Hymenoptera as Indicators of the Diversity of Arthropods: Restoration of the Oak Savanna
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Abstract
Biological indicators can be used in a variety of ways in developing methods to conserve biodiversity, through environmental change, ecological transitions and biological diversity (Samways 2005). Studies suggest that Hymenoptera are potential candidates to be used as biological indicators (Duelli and Obrist 1998; New 2012; Menke 2015). More specifically, Hymenoptera can be indicators of the diversity of arthropods (New 2012). As oak savannas are drastically declining, restoration efforts attempt to limit the invasion of woody species, by thinning and prescribing fire burns (Brudvig and Asbjornsen 2007). Oak savannas are attempting to be restored in Ryerson woods in Illinois. In this study, Hymenoptera are compared to arthropod community structure at 44 sites within Ryerson Woods that have undergone vegetation thinning treatments. I concluded that in Midwestern oak savannas, Hymenoptera can be used as an indicator of diversity of arthropods, to document the relative success of restoration.

Introduction
Efforts to conserve biodiversity are often limited by lack of resources and time, which stresses the need for developing efficient methods to document geographic patterns (Kerr et al. 2000; Hughes et al. 2008). In the past, plant ecologists have used indicators to assess soil productivity and vegetation structure in order to determine relative success of land management techniques (Patton 1992). However, contemporary research suggests that animals, specifically insects can be used as indicators of community responses to disturbances (Menke et al. 2015). Determining an appropriate indicator is crucial to predict changes in arthropod community structure caused by land management and conservation efforts. Broadly speaking, there are three main biological indicator categories, environmental, ecological and biodiversity (Samways 2005; New 2012). These indicators can be used to detect and monitor some sort of change, in this case conservation efforts to restore oak savannas in Illinois (Samways 2005). Environmental indicators are used to identify changes in environmental states, whereas ecological indicators are used to identify how changes in environmental states impact biotic systems (Samways 2005; New 2012). Identifying specific ecological changes requires that indicators must have narrow tolerances to the specific ecological factor in question (Patton 1992). Higher taxa groups have a wide variety of ecological tolerances, which makes them impractical to be used as ecological indicators (Kerr et al. 2000; New 2012). The aim of this study is to identify changes in arthropod community structure, rather than address specific changes in environmental factors. It is for this reason that this study has chosen to use a biological indicator to measure biodiversity.

Biodiversity indicators are used as a proxy to measure diversity within a specific area as well as monitor changes in biodiversity caused by environmental alterations (Samways 2005; New 2012). Higher taxa can be used as an indicator, as this study aims to measure biodiversity at the habitat scale (i.e. Oak savanna restoration site) (Kerr et al. 2000). When selecting the appropriate biodiversity indicator, it is essential to choose a taxa that is representative of biodiversity in the community of interest. Efforts to conserve members of the indicator taxa may then be effective in preserving local biodiversity (Duelli and Obrist 1998; Kerr et al. 2000). However, one must be conscious of the spatial scale when selecting a biodiversity indicator (Kerr et al. 2000; Samways 2005). Some key characteristics of an appropriate indicator include, commonness, high abundance levels and ecologically diversity. The ability to effectively capture the desired organisms and the relative cost of sampling also play a major factor when considering the appropriate indicator group (Kerr et al. 2000; Gayubo et al. 2005; New 2012). Caution should be taken when considering higher groups such as Hymenoptera as a whole, however, such high taxa can be used as a biodiversity indicator as they reflect a wide variety of responses to disturbances (New 2012).

The aim of this study was to test the efficacy of Hymenoptera as biological indicators of arthropod diversity, across five experimental thinning treatments, in an oak savannas restoration site in Northern Illinois. In the Midwest, highly fragmented oak savannas are considered to be the primary ecotone joining deciduous forests and grasslands (Kerr et al. 2000; Menke et al. 2015). Oak savannas are globally endangered, as they have been reduced to less than a tenth of a percent of their native range due to anthropogenic disturbances and a reduction in fire frequencies, caused by climate transition to a cooler and wetter environment (Abrams 1992; Kerr et al. 2000). Over time this has promoted invasion of woody species, which in turn, alters vegetation structure and species composition (Brudvig and Asbjornsen 2007). Though restoration of oak savannas should be approached in a site-specific manner, general guidelines have been described (Dettman et al. 2009). Thinning and reduction of woody species allows for reestablishment of overstory canopy structure, however, prescribed fires are often implemented in sites due to the rapid regeneration times of woody species (Brudvig and Asbjornsen 2007). Prior to regeneration of woody species, oak savannas exhibit distinct changes in vegetation structure, specifically, an increase in understory vegetation and a decrease in leaf litter (Brudvig and Asbjornsen 2007).

Recent studies have suggested that Hymenopterans can be used as indicators of other arthropod taxa (Duelli and Obrist 1998; New 2012). Hymenoptera have been considered to be the largest variety biologically of all the insects (New 2012). Assemblage composition and species richness are among many factors that suggest that Hymenoptera can be used as biological indicators across a wide variety of environmental alterations. Hymenoptera can also be used to indicate
the relative health of an environment because of their presence in a wide range of functional groups and their significant role within complex interaction webs (New 2012). A study by Gayubo et al. (2005) suggested that sphecoidea wasps from a variety of families could be used as indicators of biodiversity of other taxa. Ants have also been suggested as suitable indicators as they are correlated with invertebrate taxas assemblage, in addition to having low sampling costs (Majer et al. 2004; New 2012). Ants can also be used as biological indicators, as they persist in large populations and develop permanent-nests (Talbot 1934; New 2012). While there are a variety of ways in which Hymenoptera construct their nests, the majority of the ants in oak savannas prefer to burrow directly into the soil or into leaf litter. The primary ecological service that ants provide in an oak savanna, is the cycling of nutrients (New 2012). This suggests that Hymenoptera can valuable in assessing ecological patterns in the presence of significant environmental changes caused by land management efforts. Understanding possible effects of habitat disturbances on arthropod community structure is essential to the utilization of biological indicators. Determining effects of environmental threats on diversity and relative health of Hymenoptera can be challenging because of the variety at which different functional groups respond to perturbation (New 2012). However, this supports how valuable Hymenoptera can be.

### Methods

#### Study Design.

The following methods are based on a similar study by Menke & Vachter (2014). Arthropod order diversity was surveyed at 44 sites, between June and July in 2015, using the pitfall trap method of collection. The oak savanna restoration sites, located throughout Ryerson County Illinois, varied in treatments and have been under oak savannah restoration since 2013 (Fig. 1). To observe the relative success of restoration I compared five thinning treatments: Gap (Group selection), Light Thinning, Moderate Thinning, Understory Thinning Only (Group Shelterwood) and Woodland between the years 2015 and 2013 (Fig. 2).

The following methods are based on a similar study by Menke & Vachter (2014). In 2013 and 2015, 5 50-mL centrifuge tube (27mm di-

### Table 1: Treatment methods of the 44 study sites in Ryerson County, Illinois. The percentages represent the variation in thinning intensity for each treatment method within Ryerson Woods. The first two columns with percentages represent the level of thinning to the understory and overstory for each treatment.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Basal Area Removed (year 1)</th>
<th>Basal Area Removed (year 2)</th>
<th>Total Basal Area Removed</th>
<th>Canopy Openness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy Thinning</td>
<td>5%</td>
<td>20%</td>
<td>25%</td>
<td>0%</td>
</tr>
<tr>
<td>Moderate Thinning</td>
<td>5%</td>
<td>10%</td>
<td>15%</td>
<td>0%</td>
</tr>
<tr>
<td>Light Thinning</td>
<td>5%</td>
<td>5%</td>
<td>10%</td>
<td>0%</td>
</tr>
<tr>
<td>Group Shelterwood</td>
<td>10%</td>
<td>5%</td>
<td>15%</td>
<td>0%</td>
</tr>
<tr>
<td>Understory Removal Only</td>
<td>10%</td>
<td>15%</td>
<td>25%</td>
<td>0%</td>
</tr>
<tr>
<td>Overall</td>
<td>4,703</td>
<td>44</td>
<td>209</td>
<td>19</td>
</tr>
<tr>
<td>Gap</td>
<td>1,198</td>
<td>12</td>
<td>64</td>
<td>16</td>
</tr>
<tr>
<td>Light Thinning</td>
<td>1,203</td>
<td>8</td>
<td>38</td>
<td>15</td>
</tr>
<tr>
<td>Moderate Thinning</td>
<td>1,107</td>
<td>9</td>
<td>42</td>
<td>16</td>
</tr>
<tr>
<td>Understory Removal Only</td>
<td>446</td>
<td>6</td>
<td>27</td>
<td>15</td>
</tr>
<tr>
<td>Woodland</td>
<td>749</td>
<td>9</td>
<td>38</td>
<td>16</td>
</tr>
</tbody>
</table>

### Table 2: Summary of results found across treatments in 2015. The columns are, the respective treatments & overall results, total number of individuals caught, number of sites, number of pitfall traps, order richness, mean order richness per site, total Hymenoptera abundance and the number of traps hymenoptera appeared in (occurrence).

as a biodiversity indicator as it in general terms, reflects a variety of responses within the community of arthropods. Due to strong their ecological role, a significant reduction of Hymenoptera can have strong effects on the biota within a community (New 2012). Conservation efforts must take into account the level at which a disturbance will impact vital resources and the interactions among the biotic community (New 2012). This stresses the importance of determining patch suitability prior to restoration efforts. Dispersal ability plays a major role in the capability to escape a microclimate that is unsuitable and colonize areas that are suitable (New 2012). Land management and restoration efforts have the potential to cause indirect and direct effects on arthropod community structure via habitat alteration (Di Giulio et al. 2001). For example, altering plant species composition and vegetation structure can affect microclimate and microhabitat characteristics thereby indirectly effecting arthropod community structure (Cury 1994; Siemann et al. 1997; Di Giulio et al. 2001). This is especially the case due to the sensitivity of Arthropod communities in response to biotope alterations. Indirect effects arise from changes in canopy and shrub cover, ground vegetation cover such as leaf litter, and soil properties (Cury 1994; Siemann et al. 1997; New 2012). Primary soil properties that are known to influence arthropods include moisture, temperature and organic matter (Cury 1994; Siemann et al. 1997). Changes in microclimate variables such as temperature can be altered due to restoration treatments that involve vegetation thinning. Though leaf litter has been shown to ameliorate environmental restrictions caused by increased temperatures, vegetation thinning can drastically reduce the amount of leaf litter (Cury 1994). An increase in light penetration through the oak savanna canopy also has the potential to exacerbate evaporation of soil moisture and cause a raise in soil temperature. This can be a limiting factor to arthropods that are susceptible to desiccation (Cury 1994). Given that Hymenoptera have wide biological variety and the majority are resilient to habitat disturbances, I hypothesize that 1) There will be a decrease in abundance of Hymenoptera due to thinning disturbance, however abundances will remain significantly similar across treatments, 2) Arthropods will have higher order richness when Hymenoptera are present within a sampled location, 3) Arthropod order richness will increase when Hymenoptera abundance increases, and 4) Arthropod abundance will increase when Hymenoptera abundances. To summarize, I predict that Hymenoptera can be used as an appropriate indicator of arthropod biodiversity, allowing the documentation of oak savanna restoration success.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Individuals</th>
<th>Sites</th>
<th>Pitfall Traps</th>
<th>Orders</th>
<th>Mean Orders ± SE</th>
<th>Hymenoptera Abundance</th>
<th>Hymenoptera Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>4,703</td>
<td>44</td>
<td>209</td>
<td>19</td>
<td>8.25 ± 0.41</td>
<td>478</td>
<td>61.70%</td>
</tr>
<tr>
<td>Gap</td>
<td>1,198</td>
<td>12</td>
<td>64</td>
<td>16</td>
<td>8.5 ± 0.89</td>
<td>126</td>
<td>62.50%</td>
</tr>
<tr>
<td>Light Thinning</td>
<td>1,203</td>
<td>8</td>
<td>38</td>
<td>15</td>
<td>8.44 ± 0.34</td>
<td>114</td>
<td>63.20%</td>
</tr>
<tr>
<td>Moderate Thinning</td>
<td>1,107</td>
<td>9</td>
<td>42</td>
<td>16</td>
<td>8.5 ± 0.38</td>
<td>112</td>
<td>59.50%</td>
</tr>
<tr>
<td>Understory Removal</td>
<td>446</td>
<td>6</td>
<td>27</td>
<td>15</td>
<td>8.43 ± 1.09</td>
<td>39</td>
<td>55.60%</td>
</tr>
<tr>
<td>Woodland</td>
<td>749</td>
<td>9</td>
<td>38</td>
<td>16</td>
<td>8.35 ± 0.42</td>
<td>87</td>
<td>65.80%</td>
</tr>
</tbody>
</table>
the relationship because of the large difference in the number of traps in which Hymenoptera were present or absent. This was the case for both 2015 (131 present and 69 absent) and 2013 (196 present and 27 absent). Second, I used regression analysis to determine if there was a significant relationship between Hymenoptera abundance and arthropod order richness per pitfall trap, for both 2013 and 2015. Third, I used regression analysis to determine if this relationship was consistent across all treatments. Treatments Individuals Sites Pitfall Traps Orders Mean Orders ± SE Hymenoptera Abundance Hymenoptera Occurrence Overall 4,703 44 209 19 8.25, 0.41 478 61.70% Gap 1,198 12 64 16 8.5, 0.89 126 62.50% Light Thinning 1,203 8 38 15 8.44, 0.34 114 63.20% Moderate Thinning 1,107 9 42 16 8.5, 0.38 112 59.50% Understory Removal Only 446 6 27 16 8.43, 1.09 39 65.60% Woodland 749 9 38 16 8.35, 0.42 87 65.80%

Results

Overall, 4,703 individuals representing 19 orders (mean ± SE, 8.25, 0.41) were captured in 209 pitfall traps in 44 oak savanna restoration sites. Collombola was the most common order caught across all treatments, appearing 2,338 times and occurring in 49.7% of the traps. The least common order caught was Lepidoptera, appearing only once across all treatments (Fig. 2 and Table 2). Hymenoptera abundance was the highest in the Light Thinning treatment (1,203 individuals), however Hymenoptera occurrence was highest in the Woodland treatment (65.8%). Hymenoptera abundance was lowest in the Understory Removal Only treatment (39 individuals) and also had the lowest occurrence (55.6%). Comparison of order accumulation curves for all sites between 2013 and 2015, demonstrated that pitfall traps in 2015 captured more orders than pitfall traps in 2013, though results were not statistically significant, as shown by the overlap of 95% confidence intervals (Fig.3).

Hymenoptera were captured in 87.9% of the 223 pitfall traps in 2013 (196 present and 27 absent) and 65.5% of the 200 pitfall traps in 2015 (131 present and 69 absence). In 2013, mean order richness was significantly larger in the presence of Hymenoptera, compared to absence of Hymenoptera (mean ± SE, present 5.2 ± 0.11, absent 4.5 ± 0.32, t259 = -2.08, p = 0.045) and in 2015 (mean ± SE, present 4.2 ± 0.14, absent 2.8 ± 0.16, t199 = -6.37, p < 0.0001) (Fig.4). Mean order richness significantly decreased between 2013 and 2015 when Hymenoptera were present in the pitfall trap (t259 = -5.76, p < 0.0001). Significant decrease in mean order richness between 2013 and 2015 was also seen in the absence of Hymenoptera in the pitfall trap (t40 = -4.66, p <0.0001).

Figure 3. Trap-level rarefaction curves for all 44 sites in 2015 (209 traps, dotted line) and 45 sites in 2013(224 traps, solid line) with 95% confidence intervals.

Relationship between order richness and Hymenoptera abundance in 2013 was positive though not significant (F1, 222 = 0.3704, p = 0.5433), while there was significant positive relationship between order richness and Hymenoptera abundance in 2015 (F1, 199 = 13.78, p = 0.00027) (Fig. 5A and B). A significant positive relationship between order richness and Hymenoptera abundance was found when combining 2013 and 2015 data (F1, 422 = 17.47, p < 0.0001) (Fig. 5C). There was a significant positive relationship between average Hymenoptera abundance and average arthropod abundance per site when combining 2013 and 2015 data (F1, 86 = 8.156, p = 0.0053) (Fig. 6A). There was no significant relationship between average hymenoptera abundance and average arthropod abundance per site in 2013 (F1, 42 = 0.00113, p
95

= 0.9733), while there was a significant positive relationship in 2015 (F1, 43 = 10.3575, p = 0.00249). This positive relationship was significant for the moderate thinning (F1, 8 = 5.7964, p = 0.047) and understory removal only treatments (F1, 5 = 9.42779, P-value = 0.037) (Fig. 6B). Positive relationship was found for gap, light thinning and woodland treatments, though not significant. No statistical difference was found between treatments in both 2015 (F4, 43 = 0.437, p = 0.781) and designated treatment sites 2013 (F4, 43 = 1.01, p = 0.414) (Fig. 7). Though all treatment abundances decreased no statistical difference was found between pre and one year post-treatment for Gap, Light thinning, Moderate thinning and Understory removal only. However statistical difference was found for Woodland Treatment between 2013 and 2015 (t16 = 2.46, p = 0.025).

Figure 4. Relationship between the presence or absence of Hymenoptera and mean order richness per pitfall trap. Presence (open circles) and absence (closed triangles) comparisons are shown for 2013 (pretreatment) and 2015 (1 year post-treatment). Error bars are ± SE. Asterisk represents a P-value < .05.

Discussion

In this study, I determined 1) if Hymenoptera can be used as a biodiversity indicator to document success in an oak savanna restoration, and 2) how members of the order Hymenoptera and arthropod communities found in oak savannas respond to restoration disturbances. The Woodland treatment, categorized as heavy thinning, was the only treatment that exhibited a significant reduction of Hymenoptera abundance (Fig. 7). The remaining thinning treatments (Gap, Moderate Thinning, Light Thinning and Understory Removal Only) exhibited a reduction in Hymenoptera abundances, though not significant. I found evidence supporting the candidacy of Hymenoptera as an indicator of arthropod diversity and the relative status of arthropods in an oak savanna habitat (Duelli and Obrist 1998; New 2012). In 2013 (prior to restoration treatments) and 2015 (one year following vegetation thinning treatments) incidence of Hymenoptera was an indicator of order richness (Fig. 4). Order richness was larger in the presence of Hymenoptera (Fig. 4).

I demonstrated that Hymenoptera abundance is an indicator of order richness during oak savannah restoration in 2015 and when combined with 2013 (Fig. 5B and C), however, this result was not significant in 2013 (Fig. 5A). Given the mean order richness (excluding Hymenoptera) per pitfall trap in 2015 (mean ± SE, 4.19, 0.14) and in 2013 (mean ± SE, 5.99, 0.11), as number of Hymenoptera captured in a pitfall trap increases past a certain point the order richness will not continue to increase.

Figure 5. Relationship between order richness and hymenoptera abundance. (A) Depicts relationship for 2013 (pretreatment). (B) Depicts relationship for 2015 (one-year post-treatment). (C) Depicts relationship for the combination of both years (No differences in color is shown for years because of overlap). Regression lines have been fit for respective comparisons.
Figure 6. Relationship between average arthropod abundance per site and average Hymenoptera abundance per site. (A) Depicts this relationship for 2013 (closed grey circles, R^2 dotted gray line), 2015 (closed black circles, R^2 dotted black line), and 2013 & 2015 combined (closed blue circles, R^2 dotted blue line) (B) Depicts this relationship for the individual treatments in 2015. Light thinning (R^2 = 0.0768), Understory removal only (R^2 = 0.702), Gap (R^2 = 0.0106), Moderate thinning (R^2 = 0.453), Woodland (R^2 = 0.363).

This is supported by the fact that the accumulation of orders leveled off in 2013 and 2015 (21 and 19 orders respectively), as shown in the order rarefaction curve (Fig. 1).

Furthermore, there was a large increase in the p-value when pitfall trap 61 from 2013 (178 Hymenoptera and 4 other orders), was included into the regression analysis (F1,223 = 0.307, p = 0.5801) compared to when it was excluded (F1,222 = 0.3704, p = 0.5433). I suggest that rather than abundance, species richness of Hymenoptera should be used as an indicator of arthropod order richness, as Hymenoptera have been considered to have the largest biological variety of all insects (Duelli and Obrist 1998; Kerr 2000; New 2012). However, this study could not make this comparison, because individuals captured in the study were identified to the order level rather than species level.

I demonstrated that Hymenoptera abundance is an indicator of arthropod abundance, before and during oak savannah restoration (Fig. 6A). This result was consistent across all treatments, though only significant for moderate thinning and understory removal only treatments (Fig. 6B). It is likely that significance was not found in the gap, light thinning and woodland treatments due to small sample size, as comparison were made using average abundances. However, because Hymenoptera are so biologically diverse, they are likely to be appropriate candidates to be used as indicators. Ants that occur in oak savannas, have a wide variety of functional groups (i.e. opportunists, specialists, cryptic species and climate specialists) (New 2012) Hymenoptera species are predatory, herbaceous, parasitic and represent a wide variety of functional groups seen in other arthropod orders. In this study, I have demonstrated that Hymenoptera abundance can be used as strong indicator of arthropod abundance, especially within oak savanna restoration sites.

Figure 7. Average abundance across treatments for 2015 (open circles) and 2013 (closed triangles). Error bars are ± SE. Asterisk represents a P-value < .05.

Trapping methods must be taken into consideration when selecting the appropriate indicator, to document effects of oak savanna restoration on the diversity of arthropod communities (Kerr et al. 2000). It is essential to pick an indicator group that will be captured effectively and at a relatively low cost (Kerr et al. 2000; Gayubo et al. 2005; New 2012). For example, pitfall traps are relatively inexpensive and are a popular sampling method amongst hymenopterists to collect ants and
other ground dwelling taxa (New 2012; Menke 2015. Though pitfall trap collection is not the preferred method to capture aerial and aculeate species of, the biological diversity of ground dwelling species of Hymenoptera were significant indicators of arthropod diversity, as ground dwelling Hymenoptera exhibit high levels of biological diversity (New 2012). However, implementation of window interception traps and yellow pan water flight traps could further strengthen the legitimacy of using Hymenoptera as an indicator taxa representing the diversity of oak savanna arthropod communities. Some authors suggest that Lepidoptera can be used as biological indicators, however this study used pitfall traps as a collection method which makes Lepidoptera a poor candidate to be used as a diversity indicator.

Biodiversity can be indicated only when the proper candidate taxa is selected. This can have be highly beneficial in establishing the relative success within oak savanna restoration cites. Studies have shown that plant species richness and community structure can have significant effects on the development of arthropod communities (Haddad et al. 2001). Though it has been suggested that using high taxa can have potential consequences, it is ideal when establishing overall arthropod diversity as it is representative of the diversity of the entire community (New 2012). Using a diversity indicator group such as Hymenoptera allows for preserving diversity of arthropod communities at the local scale. This study supports the use of such indicator in oak savannas at a habitat scale and has beneficial implications for future oak savanna restoration efforts.

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References


