Elin Wallquist

Amphipod fauna of a mesotrophic lake – the distribution of the invasive amphipod, *Echinogammarus ischnus*

Märlkräftsfaunan i en mesotrof sjö – spridningen av den invaderande märlkräftan, *Echinogammarus ischnus*

Biology

D-level thesis

Date/Term: 2006-12-17
Supervisor: Eva Bergman, Karlstad University
Ed Mills, Cornell University
Examiner: Larry Greenberg
Serial Number: 06:88
Abstract

In Oneida Lake, New York, USA, three species of amphipods are present: *Hyalella azteca* is native, *Gammarus fasciatus* is invasive and was first observed sometime before 1940 and *Echinogammarus ischnus* was introduced in 2001 in shallow water. The purpose of this study was to investigate the spatial and temporal abundance of amphipods in Oneida Lake. In the Great Lakes, the invasive *E. ischnus* has outcompeted *G. fasciatus* and this was also expected to occur in Oneida Lake. Quantitative field sampling of transects that extended from the shore to deeper water (3.8 m) at six sites around Oneida Lake showed that the abundance of all amphipod species had a positive correlation to the abundance of zebra mussels (*Dreissena polymorpha*). *Echinogammarus ischnus* were observed at low densities (mean, 18 no./m²) in shallow water (<0.6 m) areas with cobbles covered with zebra mussels, whereas just a few individuals were found in deep water. At all depths, *G. fasciatus* were found at high densities (mean 950 no./m²), and *H. azteca* were present at low densities (mean 77 no./m²). The main factor limiting *E. ischnus* and its coexistence with *G. fasciatus* is the lack of favourable habitat i.e. too few cobbles and too much *Cladophora spp.* and other macrophyte species growing in the lake. In addition, exposure of shallow water habitats every fall and winter as a consequence of water level manipulations produces unfavorable habitat for *E. ischnus*.

Sammanfattning

I sjön Oneida Lake, New York, USA, finns tre arter av märlkräftor (*Amphipoda*): *Hyalella azteca* är naturligt förekommande i sjön, *Gammarus fasciatus* hittades för första gången någon gång före år 1940 och *Echinogammarus ischnus* hittades för första gången 2001 på grunt vatten. Syftet med studien var att undersöka märlkräftornas utbredning och abundans över tid i Oneida Lake. I de Stora sjöarna (the Great Lakes) i Nordamerika har den invaderande *E. ischnus* konkurrerat ut *G. fasciatus* och samma sak förväntades att finna i Oneida Lake. I fält togs kvantitativa stickprover i transekter från strandlinjen och ut till djupt vatten (3,8 m), dessa visade att samtliga märlkräftars arter hade en positiv abundans korrelation med zebra musslor (*Dreissena polymorpha*). *E. ischnus* hittades i låga densiteter (medel 18 st/m²) på stenar täckta med zebra musslor på grunt vatten (<0,6 m) och endast ett fåtal individer hittades på djupt vatten. I Oneida Lake på alla djup hittades *G. fasciatus* i höga densiteter (medel 950 st/m²) medan *H. azteca* endast fanns i låga densiteter (medel 77 st/m²). Största anledningen till *E. ischnus* begränsning till samexistens med *G. fasciatus* är avsaknaden av gynnade habitat i sjön, det vill säga för få områden med stenar, samt att det växer för mycket alger (*Cladophora spp.*). Även vattnen är avsaknad för *E. ischnus*, då habitat på grunt vatten blir exponerande.
Introduction

The Great Lakes in North America are among the most highly invaded ecosystems in the world. The main reason is commercial shipping, as the number of invasive species has increased in association with this vector over the past three decades. (Mills et al. 1993, Ricciardi 2001) Establishment of non-indigenous species in the watershed can have a profound effect on both biotic and abiotic factors in the ecological system, as well as on the economical system (Mills et al., 1993; Pimentel 2005). Many of the non-indigenous species in the Great Lakes originate from the Ponto-Caspian region, i.e. Black Sea, Azov Sea and Caspian Sea (Mills et al., 1993; Ricciardi & Maclsaac 2000; Bij de Vaate et al, 2002; Vanderploeg et al. 2002), like the amphipod *Echinogammarus ischnus*, Stebbing (Dermott et al. 1998). *Echinogammarus ischnus* is a euryhaline, lotic amphipod, common in large slow-moving rivers with rocky substrate and is often associated with the zebra mussel (*Dreissena polymorpha*, Pallas) (Köhn & Waterstraat 1990; Palmer & Ricciardi 2004). It reproduces sexually and may in some cases, breed through the year, depending on the physical properties of the habitat (Köhn & Waterstraat, 1990; Konopacka and Jesionowska, 1995; Witt et al. 1997).

During the 1990’s, *E. ischnus* colonized Western Europe via rivers and man-made canals (Bij de Vaate et al., 2002), as well as the Great Lakes (Dermott et al. 1998). It was found in the in Detroit River in 1995 (Witt. et al., 1997), but archived samples show that it was present at least one year earlier in Lake Erie (Van Overdijk et al. 2003). *Echinogammarus ischnus* likely entered the Great Lakes via ballast water associated with trans-oceanic ships (Holeck et al., 2004). After only three years, *E. ischnus* had spread from Lake Erie to Lake Huron, Lake Ontario and Lake Michigan (Witt, et al. 1997; Dermott et al. 1998; Nalepa et al., 2001). *Echinogammarus ischnus* was first observed in Lake Superior in 2001 (Grigorovich et al, 2003).

In the Great Lakes *E. ischnus* first established itself in the benthic wave-zone (Dermott et al. 1998), especially in rocky habitats. In one year, *E. Ischnus* in one year became the dominant amphipod and outcompeted the native amphipod *Gammarus fasciatus*, Say (Dermott et al. 1998; Nalepa et al. 2001; Van Overdijk et al. 2003). *Echinogammarus ischnus* has also been observed on deep, soft bottoms and free of zebra mussels, which is unusual for the Great Lakes, but not for the Caspian Sea (Nalepa et al. 2001). *Hyalella azteca*, Saussure, is an amphipod native to the Great Lakes, but present at low densities (van Overdijk et al. 2003). It is mostly associated with vegetation and soft sediments (Kruschwitz 1978), but in Lake Erie it has been present on rocks together with zebra mussels and the algae, *Cladophora spp.* (van Overdijk et al. 2003).

In general *E. ischnus* and *G. fasciatus* do not compete for the same food resources (González & Burkart, 2004; Limén. et al. 2005). In mussel-encrusted habitats *G. fasciatus* is more vulnerable to predation than *E. ischnus*, whereas the opposite appears to be the case when they live in habitats with macrophytes (Dermot et al. 1998; Van Overdijk et al. 2003; González & Burkart, 2004; Palmer & Ricciardi. 2004). In the Great lakes *G. fasciatus* has higher fecundity than *E. ischnus* (Dermott et al. 1998).

Amphipods prefer complex substrata over bare rocks (Van Overdijk, et al. 2003) and in 1986, when the zebra mussel invaded the Great Lakes (Hebert et al. 1989), the abundance of amphipods increased at sites where zebra mussels were present. (Wisenden & Bailey 1995; Ricciardi et al. 1997; Stewart et al., 1998; González & Downing 1999; Bially and Maclsaac
2000; Mayer et al. 2002; Palmer & Ricciardi 2004). In this study, I investigated the species composition of the amphipod fauna in Oneida Lake and focused on amphipod abundance and species composition during different seasons. Three amphipod species are present in Oneida Lake: *H. azteca* is native, *G. fasciatus* is an alien species that was first introduced sometime before 1940 (Ed Mills unpub.) and *E. ischnus* which was introduced in 2001 (Christine Mayer, unpub). The zebra mussel became established in 1991 (Ed Mills unpub). I hypothesized that *E. ischnus* would be present at all depths and in all kinds of habitats in Oneida Lake, but that its highest abundance would occur in rocky habitats encrusted with zebra mussels.

**Methods and Materials**

**Study area**

Oneida Lake, New York, USA, is a large, shallow mesotrophic lake (surface area 207 km$^2$; shoreline 88 km; average depth of 6.8 m). The lake flows into Lake Ontario via the Oswego River and to the other Great Lakes by the Erie Barge Canal system. In shallow water areas (shoreline to maximum 1.2 m), the substrata is mostly cobble, and the deeper the water gets the proportion of sand and silt increase. *Cladophora spp.* often grows on cobbles in the shallow areas and in deeper water other macrophyte species grows. Every winter the water level in the lake is lowered by one meter to assimilate spring snow melt and to prevent flooding.

Quantitative field sampling for amphipods in Oneida Lake was done in August and October 2005 and in May, June and July, 2006. Six locations with cobbles were chosen around the lake to increase the chance of finding *E. ischnus* (Fig 1). Samples were taken in transects that extended from the shore, at six depths, <0.2 m; 0.6 m; 1.2 m; 1.8 m; 3.0 m; 3.8 m. At each depth, duplicate samples were taken, except at two stations in June and July where triplicate samples were taken.

![Figure 1. Locations of the transect sites (ring and line) in Oneida Lake.](image)

At each location in shallow water (≤0,6 m) a single cobble was quickly picked up and placed in a bucket. The cobble was rinsed with water and scraped cleaned. The area of the cobble was estimated by measuring it in three dimensions (mm). The water and substrate in the bucket were sieved in a 500 micrometer sieve and the sample was preserved in 70 % ethanol. At each deep water location an Ekman grab, with an area of 225 cm$^2$, was used to collect cobble or sediment substrate, which was then sived in a 500 micrometer sieve and the sample...
was preserved in 70% ethanol. The substrate was categorized as cobble/gravel and sand/silt. The occurrence of zebra mussel, *Cladophora spp.*, and macrophytes was also noted.

In the laboratory, all amphipods were identified to species, head length was measured (0.1 mm) and the sex was determined for the mature individuals (HL > ca. 0.5 mm). In general, all amphipods were counted and measured in a sample. In one sample, the number of amphipods was high and, in this instance, amphipods were identified in only 30% of the sample, and rest of the sample was assumed to have the same relative proportion of species.

I also analyzed an annual long-term data set (1961-2004) for total phosphorus and amphipod density collected by Cornell Biological Field Station in Oneida Lake (largely found in Mayer et al. 2002). The amphipods were collected with Ekman grab at deep water sites (>3 m) in the lake.

Microsoft Excel and the statistic program SAS were used to analyze the data. Statistical significance was determined at p<0.05.

**Results**

Amphipod density in the deep water habitats has increased since 1964, at which the concentration of total P has decreased. The invasion of zebra mussel in 1991, and *E. Ischnus* in 2001, did not correspond to changes affect the density of amphipods in deep water habitat (Fig 2).

![Figure 2. Mean annual density of amphipod fauna (number/m^2) from 1964 to 2004, and mean annual total P concentration (μg/l) from 1961 to 2004, in Oneida Lake. The value for phosphorus concentration in 1967 is soluble reactive P (SRP), which is an underestimate of total P. The arrows indicate the invasion of zebra mussels and *E. ischnus*. Data from 1961 to 1997 were published by Mayer et al. (2002).](image-url)
The total number of amphipods collected in the investigation was 10,845 (E. ischnus 1.6%; G. fasciatus 83%; H. azteca 6.8%; unidentified 8.6%). The amphipod density was higher in the fall (2400 no./m², E. ischnus 4%; G. fasciatus 89%; H. azteca 7%), than in May (780 no./m², E. ischnus 0.06%; G. fasciatus 95%; H. azteca 5%), June, (700 no./m², E. ischnus 1%; G. fasciatus 89%; H. azteca 10%), and July (1200 no./m², E. ischnus 1%; G. fasciatus 91%; H. azteca 8%) (One-way ANOVA: E. ischnus F₃=7.61 P<0.0001; G. fasciatus F₃=9.72, P<0.0001; H. azteca F₃=3.31, P=0.02) (Fig 3.).

Figure 3. Mean density (number/m²) + 1 SD, of G. fasciatus, left, E. ischnus, middle and H. azteca, right in August and October (fall), May, June and July in Oneida Lake.

There was no difference in the depth distribution for G. fasciatus and H. azteca (One-way ANOVA: G. fasciatus F₅=0.50, P=0.78; H. azteca F₅=1.27, P=0.28) (Fig 4.). However E. ischnus had a higher density in shallow water (≤0.6 m) than in deep water (One-way ANOVA, F₅=4.33 P<0.0008) (Fig 4). Only three specimens of E. ischnus were found in deep-water habitats (≥1.8 m). Echinogammarus ischnus was more common in habitats with cobble/gravel than in habitats with sand/silt (Mann-Whitney, U≤4, P=0.01). The density of both G. fasciatus and H. azteca did not differ between substrates (Mann-Whitney: G. fasciatus U≤11 P=0.16; H. azteca U≤13 P=0.24). However, all amphipod species had higher densities in habitats with zebra mussels than in habitats without zebra mussels (Mann-Whitney: E. ischnus U≤4, P=0.01; G. fasciatus U≤2, P=0.004; H. azteca U≤3, P=0.008).

Figure 4. Mean density (no./m²) + 1 SD, of G. fasciatus (left), E. ischnus (middle) and H. azteca (right) at different depths in Oneida Lake.

Males were bigger than females for all species of amphipods (T-test: E. ischnus, T₇₆=1.99, P=0.0003; G. fasciatus, T₅₁₂₀=1.96, P=5*10⁻¹⁰⁰; H. azteca, T₅₂₀=1.96, P=0.001) (Fig 5). There were also a higher abundance of females than males for all three amphipod species (Percentage females %): E. ischnus 71; G. fasciatus 67; H. azteca 55).
Figure 5. Mean head length (mm ± 1 SD) of female and male *G. fasciatus*, *E. ischnus* and *H. azteca*, in Oneida Lake.

**Discussion**

The amphipod density in deep water habitats in Oneida Lake has increased since 1964 and is associated with reduced phosphorus concentrations and improved water quality. Neither the zebra mussel invasion nor the invasion of *E. ischnus* in 2001 affected amphipod abundance in deep water (Mayer et al. 2002). This study showed that the density of amphipods was positively associated with the presence of zebra mussels, which is in accordance with other studies (Wisenden & Bailey 1995; Ricciardi et al. 1997; González & Downing 1999; Bially and MacIsaac 2000; Mayer et al. 2002; Palmer & Ricciardi 2004).

Five years after the first occurrence of *E. ischnus* in Oneida Lake, the population density is still low and it is not likely that the species will be able to outcompete *G. fasciatus*. One reason for this is that habitat heterogeneity is too low in Oneida Lake, and that the most common habitat favors *G. fasciatus*. Although there are habitats with cobbles both in shallow and deep water in the lake, which should favor *E. ischnus* as laboratory and field studies by Dermott et al. (1998), Van Overdijk et al. (2003) and Palmer & Ricciardi (2004) have proved. But these cobbles are overgrown by *Cladophora spp.* and in deeper water (>1.5) there are high abundances of macrophytes, which favor *G. fasciatus* as González & Burkart (2004) have established. Furthermore, the hard bottom areas that exist in deep water usually become anoxic during part of the summer, which prevents *E. ischnus* from expanding its range to this area.

A second factor that will influence the interaction between *E. ischnus* and *G. fasciatus* is the competitive abilities of the species. Palmer & Ricciardi (2005) suggested that *E. ischnus* has a competitive advantage when resources becomes limited, but in a high productive lake as Oneida Lake *G. fasciatus* has no problem with competition from *E. ischnus*. A third factor is fecundity, and in the Great Lakes, *E. ischnus* has a lower fecundity than *G. fasciatus* (Dermott et al. 1998), which could partially explain why *E. ischnus* has not been successful in establishing a large population in Oneida Lake.

Every winter the water level is lowered in Oneida Lake by approximately one meter. This means that the most favorable habitat for *E. ischnus* disappears annually, i.e. the heterogenic shallow water habitat with many cobbles. Thus, *E. ischnus* is forced to live in an unfavorable habitat compared to *G. fasciatus* and *H. azteca* during the winter. Every spring the amphipods have to recolonize the cobbles habitat and that could favor *E. ischnus*, but later during the spring this habitat becomes covered by *Cladophora spp.* I think it would be interesting to
investigate which impact the regulation of the water level has on the amphipod fauna. How fast will the amphipods recolonize the cobble habitat during spring? How long does it take before it is a reproductive habitat again and will that differ for different amphipod species? Are some of the amphipod species better colonizers than others, and is the success of the colonization age-dependent?

Lack of genetic variation could be another reason for *E. ischnus* not becoming successfully established in Oneida Lake. In the Ponto-Caspian basin where *E. ischnus* originates, it has a large genetic variation, but in the Great lakes only a single genotype has been found (Cristescu et al., 2004).

Amphipod abundance in Oneida Lake was highest in the fall (August and October) suggesting that breeding occurred during the summer and led to increased population abundance in the fall. Another explanation could be that although many individuals died during winter, many new individual were born in the spring and during rest of the summer season and thus the highest abundance occurs in the fall. In Oneida Lake for *E. ischnus* there were more females than males present, a pattern that also was found in Lake Erie (Witt et al. 1997).

It is possible that five years are not enough for *E. ischnus* to become established in Oneida Lake, even though it went faster in the Great Lakes. However *E. ischnus* will probably not have a great deal on the ecosystem even though amphipods are a major link in the ecological food web (Bruner et al. 1994). With the introduction of *E. ischnus* to the Great Lakes, Dermott et al. (1998) have suggested that the structure in the food web will probably not change, nor will the total amphipod abundance (Ratti & Barton 2003). However there is a potentially problem with the introduction of *E. ischnus*, because the establishment of non-indigenous species may facilitates other non-indigenous, coevolved species to become established more easily (Holeck et al. 2004). Newly invaded species is always a risk, because they could outcompete native species and contribute to an environment with less species-diversity, which may be sensitive to future environmental changes. Today we see an accelerating rate of introductions of new species to the Great Lakes watershed (Ricciardi 2001) and one must be aware that it is often very expensive, time consuming and many times impossible to control or get rid of already established invasive species. Therefore it is important, as Ricciardi & Rasmussen (1998), Bij de Vaate et al. (2002), Holeck (2004) and Pimentel (2005) also conclude, to have well working policies and guidelines to limit the way new species enters new environments.

**Acknowledgments**

I wish to thank Ed Mills, who gave me the opportunity to stay at Cornell University Biological Field Station. I also thanks John Cooper for the great job he did sampling and determining amphipods during fall 2005, and Catharine Hoffman for the help with sampling. I want to thank the summer interns of 2006 for great help and a lot of fun, especially Tom Stewart and Allison Cooperman – amphipod “parties” will be remembered. Thanks to Eva Bergman, Karlstad University and Ed Mills for advice and revising my paper. Finally thanks to Willie and Jim who made “the Big House” a great place to live.
References


