A comparison of trapping techniques (Coleoptera: Carabidae, Buprestidae, Cerambycidae, and Curculionoidea excluding Scolytinae)

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Abstract

Beetles (Coleoptera) are a charismatic group of insects targeted by collectors and often used in biodiversity surveys. As part of a larger project, we surveyed a small (4 hectare) plot in the Boston Mountains of Arkansas using 70 traps of 12 trap types and Berlese–Tullgren extraction of leaf litter and identified all Buprestidae, Carabidae, Cerambycidae, and Curculionoidea (Anthribidae, Attelabidae, Brachyceridae, Brentidae, and Curculionidae excluding Scolytinae) to species. This resulted in the collection of 7,973 specimens representing 242 species arranged in 8 families. In a previous publication, we reported new state records and the number of specimens collected per species. In this publication, we used these data to determine the most effective collection method for four beetle groups: Carabidae, Cerambycidae, Curculionoidea (excluding Scolytinae), and Buprestidae. We found that the combination of pitfall and Malaise traps was most effective for Carabidae, Cerambycidae, and Curculionoidea, but that the combination of Malaise and green Lindgren funnel traps was most effective at collecting Buprestidae. Species accumulation curves did not become asymptotic and extrapolated rarefaction curves did not become asymptotic until 350–1,000 samples, suggesting that much more effort is required to completely inventory even a small site. Additionally, seasonal activity is presented for each species and the similarity and overlap between collecting dates and seasons is discussed for each family.

Key words: trapping, collecting, sampling, Coleoptera, beetle

Biodiversity hotspots are biogeographic areas with high levels of biodiversity and endemism (Meyers 1989, 1990; Meyers et al. 2000). Within United States, recognized hotspots include the southern Appalachians, temperate rainforests of the Northwest, and southern California (Meyers 1990; Calsbeek et al. 2003; Hodkinson 2010). The Interior Highlands, which comprise some of the oldest continuously exposed land worldwide and has acted as a refugium during inclimate periods, such as during times of extensive glaciation or high sea levels (Redfearn 1986; Conant 1960; The Nature Conservancy, Ozarks Ecoregion Assessment Team 2003), and has been proposed to be a hotspot on par with these (The Nature Conservancy, Ozarks Ecoregion Assessment Team 2003; Skvarla et al. 2015a,b). Many species found in the Interior Highlands have disjunct distributions, where the other portion of their range is found in places such as the southern Appalachians and the Sierra Madre in Mexico (Robison and Allen 1995; The Nature Conservancy, Ozarks Ecoregion Assessment Team 2003), which have also acted as refugia at various points in history (Petersen 1976; Ledig et al. 2000; Crespi et al. 2003; Sosa et al. 2008; Walker et al. 2009; Ruiz-Sanchez et al. 2012). Additionally, over 200 species are known to be endemic to the region (Redfearn 1986; Allen 1990; Robison and Allen 1995; Skvarla et al. 2015a,b). Yet, in comparison to other regions of high biodiversity, the Interior Highlands remain understudied. This is especially true with regards to terrestrial invertebrates, which are vital components of biodiversity and ecosystem health as they play important roles in pollination, soil formation, and fertility; decomposition and nutrient turnover; population regulation of other organisms through parasitism and predation; and can be used to assess conservation and biodiversity (Daily et al. 1997; Yen and Butcher 1997; Ward and Larivière 2004; Wickings and Grandy 2011).

As part of a larger survey of the Interior Highlands, we identified Buprestidae, Cerambycidae, Carabidae, and Curculionoidea (Anthribidae, Attelabidae, Brachyceridae, Brentidae, and Curculionidae excluding Scolytinae). These families were chosen because, at least in the Nearctic where this study was conducted, they are easily identified to family level and have an abundance of available identification tools (keys and checklists) for further identification.

The specimen collection data associated with this study has been deposited online (Skvarla et al. 2015a). Species composition,
number of specimens per species collected, new Arkansas state records were reported and discussed by Skvarla et al. (2015b). Herein we analyze the deposited dataset (Skvarla et al. 2015a) in order to compare and contrast the different collecting techniques within and between families and suggest the most efficient single and combined collection techniques.

Materials and Methods

The geological and biogeographic history of the Interior Highlands, site description, and collection methods were covered in detail by Skvarla et al. 2015b, so we provide the following summary. A 4 ha plot was established at Steel Creek along the Buffalo National River in Newton County, Arkansas, centered at approximately N 36°02.269', W 93°20.434'. The site is primarily mature second-growth deciduous forest dominated by oak (Quercus L. [Fagaceae]) and hickory (Carya Nutt. [Juglandaceae]), although American beech (Fagus grandifolia Ehrh. [Fagaceae]) and eastern red cedar (Juniperus virginiana L. [Cupressaceae]) are also abundant. A fishless pond (~14 m × 30 m) and glade with sparse grasses (~10 m × 30 m) are present within the boundaries of the site.

The following traps were maintained within the site: 5 Townes-style Malaise traps (MegaView Science Co., Ltd., Taichung, Taiwan), 25 large (30.5 cm × 46 cm) pan traps (5 of each color: blue, purple, red, yellow, white), which were arranged under the Malaise traps (1 of each color per Malaise trap); 4 SLAM (Sea, Land, and Air Malaise) traps (MegaView Science Co., Ltd., Taichung, Taiwan) with top and bottom collectors (Fig. 1); 15 Lindgren multi-funnel traps (ChemTich International, S.A., Heredia, Heredia, Costa Rica) (five of each color: black, green, purple) (Fig. 2); and 17 pitfall trap sets based on a modified design proposed by Nordlander (1987) and modified by Lemieux & Lindgren (1999) (Fig. 3). Additionally, 10 leaf litter samples were collected for Berlese extraction when traps were serviced.

Traps were not baited with commonly used attractants, such as ethanol, α- and β-pinene, acetone, acetaldehyde, and carbon dioxide (Wilson et al. 1966; Hwang et al. 1978; Montgomery and Wargo 1983; Costello et al. 2008), as the addition of such lures would have exponentially increased the number of traps required. Additionally, such lures are often most attractive to certain feeding guilds (e.g., ethanol and α- and β-pinene for wood-boring beetles, carbon dioxide for biting flies) and we felt testing individual trap/lure combinations was best left for more specific investigations.

Traps were placed nonrandomly within the plot in order to maximize the efficiency of each trap, though an attempt was made to evenly space like-traps in order to decrease the chance of interference between traps. Malaise traps were placed in perceived flight paths. SLAM and Lindgren funnel traps were suspended from the branches of large trees 4–10 meters above the ground in the lower canopy.

Berlese–Tullgren samples were collected from a variety of habitats, including thin leaf litter on open ground; thick leaf litter accumulated along logs and rocks; moss; tree holes; bark from fallen, partially decayed trees; and bark and leaf litter accumulated at the base of standing, dead trees. Tree holes were only collected once each as not to destroy potentially sensitive habitat; as the number of tree holes within the site was limited, this resulted in only a handful of collections from this habitat type. Litter was processed in the field using a litter reducer until approximately one gallon of processed litter was collected; this was stored in one gallon self-sealing bags during transport. Litter samples were collected after all traps had been serviced in order to reduce exposure to heat and reduce mortality of collected specimens. Leaf litter samples were processed for 4–7 d using modified Berlese–Tullgren funnels until the litter was thoroughly dry.

All traps were set on 13 March 2013, except Lindgren funnels, which were set on 1 April 2013. Traps were serviced approximately every 2 wk (14 ± 3 d) (see table 3 of Skvarla 2013b). The final collection of pitfall traps and pan traps occurred on 6 November 2013 and the final collection of Malaise, SLAM, and Lindgren funnel traps occurred on 4 December 2013. Berlese–Tullgren samples from 13 April, 15 May, 28 June and 6 November were not taken due to inclimate weather or were lost. Pitfall sets were lost on 13 April (one set), 15 May (one set), 28 June (four sets), 17 July (five sets). In total, 1,311 samples were collected (see table 4 of Skvarla 2013b).

Propylene glycol (in the form of Peak RV and Marine Antifreeze, Old World Industries, LLC, Northbrook, IL) was used as the preservative in all traps as it is nontoxic and has been shown to adequately preserve morphological characters while not degrading DNA (Skvarla et al. 2014). Trap catch was sieved in the field and stored in Whirl–Pak bags (Nasco, Fort Atkinson, WI) in 90% ethanol until sorting.

Samples were coarse-sorted to readily identifiable levels (usually family, occasionally genus or superfamily) using a Leica MZ16 stereomicroscope illuminated with a Leica KL1500 LCD light source and a Wild M38 stereomicroscope illuminated with an Applied
Scientific Devices Corp. Eco-light 20 fiber optic light source. After sorting, specimens were stored in 2 ml microtubes (VWR International, LLC, Randor, PA) in 70% ethanol until they were pinned or pointed as appropriate.

Carabidae, Cerambycidae, and Curculionidae were identified with the use of published keys (see Skvarla 2015b, table 5). Buprestidae were sent to Kyle Schnepp at the Florida State Collection of Arthropods for identification.

One to five voucher specimens of each species have been retained in the Dowling Lab collection at the University of Arkansas while the remaining specimens have been deposited in the University of Arkansas Arthropod Museum (UAAM).

Specimen abundance per trap per date was recorded in Excel (Microsoft 2013) and is available online (Skvarla et al. 2015a). For each family analyzed, the following procedures were followed:

A one-way analysis of variance (ANOVA) test \((a = 0.05)\) was performed in Excel to compare the effect of trap type on number of species and specimens. Due to uneven trapping effort and because traps were randomly lost due to rain and animal disturbance, we compared the average number of species collected/trap/trap type/date.

If a significant difference was detected, the means were separated using a Tukey–Kramer test \((a = 0.05)\) performed in Excel using the Real Statistics Resource Pack add-in (Zaiontz 2015). We chose to use ANOVA and Tukey–Kramer rather than their nonparametric equivalents as both tests are relatively robust if the assumption of normality is violated (Kirk 1995; Samuels and Witmer 2003) and easily performed within Excel.

EstimateS (Colwell 2013) was used to calculate the following species accumulation estimators for each trap type using all samples collected per trap type: abundance coverage-based estimator of species richness (ACE); incidence coverage-based estimator of species richness (ICE); Chao 1 richness estimator (Chao1); Chao 2 richness estimator (Chao2); first order Jackknife richness estimator (Jack1); second order Jackknife richness estimator (Jack2) (see Gotelli and Colwell [2010] for a synopsis of each estimator). Additionally, the
sample-based rarefaction curve ($S_{est}$)), which is the expected number of species in $t$ pooled samples given the reference sample, was also calculated. EstimateS was run on default settings except that classic Chao1 and Chao2 estimators were used instead of the default bias-corrected Chao1 and Chao2 as suggested by the program. One hundred randomizations of sample order were performed in order to smooth the curves. As the various estimators generally calculated similar trends, we report only Chao1 estimators for each trap type per family herein and include graphs of all of the estimators in the Supplemental Material (Supp Figs. S1–S4 [online only]). Rarefaction curves were compared based on the number of samples collected and after extrapolating the curves to a hypothetical 1,000 samples in Table 1.

### Table 1. Results of ANOVA tests comparing the effect of color on the number of specimens of different species of Buprestidae collected in Lindgren funnel traps

| Species               | Trap color | Mean | SD | Separation of means |
|-----------------------|------------|------|----|---------------------|
| Agrilus bilineatus    | Black      | 1.17 | 1  | –                   |
|                       | Green      | 0.67 | 1  | –                   |
|                       | Purple     | 0.33 | 0.5| –                   |
| Agrilus cephalicus    | Black      | 0    | 0  | b                   |
|                       | Green      | 3.75 | 1.7| a                   |
|                       | Purple     | 0    | 0  | b                   |
| Agrilus lecontei      | Black      | 0    | 0  | b                   |
|                       | Green      | 1.33 | 0.6| a                   |
|                       | Purple     | 0    | 0  | b                   |
| Agrilus obsolettoguttatus | Black  | 0    | 0  | b                   |
|                       | Green      | 2.75 | 2.1| a                   |
|                       | Purple     | 0    | 0  | b                   |
| Dicerca lurida        | Black      | 0    | 0  | b                   |
|                       | Green      | 0    | 0  | b                   |
|                       | Purple     | 2.25 | 1.5| a                   |
| Dicerca obscura       | Black      | 1    | 0  | a                   |
|                       | Green      | 0    | 0  | b                   |
|                       | Purple     | 0.25 | 0.5| b                   |
| Ptosima gibbicollis   | Black      | 0    | 0  | b                   |
|                       | Green      | 1.33 | 0.6| a                   |
|                       | Purple     | 0.33 | 0.6| a,b                 |

* $P < 0.05$ is considered significant. Significant values are indicated by an asterisk (*).

Fig 8. Similarity of trap catch as determined by Sørensen and Chao’s Sørensen Indices. Number of species collected per trap type is indicated parenthetically after each trap type.
Samples were randomized across traps within a trap type and across dates. Error bars were excluded from accumulation and rarefaction graphs in order to enhance clarity.

Species similarity between trap types and seasonality was investigated by calculating shared species indices using EstimateS. EstimateS output was organized in Excel and final graphs were constructed in Adobe Illustrator (Adobe 2012). EstimateS calculates a number of different shared species estimators; herein we report the Sørensen similarity index, an incidence-based (i.e., presence/absence) index, and Chao’s Sørensen similarity index, an abundance-based index (Chao et al. 2005). These indices indicate the similarity of the compared samples, which varies between 0 and 1 and indicate no to complete similarity. The statistical significance of similarity cannot be determined from these indices; therefore, when discussing the estimated similarity, we use the terms low (0–0.24), medium (0.25–0.49), high (0.50–0.74) and very high (0.75–1.0).

Shared species indices for trap types were calculated based on the total number of specimens per species collected per trap type. Shared species indices for collection dates were calculated based on the total specimens collected per species per date; the four trap types that collected the most species per family are reported.

The effect of Lindgren funnel trap color was investigated per species by performing a one-way ANOVA test ($\alpha=0.05$) as described earlier on the total number of specimens collected per date by each color of Lindgren funnel when more than five specimens of a species were collected by any color of Lindgren funnel trap. Collection periods in which no beetles were collected by any trap were excluded from the analyses.

### Results

#### Buprestidae

A total of 347 specimens representing 27 species and 9 genera were collected. Malaise traps caught the most species (Fig. 4a and b). Berlese–Tullgren extraction of leaf litter produced no buprestids and was not considered in the analyses. Most species were represented by fewer than 20 specimens, with 11 species (41%) being represented by singletons (Fig. 5).

There was a significant ($P<0.05$) effect of trap type on the number of species collected for the 12 trap types ($F=4.61$; df=11,189;
The mean number of species collected by Malaise traps ($M = 0.72$, $SD = 1.04$) was not significantly different from green Lindgren funnel traps ($M = 0.44$, $SD = 0.67$) and purple Lindgren funnel traps ($M = 0.31$, $SD = 0.52$) but was significantly different than all other trap types ($P > 0.05$, Tukey–Kramer). The mean number of species in upper canopy traps ($M = 0.56$, $SD = 0.83$) were significantly different from red pan traps and pitfall traps. All other trap types were not significantly different from each other: lower canopy trap ($M = 0.04$, $SD = 0.10$), black Lindgren funnel trap ($M = 0.18$, $SD = 0.17$), blue pan trap ($M = 0.08$, $SD = 0.21$), purple pan trap ($M = 0.03$, $SD = 0.08$), red pan trap ($M = 0.02$, $SD = 0.05$), white pan trap ($M = 0.08$, $SD = 0.16$), yellow pan trap ($M = 0.04$, $SD = 0.08$) ($P > 0.05$) (Fig. 4a).

The effects of the color of Lindgren funnel traps was tested for seven species. Color had a significant ($P < 0.05$, Tukey–Kramer) effect on the number of specimens collected for six species; the mean number of specimens was significantly higher in green traps for three species, significantly higher in black and purple traps for one species each, and significantly higher in both green and purple traps for one species (Table 1).

Species accumulation estimator curves for 6 of the 13 trap types (Berlese–Tullgren, upper and lower canopy traps, purple, red, and white pan, and pitfall traps) became asymptotic and coalesced with the actual number of species collected (Fig. 6, A1a–m). However, those trap types collected the fewest buprestids. Malaise and green Lindgren funnel traps are estimated to collect the most species after
1,000 samples, with green Lindgren funnels collecting the most species for the first 150 samples and Malaise traps collecting more species thereafter (Fig. 7).

Green and purple Lindgren funnel and Malaise traps exhibit, with a single exception, medium similarity with each other and medium to very high similarity with canopy traps (Fig. 8). All four trap types exhibit medium to very high similarity with black Lindgren funnel and blue pan traps and generally exhibit low similarity with yellow, purple, and red pan and lower canopy traps, though all pan traps, excepting blue, collected relatively few species.

Buprestidae exhibited distinct seasonal trends, which is reflected in the number of species collected per trap type (Fig. 4b). About 11 of 12 species that were only sampled during one trapping period and five of six species that exhibited population increases did so during the same time period; additionally, only seven species were collected after 17 July, all of which were collected before that date. When comparing trap collection dates using similarity indices, Malaise traps (Fig. 9a) typically exhibit high to very high similarity between trap dates within 6 wk of each other. Conversely, green Lindgren funnel traps, with a few exceptions, exhibited low to medium similarity regardless of the trapping periods compared (Fig. 9b). Overall, collections made within 4–6 wk of each other typically have high to very high similarity, while collections made beyond 6 wk apart show low to medium similarity (Fig. 9c) and most species were collected from late spring through early summer (early June–mid July) (Fig. 10).

Carabidae
A total of 1,964 specimens representing 62 species and 36 genera were collected. Pitfall traps caught the most species (Fig. 11a and b). Most species were represented by fewer than 20 specimens, with 17 species (27%) being represented by singletons (Fig. 12).

There was a significant \( P < 0.05 \) effect of trap type on the number of species collected for the 13 trap types (\( F = 23.55; \ df = 12,203; \ P < 0.0001 \)). The mean number of species collected by pitfall traps (\( \bar{M} = 1.84, \ SD = 0.66 \)) was significantly different
than all other trap types; green Lindgren funnel ($M = 0.60$, $SD = 0.55$) was significantly different from blue, white, and yellow pan traps but not other trap types ($P < 0.05$, Tukey–Kramer); the remaining trap types were not significantly different from each other: Berlese–Tullgren ($M = 0.49$, $SD = 0.28$), lower canopy trap ($M = 0.26$, $SD = 0.30$), upper canopy trap ($M = 0.32$, $SD = 0.35$), black Lindgren funnel ($M = 0.42$, $SD = 0.35$), purple Lindgren funnel ($M = 0.47$, $SD = 0.32$).

### Table 2. Results of ANOVA tests comparing the effect of color on the number of specimens of different species of Carabidae collected in Lindgren funnel traps

| Species            | ANOVA                      | Tukey–Kramer                  |
|--------------------|----------------------------|--------------------------------|
|                    | df | ss      | $F$  | $P$ value | Trap color | Mean | SD | Separation of means |
| Amara musculis     |    |         |      |           |            |      |    |                     |
| Between groups     | 2  | 6.5     | 1.5  | 0.274     | Black      | 3.5  | 6.08 | –                   |
| Within groups      | 9  | 19.5    |      |           | Green      | 2.42 | 2.94 | –                   |
| Total              | 11 | 26      |      |           | Purple     | 3.83 | 6.33 | –                   |
| Cymindis limbata   |    |         |      |           |            |      |    |                     |
| Between groups     | 2  | 13.17   | 0.22 | 0.801     | Black      | 0.75 | 1.5  | –                   |
| Within groups      | 33 | 971.58  |      |           | Green      | 2    | 2   | –                   |
| Total              | 35 | 984.75  |      |           | Purple     | 0.25 | 0.5  | –                   |
| Lebia viridis      |    |         |      |           |            |      |    |                     |
| Between groups     | 2  | 10.11   | 1.64 | 0.228     | Black      | 0.5  | 1.22 | –                   |
| Within groups      | 15 | 46.33   |      |           | Green      | 2.33 | 2.42 | –                   |
| Total              | 17 | 56.44   |      |           | Purple     | 1.5  | 1.38 | –                   |

* $P < 0.05$ is considered significant. Significant values are indicated by an asterisk (*).

### Table 3. Results of ANOVA tests comparing the effect of color on the number of specimens of different species of Cerambycidae collected in Lindgren funnel traps

| Species             | ANOVA                      | Tukey–Kramer                  |
|---------------------|----------------------------|--------------------------------|
|                     | df | ss      | $F$  | $P$ value | Trap color | Mean | SD | Separation of means |
| Anelaphus parallelus|    |         |      |           |            |      |    |                     |
| Between groups      | 2  | 66.89   | 0.96 | 0.433     | Black      | 4.67 | 4.73 | –                   |
| Within groups       | 6  | 208     |      |           | Green      | 8.33 | 2.31 | –                   |
| Total               | 8  | 274.89  |      |           | Purple     | 11.3 | 8.74 | –                   |
| Elaphidion mucronatum| 2  | 26.47   | 0.77 | 0.472     | Black      | 4.2  | 6.29 | –                   |
| Within groups       | 27 | 462.5   |      |           | Green      | 1.9  | 1.52 | –                   |
| Total               | 29 | 488.97  |      |           | Purple     | 3    | 3.09 | –                   |
| Elytrimitatrix undata| 2  | 0.13    | 0.06 | 0.94      | Black      | 1    | 1.22 | –                   |
| Within groups       | 12 | 12.8    |      |           | Green      | 0.8  | 0.84 | –                   |
| Total               | 14 | 12.93   |      |           | Purple     | 1    | 1   | –                   |
| Heterachthes quadrimaculatus| 2 | 2.17    | 1.15 | 0.36      | Black      | 1.25 | 1.5 | –                   |
| Within groups       | 9  | 8.5     |      |           | Green      | 0.25 | 0.5 | –                   |
| Total               | 11 | 10.67   |      |           | Purple     | 0.5  | 0.58 | –                   |
| Molorchus bimaculatus| 2  | 250.89  | 5.02 | 0.052     | Black      | 3.67 | 1.53 | –                   |
| Within groups       | 6  | 150     |      |           | Green      | 14.3 | 8.37 | –                   |
| Total               | 8  | 400.89  |      |           | Purple     | 2.67 | 1.53 | –                   |
| Neoclytus acuminatus| 2  | 1.58    | 1.6  | 0.225     | Black      | 0.5  | 0.76 | –                   |
| Within groups       | 21 | 10.38   |      |           | Green      | 0.25 | 0.46 | –                   |
| Total               | 23 | 11.96   |      |           | Purple     | 0.88 | 0.83 | –                   |
| Neoclytus mucronatus| 2  | 51.71   | 1.93 | 0.174     | Black      | 3.71 | 3.4 | –                   |
| Within groups       | 18 | 240.86  |      |           | Green      | 0    | 0 | –                   |
| Total               | 20 | 292.57  |      |           | Purple     | 2.71 | 5.35 | –                   |
| Neoclytus scutellaris| 2  | 0.13    | 2.72 | 0.106     | Black      | 1.4  | 2.61 | –                   |
| Within groups       | 12 | 41.6    |      |           | Green      | 1.4  | 1.67 | –                   |
| Total               | 14 | 41.73   |      |           | Purple     | 1.6  | 0.89 | –                   |
| Parelaphidion aspersum| 2  | 3.56    | 2.72 | 0.106     | Black      | 1.67 | 2.08 | –                   |
| Within groups       | 6  | 10      |      |           | Green      | 0.33 | 0.38 | –                   |
| Total               | 8  | 13.36   |      |           | Purple     | 0.33 | 0.38 | –                   |
| Saperda imitans     |    |         |      |           |            |      |    |                     |
| Between groups      | 2  | 8.22    | 3.7  | 0.09      | Black      | 1    | 1   | –                   |
| Within groups       | 6  | 6.67    |      |           | Green      | 0    | 0   | –                   |
| Total               | 8  | 14.89   |      |           | Purple     | 2.33 | 1.53 | –                   |
| Stenosphenus notatus| 2  | 370     | 2.72 | 0.106     | Black      | 0.4  | 0.55 | –                   |
| Within groups       | 12 | 817.6   |      |           | Green      | 1.4  | 1.34 | –                   |
| Total               | 14 | 1,187.6 |      |           | Purple     | 11.4 | 14.2 | –                   |
| Xylotrechus colonus |    |         |      |           |            |      |    |                     |
| Between groups      | 2  | 78.79   | 4.83 | 0.015*    | Black      | 3.72 | 2.8 | a,b                  |
| Within groups       | 30 | 244.73  |      |           | Green      | 0.09 | 0.3 | b                   |
| Total               | 32 | 323.52  |      |           | Purple     | 2.82 | 4.07 | a,b                  |

* $P < 0.05$ is considered significant. Significant values are indicated by an asterisk (*).
The effects of the color of Lindgren funnel traps was tested for three species. Color did not have a significant effect on the number of specimens collected at the $P < 0.05$ level (Table 2).

Species accumulation estimator curves for 9 of the 13 trap types (Berlese–Tullgren, upper and lower canopy traps, black and green Lindgren funnel traps, blue, purple, red, and white pan traps) became asymptotic (Fig. 13, A2a–m). However, those trap types collected the fewest carabids and in only the white pan traps, which collected the fewest species, did the estimators and actual number of species collected coalesce. Pitfall, Malaise, and purple Lindgren funnel traps were estimated to collect the most species after 1,000 samples (Fig. 14).

Pitfall traps exhibited medium to very high similarity ($S_{\text{Sørensen}} = 0.47$, Chao’s $S_{\text{Sørensen}} = 0.82$) with Berlese–Tullgren sampling (Fig. 15). Lindgren funnel, Malaise, and canopy traps exhibited medium to very high similarity ($S_{\text{Sørensen}} = 0.26–0.70$, Chao’s $S_{\text{Sørensen}} = 0.13–0.32$, Chao’s $S_{\text{Sørensen}} = 0.1–0.15$) with pitfall traps. Blue, purple, red, and yellow pan traps exhibited high to very high similarity with each other ($S_{\text{Sørensen}} = 0.50–0.73$, Chao’s $S_{\text{Sørensen}} = 0.60–0.90$), but low to medium similarity with white pan traps ($S_{\text{Sørensen}} = 0–0.35$, Chao’s $S_{\text{Sørensen}} = 0–0.22$). Purple and white pan traps generally exhibited

| Species                | ANOVA | Tukey–Kramer |
|-----------------------|-------|--------------|
|                       | df    | ss | $F$ | $P$ value | Trap color | Mean | SD | Separation of means |
| Anthonomus rufipennis | Between groups | 2  | 3.56 | 16 | 0.004* | Black | 0 | 0 | b |
|                       | Within groups | 6  | 0.67 |  |  | Green | 1.3 | 0.58 | a |
|                       | Total | 8  | 4.22 |  |  | Purple | 0 | 0 | b |
| Anthonomus suturalis  | Between groups | 2  | 22.93 | 4.05 | 0.045* | Black | 0.4 | 0.89 | a |
|                       | Within groups | 12 | 34   |  |  | Green | 0 | 0 | a |
|                       | Total | 14 | 56.93 |  |  | Purple | 0 | 0 | a |
| Apteromechus ferratus | Between groups | 2  | 0.08 | 0.02 | 0.983 | Black | 1.63 | 1.77 | – |
|                       | Within groups | 21 | 51.25 |  |  | Green | 1.75 | 1.67 | – |
|                       | Total | 23 | 217.83 |  |  | Purple | 1.63 | 1.19 | – |
| Conotrachelus anaglypticus | Between groups | 2  | 4.95 | 4.46 | 0.027* | Black | 1.29 | 0.95 | a |
|                       | Within groups | 18 | 10   |  |  | Green | 0.43 | 0.79 | a,b |
|                       | Total | 20 | 14.95 |  |  | Purple | 0.14 | 0.38 | b |
| Conotrachelus aratus  | Between groups | 2  | 28.58 | 1.59 | 0.228 | Black | 0.25 | 0.71 | – |
|                       | Within groups | 21 | 189.25 |  |  | Green | 1.13 | 0.99 | – |
|                       | Total | 23 | 217.83 |  |  | Purple | 2.88 | 5.06 | – |
| Conotrachelus elegans | Between groups | 2  | 16.33 | 49 | 0.005* | Black | 0 | 0 | a |
|                       | Within groups | 3  | 0.5  |  |  | Green | 0 | 0 | b |
|                       | Total | 5  | 16.83 |  |  | Purple | 3.5 | 0.71 | a |
| Conotrachelus naso    | Between groups | 2  | 1.78 | 1.54 | 0.247 | Black | 0.33 | 0.52 | – |
|                       | Within groups | 15 | 8.67 |  |  | Green | 1 | 1.1 | – |
|                       | Total | 17 | 10.44 |  |  | Purple | 0.33 | 0.52 | – |
| Cossonus impressifrons | Between groups | 2  | 6 | 6.35 | 0.019* | Black | 0 | 0 | b |
|                       | Within groups | 9  | 4.25 |  |  | Green | 0 | 0 | b |
|                       | Total | 11 | 10.25 |  |  | Purple | 1.75 | 0.96 | a |
| Cyrtepistomus castaneus | Between groups | 2  | 16.44 | 4.4 | 0.031* | Black | 0.33 | 0.82 | b |
|                       | Within groups | 15 | 28   |  |  | Green | 1.33 | 1.03 | a,b |
|                       | Total | 17 | 44.44 |  |  | Purple | 2.67 | 1.97 | a |
| Dryophthorus americanus | Between groups | 2  | 25 | 25 | <0.001* | Black | 0 | 0 | b |
|                       | Within groups | 9  |  |  |  | Green | 0 | 0 | b |
|                       | Total | 11 | 125 |  |  | Purple | 1.25 | 0 | a |
| Eugnamptus angustatus | Between groups | 2  | 5.56 | 25 | 0.001* | Black | 0 | 0 | b |
|                       | Within groups | 6  | 0.67 |  |  | Green | 0 | 0 | b |
|                       | Total | 8  | 6.22 |  |  | Purple | 1.67 | 0.58 | a |
| Hypera meles          | Between groups | 2  | 8 | 12 | 0.008* | Black | 0 | 0 | b |
|                       | Within groups | 6  | 2    |  |  | Green | 2 | 0 | a |
|                       | Total | 8  | 10 |  |  | Purple | 0 | 0 | b |
| Lechriops oculatus    | Between groups | 2  | 14.78 | 4.1 | 0.038* | Black | 0.17 | 0.41 | a |
|                       | Within groups | 15 | 27   |  |  | Green | 2.17 | 2.14 | a |
|                       | Total | 17 | 41.78 |  |  | Purple | 0.33 | 0.82 | a |
| Madarellus undulatus  | Between groups | 2  | 4.33 | 2.17 | 0.262 | Black | 0.5 | 0.71 | – |
|                       | Within groups | 3  |  |  |  | Green | 1 | 1.41 | – |
|                       | Total | 5  | 7.33 |  |  | Purple | 2.5 | 0.71 | – |

$P < 0.05$ is considered significant. Significant values are indicated by an asterisk (*)..

SD = 0.35), Malaise trap ($M = 0.49$, SD = 0.43), blue pan trap ($M = 0.15$, SD = 0.21), purple pan trap ($M = 0.29$, SD = 0.36), red pan trap ($M = 0.25$, SD = 0.35), white pan trap ($M = 0.15$, SD = 0.25), and yellow pan trap ($M = 0.06$, SD = 0.14) ($P > 0.05$) (Fig. 11a).
Fig 15. Similarity of trap catch as determined by Sørensen and Chao’s Sørensen Indices. Number of species collected per trap type is indicated parenthetically after each trap type.

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Fig 16. Sørensen and Chao’s Sørensen Indices comparing similarity of trap catch by date in Malaise and green Lindgren funnel traps and all trap catch combined.
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medium to very high similarity with nonpan traps ($S_\text{ø}rensen = 0.26–0.59$, Chao’s $S_\text{ø}rensen = 0.25–0.86$), while yellow pan traps exhibited the lowest similarity with nonpan traps ($S_\text{ø}rensen = 0–0.18$, Chao’s $S_\text{ø}rensen = 0–0.19$).

The number of carabid species collected remained relatively constant throughout the study with a small increase in early summer (June) (Fig. 11b). When comparing trap collection dates using similarity indices, pitfall traps generally exhibited at least medium similarity regardless of the date considered and high to very high similarity between dates within 2–4 wk of the date considered (Fig. 16a). Malaise traps exhibited high to very high similarity among spring and fall dates, but no similarity between them (Fig. 16b).
When all traps were combined, the similarity between dates was similar to that exhibited by pitfall traps (Fig. 16c).

About 6 of the 27 species (22%) were collected in sufficient numbers to examine species-level phenology, while another 6 were collected over multiple dates but in low numbers that did not allow any interpretation of phenology; 15 of the species collected (55%) were found in low numbers during only a few trapping periods (Fig. 17).

Cerambycidae
A total of 1,885 specimens representing 82 species and 57 genera were collected. Malaise and canopy traps (upper collector) caught the most species (Fig. 18a and b). Berlese–Tullgren extraction of leaf litter produced no cerambycids and is not considered in the analyses. Half of all species were represented by six or more specimens, while 16 species (19.5%) were represented by a single specimen (Fig. 19).

There was a significant \( P < 0.05 \) effect of trap type on the number of species collected for the 12 trap types \( (F = 7.22, df = 11,189; P < 0.0001) \). The mean number of species collected by Malaise traps \( (M = 2.62, SD = 3.19) \) and upper canopy traps \( (M = 2.40, SD = 3.01) \) were not significantly different from black Lindgren funnel traps \( (M = 1.40, SD = 1.51) \), green Lindgren funnel traps \( (M = 1.12, SD = 1.04) \) and purple Lindgren funnel traps \( (M = 1.60, SD = 1.52) \) but were significantly different than all other trap types \( (P < 0.05, Tukey–Kramer) \). Lindgren funnel traps were not significantly different from pan traps, lower canopy traps, or pitfall traps. Pan traps, lower canopy traps, and pitfall traps were not significantly different from each other: lower canopy trap \( (M = 0.14, SD = 0.36) \), blue pan trap \( (M = 0.14, SD = 0.23) \), purple pan trap \( (M = 0.14, SD = 0.21) \), red pan trap \( (M = 0.14, SD = 0.20) \), white pan trap \( (M = 0.15, SD = 0.12) \), yellow pan trap \( (M = 0.06, SD = 0.20) \), pitfall trap \( (M = 0.02, SD = 0.06) \) (Fig. 21a) \( (P > 0.05) \).

The effects of the color of Lindgren funnel traps was tested for 12 species. Color had a significant \( P < 0.05 \) effect on the number of specimens collected for Xylotrechus colonus (Fab.) but not other species; the mean number of specimens collected for X. colonus by black Lindgren funnel traps was significantly higher than green traps but not purple traps and that purple and green traps were not significantly different \( (P < 0.05, Tukey–Kramer) \) (Table 3).
Species accumulation estimator curves for 6 of the 12 trap types (lower canopy and blue, purple, red, white and yellow pan traps) became asymptotic (Fig. 20, A3a–m). However, those trap types collected the fewest cerambycids and in only the yellow pan traps, which collected the fewest species, did the estimators and actual number of species collected coalesce. Malaise and upper canopy traps were estimated to collect the most species and become asymptotic after approximately 400 samples (Fig. 21).

Malaise, upper canopy, and Lindgren funnel traps had high to very high similarity (Sørensen = 0.57–0.68, Chao’s Sørensen = 0.62–0.94) (Fig. 22). The remaining traps collected significantly fewer species and will not be considered further.

Cerambycidae exhibited distinct seasonality, with most species collected during the early summer (Fig. 18b). Overall, samples collected in the summer and fall were highly similar and distinct from samples collected in the spring when examining individual trap types (Fig. 23a and b) and all traps together (Fig. 23c).

About 20 of the 82 species (24%) were collected in sufficient numbers to examine species-level phenology (Fig. 24a), while 12 (15%) were collected throughout the study but in low numbers that do not allow any interpretation of phenology (Fig. 24b) and 51 (62%) were found in low numbers during only a few trapping periods (Fig. 24c).

Curculionoidea
A total of 3,777 specimens representing 80 species and 61 genera (Anthribidae: 4 genera, 4 species; Attelabidae: 3 genera, 3 species; Brachyceridae: 1 genus, 1 species; Brentidae 1 genus, 1 species; Curculionidae: 52 genera, 71 species) were collected. Malaise and pitfall traps caught the most species (Fig. 25a and b). About 36 species (45%) collected were represented by five or fewer specimens and 20 species (25%) were represented by singletons (Fig. 26).

There was a significant ($P < 0.05$) effect of trap type on the number of species collected for the 13 trap types ($F = 5.45; df = 12,203; P < 0.0001$). The mean number of species collected by Malaise traps ($M = 2.24, SD = 1.79$) were not significantly different ($P > 0.05$,
Fig 22. Similarity of trap catch as determined by Sørensen and Chao’s Sørensen Indices. Number of species collected per trap type is indicated parenthetically after each trap type.

Fig 23. Sørensen and Chao’s Sørensen Indices comparing similarity of trap catch by date in Malaise and green Lindgren funnel traps and all trap catch combined.
Tukey–Kramer) from pitfall (M = 1.78, SD = 0.66), purple pan (M = 1.51, SD = 0.90), white pan (M = 1.43, SD = 0.94), and upper canopy traps (M = 1.31, SD = 1.23) but were significantly different than all other trap types (P > 0.05). Pitfall traps were not significantly different from purple and white pan and upper canopy traps and Berlese–Tullgren sampling (M = 1.11, SD = 0.47), but were significantly different from blue, yellow, and red pan, lower canopy, and Lindgren funnel traps. Purple pan traps were significantly different from black Lindgren funnel traps (M = 0.37, SD = 0.33), but not significantly different from all other trap types. The remaining trap types were not significantly different from each other: Blue pan (M = 0.95, SD = 0.60), yellow pan (M = 0.90, SD = 0.60), red pan (M = 0.75, SD = 0.54), green Lindgren funnel (M = 0.91, SD = 1.12), purple Lindgren funnel (M = 0.74, SD = 0.73), and black Lindgren funnel (M = 0.37, SD = 0.33) (Fig. 25a).

The effects of the color of Lindgren funnel traps was tested for 14 species. Color had a significant (P < 0.05) effect on the number of specimens collected at the P < 0.05 level for 10 species; the mean number of specimens was significantly (P < 0.05, Tukey–Kramer) higher in green Lindgren funnel traps for two species, higher in purple traps for four species, could not be separated for two species, higher in green compared to black but not purple for one species, and higher in black compared to purple but not green for one species (Table 4).

Species accumulation estimator curves for 3 of the 13 trap types (black and purple Lindgren funnel and yellow pan traps) became asymptotic (Fig. 27, A4a–m). However, those trap types collected the fewest curculionoids. Green Lindgren funnel traps were estimated to not become asymptotic and collect the most species after 1,000 samples; however, Malaise traps were estimated to collect more species than green Lindgren funnel traps for the first 250 samples (Fig. 28).

Green Lindgren funnel, Malaise, and purple pan traps exhibited high to very high similarity with respect to the species collected with each other (Sørensen = 0.55–0.61, Chao’s Sørensen = 0.71–0.90) (Fig. 29). With one exception, Berlese–Tullgren and pitfall sampling exhibited medium similarity with Green Lindgren funnel and Malaise traps (Sørensen = 0.33–0.47, Chao’s Sørensen = 0.39–0.47), but high to very high similarity with purple pan traps (Sørensen = 0.56, 0.59, Chao’s Sørensen = 0.70, 0.93). Pan traps

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**Fig 24.** Phenology of cerambycids collected during this study summed across all trap types. (24a) Species with more than five specimens collected in at least one collecting period. (24b) Species with five or fewer specimens collected in any collection period but found in at least four collection periods. (24c) Species with five or fewer specimens collected in any collection period and found in three or fewer collection periods.
exhibited high to very high similarity with each other ($Sørensen = 0.55–0.78$, Chao’s $Sørensen = 0.88–0.98$) and Malaise and upper and lower canopy traps exhibited medium to very high similarity ($Sørensen = 0.41–0.63$, Chao’s $Sørensen = 0.79–0.95$).

**Curculionoidea** exhibited seasonality, with the most species collected in the spring (Fig. 25b). Overall, samples collected within five collection periods ($\pm 10$ wk) have high to very high similarity with each other and medium to high similarity with samples further removed in time (Fig. 30c). However, individual trap types show less similarity: e.g., Malaise traps collected distinct spring and fall species assemblages that both had medium similarity with the assemblage collected in the summer (Fig. 30a), while purple pan traps collected a distinct spring assemblage that was different from that collected in summer and fall (Fig. 30b).

About 25 of the curculionoid species (35%) were collected in sufficient numbers to examine species-level phenology (Fig. 31a), while 11 (15%) were collected throughout the study but in low numbers that do not allow any interpretation of phenology (Fig. 31b). Forty-four species (64%), including all of the noncurculionid curculionoids, were found in low numbers during only a few trapping periods (Fig. 31c).

### Discussion

**Buprestidae**

Malaise, upper canopy, green and purple Lindgren funnel traps collected the most buprestid species. Malaise and upper canopy traps exhibited high to very high similarity in the species collected with each other but, with two exceptions comparing Malaise traps to green and black Lindgren funnel traps using Chao’s $Sørensen$ index, only medium similarity with Lindgren funnel traps. Additionally, Malaise and upper canopy traps collected the largest buprestids at the site—*Chrysobothris* Eschscholtz and *Dicerca* Eschscholtz—in higher abundance than other methods. This indicated that Malaise and upper canopy traps, which were constructed from similar material and collect taxa in a similar fashion, targeted a species assemblage (i.e., large species) that other methods poorly sampled and also suggested that the large species are active both near the ground and in the canopy.

Trap color appeared to be an important component of Lindgren funnel traps when targeting buprestids. Green and purple Lindgren funnel traps exhibited only medium similarity in the species collected and differentially peaked in the number of species collected. Six of seven species analyzed were caught in significantly higher numbers by specific colored traps: four were caught in higher numbers by green traps, one by purple traps, and one by black traps. Other studies have examined the role of color in attraction and trapping of Buprestidae but most have identified specimens to the family level or focused on economically important species (e.g., emerald ash borer (EAB), *Agrilus planipennis* Fairmaire) (Table 5) (note that while many studies, including some cited, here also tested chemical attractants of EAB, those cited here focus at least in part on color attraction). However, two studies (i.e., Peatrice et al. 2013; Peatrice and Haack 2015) found that, while there was no difference in the attraction of emerald ash borer to green or purple traps, other *Agrilus* Curtis species demonstrate significant preference for green or green and purple traps. It is therefore probable that green and purple Lindgren traps attract different species and that the bulk of studies that have examined color preference in emerald ash borer may not be applicable to other *Agrilus* or buprestids in general.
Malaise and upper canopy traps were estimated to collect approximately the same number of buprestid species for the first 50 samples or so; however, species accumulation curves for upper canopy traps became asymptotic by 70 samples while the extrapolated rarefaction curve for Malaise traps was not estimated to approach an asymptote until nearly 1,000 samples. This resulted in Malaise traps being expected to collect more than triple the number of species when large numbers of samples are taken.

Species accumulation curves for green and purple Lindgren funnel traps did not become asymptotic after 85 and 82 collections, respectively. Extrapolated rarefaction curves for both traps became asymptotic after approximately 350 samples. Pan traps collected the fewest buprestid species. This result was expected as previous studies found the same result (McIntosh et al. 2001). However, blue pan traps may be an exception as they collected nearly as many species as black Lindgren funnel and upper canopy traps and were estimated to collect the third most species after approximately 220 samples.

Seasonality in buprestids is attracting interest as emerald ash borer and other invasive buprestids threaten native and managed landscapes. In temperate climates similar to the site studied herein, Dodds and Ross (2002) found buprestids active throughout the summer with a peak in late summer, while Sakalian and Langourov (2004), found them to be most active in the early summer. However, Klingeman et al.
after accumulating collection data from 15,217 specimens of 135 species from North Carolina and Tennessee, found seasonality varied by species, with many species active in early summer while others are found only in the spring or are active throughout the warm months. Thus, while there is some seasonality to buprestids in general, it is likely that much of the apparent seasonality in this and other studies is due to the inclusion of a relatively few number of specimens from a limited number of species.

Carabidae

Pitfall traps are generally thought to be the most effective trap to collect carabids and are often used to collect them (Greenslade 1964; Baars 1979; Waage 1985; Desender and Maelfait 1986; Halsall and Wratten 1988; Morrill et al. 1990; Niemelä et al. 1990; Wiedenmann et al. 1992; Work et al. 2002; Raworth and Choi 2003; Buchholz et al. 2010). Unsurprisingly, pitfall traps collected the most carabid species. Leaf litter samples processed with Berlese–Tullgren extractors exhibited high species similarity with pitfall traps, which suggests both methods target the same assemblage of ground-dwelling carabids. When samples are taken from forest floor leaf litter habitat, Berlese–Tullgren samples are better suited for qualitative sampling (Sabu and Shiju 2010; Sabu et al. 2011) as the fauna collected by pitfall traps are affected by a number of factors, such as trap diameter, trap material, and activity level of target species (for a detailed discussion of issues with pitfall traps see Skvarla et al. 2014). Additionally, Spence and Niemelä 1994 found large-bodied carabids dominate pitfall catch and small-bodied species dominate litter samples, so while both methods primarily target terrestrial species and may adequately sample that community after many samples, they may preferentially sample certain species when a limited number of samples are taken.
Aerial traps (i.e., Malaise, canopy, and Lindgren funnel traps) generally exhibited only low to medium similarity with pitfall traps and collected 15 species in four tribes not caught in pitfall traps: Lebiini (*Calleida viridipennis* (LeConte), *Dromius piceus* Dejean, *Lebia analis* Dejean, *L. marginicollis*, Dejean, *L. viridis* Say, *Plochomus timidus* Haldeman), Bembidiini (*Bembidion affine* Say, *B. rapidum* (LeConte), *Elaphropus granarius* (Dejean), *Tachyta parvicornis* Notman, *Tachys columbiensis* Hayward, *Tachys oblitus* Casey), Harpalini (*Selenophorus opalinus* (LeConte), *Stenolophus ochropezus* (Say)), and Platynini (*Platynus parmarginatus* Hamilton). Species of Lebiini are arboreal and an expected component of aerial traps (Ball and Bousquet 2001). *Platynus parmarginatus*, *Tachys columbiensis*, *T. oblitus*, *Tachyta parvicornis*, and *St. ochropezus* are attracted to lights (Ciegler 2000), so may fly frequently and encounter aerial traps. *Stenolophus ochropezus* and three of the remaining species (*B. affine*, *B. rapidum*, *E. granarius*) are hygro- or mesophilous (Ciegler 2000); we therefore suggest these species were collected in aerial traps as they moved between preferred habitat patches and that pitfall traps placed near such habitat may have collected them. Considering this, aerial traps appeared to target a different, complimentary assemblage of carabids to pitfalls and Berlese extraction of leaf litter. This has been previously suggested by Ulyshen et al. (2005), who reported that canopy traps (top - bottom collector) collect smaller, more aerial carabid species more effectively than pitfall traps and should be used in combination with pitfall traps when surveying carabid diversity.

Different colored Lindgren funnel traps did not collect significantly different numbers of specimens in the two species tested. While the effect of color on the collection of carabids in Lindgren funnels traps has not been previously investigated, studies of color in pitfall traps have demonstrated that white attracts more ground beetles than other colors (Buchholz et al. 2010). The attractiveness of different colors is likely species specific and requires further investigation.

Pan traps (except white pans) exhibited low to medium similarity with pitfall and aerial traps. However, pan traps collectively only caught three species—*Clivina pallida* (Say), *Cyclotrachelus torvus*
Fig 29. Similarity of trap catch as determined by Sørensen and Chao’s Sørensen Indices. Number of species collected per trap type is indicated parenthetically after each trap type.

Fig 30. Sørensen and Chao’s Sørensen Indices comparing similarity of trap catch by date in Malaise and green Lindgren funnel traps and all trap catch combined.
LeConte), Galerita janus (Fab.)—that were unique to pan traps and one species—Galerita bicolor (Drury)—in higher numbers in pan traps than other trap types. Of the three unique species, two were represented by singletons and one by two specimens, suggesting they were either uncommon in the habitat or none of the methods employed were effective for collecting them. We therefore suggest that, while pan traps exhibited low similarity with other trap types, they are generally ineffective for collecting carabids when not placed flush with the ground like pitfall traps.

Species accumulation curves for pitfall, Malaise, and purple Lindgren funnel traps did not become asymptotic after 268, 95, and 82 2-wk samples, respectively, and extrapolated rarefaction curves for all three trap types did not become asymptotic after 1,000 samples. This indicated that significantly more trapping effort is needed in order to inventory all species at the site. Additionally, the extrapolated rarefaction curves suggest Malaise traps may collect more species than pitfall traps after approximately 500 samples.

Most species collected in large numbers were active during at least two seasons and only four species—Amara musculis (Say), Calathus opacus LeConte, Calleida viridipennis (Say), Cicindela sexguttata Fab.—were found during a single season. Of these, Cicindela sexguttata and Calleida viridipennis were found during the spring and early summer, respectively, when they are known to be most active (Zhou et al. 1993; Pearson et al. 2006). Amara musculis and Calathus opacus, however, are reported to be active outside the periods they were collected (Ciegler 2000).

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### Fig. 31a
**Curculionidae**

- Lechirops oculatus
- Conotrachelus elegans
- Pseudobaris nigrina
- Conotrachelus aratus
- Eubulus bisignatus
- Anthonomus suturalis
- Eubulus obliquefasciatus
- Cercopoeus chrysorrhoeus
- Aptermecus ferratus
- Dichoxenus setiger
- Conotrachelus naso
- Pseudopentarthis simplex
- Dryophthorbus americanus
- Oopeterus perforatus
- Conotrachelus analgpticus
- Cophes fallax
- Cryptorhynchus tristis
- Euiroptus sp. 1
- Cyrtipostomen castaneus
- Otioryynchus rugosostriatus
- Canistes schusteri
- Pandeletius hilaris
- Epacates Infatus
- Conotrachelus carinifer
- Conotrachelus posticatus

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**Fig. 31.** Phenology of curculionoids collected during this study summed across all trap types. (a) Curculionidae with more than five specimens collected in at least one collecting period. (b) Curculionidae with five or fewer specimens collected in any collection period but found in at least four collection periods. (c) Curculionidae with five or fewer specimens collected in any collection period and found in three or fewer collection periods. (d) Anthribidae. (e) Attelabidae. (f) Brachyceridae. (g) Brentidae.
Most species collected in low numbers were taken during the summer, with one species collected only in the spring and four species collected only in the fall.

*Rhadine ozarkensis* Sanderson and Miller is likely the only species that is truly rare, as it is known only from the type series, which was collected from the twilight and dark zone of Fincher’s Cave in adjacent Washington County (Sanderson and Miller 1941; P. Messer personal communication). Other species that were collected in low numbers were likely either uncommon transients in the surveyed habitat or were present in the habitat but not readily collected by the methods employed.

Although the most abundant species were generally present throughout the warm months, we suggest traps be continuously employed rather than during a single season because species compositions varied somewhat between seasons and species abundances varied markedly. If traps cannot be used continuously, then representative samples should be taken during each season.

**Cerambycidae**

Cerambycidae have been collected using a variety of methods, including active methods such as beat-sheeting and sweeping of vegetation (Yanega 1996) and passive methods such as light trapping (Yanega 1996), rearing traps (Yanega 1996; Ferro et al. 2009; Ferro and Carlton 2011), pan traps (de Groot and Nott 2001), Malaise and canopy traps traps (Vance et al. 2003; Noguera et al. 2007; Dodds et al. 2010), clear window traps (Ulyshen and Hanula 2007; Bouget et al. 2009; Sama et al. 2011) and silhouette intercept traps such as Lindgren funnel and panel traps (Dodds et al. 2010; Miller and Crowe 2011). Of the trap types included in this study, Malaise
Vernal Aestival Autumnal

| Species                  | 13 March | 1 April | 2 April | 5 April | 10 May | 17 May | 22 June | 28 June | 7 July | 13 August | 20 August | 25 September | 2 October | 9 November | 16 November |
|--------------------------|----------|---------|---------|---------|--------|--------|--------|--------|--------|-----------|-----------|---------------|-----------|-------------|-------------|
| Sitona lineatus          |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |
| Auleutes nebulosus       |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |
| Tychius prolixus         |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |
| Tomolips quercicola      |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |
| Hypera compta            |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |
| Acoptus suturalis        |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |
| Tyloderma foveolatum     |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |
| Madarellus undulatus     |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |
| Dietzella zimmermanni    |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |
| Nicentrus lecontei       |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |
| Magdalis barbita         |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |
| Anthonomus nigrinus      |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |
| Anthonomus rufipennis    |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |
| Tachyerges niger         |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |
| Magdalis armicollis      |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |
| Laemosaccus nephele      |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |
| Cophes obtentus          |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |
| Idiostethus subcalvus    |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |
| Mecinus pascuorum        |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |
| Buchananius sulcatus     |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |
| Stenoscelis brevis       |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |
| Craponius inaequalis     |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |
| Rhinoneus percariopius    |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |
| Caudophilus dubius       |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |
| Myrmex myrmex            |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |
| Plocamus hispidulus      |          |         |         |         |        |        |        |        |        |           |           |               |           |             |             |

**Fig 31.** Continued.

and canopy traps collected the highest number of species and had significant similarity. This is useful for vertical stratification studies (Vance et al. 2003) as they do not collect different assemblages so are comparable. However, when conducting faunal surveys it would be more efficient to choose a complimentary trap rather than include both Malaise and canopy traps.

Lindgren funnel traps were estimated to collect approximately the same number of species after 600 samples and exhibited high to very high similarity in the species collected with Malaise and upper canopy traps and between differently colored Lindgren funnel traps. Trap color did not generally affect the response of species to the traps as only one of the nine species analyzed, *Xylotrechus colonus*, was attracted in significantly higher numbers to one color (black) over another (green). Only a few studies have examined the role of color in attraction and trapping of cerambycids: Shipman (2011) and Skvarla and Holland (2011) found that when analyzed at the family level, longhorns are preferentially attracted to red and purple, respectively, though neither study included a large diversity of color choices and Sakalian et al. (1993) and Imrei et al. (2014) found that individual species are attracted to yellow. Other studies (Macias-Samano n.d.) found no effect of color when trapping cerambycids. It is likely that color attraction is species-specific and tied to biological traits, such as flower feeding and host-finding. Our data suggest that many cerambycids were attracted to the vertical silhouette of the
trap regardless of the color used. Additionally, all but two species—*Molorchus bimaculatus* Say and *Stenosphenus notatus* (Oliver), both of which were collected in the spring—were collected in similar or higher numbers in Malaise and/or upper canopy trap collectors, so we suggest that unbaited Lindgren funnels should generally not be considered if Malaise or canopy traps are also used.

Species accumulation curves for Malaise, upper canopy, and black, green, and purple Lindgren funnel traps did not become asymptotic after 95, 72, 85, 85, and 82 samples, respectively, and extrapolated rarefaction curves for the five trap types became asymptotic after approximately 400, 500, 500, 350, and 200 samples, respectively. This indicated that significantly more trapping effort is needed in order to inventory all species at the site.

Of the 20 species collected in high enough abundance to examine phenology, 4 reached peak densities in the spring and 16 reached peak densities during the late spring to mid-summer. Species that were found in more than three collection periods but not in high numbers exhibited a similar pattern, with 3 of 12 species being present only in the spring and 9 of 12 species being present from late spring through summer. Of the rarely collected species found in low numbers during three or fewer collection periods, approximately half were found in the spring and half during the summer; only two
species—*Hyperplatys maculata* Blatchley and *Oncideres cingulata* (Say)—were found only in the fall. While there were a few cerambycids that can be collected during the fall and a few that may be collected in the early spring, the most efficient collection effort was from the late spring through mid- to late summer when most species reach their peak populations.

### Curculionoidea

Weevils are a diverse group of beetles and no one method is commonly used to collect their diversity (Table 6). The most effective combination of traps should target both aerial and terrestrial species. Of the traps included in this study, Malaise and upper canopy collected the most aerial species on an average; however, when extrapolating to 1,000 samples, Malaise traps were estimated to collect the most species for the first 250 samples and green Lindgren funnels were estimated to collect the most species after 250 samples. Depending on the number of samples to be collected, either trap would be an acceptable choice for collecting flying weevils.

Pitfall traps and Berlese–Tullgren extraction collected the most terrestrial species on an average and did not differ significantly with respect to the numbers collected. However, Berlese–Tullgren extraction is estimated to collect 20 addition species after 1,000 samples. Depending on the facilities available, either method would be acceptable when targeting terrestrial weevils.

Purple and white pan traps also collected high numbers of species, but exhibited high similarity with Malaise, canopy, and pitfall traps and Berlese sampling in the species collected, which suggests pan traps were collecting both aerial and terrestrial species. Because pan traps were set under Malaise traps in this study, it is unknown whether pan traps set alone would be as effective as was suggested by these results. However, the addition of pan traps should be considered if Malaise traps are also being employed.

The attractiveness of various colors to different weevils has been previously investigated, almost exclusively in relation to pestiferous species in agricultural settings (Roach et al. 1972; Leggett and Cross 1978; Riley and Schuster 1994; Smart et al. 1997; Leskey 2006; Reddy and Raman 2011; Abugaula and Al-Deeb 2012). In this study, 10 of the 14 weevil species analyzed were collected in significantly higher numbers by at least one color of Lindgren funnel trap: one species was most attracted to black traps, three were most attracted to green traps, four were most attracted to purple traps, and one was attracted to both green and purple traps. Three of the four species in which no difference was detected were collected in higher abundance in Malaise traps; these species were likely flying around in abundance and happened to be collected in funnel traps.

The weevils collected exhibited a diversity of activity periods. Some species were most abundant during one or two seasons (e.g., *Apteromechus ferratus* (Say), *Conotrachelus Aratus* (Germar), *Cercoepus chrysorhoeus* (Say)) but were collected in low numbers throughout the year; others exhibited a bimodal distribution in abundance (e.g., *Conotrachelus nason* LeConte, *C. posticatus* Boheman) or were present during only one season (e.g., *Eubulus bisignatus* (Say), *Anthonomus suturalis* LeConte). More than half (51%) of species represented by one or a few specimens were collected in the spring, while only 17% of such species were collected in the summer or more than one season and 14% were collected only in the fall; additionally, only 16 of the 71 species collected (22%) were not collected at all during the spring.

The number of species collected peaked in the spring and declined thereafter. A small percentage of species were present only in the summer or fall, and those were collected in low numbers that are not indicative of phenology. Additionally, only a few species were most abundant in the summer and fall and a majority of these were also present during the spring. Thus, if collections are limited, spring is the most effective time to sample.

### Conclusions

The combination of pitfall and Malaise traps most efficiently sampled Carabidae, Cerambycidae, and Curculionoidea. Pitfall traps collected terrestrial carabids and curculionoids and Malaise traps collected cerambycids and the aerial assemblage of carabids and curculionoids. Large buprestids were collected by Malaise traps, but the smaller species (e.g., *Agrilus*) were most effectively green Lindgren funnel traps.

Pan traps were generally ineffective at collecting aerial, wood-boring groups (Buprestidae, Cerambycidae). When targeting terrestrial species, pan traps act as pitfall traps (Skvarla et al. 2014). However, the pan traps in this study were not sunk into the ground and flush with the surface as the pitfall traps were, so their effectiveness at collecting curricular species may have been diminished.

The color of Lindgren funnel traps was an important factor for many species of Buprestidae and Curculionidae, but not Carabidae or most species of Cerambycidae. The effect of color in trapping different taxa is understudied and studies that examine the attraction of color to pest species may not apply to the genus or family more generally (e.g., applying studies that targeted emerald ash borer (A. *planiennis*) to *Agrilus* or Buprestidae more generally).

Most taxa exhibited seasonality, with the highest number of species in all families present in the spring or early summer, although a minority of species were present only during the summer or fall. When targeting these the taxa included herein, the most effort should be made during the spring and early summer with supplemental collections made during mid- to late-summer and fall.

Finally, none of the accumulation curves for the three most effective collection methods per family became asymptotic after 85 (green Lindgren funnel), 95 (Malaise trap), or 268 (pitfall trap) samples. Extrapolated rarefaction curves were not estimated to become

### Table 6. Select references pertaining to trapping Curculionidae

| Trap type                | Select references                                      |
|-------------------------|--------------------------------------------------------|
| Malaise trap            | Dutcher et al. (1986); Anderson (2008a); Ohsawa (2008); Hespenheide (2009) |
| Pan trap                | Setyo Leksono (2005)                                   |
| Pitfall trap            | Raffa and Hunt (1988); Levesque and Levesque (1994); Hanula (1990) |
| Berlese extraction      | Boland and Room (1983); Sakchoowong et al. (2007)      |
| Lindgren funnel trap    | Anderson (2008b); Hanula et al. (2011); Brar et al. (2012); Nam et al. (2013); Rassati et al. (2014) |
| Window trap             | Levesque and Levesque (1994); Anderson (2008a); Anderson (2008b) |
asymptotic until 350 to more than 1,000 samples, depending on the trap and target taxon. This suggested that much more effort is needed when collecting beetles as the rarest species are often those that tell the most about biodiversity.

**Supplementary Data**

Supplementary data are available at Journal of Insect Science online.

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