Journal of Great Lakes Research 36 (2010) 577–581

Contents lists available at ScienceDirect

Journal of Great Lakes Research

journal homepage: www.elsevier.com/locate/jglr

Notes

First occurrence of the mysid *Hemimysis anomala* in an inland lake in North America, Oneida Lake, NY

Thomas E. Brooking [a,*], Lars G. Rudstam [a], Scott D. Krueger [a], James R. Jackson [a], Amy B. Welsh [b], William W. Fetzer [a]

[a] Cornell University Biological Field Station, Department of Natural Resources, Cornell University, 900 Shackelton Point Road, Bridgeport, NY 13030, USA
[b] State University of New York at Oswego, Department of Biological Sciences, 7060 State Route 104, Oswego, NY 13126, USA

ARTICLE INFO

Article history:
Received 11 January 2010
Accepted 5 April 2010

Communicated by Dr. Joseph Makarewicz

Index words:
Hemimysis anomala
Exotic species
Oneida Lake

ABSTRACT

Hemimysis anomala (Crustacea, Mysidae) is a recent invader to North America that until now was reported only from the Laurentian Great Lakes and their immediate embayments, along with the St. Lawrence River. In August 2009, we identified *Hemimysis* in diets of white perch and yellow perch in Oneida Lake, NY. Night time vertical plankton net tows detected *Hemimysis* at four sites across the lake. *Hemimysis* in fish diets (5.5–8.6 mm) were larger than in net tows (2.2–7.0 mm) and reproduction is occurring as some females had brood sacs. This is the first documented introduction of *Hemimysis* to an inland lake in North America, outside the Great Lakes. Oneida Lake is located 53 river km upstream from Lake Ontario, the nearest known source of *Hemimysis*. No genetic differences were found between *Hemimysis* in Oneida Lake and Lake Ontario, indicating this is likely the source of introduction. Several large rapids, locks, and dams separate the two lakes, and as a result the most likely vector of introduction to Oneida Lake is pleasure boat or light commercial traffic via the canal system or overland transport. The presence of *Hemimysis* in Oneida Lake 3 years after it was first found in Lake Ontario suggests this species may spread rapidly throughout the basin. Despite an intensive monitoring program on Oneida Lake directed at fish, zooplankton, and limnology, *Hemimysis* was only detected in fish diets and night time zooplankton tows, indicating it may go undetected in lakes for some time using traditional daytime net tows.

Introduction

Both intentional and accidental introductions of freshwater mysids have impacted many freshwater lakes world-wide (Lasenby et al., 1986; Wittman and Ariani, 2009; Rudstam and Johannssen, 2009). *Hemimysis anomala* ("bloody-red shrimp") is the first non-native freshwater mysid to invade the Laurentian Great Lakes. Native to the Ponto-Caspian region, the species was first detected in 2006 in Lake Ontario close to Oswego, as well as in Lake Michigan, near Muskegon (Pothoven et al., 2007; Walsh et al., 2010). By 2009, *Hemimysis* had been detected throughout most of the Great Lakes (except Lake Superior) including embayments and outlets like the St. Lawrence River, but had not been reported from any inland water body (Kestrup and Ricciardi, 2008; National Oceanic and Atmospheric Administration, 2009). *Hemimysis* seek rocky crevices near bottom during the day to avoid predation and are found in warmer, littoral waters rather than pelagic, colder waters preferred by the native mysid *Mysis diluviana* (Boscarino et al., 2007, 2009; formerly known as *Mysis relicta*; Audzijonyte and Väinölä, 2005).

Potential impacts of *Hemimysis* on food web interactions are varied. In Europe, *Hemimysis* are omnivorous, feeding mainly on zooplankton, detritus, phytoplankton, green algae and diatoms (Borcherding et al., 2006; Dumont, 2006; Kipp and Ricciardi, 2007). Ketelaars et al. (1999) attributed reduced zooplankton biomass and diversity to highly abundant *Hemimysis* populations in some European reservoirs. They are eaten by fish, and fish consuming *Hemimysis* can show high growth rates. Borcherding et al. (2006) reported *Hemimysis* were considered a high energy food source and were 20–100% of the diet of YOY European perch *Perca fluviatilis*. They also found "supernormal growth performance" of YOY European perch in laboratory feeding experiments with *Hemimysis*. Walsh et al. (2010) suggested that *Hemimysis* present a new prey item of relatively high energy density to near shore fishes in Lake Ontario, and hypothesized that they may form a trophic triangle with zooplankton and planktivorous fish. In Lake Ontario alewife *Alosa pseudoharengus*, yellow perch *Perca flavescens*, rockbass (*Ambloplites rupestris*), and white perch *Morone americana* have been shown to prey on *Hemimysis* (Kipp and Ricciardi, 2007; Lantry et al., 2010).

In this paper, we document the presence of *Hemimysis* in a large, shallow inland lake in New York (Oneida Lake) and describe distribution

* Corresponding author.
E-mail addresses: teb1@cornell.edu (T.E. Brooking), lgr1@cornell.edu (L.G. Rudstam), sdk24@cornell.edu (S.D. Krueger), jrj26@cornell.edu (J.R. Jackson), amy.welsh@oswego.edu (A.B. Welsh), wwf3@cornell.edu (W.W. Fetzer).

0380-1330/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.jglr.2010.04.004

patterns in the lake through analysis of fish diets and directed sampling. We describe sampling routines in which *Hemimysis* was and was not observed. We also analyze possible vectors of invasion, based on physical characteristics of the watershed, and compare genetic characteristics of *Hemimysis* in Oneida Lake with those found in Lake Ontario. The presence of *Hemimysis* in an inland lake only 3 years after they were first discovered in Lake Ontario (though they may have been present longer) suggests that this species may spread faster than what was currently believed or hypothesized (Koops et al., 2010).

Methods

Oneida Lake is a shallow, productive 20,700-ha lake in the Oswego River watershed of New York and is located 53 river km upstream of Lake Ontario. The New York State Barge Canal system passes through Oneida Lake, connecting the Oneida/Oswego River drainage to the west and the Mohawk/Hudson River drainage to the east. The lake experiences heavy recreational fishing pressure and is also popular with recreational boaters (Connelly et al., 1997). The fish community is a mix of warmwater and coolwater species, including walleye *Sander vitreus*, yellow perch, smallmouth bass *Micropterus dolomieu*, and largemouth bass *Micropterus salmoides*; white perch and gizzard shad *Dorosoma cepedianum* have been abundant during recent decades. Oneida Lake has a mean depth of 6.8 m and is considered mesotrophic (Mills et al., 1978; Idrisi et al., 2001). It is well mixed and seldom exhibits prolonged periods of stratification. Summer temperatures often exceed 25 °C, and winter temperatures are often near 0 °C. A monitoring program on Oneida Lake funded by Cornell Biological Field Station (CBFS) through Cornell University and the New York State Department of Environmental Conservation includes bottom trawling, gillnetting, zooplankton tows, and benthos grabs and has been ongoing since the 1950s (Rudstam et al., 2009).

Fish diets were sampled from fish caught in standardized gillnet sets from June through September (Rudstam and Jackson, 2008). In 2009, the nets were set at one site per week for 15 weeks, from 3 June to 9 September 2009. Nets were set at dusk and retrieved just after sunrise for an average soak time of approximately 12 h. Site locations are fixed and have been standardized since 1957 to cover a wide range of substrates, drop-offs, and mid-lake habitats (Fig. 1). Diets were recorded on all fish species, consisting mainly of walleye, yellow perch, white perch, freshwater drum *Aplodinotus grunniens*, sunfish (*Lepomis* sp.), and smallmouth bass. Diet items were removed by dissection and examined immediately and visually categorized by major taxa and enumerated when feasible. *Hemimysis* from fish diets were preserved in ethanol, then later measured, and sex and maturity stage determined. We measured total body length from the anterior tip of the carapace to the posterior margin of the telson using a projection setup to the nearest 0.1 mm (Pothoven et al., 2007).

Directed sampling for *Hemimysis* was initiated after initial discovery in fish diets. Vertical tows with a 0.5-m diameter plankton net (500-μm mesh) were made during the nights of 1 and 2 September 2009 at 22 sites lake wide (Fig. 1). Sites were from 2.5 to 10 m deep with the majority of the sites at less than 5 m deep (Table 1). Samples were preserved in 70% ethanol and returned to the lab for identification, measurement of total length, and determination of sex and maturity stage.

A sample of *Hemimysis* was analyzed for genetic comparison with the Lake Ontario population at the State University of New York at Oswego. DNA was extracted from 13 specimens using the Gentra Puregene Tissue Kit, according to manufacturer's protocol. A ~556 bp portion of the mitochondrial cytochrome oxidase I subunit gene was amplified. Two PCR reactions were conducted for each sample using the HemiHatF–HemiCapR primer combination and the HemiCapF–HemiHatR primer combination (Audzijonyte et al., 2008). Approximately 10 ng of DNA were amplified in 20-μl reactions using 1× PCR buffer, 3 mM $MgCl_2$, 0.2 mM dNTPs, 0.5 μM of each primer, and 0.5 U of Qiagen HotStarTaq polymerase. Thermal cycler conditions were as follows: 95 °C for 2 min; 30 cycles of 95 °C for 30 s, 50 °C for 30 s, and 72 °C for

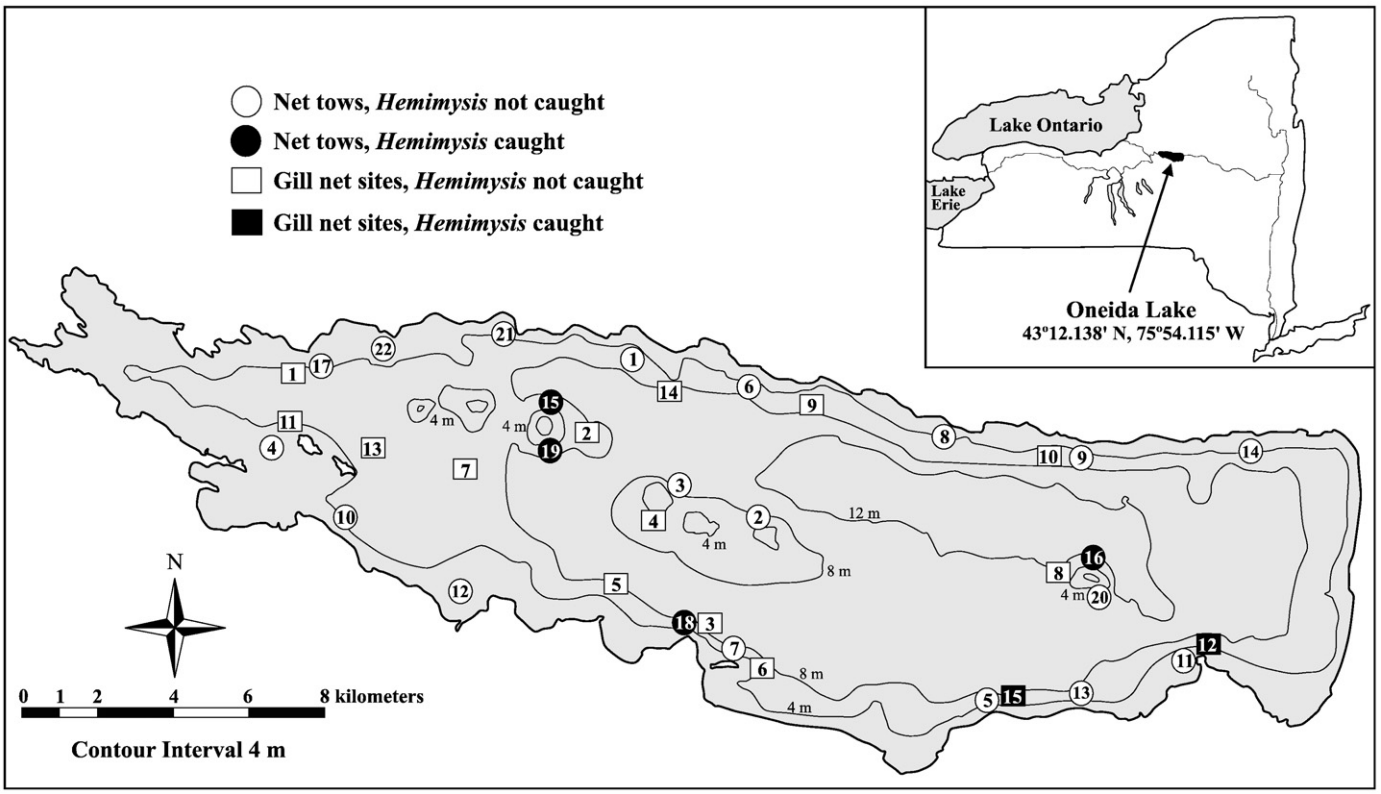

Fig. 1. Map of Oneida Lake showing sites where *Hemimysis* were caught and not caught, using ½-m net tows at night and fish diets from gillnet sampling.

Table 1
Catch of *Hemimysis anomala* in ½-m vertical plankton net tows at night, 30 August–2 September 2009. Density was calculated as the number of individuals captured divided by the surface area of the net, and also by the volume strained. Site numbers refer to the map in Fig. 1.

Site #	Site	Depth (m)	Catch	Density (#/m^2)	Density (#/m^3)
1	Bernhards Bay	5.0	0	0.0	0.0
2	Buoy 121	2.5	0	0.0	0.0
3	Buoy 125	7.5	0	0.0	0.0
4	Buoy 133	3.0	0	0.0	0.0
5	Bushnell Point	6.0	0	0.0	0.0
6	Cleveland	4.5	0	0.0	0.0
7	Dutchmans Island	5.0	0	0.0	0.0
8	Godfrey Point	3.0	0	0.0	0.0
9	Jewell	5.0	0	0.0	0.0
10	Lakeshore Road	5.0	0	0.0	0.0
11	Lewis Point	3.0	0	0.0	0.0
12	Maple Bay	3.0	0	0.0	0.0
13	Messenger Bay	6.0	0	0.0	0.0
14	North Bay	3.0	0	0.0	0.0
15	North of Dakin Shoal	5.0	1	5.1	1.0
16	North of Messenger Shoal	4.0	27	137.8	34.4
17	Phillips Point	3.5	0	0.0	0.0
18	Shackelton Point	4.0	1	5.1	1.3
19	South of Dakin Shoal	3.0	8	40.8	13.6
20	South of Messenger Shoal	10.0	0	0.0	0.0
21	Taft Bay	5.0	0	0.0	0.0
22	Three Mile Bay	4.0	0	0.0	0.0
		Total catch	37	-	-
		Mean	1.7	8.6	2.3
		Range	0 - 27	0 - 137.8	0 - 34.4

1 min; followed by a 72 °C extension for 5 min. PCR products were purified, sequenced, and visualized on a Beckman Coulter CEQ8000 Genetic Analysis System, according to manufacturer's protocol. Sequencing product was purified using ethanol precipitation and capillary electrophoresis was done on a Beckman Coulter CEQ8000 Genetic Analysis System. Resulting sequences were aligned using the software BIOEDIT (Hall, 1999) and sequences were compared to published *Hemimysis anomala* (GenBank accession numbers EU029162–EU029170). Haplotype frequencies were compared to those observed from 13 individuals in southern Lake Ontario (Questel et al., State University of New York at Oswego, unpublished data 2009) and an exact test of population differentiation (Raymond and Rousset, 1995) was conducted using the software ARLEQUIN (Excoffier et al., 2005).

Results

During 2009, we examined diets of 404 white perch and 467 yellow perch captured in gill nets. The first *Hemimysis* from Oneida Lake were found on 20 August 2009 in the diet of a 233-mm adult male white perch caught in a standard gillnet at Lewis Point (Fig. 1). *Hemimysis* were subsequently identified in the diets of eight sub-adult and adult white perch (133–310 mm) and one adult yellow perch (256 mm) captured in gill nets 9 September 2009 at Bushnell Point. No *Hemimysis* were observed in fish diets from any of the other 13 gill net sites. Both sites where *Hemimysis* were observed in fish diets are within 5 km of each other in the southeastern part of the lake and are both rocky substrates on or near drop-offs. Individual *Hemimysis* were not counted from every diet; however, we estimated that some diets contained >100 individuals. No *Hemimysis* were observed in the diets of 188 walleye, 31 freshwater drum, 28 smallmouth bass, 22 pumpkinseed sunfish *Lepomis gibbosus*, or eight white bass *Morone chrysops* examined across the 15 sites (all adult fish). *Hemimysis* from fish stomachs were mostly adults (94%) and averaged 7.1 mm total length (± 0.14 SE; range 5.5–8.6 mm; $n = 33$; Fig. 2). Many females were carrying broods in their brood sacs.

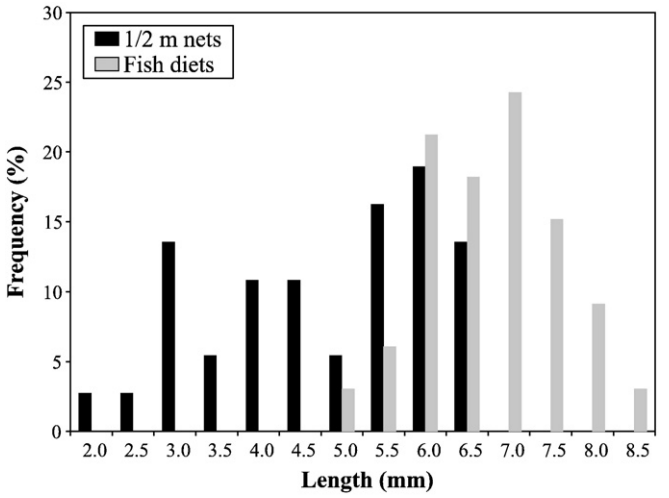

Fig. 2. Length frequency distribution of *Hemimysis anomala* from ½-m vertical net tows and from fish diets.

Vertical net tows at night caught *Hemimysis* at four of 22 sites (Table 1). The four sites where *Hemimysis* were caught spanned 17 km of the lake's 32-km length (Lewis Point to Dakin Shoal, Fig. 1). All four sites were rocky areas in 3–5 m of water near shallow, mid-lake shoals or rocky points along shore. *Hemimysis* from the net samples averaged 5.1 mm total length (± 0.22; range 2.2–7.0; $n = 37$). Both juveniles (32%) and adults were present, including individuals as small as 2.2 mm. Net tows caught many smaller individuals than were found in fish diets (Fig. 2) and mean size was significantly smaller (two-sample t-test; $t < 0.01$).

Genetic analysis was successful on 11 of the 13 specimens. Two haplotypes were identified: Haplotype A and Haplotype B1. Haplotype B1 was the most common haplotype, with a frequency of 0.82. There were no significant genetic differences between the Oneida Lake population and the southern Lake Ontario population (exact test of population differentiation; $p = 0.38$).

Discussion and conclusions

Hemimysis were found in 2009 at four sites across the lake and also observed in the stomach of fish from an additional two sites in Oneida Lake, representing a large area of the lake (Fig. 1). *Hemimysis* were found in large numbers in some fish diets and in one net sample. This wide distribution, as well as the presence of gravid females and juveniles, indicates that the species appears to be established and reproducing in Oneida Lake. However, *Hemimysis* were not found in fish diets at 13 of the 15 gillnet sites, or at 18 of the 22 *Hemimysis* netting sites, indicating that they are presently not distributed throughout the entire lake. The largest catches of *Hemimysis* were around rocky shoals and points. *Hemimysis* are known to inhabit rocky crevices and jetties (Janas and Wysocki, 2005; Holdich et al., 2006). In Europe, *Hemimysis* densities can be quite high, with densities as high as >6 individuals/L reported (Ketelaars et al., 1999; Borcherding et al., 2006). The mean size of *Hemimysis* found in fish diets (5.5–8.6 mm) was significantly larger than found in net tows (2.2–7.0 mm) suggesting fish may select for larger individuals, though sample sizes were limited. We found *Hemimysis* in adult white perch and yellow perch diets, and they have been reported in diets of alewife, yellow perch, and rock bass in Lake Ontario (Lantry et al. 2010). Sizes of *Hemimysis* in Oneida Lake were similar to sizes reported in Lake Ontario (1.6–8.2 mm; Marty et al., 2010), Lake Michigan (mean sizes 6.9–7.0 mm; Pothoven et al., 2007), and the St. Lawrence River (mean sizes 5.6–7.3 mm; Kestrup and Ricciardi, 2008).

There is no evidence that *Hemimysis* were present prior to the summer of 2009. Diet analysis from gill netting has been performed

annually for >50 years (Rudstam and Jackson, 2008; Rudstam et al., 2009). In recent years we have examined between 350–700 adult and sub-adult white perch and 450–700 adult and sub-adult yellow perch diets per year, and no *Hemimysis* were found prior to 2009. In addition, no *Hemimysis* were found in a large diet study on young-of-year (YOY) yellow perch from inshore seining and offshore trawling in 2007 (1,592 diets) and 2008 (1,082 diets; Fetzer, CBFS, unpublished data 2009).

It is worth noting that *Hemimysis* did not show up in any other standard sampling on Oneida Lake except for fish diets. The annual monitoring program in 2009 included approximately 125 daytime vertical plankton tows, 360 daytime high speed larval fish tows, a diving survey for zebra mussels with 75 samples at 25 sites, 36 day time benthic grabs, 140 bottom trawl samples, 90 seine hauls, and various other sampling (Rudstam, CBFS, unpublished data 2009); none of which encountered *Hemimysis*. Other research suggests that targeted sampling at night is often required to detect *Hemimysis* due to diurnal migration patterns similar to *Mysis diluviana* (Boscarino et al., 2009) and to specific habitat selection (rocks), especially when they are at low densities (Ketelaars et al., 1999; Walsh et al., 2010; Wittman and Ariani, 2009). Invertebrates near bottom in rocky areas are difficult to sample with conventional benthic grabs. Our initial detection came from examination of fish diets, and Lantry et al. (2010) also found fish diets in Lake Ontario to be effective at detecting the presence of *Hemimysis*. Thus, this species may remain undetected even in lakes with sampling directed at zooplankton and benthos unless targeted night time tows or fish diets are included in surveys.

Borcherding et al. (2006) indicated that *Hemimysis* prefer areas with temperatures less than 20 °C, but they are known to occur in water temperatures up to 28 °C. At the time of sampling in Oneida Lake (end of August–beginning of September), the lake was isothermal at 21.3–22.5 °C, which was apparently suitable for *Hemimysis*. Borcherding et al. (2006) also reported that *Hemimysis* may survive temperatures close to 0 °C over winter, and *Hemimysis* have also been sampled from the Great Lakes at temperatures as low as 2 °C (Marty et al., 2010). Oneida Lake reaches very low temperatures in the winter (almost always <1 °C, sometimes for >90 days; Fitzgerald et al., 2006) and summer temperatures close to 28 °C have been observed (Jackson et al., 2008). If *Hemimysis* can survive at the temperature extremes found in Oneida Lake, there are few lakes in the Northeast where they would be thermally limited.

Genetic analysis suggested that *Hemimysis* in Oneida Lake were closely related to the Lake Ontario population. Though Oneida Lake is connected to Lake Ontario, many physical barriers exist which make natural migration of *Hemimysis* into the lake unlikely. Oneida Lake is 53 river km upstream of Lake Ontario, the nearest source of *Hemimysis*. Large rapids with strong currents exist in the main channel of the Oswego River. Hydropower dams and water control structures are located in Oswego (two dams), Minetto, Fulton (two dams), Phoenix, and Caughdenoy. It seems unlikely that a small mysid could navigate upstream under such conditions and over such a large distance. The canal system circumvents these dams and rapids with locks capable of transporting recreational and light commercial boat traffic. The maximum depth of 4.3 m and maximum vessel height of 6.4 m in these locks and canals effectively excludes commercial ocean-going vessels. Oneida Lake also receives large amounts of overland boat transport; it is one of the most heavily fished lakes in the state, and has some of the most heavily used boat launches in the state (Connelly et al., 1997). Thus, the most likely vector of *Hemimysis* introduction to Oneida Lake is pleasure boat traffic or light commercial traffic, either through the canal or overland transport.

Koops et al. (2010) determined that the ecological risk of *Hemimysis* to the Great Lakes was high, and that the risk to inland lakes was moderate to high. Given the spread of *Hemimysis* to Oneida Lake only 3 years after they were detected in Lake Ontario (though they may have been present longer), it is likely that the risk of spread to inland lakes is higher than previously thought. A key uncertainty in the risk assessment was the probability of establishment which may be higher than previously hypothesized. Propagule pressure may also be higher than previously expected. Furthermore, continued spread through river systems seems likely; *Hemimysis* are known to inhabit rivers in Europe (bij de Vaate et al., 2002; Holdich et al., 2006) and have been found in the St. Lawrence River (Kestrup and Ricciardi, 2008). *Hemimysis* now have the potential to spread through the canal and river systems from Oneida Lake into the Oswego River, Erie Canal, and Finger Lakes systems to the west and to the Mohawk and Hudson River drainages to the east.

Acknowledgments

This study was funded in part through the New York State Department of Environmental Conservation Federal Aid to Sportfish Restoration Funds, with additional funding from Cornell University, the Great Lakes Fisheries Commission and New York Sea Grant. We would like to thank Roland Wang for help counting samples, along with Kristen Holeck, Brent Boscarino, and Chris Hotaling for sharing the results of their sampling and general help on the project. This is Contribution Number 273 of the Cornell University Biological Field Station.

References

Audzijonyte, A., Väinölä, R., 2005. Diversity and distributions of circumpolar fresh- and brackish-water *Mysis* (Crustacea: Mysida): descriptions of *M. relicta* Lovén, 1862, *M. salemaai* n.sp., *M. segerstralei* n.sp. and *M. diluviana* n.sp., based on molecular and morphological characters. Hydrobiologia 544, 89–141.

Audzijonyte, A., Wittmann, K.J., Väinölä, R., 2008. Tracing recent invasions of the Ponto-Caspian mysid shrimp *Hemimysis anomala* across Europe and to North America with mitochondrial DNA. Divers. Distrib. 14, 179–186.

bij de Vaate, A., Jazdzewski, K., Ketelaars, H.A.M., Gollasch, S., Van der Velde, G., 2002. Geographical patterns in range extension of Ponto-Caspian macroinvertebrate species in Europe. Can. J. Fish Aquat. Sci. 59, 1159–1174.

Borcherding, J., Murawski, S., Arndt, H., 2006. Population ecology, vertical migration and feeding of the Ponto-Caspian invader *Hemimysis anomala* in a gravel-pit lake connected to the River Rhine. Freshw. Biol. 51, 2376–2387.

Boscarino, B.T., Rudstam, L.G., Mata, S., Gal, G., Johannsson, O.E., Mills, E.L., 2007. The effects of temperature and predator–prey interactions on the migration behavior and vertical distribution of *Mysis relicta*. Limnol. Oceanogr. 52 (4), 1599–1613.

Boscarino, B.T., Rudstam, L.G., Loew, E., Mills, E.L., 2009. Predicting the vertical distribution of the opossum shrimp *Mysis relicta* in Lake Ontario: a test of laboratory-based light preferences. Can. J. Fish Aquat. Sci. 66, 101–113.

Connelly, N.A., Brown, T.L., Knuth, B.A., 1997. New York statewide angler survey 1996. Angler effort and expenditures. New York Department of Environmental Conservation, Albany, NY.

Dumont, S., 2006. A new invasive species in the north-east of France, *Hemimysis anomala* G. O. Sars, 1907 (Mysidacea). Crustaceana 79, 1269–1274.

Excoffier, L., Laval, G., Schneider, S., 2005. Arlequin ver. 3.0: an integrated software package for population genetics data analysis. Evol. Bioinform. Online 1, 47–50.

Fitzgerald, D.G., Forney, J.L., Rudstam, L.G., Irwin, B.W., VanDeValk, A.J., 2006. Gizzard shad put a freeze on winter mortality of age-0 yellow perch but not white perch. Ecol. Appl. 16, 1487–1501.

Hall, T.A., 1999. BioEdit: a user-friendly biological sequence alignment editor and analysis program for Windows 95/98/NT. Nucl. Acids Symp. Ser. 41, 95–98.

Holdich, D., Gallagher, S., Rippon, L., Harding, P., Stubbington, R., 2006. The invasive Ponto-Caspian mysid, *Hemimysis anomala*, reaches the UK. Aquat. Invasions 1, 4–6.

Idrisi, N., Mills, E.L., Rudstam, L.G., Stewart, D.L., 2001. Impact of zebra mussels *Dreissena polymorpha* on the pelagic lower trophic levels of Oneida Lake, New York. Can. J. Fish Aquat. Sci. 58, 1430–1441.

Jackson, J.R., VanDeValk, A.J., Forney, J.L., Lantry, B.F., Brooking, T.E., 2008. Long-term trends in burbot abundance in Oneida Lake, New York: Life at the southern edge of the range in an era of climate change. Am. Fish Soc. Symp. 59, 131–154.

Janas, U., Wysocki, P., 2005. *Hemimysis anomala*—first record in the Gulf of Gdańsk. Oceanologia 47, 405–408.

Kestrup, A.M., Ricciardi, A., 2008. Occurrence of the Ponto-Caspian mysid shrimp *Hemimysis anomala* in the St. Lawrence River. Aquat. Invasions 3, 461–464.

Ketelaars, H.A.M., Lambreqts-van de Clundert, F.E., Carpentier, C.J., Waqenvoort, A.J., Hooqenboezem, W., 1999. Ecological effects of the mass occurrence of the Ponto-Caspian invader *Hemimysis anomala* in a freshwater storage reservoir in the Netherlands, with notes on its autecology and new records. Hydrobiologia 394, 233–248.

Kipp, R.M., Ricciardi, A., 2007. *Hemimysis anomala* Fact Sheet. Great Lakes Aquatic Nonindigenous Species Information System. http://www.glerl.noaa.gov/res/Programs/ncrais/glansis.html.

Koops, M.A., Gerlofsma, J., Marty, J., 2010. Risk assessment of the bloody red shrimp (*Hemimysis anomala*) in Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2009, 107.

Lantry, B.F., Walsh, M.G., Johnson, J.H., McKenna Jr., J.E., 2010. Occurrence of the Great Lakes' most recent invader *Hemimysis anomala* in the diet of fishes in southeastern Lake Ontario. J. Great Lakes Res. 36, 179–183.

Lasenby, D.C., Northcote, T.G., Fürst, M., 1986. Theory, practice, and effects of *Mysis* introductions to North American and Scandinavian lakes. Can. J. Fish Aquat. Sci. 43, 1277–1284.

Marty, M., Bowen, K., Koops, M.A., Power, M., 2010. Distribution and ecology of *Hemimysis anomala*, the latest invader of the Great Lakes basin. Hydrobiologia 647, 71–80.

Mills, E.L., Forney, J.L., Clady, M.D., Schaffner, W.R., 1978. Oneida Lake. In: Bloomfield, J.A. (Ed.), Lakes of New York State: Ecology of the lakes of western New York, 2. Academic Press, New York, pp. 367–451.

National Oceanic and Atmospheric Administration, 2009. Great Lakes Aquatic Nonindigenous Species Information System. http://www.glerl.noaa.gov/res/Programs/ncrais/glansis.html.

Pothoven, S.A., Grigorovich, I.A., Fahnenstiel, G.L., Balcer, M.D., 2007. Introduction of the Ponto-Caspian bloody-red mysid *Hemimysis anomala* into the Lake Michigan basin. J. Great Lakes Res. 33, 285–292.

Raymond, M., Rousset, F., 1995. An exact test for population differentiation. Evolution 49, 1280–1283.

Rudstam, L.G., Jackson, J.R., 2008. Gill net survey of fishes of Oneida Lake, New York, 1957–2007. http://ecommons.library.cornell.edu/handle/1813/11216.

Rudstam, L.G., Johannssen, O.E., 2009. Advances in the ecology of freshwater mysids. Aquat. Biol. 5, 246–248.

Rudstam, L.G., Jackson, J.R., Brooking, T.E., Krueger, S.D., Forney, J.L., Fetzer, W.W., et al., 2009. Oneida Lake and its fishery 2008. New York Federal Aid in Sport Fish Restoration Study 1 F-56-R. New York State Department of Environmental Conservation, Albany, NY. 50 pp.

Walsh, M.G., Lantry, B.F., Boscarino, B.T., Bowen, K., Gerlofsma, J., Schaner, T., 2010. Early observations on an emerging Great Lakes invader *Hemimysis anomala* in Lake Ontario. J. Great Lakes Res. 36, 499–504.

Wittman, K.J., Ariani, A.P., 2009. Reappraisal and range extension of non-indigenous *Mysidae* in continental and coastal waters of eastern France. Biol. Invasions 11, 401–407.