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Calling on the Public: Where in the Great Lakes Basin Is the Newest Aquatic Invader, *Hemimysis anomala*?

David F. Reid, Rochelle Sturtevant* and Steven Pothoven

NOAA-National Center for Research on Aquatic Invasive Species, Great Lakes Environmental Research Laboratory (*also Great Lakes Sea Grant Network), Ann Arbor, MI 48105

A new aquatic invader, the bloody-red mysid shrimp (Figure 1), was discovered in the Great Lakes in 2006, but has been confirmed only at two locations (Figure 2). Scientists believe it probably has a wider distribution, but has not been previously reported either because people didn't recognize it as a new organism, or simply didn't see it.

Hemimysis anomala is difficult to locate because it is nocturnal, preferring to hide in rocky cracks and crevices near the bottom along the shoreline during daylight. However, it also sometimes exhibits a unique swarming behavior, forming small dense reddish-tinged clouds containing thousands of individuals concentrated in one location, usually visible just below the waters surface in a shadow zone (Figure 3). This is the basis for a new

Continued on p.2

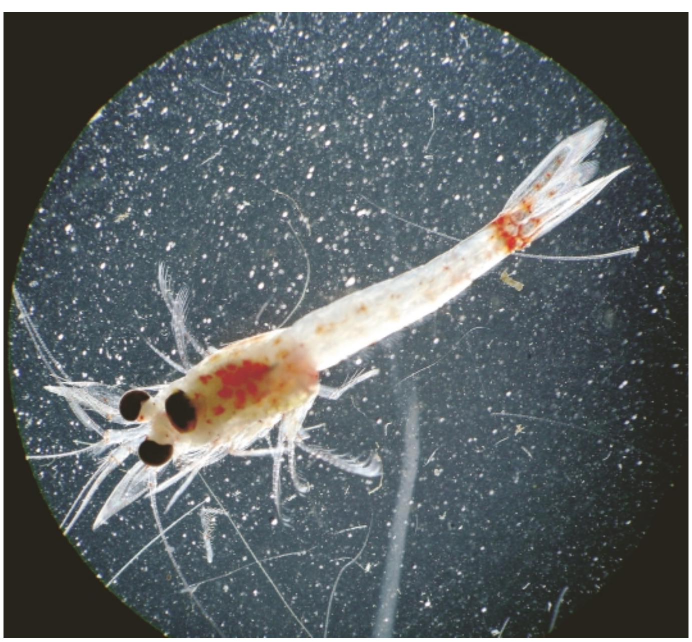

Figure 1. *Hemimysis anomala* collected near Muskegon, Michigan in November 2006. Photo: NOAA

ECOLOGY

Forecasting the impacts of *Hemimysis anomala*: the newest invader discovered in the Great Lakes

Anthony Ricciardi

Redpath Museum, McGill University, Montreal, Quebec, Canada H3A 2K6; tony.ricciardi@mcgill.ca

Introduction

Over the past few decades, the Great Lakes have experienced a wave of invasions by species indigenous to the fresh-water and brackish-water margins of the Black, Caspian and Azov seas - the Ponto-Caspian region. A dozen free-living species of protists, mussels, crustaceans and fishes, in addition to several species of parasites, from this region have been discovered in the Great Lakes since the 1980s (Ricciardi 2006). During this period, numerous Ponto-Caspian species invaded European ports and thus gained opportunities for transport by ships to North America (Ricciardi & MacIsaac 2000; bij de Vaate et al. 2002; Janas & Wysocki 2005), as has occurred recently with the bloody-red mysid *Hemimysis anomala* (Pothoven et al. 2007). Their introduction to the Great Lakes has apparently continued after ballast water regulation was implemented in 1993, possibly because many Ponto-Caspian species possess a broad tolerance to salinity that permits them to survive varying conditions in the residual waters of ballast tanks (Reid & Orlova 2002; Ricciardi 2006). Indeed, we can anticipate future invasions by Ponto-Caspian invertebrates and fishes as they expand their ranges into western Europe from whence the Great Lakes receives the bulk of its shipping traffic (Ricciardi & Rasmussen 1998; Rodionova et al. 2005).

Ponto-Caspian species occupy nearly every trophic level of Great Lakes food webs. They have produced substantial ecological changes in the Great Lakes basin and elsewhere in their invaded range (Vanderploeg et al. 2002; Ojaveer et al. 2002), which begs the question: How will the latest Ponto-Caspian invader, *Hemimysis anomala*, affect the ecology of the Great Lakes? The impacts of an invader vary with environmental conditions and are notoriously difficult to forecast (Parker et al. 1999; Ricciardi 2003). One generalization that has emerged from numerous case studies is that the greatest impacts

Continued on p.4

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Telephone: (585) 395-2638
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"Calling on the Public..." continued from p.1

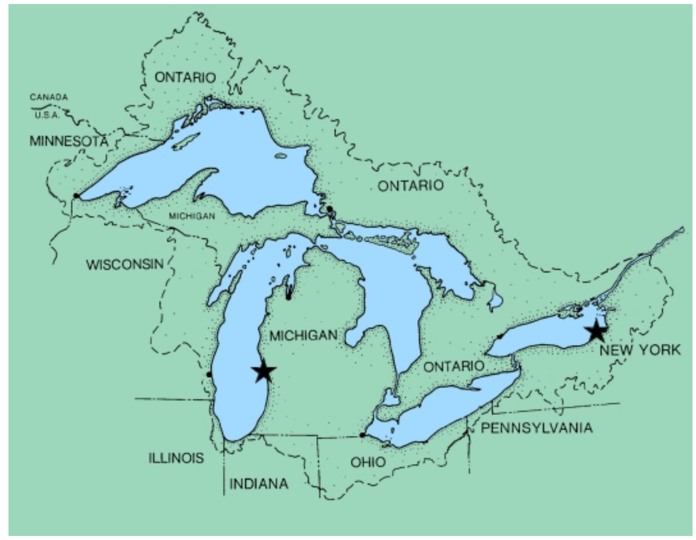

Figure 2. Confirmed populations (stars) of *Hemimysis anomala* found in 2006.

survey and monitoring program being established which is asking for public assistance in locating other occurrences of this organism. See ***Hemimysis* Survey and Monitoring Network** (below) for information about how to participate and how to report your observations.

Discovery

In early 2006, Jack Workman, a deckhand assigned to the research vessels at NOAA's Lake Michigan Field Station on the channel from Lake Michigan into Muskegon Lake, was working by the small boat basin adjacent to the Field Station when he noticed an unusual swarm of small organisms just below the water's surface in the shadow of the retaining wall. Workman brought the swarm to the attention of biologist Steve Pothoven, who then collected specimens and realized they were a mysid shrimp (order Mysidacea), similar to, but not the same as the native Great Lakes mysid, the Opossum Shrimp (*Mysis diluviana*, see Audzijonytë and Väinölä 2005; Dooh et al. 2006). Pothoven sent samples to a taxonomic expert who identified them as the bloody-red mysid *Hemimysis anomala* G.O. Sars, 1907, another native of the Ponto-Caspian region not previously reported in the Great Lakes. Mysids in general are often referred to as "opossum shrimp" because females typically carry their eggs in a pouch, so this "common name" is not unique to the native Great Lakes species. *Mysis diluviana* is, however, the only native mysid in the Great Lakes and is a deep cold water species not usually found in shallow coastal habitats.

A survey of the Muskegon area in late November found a small population in the Muskegon channel, but not in Muskegon Lake or in Lake Michigan outside the channel. The population within the swarm included over 500 individuals per cubic meter, almost two-thirds females, approximately half as many males, and some juveniles. The State of

Figure 3. Swarms of *Hemimysis anomala* appear as dense reddish-tinged clouds of hundreds to thousands of the small insect-like organisms. Photo: NOAA

Michigan Department of Environmental Quality was notified in early December. In January 2007 another population that had been sampled in May 2006 near Nine-Mile Point in eastern Lake Ontario was announced (J. Wyda, personal communication). That population was confirmed as *H. anomala* by a taxonomic expert in Europe. Both immature and mature organisms were reportedly found there also.

About the Species

A scientific article on the species and its discovery will be published in the March issue of the *Journal of Great Lakes Research* (Pothoven et al. 2007). An information brochure and a scientific fact sheet are available on line:

Information Brochure:
http://www.glerl.noaa.gov/res/Programs/ncrais/hemimysis/hemi_brochure.html
Scientific Fact Sheet:
http://www.glerl.noaa.gov/res/Programs/ncrais/hemimysis/hemi_sci_factsheet.html

How It Likely Got Here

Hemimysis anomala is widespread in Europe, having expanded due to stocking, the construction of canals connecting previously separated river basins, reservoir construction and transport by commercial ships (Ketelaars et al. 1999). The most likely means of introduction of this species to the Great Lakes was discharge of foreign ballast water. However, some species of mysids are also used by aquarists as a high-nutrition food for aquarium fish, but we have not found any records that *Hemimysis anomala* is used this way.

The Great Lakes have been under a ballast water exchange requirement since 1993 to reduce or eliminate the likelihood of new aquatic invaders by flushing coastal organisms from tanks and exposing them to high (oceanic) salinity. Although the upper salinity tolerance reported for this organism is ~18 ppt (Pothoven et al. 2007), the omission of NOBOB (no-ballast-on-board) vessels was a large gap in the protection framework afforded by ballast water exchange. Johengen et al. (2005) showed that NOBOB ballast tanks have residual water and sediment that can contain live organisms from other ecosystems and such organisms can potentially be discharged from NOBOB ballast tanks during ballasting operations in the Great Lakes. They also found that about 1/3 of the vessels they surveyed contained residual low-salinity or fresh water in their ballast tanks. Since NOBOB vessels were not subject to a minimum salinity requirement until mid-2006, *Hemimysis* could have been transported in such low salinity residual ballast water in any of the thousands of NOBOBs that entered the Great Lakes since 1993. Now that it is in the Great Lakes, domestic ships provide an additional vector for spreading the invader around the basin, also through internal ballast water transport and discharge. *Hemimysis* may also invade other nearby aquatic ecosystems through interbasin connections, specifically, the Chicago Sanitary and Ship Canal, which hydraulically connects Lake Michigan to the Mississippi Rivers system, and the St. Lawrence River, which connects to Lake Champlain through the Chambly Canal and Richelieu River. Transport in bait buckets and recreational boats could also provide a means of spreading to inland lakes.

Typically, we require multiple confirmed discoveries of adult and juvenile life stages over at least two consecutive years in order to list a species as an invader. For *Hemimysis* there are confirmed records of multiple discoveries of both adults and juveniles, but only from one year (to date). However, the population density and composition at the Muskegon site suggests that it may have been present for more than one year before being discovered. In addition, we have unconfirmed anecdotal information that it may also be present in Grand Haven, Michigan, and may have already been observed by vessel operators near the Lake Ontario location for several years. This species has no difficulty surviving winters in northern Europe, so we expect it will survive Great Lakes winters also. Thus we are classifying it as a new invader. A fact sheet on *Hemimysis* is available at:
http://www.glerl.noaa.gov/res/Programs/ncrais/hemimysis/hemi_sci_factsheet.html

The Rapid Research Response Plan

A planning meeting was hosted in mid-January by NOAA with the assistance of the USEPA Great Lakes National Program Office to organize a "Rapid Research Response Plan" for *Hemimysis* within the Great Lakes Basin. Three general research needs were identified and are listed here, roughly in order of priority; all three should be considered interdependent:

1. Establish and verify the distribution of this species around the basin. Scientists suspect that *Hemimysis* is not limited only to the two known sites, and suspect that these populations may represent secondary invasions,

likely having spread from one or more other invasion sites. It is important to determine the distribution and population density of the new species in order to implement steps that may reduce its spread and also as input to risk assessment analyses and to guide future research plans. Establishment of a volunteer survey and monitoring network was proposed and is being organized.

2. Assess the vectors involved in the introduction and (potential) spread of *Hemimysis* to and within North America - the highest risk vector being ballast water movements, and interbasin canals, but also potentially bait buckets and recreational boats. This information will guide monitoring, help predict how and where it may spread outside the basin, and direct efforts to prevent or minimize expansion. This would involve a combination of monitoring, mapping, and genetic studies.
3. Predict the ecological impacts of *Hemimysis anomala* in the Great Lakes region. Early understanding of potential impacts, particularly to ecosystem services enjoyed by humans, is a key step in determining the relative priority that should placed on any new invader.

The complete outline of the Rapid Research Response Plan can be found on-line at:
http://www.glerl.noaa.gov/res/Programs/ncrais/hemimysis/hemi_rrr_plan.html

Hemimysis Survey and Monitoring Network

Determining the basin-wide distribution of *H. anomala* was identified as the top priority for immediate action. A three-tiered survey and monitoring network was outlined, requiring participation by various groups:

1) A public outreach network to engage and involve the general public in the search for *Hemimysis*. Information has been posted about what to look for and where to look:
http://www.glerl.noaa.gov/res/Programs/ncrais/hemimysis/finding_hemi.html
A website for reporting findings (positive or negative) has also been established:
http://www.glerl.noaa.gov/res/Programs/ncrais/hemimysis/hemi_sighting.html
2) A network of basin-wide site-specific technical volunteers with appropriate training and resources who are willing to respond to public reports of *Hemimysis* sightings in their area by accessing the reported location and attempting to verify their presence, and if possible, collect samples for taxonomic verification and genetic analysis.
3) Multi-institutional technical personnel with appropriate field-sampling capabilities and resources, such as agency and academic scientists, who are willing to conduct surveys for the presence of *Hemimysis* at various sites around the Great Lakes basin. Development of recommended sampling methodologies and monitoring protocols is a key first step.

One of the important needs and uses for a rapid survey and longer-term monitoring program is that as locations with populations are identified, appropriate information can be provided to the shipping industry (domestic and saltwater fleet representatives), the boating public (marinas, sport fishing associations, etc.), aquarium hobbyists, and the scientific community (especially with respect to field gear). These organizations can act on information about new species, such as *Hemimysis*, to avoid aiding in their spread.

The *Hemimysis* Survey and Monitoring Network will include inland lakes, since there is great potential for *Hemimysis* to reach inland lakes via recreational boats and bait buckets, especially those close to the Great Lakes and their harbors and embayments.

For more information about *Hemimysis*, see
http://www.glerl.noaa.gov/hemimysis/

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ECOLOGY

"Forecasting the Impacts..." continued from p.1

are caused by the introduction of a novel organism - a species that has no ecological analogue in the region and so is more likely to use resources differently than resident species (Ricciardi & Atkinson 2004). Virtually all Ponto-Caspian invaders in the Great Lakes fit this category, because they are phylogenetically and ecologically distinct from resident native species. Although *H. anomala* is morphologically similar to the North American opossum shrimp *Mysis diluviana*, the latter lives primarily below the thermocline of deep lakes, whereas *H. anomala* inhabits a broad range of depths (<1 m to >50 m), including nearshore environments (Salemaa & Hietalahti 1993). Ponto-Caspian mysids are metabolically adapted to higher temperatures than cold-water *Mysis* spp. (Bondarenko & Yablonskaya 1979), indicating that *H. anomala* may become abundant in areas of the Great Lakes historically devoid of mysids. The presence of juveniles and reproductive females within a dense population suggests that *H. anomala* is already well established in both southern Lake Michigan (Pothoven et al. 2007) and at Nine Mile Point in Lake Ontario (J. Wyda, pers. comm.), in littoral areas where *M. diluviana* does not exist. Furthermore, *H. anomala* can invade lotic environments (bij de Vaate et al. 2002; Holdich et al. 2006) and will likely spread into the St. Lawrence River. Populations will be patchy, owing to the tendency of mysids to aggregate into locally dense swarms around rocky areas, but not in densely vegetated and highly silted areas (Janas & Wysocki 2005; Pothoven et al. 2007).

The simplest method of gaining predictive information about an invader's impacts is to compare its effects in different ecosystems and geographic regions in which it has been introduced (e.g., Crivelli 1983; Grosholz & Ruiz 1996; Ricciardi 2003). An analysis of the kinds of impacts and their direction and magnitude across multiple invaded sites can determine whether the effects of an invader are consistent, and therefore predictable, in different environments (e.g. Ward & Ricciardi 2007). When the invader lacks a sufficiently detailed impact history, we might then examine the histories of functionally similar organisms, with the assumption that species that use resources in similar ways are likely to exert similar impacts. Here, I use both empirical approaches to forecast *H. anomala*'s potential impacts in the Great Lakes.

Impact history of *Hemimysis anomala* in Europe

Hemimysis anomala was deliberately stocked in the reservoirs of the Dnieper and Volga Rivers during the 1950s and '60s to enhance food resources for fish (Pligin & Yemel'yanova 1989). It was discovered in the Baltic Sea in the Gulf of Finland in 1992 and subsequently spread 200 km along the Scandinavian coast (Salemaa & Hietalahti 1993; Lundberg & Svensson 2004). It was also recorded in the Rhine River basin in 1997, the River Main in 1998, the Danube River in 1999, and the Trent River and surrounding areas of the English Midlands by 2004 (bij de Vaate et al. 2002; Dumont 2006; Borcherding et al. 2006; Holdich et al. 2006).

Like most mysids, *H. anomala* is an opportunistic omnivore that feeds primarily on large zooplankton, but also consumes detritus (plant and animal remains), phytoplankton (particularly filamentous green algae and diatoms), and insect larvae, and is occasionally cannibalistic (Ketelaars et al. 1999; Borcherding et al. 2006; Dumont 2006). Younger individuals (< 4mm total length) feed mainly on phytoplankton. The proportion of zooplankton consumed in the mysid's diet increases with its body size (Borcherding et al. 2006). In some European

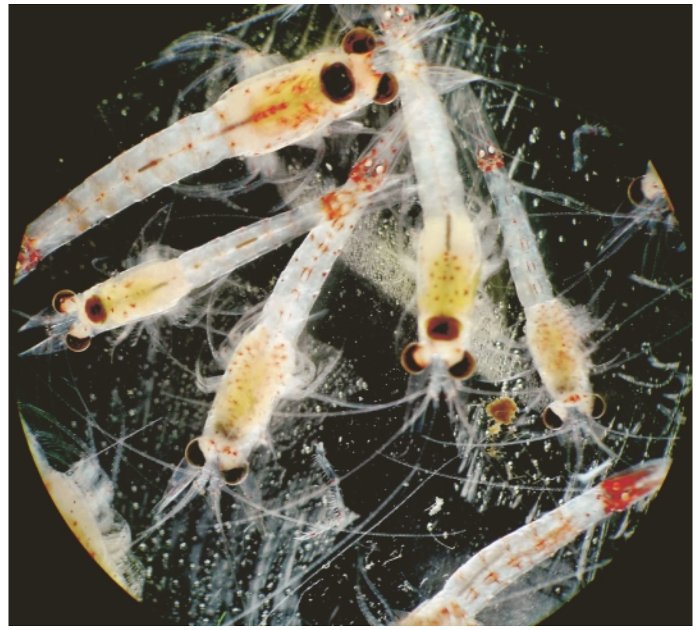

Figure 1. *Hemimysis anomala* collected near Muskegon, Michigan in November 2006. Organisms shown here are 5-9 mm long. Photo: NOAA

reservoirs (Ketelaars et al. 1999), *H. anomala* has severely reduced zooplankton biomass and diversity, with cladocerans, rotifers and ostracods being most affected. Furthermore, *H. anomala* may compete with, or prey upon, other invertebrate predators, such as *Bythotrephes longimanus* and *Leptodora kindti*. Its omnivory may reduce local phytoplankton, if small-sized juvenile mysids are abundant (Ketelaars et al. 1999; Borcherding et al. 2006); however, phytoplankton biomass may increase dramatically in lakes following mysid invasions (see below). *Hemimysis* feeds rapidly, even at low prey densities, and its fecal pellets may alter the local physico-chemical environment (Ketelaars et al. 1999; Olenin and Leppäkoski 1999; Pienimäki and Leppäkoski 2004).

Owing to its lipid content, *H. anomala* is regarded as a high-energy food source that can enhance the growth of planktivores. Young-of-the-year European perch (*Perca fluviatilis*) in a gravel-pit lake increased their predation on *H. anomala* from 20% in August to 100% in November, and this diet shift was correlated with an increasing lipid content in the perch (Borcherding et al. 2006). However, introduced mysids have had mixed effects on fish growth and productivity (see below).

Lessons from other mysid introductions

Recognized as a potentially important supplementary food source for freshwater fishes, mysids (*Mysis*, *Hemimysis*, *Limnomysis*, *Neomysis* and others) have been stocked in lakes throughout North America and Europe (Lasenby et al. 1986; Pligin & Yemel'yanova 1989; Northcote 1991). A consistent impact of these introductions is the decline or temporal displacement of macrozooplankton, particularly cladocerans (Rieman & Falter 1981; Richards et al. 1991; Spencer et al. 1991; Martinez & Bergersen 1991; Langeland et al. 1991a,b; Kinsten & Olsen 1981). Smaller zooplankton, including rotifers, may increase in abundance or shift in species composition (Kinsten & Olsen 1981; Koksvik et al. 1991). Overall, a strong (>60%) reduction in zooplankton density and biomass is typically observed (Langeland et al. 1991a,b; Koksvik et al. 1991; Spencer et al. 1999). These alterations have had cascading effects on upper trophic levels (e.g. Spencer et al. 1991). Introductions of mysids have preceded the increased growth of salmonids in some lakes, whereas in most other lakes they are associated with declines in the growth, abundance and productivity of pelagic fishes (Lasenby et al. 1986; Langeland et al. 1991a,b; Bowles et al. 1991; Spencer et al. 1991; Tohtz 1993). By contrast, benthic fishes such as percids, centrarchids and burbot may benefit from the availability of mysid prey (Bowles et al. 1991; Langeland et al. 1991b). Through direct transmission and indirect effects on the food web, introduced mysids can also cause increased parasitism by nematodes, cestodes and acanthocephalans in fishes (Lasenby et al. 1986; Northcote 1991).

Increased phytoplankton production has been observed in some lakes during the development of mysid populations (Kinsten & Olsen 1981; Koksvik et al. 1991). Phytoplankton biomass nearly doubled in one Scandinavian lake, a few years after the introduction of *Mysis relicta* (Koksvik et al. 1991). This is likely in response to the reduction of large-sized cladocerans and to benthic feeding activities that disturb sediments and release phosphorus (Kasuga & Otsuki 1984, cited in Northcote 1991). Furthermore, feeding activities that involve the fragmentation of diatom frustules release dissolved organic carbon and silica (Northcote 1991). However, nutrient cycling in the upper water column may be limited because mysids remain in deeper waters throughout much of the day (Chipps & Bennett 2007).

Mysids recycle contaminants by grazing on floating detritus in the water column or by preying on benthic invertebrates, and then serving as prey for fish (Evans et al. 1982). Their vertical migrations result in the transport of heavy metals between benthic and open-water food webs (Northcote 1991). A mysid introduction can increase the biomagnification of contaminants in higher consumers through a lengthening of the food chain; for example, concentrations of polychlorinated biphenyls and mercury in lake trout have been shown to be higher in lakes containing mysids than in mysid-free lakes (Rasmussen et al. 1990; Cabana et al. 1994).

Conclusions

The European literature does not provide sufficient information to make confident predictions regarding the impacts of *H. anomala* in the Great Lakes. The few impact studies that have been done for this species suggest a strong potential for food web disruption, consistent with most other mysid introductions. A population density of 0.5 ± 0.1 individuals/L recorded at the Lake Michigan site (Pothoven et al. 2007) is already within the range found in some European reservoirs invaded by *H. anomala*, and is higher than maximum densities recorded for several other mysid species (Ketelaars et al. 1999).

There are virtually no published studies on the longterm dynamics of *H. anomala*. An abundant and expanding population subsequently declined and disappeared from a Dnieper River reservoir, apparently as a result of water quality degradation (Pligin & Yemel'yanova 1989). A major question is whether planktivores can limit the local abundance and spatial distribution of *H. anomala* in the Great Lakes. Mysids are able to evade many predators through their rapid escape response and by hiding amongst bottom sediments during daylight hours (Northcote 1991). However, there are efficient planktivores in the Great Lakes such as alewife *Alosa pseudoharengus* (Evans 1990), which feed selectively on *M. diluviana* and are able to adjust their own diel vertical migrations to coincide with the mysid (Janssen & Brandt 1980; Pothoven & Vanderploeg 2004). Competitive interactions might further limit the local abundance of mysids; for example, competition with the introduced fish-hook waterflea *Cercopagis pengoi* (which has also invaded the Great Lakes) reduced *Neomysis* densities in the Gulf of Riga (Kotta & Kotta 2006). The complexity of such interactions presents a challenge to predicting impacts. Nonetheless, given *H. anomala*'s recent invasion history in Europe and the history of mysid invasions in general, local food web disruptions and altered nutrient and contaminant cycling in the Great Lakes seem likely to occur if the species becomes abundant and continues to spread in the basin.

About the author

Anthony Ricciardi is a professor of environmental science at McGill University (Montreal, Canada), where he teaches a course on invasive species biology. He holds a Quebec Strategic Professorship at McGill. Since 1991, he has examined the causes and consequences of invasions in freshwater ecosystems. His research is focused on predicting the ecological impacts of non-native invertebrates and fishes, using empirical modelling, meta-analysis, and field experiments.

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Quagga Mussels Cross Continental Divide

Linda Drees

Chief, Invasive Species Branch, Natural Resource Program Center, National Park Service; linda_drees@nps.gov

Quagga mussels (*Dreissena bugensis*), an aquatic invasive species similar in characteristics and impact to the zebra mussel were discovered in Lake Mead National Recreation Area (NRA) on Saturday, January 6, 2007. Subsequently, Quagga mussels have been found in