SHORT COMMUNICATIONS

ZEBRA MUSSEL, *DREISSENA POLYMORPHA* (PALLAS), ATTACHMENT TO ODONATA LARVAE

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The attachment of zebra mussels to anisopteran larvae in a lake where the mussels have recently invaded was documented. Fifty-one larvae were collected and the majority (63%) had been colonized by one or more zebra mussels. Some dragonfly larvae were heavily infested, carrying up to 8 zebra mussels and more than their own mass in attached zebra mussels. Potential ramifications of zebra mussel attachment on larval dragonflies are discussed and a framework for future research on these effects is suggested.

INTRODUCTION

Zebra mussels (*Dreissena polymorpha*), palaearctic natives of the Caspian region, were accidentally introduced into North America in the mid-1980s through ship ballast water and spread rapidly through the Great Lakes and the Mississippi River basin (USGS, 2005). This spread has included movement of zebra mussels into rivers and smaller lakes in the region, where they interact with the native fauna through both direct (e.g., attachment) and indirect (e.g., competition, change in habitat) pathways (GILLIS & MACKIE, 1994; SCHLOESSER & NALEPA, 1994; RICCIARDI et al., 1995, 1996). Attachment to mobile macroinvertebrates has been described for snails (TUCKER, 1994), crayfish

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(BRAZNER & JENSEN, 2000) and anisopteran odonate larvae (TUCKER & CAMERER, 1994; O'BRIEN, 2001; CHRISCINSCKE, 2001; WEIHRAUCH & BORCHERDING, 2002). Studies in odonates have not, however, quantified the frequency with which direct attachment occurs within a population or the burden this may impose on larvae.

This study documented the frequency of zebra mussel attachment on larval odonates in a lake where the mussels have only recently invaded, and considered potential negative effects of this direct interaction. We quantified the number of zebra mussels dragonfly larvae carried. We also estimated the mass of those zebra mussels and the fraction of larval body mass these burdens represented. Finally, we discuss the potential for direct impacts of zebra mussels on dragonfly larvae and suggest what questions needed to be addressed to understand the effects of direct attachment by zebra mussels on dragonfly populations.

METHODS

Larval dragonflies were collected on 29 May 2005 from Douglas Lake at the University of Michigan's Biological Station (45°35′N, 84°42′W) near Pellston, Michigan, USA. Douglas Lake is a sandy-bottomed, mesotrophic lake with high water clarity. Zebra mussels were first recorded in Douglas Lake in 2002 and have spread rapidly, visibly colonizing a large portion of the living and non-living hard substrates near shore. Dragonflies were collected by walking two 700 m parallel transects at depths of approximately 0.1 m and 1 m in the littoral zone. Transects paralleled the shore. All dragonflies observed along transects were collected using d-frame dipnets. Additionally, sections where the sandy bottom was obscured with debris were dipnetted in to collect larvae associated with this debris. Given the high level of water clarity and general lack of submerged vegetation, larvae were easily observed and collected, and little bias in species or attachment rate was expected. However, the attached zebra mussels may disrupt the visual pattern of the larval form, resulting in some bias in favor of collecting larvae without attached mussels. This suggests that our estimates of attachment frequency are conservative. There may, however, have been a bias in the size distribution of larvae collected as many larvae in these shallower areas were in their final instar and were present in these areas most likely because they were moving towards shore to emerge. Therefore, these results likely reflect levels of colonization on individuals nearing emergence and are not necessarily applicable to all developmental stages. Larvae were brought back to the biological station where they were housed individually in plastic cups filled with well water.

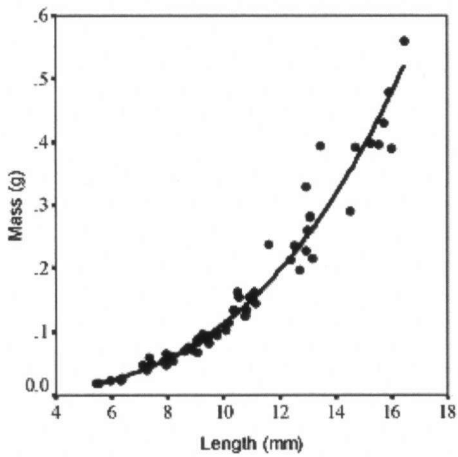

Fig. 1. Zebra mussel length and mass relationships. Observed lengths and weights are indicated by dots. The solid line indicates the power function fit to the length-mass data used to estimate the mass of zebra mussels attached to dragonflies.

Dragonfly larvae were weighed with zebra mussels still attached, because removing zebra mussels damages both larvae and mussels, making it difficult to accurately weigh either. We instead estimated mass of larvae and attached zebra mussels. Dragonflies and attached zebra mussels were lightly patted dry, weighed to the nearest milligram, and then the length of each attached mussel was measured (± 0.05 mm) using Vernier calipers. To estimate the mass of zebra mussels carried by dragonflies we collected 59 mussels from hard substrates in the lake across the size range observed attached to dragonflies. The length of these mussels was measured using the same calipers and then mussels were patted dry and weighed on the same scale. These data were used to estimate the mass-length relationship in zebra mussels of this size range.

DATA ANALYSIS. – The length and mass of collected zebra mussels were best described using a power function ($r^2 = 0.98$, $p < 0.001$). This relationship was used to estimate the mass of each zebra mussel carried by dragonfly larvae based on the length of the mussel using the fitted equation: mass(g) = 9.1E-05 – ($\text{length}^{3.09}$) (Fig. 1). To estimate larval dragonfly mass, the estimated mass of zebra mussels carried by each larva was subtracted from the total mass measured of the larva and attached mussels. The mass-specific mussel load carried by larvae was calculated for each larva by dividing the estimated total mass of zebra mussels on a larva by the estimated mass of that larva.

RESULTS

Of the 51 dragonfly larvae collected, 32 (63%) carried at least one zebra mussel. The two most common dragonfly species collected, *Hagenius brevistylus* (head width: 6.88 ± 0.29) and *Didymops transversa* (head width: 7.83 ± 0.14) (means ± 1 s.e.) both had greater than 50% infestation rates (Tab. I). Larvae carried up to eight zebra mussels although most individuals carried fewer than this (Figs 2, 3a). However, even a larva carrying relatively low numbers of mussels could have heavy burdens (Fig. 3b). Zebra mussels of the size carried by dragonfly larvae averaged 10.4 ± 0.38 mm and 0.16 ± 0.02 g (means ± 1s.e.). The mass specific burden of attached zebra mussels for an individual larva was estimated to range from 1.3% to 112% of the individual's mass (Tab. I).

Table I

Summary of the proportion and mass of zebra mussels carried on the two most commonly collected species of dragonfly larvae. Three *Didymops transversa* carrying zebra mussels died prior to being weighed and so were not included estimates of mass

Species	Percent carrying zebra mussels	Estimated mass of zebra mussels carried per infested individual Mean ± 1 s.e. (g)	Estimated percent body mass carried by infested individuals a. Range b. Mean ± 1 s.e.
Hagenius brevistylus	77% (n = 30)	0.39 ± 0.08 (n = 23)	a. 1.3 - 99% b. 25 ± 5%
Didymops transversa	69% (n = 13)	0.57 ± 0.08 (n = 6)	a. 31 - 112% b. 66 ± 12%

DISCUSSION

This study is the first we are aware of to document the frequency of zebra mussel attachment within a population and the numbers and mass of zebra mussels that an individual larva may carry. Although zebra mussels have only recently invaded Douglas Lake, the majority of dragonfly larvae collected had at least one attached mussel. The high frequency of attachment suggests that this phenomenon may be widespread in lakes where zebra mussels are present. Furthermore, as dragonfly larvae molt their exoskeleton periodically, the level of colonization should be affected by how recently each larva molted. As we did not know the time since each larva had last molted, we could not assess whether larvae with no or few zebra mussels may have just recently molted. It is possible that most larvae experience zebra mussel attachment at some point in their molting cycle, potentially expanding the proportion of the population affected by zebra mussels beyond the level we measured.

The numbers and relative mass of zebra mussels carried by larvae have the potential to have significant negative impacts on larval dragonfly populations. Discussion of the direct effects of zebra mussels on odonate larvae has focused on the potential for zebra mussels to act as a mechanical block preventing larvae from emerging into the adult stage (O'BRIEN, 2001; WEIHRAUCH & BORCHERDING, 2002). This may increase mortality rates if individuals are prevented from emerging, or if the emergence process is slowed thereby increasing the length of time that individuals are exposed to the risk of predation or weather related mortality during this period. Whether zebra mussel attachment influences mortality during emergence remains an issue of significant concern and should be addressed through experimental rearing of larvae with attached zebra mussels.

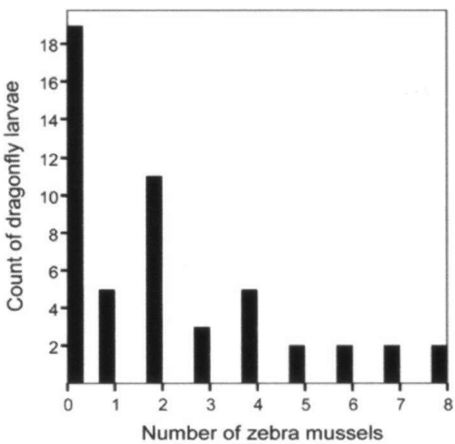

Fig. 2. Histogram of the count of larvae with the number of zebra mussels carried by each larva.

Zebra mussels attached to odonate larvae may also have multiple impacts during the larval stage prior to final emergence. First, zebra mussels can kill larvae directly by pinning individuals to hard substrates. Although we have no data on direct mortality from zebra mussel attachment, we found a single dragonfly larva dead and tied to a submerged log by the byssal threads of zebra mussels attached to the larva. While this appears unlikely to be a significant source of mortality, it has been observed previously in another species, *Gomphus vastus* (TUCKER & CAMERER, 1994) and further observations should be reported to assess its frequency. Second, the heavy burdens carried by many larvae may impose significant energetic costs. Zebra mussel mass expressed as a percentage of larval body mass ranged from 1.3% to more than 100%. At the low end of this range the increased energetic costs are likely to be minimal, but larvae carrying a mass equivalent to or greater than their own are likely to incur some energetic costs from this burden. The effect of this burden on larval growth rates can have multiple impacts including increasing the length of time individuals are exposed to larval predators and potentially shifting the timing of emergence, altering the breeding phenology of populations exposed to zebra mussels. Finally, zebra mussels may affect larval maneuverability. Larva with zebra mussels attached to the ventral surface (e.g., Fig. 3b) are likely to be destabilized and may have difficulty burrowing into sediments, factors that can affect prey capture and predator avoidance. Understanding the effects of zebra mussel attachment on populations of dragonfly larvae will require addressing the multiple ways in which mussels affect mortality and growth.

We found that odonate species differed in their relative zebra mussel burdens. Although *H. brevistylus* had a slightly higher frequency of zebra mussel infestation, on average individuals carried a smaller absolute and proportional mass in zebra mussels than *D. transversa*. The relative impact of zebra mussel attachment on the energetic costs to larvae may differ between species and also be size dependent. This should be addressed through growth rate studies that examine the effect of different levels of zebra mussel burden on larval growth across a range of dragonfly species that differ in body size. Additional work should be conducted to assess the potential for zebra mussels to affect community structure in lar-

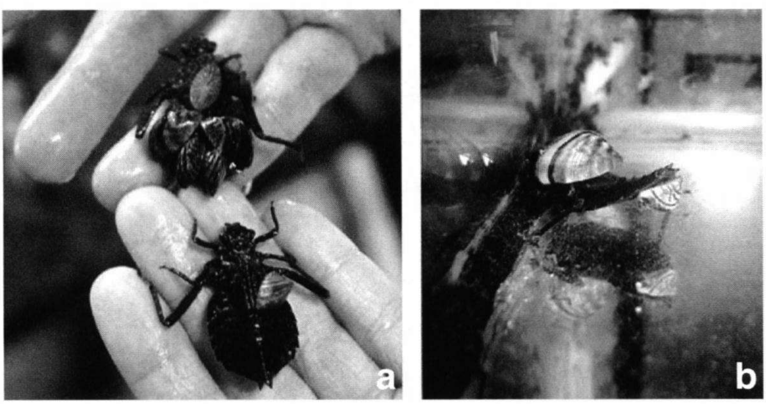

Fig. 3. (a) *Hagenius brevistylus* larvae colonized by zebra mussels (*Dreissena polymorpha*) [Photographed by G. Burkart]. (b) *H. brevistylus* carrying two zebra mussels, one dorsally and one ventrally. Larva is oriented with anal appendages facing viewer. Wing pads are covered by a single large zebra mussel [Photographed by S. McCauley].

val odonates by differentially affecting species survival and growth. Body shape and size (particularly surface area) may be important factors affecting levels of attachment. The most common species in our collection, *H. brevistylus*, had relatively high rates of zebra mussel attachment that may be related to its coin-like body shape which provides a relatively large surface area for attachment. Species with more fusiform larval shapes (e.g., *Dromogompus* sp.) appeared to have lower infestation rates although larger sample sizes of these species are required to evaluate this more fully. Nonetheless, if odonate species are differentially vulnerable to the effects of zebra mussel attachment, zebra mussels may alter the structure of dragonfly communities in lakes where this exotic species has become established.

Further work is required to understand the population and community level effects of zebra mussel attachment on dragonfly larvae. There is a general lack of information on how common zebra mussel attachment on odonate larvae is and how infestation levels vary across species and habitats. There are also a number of questions amenable to experimental manipulation that should be pursued including lethal and non-lethal effects on larval survival and growth rates. Although our knowledge of which species may be affected by zebra mussel attachment is growing (WEIHRAUCH & BORCHERDING, 2002), additional surveys that quantify zebra mussel colonization rates across species and habitats are needed to help guide future research assessing the effects of zebra mussels on odonate communities.

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REFERENCES

BRAZNER, J.C. & D.A. JENSEN, 1994. Zebra mussel [Dreissena polymorpha (Pallas)] colonization of rusty crayfish [Orconectes rusticus (Girard)] in Green Bay, Lake Michigan. *Am. Midl. Nat.* 143: 250-256.

CHRISCINSCKE, M., 2001. Zebra mussels observed on dragonfly larvae in otter lake. *Williamsonia* 5: 9.

GILLIS, P.L. & G.L. MACKIE, 1994. Impact of the zebra mussel, Dreissena polymorpha, on population of Unionidae (Bivalvia) in Lake St. Clair. *Can. J. Zool.* 72: 1260-1271.

O'BRIEN, M., 2001. Zebra mussels and Odonata larvae. *Williamsonia* 5: 9.

RICCIARDI, A., F.G. WHORISKEY & J.B. RASMUSSEN, 1995. Predicting the intensity and impact of Dreissena infestation on native unionid bivalves from Dreissena field density. *Can. J.*

Fish. aquat. Sci. 52: 1449-1461.

RICCIARDI, A., F.G. WHORISKEY & J.B. RASMUSSEN, 1996. Impact of the Dreissena invasion on native unionid bivalves in the upper St. Lawrence River. *Can. J. Fish. aquat. Sci.* 53: 1434-1444.

SCHLOESSER, D.W. & T.F. NALEPA, 1994. Dramatic decline of unionid bivalves in offshore waters of western Lake Erie after infestation by the zebra mussel, Dreissena polymorpha. *Can. J. Fish. aquat. Sci.* 51: 2234-2242.

TUCKER, J.K., 1994. Windrow formation of two snails (Families Viviparidae and Pleuroceridae) colonized by the exotic zebra mussel, Dreissena polymorpha. *J. Freshw. Ecol.* 9: 85-86.

TUCKER, J.K. & J.B. CAMERER, 1994. Colonization of the dragonfly Gompus vastus Walsh, by the zebra mussel Dreissena polymorpha (Pallas) (Anisoptera: Gomphidae; Bivalvia, Eulamellibranchia: Dreissenidae). *Odonatologica* 23: 179-181.

USGS, 2005. Available at: *http://www.umesc.usgs.gov/invasive_species/zebra_mussels.html*

WEIHRAUCH, F. & J. BORCHERDING, 2002. The zebra mussel, Dreissena polymorpha (Pallas), as an epizoon of anisopteran larvae (Anisoptera: Gomphidae, Corduliidae, Libellulidae). *Odonatologica* 31: 85-94.