with the pathways approach taken in the OPAIS is that it does not prioritize the pathways, in particular the need to focus on the ballast pathway. In addition, the Plan does not provide specific priority actions in dealing with each pathway. Furthermore, effective response protocols to deal with invasive species have not been established at either the provincial or federal levels (Gelinas 2003 and Miller 2003, as cited in Kerr *et al.* 2005)

Pathways for Species Introductions and Examples of AIS in Ontario: *Ballast water.* Commercial shipping moves about 5 million tonnes of ballast water annually into the Great Lakes (Aquatic Sciences Inc. 1996), and discharge of ballast water (or sediment) is the single most important source for AIS entering the Great Lakes (Ricciardi 2006). Living aquatic organisms or their propagules in the residual ballast water/sediment of so called "no-ballast-on-board" (NOBOB) ships have the potential to become successfully established when the ballast is mixed with inflowing water and subsequently discharged into the Great Lakes Basin (Bailey *et al.* 2005a). Historically, approximately 30% of the known cases of aquatic invasions into the Great Lakes are attributed to transoceanic commercial shipping, and since the completion of the St. Lawrence Seaway in 1959, this percentage has increased to approximately 67% (Grigorovich *et al.* 2003). In June 2006, Transport Canada introduced ballast control and management regulations (http://www.tc.gc.ca/MarineSafety/TP/Tp13617/menu.htm), which are intended to reduce the risk of introducing AIS into Canadian waters through vessels' ballast water. The current US regulations are essentially the same as the Canadian ones, except that the management of NOBOB ships is recommended in the US and is mandatory in Canada (Sarah Bailey, DFO, Burlington, Ontario, personal communication, November 2007). The efficiency of the ballast control measures will have to be evaluated, and it remains to be seen if they can diminish or eliminate this pathway for the introduction of AIS of mainly Ponto-Caspian origin into the Great Lakes and beyond. Grigorovich *et al.* (2003) have identified 63 new species that pose an invasion risk, 16 of which have been rated as "high risk" with potentially devastating effects to the Great Lakes Basin ecosystem.

Recreational watercraft. Recreational watercraft constitute another important pathway for species introductions and the regional spreading of alien species once they have been introduced into an area such as the Great Lakes Basin. Powerboats, sailboats, fishing boats or personal watercraft can all act as transfer agents of alien species between water bodies if no care is taken to inspect and, if necessary, clean these watercraft before they are moved to a new location. In the past, recreational watercraft have repeatedly facilitated the spread of zebra mussel, Eurasian water-milfoil (*Myriophyllum spicatum*), and other invasive species. Zebra mussels are probably the best known invasive species in North America. They have completely altered the way we use our lakes and rivers, and have had costly and devastating impacts (Colautti *et al.* 2006).

Fishing. Commercial and recreational fishing also can serve as a pathway for species introductions or their further spread via contaminated fishing gear. Two prime examples are the spiny water flea (*Bythotrephes longimanus*) and the fishhook water flea (*Cercopagis pengoi*), which invaded the Great Lakes in 1984 (Mills *et al.* 1993) and 1998 (MacIsaac *et al.* 1999), respectively. Both species have a propensity to attach to fishing lines or commercial fishing gear and are easily spread to other water bodies (Jacobs and MacIsaac 2007). Their dispersal is further facilitated by the fact that *B. longimanus* and *C. pengoi* can reproduce parthogenetically and form resting eggs that are resistant to adverse environmental conditions for weeks or longer (Jacobs and MacIsaac 2007). After the initial invasion of Lake Huron, the spiny water flea has spread into many Shield lakes in Ontario (Boudreau and Yan 2003). *Bythotrephes longimanus* and *C. pengoi* are predatory and often have a competitive advantage over native species of zooplankton. The spiny water flea has dramatically altered the species composition and size structure (Yan and Pawson 1997) and the species richness (Yan *et al.* 2002) of crustacean zooplankton in Ontario lakes. *Bythotrephes longimanus* and *C. pengoi* also compete with juvenile fish for food, without being a suitable prey themselves for gape-limited fish predators (Jacobs and MacIsaac 2007).

Bait bucket transfer and unauthorized introductions. The transfer of alien species between water bodies by bait buckets or unauthorized fish introductions are two further pathways for AIS of concern. Bait bucket transfers seem to happen largely because of a lack of angler awareness. In a 1998 survey, 46% of Ontario anglers reported disposing of bait in the water occasionally or all the time (Dextrase and MacKay 1999, as cited in Kerr *et al.* 2005). Examples of baitfish introductions of AIS into Ontario waters include the rusty crayfish (Figure 1), round goby (*Negobius melanostomus*), rainbow smelt (*Osmerus mordax*), and ruffe (*Gymnocephalus cernuus*). Disease transmission has also been attributed to bait bucket transfer of the vectors (Kerr *et al.* 2005). In addition to the 8–9 million fishes that are released annually by the OMNR into >1400 Ontario waters (Kerr *et al.* 2005), unauthorized fish introductions (i.e., the stocking of fish without a license) are a growing problem that has resulted in the spread of species beyond their natural range. Such stockings are often conducted by well-meaning individuals to improve a fishery, without recognizing the potential negative impacts on the native fish community. Species that are most commonly introduced into Ontario waterbodies include smallmouth bass (*Micropterus dolomieu*), rock bass (*Amblopites rupestris*), yellow perch (*Perca flavescens*), and black crappie (*Pomoxis nigromaculatus*).

Aquarium trade, live fish markets, and water gardens. Approximately 100 species of ornamental fish have been introduced into natural waters via the North American aquarium trade and almost 40 of these species have established populations (Crossman and Cudmore 1999, as cited in Rixon *et al.* 2005). Of these ornamental fish, at least four species have subsequently spread into the Great Lakes, as have four mollusk and three plant species that originally entered North America with the aquarium trade (Rixon *et al.* 2005). A recent risk assessment of the potential invasion of fish, mollusks and macrophyte species sold in pet stores and live fish markets near Lakes Erie and Ontario concluded that three plant (Indian swampweed [*Hygrophila polysperma*], parrot feather [*Myriophyllum aquaticum*], Brazilain waterweed [*Egeria densa*]) and four fish species (oriental weatherfish [*Misgurnus anguillicaudatus*], white cloud mountain minnow [*Tanichthys* albonubes], bighead carp [*Aristichthys nobilis*], grass carp [*Ctenopharyngodon idella*]) have a high probability of establishment in the Great Lakes (Rixon *et al.* 2005). A further plant (two-leaf watermilfoil [*Myriophyllum heterophyllum*]) and two fish species (weather loach [*Misgurnus fossilis*], striped bass [*Morone saxatilis*]) have the potential of establishment in the Great Lakes (Rixon *et al.* 2005).

Water gardens are rapidly gaining popularity in North America and are an emerging pathway for species introductions that adds to the existing threats of the aquarium trade/live fish markets. A recent Minnesota study found that >90% of wetland and aquatic plant orders included prohibited exotic species and species not specifically requested, and 80% included unintended animals, including macroinvertebrates and fish (Maki and Galatowitsch 2004). Some of the prominent emergent horticultural invaders include the common reed (*Phragmites communis*), flowering rush (*Butomus umbellatus*), yellow iris (*Iris pseudacorus*), and the European frog-bit (*Hydrocharis morsus-ranae*).

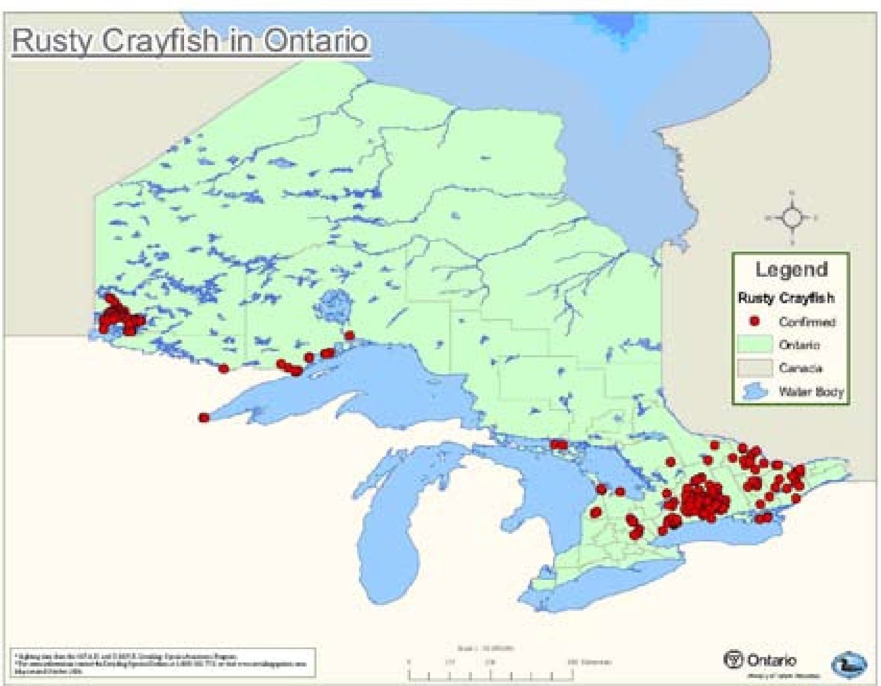


Figure 1. Distribution of the rusty crayfish (*Orconectes rusticus*) in Ontario. OFAH = Ontario Federation of Anglers and Hunters, OMNR = Ontario Ministry of Natural Resources

Increasing Awareness and Prevention through the ISAP, other Programs and Regulations. To protect Ontario waters from AIS, the ISAP has distributed pamphlets and posted notices that provide readers with a set of measures that will reduce the risk of dispersal of alien species (Table 1). Other public awareness programs include the “Do Not Dump Bait Buckets” initiative. Its goal is to reinforce the message that it is illegal to transfer baitfish from one water body to another. To this end, educational materials are distributed to the public. Also, attempts are being made to engage the baitfish industry

Table 1. Poster alerting the public to aquatic invasive species and giving advice on how to treat watercraft that are to be transferred between water bodies.

Recreational Watercraft **Stop Aquatic Hitchhikers!** **BEFORE LEAVING ANY WATERBODY…** • **Inspect and remove any visible plants or animals.** • **Drain** water from motor, livewell, bilge and transom wells while on land. **AT HOME…** • **Rinse** your boat and equipment with hot tap water (>40 °C) **OR** • **Spray** your boat and equipment with high pressure water (250 psi) **OR** • **Dry** your boat and equipment for at least 5 days before transporting to another water body.

through the Hazard Analysis and Critical Control Points (HACCP) initiative. The HACCP refers to a protocol that was originally developed for the seafood industry but has recently been applied by the bait and aquaculture industry in the US to prevent the spread of AIS. Although not yet formally applied under Ontario jurisdiction, this protocol has been used as an example on how bait harvesters, dealers, and government agency staff can work closely to develop plans to reduce the risks of spreading AIS through the harvest, sale, and distribution of live bait. For example, this approach has been used to establish standards and procedures to "certify" bait as free of AIS in some US jurisdictions.

Recently, the use of crayfish as bait has been reviewed under the Ontario Environmental Bill of Rights, and after public consultation, existing regulations were changed and took effect on 1 January 2007 (Tom Mosindy, personal communication). Bait harvesters will no longer be permitted to commercially harvest and sell crayfish, mainly to prevent the further spread of rusty crayfish. Anglers with a valid fishing license can capture 36 crayfish for personal use, but these crayfish must only be used as bait in the same water body where they were caught. They may not be transported overland. Manitoba has recently prohibited the use of all crayfish as bait (Wendy Ralley, Manitoba Water Stewardship, personal communication). Other related initiatives that further try to increase public awareness about the contribution of fish bait as a source of AIS are DFO's "Great Canadian Baitfish Survey" and a risk assessment of harvester/dealer/angler practices.

A public awareness program has also been directed toward the water garden and aquarium trade. In addition to raising the general awareness of the impacts of releasing non-native species into the environment, this specific program promotes, for example, the use of native plants for shoreline restoration and engages the industry to educate customers and to adhere to best management practices. The awareness program is supported by initiatives such as the "Water Garden/Aquarium End User Surveys" (undertaken by DFO) and reviews and risk assessments of species sold by the industry. These reviews form the basis for regulatory initiatives that may prohibit the sale/importation of AIS of concern.

Current challenges. Despite many positive responses to public awareness programs, public outreach still faces many challenges. For example, an angler survey conducted jointly by the OMNR and the Ontario Federation of Anglers and Hunters in 2004 concluded that 97% of respondents believed it was important to take precautions to prevent the spread of invading species. This positive news was put in perspective when individuals were asked about their own behaviour: 53% of respondents said that they did not take precautions to prevent the transport of AIS from one body of water to another because they did not believe that they were boating in infested waters (78%) and/or they did not know what to do (55%).

Management options and needs for the control of AIS have been formulated, particularly for the Great Lakes (Bailey 2005a). Together with increasing public awareness of the problems and costs associated with AIS, the enforcement of existing regulations and the creation of new ones could help to contain established invaders and reduce the rate of, or even prevent the establishment of, additional AIS. The failures of most previous prevention or eradication programs aimed at alien species indicate that effective prevention and control of AIS require a long-term, large-scale strategy, rather than focusing on the suppression of the currently most notorious invaders (Mack *et al.* 2000).

Conclusion. The introduction of AIS within the Great Lakes and subsequent dispersal to our inland waters is a critical issue. Reducing the impacts of known AIS and preventing the introduction of new ones requires a combination of approaches focused on the specific pathways of introduction. Approaches must combine a long-term strategy, public outreach, industry-led "best management practices", and regulation.

Acknowledgements. Much of this paper was based on a presentation by Francine MacDonald at the workshop. I thank her for her cooperation in preparing the paper. I also wish to thank Sarah Bailey and Tom Mosindy

for providing information and references, and David Rosenberg for editing the manuscript.

References

Aquatic Sciences Inc. 1996. Examination of aquatic nuisance species introductions to the Great Lakes through commercial shipping ballast water and assessment of control options. Phase I and Phase II. ASI project E9225/E9285. St. Catharines, Ontario.

Bailey, S.A., I.C. Duggan, P.T. Jenkins, and H.J. MacIsaac. 2005a. Invertebrate resting stages in residual ballast sediment of transoceanic ships. Canadian Journal of Fisheries and Aquatic Sciences 62:1090–1103.

Bailey, S.A., D.F. Reid, R.I. Colautti, T. Therriault, and H.J. MacIsaac. 2005b. Management of nonindigenous species in the Great Lakes. Toledo Journal of Great Lakes' Law, Science and Policy 5:101–112.

Boudreau, S.A., and N.D. Yan. 2003. The differing crustacean zooplankton communities of Canadian Shield lakes with and without the nonindigenous zooplanktivore *Bythotrephes longimanus*. Canadian Journal of Fisheries and Aquatic Sciences 60:1307–1313.

Colautti, R.I., S.A. Bailey, C.D.A. Van Overdijk, K. Amundsen, and H.J. MacIssac. 2006. Characterised and projected costs of non indigenous species in Canada. Biological Invasions 8:45–59.

Grigorovich, I.A., R.I. Colautti, E.L. Mills, K. Holeck, A.G. Ballert, and H.J. MacIsaac. 2003. Ballast-mediated animal introductions in the Laurentian Great Lakes: Retrospective and prospective analyses. Canadian Journal of Fisheries and Aquatic Sciences 60:740–756.

Jacobs, M. J., and H.J. MacIsaac. 2007. Fouling of fishing line by the waterflea *Cercopagis pengoi*: A mechanism of human mediated dispersal of zooplankton? Hydrobiologia 583:119–126.

Kerr, S.J., C.S. Brousseau, and M. Muschett. 2005. Invasive aquatic species in Ontario: A review and analysis of potential pathways for introduction. Fisheries 30(7):21–30.

Lozon, J.D., and H.J. MacIsaac. 1997. Biological invasions: Are they dependent on disturbance? Environmental Reviews 5:131–144.

MacIsaac, H.J., I.A. Grigorovich, J.A. Hoyle, N.D. Yan, and V.E. Panov. 1999. Invasion of Lake Ontario by the Ponto-Caspian predatory cladoceran *Cercopagis pengoi*. Canadian Journal of Fisheries and Aquatic Sciences 56:1–5.

Mack, R.N., D. Simberloff, W.M. Lonsdale, H. Evans, M. Clout, and F.A. Bazzaz. 2000. Biotic invasions: causes, epidemiology, global consequences, and control. Ecological Applications 10:689–710.

Maki, K., and S. Galatowitsch. 2004. Movement of invasive aquatic plants into Minnesota (USA) through horticulture trade. Biological Conservation 118:389–396.

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

Munawar, M., I.F. Munawar, N.E. Mandrak, M. Fitzpatrick, R. Dermott, and J. Leach. 2005. An overview of the impact of non indigenous species on the food web integrity of North American Great lakes: Lake Erie example. Aquatic Ecosystem Health and Management 8:375–395.

Pimentel, D. 2002. Introduction of non-native species in the world. Pages 3–8 in D. Pimentel (editor). Biological invasions: economic and environmental costs of alien plant, animal, and microbe species. CRC Press, Boca Raton, Florida.

Ricciardi, A. 2006. Patterns of invasion of the Laurentian Great Lakes in relation to changes in vector activity. Diversity and Distributions 12:425–433.

Ricciardi, A., and S.K. Atkinson. 2004. Distinctiveness magnifies the impact of biological invaders in aquatic ecosystems. Ecology Letters 7:781–784.

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.

Rixon, C.A.M., I.C. Duggan, N.M.N. Bergeron, A. Ricciardi, and H.J. MacIsaac. 2005. Invasion risks posed by the aquarium trade and live fish markets on the Laurentian Great Lakes. Biodiversity and Conservation 14:1365–1381.

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

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

3.2 Dominance by Crayfish in Benthic Freshwater Ecosystems

W. Momot

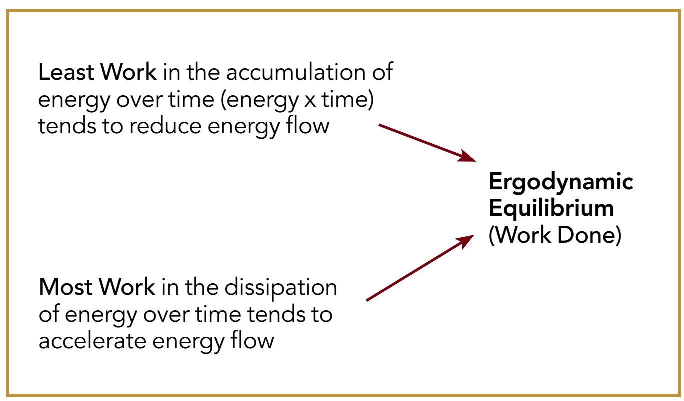
Introduction. Most surveys of aquatic ecosystems reveal that only a few species within certain phyla will dominate the benthic community. Freshwater crayfish often comprise 40–60% of the total zoobenthic biomass of many lakes and streams (Momot 1984, 1995). Why is this so? What characteristics qualify these crayfish as dominant organisms? How do these traits contribute to their success? What are the consequences for the benthic community? Typical characteristics of a dominant species are: 1) a large adult size, 2) long life, 3) a terminal position in the food web, 4) a high biomass/production (B/P) ratio (the reciprocal of the P/B ratio), 5) high biomass levels maintained over the long term, and 6) a tendency to self-regulate their population size. Dominant species also display internally modulated growth and relatively uniform age distribution, and place constraints on species below them in the foodweb hierarchy (Vannote 1963, Mason 1974, Momot 1986, 1995, Rabeni 1992, Nystrom 2002). All of these characteristics can be ascribed to freshwater crayfish, yet there is no general explanation for such patterns.

To examine this conundrum, I draw upon the provocative idea that the observed responses of ecosystems must be governed by the laws of thermodynamics (Johnson 2001). How do these laws explain energy transfers in ecosystems? According to Johnson (2001), all organisms and ecosystems are subject to the laws of thermodynamics, which seemingly produce enigmatic emergent patterns in nature. Such patterns are particularly evident in inaccessible boreal and arctic lakes located in hostile climates. These lakes have the following common characteristics: 1) a short, open-water period, 2) low water temperatures, 3) low primary production, and 4) simple feeding relationships. In such lakes, linear food chains and limited energy reserves stored as detritus serve to moderate fluctuations in energy input (Wetzel 2001).

According to Johnson (2001), lakes over long periods of time can approximate a relatively closed system nested within the relatively more open system of the tundra and/or the boreal forest. A closed system with regular energy inputs develops a structure influenced by two main countervailing forces: 1) a tendency to increase the total energy assimilated while reducing or minimizing energy flow, and 2) an anti-symmetric tendency to accelerate energy flow. These countervailing forces operate along with a third force - a gravity field. To exist, an ecosystem over time must maximize the amount of energy captured by delaying the rate of energy flow during the energy transfer process so that such values exceed the opposing force (the tendency to minimize the time delay) until the system approaches the lowest possible state of specific energy dissipation, called the "climax state" (Johnson 2001). This approximation of an equilibrium state is characterized by a process that maximizes the acquisition of energy from the environment and its retention for the maximum time period possible.

Biological systems can exist only with a continuous input of energy. They are, therefore, contingent on work done per unit time. To examine the dynamics of work, Johnson (2001) formulated certain Principles of Ergodynamics. Work may be done in thermodynamic equilibrium and in the presence of appropriate substrates. The system comes to a steady state if energy input is maintained at a constant level (Table 2). The system moves away from thermodynamic equilibrium towards ergodynamic equilibrium under appropriate conditions with appropriate substrates, resulting in an increase in internal energy and internal order. The critical feature is that work is done by imposing a time delay on the passage of energy from one state to another. The result is an increase in potential energy in some part of the system. The amount of work done is always the least possible for the prevailing conditions and constraints. The more slowly work is done, the more efficiently it is performed. The least work dominates over the short term, but the most work will win out in the long run. Biological processes are thus viewed as a struggle between the principle of least work and the principle of most work (Table 2). Most work wins only through an increase in work done.

Table 2. Relationship between Least Work and Most Work resulting in ergodynamic equilibrium.



The above process is biologically contingent on various physiologies of the species involved, their heterotrophic interactions, and the nature of the environment. Johnson (2001) initially observed such patterns in arctic lakes having Arctic char, Salvelinus alpinus, as a single dominant terminal predator. The modal configuration of the size-frequency distribution was indefinitely maintained and composed of old fish if there was no major environmental change. If disturbed (i.e., the population was reduced in size and number), the age–size structure of the Arctic char eventually returned to its original configuration within eight years of no fishing. Similar patterns, showing a return to the original age–size distribution after a disturbance, have been observed in boreal lakes with two main predatory fish species (Spencer *et al.* 2002) or with a single crayfish species (Momot 1986, 1995).

What are the factors responsible for these phenomena? Johnson's (2001) most important observation—that energy distribution is pyramidal—forces a major shift in thinking about what structures animal populations. If energy accumulation rather than energy transfer structures communities, then energy-density (joules/gram) increases over time and space at the top of an energy-distribution pyramid. This theoretical concept would explain the observed increases in mean age, abundance, size, and uniformity observed in top terminal predators compared to other species found in the community (Johnson 2001).

How can the above principles be used in studies of freshwater crayfish? Energy accumulates over time in biological systems. This accumulation is expressed as a tangible living substance, some of which can reach a maximum value, as illustrated by the large size, long life span and maximum abundance characteristic of terminal dominant predators. Such a tendency is observable in all organisms, but not all species will become terminal predators.

An increase towards maximum energy accumulation over time is expressed as increased energy-density in both time and space. Therefore, there is a tendency in crayfish populations towards increased mean size, life span, specific energy-density, uniformity, and abundance. For example, uniformity in size of individuals in a crayfish population is a means of attaining a state of least energy flow because distribution of energy among the largest possible group of uniformly sized individuals represents a condition of maximum energy accumulation relative to energy input. Greater biomass for the same energy input is attained by a population of uniformly sized individuals. In addition, the higher the mean age and the more uniform the size of individuals, the less demand for younger, smaller (more energy expensive) replacements. One result is the low recruitment rates often seen for crayfish relative to other populations of benthic freshwater invertebrates (Momot 1986, 1995). Another result is the high total biomass, relative to other invertebrates, achieved by crayfish populations and an overlap of older-aged animals within the modal size group. This characteristic of crayfish populations makes aging by length-frequency distribution difficult for long-lived specimens (Reynolds 2002). The end result is simply a more uniform energy distribution in symmetrically interacting individuals displaying indeterminate growth. These individuals are part of a loosely integrated thermodynamic unit expressed as a dominant species attaining maximum biomass through efficient energy usage. Hence, crayfish populations often achieve maximum biomass per unit energy assimilated, the least-specific energy dissipation, and the least-specific entropy production.

As to interspecific interactions and the question of why crayfish are so dominant among the zoobenthos, it has been shown that all species inherently attempt to accumulate energy and delay their maximum passage through the system (Johnson 2001). Therefore, in theory, many different species in different phyla could assume dominance. In reality, however, each species population serves to dampen energy dissipation. This dampening function increases as we ascend a trophic hierarchy. The extent to which any species approaches such a state of least dissipation depends on interspecific interactions, i.e., the extent to which it is consumed by others as well as the characteristics of its life history deemed important to its survival.

Thus, an examination of stomach contents suggests a detritivore-herbivore habit, but bioenergetic studies of crayfish suggest carnivory as a main pathway for energy accumulation (Momot 1995). Polytrophic foraging enhanced by a flexible enzyme system allow crayfish to feed upon and ingest a wide variety of foods (Musgrove 1993, Whitledge and Rabeni 1997). A long life span allows them to outlive their prey, such as aquatic insects and other crustaceans, by a considerable margin. A long life span, combined with their capacity to store large energy reserves, often allows crayfish to act as terminal predators in many lakes and streams (Momot 1995, Nystrom 2002).

The sum of all these dissipative actions must equal the input at the steady state for any ecosystem to exist (Johnson 2001). Hence, each species in a community attempts to achieve a state of least energy flow and, thus, a maximization of its biomass, which results in a cohesion among species populations at higher levels of abstraction (ecosystem, biosphere). The community as a whole attempts to dampen environmental fluctuations, which helps stabilize microclimate and environmental chemistry. Assuming that energy distribution and energy flow establish patterns within such an ecosystem, we expect that it is the simpler, more autonomous systems that would more clearly display such emergent patterns (e.g., arctic and boreal lakes). Thus, the general characteristics of a dominant species become strongly pronounced in arctic and boreal lakes. In addition, the general pattern of energy flow is from small-sized, highly fluctuating populations to large, long-lived populations that impose an increasing degree of continuity and stability (Johnson 2001, Spencer *et al.* 2002). Each species population acquires maximum free energy, thus acting as a time delay to the maximum passage of energy through the community. Differences in their capacities to acquire and conserve energy produce a hierarchy of populations that, through their interactions, serve as coherent units within this hierarchy (Johnson 2001).

The ecosystem itself also serves as a series of coupled shock absorbers. Each species population imposes a damping moment on fluctuations in energy input because it delays energy flow to its maximum capacity. Hence, the greater the species diversity and the greater the number of expensive energy transfer interactions (e.g., predation between species), the greater the energy expended in maintaining the system. Thus, low-diversity systems accumulate high biomass despite low primary productivity, whereas high-diversity systems have low biomass relative to energy input (Johnson 2001). Most high-biomass accumulation is by terminal predators in low-diversity systems, despite the low primary productivity of such systems.

The earth functions as a closed system for long periods of time, exchanging only energy and entropy with the external universe, within which operate a multiplicity of subsystems comprised of ecosystems. Significant alterations (glaciation, volcanism, and meteor strikes) are usually widely spaced in time, allowing rapid adjustment by the flora and fauna. These ecosystems and the species populations within them serve as dissipative units of energy. Viewing species populations and ecosystems as coherent dissipative units, in which energy accumulation over time is expressed as joule-seconds, thus helps describe and explain these systems. These basic properties provide an explanation for many observed generalities in the ecology and evolution of crayfish and other living things. Let us examine three explanatory consequential examples: the B/P ratio, the r-K selection spectrum, and stability-diversity.

B/P Ratio of Crayfish Populations. The B/P ratio is the dimensional equivalent to the reciprocal of the mean age of the population in all species. The B/P ratio also represents the reciprocal of mean energy residence time and therefore energy turnover time, thus making it a good relative measure of energy flow (i.e., the energy input per unit time necessary to support a unit of energy in the biomass of an ecosystem) (Johnson 2001). Hence, the smaller the B/P, the greater the energy flow. Thus, B/P becomes essentially the time factor when computing energy dissipation over time. Two trends in B/P ratio can be recognized in aquatic ecosystems. It tends to increase along the food chain (Table 3). This increase implies that generation time increases at each ascending hierarchical level, and a concomitant second trend is that total energy declines at each subsequent level. Within an ecosystem, energy transfers from populations with a high degree of fluctuation (low B/P) and rapid life-cycle response time to those with low fluctuation (high B/P) (e.g., crayfish;

Table 3. Examples of the annual biomass/production (B/P) ratio of species within four higher taxa of aquatic invertebrates.

Taxon	B/P ratio	Reference
Cladocera		
Bosmina sp.	0.07	Edmonson and Winberg (1971)
Copepoda		
Acanthodiaptomus denticanus	0.38	Winberg (1971)
Artodiaptomus bacillifer	0.40	Winberg (1971)
Artodiaptomus var. *fadeevi*	0.40	Winberg (1971)
Cyclops strenuous var. *sevanii*	0.22	Winberg (1971)
Amphipoda		
Gammarus lacustris	0.33; 0.50	Winberg (1971)
Gammarus fasciatus	0.34	Winberg (1971)
Monoporeia affinis	0.29; 0.52	Winberg (1971)
Hyalella azteca	0.25−0.26	Cooper (1965), Lindeman and Momot (1983)
Gammarus pulex	0.15	Edmonson and Winberg (1971)
Decapoda		
Cherax destructor	0.48	Woodland (1967)
Orconectes virilis	0.52−0.83; 0.67−2.00	Momot and Gowing (1977), Momot (1978)
Orconectes propinquus	1.11	Vannote (1963)
Pacifastacus leniusculus	1.11	Mason (1974)
Astacus astacus	1.43	Cukerzia (1975)
Austropotamobius pallipes	2.50−3.33	Brown and Bowler (1977)

Table 3). The result is that, at each hierarchical level, there is an increasing contribution to the stability of the whole ecosystem, eventually forming a hierarchy of coupled stabilizers with the dominant species (e.g., crayfish as a terminal benthic predator among the zoobenthos) often imposing the main stability characteristics on the benthic community (e.g., see Whitledge and Rabeni 1997, Nystrom 2002).

Thus, B/P as a measure of reaction time determines the hierarchical structure of the system. It is the time component that is of importance, not the work itself (energy x time), even though individual species pursue the thermodynamic goal of maximization of energy x time. Furthermore, the increase in B/P of each species population along the food chain is attained, as seen in freshwater crayfish, through increasing size, increasing life span, fewer juveniles and greater size uniformity relative to other freshwater invertebrates (Momot 1984, 1995). Correspondingly, B/P decreases in crayfish populations along a gradient of increasing energy flow from boreal to more tropical areas. Note the much lower B/P for the tropical species *Cherax destructor*, compared to the boreal species *Astacus astacus* (Table 3). This decrease in the B/P ratio parallels the increase in species diversity, increase in mean annual temperatures, and decreases in climatic variability between seasons and years because, in the tropics, energy is dissipated among a large variety of species with complex interactions and less variable energy inputs. If the overall gradient of energy is augmented by increased average annual temperatures, respiration and energy flow are stimulated, causing a decrease in B/P in the wet tropics (Johnson 2001).

The r-K Spectrum and Crayfish Populations. Life-history theory has shifted away from r-K selection, but the themes of density-dependent regulation, resource availability, and impacts of environmental fluctuations are among the many ecological features best characterized by a r-K selection scheme (Reznick *et al.* 2002). Furthermore, consideration of the thermodynamic laws encourages us to reconsider the value of the r-K approach for the following discussion of life-history theory. The life history of most species represents combinations of r and K features, with r-species having rapid population turnover times, whereas K species have large size and great age (Reznick *et al.* 2002). Thus, among most benthic species we see a gradient from high r, low K features for species at lower trophic levels, to high K, low r features for terminal benthic predators such as crayfish (Lindquist and Huner 1999).

Some species survive over evolutionary time by increasing the time component of their energy dissipation, growing to a large size, and thus reducing the probability of being consumed. This strategy is especially true for crayfish (Rabeni 1992). K-selected species most closely approach the asymptotic value of their energy x time (work) and are usually dominant, whereas other species have a life-history strategy that emphasizes the acquisition component of work, thus being closer to a r strategy in the r-K continuum. The latter species frequently have short life spans and live under specialized conditions. Time is thus a critical factor in determining the hierarchical level of a species, which can only be attained in benthic species with a long life span and a large body size (e.g., freshwater crayfish; Reynolds 2002). Hence, the special combination of large size, long generation time, and the tendency to simultaneously maximize both ensures that crayfish remain at or near the apex of the benthic dominance hierarchy.

Within aquatic subsystems the principle of least work is dominant, whereas between subsystems the principle of most work predominates. At the biosphere level, least work must dominate or the system fails. The unifying factor appears to be that energy transfer is from high to low areas of flux. Thus, subsystems in the biosphere function as do populations within an ecosystem, again as a series of shock absorbers. The annual spike of production in arctic and boreal lakes encourages the development of migratory invasions. The extent of energy transfer between species is modulated by the degree of autonomy of the system and the defenses against predation or grazing adopted by the population concerned. The general movement of biological material during annual migrations and by invasive species and their superior acquisition of biological material that evolved since the last glaciation in North America are reflected in the very successful invasion of northern boreal lakes by *Orconectes rusticus* (Momot 1991, Taylor *et al.* 1996).

Successful invasions by southern crayfish such as *O. rusticus* into autonomous northern lakes may be linked to the replacement of bioenergetically less successful species by more successful ones. These species are able to capture more energy per unit time, physiologies permitting (i.e., species more physiologically attuned to least work; Momot 1995). Based on this premise, species replacement capacity could be predicted by ordering the physiological capacity of various native species with regard to oxygen uptake, food conversion, and temperature tolerance reflecting bioenergetic activity for capturing energy flow along climatic gradients, and by comparing these features to those of potential invaders.

The same trend of a gradient in increasing energy flow augmented by increasing average ambient temperature is seen as species diversity tends to increase from the poles to the wet tropics. In this case, there is also an overall gradient of increasing energy flow to be considered. If augmented by increasing mean ambient temperatures, this increased energy flow stimulates increased respiration and energy flux and decreases B/P (e.g., wet tropics). An invading species from lower latitudes that features a wide-ranging tolerance for temperature changes and tolerance of hypoxia would have an extreme bioenergetic advantage at higher latitudes. Perhaps possession of these traits accounts for *Procambarus clarkii* being such a successful and widespread colonizer of nearly every aquatic habitat into which it has been accidentally or deliberately introduced (Lindquist and Huner 1999).

Crayfish as Ecosystem Stabilizers. A time delay on energy flux is an inherent stabilizing property of living things. Stability is such an inherent characteristic of the biological system that such a time delay is fundamental to life (Johnson 2001). Lake and river ecosystems can also function as a series of coupled shock absorbers, with their populations ranging from intensely fluctuating primary producers to relatively stable, long-lived crayfish. Each population in the sequence of energy transfers imposes an increasing degree of control (Johnson 2001). Thus, a dominant taxon like crayfish helps endow the system with its main stability characteristics, and helps the system approach its maximum potential energy accumulation over the longest period of time. Such dominants are limited by space, energy, and inherent physiology. Ecosystems can only follow trends in environmental change after an appropriate time lag. They are only as stable as their long-term energy cycle, and so stability is a means of achieving survival in the face of environmental fluctuations. These fluctuations cause disturbances that can be internal or external. An external disturbance is a short-term stress normally producing only quantitative changes in state variables but not in driving variables. Thus, stability is the ability of a system to maintain or return to its ground state after external perturbation. According to thermodynamic principles, the degree of stability depends on three characteristics: 1) the amplitude of the deflection from the ground state, 2) the rapidity of response to the perturbation, and 3) the rate at which the deflection is damped (Johnson 2001). The first characteristic indicates that the greater the initial biomass of the species concerned, the greater the biomass deflection that can be tolerated without disruption of the system. The second and third characteristics are mutually antagonistic: a well-damped system returns slowly and monotonically to ground state but a rapid response is less-well-damped. Thus, a stable system will exhibit a well-balanced combination of rapid response time and strong damping. Stability of the system is contingent on its being a closed autonomous system, with relatively constant energy input, and in an environment free from long-term trends. Diversity is related to the numbers in an area (species richness or abundance) and the evenness with which species are distributed. High diversity is the result of a large number of species that are relatively uniformly distributed in the area considered, whereas low diversity is often the result of a small number of species with disparate abundances. As total energy input of the system declines so does diversity, and as energy flow increases it results in a lower standing biomass per unit energy input (lower B/P). As energy flow increases so does energy-density of components and system complexity both at the individual or ecosystem level. Global energy flow is from ecosystems with high B/P (slow turnover) to systems of lower B/P (rapid turnover). This flow contrasts to energy transfer within ecosystems, which is from populations of rapid turnover (low B/P) to populations of relatively slow turnover (high B/P), such as crayfish. Cropp and Gabric (2002) even suggest meeting thermodynamic imperatives may provide whole-ecosystem selection pressures that will force ecosystems to a state most resilient to perturbation. Such evolutionary changes can only be speculated upon, especially when considering the impact of selective and nearly total harvests of many formerly dominant species in freshwater and, particularly, in marine ecosystems. These reductions in population harvest can lead to the survival of fast-growing genotypes, broadened age structures as essential to maintenance of natural genetic variation, and the ecosystem services provided by large dominants in maintenance of stability and continuity of these ecosystems (Conover and Munch 2002).

References

Brown, D.J., and K. Bowler. 1977. A population study of the British freshwater crayfish *Austropotamobius pallipes* (Lereboullet). Freshwater Crayfish 3:33–49.

Conover, D.O., and S.B. Munch. 2002. Sustaining fisheries over evolutionary time scales. Science 297:94–96.

Cooper, W.E. 1995. Dynamics and productivity of a natural population of a freshwater amphipod, *Hyalella azteca*. Ecological Monographs 35:377–394.

Cropp, R., and A. Gabric. 2002. Ecosystem adaptation: do ecosystems maximize resilience? Ecology 83:2019–2026.

Cukerzia, J. 1975. Die Zahl, Struktur und Produktivität der isolierten Population von *Astacus astacus* L. Freshwater Crayfish 2:513–527.

Edmonson, W.T., and G.G. Winberg. 1971. A manual on methods for the assessment of secondary productivity in fresh waters. IBP Handbook No. 17. Blackwell Scientific Publications, Oxford and Edinburgh, UK. 358 p.

Johnson, L. 2001. Imperfect symmetry: Action principles in ecology and evolution. Pages 229–285 in S.E. Jorgensen (editor). Thermodynamics and ecological modelling. CRC Press, Boca Raton, Florida.

Lindeman, D., and W.T. Momot. 1983. Production of the amphipod, *Hyalella azteca*, in a northern Ontario lake. Canadian Journal of Zoology 61:2051–2059.

Lindquist, O.V., and J. Huner. 1999. Life history characteristics of crayfish. What makes them good colonizers? Pages 23–30 in F.G. Gherardi and D. Holdich (editors). Crayfish in Europe as alien species. A. Balkema, Rotterdam, The Netherlands.

Mason, J.C. 1974. Crayfish production in a small woodland stream. Department of the Environment/ Fisheries and Marine Service. Pacific Biological Station, Nanaimo, BC. 30 p.

Momot, W.T. 1978. Annual production and production/ biomass ratios of the crayfish, *Orconectes virilis*, in two northern Ontario lakes. Transactions of the American Fisheries Society 107:776–784.

Momot, W.T. 1984. Crayfish production: a reflection of community energetics. Journal of Crustacean Biology 4:35–54.

Momot, W.T. 1986. Production and exploitation of the crayfish, *Orconectes virilis*, in northern climates. Pages 154–167 in G. Jamieson and N. Bourne (editors). North Pacific Workshops in Stock Assessment and Management of Invertebrates. Canadian Special Publication of Fisheries and Aquatic Sciences 92.

Momot, W.T. 1991. Potential and exploitation of freshwater crayfish in coolwater systems: Management guidelines and issues. Fisheries 16(5):14–21.

Momot, W.T. 1995. Redefining the role of crayfish in aquatic ecosystems. Reviews in Fisheries Science 3:33–63.

Momot, W.T., and H. Gowing. 1977. Results of an experimental fishery on the crayfish *Orconectes virilis*. Journal of the Fisheries Research Board of Canada 34:2056–2066.

Musgrove, R.J. 1993. Energy use and size in juvenile yabbies, *Cherax destructor* Clark (Parastacidae). Freshwater Crayfish 9:213–225.

Nystrom, P. 2002. Ecology. Pages 192–235 in D. Holdich (editor). Biology of freshwater crayfish. Blackwell Science Ltd., London, UK.

Rabeni, C.F. 1992. Trophic linkage between stream centrarchids and their crayfish prey. Canadian Journal of Fisheries and Aquatic Sciences 49:1714–1721.

Reynolds, J.D. 2002. Growth and reproduction. Pages 152–184 in D. Holdich (editor). Biology of freshwater crayfish. Blackwell Science Ltd., London, UK.

Reznick, D., M.J. Bryant, and F. Bashe. 2002. r and K selection revisited: the role of population regulation in life-history evolution. Ecology 83:1509–1520.

Spencer, S., P.J. Colby, W.T. Momot, and M. Fruetel. 2002. Response of a walleye population to pulse fishing in Henderson Lake, Ontario. North American Journal of Fisheries Management 22:842–851.

Taylor, C.A., M.L. Warren, Jr., J.F. Fitzpatrick, H.H. Hobbs, III, R.F. Jezerinac, W.L. Pflieger, and H.W. Robinson. 1996. Conservation status of crayfish in the United States and Canada. Fisheries 21(4):25–38.

Vannote, R.L. 1963. Community productivity and energy flow in an enriched warm water stream. PhD Dissertation, Michigan State University, East Lansing, Michigan. 156 p.

Wetzel, R.G. 2001. Limnology: Lake and river ecosystems. 3rd edition. Academic Press, New York. 1006 p.

Whitledge, G.W., and C.F. Rabeni. 1997. Energy source and ecological role of crayfishes in a Missouri Ozark stream: Insight from stable isotopes and gut analysis. Canadian Journal of Fisheries and Aquatic Sciences 54:2555–2563.

Winberg, G.G. 1971. Methods for the estimates of production of aquatic animals. Academic Press, New York. 175 p.

Woodland, D.J. 1967. Population study of a freshwater crayfish Cherax albidus Clark. Particular reference to the ecoenergetics of a population. PhD Dissertation, New England University, New South Wales, Australia.

3.3 The Dorset Environmental Science Centre Crayfish Sampling Protocol

K.M. Somers and R.A. Reid[2]

Introduction. The role of crayfish in aquatic ecosystems can range from detritivore to herbivore to carnivore (Momot *et al.* 1978, Momot 1995, Whitledge and Rabeni 1997, Dorn and Wojdak 2004). In addition, crayfish may be exceedingly rare or can comprise up to 40–60% of the total benthic biomass in some lakes (Jones and Momot 1981, Momot 1984). Recent interest in the ecological impacts and associated costs of nonindigenous species (Colautti *et al.* 2006) and recognition of the impacts of introduced crayfish species (Berrill 1978, Lodge and Lorman 1987, Hanson *et al.* 1990, Wilson *et al.* 2004) have fuelled a growing concern for the potential effects of the introduced crayfish *Orconectes rusticus* on freshwater ecosystems of northwestern Ontario and Manitoba (Momot 1997).

Crocker and Barr (1968) first reported the presence of *O. rusticus* in Lake of the Woods in northwestern Ontario in 1963. This species is one of two introduced crayfish species in Ontario, both originating from the Ohio River basin (Crocker and Barr 1968). In 1985, *O. rusticus* was found in Pounsford Lake on the Sibley Peninsula, near Thunder Bay (Momot 1992), and subsequently the species was reported from several more lakes and rivers around Thunder Bay, as well as Lake Superior (Momot 1997).

The presence of *O. rusticus* in northwestern Ontario, its propensity to invade new waters and restructure aquatic ecosystems (Lodge and Lorman 1987, Lodge *et al.* 1994, Taylor and Redmer 1996, Wilson *et al.* 2004), and the fact that Lake of the Woods is located within the Arctic drainage have raised concerns that this nonindigenous species is poised to significantly expand its range into northern waters. As a result, a workshop was held in Winnipeg, Manitoba, on 2–3 May 2006, to develop a program to monitor the current distribution and anticipated range expansion of *O. rusticus* in Lake of the Woods and downstream in the Winnipeg River. The crayfish sampling protocol used by Ontario Ministry of the Environment staff at the Dorset Environmental Science Centre (Reid and David 1990, David *et al.* 1994) was presented as an example for the Lake of the Woods/Winnipeg River monitoring program. This paper describes the Dorset crayfish sampling protocol, its origin and selected results based on 17 years of monitoring crayfish relative abundances in lakes in the Muskoka–Haliburton region of south-central Ontario.

We conclude by describing the historical invasion of *O. rusticus* in Trout Lake, Wisconsin (e.g., Wilson *et al.* 2004) as an indication of what might occur in northwestern Ontario and Manitoba.

Background. Monitoring programs at the Dorset Environmental Science Centre (formerly the Dorset Research Centre) were initiated in the mid to late 1970s to address changes in water quality associated with shoreline development (i.e., the building of cottages and permanent residences around softwater lakes on the Precambrian Shield; Dillon *et al.* 1994). These programs focused on water quality, specifically nutrients, as well as phytoplankton and zooplankton communities. However, the discovery of acid precipitation in the late 1970s (Dillon *et al.* 1978) shifted efforts to a wider array of water-quality parameters resulting in a long-term monitoring program documenting changes in the water chemistry of acid-sensitive lakes on the Shield (Dillon *et al.* 1987, Neary and Dillon 1988).

Given the observed effects of acidification on water quality (Dillon *et al.* 1987, Clair *et al.* 1995) and associated lake benthos (Stephenson *et al.* 1994), including the extirpation of crayfish populations (Davies 1989, France and Collins 1993), interest in monitoring the anticipated improvements in water quality due to SO2 emission controls (Jeffries *et al.* 1992, 2000) led to the establishment of the Long Range Transport of Atmospheric Pollutants (LRTAP) biomonitoring program (Shaw *et al.* 1992). This joint program involved both federal and provincial governments and included a crayfish monitoring component (Shaw *et al.* 1995). In the mid-1980s a crayfish sampling workshop was held at Dorset. The current Dorset crayfish sampling protocol evolved from that workshop and subsequent sampling trials on Dorset-area lakes (Reid and David 1990, Somers and Green 1992, Somers *et al.* 1997). This protocol has been used to monitor crayfish populations in 17 lakes for up to 18 years (e.g., David *et al.* 1994).

Crayfish Sampling Methods. Crayfish catches based on baited traps are widely recognized as being biased relative to other types of sampling methods (Abrahamsson 1966, 1983, Somers and Stechey 1986, Stuecheli 1991). Traps typically catch large males of the most aggressive species. There are many methods for catching crayfish, ranging from dip nets, throw nets, and seines (Taylor and Redmer 1996, Dorn *et al.* 2005), to collections along transects or in quadrats by divers using snorkels or SCUBA (Allison and Harvey 1981, Lamontagne and Rasmussen 1993, Kershner and Lodge 1995), to electrofishing (Westman *et al.* 1978, Rabeni *et al.* 1997). Although each sampling method has strengths and weaknesses, traps are readily available, easily and widely used, and their biases are well known.

[2]Address for R.A. Reid: Dorset Environmental Science Centre, 1026 Bellwood Acres Road, P.O. Box 39, Dorset, ON, Canada P0A 1E0

Crayfish species assemblages and relative abundances vary among lakes within the same basin (Capelli and Magnuson 1983, David *et al.* 1997) and can vary within the same lake (e.g., Lodge *et al.* 1986, Kershner and Lodge 1995). This variation undoubtedly is a function of habitat differences within and among lakes (Flint and Goldman 1977, Jones and Momot 1981) as well as other factors such as the type and density of predatory fishes (Collins *et al.* 1983, Kershner and Lodge 1995). Crayfish abundances and available habitat types vary with depth (Momot and Gowing 1972). For example, Somers and Stechey (1986) caught 2/3 of their crayfish in the first six traps of a series of 36 traplines based on 15 traps that were individually spaced at 3-m intervals along each trapline. This pattern with depth was evident in catches of *Cambarus bartoni*, but not *Orconectes virilis*. Momot and Gowing (1972) found that female *O. virilis* moved to deeper water as the summer progressed. These types of sex- and size-related differences in habitat use and depth generally reflect intra-specific aggression, where male crayfish being more aggressive than females tend to displace females to suboptimal habitats (Abrahamsson 1966, Bovbjerg and Stephens 1974). Inter-specific aggression can also affect spatial patterns in the distribution of crayfish (e.g., Bovbjerg 1970, Berrill 1978) because more-aggressive species will displace less-aggressive species (e.g., Rorer and Capelli 1978, Capelli and Munjal 1982).

Malley and Reynolds (1979) cautioned that sampling designs for aquatic invertebrates must consider the effects of life history. Crayfish catches are influenced by the time of year or sampling season (Somers and Green 1993, Richards *et al.* 1996). In Ontario, most adult orconectid crayfish moult in the spring and/or autumn and females carry eggs in the spring (Crocker and Barr 1968). Egg-bearing females and recently moulted adults are rarely caught in traps (Somers and Green 1993). In addition, trap catches of crayfish are generally correlated with water temperature, with the largest catches in mid-summer when water temperatures are also highest (e.g., Somers and Stechey 1986, Somers and Green 1993, Richards *et al.* 1996).

Different species and sexes respond to temperature in different ways (Momot and Gowing 1972, Richards *et al.* 1996). For example, Somers and Stechey (1986) found that the temperature-by-species interaction represented the greatest temperature-related effect on trap catches of *C. bartoni* and *O. virilis* (ANOVA, $F = 10.3$, $P < 0.001$) in Lake Opeongo in Algonquin Provincial Park. The F value in ANOVA can be interpreted as a type of signal-to-noise ratio, so catches of the two species responded quite differently to changes in water temperature.

Crayfish Sampling According to the Dorset Protocol. In the Dorset protocol, crayfish are collected with commercially available wire-mesh "Gee" minnow traps. Funnel entrances in the traps are enlarged to 3.5-cm diameter to accommodate large crayfish (Collins *et al.* 1983, Stuecheli 1991). Traps are set in traplines consisting of six traps individually attached to a rope at 3-m intervals. Traplines are set in a stratified, random fashion to address spatial heterogeneity of lake substrates. Each lake is initially circumnavigated with a boat and the bottom habitats up to a 1-m depth are mapped according to predominant substrate type (David *et al.* 1994). Fifty-metre-long segments of shoreline are identified on maps with the dominant nearshore habitat type (Figure 2). Different crayfish species display preferences for particular habitats (Crocker and Barr 1968), so our efforts are focused on rock (i.e., cobbles and boulders, but not bedrock), macrophyte, and detritus-dominated habitats. To stratify effort across the lake, the entire shoreline is divided into thirds and a 50-m segment of shoreline is randomly selected from each third of the lake until all three habitat types have been selected (i.e., one habitat type per third). Sites are chosen to avoid inflows and outflows, drop-offs, and developments (e.g., docks, boat-houses, and cottages). Three traplines are set perpendicular to shore within each 50-m segment. Traplines are set at least 5–10 m apart to reduce competition between traps. Acosta and Perry (2000) have estimated that a single baited trap samples an area of approximately 56 m^2, or a radius of 4–6 m.

Each trapline is tied to the shore; the first trap is placed at a depth of approximately 0.5–1 m. The remaining traps are lowered to the lake bottom from a boat that is slowly backed away from shore. Special attention is paid to ensure that traps are not suspended from submerged tree branches or between large boulders. Depending on the slope of the littoral area, the sixth trap may rest at a depth of up to 6 m. A total of 54 traps, comprising nine traplines, is set in each lake for one night. Traps are set overnight for a period of 12–24 hours. Catches are identified to species and expressed as a catch per unit effort (CUE: number caught per trap per night).

Temperature and life history have known effects on crayfish catchability, so the Dorset crayfish sampling protocol focuses trapping effort on the mid-summer period of July and August when surface water temperatures have stabilized above 20°C and crayfish are in an inter-moult condition (Somers and Green 1993, David *et al.* 1994).

The type of bait is also known to affect the relative numbers, average length, and species composition of crayfish in the catch (Somers and Stechey 1986, Kutka *et al.* 1992). Therefore, a type of bait was selected that

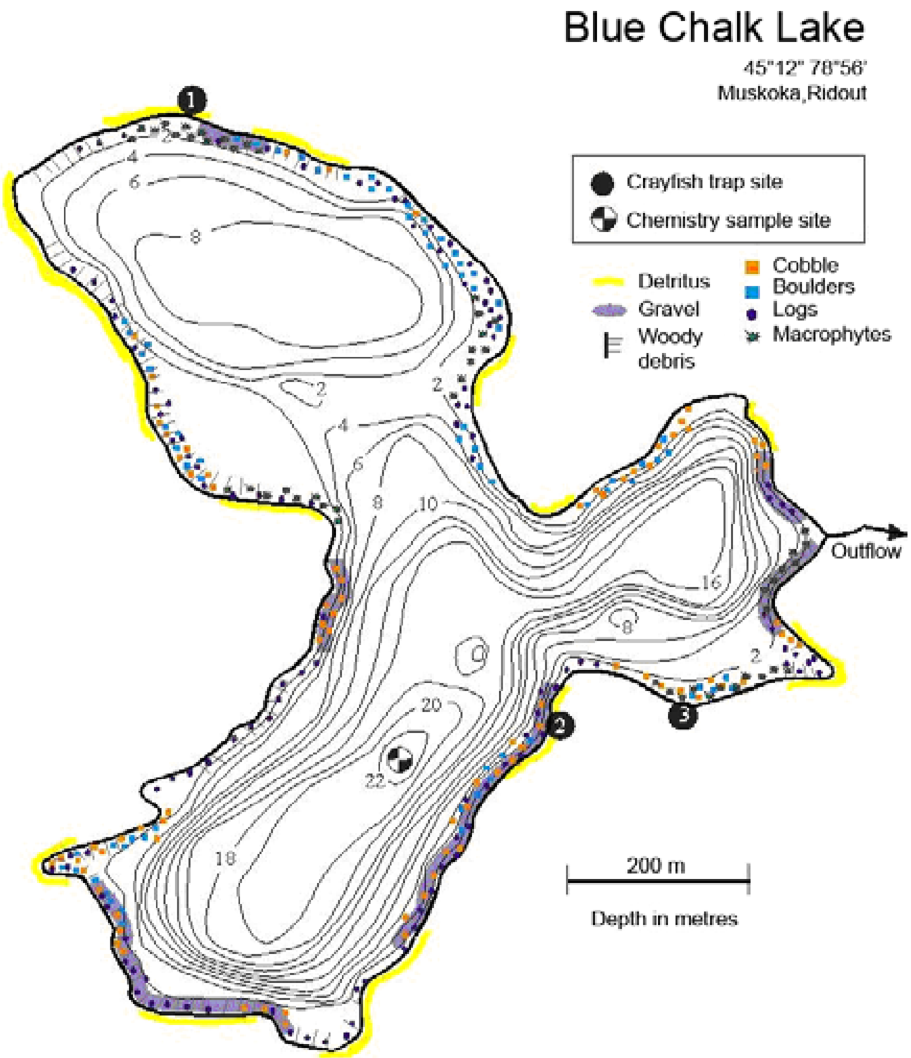


Figure 2. Bathymetric map for Blue Chalk Lake illustrating the location of the three crayfish trapping sites: 1 = macrophyte, 2 = detritus, and 3 = rock habitats.

caught roughly equal proportions of two crayfish species, *C. bartoni* and *O. virilis*, commonly found in south-central Ontario lakes. Fish-flavoured canned cat food was chosen as the bait, based on a comparison of trap catches using chicken, fish, liver, and cereal dog-food baits and a significant bait-by-species interaction (ANOVA F = 6.29, P < 0.001; Somers and Stechey 1986). Each trap is baited with a 35-mm film canister that is perforated with 6–10 holes made by a one-hole paper punch. Canisters are filled with bait, frozen in advance and one per trap is used.

Sampling Repeatability. During the course of our ongoing monitoring program (David *et al.* 1994), five lakes were re-sampled to establish the repeatability of our CUE estimates. All five lakes were sampled in late June through August. Three lakes were re-sampled on successive nights (two lakes in 1989 and one in 1995), one lake was re-sampled after 23 days (1990), one after 54 days (1995), and one of the original three lakes was re-sampled a second time after 44 days (1995). The resultant catches were expressed as number caught per trap per night separated according to species (i.e., *C. bartoni*, *O. virilis*, or *Orconectes propinquus*) and plotted relative to a 1:1 line. Precision was evaluated using a Pearson product–moment correlation, and bias was examined using a simultaneous F test assuming a slope of 1 and intercept of 0 (see Yang *et al.* 2004).

The CUE data, based on repeated sampling, were significantly correlated (r = 0.688, P = 0.009) indicating good precision (Figure 3), but the simultaneous F test was significant indicating a nontrivial bias from the 1:1 line through 0 (F = 5.87, P = 0.019). Removal of an outlier associated with samples collected 44 days apart improved precision (r = 0.903, P < 0.001) and resulted in a nonsignificant simultaneous F test (F = 1.14, P = 0.358) indicating no significant bias. The outlier represented *O. propinquus* collected on 9 July compared with the catch collected on 22 August (i.e., 44 days apart). By contrast, catches taken 23 and 54 days apart fell very close to the 1:1 line suggesting that the protocol produces CUE estimates with good precision and relatively little bias due to seasonality.

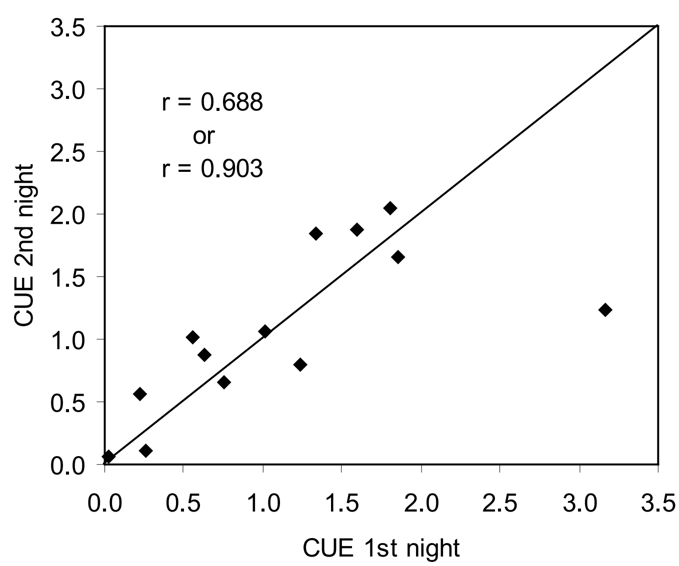


Figure 3. Variation in crayfish catch per unit effort (CUE) from five south-central Ontario lakes that were repeatedly sampled over mid summer using the Dorset sampling protocol. The Pearson correlation (r) with and without the single outlier is indicated.

Variability in CUE with Depth and Habitat. Crayfish populations in Blue Chalk Lake were sampled each year for 18 years as part of our long-term monitoring program. The CUE data (Figure 4) based on three traps per depth (or position in a trapline) for each of three habitat types averaged across the 18 years illustrate species-specific differences in habitat use. For example, *C. bartoni* was not caught at the macrophyte site, and CUE for this species was highest in the deeper detritus-site traps. By contrast, the CUE of *O. propinquus* was greatest for the trap nearest shore and decreased with depth in all three habitats. The CUE of *O. virilis* illustrated the same pattern as for *O. propinquus* in the rock and detritus habitats, but the highest CUE was recorded for the deeper traps in the macrophyte habitat.

The CUE data are presented as the 18-year average and standard deviation (SD, Figure 4). The SDs generally scale with the mean such that larger SDs are often associated with larger means. In this case, SDs and means can be used to calculate a coefficient of variation (i.e., CV = (SD/Mean)*100) to estimate relative sampling precision (Reid *et al.* 1995). In most instances, CVs are <30% suggesting reasonably good precision using this sampling protocol.

Long-Term Trends in Crayfish CUE. Somers (1997) used power analysis and linear regression to estimate the likelihood of detecting long-term trends in crayfish relative abundance, based on CUE data collected over the first few years of this program. Unfortunately, the small number of observations, occasional outliers, and nonlinear nature of the data indicated that traditional linear regression often lacked power. A robust alternative to regression for trend detection is the Mann–Kendall trend test with an adjustment for serial autocorrelation (Van Belle and Hughes 1984, Yu *et al.* 1993, Hamed and Rao 1998). The Mann–Kendall trend test is analogous to a Kendall rank correlation between the variable of interest (e.g., crayfish CUE) and year. Used in this context, the test identifies significant monotonic trends over time.

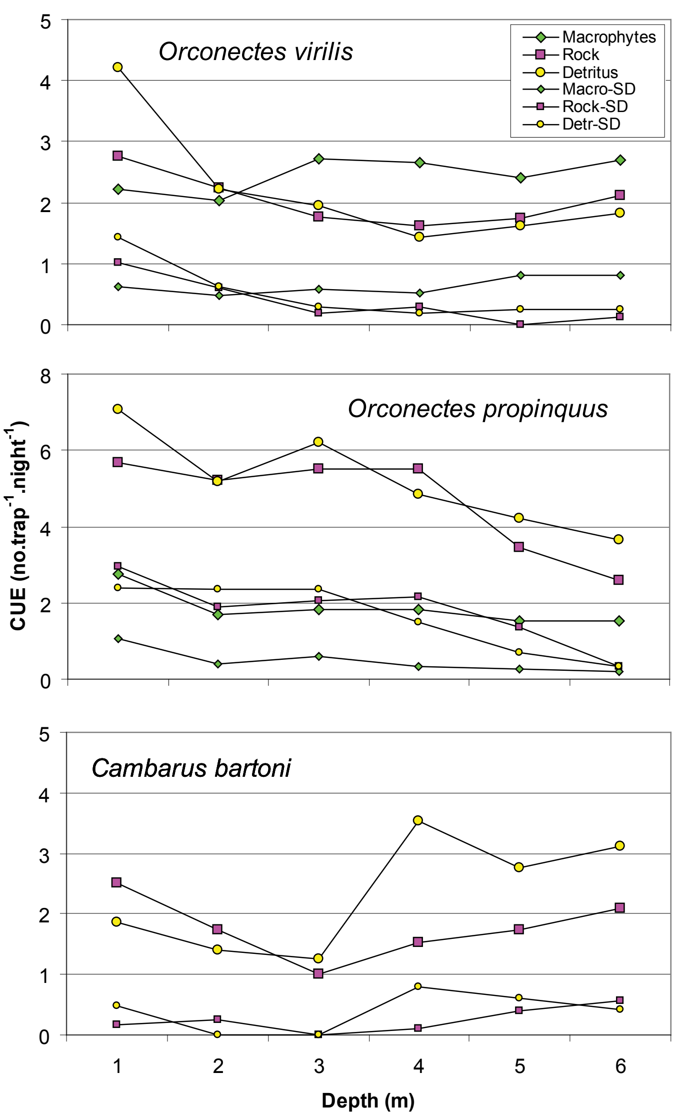


Figure 4. Depth-related variation in crayfish catch per unit effort (CUE) from three habitats in Blue Chalk Lake. Means and standard deviations (SD) are based on three traps at each depth averaged over 18 years of sampling.

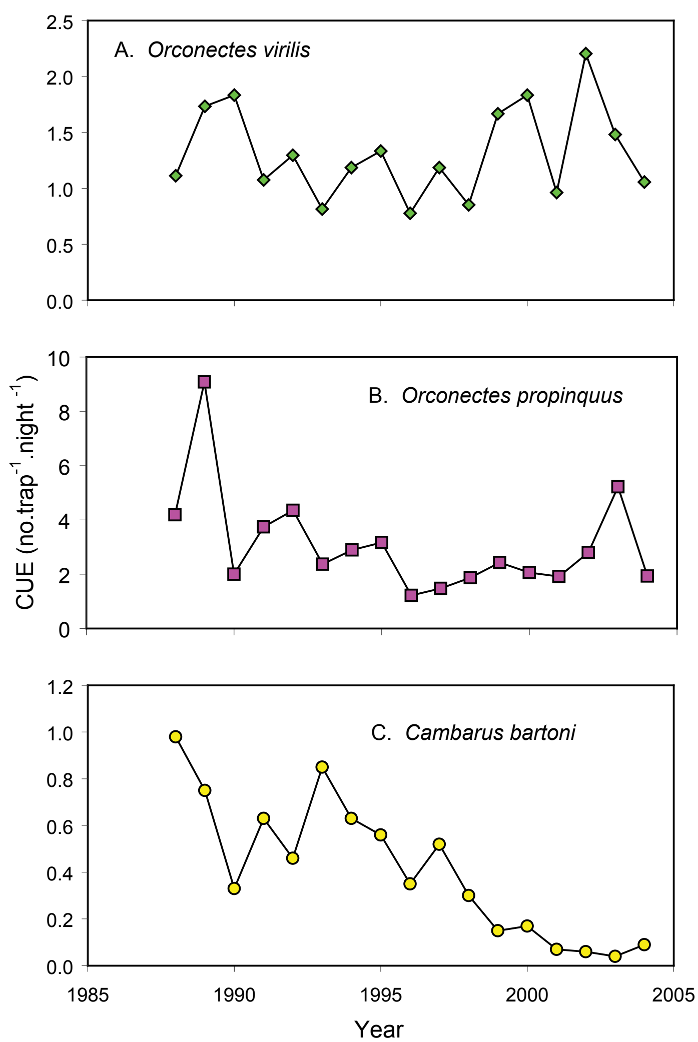


Figure 5. Catch per unit effort (CUE) for three crayfish species from Blue Chalk Lake for 1988–2004.

To illustrate the Mann–Kendall trend analysis, CUE versus year was plotted for trap catches of *O. virilis*, *O. propinquus*, and *C. bartoni* from Blue Chalk Lake (Figure 5). The linear regression between *O. virilis* CUE and year was not significant ($r = -0.100$, $F = 0.152$, $P = 0.703$), and neither was the Mann–Kendall trend ($Z = 0.247$, $P = 0.402$). The CUE of *O. propinquus* was weakly correlated with year ($r = -0.407$, $F = 2.971$, $P = 0.105$), but both the linear and monotonic trends were not significant ($Z = -1.318$, $P = 0.094$). By contrast, *C. bartoni* CUE indicated a strong linear trend ($r = -0.860$, $F = 42.757$, $P < 0.001$), and the monotonic trend was also significant ($Z = -4.078$, $P < 0.001$). When the Mann–Kendall trend test was corrected for autocorrelation, the trend only approached significance ($Z = -1.574$, $P = 0.058$).

Crayfish CUE data are collected annually, so there is a possibility that CUEs from successive years are influenced by the previous year's relative abundance. For example, Momot and Gowing (1977) reported strong density-dependent patterns in populations of *O. virilis* from three Michigan lakes. As a result, serial autocorrelation should be examined in any trend assessment (e.g., Hamed and Rao 1998). The serial correlations with a one-year lag for *O. virilis* and *O. propinquus* were nonsignificant ($P > 0.75$; see Figure 5), whereas the serial correlation for *C. bartoni* was highly significant ($r1 = 0.720$, $P < 0.002$).

Results from the Dorset long-term monitoring program were tabulated for three crayfish species from 7–10 lakes to further illustrate temporal trends in crayfish CUE (Table 4). Both linear (Pearson r) and monotonic trend (Mann–Kendall Z) statistics are presented with associated probabilities (P values). Some time series exhibited temporal autocorrelation, so the autocorrelation adjustment for the Mann–Kendall trend test (Hamed and Rao 1998) is also reported (Table 4).

Table 4. Linear (Pearson r and associated P value), monotonic (Mann–Kendall [MK] Z and associated P value), and autocorrelation-adjusted (Adjusted MK Z and associated P value) trend analyses for the three common crayfish species in various Dorset-area lakes for 1988–2004.

Lake	Years	Pearson		MK		Adjusted MK	
	(n)	r	P	Z	P	Z	P
			Orconectes virilis				
Blue Chalk	17	0.100	0.703	0.247	0.402	0.096	0.462
Crosson	17	−0.689	0.002	−2.925	0.002	−1.121	0.131
Hamer	16	−0.690	0.003	−3.295	<0.001	−1.284	0.100
Heney	15	−0.195	0.486	0.371	0.355	0.144	0.443
Red Chalk E	11	−0.376	0.254	1.936	0.026	0.794	0.214
Red Chalk M	11	−0.169	0.620	2.224	0.013	0.880	0.189
Skidway	8	−0.144	0.734	−2.678	0.004	−1.035	0.150
			Orconectes propinquus				
Blue Chalk	17	−0.407	0.105	−1.318	0.094	−0.568	0.285
Clear	16	−0.753	0.001	−3.543	<0.001	−1.374	0.085
Delano	12	0.004	0.991	−0.288	0.387	−0.111	0.456
Harp	17	0.079	0.762	0.577	0.282	0.223	0.412
Red Chalk E	11	−0.430	0.187	2.266	0.012	0.896	0.185
Red Chalk M	11	−0.488	0.128	2.266	0.012	0.885	0.188
Westward	16	−0.178	0.509	−0.865	0.194	−0.340	0.367
Young	16	0.486	0.056	0.783	0.217	0.302	0.381
			Cambarus bartoni				
Blue Chalk	17	−0.860	<0.001	−4.078	<0.001	−1.574	0.058
Clear	16	−0.608	0.013	−3.666	<0.001	−1.431	0.076
Cradle	12	−0.919	<0.001	−2.925	0.002	−1.364	0.086
Crosson	17	−0.596	0.012	−1.401	0.081	−0.539	0.295
Delano	12	0.014	0.966	−0.206	0.418	−0.080	0.468
Harp	17	−0.448	0.071	−0.741	0.229	−0.286	0.387
Pearceley	14	−0.611	0.020	−1.195	0.116	−0.462	0.322
Pincher	12	−0.088	0.786	−0.330	0.371	−0.125	0.450
Red Chalk M	11	−0.454	0.160	−0.536	0.296	−0.207	0.418
Westward	16	−0.716	0.002	−2.925	0.002	−1.117	0.132

Significant linear trends were evident in two of seven populations of *O. virilis* (Table 4). However, significant monotonic trends were found for five of these populations, although none of these trends was significant when serial autocorrelation was removed ($P > 0.05$). Trends in the *O. propinquus* CUEs were somewhat weaker than those for *O. virilis*, with a significant linear trend in only one of the eight populations and significant monotonic trends in three populations. Just like *O. virilis*, all of the *O. propinquus* Mann–Kendall trend tests adjusted for autocorrelation were not significant. By contrast, six of 10 *C. bartoni* populations revealed significant linear trends, but only four Mann–Kendall trend tests were significant suggesting that outliers may have biased the Pearson correlation results. As before, the correction for serial autocorrelation indicated that these trends were not significant, so we suspect that this correction may be too restrictive for these short time series (e.g., see Mizon 1995).

Temporal Coherence in Crayfish CUE. David *et al.* (1994) and Somers *et al.* (1997) examined temporal patterns in crayfish CUEs using Pearson correlations between CUEs for a series of Dorset-area lakes. Common patterns across a number of lakes suggested a regional signal affecting multiple lakes in a similar way. Dillon *et al.* (2003) used this same approach to evaluate temporal coherence in sulphate concentrations in Dorset lakes, as did Rusak *et al.* (1999) who found temporally coherent patterns in zooplankton abundances in Dorset lakes. We focused on the *O. propinquus* CUEs to explore temporal coherence in the crayfish data, and used Brien's test, which compares a matrix of Pearson correlations (Brien *et al.* 1984). We first tested whether the correlations were significantly different (i.e., were the correlations homogeneous?), and then tested if the average correlation differed significantly from zero. If the initial test indicated that the correlations differed significantly, we searched for homogeneous subsets of lakes using the clustering strategy in Dillon *et al.* (2003). We standardized CUEs to Z scores by subtracting the multi-year mean and dividing by the SD to illustrate temporal patterns. This standardization put each series on a similar scale with units in SDs.

Correlations between the CUEs for the eight *O. propinquus* populations ranged from 0.786 to −0.552 (Table 5A). Brien's test revealed that the correlations were significantly different (Chi-square = 71.3, $P < 0.001$; Table 5B) indicating that temporal patterns in the *O. propinquus* CUEs differed among lakes. This heterogeneity is illustrated in the temporal-coherence plot of all eight lakes (Figure 6A). A subset of four lakes was homogeneous (Chi-square = 8.89, $P = 0.113$), and the average correlation for these lakes was significantly different from zero ($r = 0.646$, Chi-square = 55.2, $P < 0.001$). The temporal trend for these four lakes reflects a initial decrease in CUE that plateaued for the 1990s and then increased in the first few years after 1999 (Figure 6B). The similarity in CUE among three of these lakes is not surprising because Blue Chalk Lake drains into Red Chalk E, which is a separate (eastern) basin linked to the main basin of Red Chalk M. However, Harp Lake is roughly 35 km from the other three lakes suggesting

Table 5. Correlation matrix for Orconectes propinquus catch per unit effort (CUE) data for eight lakes (A) and associated Chi-square tables from Brien's test (B).

A. Correlation matrix with Pearson correlations below and associated P values above the diagonal.

Lake name	BC	CL	DO	HP	RCE	RCM	WD	YG
Blue Chalk	-	0.515	0.155	0.055	<0.001	<0.001	0.266	0.994
Clear	0.170	-	0.649	0.823	0.693	0.787	0.576	0.411
Delano	0.361	−0.119	-	0.999	0.263	0.048	0.833	0.711
Harp	0.473	−0.059	0.000	-	0.060	0.079	0.022	0.057
Red Chalk E	0.786	0.103	0.288	0.465	-	0.002	0.855	0.199
Red Chalk M	0.759	0.071	0.486	0.437	0.698	-	0.837	0.897
Westward	−0.286	0.146	−0.055	−0.552	−0.048	−0.054	-	0.838
Young	−0.002	−0.213	−0.097	0.470	0.328	0.034	−0.054	-

B. Brien's test Chi-square tables. df = degrees of freedom.

Test	df	Chi-square	P value	df	Chi-square	P value
	All 8 lakes			Best subset of 4 lakes		
Grand Mean	1	30.176	<0.001	1	55.204	<0.001
Main effects	7	33.885	<0.001	3	7.298	0.063
Interactions	20	37.392	0.010	2	1.595	0.450
Equal correlations	27	71.277	<0.001	5	8.893	0.113
Total	28			6		

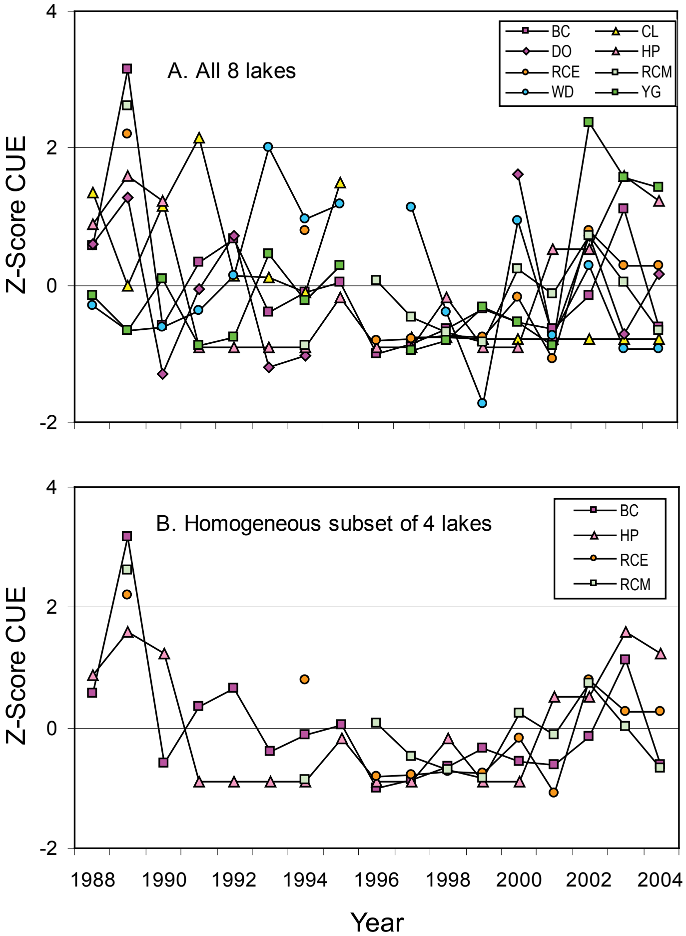


Figure 6. Standardized (Z-score) catch per unit effort (CUE) data for *Orconectes propinquus* from (A) all eight Dorset-area lakes, and (B) the four-lake subset exhibiting the same temporally coherent pattern. Lake codes in the legends are listed in Table 5.

that *O. propinquus* populations in these four lakes may be influenced by a regional, perhaps climatic, factor (e.g., see Rusak *et al.* 1999, Dillon *et al.* 2003). Further analyses to resolve and explain regional patterns in crayfish CUEs in Dorset-area lakes are ongoing.

Lessons from the Invasion of Trout Lake, Wisconsin, by *O. rusticus*. We briefly describe the invasion of Trout Lake, Wisconsin, by *O. rusticus* (Figure 7A) as an example of the potential impact that *O. rusticus* may have on Lake of the Woods, the Winnipeg River, and downstream waters in the Arctic basin. The spread of *O. rusticus* in Trout Lake is well documented (Lodge *et al.* 1986, Kershner and Lodge 1995, Byron and Wilson 2001, Wilson *et al.* 2004), as are the impacts of this crayfish on macrophytes and benthos (Lodge and Lorman 1987, Olsen *et al.* 1991, Lodge *et al.* 1994). *Orconectes rusticus* was reported in Lake of the Woods and several other areas in Ontario by Crocker and Barr (1968). Subsequent observations suggest that *O. rusticus* is spreading into nearby lakes and rivers (Berrill 1978, Momot 1992, 1997), including the Great Lakes (Momot 1997). Capelli and Magnuson (1983) suggest that *O. rusticus* was probably introduced into northern Wisconsin in the 1960s. The native crayfish species in Trout Lake (surface area: 1608 ha) was *O. virilis*, but by 1973 *O. propinquus* had invaded the lake and largely displaced *O. virilis* (Lodge *et al.* 1986). *Orconectes rusticus* also invaded Trout Lake sometime between 1973 and 1979. Subsequently, the relative abundances of *O. propinquus* decreased and *O. virilis* increased; however, trap catches were exclusively *O. rusticus* by the late 1990s (Wilson *et al.* 2004; Figure 7A). For comparison, trap catches in the neighbouring Big Muskellunge Lake (surface area: 396 ha) reflect a similar introduction of *O. propinquus* in the early 1980s and the virtual disappearance of the native crayfish *O. virilis* by the end of the 1990s, but no introduction of *O. rusticus* (Figure 7B). The CUE of *O. virilis* in both lakes peaked at 4–6 crayfish per trap. In Trout Lake, *O. propinquus* CUE approached 8–10 crayfish per trap, but dropped to 0 after *O. rusticus* became established. Since 1995, the CUE of *O. propinquus* in Big Muskellunge has ranged from 4–14 crayfish per trap, with a long-term average of 9.5. In Trout Lake, the CUE of *O. rusticus* has followed a similar long-term trajectory since 1995, but the CUE has been much higher, ranging from 14–36 crayfish per trap, with an average of 25.7. These data suggest that lake invasions by *O. rusticus* do not follow the typical boom-and-bust pattern, but result in a new, larger crayfish relative abundance over the long term (see also Olsen *et al.* 1991, Momot 1997, Wilson *et al.* 2004).

Coincident with the introduction and replacement of native crayfish populations by *O. rusticus* in Trout Lake was a dramatic reduction in littoral macrophytes and associated benthos (Lodge and Lorman 1987, Olsen *et al.* 1991, Lodge *et al.* 1994, Wilson *et al.* 2004). The varied role of crayfish in littoral ecosystems (Momot *et al.* 1978, Hanson *et al.* 1990, Dorn and Wojdak 2004), the ability of *O. rusticus* to consume an inordinate proportion of the littoral production (Momot 2009), and its ability to reach unusually high relative abundances (Momot 1997, Wilson *et al.* 2004) sound a warning that the introduction of *O. rusticus* into Lake of the Woods, the Winnipeg River, and the downstream Arctic basin has the potential to change these aquatic ecosystems to a greater extent than other introduced species.

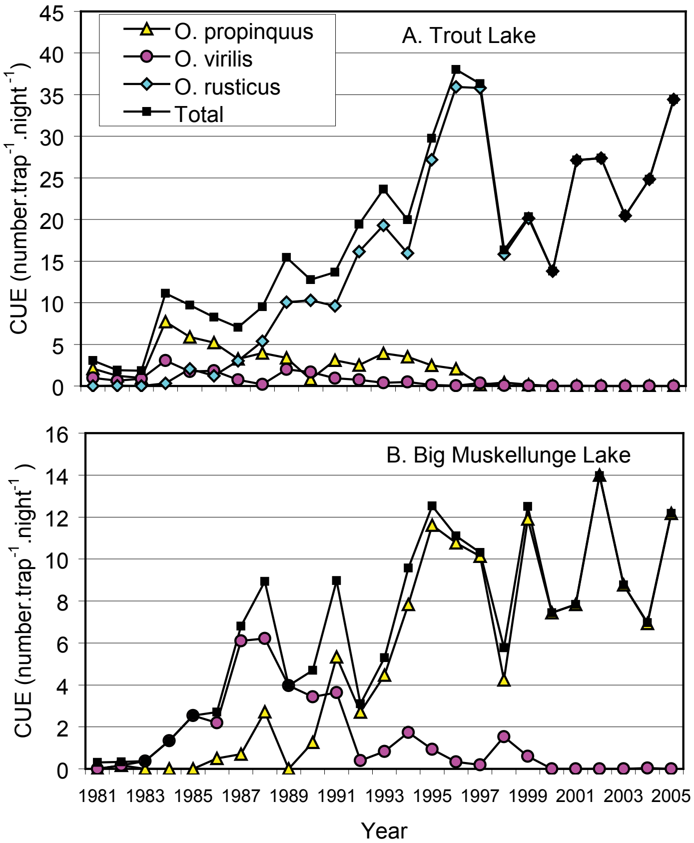


Figure 7. Crayfish catch per unit effort (CUE) data for Trout (A) and Big Muskellunge (B) lakes in Wisconsin illustrating long-term changes associated with introductions of *O. propinquus* and *O. rusticus*. Note the differences in the scale of the Y-axes. All data are from the Long-Term Ecological Research (LTER) web site: http://www.limnology.wisc.edu/.

Acknowledgements. We thank Peter Dillon and Wolfgang Scheider for their long-term support of the crayfish monitoring program at the Dorset Environmental Science Centre. A large number of people contributed to the original concept and final design of this program. Greg Mierle, Ian Davies, and Sheila David were instrumental in this regard. We also thank the many summer students who assisted with the crayfish sampling program. Jim Rusak and Barbara Benson helped access and summarize the Trout Lake and Big Muskellunge Lake Long-Term Ecological Research (LTER) data. Brie Edwards created Figure 2. We thank Michael Turner and Tom Mosindy for inviting us to present the Dorset crayfish sampling protocol at this workshop, and David Rosenberg and Wolfgang Jansen for editorial guidance with this summary.

References

Abrahamsson, S.A.A. 1966. Dynamics of an isolated population of the crayfish *Astacus astacus* Linne. Oikos 17:96–107.

Abrahamsson, S.A.A. 1983. Trappability, locomotion, and diel pattern of activity of the crayfish *Astacus astacus* and *Pacifastacus leniusculus* Dana. Freshwater Crayfish 5:239–253.

Acosta, C.A., and S.A. Perry. 2000. Effective sampling area: A quantitative method for sampling crayfish populations in freshwater marshes. Crustaceana 73:425–431.

Allison, W.R., and H.H. Harvey. 1981. Methods for assessing the benthos of acidifying lakes. Pages 1–14 in R. Singer (editor). Effects of acidic precipitation on benthos: Proceedings of a Symposium on Acidic Precipitation on Benthos, 8–9 August 1980, Hamilton, New York. North American Benthological Society, Springfield, Illinois.

Berrill, M. 1978. Distribution and ecology of crayfish in the Kawartha Lakes region of southern Ontario. Canadian Journal of Zoology 56:166–177.

Bovbjerg, R.V. 1970. Ecological isolation and competitive exclusion in two crayfish (*Orconectes virilis* and *O. immunis*). Ecology 51:225–236.

Bovbjerg, R.V., and S.L. Stephen. 1974. Behavioral changes with increased density in the crayfish *Orconectes virilis*. Freshwater Crayfish 2:429–441.

Brien, C.J., W.N. Venables, A.T. James, and O. Mayo. 1984. An analysis of correlation matrices: Equal correlations. Biometrika 71:545–554.

Byron, C.J., and K.A. Wilson. 2001. Rusty crayfish (*Orconectes rusticus*) movement within and between habitats in Trout Lake, Vilas County, Wisconsin. Journal of the North American Benthological Society 20:606–614.

Capelli, G.M., and J.J. Magnuson. 1983. Morphoedaphic and biogeographic analyses of crayfish distribution in northern Wisconsin. Journal of Crustacean Biology 3:548–564.

Capelli, G.M., and B.L. Munjal. 1982. Aggressive interactions and resource competition in relation to species displacement among crayfish of the genus *Orconectes*. Journal of Crustacean Biology 2:486–492.

Clair, T.A., P.J. Dillon, J. Ion, D.S. Jeffries, M. Panineau, and R.J. Vet. 1995. Regional precipitation and surface water chemistry trends in southeastern Canada (1983-1991). Canadian Journal of Fisheries and Aquatic Sciences 52:197–212.

Colautti, R.I., S.A. Bailey, C.D.A. van Overdijk, K. Amundsen, and H.J. MacIsaac. 2006. Characterised and projected costs of nonindigenous species in Canada. Biological Invasions 8:45–59.

Collins, N.C., H.H. Harvey, A.J. Tierney, and D.W. Dunham. 1983. Influence of predatory fish density on trapability of crayfish in Ontario lakes. Canadian Journal of Fisheries and Aquatic Sciences 40:1820–1828.

Crocker, D.W., and D.W. Barr. 1968. Handbook of the crayfishes of Ontario. University of Toronto Press, Toronto, Ontario. 158 p.

David, S.M., K.M. Somers, and R.A. Reid. 1994. Long-term trends in the relative abundance of crayfish from acid sensitive, softwater lakes in south central Ontario: A data summary for the first 5 years, 1988–1992. Report PIBS 2994. Ontario Ministry of the Environment, Dorset, Ontario. 38 p. + appendices. (ISBN 0-7778-1924-4)

David, S.M., K.M. Somers, R.A. Reid, and R.I. Ingram. 1997. Crayfish species assemblages in softwater lakes in seven tertiary watersheds in south-central Ontario. Report PIBS 3568E. Ontario Ministry of the Environment, Dorset, Ontario. 102 p. (ISBN 0-7778-6504-1)

Davies, I.J. 1989. Population collapse of the crayfish *Orconectes virilis* in response to experimental whole-lake acidification. Canadian Journal of Fisheries and Aquatic Sciences 46:910–922.

Dillon, P.J., D.S. Jeffries, W. Snyder, R. Reid, N.D. Yan, D. Evans, J. Moss, and W.A. Scheider. 1978. Acidic precipitation in south-central Ontario: recent observations. Journal of the Fisheries Research Board of Canada 35:809–815.

Dillon, P.J., R.A. Reid, and E. de Grosbois. 1987. The rate of acidification of aquatic ecosystems in Ontario, Canada. Nature 329:45–48.

Dillon, P.J., W.A. Scheider, R.A. Reid, and D.S. Jeffries. 1994. Lakeshore capacity study: Part I – test of effects of shoreline development on the trophic status of lakes. Lake and Reservoir Management 8:121–129.

Dillon, P.J., K.M. Somers, J. Findeis, and M.C. Eimers. 2003. Coherent responses of lakes in Ontario, Canada to reductions in sulphur deposition: the effects of climate on sulphate concentrations. Hydrology and Earth System Sciences 7:583–595.

Dorn, N.J., and J.M. Wojdak. 2004. The role of omnivorous crayfish in littoral communities. Oecologia (Berlin) 140:150–159.

Dorn, N.J., R. Urgelles, and J.C. Trexler. 2005. Evaluating active and passive sampling methods to quantify crayfish density in a freshwater wetland. Journal of the North American Benthological Society 24:346–356.

Flint, R.W., and C.R. Goldman. 1977. Crayfish growth in Lake Tahoe: effects of habitat variation. Journal of the Fisheries Research Board of Canada 34:155–159.

France, R.L., and N.C. Collins. 1993. Extirpation of crayfish in a lake affected by long-range anthropogenic acidification. Conservation Biology 7:184–188.

Hamed, K.H., and A.R. Rao. 1998. A modified Mann-Kendall trend test for autocorrelated data. Journal of Hydrology 204:182–196.

Hanson, J.M., P.A. Chambers, and E.E. Prepas. 1990. Selective foraging by the crayfish *Orconectes virilis* and its impact on macroinvertebrates. Freshwater Biology 24:69–80.

Jeffries, D.S., D.C.L. Lam, I. Wong, and R.M. Bloxam. 1992. The predicted effect of SO2 emission controls on the water quality of eastern Canadian lakes. Environmental Monitoring and Assessment 23:99–113.

Jeffries, D.S., D.C.L. Lam, I. Wong, and M.D. Moran. 2000. Assessment of changes in lake pH in southeastern Canada arising from present levels and expected reductions in acidic deposition. Canadian Journal of Fisheries and Aquatic Sciences 57:40–49.

Jones, P.D., and W.T. Momot. 1981. Crayfish productivity, allochthony, and basin morphology. Canadian Journal of Fisheries and Aquatic Sciences 38:175–183.

Kershner, M.W., and D.M. Lodge. 1995. Effects of habitat and fish predation on the distribution of an exotic crayfish, *Orconectes rusticus*. Journal of the North American Benthological Society 14:414–422.

Kutka, F.J., C. Richards, G.W. Merick, P.W. Devore, and M.E. McDonald. 1992. Bait preference and trapability of two common crayfishes in northern Minnesota. Progressive Fish-Culturist 54:250–254.

Lamontagne, S., and J.B. Rasmussen. 1993. Estimating crayfish density in lakes using quadrats: maximizing precision and efficiency. Canadian Journal of Fisheries and Aquatic Sciences 50:623–626.

Lodge, D.M., M.W. Kershner, J.E. Aloi, and A.P. Covich. 1994. Effects of an omnivorous crayfish (*Orconectes rusticus*) on a freshwater littoral food web. Ecology 75:1265–1281.

Lodge, D.M., T.K. Kratz, and G.M. Capelli. 1986. Long-term dynamics of three crayfish species in Trout Lake, Wisconsin. Canadian Journal of Fisheries and Aquatic Sciences 43:993–998.

Lodge, D.M., and J.G. Lorman. 1987. Reductions in submersed macrophyte biomass and species richness by the crayfish *Orconectes rusticus*. Canadian Journal of Fisheries and Aquatic Sciences 44:591–597.

Malley, D.F., and J.B. Reynolds. 1979. Sampling strategies and life history of non-insectan freshwater invertebrates. Journal of the Fisheries Research Board of Canada 36:311–318.

Mizon, G.E. 1995. A simple message for autocorrelation correctors: don't. Journal of Econometrics 69:267–288.

Momot, W.T. 1984. Crayfish production: A reflection of community energetics. Journal of Crustacean Biology 4:35–54.

Momot, W.T. 1992. Further range extensions of the crayfish *Orconectes rusticus* in the Lake Superior Basin of northwestern Ontario. Canadian Field-Naturalist 106:397–399.

Momot, W.T. 1995. Redefining the role of crayfish in aquatic ecosystems. Reviews in Fisheries Science 3:33–63.

Momot, W.T. 1997. History of the range extension of *Orconectes rusticus* into northwestern Ontario and Lake Superior. Freshwater Crayfish 11:61–72.

Momot, W.T. 2009 . Dominance by crayfish in benthic freshwater ecosystems. Pages xx–xx in D.M. Rosenberg, M.A. Turner, W. Jansen, T. Mosindy, and D. Watkinson (editors). Threats to Lake of the Woods and the Winnipeg River by the rusty crayfish, *Orconectes rusticus*, an aquatic invader. NWSI Technical Workshop Report TWR-xx [month] 2009.

Momot, W.T., and H. Gowing. 1972. Differential seasonal migration of the crayfish, *Orconectes virilis* (Hagen), in marl lakes. Ecology 53:479–483.

Momot, W.T., and H. Gowing. 1977. Production and population dynamics of the crayfish *Orconectes virilis* in three Michigan lakes. Journal of the Fisheries Research Board of Canada 34:2041–2055.

Momot, W.T., H. Gowing, and P.D. Jones. 1978. The dynamics of crayfish and their role in ecosystems. American Midland Naturalist 99:10–35.

Neary, B.P., and P.J. Dillon. 1988. Effects of sulphur deposition on lake chemistry in Ontario, Canada. Nature 333:340–343.

Olsen, T.M., D.M. Lodge, G.M. Capelli, and R.J. Houlihan. 1991. Mechanisms of impact of an introduced crayfish (*Orconectes rusticus*) on littoral congeners, snails, and macrophytes. Canadian Journal of Fisheries and Aquatic Sciences 48:1853–1861.

Rabeni, C.F., K.J. Collier, S.M. Parkyn, and B.J. Hicks. 1997. Evaluating techniques for sampling stream crayfish (*Paranephrops planifrons*). New Zealand Journal of Marine and Freshwater Research 31:693–700.

Reid, R.A., and S.M. David. 1990. Crayfish distribution and species composition in Muskoka and Haliburton lakes. Report DR 90/1. Ontario Ministry of the Environment, Dorset, Ontario. 71 p. (ISBN 0-7729-6560-9)

Reid, R.A., K.M. Somers, and S.M. David. 1995. Spatial and temporal variation in littoral-zone benthic invertebrates from three south-central Ontario lakes. Canadian Journal of Fisheries and Aquatic Sciences 52:1406–1420.

Richards, C., F.J. Kutka, M.E. McDonald, G.W. Merrick, and P.W. Devore. 1996. Life history and temperature effects on catch of northern orconectid crayfish. Hydrobiologia 319:111–118.

Rorer, W.E., and G.M. Capelli. 1978. Competitive interaction between two Mountain Lake crayfish species with life history notes. Virginia Journal of Science 29:245–248.

Rusak, J.A., N.D. Yan, K.M. Somers, and D.J. McQueen. 1999. The temporal coherence of zooplankton population abundances in neighboring north-temperate lakes. American Naturalist 153:46–58.

Shaw, M.A., I.J. Davies, E.A. Hamilton, A. Kemp, R. Reid, P.M. Ryan, N. Watson, W. White, and K.M. Murphy. 1995. The DFO national LRTAP biomonitoring programme: baseline characterization 1987–1989. Canadian Technical Report of Fisheries and Aquatic Sciences number 2032.

Shaw, M.A., S. Geiling, S. Barbour, I.J. Davies, E.A. Hamilton, A. Kemp, R. Reid, P.M. Ryan, N. Watson, and W. White. 1992. The Department of Fisheries and Oceans National LRTAP biomonitoring programme: site locations, physical and chemical characteristics. Canadian Technical Report of Fisheries and Aquatic Sciences Number 1875.

Somers, K.M. 1997. Power analysis: a statistical tool for assessing the utility of a study. Report PIBS 3544E. Ontario Ministry of the Environment, Dorset, Ontario. 35 p. (ISBN 0-7778-6958-6)

Somers, K.M., and R.H. Green. 1993. Seasonal patterns in trap catches of the crayfish *Cambarus bartoni* and *Orconectes virilis* in six south-central Ontario lakes. Canadian Journal of Zoology 71:1136–1145.

Somers, K.M., R.A. Reid, S.M. David, and R. Ingram. 1997. Are the relative abundances of orconectid crayfish better indicators of water-quality changes than cambarid abundances? Freshwater Crayfish 11:249–255.

Somers, K.M., and D.P.M. Stechey. 1986. Variable trappability of crayfish associated with bait type, water temperature and lunar phase. American Midland Naturalist 116:36–44.

Stephenson, M., G. Mierle, R.A. Reid, and G.L. Mackie. 1994. Effects of experimental and cultural lake acidification on littoral benthic macroinvertebrate assemblages. Canadian Journal of Fisheries and Aquatic Sciences 51:1147–1161.

Stuecheli, K. 1991. Trapping bias in sampling crayfish with baited funnel traps. North American Journal of Fisheries Management 11:236–239.

Taylor, C.A., and M. Redmer. 1996. Dispersal of the crayfish *Orconectes rusticus* in Illinois, with notes on species displacement and habitat preference. Journal of Crustacean Biology 16:547–551.

Van Belle, G., and J.P. Hughes. 1984. Nonparametric tests for trend in water quality. Water Resources Research 20:127–136.

Westman, K., O. Sumari, and M. Pursianinen. 1978. Electric fishing on sampling crayfish. Freshwater Crayfish 4:251–256.

Whitledge, G.W., and C.F. Rabeni. 1997. Energy sources and ecological role of crayfishes in an Ozark stream: insights from stable isotopes and gut analysis. Canadian Journal of Fisheries and Aquatic Sciences 54:2555–2563.

Wilson, K.A., J.J. Magnuson, D.M. Lodge, A.M. Hill, T.K. Kratz, W.L. Perry, and T.V. Willis. 2004. A long-term rusty crayfish (*Orconectes rusticus*) invasion: Dispersal patterns and community change in a north temperate lake. Canadian Journal of Fisheries and Aquatic Sciences 61:2255–2266.

Yang, Y., R.A. Monserud, and S. Huang. 2004. An evaluation of diagnostic tests and their roles in validating forest biometric models. Canadian Journal of Forestry Research 34:619–629.

Yu, Y.-S., S. Zou, and D. Whittemore. 1993. Non-parametric trend analysis of water quality data of rivers in Kansas. Journal of Hydrology 150:61–80.

3.4 Aquatic Invasive Species in Canada – An Action Plan

S. Cosens

The World Conservation Union rates invasive alien species as the second worst threat to biodiversity after habitat loss. World leaders have recognized the threat posed by invasive alien species since 1992, when they agreed on the UN Convention on Biodiversity. In response to the UN Convention, Canada developed the 1995 Canadian Biodiversity Strategy, which recognized the need to conserve biodiversity and promote the sustainable use of biological resources through increased understanding, legislation, incentives, and other means. In it, the federal, provincial, and territorial governments expressed a commitment to take all necessary steps to prevent the introduction of harmful alien species and eliminate or reduce their effects on ecosystems.

In September 2001, federal, provincial, and territorial ministers of forests, fisheries and aquaculture, endangered species, and wildlife identified invasive alien species as a priority, calling for the development of a Canadian plan to deal with the threat.

Later that year, a national workshop brought together stakeholders to determine the basic approach and underlying principles for the Canadian plan. A blueprint for the Canadian plan was approved at the Ministers' meeting in September 2002. The Ministers also created specific working groups to cover issues related to aquatic species, terrestrial animals, terrestrial plants, and leadership and coordination.

The Aquatic Invasive Species Task Group developed the Canadian action plan for aquatic invasive species (AIS). The task group includes representatives from Fisheries and Oceans Canada (DFO), every province and territory, as well as special advisors from Transport Canada, Environment Canada, and the Department of National Defense. A key objective under DFO Science's current priority of supporting ecosystem-based management is that of looking at the impacts of AIS.

Management Issues. Efforts to resolve AIS problems are complicated and the solutions often involve trade-offs. For example, allowing a species to spread may irreversibly alter the ecosystem but efforts to limit its spread may require the use of toxic chemicals, hamper trade in certain commodities, or increase shipping costs. Management strategies must be based on an analysis of the potential risks and benefits of specific actions relative to environmental and economic interests.

Although primary responsibility and authority, within the Federal Government, rests with DFO and Environment Canada, management actions can also involve Transport Canada, Industry Canada, the Canadian Food Inspection Agency, the Canadian Border Services Agency, Health Canada, and others. Provincial and territorial governments share responsibility, as do organizations such as the International Joint Commission and the Great Lakes Fishery Commission. Industry, a variety of non-government organizations, Aboriginal peoples, and the general public are also involved.

Strategic Approach. Rather than dealing individually with hundreds of unwanted species that are or could become established in Canada, the most effective approach to controlling AIS is thought to involve managing the pathways or vectors through which AIS either enter Canadian waters or spread within the country. In consultation with stakeholders, seven key pathways have been identified:

- shipping
- recreational and commercial boating
- the use of live bait
- the aquarium/water garden trade
- live food fish
- unauthorized introductions and transfers
- canals and water diversions.

Strategies required to respond to the threat of AIS apply across pathways and species and can be harmonized between jurisdictions. These include:

- legislation, regulation, and compliance
- risk management (risk assessment, early detection, and rapid response)
- engagement of Canadians (stewardship, education, and awareness)
- science (monitoring, research, and risk analysis).

There is currently a shortage of knowledge about the biology of invasive species, their environmental, social, and economic effects, as well as the most effective tools and procedures to deal with them. There is a need for predictive rather than reactive management of AIS, which involves using risk assessment tools and models and developing new ones as needed. Science support is needed for resource-based decision-making, including the development of policy, legislation, and programs. Best practices in controlling the spread of invasive species have yet to be developed.

To support a risk-based approach to setting research, monitoring, and management priorities, a National Centre of Expertise for risk assessment has been established at the Canada Centre for Inland Waters (CCIW) in Burlington, Ontario. Originally referred to as BRACE (Biological Risk Assessment Centre of Expertise), the Centre[3] is run out of the Great Lakes Laboratory of Fisheries and Aquatic Science, with a management and reporting structure as follows:

- Directorate with Nick Mandrak as Director and Becky Cudmore (proposed) as the National Coordinator.
- The National Executive Committee (NEC) is chaired by the BRACE Director, and membership consists of the National Coordinator plus a representative from each region (the Central and Arctic Region of DFO has three) and national headquarters. For the most part, the NEC membership is from management staff, although some regions have appointed a scientist working on AIS issues.
- The Expert Network consists of risk assessment and AIS experts from within and outside DFO (e.g., researchers involved with the National Science and Engineering Research Council AIS Network).

The terms of reference for BRACE were written in autumn of 2005. The Centre addresses biological risk assessment only and, for the near future, will only be conducting risk assessments for AIS. Risk assessment standards will be peer-reviewed following the National Advisory Process. Workshop proceedings and all advisory documents will follow the BRACE peer-review procedure, be approved by the BRACE Directorate, and will be published by the Canadian Science Advisory Secretariat (CSAS). Outreach to the general public will be done through a risk assessment tracking page on the CSAS website. Operation of the Centre began as of April 2006. AIS research and monitoring are not part of the Centre's terms of reference.

Next Steps. A regional workshop is being planned for CCIW in October 2006 to set priorities for monitoring.[4] Goals are to:

- establish a list of priority species for monitoring
- identify key pathways for introduction
- identify priority locations for monitoring activities
- identify ongoing AIS monitoring.programs.underway in the Central and Arctic Region.

Risk assessments planned for 2006/2007 include:

- East Coast tunicates (lead: to be determined)
- West Coast tunicates (lead: Tom Therriault)
- National pathways of live food fish, aquarium, water garden, and baitfish (leads: Nick Mandrak, Becky Cudmore)
- Ponto-Caspian fishes to Great Lakes (leads: Nick Mandrak, Becky Cudmore).

[3]Now called CEARA (Centre of Expertise on Aquatic Risk Assessment).

[4]This workshop was held as planned.

4.0 Results

4.1 Impacts/Risks of Rusty Crayfish Invasion

The large group discussion on day 1 of impacts/risks of rusty crayfish invasion identified eight potential problems for attention (Table 6). The information presented in Table 6 should be useful in deciding if an impact warrants further attention, if something can be done about already invaded or about-to-be invaded systems, potential partners, and possibilities for monitoring.

4.2 Day 1 – Lake of the Woods

4.2.1 Invasive Crayfish: A Lake of the Woods Perspective

T. Mosindy

Introduction. This presentation briefly describes the Lake of the Woods study area, along with the operational organization and role of the Lake of the Woods Fisheries Assessment Unit (FAU), OMNR. It also presents the known distribution of various crayfishes, including invasive species in Lake of the Woods, and outline a draft proposal to monitor crayfish species in the Lake during the summer of 2006.

Study Area. Lake of the Woods is located in northwestern Ontario where Ontario, Minnesota and Manitoba meet. It forms part of the Winnipeg River–Nelson River basin, which eventually empties into Hudson Bay. The basin upstream of Lake of the Woods drains >7 million ha, eastwards along both sides of the US–Canada border to the height of land separating it from the Great Lakes basin. At this point, the headwaters are <100 km from Lake Superior. The south end of Lake of the Woods is located <100 km from the headwaters of the Mississippi basin and the Red River–Nelson River basin. The Lake's location and its popularity as a tourism destination make it especially vulnerable to introductions of aquatic organisms.

Lake of the Woods is the second largest lake inland of the Great Lakes in Ontario, next to Lake Nipigon. The Lake is about 105 km long and 90 km wide, covering >384,000 ha of which two-thirds lies in Ontario. The Rainy River, which flows in at the extreme southeastern corner of the Lake, supplies >70% of the inflow. Other rivers and streams flowing into the Lake are much smaller in size and many are seasonally intermittent. The Lake drains northward through three outlets at Kenora, which join to form the Winnipeg River. Lake levels have been

Table 6. Preliminary list of rusty crayfish impacts and risks (as gathered from large group discussions on day 1; prepared by J. Stewart).

Problem	Description	Impact
Loss of macrophyte beds	The loss of macrophyte beds is an established impact of a rusty crayfish invasion. Macrophyte beds are important for energy capture, stabilizing soft sediments, and as a nursery habitat for small fish. Some lake users may see the removal of weeds as a benefit.	Biological
Species replacement	Rusty crayfish will eventually dominate other crayfish species, replacing them in an ecosystem.	Biological
Fish reproductive success	Emerging research is showing that the rusty crayfish can impact the reproductive success of some fish species. The crayfish can displace fish from spawning habitats and then consume eggs.	Biological
Fish species loss	Rusty crayfish can lead to a reduction of certain fish species, which would have a direct impact on the recreational and commercial fisheries in an area.	Biological, socioeconomic
Gill net impact	In areas of high density, the rusty crayfish will attack fish caught in gill nets, which would impact both the quantity and quality of the catch from nets set for both research and commercial purposes.	Biological, socioeconomic
Biodiversity concerns	This species has the potential to disrupt ecosystems and alter the biodiversity of aquatic ecosystems.	Biological
Tourism impact	Rusty crayfish can have a large impact on the tourism industry. For example, outfitters and lodge operators would suffer economic losses if sport-fish populations declined and sport-fishing enthusiasts were no longer drawn to the area. Potential spinoff impacts of tourism decline include a reduction of tourism dollar circulation in local communities and a reduction in service-industry jobs.	Socioeconomic
Loss of traditional resources	A reduction in fish populations would impact Aboriginal communities socioeconomically due to the loss of a local food and income source.	Biological (loss of resources), socioeconomic (loss of food/income)

controlled since the mid-1890s by hydropower dams at the two principal outlets. Water levels fluctuate between 0.9–1.2 m annually. The dams raised historic Lake levels by about 0.9 m (Lake of the Woods Control Board 2002).

Lake of the Woods is extremely irregular in shape. The Aulneau Peninsula, which forms a large landmass close to the centre of the Lake, essentially divides it into northern and southern portions. Although all of the Lake is located on the Canadian Shield, the southwestern portion was once part of glacial Lake Agassiz (Schwartz and Thiel 1963), which left a rich bed of lake sediments on the surrounding land and lake bottom. This geological history has had a major influence on the Lake's physical, chemical, and biological characteristics. The southern portions of the Lake have a much gentler relief than the northern and eastern areas, which lie directly on the heavily glaciated Shield. The landscape of the southern half of the Lake is characterized by few islands and wide-open stretches of water, but the northern and eastern shorelines are steep and rocky with numerous indented bays and thousands of small rocky islands. There are >10,000 km of mainland and island shoreline on the Ontario side alone.

Lake of the Woods is an extremely complex lake. It can be viewed as seven or eight separate lakes or lake-like basins. The Ontario waters of the Lake have been arbitrarily divided into seven sectors for management and assessment purposes based on observed differences in physical and chemical characteristics, fish communities, and user-group patterns on the Lake (Figure 8).

Both physical and chemical characteristics vary considerably between sectors. The northern sectors tend to be deeper, clearer, and less productive than the southern ones. Overall, the Lake is relatively shallow, on average only 7.9 m deep. Mean depths range from about 4.9 m in Sector 4 (Sabaskong Bay) to 13.1 m in Sector 3 (Whitefish Bay). Secchi readings range from 1.1 m in Sabaskong Bay to >5 m in Whitefish Bay. Total dissolved solids (TDS) for most sectors average around 86–87 mg/L, ranging from 67 mg/L in Whitefish Bay to 126 mg/L in Sector 7 (Shoal Lake). Total phosphorus concentrations in the spring average from 9.8 µg/L in Whitefish Bay to almost 29 µg/L in US waters of the Big Traverse. Alkalinities range from 35 mg/L in Whitefish Bay to >51 mg/L in Little Traverse Bay (south Sector 6). Calcium concentrations average between 11.5–13.5 mg/L for most sectors, except Shoal Lake where mean concentrations of 19 mg/L have been recorded.

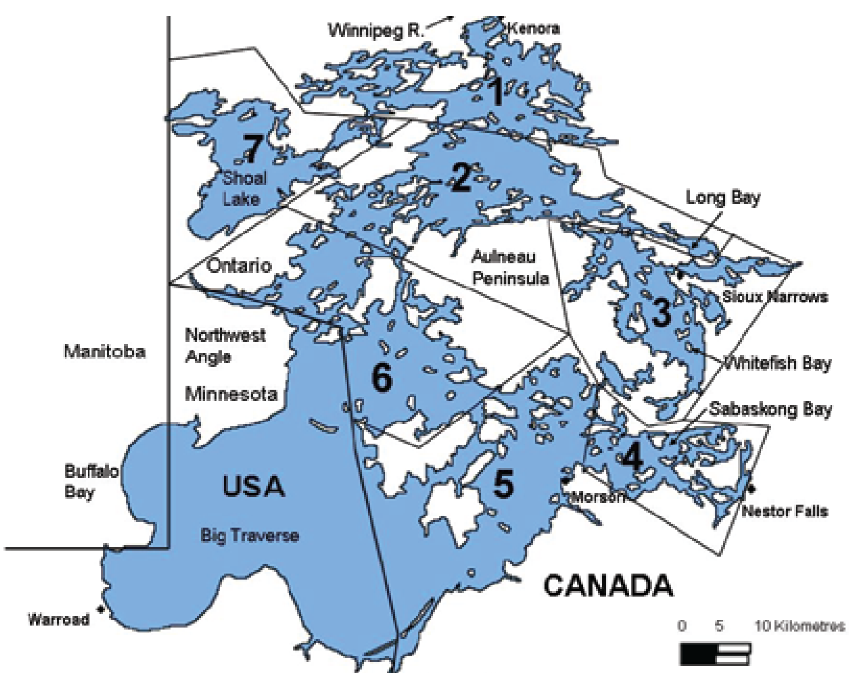


Figure 8. Lake of the Woods showing division into sectors.

Lake of the Woods has one of the richest fish assemblages of any lake in northern Ontario, with >54 species identified. Almost all sectors of the Lake have a percid-dominated fish community. Native species include walleye (*Sander vitreus*), sauger (*Sander canadensis*), yellow perch (*Perca flavescens*), white sucker (*Catostomus commersoni*), cisco (*Coregonus artedi*), lake whitefish (*Coregonus clupeaformis*), lake trout (*Salvelinus namaycush*), northern pike (*Esox lucius*), muskellunge (*Esox masquinongy*), and lake sturgeon (*Acipenser fulvescens*). Lake trout, representing the coldwater fish community, are only resident in Whitefish Bay and the Clearwater Bay area at the northwest corner of the Lake. A number of species are not native to the Lake but were introduced intentionally and have become well-established sport and commercial species. These species include members of the centrarchid family such as smallmouth bass (*Micropterus dolomieu*), largemouth bass (*Micropterus salmoides*), and black crappie (*Pomoxis nigromaculatus*). Only rock bass (*Ambloplites rupestris*) and pumpkinseed (*Lepomis gibbosus*) are native members of this family in the Lake. Other introduced fish species include banded killifish (*Fundulus diaphanus*) and rainbow smelt (*Osmerus mordax*), the most recent introduction. Smelt came from further upstream in the basin, probably from introductions into lakes in the Quetico area in the late 1950s. They were first identified at the mouth of the Rainy River in 1991 and were caught in the screens of Norman Dam at Kenora in the spring of 1994. They had become established in all parts of the Lake, including Shoal Lake and Whitefish Bay, by 1999. Their abundance is increasing, and the fish community along with the rest of the ecosystem is still adjusting to their presence.

Lake of the Woods FAU. The primary role of the Lake of the Woods FAU is to provide information and transfer knowledge to support management of the Lake of the Woods fishery at a local level, and to support the OMNR fisheries management program. This unit is one of three FAUs in the northwest region of Ontario, which are assigned to Northwest Science and Information, Science and Information Resources Division in Thunder Bay.

The Lake of the Woods FAU is also part of a provincial network of 11 FAUs located on lakes throughout Ontario, including the Great Lakes. Although their primary focus is on the fish community, FAUs also monitor other aspects of the aquatic ecosystem related to the fishery. Both long-term monitoring and trend-through-time analysis are used to detect changes in stress factors that act on a fish community and community indicators or variables that describe the fish community over time. One of the primary functions of FAUs is to monitor the response of fish communities to six sources of stress: exploitation, physical alterations, introductions, water-level fluctuations, acidification, and eutrophication. Exploitation is recognized as the principal stressor on the fish community of Lake of the Woods but other stressors are involved. FAUs also regularly collect data on a variety of physical, chemical, and biological parameters to identify changes in the aquatic ecosystem over time. Community monitoring not only involves sampling the fish community but also other ecosystem components including primary and secondary production.

The fisheries assessment program on Lake of the Woods is set up to monitor two adjacent sectors on the Lake for two consecutive years and then move on. In this way, a full rotation of the Lake is completed every six years. Shoal Lake has been monitored separately. Lakewide programs are also conducted, such as the open-water creel survey, which covers all the Ontario waters of the Lake every three years. Baseline studies of Lake of the Woods were completed during the 1960s by OMNR, and the Lake of the Woods FAU program has been run annually since the late 1970s. Fisheries information on the Lake is summarized and reported in the Ontario–Minnesota Boundary Waters Fisheries Atlas every six years.

Invasive Crayfish in Lake of the Woods. The incidence of crayfish, especially the rusty crayfish (*Orconectes rusticus*), in FAU sampling gear (e.g., fish community index gill nets and beach seines) has increased over the last three decades. Numbers of these crayfish have increased to the extent that they pose a major inconvenience when sampling gill net catches. Besides the extra time required to disentangle them, crayfish often remove the scales from larger fish and consume smaller ones caught in the nets before processing can occur.

Rusty crayfish were first reported on Lake of the Woods from the Whitefish Bay–Long Bay area (Sector 3, Figure 8), just east and north of Sioux Narrows in the 1960s (Crocker and Barr 1968). Based on catches in FAU nets from 1968–2000, rusty crayfish appear to have spread throughout Whitefish Bay and northwards along the eastern shore to Kenora (Sector 1) and westwards along the Barrier Islands. By the early 1990s, rusty crayfish had been observed as far west as Big Narrows near Portage Bay (Sector 2) and as far south as Hay Island in Sabaskong Bay. This latter site is close to Turtle Portage, which had remained open as a navigable channel between Whitefish and Sabaskong Bays until the early1990s. Rusty crayfish had not been observed in Shoal Lake, the Ptarmigan and Clearwater Bay area (Sector 1), and most of the area south of the Aulneau Peninsula including the American waters. From 2000–2005, their distribution appeared to have expanded in the Lake, northwards around Kenora and westwards into Ptarmigan Bay past Brule Point. Rusty crayfish were also found in FAU sampling gear south of Big Narrows at locations in Monument Bay and the Monkey Rocks near the Northwest Angle (Sector 6). Their distribution also appeared to have expanded in Sabaskong Bay, south and west from Hay Island. There were still no reports of rusty crayfish from Shoal Lake, the Clearwater Bay area, and most of the waters south of the Aulneau Peninsula to the mouth of the Rainy River and the Big Traverse.

Two other non-native crayfish, the papershell (*O. immunis*) and the northern clearwater (*O. propinquus*) have been observed in Lake of the Woods. The papershell was reported from Snake Bay on the eastern side of Whitefish Bay sometime after 1975 (F.W. Schueler, personal communication, in Dubé and Renaud 1994). Several specimens were recovered from FAU gill nets during 2005, providing evidence that papershell crayfish had expanded their distribution in Whitefish Bay as far south as Alfred Inlet. Although the northern clearwater crayfish was first reported in Whitefish Bay near Sioux Narrows in the mid 1960s (F.W. Schueler, personal communication, in Dubé and Renaud 1994), its present distribution remains unknown.

Draft Monitoring Plan for Lake of the Woods – 2006. A draft plan to monitor for invasive crayfish on Lake of the Woods during the summer of 2006 was proposed with the following objectives:

- to capture the invasion fronts
- to determine the relative abundance of crayfish by species and by preferred habitat
- to identify factors that might influence the direction and invasion rate.

Lake of the Woods covers a large area, so there is a need to focus sampling efforts on a smaller spatial scale, given the time and resources available. It was recommended that sampling during 2006 be concentrated around known invasion fronts, as indicated from current FAU distribution maps for the native virile crayfish (*O. virilis*) and the invasive rusty crayfish.. Sampling could begin in areas where only virile crayfish currently exists and proceed to where both species co-exist or where only rusty crayfish are found.

The draft plan also recommended that sampling be stratified based on three habitat types: rock, macrophytes, and detritus. Shoreline areas would be divided into 500-m-long sections that would represent primary sampling units. Available habitat within these units would be further subdivided into smaller 50-m-long homogenous segments. Sampling crews would randomly select one site of each habitat type to sample within each 500-m shoreline section.

It was recommended that monitoring should occur during the mid-summer months of July and August, assuming that these months represent the most stable activity period for both the virile and rusty crayfish given the effects on behaviour of temperature, reproductive cycle, and moulting. Surface water temperatures on Lake of the Woods during this period are usually >20°C.

Sampling protocols would generally follow methods outlined in Somers and Green (1993) as follows:

- traps set overnight – 18–24 h
- 9–12 trap lines per night
- 6 traps per trap line
- baited with one cat-food-filled photo-film canister per trap
- set perpendicular to shoreline
- minimum 0.5–1 m depth
- avoid docks and developed areas (e.g., cottage properties)
- marker buoys at both ends of a line
- crayfish processed and released alive at each trap site.

Information to record:

- location of both ends of each trap line using GPS (global positioning system)
- habitat type
- lift and set times
- depths at both ends and mid-point of a line
- surface temperatures at deepest end of a line
- number of crayfish of each species in each trap (1–6)
- size (carapace length in mm) and sex of each individual
- water quality – Secchi depth and conductivity included in sampling protocol.

Auxiliary sampling could include:

- beach seining at FAU index beach seine sites located close to the general sampling areas
- habitat mapping to supplement FAU habitat maps (e.g., shoreline substrate type, macrophyte cover % and type)
- more detailed water-quality sampling in focal areas of the study
- sub-sampling crayfish for other analyses (e.g., stable isotopes to determine changes in food webs in areas dominated by one or more species)
- mark–recapture studies at the invasion front to identify invasion rates.

References

Crocker, D.W., and D.W. Barr. 1968. Handbook of the crayfishes of Ontario. Royal Ontario Museum Life Sciences Miscellaneous Publication. University of Toronto Press, Toronto, Ontario. 158 p.

Dubé, J., and M. Renaud. 1994. Premières mentions de l'écrevisse *Orconectes immunis* au Québec. Canadian Field-Naturalist 198:337–340.

Lake of the Woods Control Board. 2002. Managing the water resources of the Winnipeg River drainage basin. Lake of the Woods Control Board Brochure 2002/11. 20 p.

Schwartz, G.M., and G.A. Thiel. 1963. Minnesota's rocks and waters. University of Minnesota Press, Minneapolis, Minnesota. 366 p.

Somers, K.M., and R.H. Green. 1993. Seasonal patterns in trap catches of the crayfish *Cambarus bartoni* and *Orconectes virilis* in six south-central Ontario lakes. Canadian Journal of Zoology 71:1136–1145.

4.2.2 Small Group Discussions

The following material reports the answers by the three small groups to the four questions asked about the proposed Lake of the Woods monitoring plan (see Appendix E for full questions/guidelines).

4.2.2.1 Question 1

What are the strengths and weaknesses of the draft monitoring plan?

Group 1 (Reporter: R. Vinebrooke)

1. The perceived primary strength of the plan was the proposed use of a sampling protocol that had already been rigorously tested and refined by the Dorset group. Specifically, use of the stratified random design can potentially help ensure representative sampling of the distribution of rusty crayfish.

2. However, a concern involved the feasibility of scaling up to a large lake a sampling method that was originally designed for use only in small lakes (for further details see Question #2, Group 1 below).
3. Another concern was the lack of well-defined objectives. It was unclear whether the primary goal of the monitoring plan was to assess the distribution or impact of rusty crayfish, or both.
   a. It was recommended that more explicit objectives be identified because their nature will directly influence the sampling method.
   b. Also, more defined objectives will better facilitate future public outreach efforts.

Group 2 (Reporter: B. Hann)

1. Strengths
   a. Consistency of sampling methods is a great improvement in approach. Using the Ontario Ministry of the Environment (OME) protocol will permit comparison with other lakes that have been intensively studied.
   b. Calibration between old methods vs new methods is needed. Try using both methods at some sites to permit cross-calibration.
   c. Use previously collected occurrence data to get an idea of the rate of advance of the invasion front.
2. Weaknesses
   a. A large expenditure of effort is required if all three invasion fronts are to be studied this summer. How wide is the invasion front? Sample across the invasion front, from the region where there are lots of rusty crayfish to areas where there are no rusty crayfish.
   b. Is the intensity of sampling sufficient to have a reasonable probability of collection of a species when it is rare?
3. Gaps/improvements in the draft plan
   a. Can you identify crayfish from fish gut contents?
   b. Are there gaps in sightings from year to year?
   c. Can you concentrate efforts on one invasion front to get a better understanding (e.g., in Clearwater Bay) of where the invasion front is located?
   d. What species (native or exotic) are typical of different habitat types?
   e. Can you separate characteristics of invasion fronts from selection of habitat types by species?
   f. Can you limit sampling in advance of a front?
   g. Can you incorporate active sampling (e.g., dip nets, trawls) to increase the probability of detecting a species that is rare?

Group 3 (Reporter: K. Somers)

1. Strengths
   a. Data can be shared/compared with others (e.g., integration with the Department of Natural Resources).
   b. The program can build on earlier methods used.
2. Weaknesses
   a. The methods to be used have been tested on small lakes; success on a large lake is not guaranteed (e.g., problems with storms?).
   b. Gear efficiency is unknown (e.g., too many traps may compete with each other).
   c. Alternate methods should be considered as a backup (i.e., active gear vs passive gear issues).
   d. What will the supplementary data collected be used for (e.g., do you need to measure all animals)?
   e. The spatial location and extent of the fronts are unknown (therefore, focus either on the fronts or previously uninvaded areas).
3. "Neutral" comments/suggestions for improvements
   a. The sampling protocol should be adaptive.
   b. Consider other methods:
      i. trawling (at night – safety) to get a broader picture of distribution and, especially, locating front(s)
      ii. sample deeper water having softer sediments
      iii. use "entangling" gear like gillnet mesh
      iv. use other types of traps (i.e., problems storing non-stackable traps).
   c. Consider using a volunteer network (to aid in sampling).

4.2.2.2 Question 2

Is the intensity of sampling sufficient to meet the monitoring objectives?

Group 1

1. Inadequate sampling effort resulting in poor representation of the distribution of rusty crayfish was identified as a key potential shortcoming of the proposal.
2. It was recommended that power analyses using either previously collected data, or during 2006, be conducted to determine the adequacy of the proposed sampling effort.
3. Limited sampling effort should focus more on "non-invaded" areas than on invaded areas for several reasons:
   a. to confirm the status of each area because previous sampling may have been inadequate to detect the presence of rusty crayfish

b. to provide "baseline" information regarding the ecological conditions of non-invaded areas against which the effects of crayfish in other areas can be compared
c. doubtful whether previous sampling efforts provided sufficient detection and resolution to truly identify discrete "invasion fronts".

Group 2

1. Do mark–recapture at the invasion front (e.g., Ptarmigan Bay)? Need development of tools to predict behaviour. There is probably too much work during the first year.
2. Logistically select one invasion front (e.g., Ptarmigan Bay–Clearwater Bay) and concentrate efforts there (close to Kenora, etc.).
3. What would be lost if efforts were to be concentrated on one invasion front (e.g., Clearwater Bay)? US counterparts are monitoring the southern end of Lake of the Woods (e.g., Big Traverse Bay). Is there any unique habitat found at the other two fronts that is not found in Clearwater Bay?
4. Measure the gradient in environmental parameters across the invasion front? Known distribution of rusty crayfish in oligotrophic conditions; is it moving toward more eutrophic conditions?
5. Can old data be used in the context of new data? What about calibration of methods (e.g., trap lines set adjacent to index net sites for sampling fish communities)?

Group 3

1. Study personnel need training regarding taxonomic identification of specimens (save representative specimens).
2. Trap density (i.e., too many vs too few) may be an issue.
3. What will the resultant data be used for? For example, will length data be used for determination of average size or size distributions? Perhaps composition of the catch is more important than numbers.
4. Do you need to sample bedrock or sand to prove no crayfish are present in these habitats?
5. There are no "control" sites (i.e., all *O. rusticus* or all *O. virilis*) included in the program.
6. Will sites be sampled over time to show temporal changes?
7. Monitoring fronts:
    a. How many should be monitored–all three?
    b. Will enough animals be captured to detect movement of a front?

4.2.2.3 Question 3

What are the key research needs for Lake of the Woods and how would meeting these needs affect short- and long-term monitoring plans?

Group 1

1. Our group believed that it was important to examine the linkage between water quality and rusty crayfish:
    a. Specifically, bioturbation of littoral sediments and elimination of sediment-stabilizing macrophytes by rusty crayfish was hypothesized to increase nutrient release to surface waters.
    b. Conversely, anthropogenic increases in lake productivity (e.g., southern Lake of the Woods basin) could possibly enhance invasion by crayfish and other species that originate from more productive temperate areas.
2. Another identified research need was the linkage between the productive capacity of Lake of the Woods for harvestable fish and rusty crayfish:
    a. Rusty crayfish could negatively impact fish via predation (e.g., eggs and larval stages) and competition for benthic prey.
    b. Certain benthivorous fish could benefit from increased crayfish production via increased food availability.
3. More information was also needed regarding the two key factors (habitat availability and abundance of predatory fish) that regulate crayfish population growth in Lake of the Woods.
4. Identification of key dispersal vectors and pathways in Lake of the Woods were also considered important to modeling further invasion of the lake and the Winnipeg River system.

Group 2

1. What are the habitat preferences with regard to species?
2. Is the Winnipeg River a block to transit?
3. Are there scale effects (i.e., are neighbouring small, less-complex Shield lakes vulnerable)?
4. Does invasion occur against the flow (i.e., up-river from the Winnipeg River into adjacent lakes)?
5. Is there a literature review, and have knowledge gaps been identified?

Group 3

1. Is someone monitoring change in status of macrophyte beds?
2. Is there a potential contaminants problem (linkage to Environment Canada studies in BC)?
3. Will there be impacts on lake sturgeon?

4. Will fish diets change (*O. virilis* to *O. rusticus* in diet? Change in benthos eaten)?
5. Will there be changes in food webs? (Archive samples – including predators – for future stable isotope studies; see point d.)
6. Will there be a change in energy flow (i.e., energy sequestration in *O. rusticus*)?

4.2.2.4 Question 4

Who are the likely key supporters or partners in monitoring, research, and management processes for the rusty crayfish, and what role would each of these supporters/partners play?

Group 1

1. Environment Canada, OME, and the Lake of the Woods Cottage Association were all identified based on their common interest in water quality.
2. The OMNR, anglers and hunters, outfitters, and tourism associations were identified based on their interest in recreational fisheries.
3. Ducks Unlimited and the Canadian Wildlife Service (Environment Canada) were considered possible partners because of the potential indirect impacts of rusty crayfish on waterfowl habitat.

Group 2

Lake of the Woods District Property Owners Association Inc. (LOWDPOA)

Lake Partners Program (OME)

Lodge owner associations

Fishing associations

Tourist outfitters

Anishinaabeg of Kabapikotowangag Resource Council (AKRC), First Nations (gill netting on Winnipeg River)

Manitoba Hydro (Research and Development Department)

Ontario Power Generation

Cottagers' associations (e.g., Whiteshell, Manitoba Cottage Owners' Association)

Baitfish Association

Liquor Control Board of Ontario (LCBO)

Commercial Fishers' Federation

Manitoba Department of Natural Resources

OMNR

DFO

Academia (National Science and Engineering Research Council [NSERC])

Tembec, Pine Falls

Group 3

Aboriginal groups

Ontario Baitfish Association

LOWDPOA and other volunteer groups[5]

Lake of the Woods Water Quality Sustainability Foundation[5]

Environment Canada (water quality, contaminants, benthic community)[6]

US Department of the Interior (Voyageur National Park)[6]

Manitoba Government (supporting role)

OME[6]

International Joint Commission (international waters)[6]

Minnesota Department of Natural Resources[6]

4.2.3 Summary of Large Group Discussion

Several participants remarked at the similarity in comments produced by the three small groups. The discussion in plenary could be organized under four subheadings: 1) the focus of the sampling program, 2) the need to remain adaptive, 3) the details of the sampling program, and 4) possible partners/volunteer networks. T. Mosindy presented a revised sampling program, but there was so much discussion surrounding his points that the matter remained unresolved by the end of the session (but see Section 5.1).

4.2.3.1 Focus of the sampling program

The group debated the merits of an extensive vs an intensive approach. Those in favour of an extensive approach argued that it was more important to limit the spread of the rusty crayfish (W. Momot) or reduce their density (M. Paterson) than to collect detailed data. Therefore, presence/absence data and relative abundance of species over a large area were more important than detailed population work in a smaller area. Those participants supporting intensive studies thought that, given the resources available, concentrating on specific habitats of high priority (e.g., small bays), areas specifically affected by rusty crayfish, or invasion fronts would be the best approach. Concentrating on an area severely affected by rusty crayfish would demonstrate to the public the extent of harm caused (and may be a lever for obtaining funding). In addition, concentration on identification of areas of high concern could lead to the development of interesting research questions. There seemed to be more support for an intensive rather than extensive focus, although only two participants offered a suggestion for specific study areas (in response to a request by M. Turner to name such areas): the eastern part of the Lake (R. Fudge, G. Olson). K. Somers may have found the middle road by suggesting that an extensive approach would be valuable to broaden interest and concern about the rusty crayfish problem in Lake of the Woods, perhaps resulting in funding support that would enable more detailed scientific studies.

[5]Public education, volunteer participation, and lobby functions

[6]Potential funding source

4.2.3.2 Need to remain adaptive

Several participants advised that the sampling protocol needed to be adaptive, especially because the amount of material that can be handled per day was unknown (T. Mosindy). In fact, the first year may be needed to figure out the sampling program (W. Momot). B. Hann felt that the protocols needed to be properly scaled, but that once figured out, the design should remain constant. T. Mosindy agreed with this last point.

4.2.3.3 Sampling program details

R. Vinebrooke suggested that a power analysis be done on existing data to determine the number of samples needed to achieve a known variability. Several participants were concerned that scaling up a sampling program developed for small lakes (i.e., the Dorset protocol) to a large lake may be troublesome, although small group 3 thought that the application of a well-developed protocol was a strength. All three small groups recommended that active sampling (e.g., trawls) accompany the passive sampling (i.e., traplines) being planned. The use of active sampling would test the validity of existing data, and calibrate the use of traplines (T. Mosindy). However, the main method used would be baited traplines stratified according to habitat. The possibility of sampling stomach contents of fish was raised again. Last, K. Somers advised on the importance of only collecting data to answer questions posed. Collecting such data will save considerable time. Maybe just the numbers of crayfish caught will suffice (cf. measuring and sexing specimens). There is a difference between collecting data for tens to hundreds of specimens in the Dorset lakes vs the possible numbers generated from Lake of the Woods.

4.2.3.4 Possible partners/networking

A few participants were impressed by the comprehensive list of possible partners produced by the small groups (especially small group 3). Not all of these potential partners will be able to provide financial support, but they can provide other kinds of support (F. MacDonald). Surprise was expressed that the LCBO appeared on the list from small group 2, but G. Olson reported that Banrock Station Wines, a client of the LCBO, committed >$1 million to restoration of Atlantic salmon in Lake Ontario. T. Mosindy wanted to use networking for a public education program on harmful crayfish in Lake of the Woods. Impacts from elsewhere in North America could be shown, with the message that people who use Lake of the Woods should care about the rusty crayfish threat.

4.3 Day 2 – Winnipeg River

4.3.1 Winnipeg River Sampling Program (D. Watkinson)

Introduction. The Winnipeg River is >250 km in length. It flows northwest from Lake of the Woods through predominately Canadian Shield for the first 150 km until it begins to cut through Lake Agassiz deposits. There are eight hydroelectric facilities on the Winnipeg River that effectively act as barriers to upstream movement. In July 2005, the first confirmed specimen of rusty crayfish (*Orconectes rusticus*) in the Winnipeg River was collected 8 km downstream of Lake of the Woods.

Methods. In 2006, we are initiating a sampling program to monitor the current distribution and abundance of crayfish in the Winnipeg River system. The first sampling reach will be between the Whitedog Falls and Pointe du Bois generating stations (Reach 1, Figure 9). If no rusty crayfish are sampled within Reach 1, the reach immediately upstream between Whitedog Falls and Norman generating stations, where rusty crayfish are known to occur, will be sampled (Reach 2, Figure 9). If rusty crayfish are found in Reach 1, sampling will be directed downstream to the two reaches between Pointe du Bois and Slave Falls generating stations (Reach 3, Figure 9), and between Slave Falls and Seven Sisters generating stations (Reach 4, Figure 9). Crayfish will be sampled in July and early August, when water temperatures are warmest and crayfish activity is at a maximum. Our budget allows for two, three-night sampling periods.

A modified Gee minnow trap will be used to sample the crayfish quantitatively (Somers and Green 1993). The traps will be baited with fish-flavoured cat food, placed in perforated film canisters, to allow crayfish detection of the bait. The following numbers of traps set apply to sampling in a single reach. However, the strategy may be adjusted depending on initial findings of crayfish distribution. Six traps will be evenly spaced 3 m apart on a single line and nine lines will be set each night. Thus, 54 traps will be set each of the three nights during the first sampling period (= 162 traps), and a total of 324 traps will be set over the two sampling periods.

Habitat will be assessed prior to setting the traps, and sampling will be limited to the most productive habitat for rusty crayfish. Traps will be set perpendicular to shore with a minimum depth of 0.5–1 m near shore and a maximum depth of 3–4 m off shore. Set times will vary from 14–24 h. Sampling locations will be selected so that flow is negligible (<10 cm/s). Sampling will also be restricted, when possible, to locations that are <1 km from the main channel of the river.

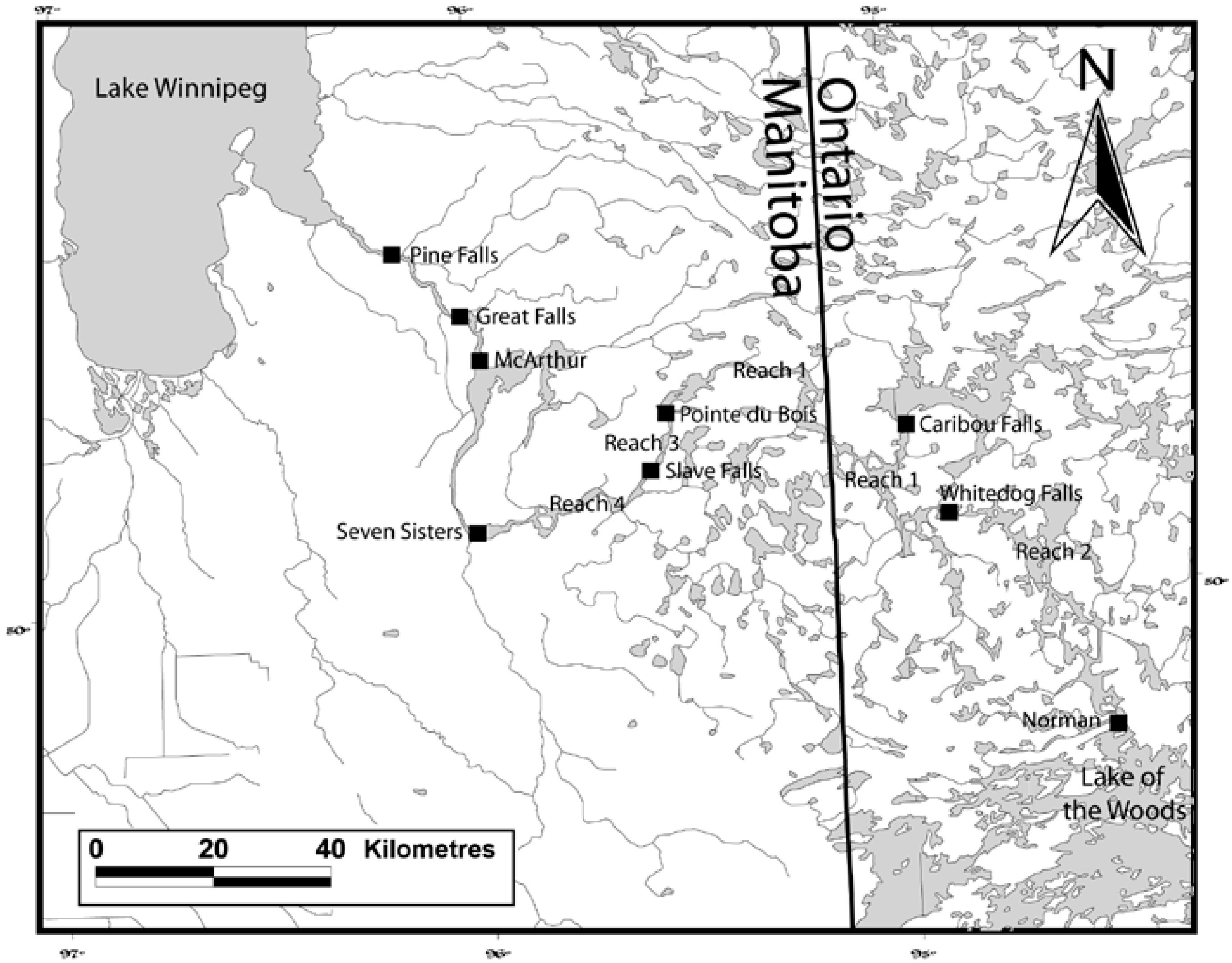


Figure 9. Reaches of the Winnipeg River to be sampled for rusty crayfish (Reaches are defined in the text).

Table 7. Data sheet for collection of rusty crayfish from the Winnipeg River.

Site #	Date (dd/mm/yy)
Waterbody	Time set
Location description	Time retrieved
Near shore	Water depth (m)
Latitude	Near shore
Longitude	Midpoint
Offshore	Offshore
Latitude	Water temperature (°C @1 m)
Longitude	Secchi depth (cm)
Collectors	Conductivity (µS/cm)
	Velocity (cm/sec)
	Substrate (%)

Trap	Species	Sex (M/F)

Trap	Species	Sex (M/F)

Active sampling will also be conducted during both daytime and nighttime hours using snorkeling equipment and small dip nets, and by electrofishing. Nighttime searching will be assisted by spotlights. Table 7 details the environmental variables we will measure at each sampling location and the additional site information to be recorded.

The following questions need to be answered because they will affect the sampling plan:

- How tolerant of current are rusty crayfish?
- If detection is the most important variable, then what habitat do we want to sample?
- How many traps are practical to set and retrieve in a day of sampling?
- Are there other sampling methods we should be considering?
- Do dispersion rates in a river differ from those in a lake? If so, what are the expected movement distances in a river?
- Will hydro facilities act as barriers to crayfish movement?

Future Sampling Plans. We will examine the results of the 2006 survey this winter to decide how to best approach the project for 2007. Successful identification of the invasion front will allow calculation of annual movement (providing sufficient funding is in place to continue annual surveys). Continued sampling may also identify mechanisms of invasion. For example, if rusty crayfish are distributed immediately upstream but not downstream of a hydro generating station, the dam may be acting as a barrier to downstream movement. If crayfish distribution is discontinuous, point-source introductions are likely occurring.

Reference

Somers, K.M., and R.H. Green. 1993. Seasonal patterns in trap catches of the crayfish *Cambarus bartoni* and *Orconectes virilis* in six south-central Ontario lakes. Canadian Journal of Zoology 71:1136–1145.

4.3.2 Small Group Discussions

The following material reports the answers by the three small groups to the four questions asked about the proposed Winnipeg River monitoring plan (see Appendix E for full questions/guidelines).

4.3.2.1 Question 1

What are the strengths and weaknesses of the draft monitoring plan?

Group 1

1. The proposed flexibility of the sampling plan was considered a strength given the high degree of uncertainty surrounding the presence of rusty crayfish in the river.
2. The perceived high spatial heterogeneity and large scale of the system together with severely limited sampling resources caused us to question the crayfish-detection capacity of the study.

Group 2

1. What is the goal for this summer? The invasion front is to be identified by using a hierarchical plan for studying the river. It's a good plan to section the river and assess the probability of crayfish being found, then adjusting the strategy depending on outcome. The sampling program starts in the middle of the Winnipeg River and moves upstream with negative sampling, i.e., the absence of rusty crayfish could be interpreted to mean that rusty crayfish have not gotten that far down the river or that they have not been found in the trapping effort.
2. Get hydro operators to check screens in the turbine area for the presence of crayfish.
3. Target backwaters above each dam, especially Whitedog Dam.
4. Does any information exist regarding the distribution of native crayfish in the Winnipeg River or Lake Winnipeg?

Group 3

1. Strengths
   a. Both passive (traps) and active (snorkeling) methods are being used.
   b. Use of dam sites:
      i. may get assistance from Manitoba Hydro
      ii. dams are located where river width is at a minimum, so both sides can be sampled with little travel (logistics benefit).
2. Weaknesses
   a. What questions are being asked? If the goal of the study is simply to find out where rusty crayfish occur, then don't worry about design, just use lots of traps to increase sensitivity.
   b. Lack of knowledge:
      i. there is no existing distribution database for Manitoba: rusty crayfish may already be present elsewhere (including throughout the Winnipeg River), and you have no idea of the presence of *O. propinquus*
      ii. need information on flow tolerances.
   c. The plan does not involve enough sampling to get information on either relative abundance or habitat preference.
   d. The logistics are challenging: the study is spread too thin.

3. Addressing weaknesses
    a. Focus the study on the hydro dams to improve efficiency:
        i. hydro dams are run-of-the-river and are not likely barriers to downstream movement
        ii. focus efforts below each dam and sample all the dams in the system as an initial assessment of the spatial extent of crayfish in the River.
    b. The keys to understanding the distribution of crayfish are cover (need to avoid predation) and food. If there is no cover and no food, then the likelihood of finding crayfish is low.
    c. There is a need to document sites without rusty crayfish as well as those sites where they are present. If you know crayfish abundance before a site is invaded, you can document impact as it moves downstream.

4.3.2.2 Question 2

Is the intensity of sampling sufficient to meet the monitoring objectives?

Group 1

1. Given the proposed limited sampling of the river, we strongly recommend that efforts be focused solely on collection from optimal crayfish habitats (i.e., extensive areas of cobble).
2. Restrict data collection to presence/absence reporting rather than estimates of abundance, which will likely be highly unreliable given the low sampling effort.
3. Detection should be the primary objective of this study, and not satisfaction of statistical issues, such as the use of stratified random sampling.
4. Target sampling above and below dams to determine the importance of man-made barriers to crayfish dispersal.
5. Use an active sampling technique (e.g., kick-sweep technique) to supplement minnow-trapping, which may prove unsuccessful if crayfish movements are suppressed by fish predation in the area.

Group 2

1. If detection is most important, where do we need to sample?
    a. How much current do they tolerate?
    b. What is the most productive habitat?

    Identify presence/absence and species only; there is no need for information on sex, size, depth, etc.

    Maximize the number of sites and choose optimal habitat (e.g., among rocks near shore).
2. Can we handle the number of traps we plan to use? Or, do we need more traps?
3. Is there a different method we should consider?

    If the goal is to identify where rusty crayfish are present in the Winnipeg River, then dispense with traplines to maximize the number of habitats, sites, and localities that you can sample. Place traps in optimal habitat.

    Is <1 km off the main channel the best estimate of "good habitat", or where is the best probability of detecting presence/absence of crayfish?

    Consider all methods of baiting to attract crayfish.
4. What kind of trap spacing is appropriate with stratified or stratified random sampling?

    Presence/absence or an opportunistic approach are better than a stratified sampling approach to detect the crayfish front.

    There is no need for six trap lines. Set individual traps in what appears to be "best habitat". This summer, with a limited availability of trap-nights, the best statistical design is not relevant. There should be no attempt to extract density data, just presence/absence and species information.
5. Will the hydro facilities act as a barrier to movement?

    Bottom-draw passage through Norman Dam may facilitate passage of crayfish downstream.

    Get hydro operators to check screens in the turbine area for the presence of crayfish.

    Target backwaters above each dam, especially Whitedog Dam.

Group 3

1. Responses to specific questions:
    a. How much current do they tolerate?

        Literature from the 1980s in either the Canadian Journal of Zoology or the Canadian Journal of Fisheries and Aquatic Sciences deals with this question.
    b. Can we handle the number of traps we plan to use? Or, do we need more traps?

        You may be able to set more traps if focus is on dams.
    c. What kind of trap spacing is appropriate with stratified or stratified random sampling?

        These designs are too elegant to be important for "detection sampling".
    d. Will the hydro facilities act as a barrier to movement?

        Probably not for downstream movement.
2. Additional comments:
    a. Sample below all dams
        i. may be a safer area (than upstream) in the event of fluctuations in water levels (downstream levels change less than upstream)

    ii. consider effects of draw-down practices (i.e., impact on wetted habitat)
    iii. need to know where *O. rusticus* do not occur as well as where they occur; may be able to show displacement/replacement of native fauna as front advances.
  b. How do *O. rusticus* move downstream? Is it a linear downstream march or a series of steps from pool (lake) to pool (lake) of optimal habitat?
  c. Behavioural dominance by males is important. A population build-up may be required to push out subordinate males to new habitats (i.e., could be a series of downstream pulses).

4.3.2.3 Question 3

What are the key research needs for the Winnipeg River and how would meeting these needs affect short- and long-term monitoring plans?

Group 1

1. Determine the impact of dams on crayfish invasion pattern.
2. Determine to what extent bait fishermen contribute to the dispersal of crayfish along the River.
3. Determine the effectiveness of fisheries management as a control of rusty crayfish.
   a. Catch and release large sportfish species that are known predators of reproductive adult stages of crayfish.
4. Determine the distribution and abundance of native crayfish habitats along the river.
   a. This information will be vital to modeling future invasion potential of rusty crayfish in the Winnipeg River.

Group 2

1. Future monitoring should be focused on movement of the front and determining the density of crayfish where they are known to occur.
2. Given that the dams on the Winnipeg River have been constructed over many years, they are probably of varying design. What types of dams slow passage of crayfish?
3. After the invasion front has been identified in 2006, track movement downstream in subsequent years of monitoring effort.
4. What is favoured habitat for rusty crayfish in the Winnipeg River?
5. What other species of crayfish occur along the Winnipeg River and how does their preferred habitat compare with that of the rusty crayfish, i.e., is rusty displacing native crayfish?
6. Are the effects of rusty crayfish in a river setting similar to the effects they have in Lake of the Woods and other lakes?
7. Make use of researchers on sturgeon to look at gut contents.
8. Volunteer observation and education are important to contribute to getting reports downriver.

Group 3

1. The first priority is to determine distribution. Other research needs will follow once distribution is known.
   a. By-catch information from fishery gill netting/index netting may provide additional distribution information.
2. There is a need to develop better – more adaptive – sampling gear.
   a. Use fish stomach contents as an alternative way to sample crayfish.
3. What is the effect of nearshore habitat restructuring by rusty crayfish (i.e., elimination of macrophytes) on small fish?
4. Need a better understanding of the role of crayfish in fisheries resources of large, complex systems like the Winnipeg River. Will a change from *O. virilis* to *O. rusticus* affect fish?
5. What is the effect of river water-level fluctuations?
   a. Will fluctuations affect distribution, movement, or recruitment (e.g., stranding of juveniles may affect recruitment)?
   b. Distribution may differ between rivers that fluctuate a lot and those that have more stable water levels.
6. What are the effects on dispersal of steep walls along a river?
   a. A lack of good habitat may speed/slow dispersal.
7. Will dams slow the spread of crayfish?
   a. Slowing is not likely for downstream movement, but dams may prevent movement up Winnipeg River tributaries.

4.3.2.4 Question 4

Who are the likely key supporters or partners in monitoring, research, and management processes for the rusty crayfish, and what role would each of these supporters/partners play?

Group 1

Whiteshell Cottage Owners Association

Commercial bait fisheries and Lake Winnipeg fisheries

Manitoba Hydro

Angling associations

Native groups

University of Manitoba Aquatic Biology Research Group

Group 2

LOWDPOA (awareness and education)

Article in Area News on rusty crayfish to raise awareness of the problem and to aid in recognition of invasive species compared with native species

First Nations communities (monitoring, traditional ecological knowledge)

Hydro dam operators

Group 3

Dam operators

- may be a source of funding
- may be a source of "catches" on screens and/or active sampling
- can provide logistics, access, and a source of expertise and knowledge

Cottagers (pros and cons)

- can provide a source of volunteers for a sampling network

Baitfish associations

- may be able to help prevent spread

OMNR

- may be able to help with logistics
- data may be available from other monitoring programs (e.g., *O. rusticus* entangled in fish nets)
- need to educate biologists to look for and identify *O. rusticus* (may help chart distribution)

4.3.3 Summary of Large Group Discussion

Once again, several participants commented on the similar replies to the four questions provided by the small groups, which makes it easier to adopt suggestions (R. Hesslein). W. Ralley thought the sampling program was ambitious, and was designed to answer questions "quickly and with limited resources". R. Vinebrooke compared the Lake of the Woods program to the Winnipeg River program: the former was a more developed project with more resources available, whereas the latter is still in its infancy with few resources available. Most of the discussion centered on sampling strategy and the information needed from sampling. Other subjects discussed included: gaps in knowledge, the behaviour of crayfish in relation to water flow, properties of dams on the Winnipeg River, and partners.

4.3.3.1 Sampling program and information needed from sampling

A few participants recommended that the program be kept simple and focused on its primary goals; the program will fail if something elaborate is attempted. The program must also be adaptive, especially given the constraints of funding and time. Statistical design is not needed; rather, effort should be concentrated on finding *O. rusticus* in the Winnipeg River (R. Vinebrooke). Where it is likely to occur is a priority, and non-detects are important. N. Geard thought it was important to limit work to dams at first, and that time could be saved if the crayfish were not found at Whitedog Dam. With regard to information needed from sampling, there was discussion about the importance of recording water levels. However, R. Hesslein pointed out that water levels will not change from day to day but they will change from hour to hour because the system does not have enough storage for day-to-day fluctuations. Hourly flow and temperature records are available from Manitoba Hydro. Some participants felt it was sufficient to document presence/absence of crayfish; others felt that numbers and species were the minimum data needed to determine presence and optimal habitat. Size and sex of individuals were not needed.

4.3.3.2 Gaps in knowledge

B. Hann and M. Turner both asked if there was any information available on the distribution of *O. virilis* in the Manitoba part of the Winnipeg River? In fact, what do we know about the native Manitoba fauna in the Winnipeg River? K. Somers pointed out that Lake of the Woods and the Winnipeg River are both complex systems that present unique challenges. It may be hard to apply information from other systems because Lake of the Woods and the Winnipeg River are unique systems. Some concern was expressed that we could only plan for 2006 (rather than 2006–2010) because of our ignorance.

4.3.3.3 Behaviour of crayfish in relation to flow

K. Somers wondered if *O. rusticus* is attracted to moving water. If so, they will probably get washed through the dams. If not, they will probably stay in the slow-water areas in the River. R. Hesslein explained that the upstream side of these dams had low-velocity intakes; flow was faster on the downstream side, and in mid-channel (vs shore).

4.3.3.4 Properties of dams in the Winnipeg River

R. Hesslein and S. McLeod discussed how the dams on the Winnipeg River are old so they have different designs than modern dams. They have low heads (i.e., just above the bottom of the River) and entry to the turbines is low velocity (at least for the Manitoba dams). These dams try to draw on the entire water column. For example, the Pointe du Bois dam is quite old, and uses a very different kind of turbine. The turbines turn slowly, so rusty crayfish could get through. Screen mesh size is quite large because the screens are meant to keep out large debris. However, screens for the cooling water have smaller meshes, so they may be collecting fauna.

4.3.3.5 Possible partners/networking

F. MacDonald and K. Saunders thought that an outreach program should be centered around slowing the spread of the rusty crayfish, and halting re-introductions. Outreach should also inform the public about the research programs in progress. S. Cosens felt that as many helpers as possible should be brought in (e.g., Manitoba Hydro, cottagers, First Nations). All partners can add information; most people would be willing (D. Leroux). W. Ralley indicated that there are a number of agencies that could get involved. Those agencies that are presently doing surveys can be used to ask the public pertinent questions.

4.3.3.6 D. Watkinson's summary

D. Watkinson was able to provide a revised sampling program for the Winnipeg River in light of the large group discussion. In general, his discussion followed some of the themes outlined in Section 4.3.3:

Sampling strategy and information needed

- Don't spread the effort too thin.
- An elegant design is not needed; focus on the best habitat to capture *O. rusticus* (likely rocky habitat).
- Multiple introductions may be occurring along the River, so a true invasion front may be difficult to determine.
- Target dams on the Winnipeg River; sample below dams but also above them, if logistics permit; focus traps in small areas to increase the probability of capture; sample nearshore areas.
- Combine trap sampling with kick-net sampling; throw out fish carcasses as larger bait; clean screens at hydro dams.
- In the interests of keeping the data collected simple, drop carapace length and sex from the data collected.

Future research

- Investigate the ability of crayfish to pass through dams.
- Collect abundance and distribution data.

Partners

- Dam operators
- Regional biologists/technicians in Ontario could be made aware that information on *O. rusticus* is welcome.
- Material on the study could be disseminated to people living around Lake of the Woods to enable them to recognize rusty crayfish. (e.g., use the Lake of the Woods cottagers' newsletter).
- Informational posters (like Fish Futures) could be developed and placed at boat launches.

5.0 Discussion

5.1 Key Monitoring Recommendations to be Implemented

By the end of the Workshop, T. Mosindy and D. Watkinson were able to present key take-home messages regarding modifications to their 2006 sampling programs on Lake of the Woods and the Winnipeg River.

5.1.1 Lake of the Woods

Monitoring plans for 2006 summer sampling will be simplified as a result of input from the group, and the sampling plan will become adaptive.

Sampling will be concentrated on non-invaded areas; some pre-invasion data (e.g., habitat mapping) have already been collected from these areas. However, post-invasion areas will also be examined (e.g., Lobstick Bay) for pertinent data (to scale the invasion, describe impacts at the invasion front, identify habitat and pathways of invasion).

The plan will use active sampling (e.g., baiting, seines) in addition to passive traps.

Effort will be spent looking at groups of invading species following common pathways, rather than single invading species (B. Hann's idea; see below). Some concern was also expressed about the movement from Manitoba to Ontario (e.g., with bait).

US agencies have greater capacity to monitor than we do; perhaps they can be involved.

There is a real need to educate the public about aquatic invasive species (e.g., moving bait across provincial boundaries).

Specifically, T. Mosindy provided the following revised sampling strategy after the workshop:

Changes of Invasive Crayfish Monitoring Protocol: Lake of the Woods

Overall, participants at the workshop approved of the proposed monitoring plan and protocol for the 2006 Lake of the Woods survey, with only minor changes. Large group discussions and comments by individuals supported the use of a stratified survey design and an existing protocol used to monitor crayfish populations in south-central Ontario lakes (see Section 3.3 Somers and Reid).

Recommended modifications to the 2006 monitoring plan were as follows:

- Restrict the 2006 Lake of the Woods survey to one known invasion front, given the Lake's size, complexity, and amount of resources committed to the project. The Clearwater–Ptarmigan Bay area was chosen, owing to its close proximity to Kenora and relatively small surface area.

- A primary survey objective was to delineate the current invasion front, sampling should initially focus on areas known to harbour only the native crayfish *O. virilis*. Monitoring would then progress along both mainland and island shorelines towards locations where rusty crayfish had last been observed.
- Keep it simple and be consistent. Do not collect information on sex or size of crayfish that are captured in traps during the survey. A count of crayfish by species per trap would provide sufficient data to describe relative abundance and composition by habitat type, and help determine environmental factors that might influence direction and rate of invasion.

5.1.2 Winnipeg River

Time will be spent observing the work of T. Mosindy and G. Olson on Lake of the Woods, and the Winnipeg River sampling will follow a similar protocol. Winnipeg River sampling will be limited by the number of sampling days available.

Key areas (e.g., hydro dams) will be targeted first and specific regions next in an attempt to characterize the extent of the population.

Sampling will be limited to the most productive habitat, and the number of traps per line will be reduced.

Last, active sampling will be incorporated along with the minnow traps.

5.2 Ovearching Issues

M. Turner introduced this section of the workshop by noting that we have already dealt with existing research activities with regard to AIS, but what about other research activities in the context of multiple stressors? The resulting discussion produced two main points: pathways of invasions and effects of multiple stressors on systems.

5.2.1 Pathways of Invasions

B. Hann made the point that we should be interested in a broader suite of invasive species because a number of such species are following common pathways, i.e., a group of invasive species is coming our way. If we can identify common pathways of invasion (rather than individual species), then we can watch for new invasives with very little extra effort. For example, there is congruity between the arrival of *O. rusticus* along with invasive zooplankters in Lake of the Woods. Thus, we should be piggybacking sampling for zooplankters on sampling for crayfish; very little extra effort would be involved. Co-ordinated rather than individual efforts are needed.

Two zooplankters are of note: *Bythotrephes* and *Eubosmina*. People should be warned about the occurrence of *Bythotrephes*; it has a distinct pointed tail. *Eubosmina* has been found in Lake of the Woods and in Lake Winnipeg. Did it come down the Winnipeg River? *Eubosmina* is easily spread as wind-blown resting eggs, or on the feet of ducks. Sampling for these taxa anywhere along the Winnipeg River during the 2006 crayfish sampling season would be useful.

5.2.2 Multiple Stressors

Larger research issues overlay aquatic invasive species (M. Turner). For example, global warming will increase water temperatures, which will change the distribution of species. The activities of an invasive species like *O. rusticus*, i.e., removal of macrophytes and increased turbidity, will have ramifications on water quality. W. Momot provided evidence that the bottom sediments resuspended by the activities of *O. rusticus* causes resuspension of nutrients. B. Hann wondered if such nutrient resuspension could be linked to algal blooms in Lake Winnipeg. However, turbidity is not an issue in the South Basin of Lake Winnipeg because it is already turbid (R. Hesslein).

R. Hesslein suggested that the multiple stressors problem becomes one of doing risk assessment at a large scale. We can do risk assessment in small lakes like at the Experimental Lakes Area, but it is hard to do in the kinds of huge lakes being invaded by *O. rusticus* because of the diversity of habitats and the numerous fish species there. We cannot predict what will happen in these large systems. Should we care? How hard is it to design research to answer questions connected with the problem? Do we have any idea of the consequences of invasions into large systems?

This part of the discussion ended with a reminder by R. Vinebrooke that we need to increase our use of already published literature as a guide to the questions being asked (even though the information transfer may not be exact). Research typically starts with rigorous quantitative data collection and is followed by experimentation, but we are still in the early stages of studying these systems.

5.3 Potential Partners

A list of possible partners was compiled (by S. McLeod) from the small group presentations and large group discussions (Table 8). Much of the large group discussion on this topic on day 2 centered around the involvement of First Nations. The record of this discussion follows.

How do we get First Nations involvement (M. Turner)? They are not at the table currently, and a single contact person for Lake of the Woods cannot be identified.

Table 8. Potential partners or supporters of rusty crayfish monitoring in Lake of the Woods and the Winnipeg River.

Potential partner	Interest	Possible role(s)
Lodge owner associations and tourist outfitter associations: NOTO, NWOTO	Economic investment and returns potentially threatened	Lobby funding agencies Participate in sampling activities as volunteers
First Nations and Métis	Access to traditional resources potentially threatened	Lobby funding agencies Participate in sampling May be able to help in obtaining funding for research
Manitoba Hydro and Ontario Power Generation	Maintenance of a healthy basin and healthy stakeholder relations MB Hydro doing EA on re-development of Pointe du Bois	Potential funding agencies Participation in sampling
Resource-based industries (e.g. Tembec, Pine Falls)	Maintenance of a healthy basin and healthy stakeholder relations	Potential funding agency Lobby funding agencies
Cottager associations: LOWDPOA, LOWWSF	Maintenance of healthy waterbodies and continuance of good recreational opportunities	Public education partners Lobby funding agencies Participate in sampling
Angler and hunter organizations, including Ontario Federation of Anglers and Hunters, Manitoba Wildlife Federation	Maintenance of healthy waterbodies and continuance of good recreational opportunities	Lobby funding agencies Participate in sapling activities as volunteers Participate in public education activities
Ontario Baitfish Association	Maintenance of healthy waterbodies and continuance of good recreational opportunities Avoidance of regulations	Lobby funding agencies
Commercial fishing federation(s)	Maintenance of healthy waterbodies Economic investment and returns potentially threatened	Lobby funding agencies Participate in sampling
Governments Environment Canada MB Conservation MB Water Stewardship MNDNR OMNR DFO US National Parks Service	Maintenance of healthy waterbodies, continued economic opportunities, political pressures from those who may be forced to change or adapt In case of US parks, Voyageur National Park is potentially threatened	Funding agencies Participate in research Development and implementation of management responses
Academia and institutes including University of Manitoba Aquatic Biology Research Group	Improving state of knowledge and understanding A healthy research environment	Participate in research Co-applicants for funding
International Joint Commission	Enforcement of Transboundary Waters Treaty	Funding agency

Abbreviations:

DFO = Fisheries and Oceans Canada
EA = environmental assessment
LOWDPOA = Lake of the Woods District Property Owners Association Inc.
LOWWSF = Lake of the Woods Water Sustainability Foundation
MB = Manitoba
MNDNR = Minnesota Department of Natural Resources
NOTO = Northern Ontario Tourism Organization
NWOTO = Northwest Ontario Tourism Organization
OMNR = Ontario Ministry of Natural Resources

S. Cosens suggested contacting the Species at Risk Act group at the Freshwater Institute. They have had extensive experience with First Nations. Independent approaches to communities usually do not work.

Indian and Northern Affairs Canada may be a source of funding (D. Leroux).

There is talk of a community-based First Nations fishery for *O. rusticus* in Lake of the Woods (T. Mosindy in response to a question from M. Paterson). Can numbers be controlled that way (M. Paterson)? W. Momot responded that fishing *O. rusticus* with traps may produce an increase in numbers because males are preferentially removed and females become socially dominant. Moreover, marketing may be a problem because crayfish are not usually a favourite food item of Canadians.

5.4 Final Comments

5.4.1 Funding

R. Vinebrooke suggested that the NSERC Strategic Grant series for invasive species should be added to the list of potential stakeholders identified at the workshop. The deliverables required are similar to what we have been discussing. NSERC has ignored inland waters, except for the Great Lakes. Perhaps they should be approached with a proposal for the Lake of the Woods/Winnipeg River system? W. Momot cautioned that it may be hard to get funding for invasive crayfish work because they are inconspicuous, compared to zebra mussels. Zebra mussels became a real problem for power plants, which is how this invasive organism was recognized. The replacement of *O. virilis* by *O. rusticus* may go unnoticed. Considerable economic loss is needed to place the focus on crayfish.

5.4.2 Effects of Crayfish on Energy Flow

K. Somers reiterated the importance of getting pre-invasion data to quantify impacts once the crayfish arrive. He also stressed what W. Momot had said before: that crayfish are unique organisms at taking energy out of a system and sequestering it. *Orconectes rusticus* will change energy flow in systems they invade because this species of crayfish sequesters more energy than the other two species in Lake of the Woods. Crayfish can take 50% of the yearly energy in some natural streams (W. Momot). In invaded streams, crayfish take most of the energy, leaving fish only a small amount. Seventy-five percent of the energy sequestered by crayfish goes into the young. Crayfish populations do not crash; rather, they simply "stunt".

5.4.3 Political and Public Awareness

W. Ralley pointed out that the Premier of Manitoba is aware of invasive species problems because of Devil's Lake, and provides funding to increase awareness. Wendy is interested in targeting pathways (e.g., recreational boating, canals, diversions).

D. Leroux noted that the issue is not going to get profile until it affects recreation or business. However, he felt threatened by this particular invasive species; the Premier will have to look eastward, too.

The Devil's Lake experience shows that we need to produce a fairly targeted description of impacts caused by *O. rusticus*; otherwise, it will be hard to generate any public concern (R. Hesslein). We need to determine what ***could*** happen (e.g., use the literature); possible dangers could stir interest (and provide funding to go farther). In the meantime we need to track the progress of the *O. rusticus* invasion. Is our objective in getting funding to slow the progress of the invasion, to develop controls, or other?

DFO does not have a clear policy on freshwater invasive species (S. Cosens). Money is available for research and monitoring, but this region (Central and Arctic) is in competition with other regions of DFO (e.g., tunicates are a problem invasive in the Maritimes). However, there are ongoing discussions between DFO and the Manitoba government on invasives, and policy will develop as a result of these discussions. The direction for addressing research questions on invasives will become clearer.

K. Saunders was happy to receive the list of potential impacts/risks of rusty crayfish (Table 6), which she will distribute to stakeholders and members of LoWDPOA (1300 in Manitoba) to keep them informed.

F. MacDonald will apply the information she learned at the workshop to her organization's education programs. The Ontario Federation of Anglers and Hunters is a potential partner; it is interested in northwestern Ontario, not just southern Ontario. She expressed interest in collaborating with Manitoba, especially the Manitoba Wildlife Federation.

5.4.4 Final Wrap Up by M. Turner

We heard a large number of potential research topics in the past day and a half, from impacts on single species to disruption of structure and energy flow in entire ecosystems. We also heard about multiple stressors at work in Lake of the Woods, including the rusty crayfish. *Orconectes rusticus* is a disruptor and affects systems all along the gradient mentioned above. The best known other invasive species affecting nutrient flow is the zebra mussel (in Lake Erie).

Much information on crayfish is available from small ecosystems but not much is available from large, complex systems like Lake of the Woods, with its 10,000 km of shoreline. Nonetheless, Lake of the Woods may be a predictor of what will happen if the invasion reaches Lake Winnipeg.

We do not have enough knowledge on whether we can slow the invasion.

Opportunities for research support from DFO are uncertain, so we will need to garner support from other organizations and access new opportunities.

It would be useful to re-engage the workshop participants at a future date to discuss research challenges. In the meantime, the workshop has been a real help to the summer 2006 sampling program on Lake of the Woods and the Winnipeg River. Thank you all for participating.

6.0 Workshop Outcomes

6.1 Addressing "Next Steps"

The workshop provided valuable insights into both crayfish biology (see Section 3.2 Momot) and sampling techniques (see Section 3.3 Somers and Reid). Furthermore, discussions yielded several useful suggestions for modifying the monitoring programs that were originally proposed. Both Mosindy and Watkinson describe the changes made in their respective monitoring programs for Lake of the Woods (see Sections 5.1.1 and 6.2.1) and the Winnipeg River (see Sections 5.1.2 and 6.2.2). A commonly repeated recommendation from the workshop for both programs was to keep the programs simple and to be consistent. For example, it was concluded that a count of crayfish by species per trap would be sufficient to describe relative abundance and composition of species by habitat type, and help to determine those environmental factors that would be influenced by the direction and rate of invasion.

In Lake of the Woods, the use of a stratified survey design and the protocol currently used to monitor crayfish populations in south-central Ontario lakes (see Section 3.3 Somers and Reid) was supported. Recommendations also included restricting the survey to one known invasion front, given the size and complexity of Lake of the Woods combined with the limited resources available for the project. The Clearwater–Ptarmigan Bay area was chosen, given its proximity to Kenora and its relatively small surface area. Given the specific objective to delineate an invasion front, it was further recommended that sampling be initiated in areas known to harbour only the native crayfish *O. virilis*. Subsequent monitoring could then progress towards locations where rusty crayfish had last been observed.

Monitoring in Lake of the Woods provided several surprises (see Section 6.2.1 Mosindy; Geard 2007). The rusty crayfish invasion was more advanced than had been anticipated, which made the initial effort to find the northern invasion front more challenging. It was also discovered that the additional invasion by *O. immunis* had progressed to a much greater extent than had previously been anticipated. Unfortunately, Geard (2007) determined that islands within Lake of the Woods may facilitate the invasion by *O. rusticus*, rather than acting as a hoped-for invasion barrier. Moreover, another invader, *Bythotrephes* sp., which had recently been found in Rainy Lake, was also found in the southern end of Lake of the Woods in 2007 (T. Mosindy, personal communication).

In the Winnipeg River, a somewhat modified sampling protocol was recommended (see Section 6.2.2 Watkinson). Sampling order of the reaches was also to be prioritized to detect an invasion front in the downstream reaches and to enable the sampling plan to adapt to initial survey results. The workshop also facilitated cooperation between DFO and OMNR in terms of sharing sampling equipment and expertise.

As a consequence of monitoring >180 km of the Winnipeg River, it appears that the rusty crayfish invasion of the river has begun, but the invasion has not yet progressed as far as Manitoba (see Section 6.2.2 Watkinson; although see below), a fear of some workshop participants. The speculation that dams may be acting as a barrier to the downstream distribution of rusty crayfish could be correct. *Orconectes propinquus* was unexpectedly found in an isolated reach of the river; once again, this occurrence appears to be associated with human activity.

However, since the 2006 sampling season, it appears that Manitoba has an internal invasion front to contend with. *Orconectes rusticus* was found in Falcon Lake in July 2007 (Doug Leroux and Martin Erikson, Fisheries Branch, Manitoba Water Stewardship, personal communication, 28 August 2007). Falcon Lake is located ~20 km west of Shoal Lake and is connected to Shoal Lake (part of Lake of the Woods, see Figure 8 in section 4.2.1) by the Falcon River. *Orconectes rusticus* appears to be well-established in Falcon Lake because the species has a large range of size classes (D. Leroux, personal communication, 28 August 2007). *Orconectes rusticus* also appears to have displaced the native *O. virilis* in the western part of the Lake.

Another outcome of the workshop and the 2006 monitoring programs was that the Fisheries Branch of the Government of Manitoba decided, in 2006, to review its crayfish-related regulations. New regulations identified in the 2007 angling guide specify a zero possession limit for all species of crayfish in Manitoba. The regulation will be under the Manitoba Fishery Regulations 1987 – Schedule XI – Part I/Part II Provincial Variance. Moreover, the Government of Manitoba prepared information packages on rusty crayfish that could be used in the angling guide, in displays and user group publications, and on their website.

A working group session was organized at the Lake of the Woods Water Quality Forum, held March 2007 in International Falls, Minnesota, to encourage discussion of initiatives to study the invasives issue that were taking place in the basin. This approach was taken in lieu of the earlier idea to hold another workshop to follow up outcomes of the monitoring program, to gain access to international researchers on Lake of the Woods, which had been recognized as a limitation in the design of the 2006 workshop. Preliminary findings were presented by T. Mosindy and by M. Turner. The March 2008 forum will highlight invasive species.

As acknowledged in the workshop, the role of public education became increasingly important. In 2007, Laurie Wesson of DFO established an educational program to enhance awareness of invading species at several US–Canada border crossings (Fort Frances, Ontario–International Falls, Minnesota; Rainy River, Ontario–Baudette, Minnesota). Similarly in 2007, the Lake of the Woods DockTalk program (led by Kelli Saunders) included education of cottagers about invasive species.

The workshop was successful in several respects: scientific preparation, networking and collaboration, policy development, education of participants, and the further facilitation of public education about the issue of invasive species. From a scientific perspective, there was general agreement that "bringing people together before a project is undertaken is a great way to start", and is something that should be done more frequently (Kim Armstrong). The subsequent success of monitoring programs in Lake of the Woods and the Winnipeg River (see Sections 6.2.1 and 6.2.2, respectively) is proof.

Reference

Geard, N. 2007. Islands as an invasion pathway for the rusty crayfish, *Orconectes rusticus*. BSc Honours Thesis, University of Winnipeg, Winnipeg, Manitoba. 37 p.

6.2 2006 Monitoring Programs

The purpose of this section is to update the reader on the methods and results of 2006 monitoring programs on Lake of the Woods and the Winnipeg River.

6.2.1 Lake of the Woods (T. Mosindy)

Introduction. Three invasive crayfish species, the rusty crayfish (*Orconectes rusticus*) the papershell crayfish (*O. immunis*) and the northern clearwater crayfish (*O. propinquus*), were present in Lake of the Woods prior to 2006. All were first observed in the Whitefish Bay–Long Bay area (Figure 10) on the eastern side of the Lake near Sioux Narrows (Crocker and Barr 1968, Bait Association of Ontario and Ontario Ministry of Natural Resources 2005). The distribution of papershell and northern clearwater crayfish appeared to be limited to Whitefish Bay, but the rusty crayfish had invaded extensive areas, north, south, and west from its original introduction site in Long Bay during ensuing years. The Lake of the Woods FAU had identified three potential invasion fronts for this species, based on the incidental catch of crayfish in gill nets and beach seines during regular fisheries monitoring up to 2006.

Considering the recommendations of the workshop, the Lake of the Woods FAU conducted a study during the summer of 2006 with the following objectives: 1) to capture the invasion front(s), 2) to determine relative abundance by species and habitat type, and 3) to identify factors that might influence the direction and invasion rate of rusty crayfish in Lake of the Woods. This section provides a brief summary of the methods used and preliminary survey results.

Methods. Given the time and resources available, we decided to scale back our original survey proposal and to concentrate efforts on the potential invasion front closest to Kenora, located at the north end of Lake of the Woods near the entrance to Ptarmigan–Clearwater Bay, about 15 km southwest of the city (Figure 10). We also decided to work our way back, from areas known to be inhabited only by the native virile crayfish (*O. virilis*) to where both virile and invasive crayfish were found. Sampling was stratified based on the presence of three habitat types (rock, macrophytes, and soft substrates of organic and inorganic composition). We divided shorelines into primary sampling units of 500 m and attempted to identify 50-m sections of each habitat type within these sampling units. As a result, three sampling sites, each representing one of the three habitat types, were randomly selected within each shoreline segment. Existing shoreline habitat maps, along with additional mapping conducted during this project, greatly aided in the selection of potential sites. We sampled during a 10-week period from 26 June–1 September when surface water temperatures were >20 °C, assuming that this period represented the most stable crayfish activity, given known effects of temperature on reproductive cycles and moulting.

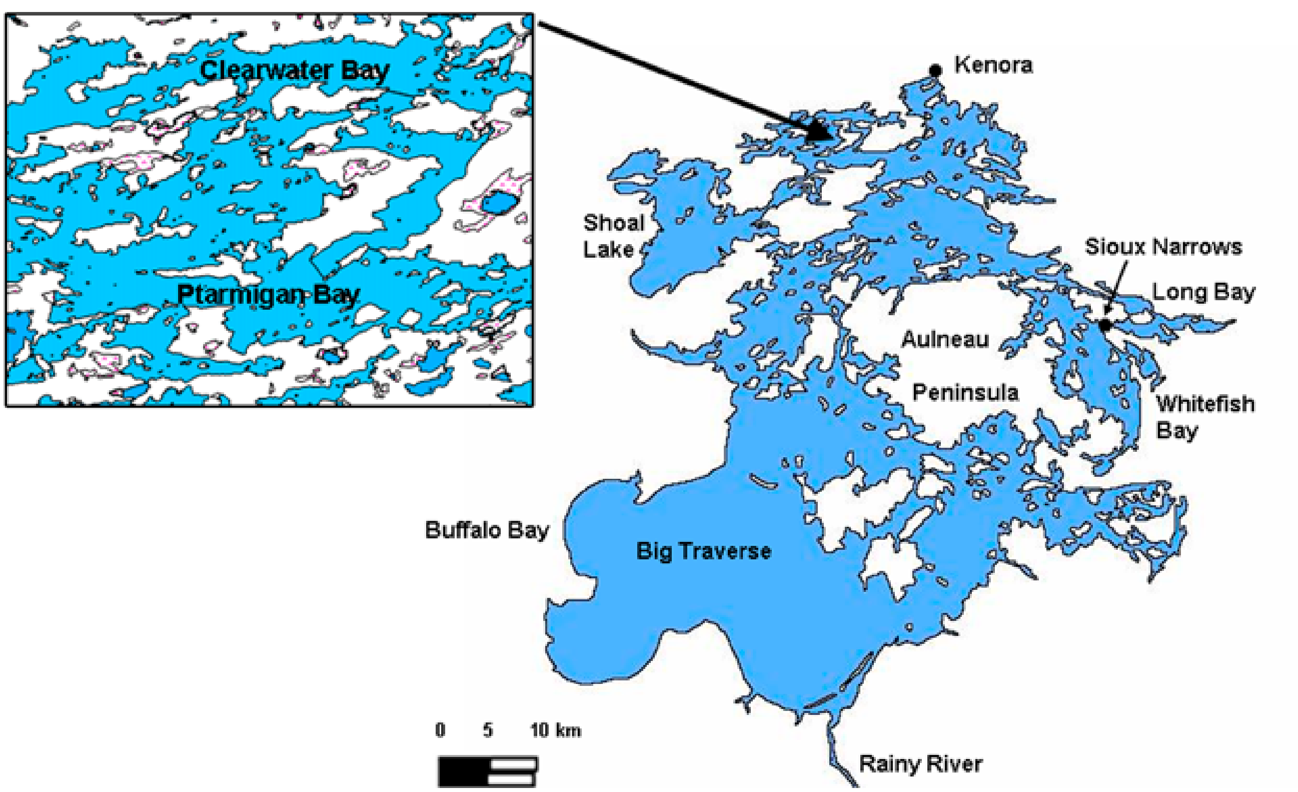


Figure 10. Lake of the Woods, Ontario with 2006 study area in Clearwater and Ptarmigan bays.

We used the Somers and Green (1993) sampling protocol, which had been proposed at this workshop in May 2006. We set traplines, comprised of six standard minnow traps spaced evenly along a 15-m line, perpendicular to shoreline sites at a minimum depth of 0.5 m. The onshore location of each trapline site was recorded as Universal Transverse Mercator (UTM) coordinates using a GPS unit (Table 9). We recorded water depths midway and at both ends of each trapline with a depth finder. We also measured the TDS concentration and surface water temperatures at each site using a TDS meter. We baited each trap with canned cat food held within a perforated plastic photo film container and set them overnight. The crayfish catch in each trap was counted by species and released onsite.

Results. We lifted a total of 2,256 traps at 376 sites and surveyed almost 65 km of mainland and insular shoreline. This area included the south shore of Ptarmigan Bay from south of Spruce Point west to the entrance of Ash Bay and along both sides of the Corkscrew Channel north to its entrance with Clearwater Bay and White Partridge Bay (Figure 11).

We found rusty crayfish at least 5–8 km west and north from where we last observed them in 2004 at the eastern end of Ptarmigan Bay near Spruce Point. We identified current invasion fronts, beyond which only native crayfish were found, at the northwest corner of Corkscrew Island in Clearwater Bay and at the eastern entrance to Ash Bay (Figure 11). Here, rusty crayfish numbers in traps increased along a gradient from west to east, whereas virile crayfish numbers decreased.

Papershell crayfish were also captured in traps during this study, representing the first observation of this species outside of Whitefish Bay on Lake of the Woods. We found papershell crayfish, along with virile and rusty crayfish, on both sides of the Corkscrew Channel north to the top end of Corkscrew Island, and along the south shore of Ptarmigan Bay, west to the entrance to Ash Bay. They appeared to be more widely distributed than rusty crayfish in Ptarmigan Bay. We found papershell crayfish along with virile crayfish well beyond the observed rusty crayfish invasion front, located just east of the entrance to Ash Bay.

We caught a total of 9827 crayfish at 376 sites, representing a mean catch of 26.2 crayfish/site or 4.4 crayfish/trap. The virile crayfish was the most common species, comprising 68.3% of the catch, followed by rusty crayfish (22.9%) and papershell crayfish (8.8%).

Table 9. Data sheets for Lake of the Woods crayfish sampling.

		Date set: Collectors:	Date retrieved:
	Site:	Site:	Site:
Waterbody			
Description			
GPS			
Time set			
Time lifted			
Water depth			
Near shore			
Midpoint			
Offshore			
Water temperature (@1 m °C)			
TDS (ppm)			
Substrate percent			

Trap	Catch per unit effort		
	O. virilis	*O. rusticus*	*O. immunis*
1			
2			
3			
4			
5			
6			

Comments:

Trap	Catch per unit effort		
	O. virilis	*O. rusticus*	*O. immunis*
1			
2			
3			
4			
5			
6			

Comments:

Trap	Catch per unit effort		
	O. virilis	*O. rusticus*	*O. immunis*
1			
2			
3			
4			
5			
6			

Comments:

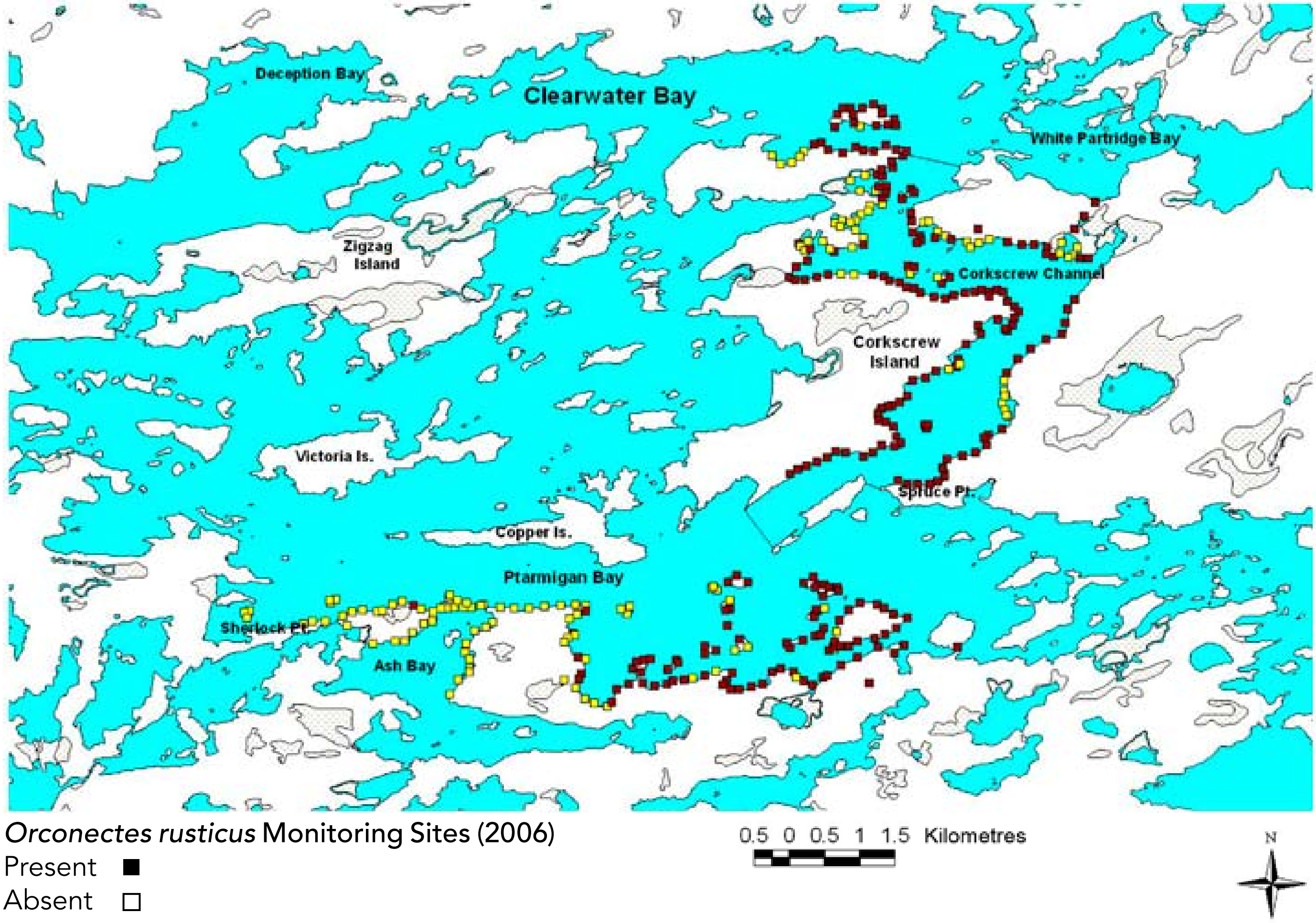


Figure 11. Catches of rusty crayfish in Lake of the Woods, Ontario, in 2006.

We observed both virile and rusty crayfish more frequently than papershell crayfish on hard, rocky substrates. Papershell crayfish appeared to prefer soft substrate areas comprised of inorganic and organic sediments.

We found rusty crayfish along with virile crayfish on most surveyed islands within the invasion fronts. However, rusty crayfish were not present on islands surrounded by maximum water depths >13 m, which corresponded to the limit of thermocline formation.

Discussion. Our sampling protocol proved to be a simple yet effective method of determining the presence, distribution, and relative abundance of both native and invasive crayfish species on a broad spatial scale. It also provided sufficient information with which to identify current invasion fronts, species habitat preferences, and environmental factors that might determine pathways for invasion. For example, from the habitat preferences seen, we can infer that *O. rusticus* is likely to compete more directly with *O. virilis* than *O. immunis*.

The presence of papershell crayfish in the Ptarmigan–Clearwater Bay area, almost 70 km from Whitefish Bay where they were last known to be present, was likely the result of introductions from angler bait buckets. This species is popular as live bait (Bait Association of Ontario and Ontario Ministry of Natural Resources 2005) and is used by bass anglers who frequent this area from the US Midwest, which further illustrates the potential role of humans as vectors for AIS distribution and the need to educate the public about risks associated with introductions through common practises.

References

Bait Association of Ontario and Ontario Ministry of Natural Resources. 2005. The essential bait field guide for eastern Canada, the Great Lakes region and northeastern United States. Edited by Guy Winterton. University of Toronto Press, Toronto, Ontario. 193 p.

Crocker, D.W., and D.W. Barr. 1968. Handbook of the crayfishes of Ontario. Royal Ontario Museum Life Sciences Miscellaneous Publication. University of Toronto Press, Toronto, Ontario. 158 p.

Somers, K.M., and R.H. Green. 1993. Seasonal patterns in trap catches of the crayfish *Cambarus bartoni* and *Orconectes virilis* in six south-central Ontario lakes. Canadian Journal of Zoology 71:1136–1145.

6.2.2 Winnipeg River (D. Watkinson and A. Batty[7])

Introduction. A recent collection of rusty crayfish (*Orconectes rusticus*) in the Winnipeg River has raised concerns about the possible downstream spread of rusty crayfish in the Winnipeg River system and potential impacts on aquatic plants, invertebrates, and fish. The only native species of crayfish known to exist in the Winnipeg River and its basin is the virile crayfish (*O. virilis*). The objective of this study was to determine the current distribution and abundance of rusty crayfish in the Winnipeg River relative to the virile crayfish.

Methods. ***Study sites –*** Our study area consisted of four reaches within the Winnipeg River. Each reach was bounded by a hydroelectric generating station at the upstream and downstream ends. Reach 1 (Figure 12) was located in Ontario between the Norman and Whitedog Falls Generating Stations. Sampling was conducted in this reach in the Big Stretch and Gunn Lake, immediately upstream and downstream of Minaki, Ontario. The second reach (Reach 2, Figure 12) included Manitoba–Ontario portions of the Winnipeg River and was located from Whitedog Falls Generating Station to the Point du Bois Generating Station. The English River, from Caribou Falls Generating Station to the Winnipeg River, was also included in this reach. The third reach (Reach 3, Figure 12) was in Manitoba from the Slave Falls Generating Station to the Seven Sisters Generating Station. The fourth reach (Reach 4, Figure 12) also was in Manitoba, from the Seven Sisters Generating Station to the McArthur Generating Station. These study reaches covered >180 river km of the Winnipeg River.

Field sampling – Spacing of collection sites within a reach was determined by approximating uniform spacing on a hydrographic chart, such that the length of the reach was sampled with the nine available trap lines, except for Reach 1 for which 17 trap lines were used (see below). At each generating station within a reach, two collection sites were sampled immediately upstream or downstream of the station. Sample sites were restricted to locations that were <1 km from the main channel of the river, and were selected to ensure water velocity was <10 cm/s. If a non-native species was captured in a reach, traps were reset starting at the furthest downstream collection site at which the invasive species was collected. Trap line density was increased near the non-native collection site to increase the probability of detecting the downstream invasion front.

Crayfish were captured using a modified Gee minnow trap with a 4-cm-diameter opening (Somers and Green 1996). Six traps were evenly spaced 3 m apart on a single line. Each trap was baited with fish-flavoured cat food, placed in a film canister with eight pre-drilled 6.35-mm holes to allow crayfish to detect the bait.

[7]Address for A. Batty: 1575 East 12th Avenue, Vancouver, BC V5N 2A2

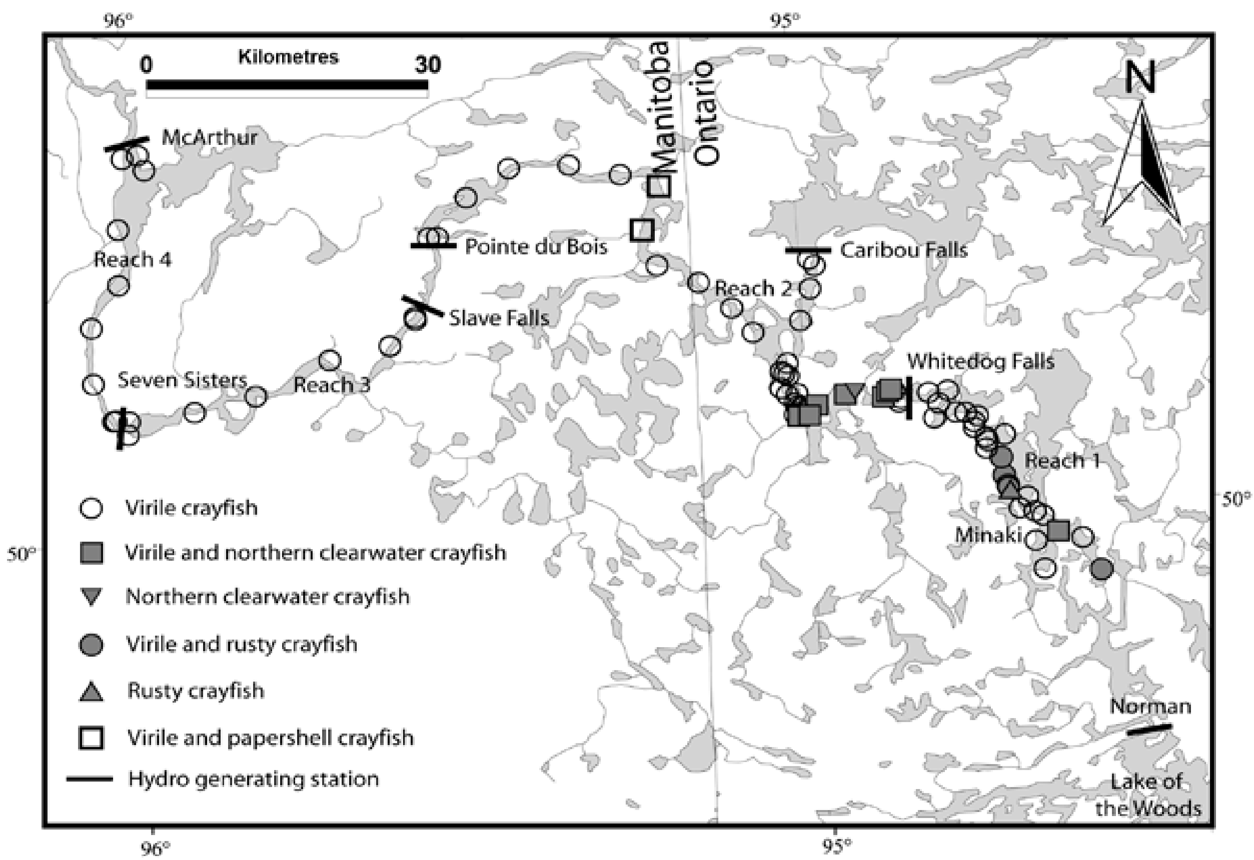


Figure 12. Sampling reaches, generating stations and collection sites on the Winnipeg River.

Trap lines were set perpendicular to shore. The first trap of each line was set near the shore in water 0.3–2.3 m deep and the sixth trap set furthest from shore in water 0.6–5 m deep. Traps were set between 11:35 h –18:28 h and pulled the next day between 6:45 h–12:45 h. A total of 528 traps was set at 88 sites.

Habitat was assessed when setting the traps. At each site, depth measurements were taken near shore, mid point, and off shore using a depth finder. As well, substrate type was assessed according to the Wentworth scale. Water temperature and conductivity were measured at each site with a conductivity meter. Secchi disk transparency was measured at each site. Coordinates of each sample site were recorded from a boat-mounted GPS.

Sampling order of the reaches was prioritized to detect an invasion front in the downstream reaches so the sampling plan could be adjusted to reflect survey results. Reach 3 was sampled 1–2 August with nine trap lines (54 traps). Reach 4 was sampled 2–3 August with nine trap lines (54 traps). Reach 2 was sampled 3–4 August in Manitoba from Pointe du Bois Generating Station upstream to the Ontario border with nine trap lines (54 traps). The Ontario portion of Reach 2, between the Whitedog Falls Generating Station and the Manitoba border, was sampled 8–11 August with nine trap lines each night (162 traps). Reach 1 was sampled 6–8 September with 17 trap lines each night (204 traps).

Results. Set times ranged from 14–23 h (Appendix F). A total of 842 crayfish was trapped. The virile crayfish was the most abundant species trapped, comprising >88% of the catch, and was trapped in all reaches (Figure 12, Table 10, Appendix F). Three non-native species of crayfish were collected. The northern clearwater crayfish was the second most abundant crayfish trapped, comprising 6.8% of the catch (Table 10). Northern clearwater crayfish were collected in Reach 2 immediately downstream of the Whitedog Falls Generating Station and one specimen was trapped in Reach 1, upstream of Minaki (Figure 12, Appendix F). Thirty-six rusty crayfish were collected in Reach 1 (Figure 12, Table 10, Appendix F). The distribution of rusty crayfish was not continuous (Figure 12). Two papershell crayfish were collected in Reach 2, upstream of the Pointe du Bois Generating Station in Manitoba (Figure 12, Table 10, Appendix F).

Table 10. Crayfish catch by species.

Species	Common name	Number of crayfish	Percent
Orconectes virilis	Virile	747	88.7
O. propinquus	Northern clearwater	57	6.8
O. rusticus	Rusty	36	4.3
O. immunis	Papershell	2	0.2
All species		842	100.0

Five of the 88 trap lines set did not catch any crayfish (Table 11). The average number of crayfish per trap line was 9.57. Virile crayfish alone were trapped at 67 sites, northern clearwater and virile crayfish were trapped together at eight sites, northern clearwater crayfish were trapped at one site, rusty and virile crayfish were trapped together at four sites, rusty crayfish alone were trapped at one site, and papershell and virile crayfish were collected together at two sites. The maximum catch per trap line was for a site with only virile crayfish (Table 11). The highest average catch per trap line occurred at sites where both virile crayfish and northern clearwater crayfish were present (Table 11). The number of crayfish per trap line ranged from 0–34 (Table 11, Appendix F).

Table 11. Summary of crayfish catch based on combination of species trapped at a site.

Species	Number of trap lines	Maximum catch per trap line	Average catch per trap line
Orconectes virilis	67	34	9.63
O. propinquus and *O. virilis*	8	22	15.38
O. propinquus	1	13	13.00
O. rusticus and *O. virilis*	4	20	10.75
O. rusticus	1	1	1.00
O. immunis and *O. virilis*	2	13	8.50
No catch	5	0	0
All species	88	34	9.57

The dominant substrates at collection sites were boulder, bedrock and silt, with composition values of 45.5%, 18.3%, and 15.9%, respectively (Table 12). Collection site water temperature ranged from 18.2–24.4°C, conductivity ranged from 85–130 µS/cm, and Secchi depth transparency ranged from 0.67–3.0 m.

Table 12. Total per cent composition of substrate at the collection sites (N = 88).

Substrate	Percent composition
Clay	3.4
Silt	15.9
Sand	9.8
Gravel	1.5
Cobble	4.5
Boulder	45.5
Bedrock	18.3

Discussion. Rusty crayfish are a well-known invader, and their presence has been linked to a wide range of ecological changes. Their most prominent impact is the decline in macrophyte abundance and species richness (Lodge *et al.* 1994, Rosenthal *et al.* 2006). Other impacts include: decreased numbers of fish that share prey taxa with the rusty crayfish (Wilson *et al.* 2004), decreased snail abundance and increased periphyton abundance (Lodge *et al.* 1994), and decreased abundance of invertebrates (Diptera, Ephemeroptera, and Odonata; McCarthy *et al.* 2006). These impacts are often interconnected. For example, consumption of snails increases the presence of periphyton, and decreases in macrophytes reduce the presence of some invertebrates (Lodge *et al.* 1994). Similar impacts on the Winnipeg River can be expected.

Rusty crayfish can also affect other crayfish in the same water body. Rusty crayfish often out-compete and displace virile crayfish (Hill and Lodge 1999). Rusty crayfish ecologically and genetically displace northern clearwater crayfish, the latter through creation of fertile hybrids that mate disproportionately with rusty crayfish (Perry *et al.* 2001). Wilson *et al.* (2004) reported that rusty crayfish eliminated both northern clearwater and virile crayfish in a lake, but total crayfish abundance continued to rise. The Winnipeg River may face similar changes, but further research is needed to assess future changes in crayfish species composition and abundance. Data collected during the 2006 survey can at least be used as a baseline from which to detect changes in these crayfish community characteristics.

The source of the rusty crayfish's introduction into new areas of the Winnipeg River is uncertain. However, there is usually a connection between the appearance of rusty crayfish and human activity (e.g., Capelli and Magnuson 1983). The distribution of non-native species of crayfish overlapped with the communities of Whitedog and Minaki. The papershell crayfish was distributed near remote fishing camps. The distribution of rusty crayfish near Minaki is indicative of multiple point-source introductions.

Controlling the spread of rusty crayfish after invasion of a water body is difficult, so the best approach is to prevent original introduction. However, Hein *et al.* (2006) estimated that 55% of the population of rusty crayfish was removed by a combination of trapping and changing angling regulations. Research is needed on possible methods of control to minimize the impacts of rusty crayfish and their movement downstream in the Winnipeg River.

References

Capelli, G.M., and J.J. Magnuson. 1983. Morphoedaphic and biogeographic analysis of crayfish distribution in northern Wisconsin. Journal of Crustacean Biology 3:548–564.

Hein, C.L., B.M. Roth, A.R. Ives, and J. Vander Zanden. 2006. Fish predation and trapping for rusty crayfish (*Orconectes rusticus*) control: A whole lake experiment. Canadian Journal of Fisheries and Aquatic Sciences 63:383–393.

Hill, A. M., and D.M. Lodge. 1999. Replacement of resident crayfishes by an exotic crayfish: The roles of competition and predation. Ecological Applications 9:678–690.

Lodge, D.M., M.W. Kershner, J.E. Aloi, and A.P. Covich. 1994. Effects of an omnivorous crayfish (*Orconectes rusticus*) on a freshwater littoral food wed. Ecology 75:1265–1281.

McCarthy, J.M., C.L. Hein, J.D. Olden, and M.J. Vander Zanden. 2006. Coupling long-term studies with meta-analysis to investigate impacts of non-native crayfish on zoobenthic communities. Freshwater Biology 51:224–235.

Perry, W.L., J.L. Feder, and D.M. Lodge. 2001. Implications of hybridization between introduced and resident *Orconectes* crayfishes. Conservation Biology 15: 1656–1666.

Rosenthal, S.K., S.S. Stevens, and D.M. Lodge. 2006. Whole-lake effects of invasive crayfish (*Orconectes* spp.) and the potential for restoration. Canadian Journal of Fisheries and Aquatic Sciences 63:1276–1285.

Somers, K.M., and R.H. Green. 1993. Seasonal patterns in trap catches of the crayfish *Cambarus burtoni* and *Orconectes virilis* in six south-central Ontario lakes. Canadian Journal of Zoology 71:1136–1145.

Wilson, K.A., J.J. Magnuson, D.M. Lodge, A.M. Hill, T.K. Kratz, W.L. Perry, and T.V. Willis. 2004. A long-term rusty crayfish (*Orconectes rusticus*) invasion: Dispersal patterns and community change in a north temperate lake. Canadian Journal of Fisheries and Aquatic Sciences 61:2255–2266.

Appendix A

Acronyms used in this report

AIS – aquatic invasive species

AKRC – Anishinaabeg of Kabapikotowangag Resource Council

B/P – biomass/production

BRACE – Biological Risk Assessment Centre of Expertise

CCIW – Canada Centre for Inland Waters

CEARA – Centre of Expertise on Aquatic Risk Assessment

COSEWIC – Committee on the Status of Endangered Wildlife in Canada

CSAS – Canadian Science Advisory Secretariat

CUE – catch per unit effort

CV – coefficient of variation

df – degrees of freedom

DFO – Fisheries and Oceans Canada

EA – environmental assessment

FAU – Fisheries Assessment Unit

GPS – global positioning system

HACCP – Hazard Analysis and Critical Control Points

ISAP – Invading Species Awareness Program

LOWDPOA – Lake of the Woods District Property Owners Association Inc.

LOWWSF – Lake of the Woods Water Sustainability Foundation

LCBO – Liquor Control Board of Ontario

LRTAP – Long Range Transport of Atmospheric Pollutants

LTER – Long-Term Ecological Research

MB – Manitoba

MNDNR – Minnesota Department of Natural Resources

NEC – National Executive Committee

NGO – non-governmental organization

NOBOB – no ballast on board

NOTO – Northern Ontario Tourism Organization

NSERC – Natural Science and Engineering Research Council

NWOTO – Northwest Ontario Tourism Organization

OME – Ontario Ministry of the Environment

OFAH – Ontario Federation of Anglers and Hunters

OMNR – Ontario Ministry of Natural Resources

OPAIS – Operational Plan for Aquatic Invasive Species

SD – standard deviation

TDS – total dissolved solids

UTM – Universal Transverse Mercator

Appendix B

Participants, E-mail Addresses and Affiliations

Participant	E-mail or Telephone	Organization
Kim Armstrong	kim.armstrong@ontario.ca	Ontario Ministry of Natural Resources
Sue Cosens	sue.cosens@dfo-mpo.gc.ca	Fisheries and Oceans Canada
Dan Drimes	ddrimes@gov.mb.ca	MB Water Stewardship (zebra mussel inspector)
Trevor Dysart	tdysart@gov.mb.ca	MB Water Stewardship student (zebra mussel inspector)
Martin Erickson	maerickson@gov.mb.ca	MB Conservation (Chair MB I&T Committee)
Nola Geard	nola_geard@hotmail.com	University of Winnipeg
Brenda Hann	hann@ms.umanitoba.ca	University of Manitoba
Ray Hesslein	ray.hesslein@dfo-mpo.gc.ca	Fisheries and Oceans Canada
Doug Leroux	dleroux@gov.mb.ca	MB Water Stewardship (Fisheries Branch)
Francine MacDonald	francinem@ofah.org	Ontario Federation of Anglers and Hunters
Sheldon McLeod	slmcleod@shaw.ca	SLMcLeod Consulting
Tom Mosindy	tom.mosindy@ontario.ca	Ontario Ministry of Natural Resources
Walter Momot	807-939-1233	Canadian citizen
Gavin Olson	gavin.olson@ontario.ca	Ontario Ministry of Natural Resources
Mike Paterson	mike.paterson@dfo-mpo.gc.ca	Fisheries and Oceans Canada
Wendy Ralley	wralley@gov.mb.ca	Manitoba Water Stewardship
David Rosenberg	dave.rosenberg@dfo-mpo.gc.ca	Canadian citizen
Kelli Saunders	ksaunders@lowwsf.com	Lake of the Woods Water Sustainability Foundation
Keith Somers	keith.somers@ene.gov.on.ca	Ontario Ministry of Environment
Jennifer Stewart	jenprochera@hotmail.com	Canadian citizen
Michael Turner	michael.turner@dfo-mpo.gc.ca	Fisheries and Oceans Canada
Rolf Vinebrooke	rolfualberta.ca	University of Alberta, Biological Sciences
Doug Watkinson	doug.watkinson@dfo-mpo.gc.ca	Fisheries and Oceans Canada

Appendix C

Agenda for the Rusty Crayfish Monitoring and Research Workshop

2–3 May 2006
Winnipeg, MB
Holiday Inn Astoria (Madison Room)
2935 Pembina Highway

Time	Item
2 May 2006	
0830 hr	Registration and Coffee
0900 hr	Workshop Objectives, Introductions and Review of Agenda
	Background Presentations: • Overview of invasive species and resultant risks (Francine MacDonald) • AIS issue and DFO programming (Sue Cosens) • Crayfish biology and role in foodwebs and case history of Lake Superior regional invasion (Walter Momot) • Southeast Ontario Crayfish Monitoring Program and Wisconsin invasion case history (Keith Somers)
	Defining the Impacts and Risks (Large Group Work)
	Lunch
	Lake of the Woods (LoW) (Tom Mosindy): • LoW setting; • Synopsis of historical OMNR records; • Draft monitoring plan for LoW
	Small Group Work on LoW Monitoring Plan
	Plenary Sharing of Small Group Work – Building Consensus
	End of Day One Workshop
1700 hr	Reception
3 May 2006	
0800 hr	Review of Day One Outcomes and Agenda for Day Two
	Winnipeg River (Doug Watkinson): • Background to Winnipeg River • Draft monitoring plan for Winnipeg River
	Small Group Work on Winnipeg River Monitoring Plan
	Plenary Sharing of Small Group Work
	Possible Synergies: Collaboration and Partnerships (Large Group Work)
	Next Steps Including Review of Impact Statement from Day One and Setting the Stage for Sharing the Results of the 2006 Monitoring; "Parked" Issues
1230 hr	Lunch

Appendix D

Template for List of Impacts and Risks of Rusty Crayfish Invasion

Impact description, including type (biological, physical or socio-economic)	+ve or –ve	Probability of occurrence (high, medium or low)	Severity (high, medium or low)	Extent (large, medium or small area)	Duration (short, medium or long-term with some elaboration)	Other comments

Appendix E

Small Groups

A: Lake of the Woods

Participant	Organization	Facilitator	Reporter	Comments
Group 1				
Kim Armstrong	ON	X		
Mike Paterson	CA			Large group reporter
Rolf Vinebrooke	UN		X	
Francine MacDonald	PR			
Kelli Saunders	PR			
Group 2				
Sheldon McLeod	PR	X		
Brenda Hann	UN		X	
Doug Watkinson	CA			
Doug Leroux	MB			
Ray Hesslein	CA			
Gavin Olson	ON			
Group 3				
Martin Erikcson	MB			
Walter Momot	PR			
Jennifer Stewart	PR	X		
Keith Somers	ON		X	
Michael Turner	CA			
Nola Geard	UN			Large group reporter
Not used as a small group participant				
Tom Mosindy	ON	Will move among groups during Lake of the Woods exercise		
David Rosenberg	PR	Will move among groups during both exercises		
Indeterminate				
Sue Cosens	CA			
Dan Drimes	MB			
Trevor Dysart	MB			
Wendy Ralley	MB			
Bob Fudge	CA			
Organization				
CA = Canada				
MB = Manitoba				
ON = Ontario				
PR = Private				
UN = University				

Appendix E (cont.)

Small Groups (cont.)

B: Winnipeg River

Participant	Organization	Facilitator	Reporter	Comments
Group 1				
Sheldon McLeod	PR	X		
Rolf Vinebrooke	UN		X	
Michael Turner	CA			
Doug Leroux	MB			
Francine MacDonald	ON			
Group 2				
Jennifer Stewart	PR	X		
Keith Somers	ON		X	
Tom Mosindy	ON			
Ray Hesslein	CA			
Walter Momot	PR			
Nola Geard	UN			Large group reporter
Group 3				
Kim Armstrong	ON	X		
Brenda Hann	UN		X	
Mike Paterson	CA			Large group reporter
Gavin Olson	ON			
Kelli Saunders	PR			
Martin Erickson	MB			
Not used as a small group participant				
Doug Watkinson	CA	Will move among groups during Winnipeg River exercise		
David Rosenberg	PR	Will move among groups during both exercises		
Indeterminate				
Sue Cosens	CA			
Dan Drimes	MB			
Trevor Dysart	MB			
Wendy Ralley	MB			
Organization				
CA = Canada				
MB = Manitoba				
ON = Ontario				
PR = Private				
UN = University				

Appendix F

Data for all trap lines set in the Winnipeg River. Substrate is reported as percent composition.

Latitude	Longitude	Date set	Date retrieved	Time set	Time lifted	Water depth (m) - near shore	Water depth (m) - midpoint	Water depth (m) - offshore	Water temp. (@ 1 m, °C)	Conductivity (µS/cm)	Secchi depth (m)	clay	silt	sand	gravel	cobble	boulder	bedrock	O.virilis	O.propinquus	O.immunis	O. rusticus
50.21918	95.57548	8/01/06	8/02/06	01:54	09:22	0.5	1.4	2.0	22.8	98.1	1.65			5	5	30	60		5			
50.19386	95.61587	8/01/06	8/02/06	14:00	09:30	1.0	1.6	1.8	22.4	98.1	1.65			80			20		8			
50.19395	95.61568	8/01/06	8/02/06	14:26	09:49	0.8	0.9	0.8	23.2	98.1	1.35			5		15	80		3			
50.15642	95.65009	8/01/06	8/02/06	14:41	10:05	0.4	2.2	3.0	23.5	98.1	1.17			80			20					
50.18204	95.70643	8/01/06	8/02/06	15:31	10:26	0.3	1.6	2.4	23.5	98.0	1.41			70			30		3			
50.14790	95.81858	8/01/06	8/02/06	16:02	10:49	0.4	0.8	0.8	23.5	98.0	1.40		50	50					1			
50.12670	96.00843	8/01/06	8/02/06	17:00	11:32	1.0	1.0	1.0	23.1	98.6	1.15					25	75		8			
50.11351	96.01082	8/01/06	8/02/06	17:06	11:42	1.2	1.1	1.1	23.1	98.6	1.15					25	75		7			
50.13408	95.91077	8/01/06	8/02/06	15:27	11:12	0.4	0.6	0.9	23.1	98.6	1.28		100						20			
50.12777	96.03205	8/02/06	8/03/06	14:31	09:39	0.8	1.0	1.5	23.2	130.0	0.75		10					90	16			
50.12851	96.02869	8/02/06	8/03/06	14:39	09:55	0.4	1.5	2.3	23.2	98.7	1.05			50				50	28			
50.16643	96.06017	8/02/06	8/03/06	14:56	10:09	0.8	0.8	0.8	23.5	99.9	0.81	100							13			
50.22380	96.05977	8/02/06	8/03/06	15:12	10:37	0.8	0.8	0.8	23.5	98.6	0.95			5		15	80		14			
50.26671	96.01656	8/02/06	8/03/06	15:34	10:53	0.4	0.6	0.8	23.7	98.4	0.90			5		15	80		9			
50.32336	96.01350	8/02/06	8/03/06	15:56	11:11	0.9	1.2	1.3	23.8	99.4	0.96					10	90		9			
50.38315	95.97112	8/02/06	8/03/06	16:15	12:09	1.0	0.8	1.0	23.7	102.7	0.67	95		5					20			
50.39880	95.97974	8/02/06	8/03/06	16:29	11:52	0.8	0.8	0.8	23.9	102.2	0.86	100							9			
50.39581	96.00321	8/02/06	8/03/06	14:41	11:40	0.8	1.3	1.8	23.9	102.2	0.75						100		30			
50.30274	95.55047	8/03/06	8/04/06	16:18	11:44	0.4	0.8	1.2	23.2	97.0	1.55		20				80		4			
50.30289	95.53706	8/03/06	8/04/06	16:27	11:32	0.6	0.9	1.2	23.2	97.0	1.55								3			
50.34215	95.49129	8/03/06	8/04/06	16:45	11:14	0.6	1.4	1.6	23.0	96.0	1.40		50				50		3			
50.37011	95.42556	8/03/06	8/04/06	17:05	10:59	0.7	0.9	0.9	23.0	96.0	1.66		80				20		4			
50.37043	95.33540	8/03/06	8/04/06	17:25	10:40	0.6	0.6	0.8	23.5	96.0	1.64		60				40		8			
50.35846	95.25959	8/03/06	8/04/06	17:49	10:13	0.6	0.6	0.6	22.7	96.0	1.92					10	90		5			
50.35065	95.20158	8/03/06	8/04/06	18:05	08:49	0.4	0.5	1.3	22.9	96.0	1.58					10	90		12		1	
50.30035	95.23093	8/03/06	8/04/06	18:28	09:11	0.5	0.6	0.7	22.6	98.0	1.55		100						3		1	
50.26402	95.21123	8/03/06	8/04/06	18:47	09:26	0.8	1.2	1.4	22.7	98.0	1.60						100		2			
50.12403	94.86906	8/08/06	8/09/06	16:27	08:41	0.6	0.9	1.6	22.2	116.0	2.00						100		5			
50.12504	94.87482	8/08/06	8/09/06	16:35	08:55	1.0	1.6	2.4	22.2	116.0	2.00						70	30	16	6		
50.12033	94.88168	8/08/06	8/09/06	16:48	09:07	0.7	2.0	2.5	22.2	116.0	2.00			80			20		2	2		
50.12489	94.92705	8/08/06	8/09/06	17:02	09:32	1.0	1.7	2.3	23.2	116.0	1.62					20	80			13		
50.10499	95.01767	8/08/06	8/09/06	17:22	10:02	0.5	0.6	0.8	23.2	116.0	1.81		80	20					5			
50.14930	95.03578	8/08/06	8/09/06	17:37	10:30	0.6	1.4	2.4	22.1	114.0	2.11					10	90		19			
50.19106	95.07418	8/08/06	8/09/06	17:54	10:49	0.8	1.2	1.8	21.8	102.0	1.69			80			20		31			
50.21682	95.10332	8/08/06	8/09/06	18:09	11:06	0.6	0.6	0.6	21.6	95.0	1.65		80	20					14			
50.24448	95.15119	8/08/06	8/09/06	18:25	11:20	1.0	1.6	2.4	23.2	98.0	1.46			5				95	6			
50.26287	94.98502	8/09/06	8/10/06	12:12	11:04	0.5	0.9	1.3	20.4	85.0	1.92			15	80		5		4			
50.25591	94.97731	8/09/06	8/10/06	12:22	10:48	0.7	1.6	2.1	20.4	85.0	1.92						20	80	7			
50.23273	94.98528	8/09/06	8/10/06	12:34	10:35	0.6	0.9	1.1	21.8	86.0	1.47		20				30	50	12			
50.20041	95.00293	8/09/06	8/10/06	12:45	10:23	0.7	1.6	2.4	20.9	86.0	1.69		5				30	65	9			
50.14479	95.02496	8/09/06	8/10/06	13:10	10:05	1.2	2.4	3.3	22.7	116.0	1.80						100		19			
50.12541	95.02829	8/09/06	8/10/06	13:19	09:55	0.5	0.6	0.8	24.4	116.0	1.47			50	10	10	30		26			
50.11299	95.01406	8/09/06	8/10/06	13:28	09:40	0.6	0.7	0.9	23.1	116.0	1.56			100					17			
50.11277	94.98547	8/09/06	8/10/06	13:49	09:28	0.6	0.8	1.1	22.5	117.0	1.80			80	15		5		4	12		
50.12034	94.94371	8/09/06	8/10/06	14:00	09:10	0.7	1.3	2.0	23.4	116.0	1.60					20	80		3	19		
50.15805	95.02557	8/10/06	8/11/06	11:35	08:55	0.6	0.9	1.3	22.0	115.0	2.20						60	40	30			
50.14735	95.03093	8/10/06	8/11/06	11:48	08:37	0.6	1.0	1.1	22.1	115.0	1.95		70				30		20			
50.13234	95.03679	8/10/06	8/11/06	12:06	08:28	0.5	1.4	1.8	23.3	117.0	1.60					20	80		20			
50.12601	95.01296	8/10/06	8/11/06	12:15	08:19	0.7	1.7	2.7	22.7	116.0	1.61						100		24			

Latitude	Longitude	Date set	Date retrieved	Time set	Time lifted	Water depth (m) - near shore	Water depth (m) - midpoint	Water depth (m) - offshore	Water temp. (@ 1 m, °C)	Conductivity (µS/cm)	Secchi depth (m)	clay	silt	sand	gravel	cobble	boulder	bedrock	*O.virilis*	*O.propinquus*	*O.immunis*	*O. rusticus*
50.11655	95.01706	8/10/06	8/11/06	12:23	08:12	0.5	0.9	1.7	22.4	117.0	1.80		50				50		34			
50.11175	95.00916	8/10/06	8/11/06	12:32	08:01	0.5	2.9	5.0	22.4	117.0	1.74						80	20	19			
50.10459	95.01180	8/10/06	8/11/06	12:38	07:36	0.5	1.9	3.0	22.8	116.0	1.48						60	40	16	2		
50.10525	94.99810	8/10/06	8/11/06	12:44	07:45	0.4	1.9	3.0	22.6	117.0	1.55						100		20	1		
50.11086	94.99969	8/10/06	8/11/06	12:49	07:55	0.4	1.9	3.0	23.1	117.0	1.47		60				10	30	5	1		
49.96413	94.67165	9/06/06	9/07/06	13:22	08:30	1.3	2.0	3.4	19.8	118.0	1.70						50	50	1			
49.93489	94.66117	9/06/06	9/07/06	13:37	08:45	2.1	2.2	2.3	20.9	117.8	1.45						60	40	2			
49.97420	94.64818	9/06/06	9/07/06	13:50	09:00	1.0	1.9	2.3	20.1	117.0	1.90					20	80					
49.97296	94.63627	9/06/06	9/07/06	14:05	09:15	1.3	1.8	2.3	21.0	117.0	3.00						100		13	1		
49.93078	94.57702	9/06/06	9/07/06	14:23	09:40	1.8	1.7	2.3	21.4	117.0	1.45						30	70	1			12
49.96466	94.60273	9/06/06	9/07/06	14:33	10:05	2.3	2.5	2.8	21.0	116.0	2.00					20	80		6			
49.99872	94.67068	9/06/06	9/07/06	14:54	10:25	1.0	1.3	1.8	21.1	116.0	1.35					20	80		7			
50.01753	94.70481	9/06/06	9/07/06	15:05	10:40	2.0	2.5	3.3	20.8	117.0	2.05			10			90					1
50.06073	94.73750	9/06/06	9/07/06	15:22	11:00	1.6	2.3	1.8	20.3	117.0	1.70						100		1			
50.07389	94.70900	9/06/06	9/07/06	15:31	11:15	1.0	1.2	2.1	20.2	116.0	1.50						100		3			
50.08842	94.75247	9/06/06	9/07/06	15:46	11:30	0.7	1.1	1.8	20.2	117.0	1.95						100		10			
50.09920	94.77927	9/06/06	9/07/06	15:55	11:45	0.6	0.7	1.0	20.5	117.0	1.20						50	50	1			
50.10919	94.80429	9/06/06	9/07/06	16:12	12:00	1.0	1.3	1.6	20.2	117.0	1.47		10				90		1			
50.12168	94.78901	9/06/06	9/07/06	16:23	12:10	1.1	2.4	2.5	20.5	117.1	1.85		15				15	70	3			
50.12034	94.81848	9/06/06	9/07/06	16:45	12:25	1.4	1.5	2.0	20.3	116.9	1.55							100	1			
50.11651	94.85929	9/06/06	9/07/06	16:52	12:45	1.6	2.0	2.3	20.5	117.0	2.10		30					70	12			
50.11243	94.86285	9/06/06	9/07/06	17:15	12:40	1.1	1.0	1.2	20.5	118.0	2.10						20	80	2			
50.09440	94.81174	9/07/06	9/08/06	13:55	09:20	1.0	1.1	1.0	20.7	116.9	1.50		100						1			
50.09007	94.79747	9/07/06	9/08/06	14:05	09:10	2.0	2.8	4.0	20.7	116.8	1.50		20				80					
50.09837	94.76444	9/07/06	9/08/06	14:15	09:00	1.1	1.2	1.3	20.8	116.9	1.25						10	90	3			
50.09429	94.74721	9/07/06	9/08/06	14:30	09:35	1.9	2.2	3.1	20.6	116.0	1.60		50				50		9			
50.08239	94.75327	9/07/06	9/08/06	14:41	08:50	0.8	0.9	1.1	19.6	117.5	1.95		40					60	3			
50.07314	94.74551	9/07/06	9/08/06	14:46	08:40	2.1	2.4	3.8	19.4	117.0	1.60		30					70				
50.07222	94.73697	9/07/06	9/08/06	14:52	08:30	2.0	2.5	3.0	19.4	117.9	1.65		10				60	30	8			
50.06850	94.73429	9/07/06	9/08/06	15:00	08:25	0.8	0.8	0.8	18.4	118.0	1.60		20				80		3			
50.05709	94.73496	9/07/06	9/08/06	15:11	08:15	0.8	0.8	1.0	18.2	118.0	1.35		80				20					
50.05070	94.71581	9/07/06	9/08/06	15:22	08:00	1.0	1.2	1.6	18.4	118.0	1.40		80					20	4			1
50.03212	94.71297	9/07/06	9/08/06	15:37	07:45	0.8	0.8	0.7	19.5	118.0	1.35					100			1			19
50.02190	94.70777	9/07/06	9/08/06	15:46	07:40	1.1	1.0	1.2	20.1	117.0	1.40		30					70	2			3
50.01992	94.70805	9/07/06	9/08/06	15:51	07:25	0.8	0.9	1.1	20.1	118.9	1.40		30					70	1			
50.00981	94.68034	9/07/06	9/08/06	16:04	07:15	1.1	1.3	1.8	20.1	118.9	1.85			50	20		30		2			
49.99813	94.69231	9/07/06	9/08/06	16:12	07:05	1.8	2.2	3.0	20.1	118.9	1.85						100		4			
49.99380	94.67053	9/07/06	9/08/06	16:24	06:45	1.8	2.5	4.0	20.1	118.8	1.80						100		1			
49.98923	94.65919	9/07/06	9/08/06	16:47	06:50	0.8	1.4	0.8	20.0	119.0	2.25		20					80	7			

52627
(.2 k P.R., 10 03 15)
ISBN 978-1-4435-2303-5 (Print)
ISBN 978-1-4435-2304-2 (PDF)