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Abstract

Biodiversity, often quantified by species richness, is commonly used to evaluate and monitor the health of ecosystems and as a tool for conservation planning. The use of one or more focal taxa as surrogates or indicators of larger taxonomic diversity can greatly expedite the process of biodiversity measurement. This is especially true when studying diverse and abundant invertebrate fauna. Before indicator taxa are employed, however, research into their suitability as indicators of greater taxonomic diversity in an area is needed. We sampled invertebrate diversity in old fields in southern Michigan using pitfall trapping and morphospecies designations after identification to order or family. Correlation analysis was used to assess species richness relationships between focal arthropod taxa and general invertebrate diversity. Relationships were assessed at two fine spatial scales: within sampling patches, and locally across four sampling patches. Cumulative richness of all assessed taxa increased proportionately with cumulative invertebrate richness as sampling intensity increased within patches. At the among-patch scale, we tentatively identified Hemiptera and Coleoptera as effective indicator taxa of greater invertebrate richness. Although Hymenoptera, Araneae and Diptera exhibited high species richness, their total richness within patches was not associated with overall invertebrate richness among patches. Increased sampling throughout the active season and across a greater number of habitat patches should be conducted before adopting Hemiptera and Coleoptera as definitive indicators of general invertebrate richness in the Great Lakes region. Multiple sampling techniques, in addition to pitfall trapping, should also be added to overcome capture biases associated with each technique.

Biodiversity measurement is commonly used to evaluate and monitor the health of ecosystems and as a tool for conservation planning (Magurran 1988, Hoffmann 2010). Species richness is often used for these purposes, wherein standardized methods are used to sample and catalog species-level diversity within a designated area (Magurran 1988). Accurate species richness results can also be obtained quickly and at lower cost using morphospecies designations (Oliver and Beattie 1996), in which specimens are sorted into recognizable taxonomic units and identified at higher taxonomic levels (e.g., order, family). The use of morphospecies is not without limitations, however. Error rates for

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morphospecies determinations can be high for speciose taxa such as beetles and spiders (Derraik et al. 2002) but can be reduced if sorters are trained in recognizing taxon-specific key characteristics (Oliver and Beattie 1996). Because morphospecies determinations lack actual species names, however, information on species ecology and conservation status is lost (Goldstein 1997). Despite these limitations, the use of morphospecies allows quick sorting of specimens and can provide gross level information on the effects of invasion, disturbance or land use change on community composition and diversity.

Even with the increased efficiency that morphospecies determinations provide, the sheer magnitude and variety of specimens that result from survey collections often necessitates the use of one or more focal taxa as diversity indicators (Balmford et al. 1996, Brown 1997, Duelli and Obrist 2003). A focal taxon is an appropriate surrogate taxon or 'bioindicator' of greater taxonomic diversity when its own diversity, usually expressed in terms of species richness, is positively correlated with greater taxonomic diversity in the same area (Duelli and Obrist 1998, McGeoch 2007). This positive association is often assumed, although rarely tested before being applied (Duelli and Obrist 1998). Moreover, when relationships are tested, assumed correlations are not always upheld (Duelli and Obrist 1998, Oertli et al. 2005), may apply only in certain geographic regions (Lindenmayer et al. 2000), or at certain spatial scales (Weaver 1995, Hess et al. 2006, Gaspar et al. 2010). When seeking to use focal taxa as indicators of greater taxonomic diversity, preliminary assessments of their usefulness must be made at scales relevant to desired use.

The purpose of this study was to identify focal arthropod taxa whose diversity is indicative of larger invertebrate diversity within old field sites in southern Michigan and the Great Lakes region. Our study was motivated by an attempt to investigate the effects of an invasive plant species, spotted knapweed (*Centaurea stoebe* L.), on the local invertebrate community and consequently on ecosystem health and functioning (Coleman and Hendrix 2000, Weisser and Siemann 2004, Harvey et al. 2010). In a pilot study, we were quickly overwhelmed with the diversity and abundance of invertebrate specimens retrieved by pitfall trapping (Waller 2006) and realized a need for suitable indicator taxa for this purpose. The diversity and abundance of arthropod taxa such as ants, beetles and spiders, coupled with their relative ease of collection, suggested that these, and possibly other taxa, might be good indicators of greater arthropod and general invertebrate diversity (Waller 2006). To test the suitability of these and additional arthropod taxa as indicators of invertebrate biodiversity, we used pitfall sampling to collect invertebrates and assessed species richness relationships between focal taxa and all invertebrates at two fine spatial scales: within sampling patches, and locally across four sampling patches.

Materials and Methods

Field sites. This study was conducted in Kalamazoo County, Michigan between June and August 2005. We used pitfall trapping to sample invertebrates from three locations within the Lillian Anderson Arboretum (ARB) in Oshtemo Township, and from one location within the Chipman Preserve (CHIP) in Comstock, approximately 19 km distant from the ARB site. Sampling was conducted in patches of old fields that were once under agricultural cultivation but which had not been actively managed by human enterprise for at least ten years prior to our study. Consequently, all patches were undergoing ecological succession. Habitat patches varied in size from ca. 1400 m² to 15000 m² and all patches were bordered by hardwood trees, predominantly oak (*Quercus*), hickory (*Carya*), maple (*Acer*) and wild black cherry (*Prunus serotina* Ehrh.). Plant diversity within patches was not quantified. Qualitatively, however, the CHIP patch was composed of grasses and mixed forbs, with spotted knapweed (*Centaurea stoebe*) as the predominant forb. Vegetation cover in the three ARB

patches (ARB1-ARB3) varied from primarily grasses (ARB2) with a few mixed forbs such as horse nettle (*Solanum carolinense* L.), pokeweed (*Phytolacca americana* L.) and thistle (*Cirsium*) to predominantly mixed forbs with goldenrod (*Solidago*), vetch (*Vicia*), Queen Anne's lace (*Daucus carota* L.), spotted knapweed and *Rubus* as the most common forbs present. The three ARB patches were separated from one another by a 300-500 m expanse of forested vegetation.

Invertebrate sampling. We sampled invertebrates using pitfall traps consisting of plastic cups measuring 7.5 cm diam \times 8.5 cm deep. Pitfall traps were installed between 1000 and 1200 h at the start of a sampling period and collected 48 h later. Pitfall traps were inserted flush with the ground and partially filled with liquid to drown invertebrates that fell into traps. Seventy percent isopropyl alcohol was used as the trapping liquid in all cases except at ARB1 where we used a mixture of water and dish soap during the first sampling period. However, we found that slugs captured in soapy water secreted profuse amounts of slime that hindered specimen sorting. At CHIP, we initially added several drops of mineral oil to alcohol to reduce evaporation but this caused specimens to clump, hindering specimen sorting and identification. Excessive evaporation of untreated 70% isopropyl alcohol was not found to be a problem in subsequent trapping.

At each patch, pitfall traps were installed at 10 m intervals along two parallel 50 m transects, for a total of 12 traps per patch. Parallel transects were separated by 15 m distance. Two rounds of sampling were conducted within each patch. Sampling period I occurred in early summer, between 20 June and 9 July 2005; the second round of sampling (period II) occurred in late summer, 2-4 August 2005. Weather during both sampling periods was seasonably warm (ca. 22-28 °C), generally sunny and without precipitation.

Invertebrate sorting and identification. Specimens were identified to morphospecies and their abundance per trap was recorded. Voucher specimens were preserved in glass vials filled with 70% ethanol. Adults of each morphospecies were later identified to order, and where possible, family (most insects, spiders) or genus (ants only). We discarded larvae of holometabolous insects (<0.5% of all specimens collected) due to difficulty in identifying these to family and matching these with adult counterparts. For hemimetabolous insects and spiders, we could not reliably assign immatures of different instars to adult specimens. Therefore, we identified immatures to family level only and treated all immatures within a family as a single morphospecies distinct from adults. This conservative approach avoided inflating species richness measures. Among hemimetabolous families with immatures represented in collections, immatures accounted for 7.8% of all individuals collected, with two families (Araneae: Lycosidae and Hemiptera: Cicadellidae) accounting for 77.8 % of immature specimens.

Data analysis. We calculated Pearson product-moment correlation coefficients (r) to assess the strength of associations between focal taxa and remaining invertebrate diversity (see Gotelli and Ellison 2004). Analyses were conducted using JMP ver. 9.0 (SAS Institute). Associations were evaluated at two spatial scales: within and among patches. For within-patch evaluation of indicator taxa, we plotted the cumulative number of species per focal taxon against the corresponding cumulative number of all remaining invertebrate species (total invertebrate richness minus focal taxon richness) as successive pitfall contents were added. This allowed us to determine whether accumulated focal taxon richness was strongly correlated with accumulated invertebrate richness as sampling area increased. Plotting proceeded in order of pitfall number along transects. Data from the two sampling periods were analyzed separately to assess usefulness of focal taxa as indicators in different periods of the season. To evaluate the usefulness of focal taxa as indicators of greater invertebrate diversity over the larger among-patch spatial scale we plotted total focal taxon

richness per patch against corresponding total remaining invertebrate richness per patch, with each sampling period ($n=2$) and patch ($n=4$) representing a single data point for a total of eight observations per focal taxon assessment.

Results

A total of 6915 invertebrate specimens representing 307 morphospecies from 3 phyla was collected over the course of our study (Table 1). The vast majority of specimens were arthropods. The number of morphospecies captured per patch during a single sampling period ranged from 57 to 102, with 43 to 55% of species represented by a single specimen (singletons). Hymenoptera was the most diverse taxon, accounting for 17 to 31% of species richness per patch in a single sampling period, and 21% of richness overall. Coleoptera and Hemiptera each accounted for 17% of total morphospecies richness overall, while Araneae accounted for 16% of overall richness. Species richness for Heteroptera was very low (1-6 species) in all patches and accounted for 2-8% of total richness within patches.

Evaluation of focal taxa as indicators of invertebrate richness.

Within patches, cumulative morphospecies richness values for all focal taxa except Heteroptera consistently showed strong positive correlations with total invertebrate richness ($P < 0.05$, $r > 0.70$; Table 2, Fig. 1). At the larger among-patch scale, however, focal taxon richness was not associated with remaining invertebrate richness for most focal taxa (Table 2, Fig. 2). Hemiptera was the only taxon for which total focal taxon richness was significantly positively correlated with total invertebrate richness among patches ($P = 0.02$, $r = 0.80$; Table 2), whereas Coleoptera and "Homoptera" (paraphyletic group used for the sake of convenience: Gullan, 2001) showed marginally significant positive associations with invertebrate richness among patches ($P = 0.06$, $r = 0.69$ and $P = 0.09$, $r = 0.64$ respectively; Table 2, Fig. 2).

Despite high species richness for Araneae and Hymenoptera and their strong within-patch correlations ($r = 0.87 - 0.99$) with remaining invertebrate richness, neither of these taxa showed a significant association with invertebrate richness at the among-patch scale (Table 2). Diptera, Formicidae, and Orthoptera richness were represented by moderate to low numbers of species and their respective richness values were positively correlated with invertebrate richness within patches but not associated with total invertebrate richness among patches (Table 2).

Discussion

Our evaluation of various arthropod taxa as indicators of general invertebrate richness suggests that Hemiptera and Coleoptera have the greatest promise as useful indicator taxa in old field habitats in Michigan and the Great Lakes region. Additional sampling effort and use of a wider variety of sampling techniques is needed, however, before these promising taxa can be invoked as definitive indicators of general invertebrate richness.

The order Hemiptera (true bugs, cicadas, hoppers and allies) is underutilized as an indicator taxon relative to its diversity within arthropods (McGeoch 2007). Within Hemiptera, Duelli and Obrist (1998) showed that heteropteran diversity is a strong indicator of arthropod richness in seminatural and cultivated habitats in Switzerland. They note that the trophic variability of Heteroptera may account for its strong correlation with greater invertebrate diversity and found this suborder to be an especially efficient indicator taxon owing to the low effort required to sort and identify specimens relative to more diverse taxa such as Coleoptera and Araneae. Although our study did not find a significant association between heteropteran diversity and overall invertebrate richness among patches, this may be due to the low numbers (1 to 6) of Heteroptera species

Table 1. Summary of invertebrate diversity captured in pitfall traps from four sampling patches (ARB1, 2, 3 and Chip) during early and late summer sampling periods (I and II, respectively). Taxon values denote total number of morphospecies captured in an array of 12 pitfall traps. Row totals per sampling period are for the four sampling patches combined and do not necessarily sum across patches due to co-occurrence of some morphospecies in multiple patches. Column totals represent totals across all species within a site. Grand total for all samples combined was 307 morphospecies and 6915 individuals.

Taxon	Sampling period I					Sampling period II				
	ARB1	ARB2	ARB3	Chip	Total	ARB1	ARB2	ARB3	Chip	Total
ANNELIDA										
Oligochaeta	1		1		1					
ARTHROPODA										
Malacostraca	1	1	1		1					
Acarina	3	3	3	2	4					
Araneae	9	8	7	10	20	14	13	8	8	32
Phalangida	2	1	2		3	3	3	3	1	6
Chilopoda			1		1					
Diplopoda	4	2			4			3	2	4
Coleoptera	14	14	17	9	35	11	15	17	8	34
Collembola	1	2	1	1	2	3	4	4	4	5
Diptera	11	16	6	3	20	11	10	7	6	20
Hemiptera	12	13	15	10	27	13	16	18	5	38
Heteroptera	6	2	4	3	10	6	5	5	1	12
"Homoptera"	6	11	11	7	17	7	11	13	4	26
Hymenoptera	15	17	13	14	34	16	15	22	18	46
Formicidae	9	7	7	8	16	5	7	10	7	17

Table 1. Continued.

Taxon	Sampling period I				Sampling period II					
	ARB1	ARB2	ARB3	Chip	Total	ARB1	ARB2	ARB3	Chip	Total
Lepidoptera			1	1	2					
Mecoptera							1			1
Orthoptera	5	4	7	7	10	6	2	11	5	13
Siphonaptera						1				1
Thysanoptera	1				1		1		1	3
MOLLUSCA										
Gastropoda	1	1	1		1	2	1	3		4
Total species	80	82	76	57	166	83	90	102	58	215
Total individuals	995	1281	871	490	3637	533	1048	1421	276	3278
Total singletons	39	35	36	25	64	45	41	53	32	99

Table 2. Summary of correlation coefficient (*r*) values assessing association between focal taxon richness and remaining invertebrate richness over two spatial scales (within and among patches). Within-patch correlations were calculated separately for each sampling period (I = early summer, II = mid-summer). Among-patch correlations were calculated using values for total focal taxon richness and remaining invertebrate richness for each patch and sampling period (n = 8 total).

Focal taxon	Within-patches										Among-patches	
	Sampling period I					Sampling period II					<i>r</i>	<i>P</i> value
	ARB1	ARB2	ARB3	Chip	ARB1	ARB2	ARB3	Chip	ARB1	ARB2		
Araneae	0.95	0.96	0.89	0.94	0.98	0.87	0.93	0.96	0.00	1.00		
Coleoptera	0.98	0.94	0.98	0.90	0.96	0.97	0.95	0.81	0.69	0.06		
Diptera	0.97	0.97	0.83	0.76	0.92	0.96	0.92	0.97	0.21	0.61		
Hemiptera	0.93	0.98	0.97	0.94	0.91	0.96	0.97	0.88	0.80	0.02		
Heteroptera	0.78	0.68	0.85	0.89	0.83	0.94	0.91	n/a	0.54	0.16		
"Homoptera"	0.89	0.97	0.99	0.92	0.81	0.95	0.97	0.88	0.64	0.09		
Hymenoptera	0.93	0.89	0.97	0.96	0.99	0.89	0.94	0.98	0.31	0.46		
Formicidae	0.95	0.74	0.92	0.75	0.94	0.93	0.97	0.95	0.17	0.68		
Orthoptera	0.89	0.93	0.89	0.88	0.79	0.83	0.84	0.73	0.04	0.93		

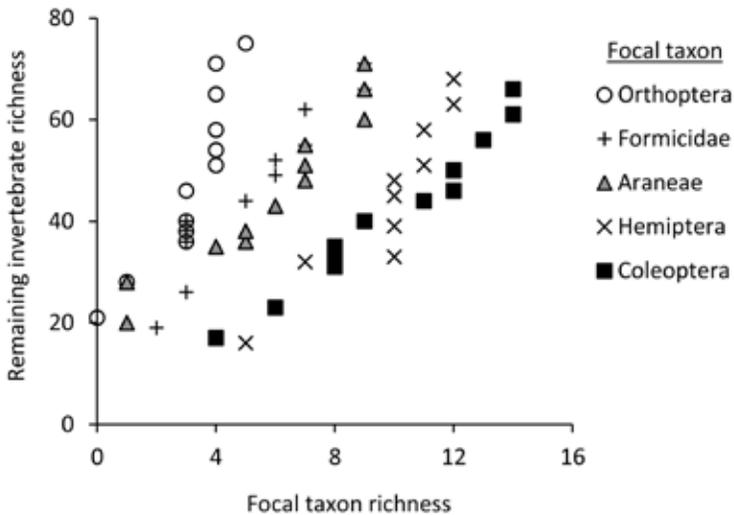


Figure 1. Scatterplots showing associations between cumulative morphospecies richness for select taxa and cumulative richness of remaining invertebrates within a sampling patch. Data points represent cumulative species richness values along two 50 m parallel transects at ARB1 during Sampling Period I. Within-patch correlation coefficients are shown in Table 2.

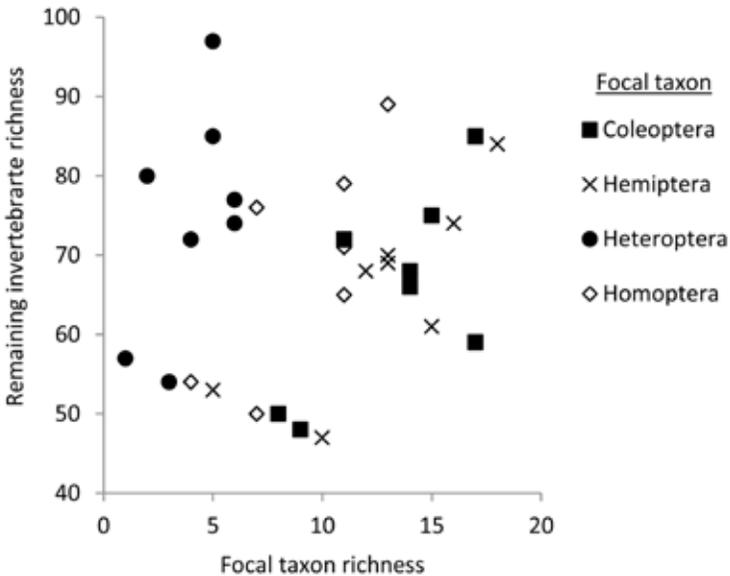


Figure 2. Scatterplots showing associations between total morphospecies richness for select taxa and remaining invertebrate richness at the among-patch scale. Data points represent total species richness per patch ($n = 4$) for each of two sampling periods (I-early and II-late summer). Among-patch correlation coefficients are shown in Table 2.

captured within patches. With increased sampling effort and use of more sampling techniques, their usefulness as an indicator taxon may be strengthened and deserves further investigation. Homopteran richness, on the other hand, was reasonably high in our study and was found to be marginally associated with general invertebrate richness across patches. Species richness was greatest within the family Cicadellidae (21 of 36 homopteran morphospecies) and diversity of this family together with Cercopidae (1 species represented in our study) has been found to be positively associated with the quality of prairie grassland vegetation in Michigan (Dunn et al. 2006). Further study of "Homoptera" and its constituent taxa as indicators of invertebrate diversity and ecosystem quality is therefore warranted. Overall, our results tentatively indicate that diversity within the order Hemiptera provides a good indication of general invertebrate diversity at our old field sites.

Coleoptera (beetles) was one of the most diverse taxa collected. This order yielded strong within-patch correlations with general invertebrate richness, and a marginally significant among-patch association with invertebrate richness. Few studies have evaluated coleopterans as surrogates for biodiversity *per se*; in most instances select beetle families have been used as environmental indicators because their diversity correlates to some biotic or abiotic factor in the environment (e.g., Pearson and Cassola 1992, Bohac 1999, McGeoch et al. 2002, Villa-Castillo 2002, McGeoch 2007). We further explored the effectiveness of specific subgroups of beetle as indicators but found that neither single families (e.g., Carabidae, Staphylinidae and Scarabaeidae) nor family combinations performed as well as the entire order as predictors of greater invertebrate diversity (data not shown). Where beetles have been used as biodiversity indicators, their appropriateness appears to depend on collection method and spatial scale. For example, Duelli and Obrist (1998) found beetles to be an unsuitable indicator taxon when using pitfall traps but obtained strong correlations between beetle diversity and invertebrate diversity when using flight traps. Sauberer et al. (2004), however, found that diversity of carabid beetles, spiders and ants collected by pitfalls showed strong cross-correlations at a larger landscape-scale, and each of these taxa was a useful indicator of broader taxonomic diversity. At the finer spatial scales of our study, beetles also showed promise as indicators of overall invertebrate richness.

Richness of Hymenoptera (wasps, ants and bees), another diverse taxon in our study, was poorly correlated with invertebrate richness among patches. This was not unexpected given that pitfall trapping is biased toward capturing ground active species and the majority of Hymenoptera captured were flying wasps that would be more effectively collected by flight traps or sweep sampling. We also investigated the suitability of the hymenopteran family Formicidae (ants) as an indicator group because pitfall trapping is an effective means by which these organisms are captured. However, we found no correlation between ant diversity and invertebrate diversity at the among-patch scale. Other studies have shown that ant diversity is often only weakly correlated with diversity of other invertebrate taxa (Alonso 2000), at least in Australia where the majority of these types of studies have been conducted. Ants can be useful indicators for monitoring environmental disturbance and recovery (Kaspari and Majer 2000, Graham et al. 2009, Hoffmann 2010) and, therefore, deserve continued investigation in other contexts. Other pitfall-collected hymenopteran families seem to be less well studied with respect to bioindication (McGeoch 2007).

Despite the relatively high species richness of Araneae (spiders) and Diptera (flies) in our samples, neither taxon proved to be a good indicator of greater invertebrate diversity at the among-patch scale. Other pitfall studies have found spiders to be a suitable diversity indicator in agricultural and alpine landscapes (Duelli and Obrist 1998, Sauberer et al. 2004, Finch and Löffler 2010) and as an indicator of environmental quality and change in agricultural landscapes (e.g., Clausen 1986, Marc et al. 1999) and forest habitats (Pearce

and Venier 2006, Gaspar et al. 2010). Consequently, their value as an indicator taxon should not be discounted. However, we found it time consuming to identify spider specimens to family level, especially with the inclusion of juveniles. The low correlation between Diptera and greater invertebrate richness may reflect the inadequacy of pitfall trapping for capturing flies. Malaise traps and sweep netting could yield different results.

Species richness of Orthoptera (grasshoppers, crickets and katydids) was lower than that of other orders but abundance of individuals was relatively high. Orthoptera have been used as a surrogate taxon for other less easily sampled taxa in arid environments (Kati et al. 2004) but their poor association with invertebrate richness among patches in our study suggests that they were less useful as indicators in mesic old field habitats.

The strong within-patch correlations between cumulative richness of most focal taxa and remaining invertebrates indicates that any taxon with four or more species per patch can serve as a surrogate of general invertebrate richness within patches. That is, as richness of the focal taxon increases, a corresponding gradual increase in general invertebrate richness is observed, rather than a rapid saturation of focal taxon richness. However, the relatively poor associations between species richness of focal taxa and remaining invertebrates at the among-patch scale shows that the richness relationship between groups varies considerably among patches.

Ideally, indicator taxa should require relatively little sampling effort and cost to collect, and limited taxonomic expertise to identify. In our study, pitfall traps captured a diverse array of invertebrates with relatively little effort and at low cost. The use of morphospecies designations simplified identification and likely provided accurate estimates of actual species richness (Oliver and Beattie 1996). From this study, we identified two promising taxa, Hemiptera and Coleoptera, as surrogates of greater invertebrate diversity. More work is needed, however, to test associations with greater invertebrate diversity more rigorously. This work includes use of more sampling techniques (e.g., sweep netting, malaise traps, intercept traps) to overcome the unique biases of each sampling technique, sampling throughout the active season to reduce the number of species represented by singleton specimens, and sampling a greater number of habitat patches to increase sample size used in tests of association. With increased sampling, additional measures such as the geometric mean of species abundance and a modified Shannon index of community diversity could be used to monitor community changes over time (Buckland et al. 2005). Knowledge of the biology of indicator taxa, and their responses to disturbance and land use change is also needed for conservation monitoring and planning purposes (Brown 1997). With these factors in mind, more intensive investigations of arthropods should be undertaken in the Great Lakes region to identify good indicator taxa that could be used to monitor ecosystem health and assess ecosystem quality, especially in light of continued environmental perturbations such as those produced by introduced, invasive species (Higman and Campbell 2009).

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