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The Distribution of Amphipods in Southeastern Minnesota and Their Relation to Water Quality and Land Use

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The distribution of the amphipods *Gammarus pseudolimnaeus* and *Hyalella azteca* was determined from 97 designated trout streams in Minnesota, along with temperature, conductivity, and nitrate levels. Streams were classified into 4 land use/geology groups. *G. pseudolimnaeus* was found in 11 counties and at 123 of 168 sites in 83 of the 97 streams sampled. *Hyalella azteca* was found in 7 counties at 26 sites in 21 streams. Spearman rank correlations showed a high degree of correlation between nitrate (range: 0-11 mg N/L), conductivity (range: 325-870 μS/cm), and geology. The relative abundance of *G. pseudolimnaeus* was negatively correlated with nitrate, geology groups, and *H. azteca* relative abundance; *G. pseudolimnaeus* was most common in low-order streams originating from diffuse springs, and *H. azteca* was more common in larger streams. The distribution of *G. pseudolimnaeus* with its strong correlation to geology may be largely influenced by land use and it may be a good long-term indicator of water quality.
INDEX DESCRIPTORS: *Gammarus pseudolimnaeus, Hyalella azteca,* water quality, distribution, Amphipoda
RUNNING HEAD: Distribution of Amphipods in Southeastern Minnesota

Gammarus pseudolimnaeus Bousfield (formerly *G. limnaeus*) is a cold water amphipod, typically associated with alkaline springs and streams (Hynes and Harper, 1972; Marchant, 1981; Newman et al., 1990) throughout the Great Lakes Region and the Central Mississippi River Basin (Bousfield, 1958; Holsinger, 1976). *Gammarus pseudolimnaeus* is an important food for trout (Newman and Waters, 1984) and is commonly found among roots and debris along the shore, in macrophyte beds and under stones in the swift current (Hynes and Harper, 1972; Marchant, 1981; Newman et al., 1990). *Hyalella azteca* (Saussure) is more typically found in warmwater lakes and streams (Strong, 1972). In Minnesota, the distribution of *G. pseudolimnaeus* has been reported to include Houston County and the extreme southeast corners of Fillmore and Winona counties (Holsinger, 1976). *Gammarus pseudolimnaeus* is known to occur in other areas of southern Minnesota, but no detailed study on the distribution of it or other Amphipoda has been conducted in Minnesota.

Water quality in the karst region of southeastern Minnesota and northeastern Iowa is heavily influenced by agriculture, especially in the region of the Galena limestone formation (Hallberg et al., 1983; Troelstrup and Perry, 1989, 1990). Springs in the area can be classified as either conduit or diffuse (Bartodziej and Perry, 1990); conduit springs are associated with fractured (e.g., karstic) aquifers and have rapid turnovers and young water, whereas diffuse springs are associated with consolidated aquifers (e.g., sandstone) and have slow turnovers and older water. In southeastern Minnesota and northeastern Iowa, the conduit springs generally drain the Galena limestone aquifer and have a short water retention and are greatly influenced by agriculture and weather (Hallberg et al., 1983; Bartodziej and Perry, 1990). These influences cause increases in nitrate and pesticide levels entering the stream (Bartodziej and Perry, 1990) and may result in pulses of increased pesticide levels after rainfall events (Hallberg et al., 1983; Quinlan and Alexander, 1987; Bartodziej and Perry, 1990). Diffuse springs which drain the St. Peter and Jordan sandstone aquifers retain water longer, and the water quality is not as greatly influenced by land use (Bartodziej and Perry, 1990).

Newman and Perry (1986) hypothesized that *G. pseudolimnaeus* occurrence and distribution may be influenced by pulsed pesticide runoff events in karst springs, partly because these amphipods are highly susceptible to pesticides (Mayer and Ellersieck, 1986). Furthermore, since amphipods are relatively slow to colonize after local extinction (e.g., Gooch and Glazier, 1991), they may be good indicators of previous disturbances. Direct detection of pulsed pesticide runoff events is difficult and expensive, especially over a large region (Schneider, 1979) and, therefore, long-term indicators of disturbance will be useful.

The objective of this study was to determine the distribution of *G. pseudolimnaeus* and other amphipods in southeastern Minnesota, and then to compare this distribution to water quality and land use.

METHODS

The study area included 168 sites in 97 designated trout streams in southeastern Minnesota. Designated trout streams are stream reaches that the Minnesota Department of Natural Resources (DNR) has determined support trout or have the potential to support trout (i.e., coldwater streams); these streams have higher water quality standards and more use restrictions than other streams. These streams were therefore considered to have suitable habitat and water quality for amphipods. Designated trout streams and sites were determined from the 1988 DNR Commissioner's Order No. 2294, the Minnesota DNR Trout Streams of Southeast Minnesota map, and United States Geological Survey (USGS) 7.5-minute topography maps. An attempt was made to select at least two sites (up- and down-stream) per stream. Sites selected were near bridges or easily accessible locations to facilitate rapid sampling and future resampling. Sampling was accomplished during March (109 sites in Fillmore, Houston and Winona counties) and summer (July through mid September; 56 sites in all counties) of 1990. Each site was sampled once with the primary interest to determine the presence of *G. pseudolimnaeus* and to relate its presence to land use and water quality; because amphipods cannot be identified in the field, no special attempt was made to sample *H. azteca*.

At each location, sampling was conducted with a D-net, used among the vegetation, along the stream bank and within the channel. Relative abundance of amphipods (0-5) was estimated by the length of time needed to collect specimens and the occurrence of amphipods in each sample. No amphipods collected within 15 minutes was ranked zero, and high numbers (e.g., 50 per net dip) collected rapidly was ranked five. Twelve or more individuals were taken at each site and preserved in 85% ethanol. For example, if very few individuals were collected (relative abundance of 1), sampling proceeded across all habitats until 12 amphipods were preserved or 15 minutes expired. At sites with greater abundances, larger numbers of all sizes were preserved from several dip samples. At each location, water samples were collected and temperature and conductivity (Horizon, model 1484-10) were measured. Water samples were stored at 4°C until analysis, and nitrate concentrations were determined within 48 hrs by the ultraviolet spectrophotometric method (APHA, 1985). Positive identifications of

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amphipods were made using Pennak (1978) for *H. azteca* and Holsinger (1976) for Gammaridae. Four taxa were identified: *H. azteca*, *G. pseudolimnaeus*, and *Crangonyx spp.* (tentatively, *C. gracilis* or *C. pseudogracilis* in two streams and *C. richmondensis* [*obliquus-richmondensis* group] at Etna Creek). Because more than one taxon was collected at a few sites, the field estimated relative abundances for these sites had to be apportioned to the identified species. Therefore, corrected relative abundances were determined for each taxa collected based on relative occurrence in the keyed samples and the relative abundance of all amphipods in the field. Failure to find amphipods does not assure they are not there, however, given the level of effort specifically aimed at locating amphipods, if they were not found, they were not very abundant.

Geology of stream sites was determined from the USGS bedrock map and was divided into the four groups defined by Troelstrup and Perry (1989). Group 1 streams drain lower members of the Prairie Du Chien sandstone and Jordan sandstone formations and flow over Jordan sandstone. Group 2 streams drain the Prairie Du Chien and St. Peter sandstone formations and flow over lower members of the Prairie Du Chien formation. Group 3 streams drain the Galena limestone formation and flow over the St. Peter sandstone and the Prairie Du Chien formation. Group 4 streams drain the Galena aquifer and flow over the Galena limestone and Decorah shale formations (Troelstrup and Perry, 1989). Although we have chosen a categorical representation of geology, the geology groups represent a gradient of spring source elevation from the Jordan aquifer and represent a gradient from predominantly diffuse to predominantly conduit spring sources (Troelstrup and Perry, 1989, 1990).

Stream order, an index of stream size, for each site was determined from the USGS 7.5-minute topography maps. First order streams have no tributaries, second order streams have only first order tributaries, and third order streams have 2 or more second order tributaries. Intermittent streams were not included in our determination of stream order, except in several cases where an intermittent stream (according to the topography map) was sampled, that stream was considered a first order stream.

The initial (March) samples were collected in the three counties in the southeastern corner of Minnesota (Fillmore, Houston and Winona); we decided to expand our range of sampling sites in the summer to better define the distribution of *G. pseudolimnaeus*. Separate analyses of each of these data sets revealed the same general patterns and relationships, so the results were combined into one analysis. Correlations between variables were determined by the Spearman rank correlation test. A complete set of data, including site locations, relative abundances, and water quality measures, is available upon request from the authors and is on file with the Entomology Museum at the University of Minnesota.

RESULTS

Gammarus pseudolimnaeus was found in samples from 123 of 168 sites in 83 of the 97 streams sampled and *H. azteca* was found at 26 sites in 21 streams (Fig. 1). Five sites in 3 streams had *Crangonyx spp.* Only nine streams had no amphipods. The sites which had the highest abundance of *G. pseudolimnaeus* were primarily on streams draining the southern basin of the Root River and on low order streams entering the Mississippi, Minnesota, and St. Croix rivers (Fig. 1).

Nitrate levels ranged from 0 to 10.7 mg NO_3-N/L, and conductivity ranged from 325 to 870 μS/cm (data available upon request). Spearman rank correlations showed high correlations between geology group, conductivity and nitrate (Table 1).

Correlations between geology and nitrate levels may be related to land use. Geology groups 1 and 2 drain sandstone formations and have low to moderate agricultural use whereas geology groups 3 and 4 drain limestone formations and are intensively agricultural (Troelstrup and Perry, 1989). The streams in geology groups 1 and 2 originate from diffuse springs which have long retention of water and are not as greatly influenced by land use whereas the streams in geology groups 3 and 4 arise from conduit springs that drain the Galena limestone aquifer and have short retention of water and are largely influenced by land use (Troelstrup and Perry, 1989; Bartodziej and Perry, 1990). Conductivity and nitrate were both significantly higher ($p<0.01$, Bonferroni test) in streams draining the limestone formations (geology groups 3 and 4) than in streams draining the sandstone formations, except that conductivity was not different between geology groups 2 and 4 (Table 2). Geology group 1 had significantly lower conductivity and nitrate than any other group ($p<0.01$, Bonferroni test).

The high correlation between geology and both nitrate and conductivity suggests a relationship between water quality, land use and geology (see also Troelstrup and Perry, 1990). Agricultural land use may influence water quality. *G. pseudolimnaeus* relative abundance varied significantly by geology group (Kruskal-Wallace Anova; $p<0.02$) and an analysis of variance components indicated a significant amount of the variation in relative abundance was explained by geology group ($p<0.05$) suggesting that land use may also influence distribution of *G. pseudolimnaeus*. Although geology group only explained 6% of the variation in *G. pseudolimnaeus* abundance, only it and *H. azteca* abundance (ca. 6%) explained significant amounts of variation; nitrate, conductivity and stream order accounted for insignificant amounts of variation. *G. pseudolimnaeus* abundance was highest at group 1 sites and lowest at group 3 sites, with groups 2 and 4 having intermediate abundances; *H. azteca* abundance was highest in groups 2 and 3 (Table 2). Relative abundance of *G. pseudolimnaeus* was negatively correlated with nitrate, and relative abundance of *H. azteca* was positively correlated with nitrate ($p<0.05$).

The relative abundance of *G. pseudolimnaeus* was negatively correlated with *H. azteca* (Table 1), and *H. azteca* relative abundance, along with geology group, explained the most variation in *G. pseudolimnaeus* abundance. These relationships may be due to biotic interactions or negatively correlated factors such as water quality or stream order (Table 1). *Gammarus pseudolimnaeus* relative abundance decreased with stream order, being most abundant in first order streams and least

Table 1. Matrix of Spearman rank correlation coefficients (N=168; * =$p<0.1$, ** =$p<0.05$, *** =$p<0.01$). Site number refers to upstream vs. downstream and Geology number refers to the geology and land use group given by Troelstrup and Perry (1989). N-*G.p.* = relative abundance of *Gammarus pseudolimnaeus*; N-*H.a.* = relative abundance of *Hyalella azteca*.

	N-*G.p.*	N-*H.a.*	Conductivity	Nitrate	Stream Order	Site Number
N-*H.a.*	-0.269***	—	—	—	—	—
Conductivity	-0.084	0.146*	—	—	—	—
Nitrate	-0.160**	0.191**	0.501***	—	—	—
Stream Order	-0.144*	0.235***	-0.083	-0.022	—	—
Site Number	-0.042	0.017	-0.049	-0.071	0.186**	—
Geology No.	-0.227***	0.170**	0.649***	0.620***	0.058	-0.120

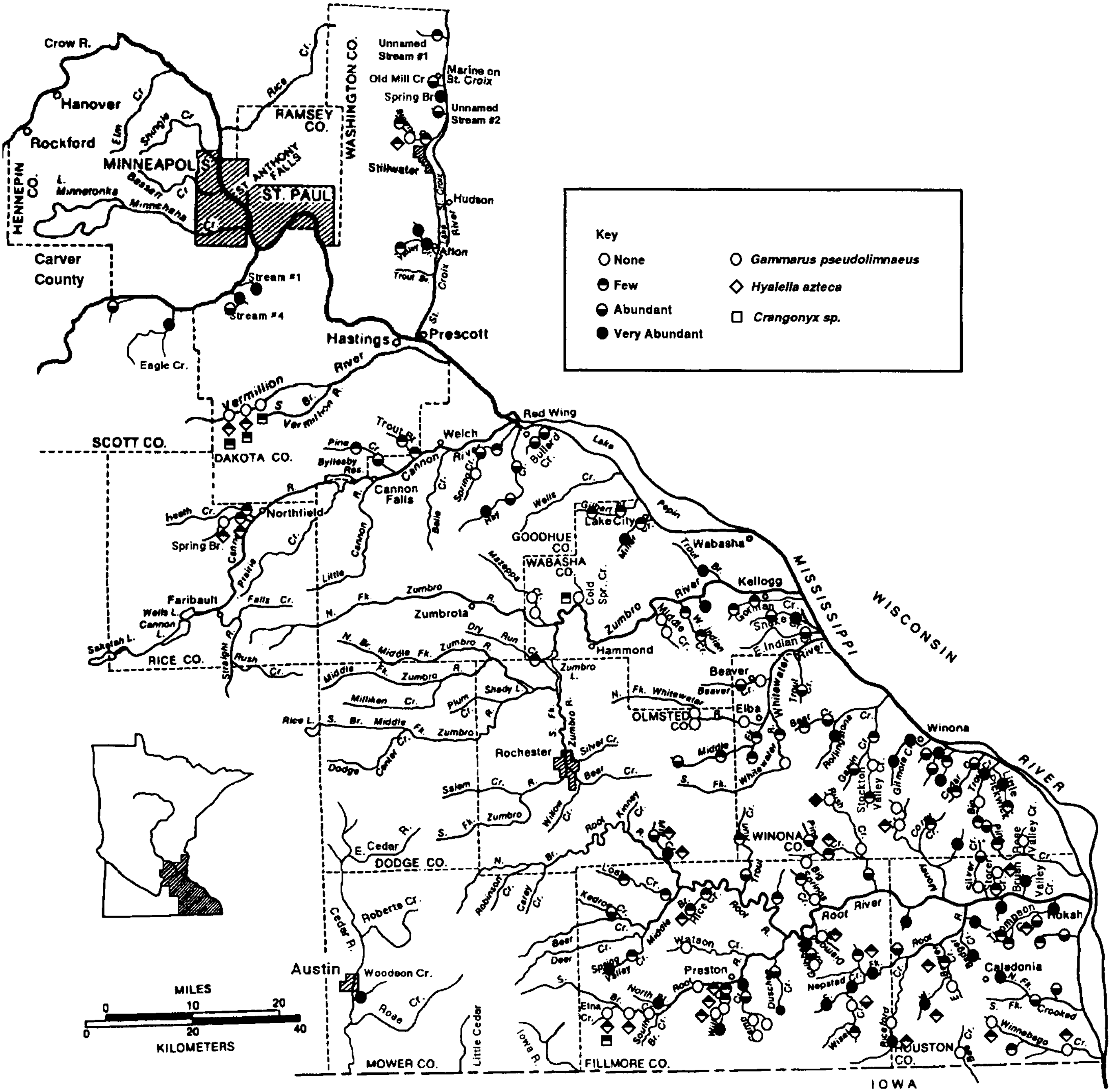

Fig. 1. The distribution of amphipods in southeastern Minnesota. For simplicity and visibility, the 6 relative abundance categories were condensed into 4 categories (0 = none; 1-2 = few; 3 = abundant; 4-5 = very abundant). The base map is modified from Waters (1977).

abundant in third order streams, whereas *H. azteca* relative abundance generally increased with stream order (Table 2). Within first order streams, *Gammarus pseudolimnaeus* was most abundant in geology groups 1, 2, and 4, however, relative abundance of *G. pseudolimnaeus* was fairly consistent among geology groups in second order streams (Table 2). *Hyalella azteca,* although not as common as *G. pseudolimnaeus,* was most abundant in second order streams draining the Prairie Du Chien and St. Peter sandstone formations (group 2).

DISCUSSION

Distribution

Our results expand the published distribution of *G. pseudolimnaeus* in Minnesota from three counties in the extreme southeast (Holsinger, 1976; Houston, Fillmore and Winona) to an 11 county block ranging south from Washington Co., west to Scott Co. and south to Mower Co. In addition to our results, *G. pseudolimnaeus* was also previously

Table 2. Relative abundance of *Gammarus pseudolimnaeus (Gammarus* Rel. Abund.) and *Hyalella azteca (Hyalella* Rel. Abund.), conductivity, nitrate and number of sites (N) sampled for each geology group and stream order. Two standard errors are given in parentheses. No 3rd order streams were sampled in geology groups 3 and 4.

Geology Group	Stream order	*Gammarus* Rel. Abund.	Conductivity µS/cm	NO_3-N (mg/L)	*Hyalella* Rel. Abund.	N
1	1	2.59 (0.40)	513.3 (18.9)	1.6 (0.2)	0.05 (0.05)	63
	2	1.93 (0.06)	504.7 (25.1)	1.9 (0.4)	0.21 (0.15)	29
	3	1.86 (1.19)	471.4 (44.2)	1.4 (0.4)	0.43 (0.60)	7
Group Mean		2.34 (0.32)	507.8 (14.5)	1.7 (0.2)	0.12 (0.07)	99
2	1	1.93 (0.63)	628.4 (23.6)	4.5 (0.8)	0.14 (0.22)	29
	2	1.80 (0.83)	592.3 (45.4)	3.6 (1.4)	0.67 (0.70)	15
	3	0.00 (0.00)	648.3 (73.6)	2.5 (2.6)	0.33 (0.67)	3
Group Mean		1.77 (0.48)	618.2 (21.2)	4.1 (0.7)	0.32 (0.27)	47
3	1	0.50 (0.66)	711.9 (72.7)	6.1 (2.3)	0.50 (0.54)	8
	2	1.80 (1.47)	657.0 (67.1)	6.3 (3.0)	0.40 (0.49)	5
Group Mean		1.00 (0.75)	690.8 (52.1)	6.2 (1.8)	0.46 (0.32)	13
4	1	2.33 (2.91)	603.3 (72.2)	5.0 (3.5)	0.33 (0.67)	3
	2	1.67 (1.61)	608:3 (33.3)	7.3 (1.9)	0.17 (0.33)	6
Group Mean		1.89 (1.35)	606.7 (30.0)	6.5 (1.8)	0.22 (0.29)	9

reported from Valley Creek in Washington Co. (Waters, 1961; Newman and Waters, 1984), and Montz (*in press*) found *G. pseudolimnaeus* in three other streams in Washington Co. In addition, Montz (*in press*) found *G. pseudolimnaeus* in tributaries to the St. Croix River in Burnett, Pierce and Polk counties in Wisconsin. We have also positively identified *G. pseudolimnaeus* from Crystal Brook, a trout stream in Washburn Co., WI. Therefore, given suitable environmental conditions (discussed below), it is likely that *G. pseudolimnaeus* occurs in Wisconsin and Minnesota throughout the lower Minnesota and St. Croix drainages and along the Mississippi River south of Minneapolis to Tennessee (Holsinger, 1976; Ciniglio and Payne, 1977). It should be noted that Newman et al. (1990) reported *G. pseudolimnaeus* from western Connecticut; this population is known to be the result of an introduction from western New York (W.A. Ellis, East Canaan, CT, pers. commun.). In addition, our report of *C. richmondensis* in Fillmore Co., MN is a major range extension for the *obliquus-richmondensis* complex.

Factors Affecting the Distribution of *G. pseudolimnaeus*

Pentland (1930) noted that temperature and vegetation were the two most important factors limiting *Gammarus* distributions, with *G. pseudolimnaeus* being restricted to springs and spring-fed waters with maximum temperatures less than 20°C. Our observations and the reports of others also suggest that *G. pseudolimnaeus* is restricted to waters that are cool in the summer, especially spring-fed waters and low order streams (Tilly, 1968; Hynes and Harper, 1972; Waters and Hokenstrom, 1980; Kennedy and Miller 1990; Newman et al., 1990). Conversely, *H. azteca* is usually associated with warmer summer waters (Bousefield, 1958; Pentland, 1930) including warm water lakes (Cooper, 1965; Strong, 1972). Therefore, higher summer temperatures may be found in higher order streams (e.g., Vannote et al., 1980) and may limit the distribution of *G. pseudolimnaeus*, whereas lower summer temperatures in low order streams may limit *H. azteca*. Because all of our sampling sites were designated trout streams, it was expected that the temperature regimes would be suitable for *G. pseudolimnaeus* at most sites; we did not sample streams that would not be expected to have appropriate temperatures for *G. pseudolimnaeus*. Conversely, we did not sample many habitats that would be expected to contain *Hyalella*, and their distribution is certainly much broader than we reported.

Contrary to some claims that amphipods are restricted to low and moderate alkalinities (Pennak, 1978), we suspect the converse is true for *G. pseudolimnaeus*. First, in our other observations and those of T.F. Waters (pers. commun.), we have not found *G. pseudolimnaeus* in the lower alkalinity streams of north-central and north-east Minnesota (see also Waters, 1961). Second, most reports of *G. pseudolimnaeus* have been from streams ranging from 40 (Tilly, 1968) to over 250 mg $CaCO_3$/L (Pentland, 1930; Waters, 1961), with many observations in between (Pentland, 1930; Waters, 1961; Newman et al., 1990). Both Pentland (1930) and Waters (1961) reported the absence of *G. pseudolimnaeus* in waters with alkalinities <100 mg $CaCO_3$/L, and Glazier and Gooch (1987) found that *G. minus* was most abundant in hardwater springs and absent from softwater springs. Many of our sites with *G. pseudolimnaeus* had conductivities >500µS/cm, which roughly corresponds to >200 mg $CaCO_3$/L (pers. obs.). Thus, we suspect that moderate- to high-alkalinity, cool water is required for *G. pseudolimnaeus*, and any negative correlation with conductivity was due to other land-use effects.

Similarly, although *G. pseudolimnaeus* is considered relatively intolerant of organic pollution (Hilsenhoff, 1982), nitrate levels up to 10 mg NO_3-N/L do not appear limiting. We found high abundances of *G. pseudolimnaeus* in streams with nitrate up to 9.5 mg/L, and *G. pseudolimnaeus* occurred in the two streams with the highest nitrate levels (10.3 and 10.7 mg/L); ten of the 37 sites with relative abundances of 4 or 5 had nitrate levels >3.5 mg/L. Others also have reported healthy *G. pseudolimnaeus* and *G. minus* populations in waters with nitrate levels as high as 1 to 10 mg/L (Minckley, 1963; Tilly, 1968; Waters and Hokenstrom, 1980; Glazier and Gooch, 1987; Bartodziej and Perry, unpubl. data). The significant negative relationship between *G. pseudolimnaeus* and nitrate was likely due to other disturbances that are correlated with nitrate, conductivity and geology. Similarly, although *Hyalella* is tolerant of poor water quality (Hilsenhoff, 1982), it is likely that its positive association with nitrate and conductivity was due to tolerance of other water quality factors rather than nitrate directly. Therefore, it is unlikely that nitrate is the proximate cause of the distribution differences, owing to its relatively low toxicity; nitrate is likely a proxy for other effects such as disturbance frequency or pesticide runoff.

It is possible that the negative relation of *G. pseudolimnaeus* to *Hyalella* was due to biotic interactions; *Hyalella* relative abundance was second only to geology group in explaining variation in *G. pseudolimnaeus* abundance. More work is needed to separate the effects of biotic interactions from water quality issues and temperature. Lastly, although aquatic vegetation and stream stability associated with vegetation development have been reported important in determining *G. pseudolimnaeus* occurrence (Pentland, 1930; Hynes and Harper, 1972; Waters and Hokenstrom, 1980; Glazier and Gooch, 1987; Newman et al., 1990; Bartodziej and Perry, unpubl. data), we found *G. pseudolimnaeus* in high abundance at many sites without watercress or dense growths of other plants. Vegetation alone did not appear to influence *G. pseudolimnaeus* distributions.

Land Use and Water Quality Effects

The local distribution of *G. pseudolimnaeus*, with its strong correlation to geology, may be influenced by land use. Land use and water quality are highly correlated with geology in southeastern Minnesota, grading from about 35% forested and 65% agricultural in the east (primarily geology group 1 streams) to less than 5% forested and more than 95% agricultural in the west (primarily group 4 streams) (Troelstrup and Perry, 1989, 1990). Furthermore, as we also found (Table 2), nitrate increases along this gradient from about 2 mg/L in geology group 1 to over 6 mg/L in geology group 4; atrazine showed a similar pattern (Troelstrup and Perry, 1989). Troelstrup and Perry (1989) proposed that the higher agricultural land use in group 3 and 4 streams, coupled with the karst geology of these groups (and hence supposedly rapid spring input of surface contaminants), resulted in poorer water quality and greater perturbations. Invertebrate biomonitoring metrics, such as diversity, Hilsenhoff's biotic index and percent Ephemeroptera, Plecoptera and Trichoptera, followed these water quality patterns (Troelstrup and Perry, 1989, 1990). Invertebrate metric scores indicative of good water quality or fewer impacts were associated with group 1 streams, and "degraded" or pollution tolerant communities were associated with group 3 and 4 streams (Troelstrup and Perry, 1989, 1990). Our observed amphipod relative abundances correspond to impacts predicted with typically used biomonitoring metrics.

It is, however, difficult to separate the effects of land use and water quality on amphipod distribution from geology. Easily measured water quality variables such as nitrate and atrazine have relatively low toxicities and rarely approach even chronic toxicity levels in southeastern Minnesota stream water at normal flows (Bartodziej and Perry, 1990). However, the conduit spring sources in geology groups 3 and 4 result in rapid throughflow of unfiltered runoff water through karst sinks and fissures (Hallberg, 1985). This rapid throughflow is conducive to pulses of pesticides that are much higher than background (Hallberg, 1985; Quinlan and Alexander, 1987; Bartodziej and Perry, 1990), but are rarely detected through routine sampling (Schneider, 1979; Haith, 1985). Therefore, pulsed runoff of pesticides could have major impacts on biotic communities, but the source will be rarely detected unless a fish kill is documented (Schneider, 1979). For example, Bartodziej and Perry (1990; unpubl. data) studied eight springs in five streams of the karst region of southeastern Minnesota and found that amphipods were not present in conduit springs (geology groups 3 and 4) but were present in diffuse springs (geology groups 1 and 2). Nitrate and atrazine were higher in the conduit springs (Bartodziej and Perry, 1990), but owing to the low toxicity of these chemicals, they concluded that these chemicals did not directly limit the invertebrates. In the present study, *G. pseudolimnaeus* was found in 55% of the 22 sites in streams originating from conduit springs and 75% of the 146 sites in streams originating from diffuse springs. Furthermore, about 9% of both the conduit and the diffuse spring stream sites had relative abundances of 5. Therefore, amphipods are not absent from conduit fed streams, but are more likely to be found in diffuse fed streams.

One of the main aims of this study was to develop an extensive data base of documented presence-absence data for *G. pseudolimnaeus* for later comparison. Some preliminary observations suggest that repeated sampling for amphipods will shed light on the occurrence of pulsed runoff events. In 1985 and 1986, *G. pseudolimnaeus* was absent from the Gribben Creek springs as well as several springs and the upper half of Duschee Creek, but was present in the lower reach of Duschee Creek near diffuse springs (Newman, pers. obs.). Amphipods were reported to be previously abundant at all of these sites (M.C. Haugstad, MN DNR pers. commun.). However, both Bartodziej and Perry (1990; unpubl. data) and Troelstrup (pers. commun.) found *G. pseudolimnaeus* at these sites in 1987 and 1988 respectively. We also compared our results with *G. pseudolimnaeus* occurrences determined by Troelstrup (pers. commun.) in 1988 for the 20 sites reported in Troelstrup and Perry (1989, 1990) that we had in common. We found *G. pseudolimnaeus* at every site Troelstrup did and also found some at several sites he did not. These observations indicate that *G. pseudolimnaeus* populations were increasing or recovering after some disturbance had eliminated them. We predict that repeated sampling for amphipods will reveal relative stability of occurrence with diffuse spring sources and a higher occurrence of both extinction and recolonization with conduit spring sources. A test of this hypothesis should help us better understand the importance and frequency of pulsed disturbance events.

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