Journal of Insect Science (*2017*) 17(1); 7: 1–28
doi: 10.1093/jisesa/iew098
Research article

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

Michael J. Skvarla,[1,2] and Ashley P. G. Dowling[1]

[1]Department of Entomology, 319 Agriculture Bldg., University of Arkansas, Fayetteville, AR 72701, USA (mskvarla36@gmail.com; adowling@uark.edu), and [2]Corresponding author, e-mail: mskvarla36@gmail.com

Subject Editor: Ted MacRae

Received 10 July 2016; Accepted 18 October 2016

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 reported 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 so 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

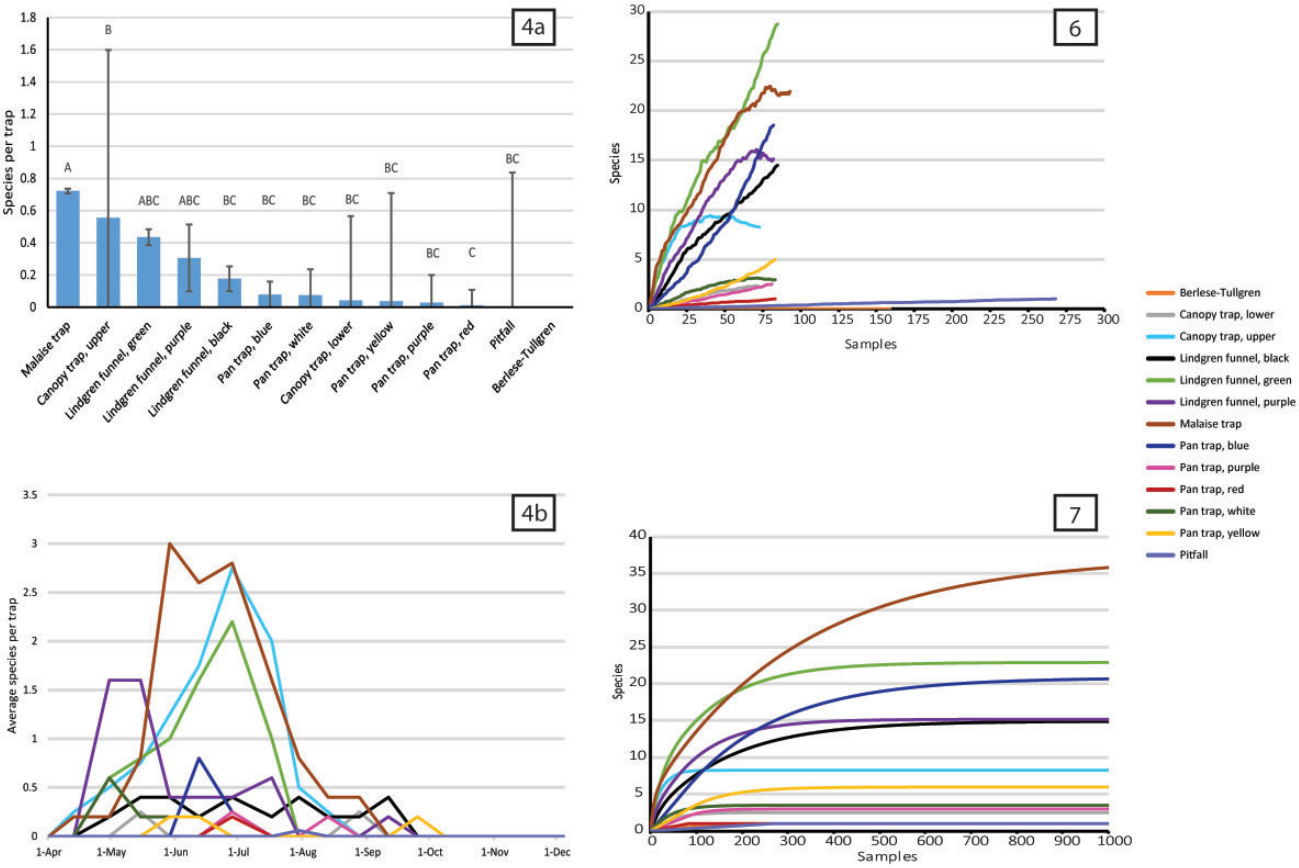
Figs. 1–3. Examples of traps used. (1) Malaise trap with pan traps underneath acting as intercept traps and a S.L.A.M. canopy trap. (2) Black Lindgren funnel trap. (3) Pitfall set. The canopy trap and Lindgren funnel trap were lowered from the canopy for the photographs.

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 2015b). 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 2015b).

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



Figs. 4, 6, 7. Average number of buprestid speciescollected per trap. The legend applies to Figs. 4b, 6, and 7. (4a) Average number of species/trap. Bars indicate 1 SD; letters indicate mean separation as determined by Tukey–Kramer test. (4b) Average number of species/trap/date. (6) Chao 1 rarefaction curves based on the data. (7) Estimated rarefaction curves (S(est)) extrapolated to 1000 samples.

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 ($\alpha = 0.05$) 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 ($\alpha = 0.05$) 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 isviolated (Kirk 1995; Samuels and Witmer 2003) and easily performed within Excel.

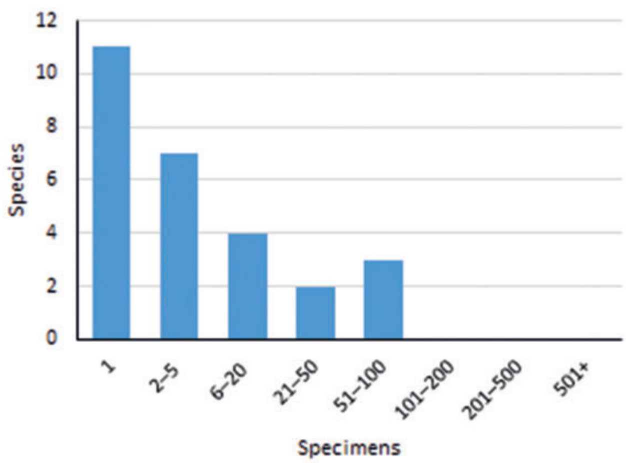


Fig 5. Total number of buprestid specimens per species collected across all traps.

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

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	ANOVA					Tukey–Kramer			
		df	ss	*F*	*P* value	Trap color	Mean	SD	Seperation of means
Agrilus bilineatus	Between groups	2	2.11	1.38	0.283	Black	1.17	1	–
	Within groups	15	11.5			Green	0.67	1	–
	Total	17	13.61			Purple	0.33	0.5	–
Agrilus cephalicus	Between groups	2	3,735	19.29	<0.001*	Black	0	0	b
	Within groups	9	8.75			Green	3.75	1.7	a
	Total	11	46.25			Purple	0	0	b
Agrilus lecontei	Between groups	2	3.56	16	0.004*	Black	0	0	b
	Within groups	6	0.67			Green	1.33	0.6	a
	Total	8	4.22			Purple	0	0	b
Agrilus obsolettoguttatus	Between groups	2	20.17	7.12	0.014*	Black	0	0	b
	Within groups	9	12.75			Green	2.75	2.1	a
	Total	11	32.92			Purple	0	0	b
Dicerca lurida	Between groups	2	13.5	4.26	0.007*	Black	0	0	b
	Within groups	9	6.75			Green	0	0	b
	Total	11	20.25			Purple	2.25	1.5	a
Dicerca obscura	Between groups	2	2.17	13	0.002*	Black	1	0	a
	Within groups	9	0.75			Green	0	0	b
	Total	11	2.92			Purple	0.25	0.5	b
Ptosima gibbicollis	Between groups	2	2.89	6.5	0.031*	Black	0	0	b
	Within groups	6	1.33			Green	1.33	0.6	a
	Total	8	4.22			Purple	0.33	0.6	a,b

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

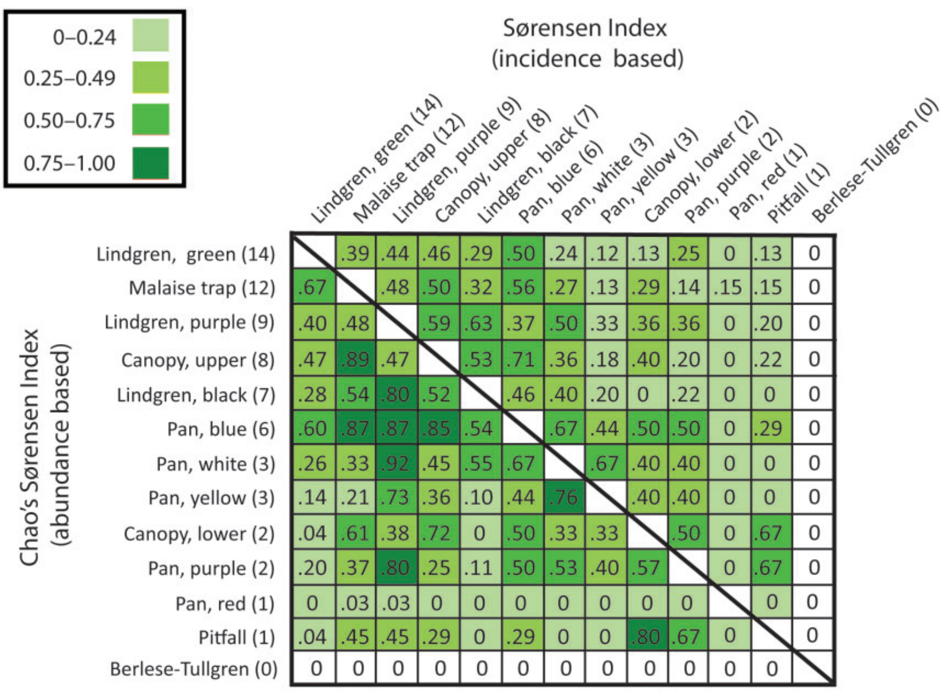


Fig 8. Similarity of trap catch as determined by Sørensen and Chao's Sørensen Indices. Number of species collected per trap type is indicated parenthetically after each trap type.

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

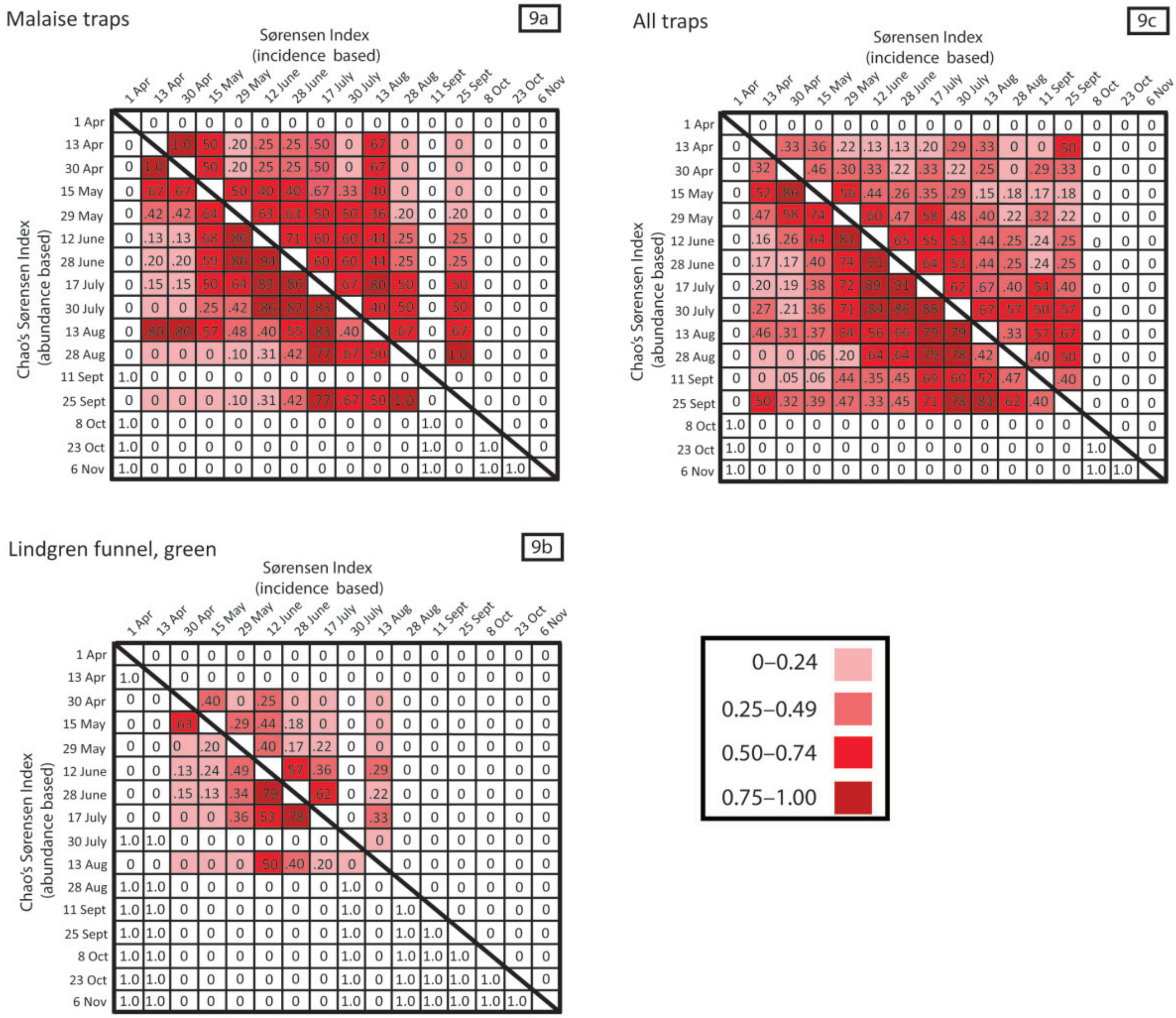


Fig 9. Sørensen and Chao's Sørensen Indices comparing similarity of trap catch by date in Malaise and green Lindgren funnel traps and all trap catch combined.

EstimateS. 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;

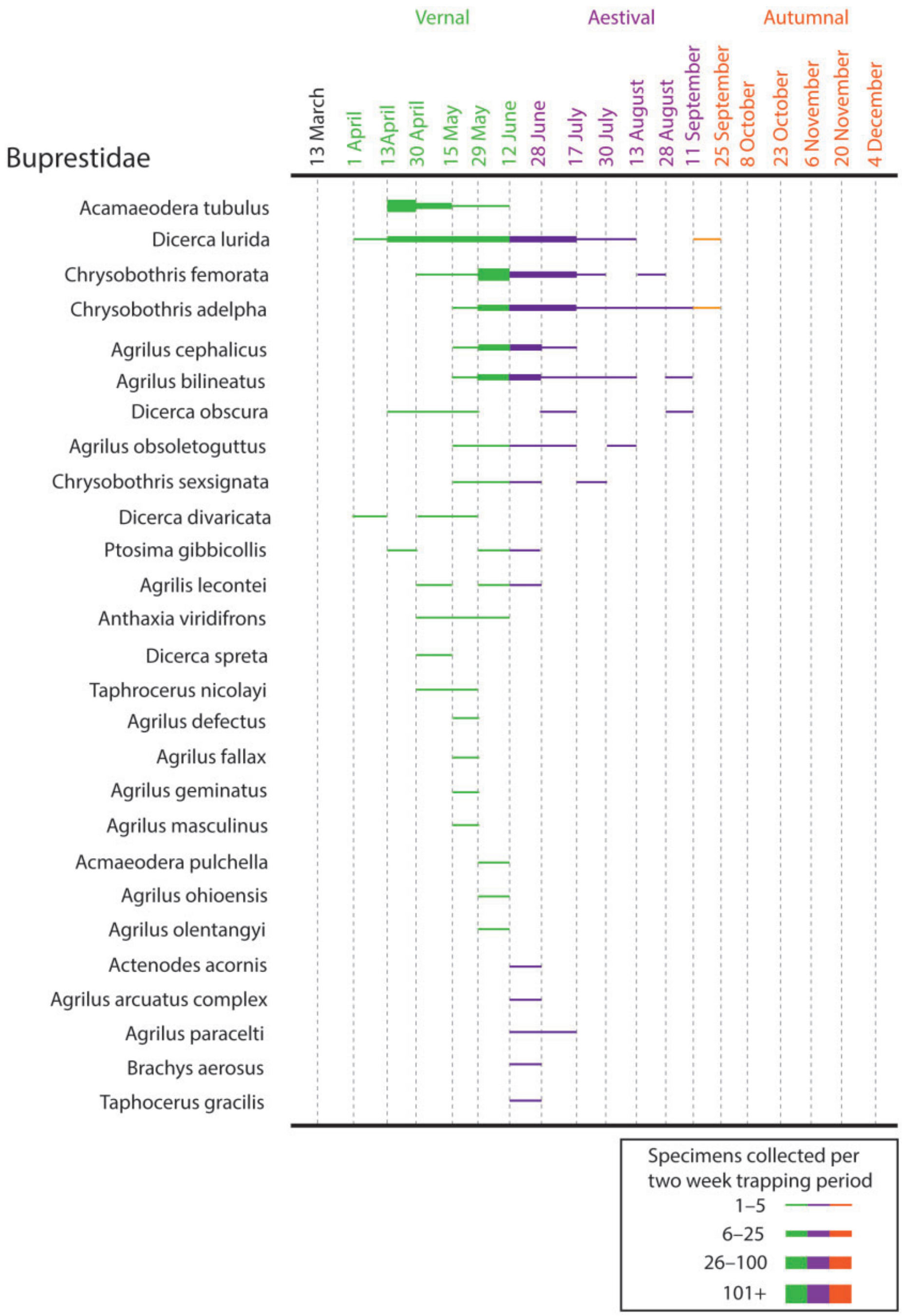
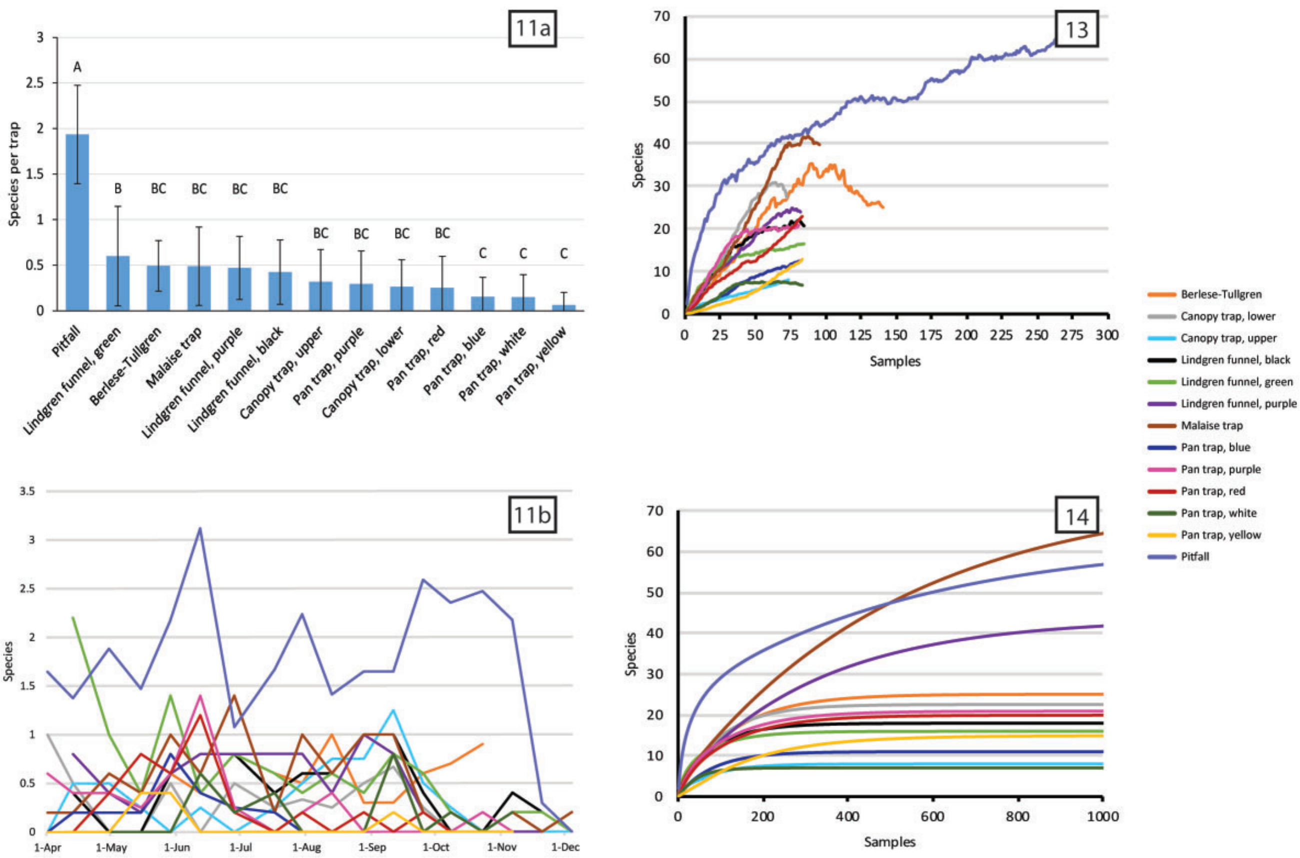


Fig 10. Phenology of buprestids collected during this study summed across all trap types.

$P < 0.0001$). 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



Figs. 11, 13, 14. Average number of carabid species collected per trap. The legend applies to Figs. 11b, 13, and 14. (11a) Average number of species/trap. Bars indicate 1 SD; letters indicate mean separation as determined by Tukey–Kramer test. (11b) Average number of species/trap/date. (13) Chao 1 rarefaction curves based on the data. (14) Estimated rarefaction curves (S(est)) extrapolated to 1000 samples.

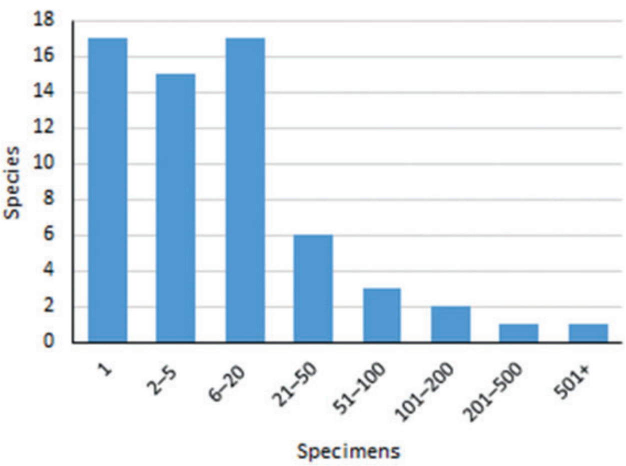


Fig 12. Total number of carabid specimens per species collected across all traps.

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 ($M = 1.84$, $SD = 0.66$) was significantly different

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	Seperation 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	6.53	–
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 as 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	Between groups	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	Between groups	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	Between groups	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	Between groups	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	Between groups	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	Between groups	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	Between groups	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	Between groups	2	3.56	2.72	0.106	Black	1.67	2.08	–
	Within groups	6	10			Green	0.33	0.58	–
	Total	8	13.56			Purple	0.33	0.58	–
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	Between groups	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 as asterisk (*).

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 ($M = 0.47$,

Table 4. Results of ANOVA tests comparing the effect of color on the number of specimens of different species of Curculionoidea collected in Lindgren funnel traps

Species	ANOVA					Tukey–Kramer			
		df	ss	*F*	*P* value	Trap color	Mean	SD	Seperation 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 sutralis	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	51.33			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	b
	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				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	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 as 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).

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 (Sørensen = 0.47, Chao's Sørensen = 0.82) with Berlese–Tullgren sampling (Fig. 15). Lindgren funnel, Malaise, and canopy traps exhibited medium to very high similarity (Sørensen = 0.26–0.70, Chao's Sørensen = 0.49–0.94) with each other, but, with a single exception, low to medium similarity (Sørensen = 0.13–0.32, Chao's Sørensen = 0.1–0.15) with pitfall traps. Blue, purple, red, and yellow pan traps exhibited high to very high similarity with each other (Sørensen = 0.50–0.73, Chao's Sørensen = 0.60–0.90), but low to medium similarity with white pan traps (Sørensen = 0–0.35, Chao's Sørensen = 0–0.22). Purple and white pan traps generally exhibited

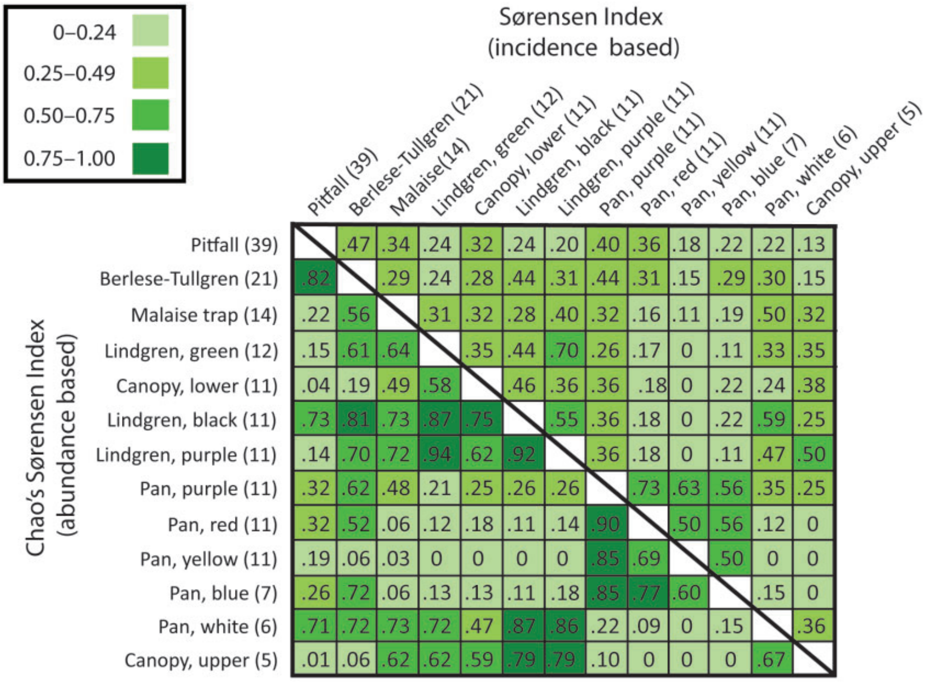


Fig 15. Similarity of trap catch as determined by Sørensen and Chao's Sørensen Indices. Number of species collected per trap type is indicated parenthetically after each trap type.

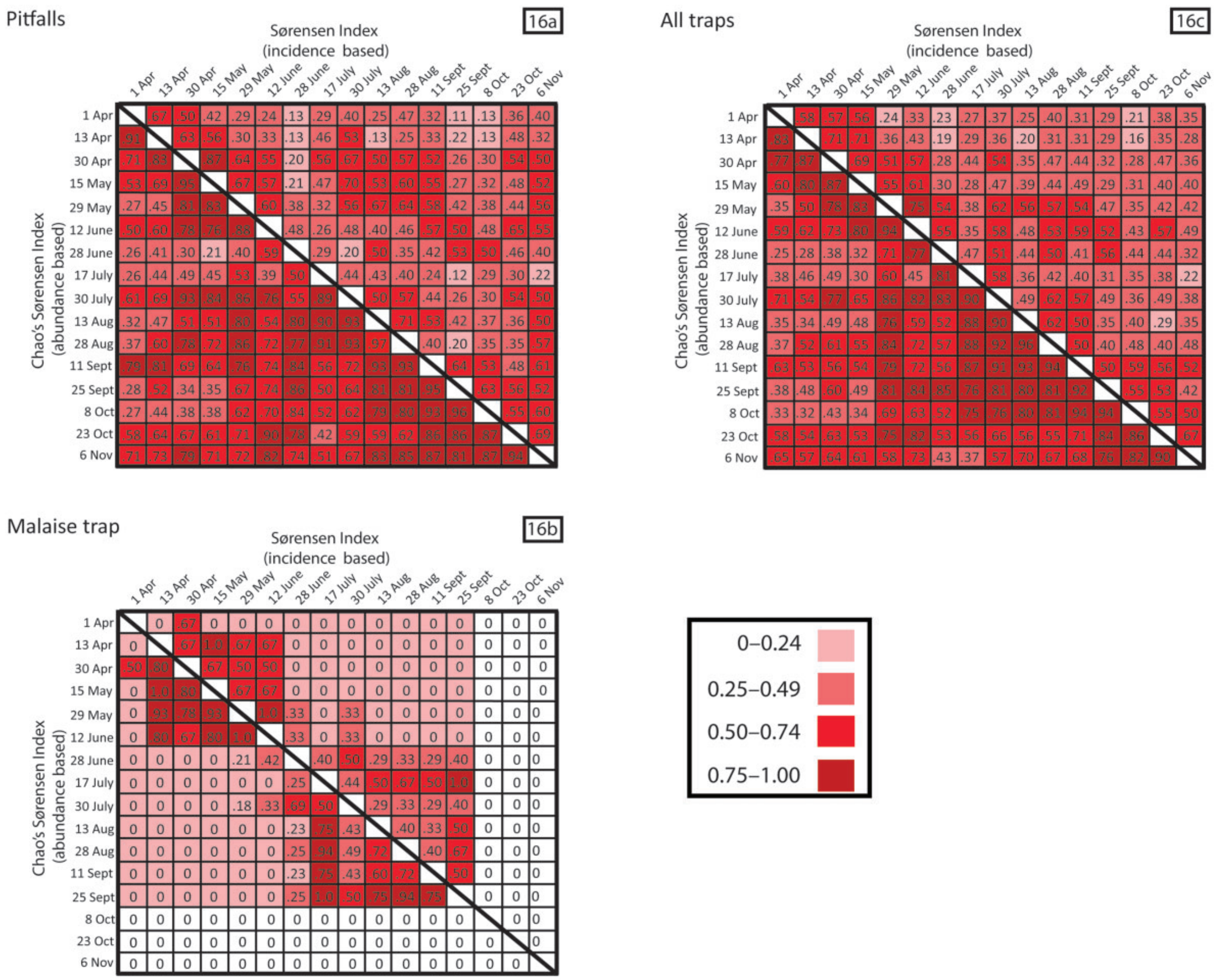


Fig 16. Sørensen and Chao's Sørensen Indices comparing similarity of trap catch by date in Malaise and green Lindgren funnel traps and all trap catch combined.

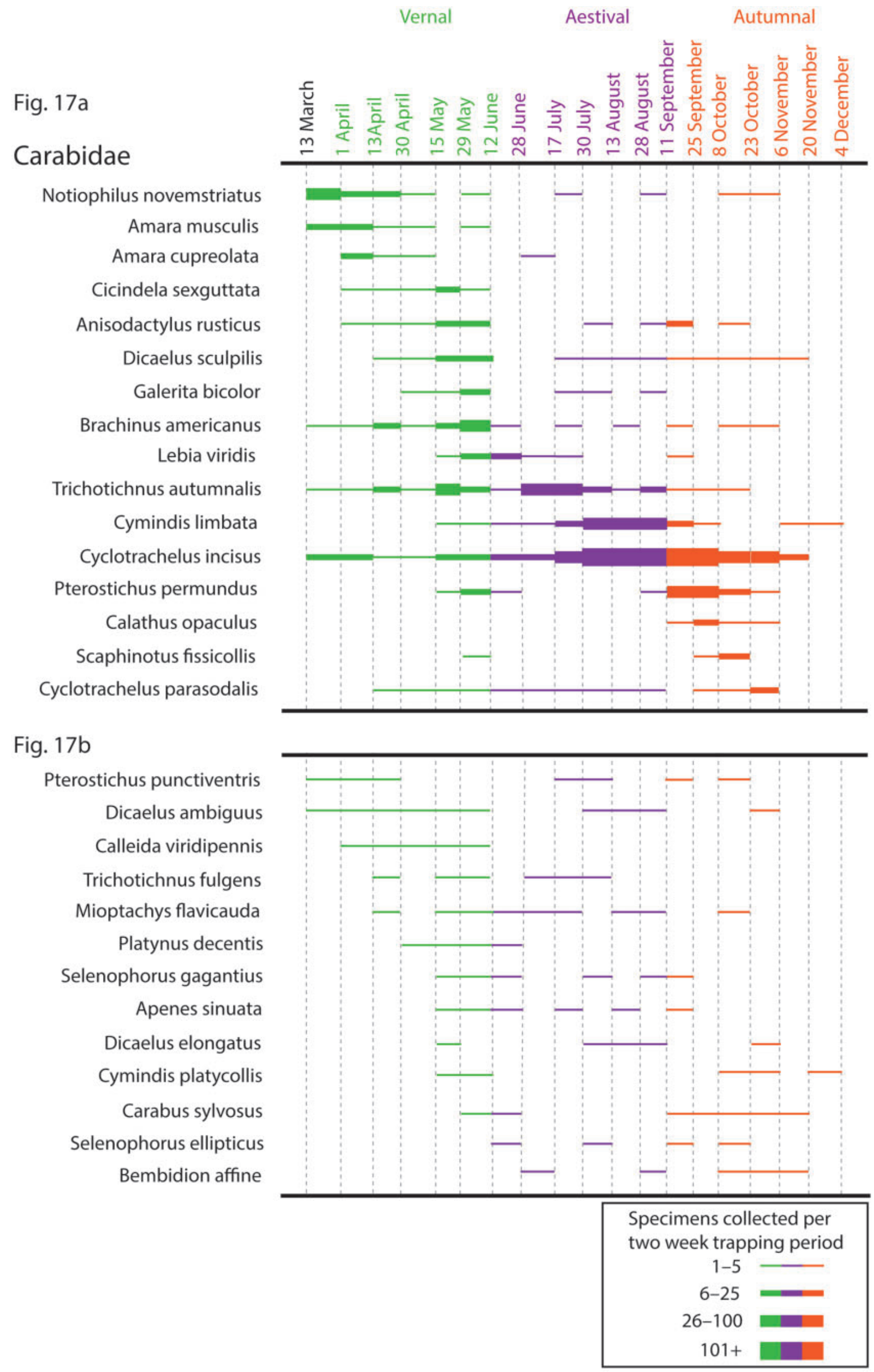


Fig 17. Phenology of carabids collected during this study summed across all trap types. (17a) Species with more than five specimens collected in at least one collecting period. (17b) Species with five or fewer specimens collected in any collection period but found in at least four collection periods. (17c) Species with five or fewer specimens collected in any collection period and found in three or fewer collection periods.

medium to very high similarity with nonpan traps (Sørensen = 0.26–0.59, Chao's Sørensen = 0.25–0.86), while yellow pan traps exhibited the lowest similarity with nonpan traps (Sørensen = 0–0.18, Chao's Sørensen = 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).

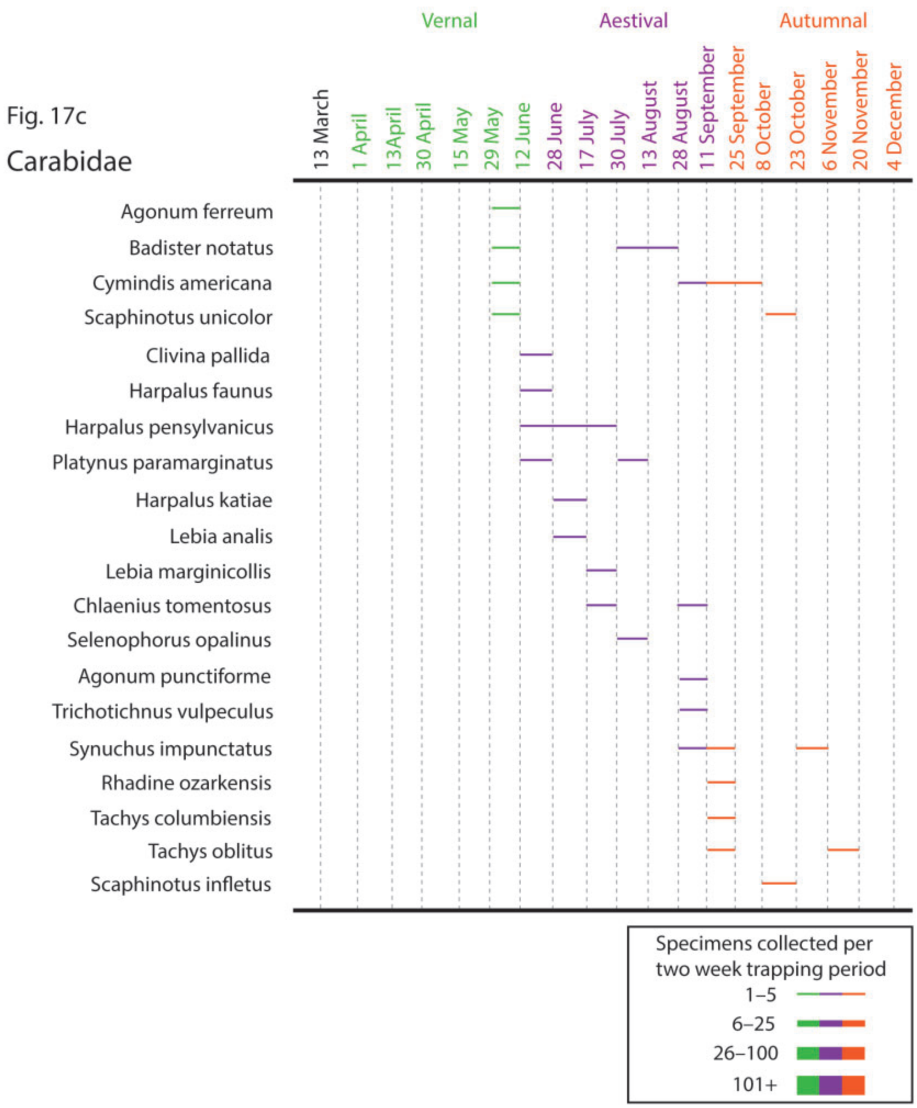


Fig 17. Continued.

When all traps were combined, the similarity between dates was similar to that exhibited by pitfall traps (Fig. 16c).

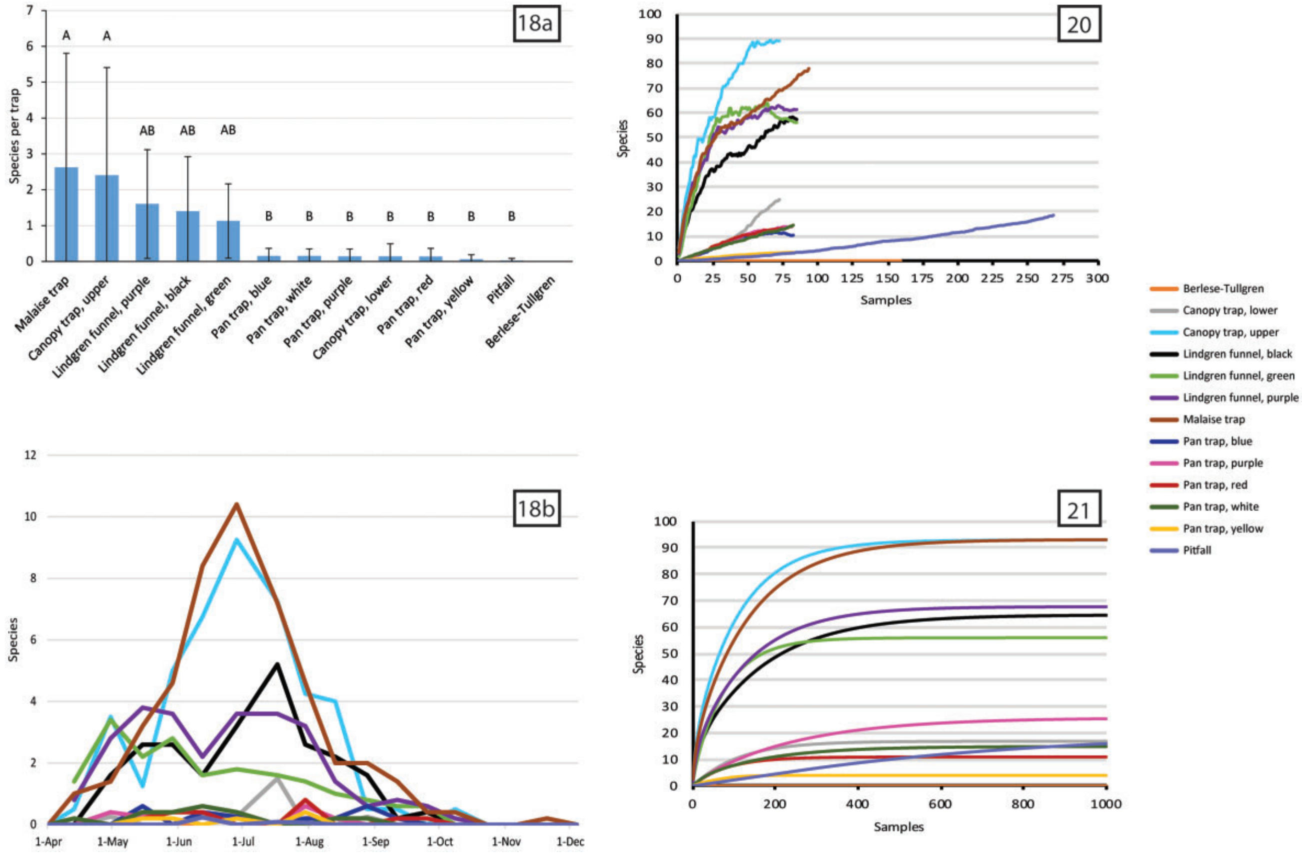
About 6 of the 27 species (22%) were collected in sufficient numbers to examine species-level phenology, while another 6 were collected over multiple dates but in low numbers that did not allow any interpretation of phenology; 15 of the species collected (55%) were found in low numbers during only a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



Figs. 18, 20, 21. Average number of cerambycid species collected per trap. The legend applies to Figs. 18b, 20, and 21. (18a) Average number of species/trap. Bars indicate 1 SD; letters indicate mean separation as determined by Tukey–Kramer test. (18b) Average number of species/trap/date. (20) Chao 1 rarefaction curves based on the data. (21) Estimated rarefaction curves (S(est)) extrapolated to 1000 samples.

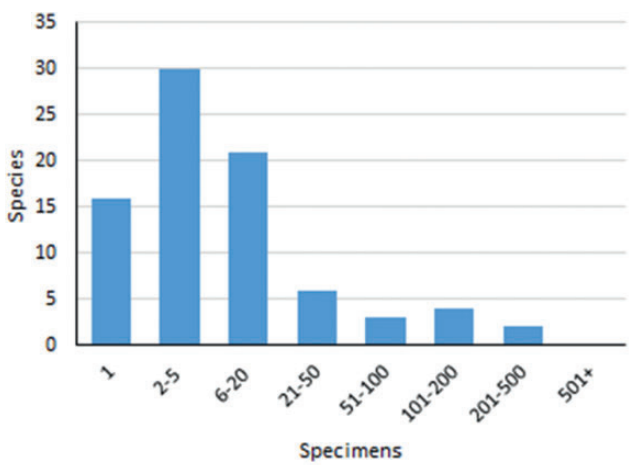


Fig 19. Total number of cerambycid specimens per species collected across all traps.

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 ($P > 0.05$,

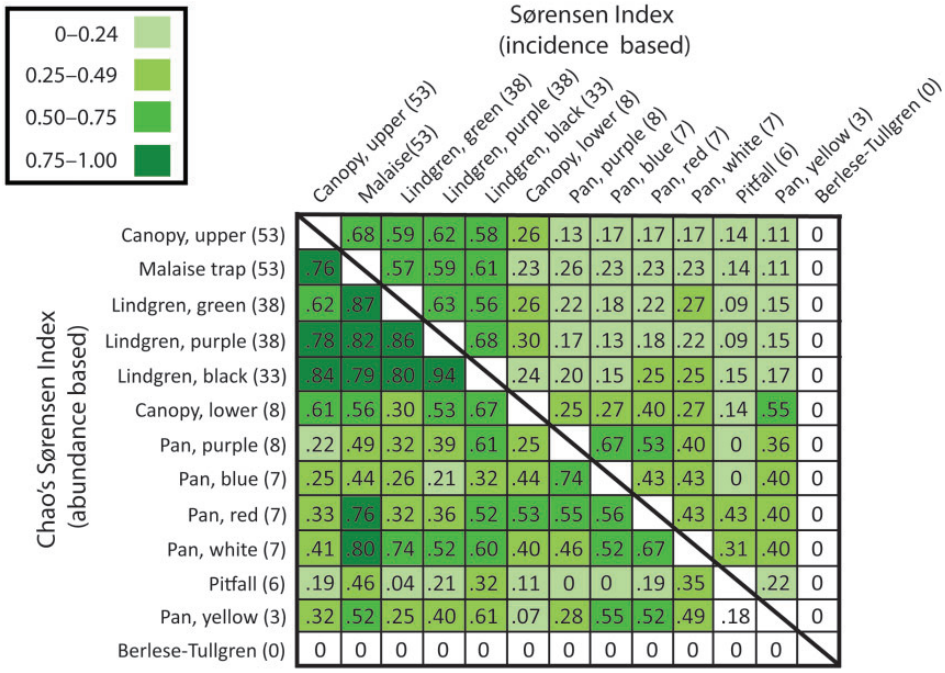


Fig 22. Similarity of trap catch as determined by Sørensen and Chao's Sørensen Indices. Number of species collected per trap type is indicated parenthetically after each trap type.

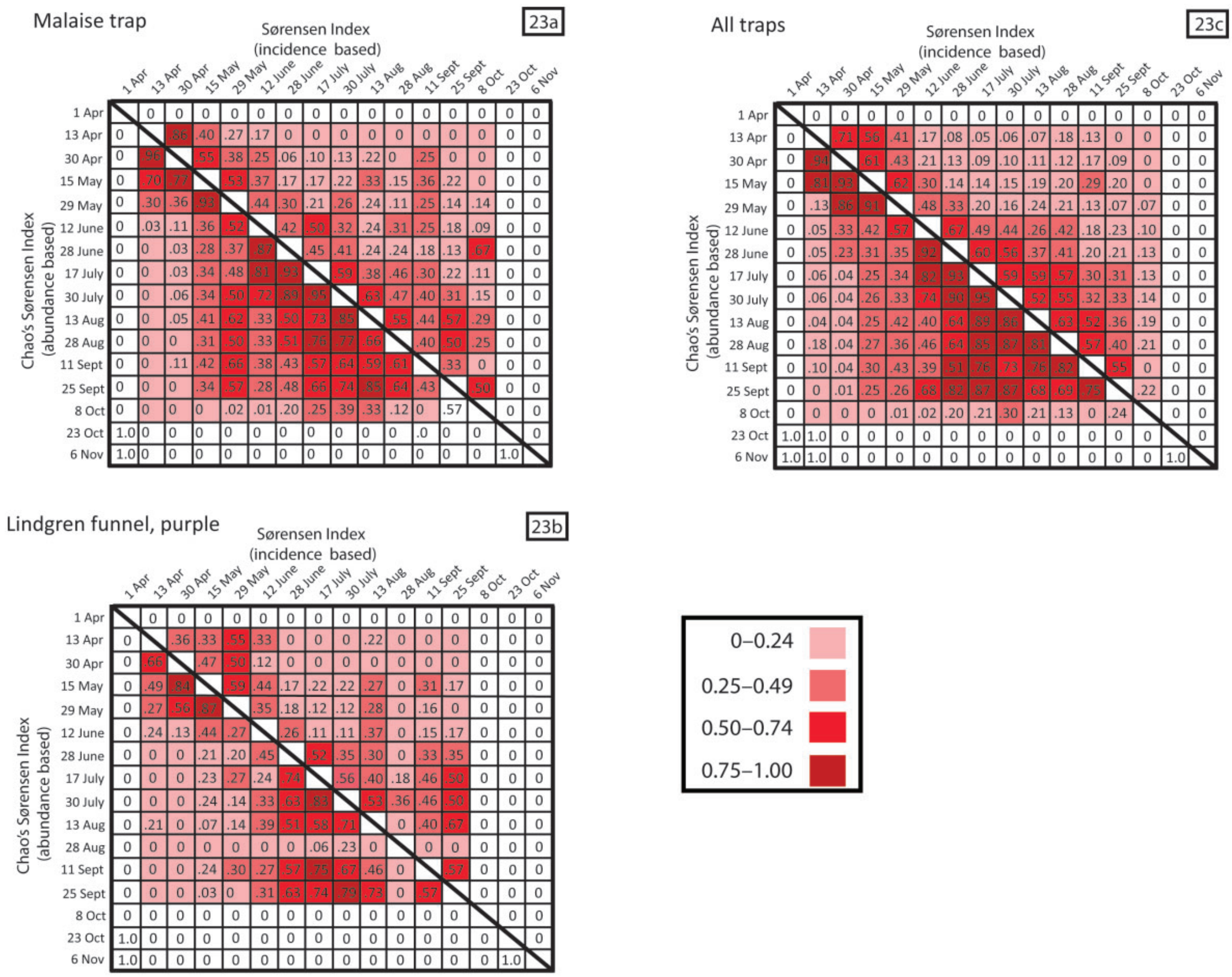


Fig 23. Sørensen and Chao's Sørensen Indices comparing similarity of trap catch by date in Malaise and green Lindgren funnel traps and all trap catch combined.

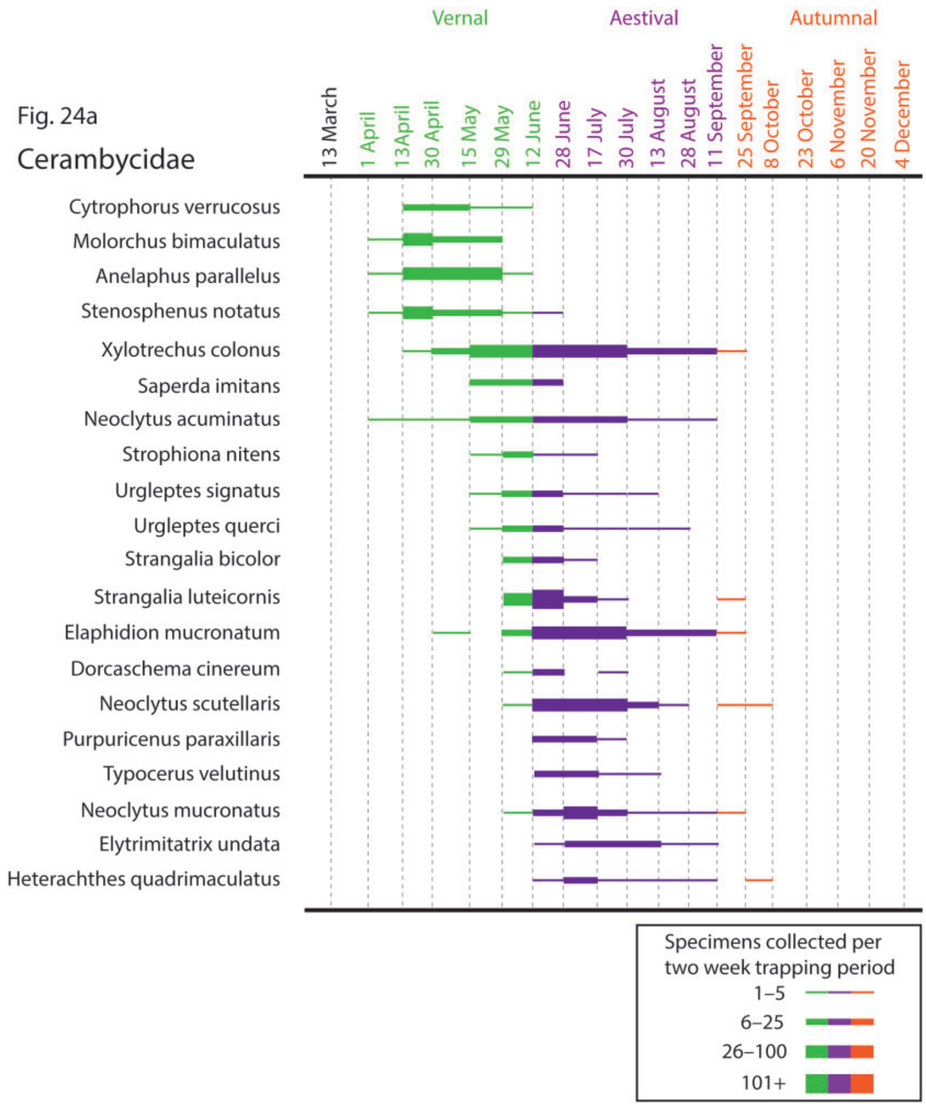


Fig 24. Phenology of cerambycids collected during this study summed across all trap types. (24a) Species with more than five specimens collected in at least one collecting period. (24b) Species with five or fewer specimens collected in any collection period but found in at least four collection periods. (24c) Species with five or fewer specimens collected in any collection period and found in three or fewer collection periods.

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

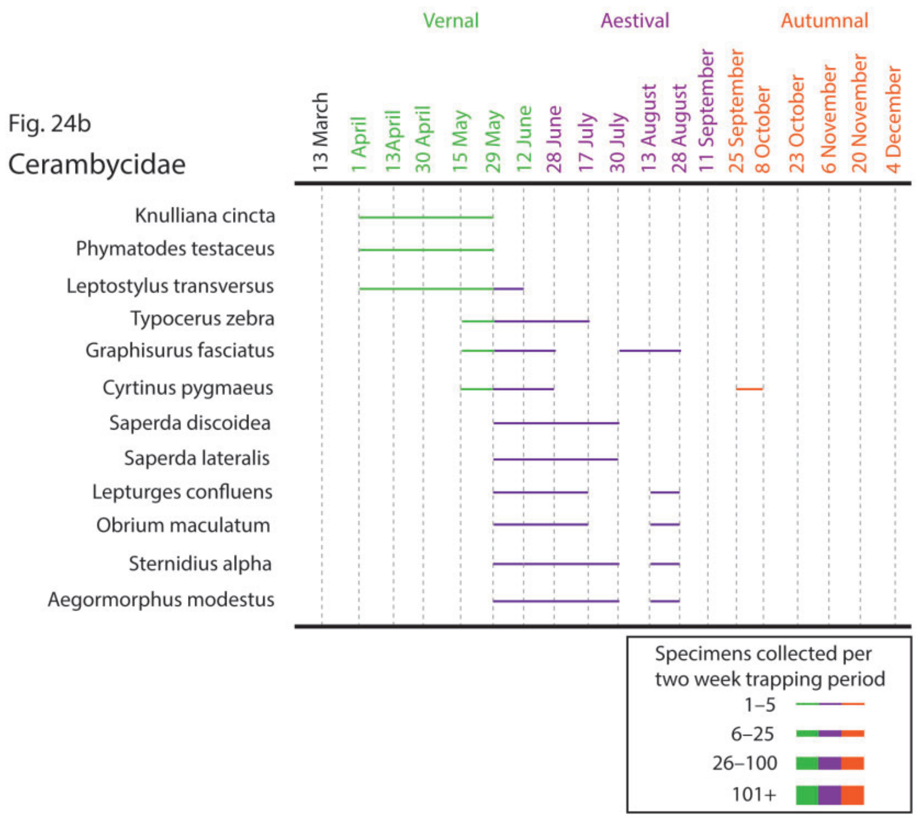


Fig 24. Continued.

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 (~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.

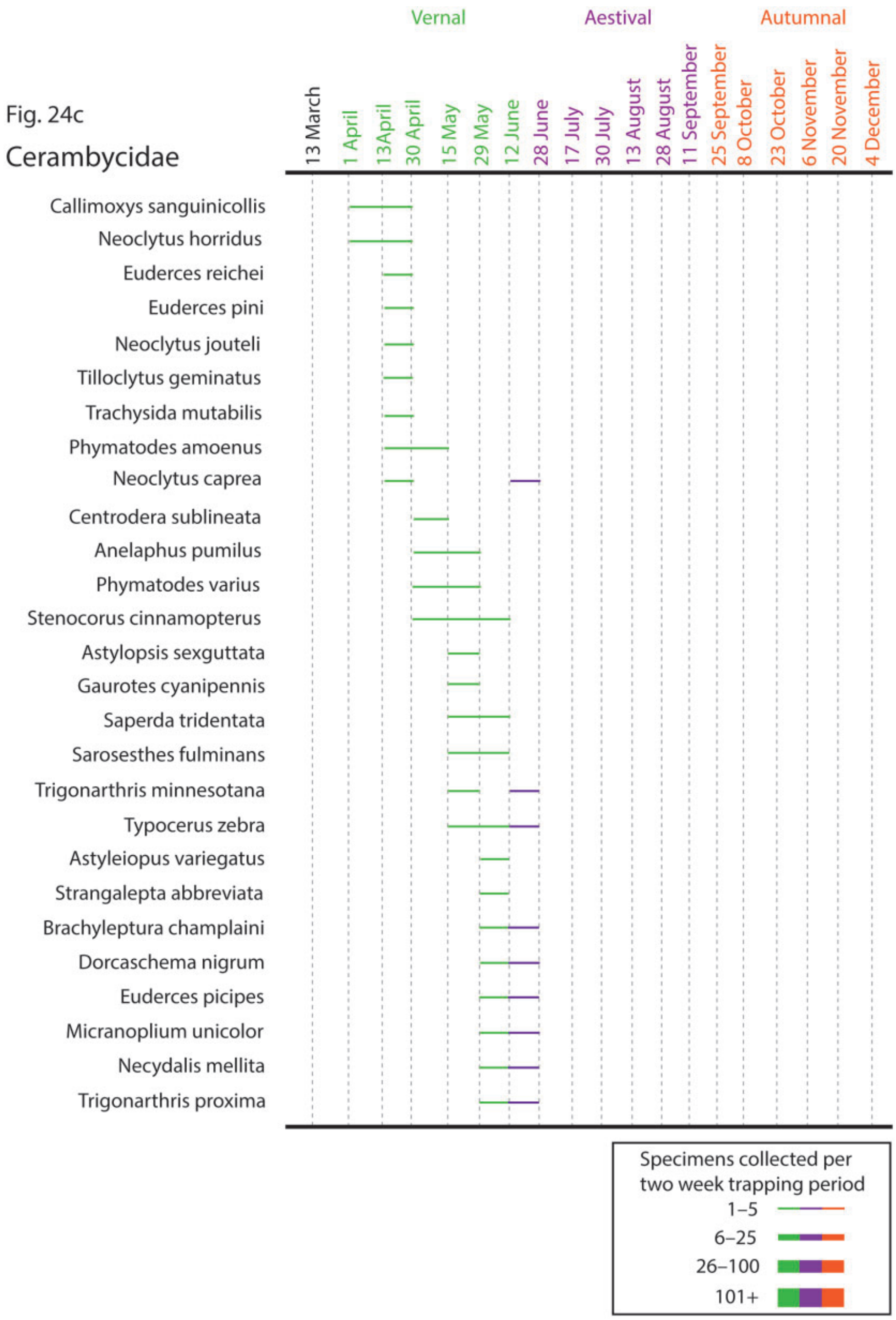


Fig 24. Continued.

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.

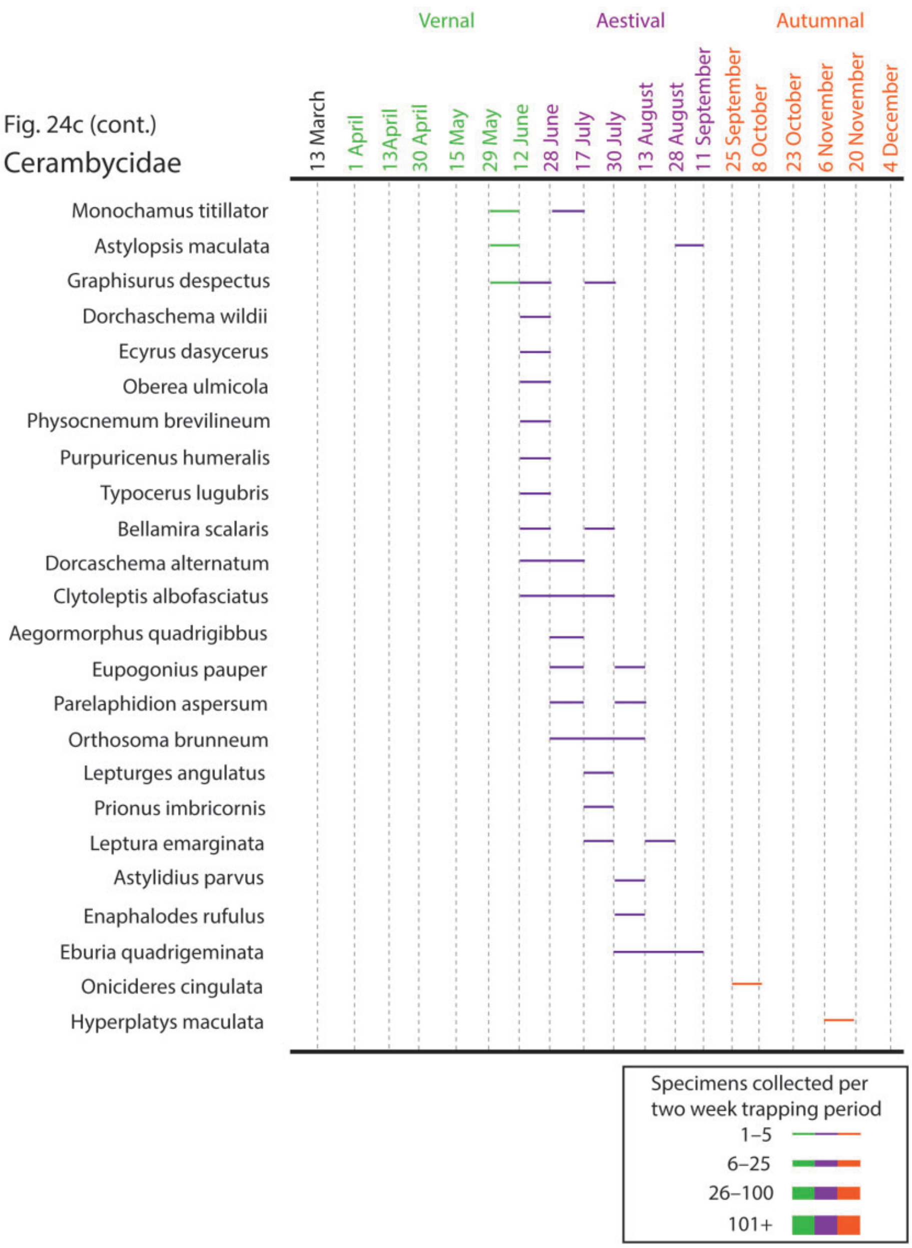
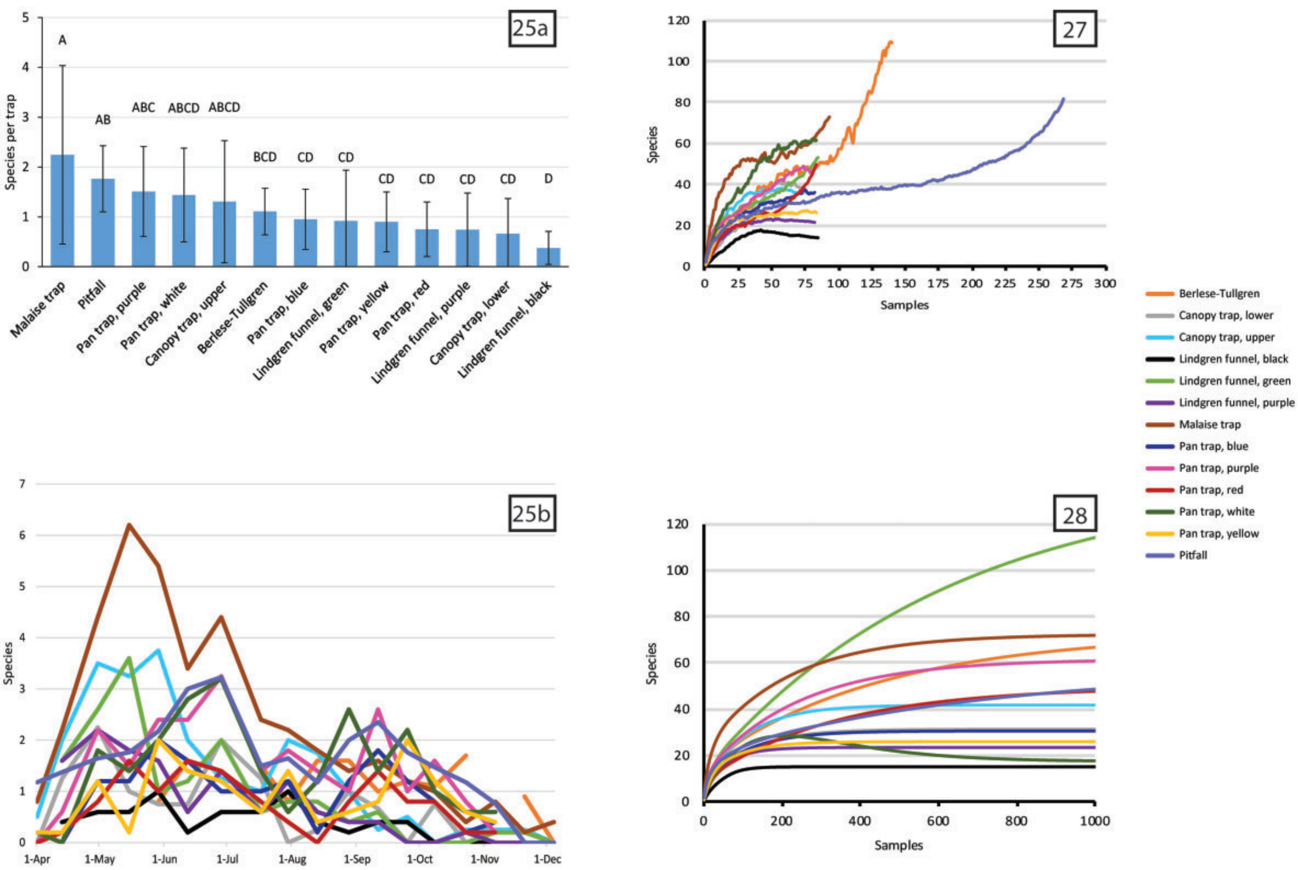


Fig 24. Continued.

(2015), 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 collected 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.



Figs. 25, 27, 28. Average number of curculionoid species collected per trap. The legend applies to Figs. 25b, 27, and 28. (25a) Average number of species/trap. Bars indicate 1 SD; letters indicate mean separation as determined by Tukey–Kramer test. (25b) Average number of species/trap/date. (27) Chao 1 rarefaction curves based on the data. (28) Estimated rarefaction curves (S(est)) extrapolated to 1000 samples.

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, *Plochionus 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.

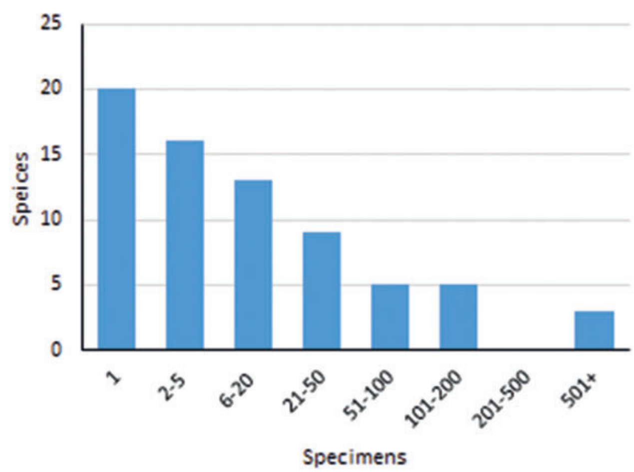


Fig 26. Total number of curculionoid specimens per species collected across all traps.

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*

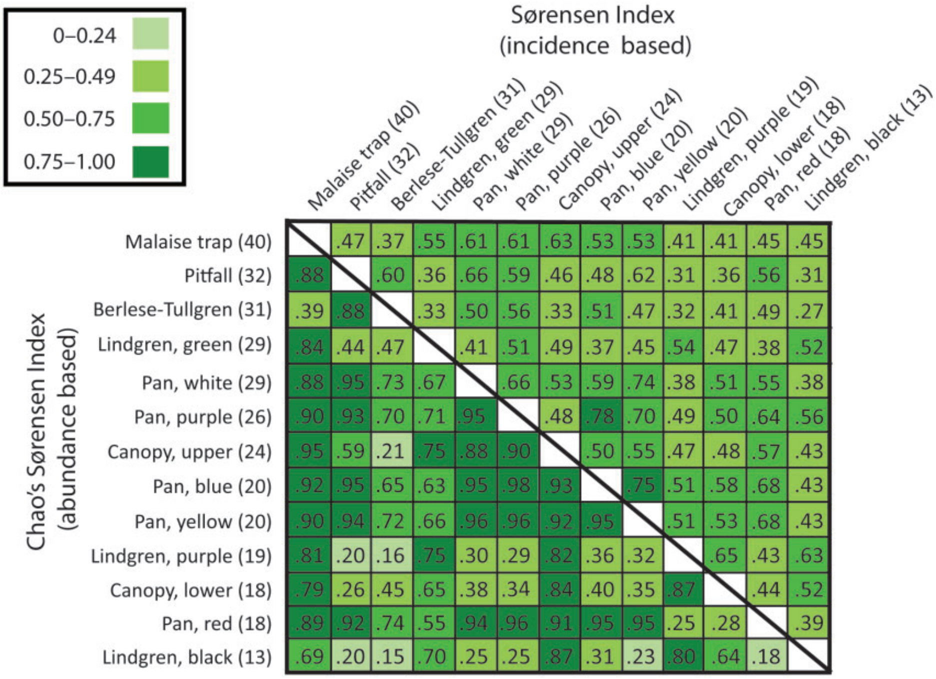


Fig 29. Similarity of trap catch as determined by Sørensen and Chao's Sørensen Indices. Number of species collected per trap type is indicated parenthetically after each trap type.

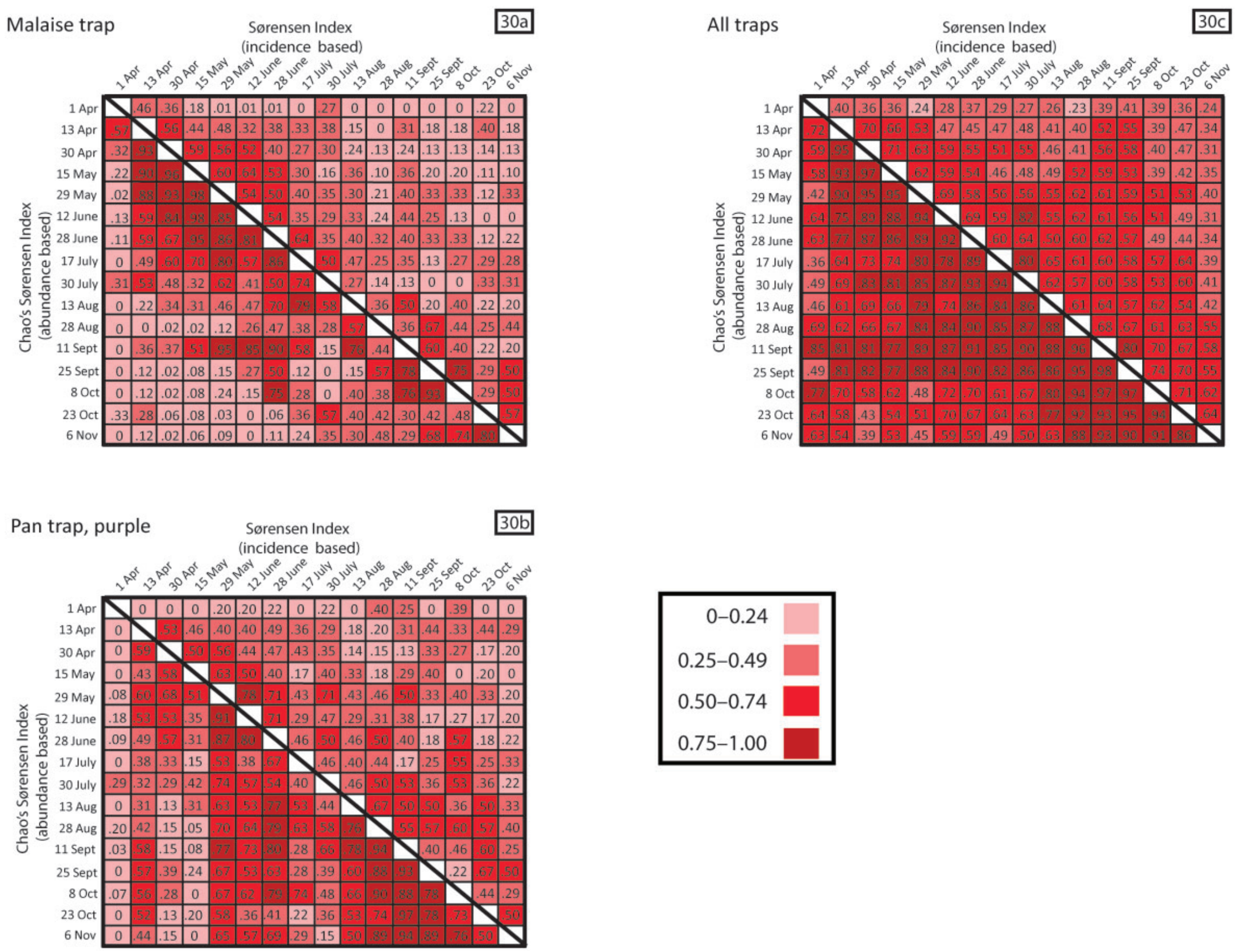


Fig 30. Sørensen and Chao's Sørensen Indices comparing similarity of trap catch by date in Malaise and green Lindgren funnel traps and all trap catch combined.

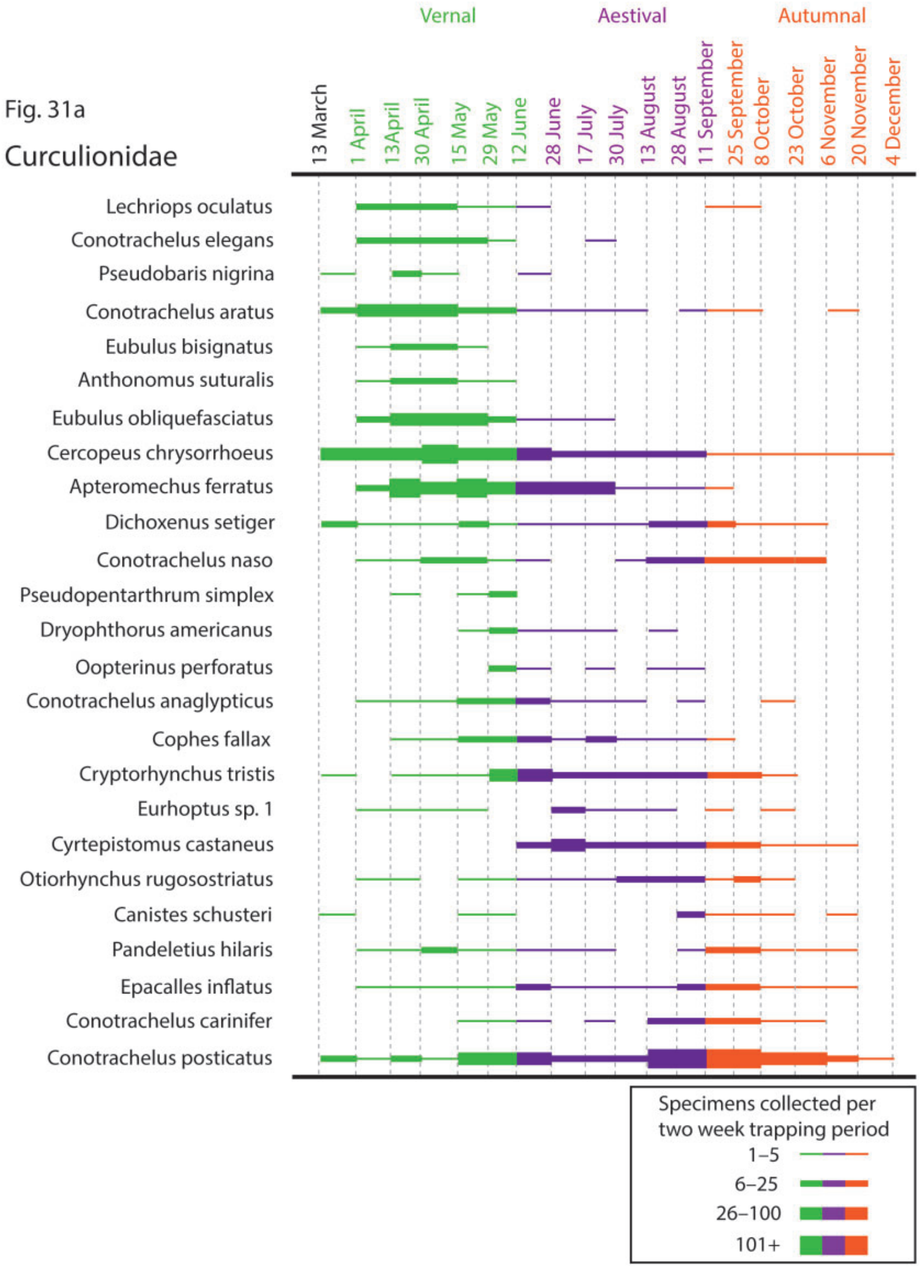


Fig 31. Phenology of curculionoids collected during this study summed across all trap types. (31a) Curculionidae with more than five specimens collected in at least one collecting period. (31b) Curculionidae with five or fewer specimens collected in any collection period but found in at least four collection periods. (31c) Curculionidae with five or fewer specimens collected in any collection period and found in three or fewer collection periods. (31d) Anthribidae. (31e) Attelabidae. (31f) Brachyceridae. (31g) Brentidae.

(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 inneffective 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 became 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 opaculus* LeConte, *Calleida viridipennis* (Say), *Cicindela sexguttata* Fab.—were found during a single season. Of these, *Cicindela sexguttata* and *Calleida viridipennis* were collected 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 opaculus*, however, are reported to be active outside the periods they were collected (Ciegler 2000).

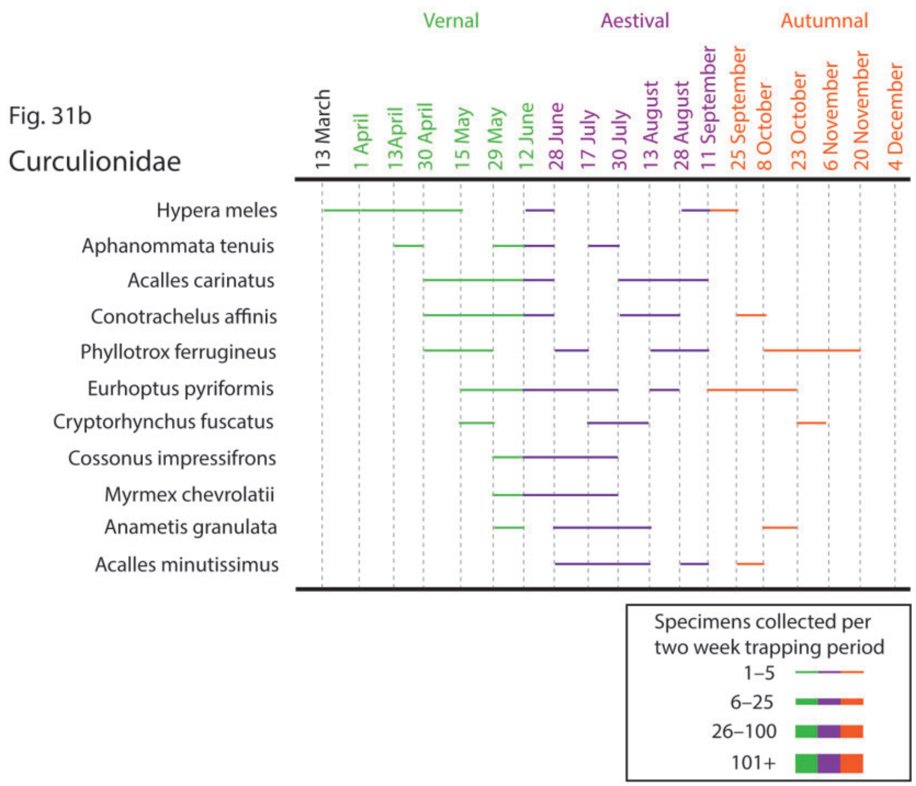


Fig 31. Continued.

Table 5. Select references pertaining to color attraction in Buprestidae

Highest-level taxon considered	Lowest taxonomic level identified	Reference
Insecta	Family	Skvarla and Holland (2011)
Coleoptera	Family	Oliver et al. (2002)
Coleoptera	Species	Sakalian et al. (1993)
Buprestidae	Species	Sakalian et al. (1993); Oliver et al. (2003); Sakalian and Langourov (2004); Peatrice et al. (2013); Peatrice and Haack (2015)
Agrilus	Species	Domingue et al. (2014)
Agrilus planipennis Fairmaire	Species	Francese et al. (2005); Otis et al. (2005); Francese et al. (2008); Lelito et al. (2008); Crook et al. (2009); Francese et al. (2010a); Francese et al. (2010b); Francese et al. (2011); Francese et al. (2013a); Francese et al. (2013b); Poland and McCullough (2014)
Agrilus sulcicollis Lacordaire	Species	Peatrice and Haack (2014)
Agrilus bilineatus (Weber)	Species	Peatrice and Haack (2014)

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

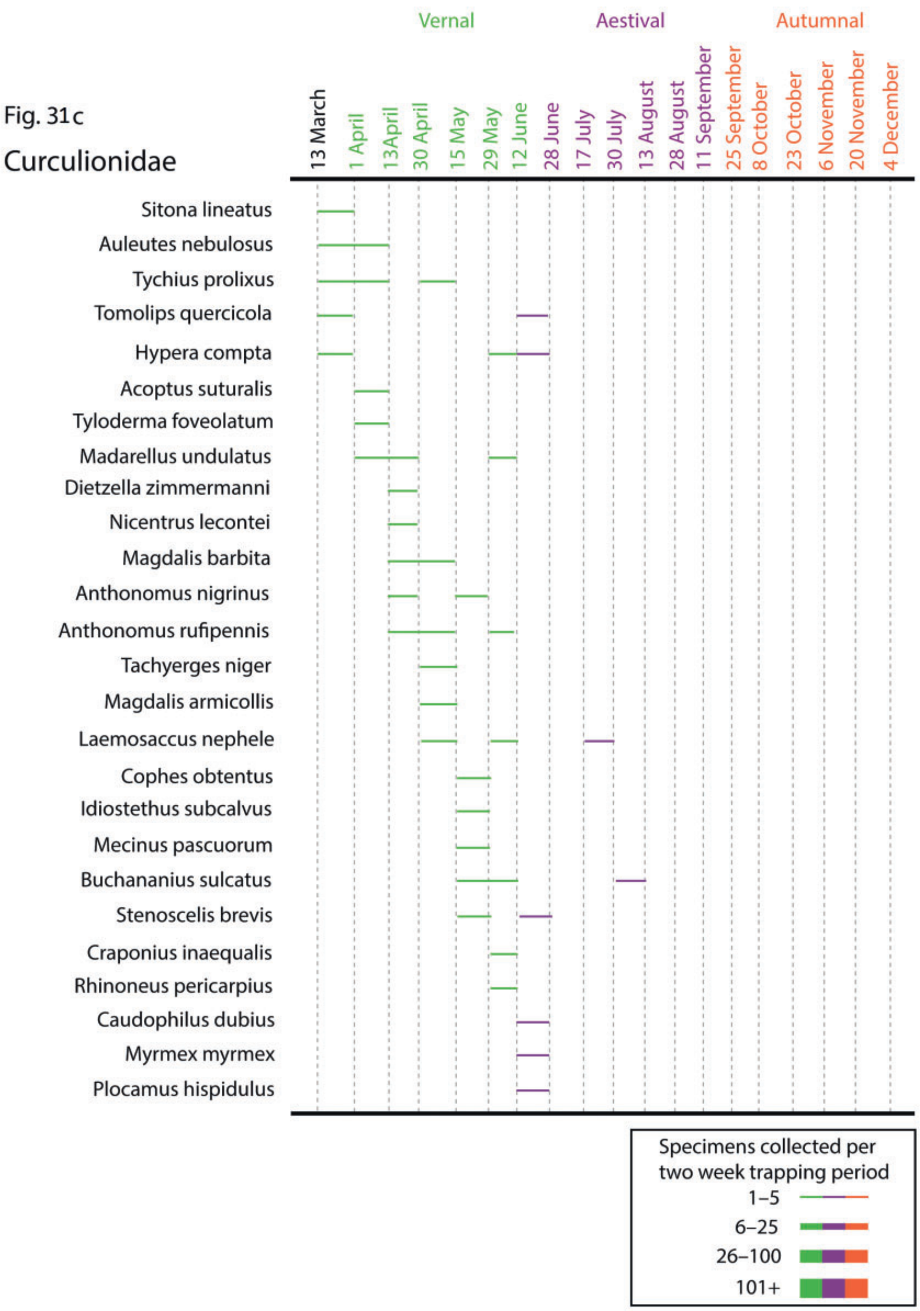


Fig 31. Continued.

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

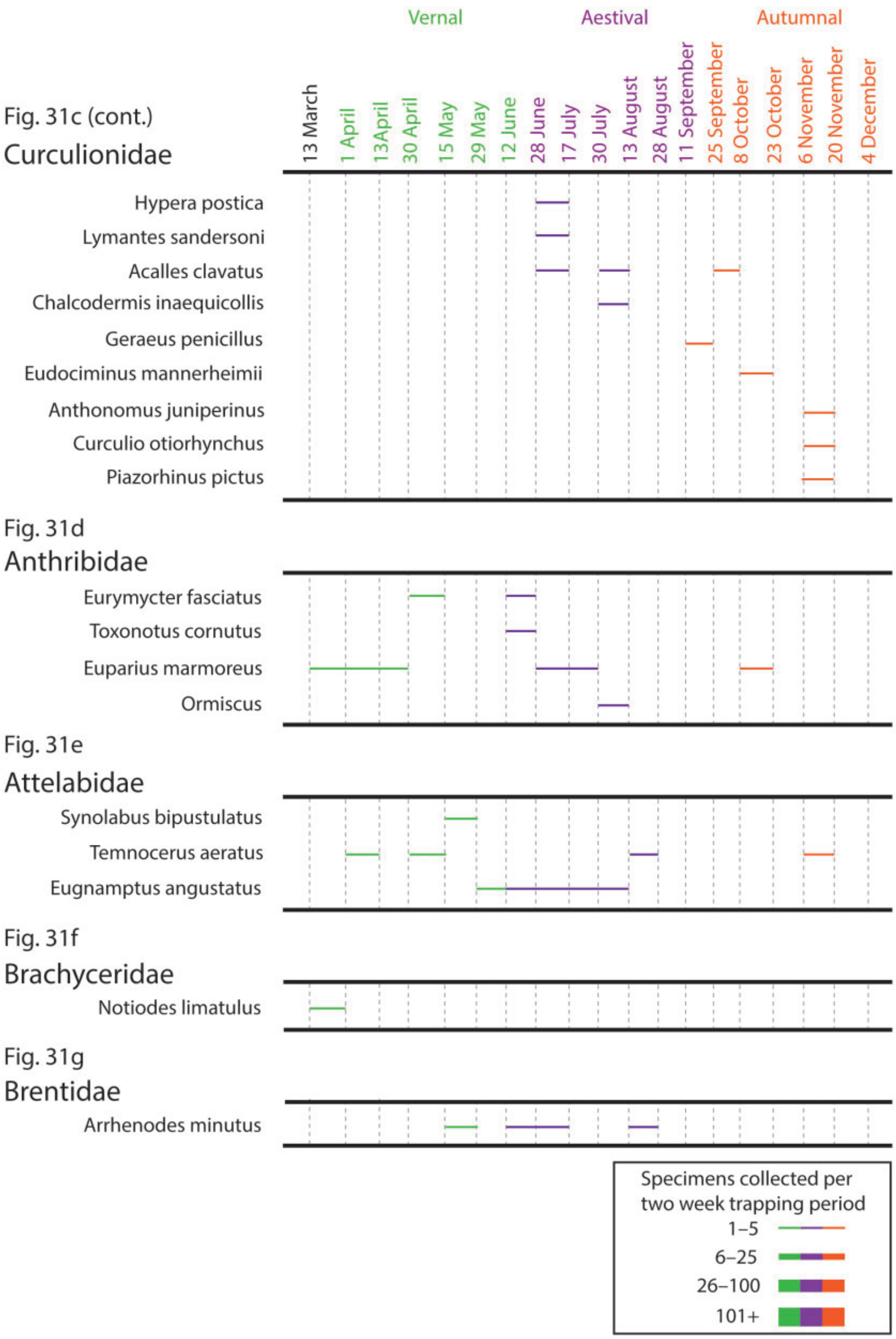


Fig 31. Continued.

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 indicateed 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 patter, 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

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)

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 the 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; Abuagla 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), *Cercopeus chrysorrhoeus* (Say)) but were collected in low numbers throughout the year; others exhibited a bimodal distribution in abundance (e.g., *Conotrachelus naso* 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, woodboring 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 cursorial 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. planipennis*) 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 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.

Acknowledgments

We thank Danielle Fisher for her assistance processing samples and curating specimens; Kyle Schnepp and Peter Messer for their assistance identifying Buprestidae and confirming and correcting identifications of Carabidae, respectively; and Ray Fisher for his endless enthusiasm and willingness to discuss this project. This project and the preparation of this publication were funded in part by the State Wildlife Grants Program (Grant # T-45) of the U.S. Fish and Wildlife Service through an agreement with the Arkansas Game and Fish Commission.

References Cited

Abuagla, A. M., and M. A. Al-Deeb. 2012. Effect of bait quantity and trap color on the trapping efficacy of the pheromone trap for the red palm weevil, *Rhynchophorus ferrugineus*. J Insect Sci. 12:article 120. (http://www.insectscience.org/12.120)

Adobe. 2012. Adobe Illustrator CS6. Adobe Systems Incorporated, San Jose, CA.

Allen, R. T. 1990. Insect endemism in the interior highlands of North America. Fla Entomol. 73: 539–569.

Anderson, R. S. 2008a. A review of the genus *Eubulus* Kirsch 1869 in the United States and Canada (Curculionidae: Cryptorhynchinae). Coleopterists Bull. 62: 287–296.

Anderson, R. S. 2008b. A review of the Neotropical genus *Alloscolytroproctus* Hustache, 1929 (Coleoptera; Curculionidae: Dryophthorinae). Zootaxa. 1816: 35–43.

Baars, M. A. 1979. Catches in pitfall traps in relation to mean densities of carabid beetles. Oecologia. 41: 25–46.

Ball, G. E., Y. Bousquet. 2001. Carabidae Latreille, 1810, pp .Xvi + 443. *In* R. H. Arnett and M. C. Thomas (eds.), American beetles, Volume 1: Archostemata, Myxophaga, Adephaga, Polyphaga: Staphyliniformia. CRC Press LLC, Boca Raton, FL.

Boland, N. P., and P. M. Room. 1983. Estimating population density of a *Cyrtobagous* sp. (Coeloptera: Curculionidae) on the floating weed salvinia using Berlese funnels. Austr J Entomol. 22: 353–354.

Bouget, C., H. Brustel, A. Brin, and L. Valladares. 2009. Evaluation of window flight traps for effectiveness at monitoring dead wood-associated beetles: the effect of ethanol lure under contrasting environmental conditions. Agric Forest Entomol. 11: 143–152.

Buchholz, S., A. M. Jess, F. Hertenstein, and J. Schirmel. 2010. Effect of the colour of pitfall ltraps on their capture efficiency for carabid beetles (Coleoptera: Carabiae), spiders (Araneae) and other arthropods. Eur J Entomol. 107: 277–280.

Calsbeek, R., J. N. Thompson, and J. E. Richardson. 2003. Patterns of molecular evolution and diversification in a biodiversity hotspot: the California Floristic Province. Mol Ecol. 12: 1021–1029.

Chao, A., R. L. Chazdon, R. K. Colwell, and T. J. Shen. 2005. A new statistical approach for assessing similarity of species composition with incidence and abundance data. Ecol Lett. 8: 148–159.

Ciegler, J. C. 2000. Ground beetles and wrinkled bark beetles of South Carolina (Coleoptera: Geadephaga: Carabidae and Rhysodidae). Biota of South Carolina, vol. 1, pp. 149. Clemson University Public Service Publishing, Clemson, SC.

Colwell, R. K. 2013. Estimate S: statistical estimation of species richness and shared species from samples. Version 9. (http://viceroy.eeb.uconn.edu/estimates/index.html).

Conant, R. 1960. The queen snake, *Natrix septemvittata*, in the Interior Highlands of Arkansas and Missouri, with comments upon similar disjunct distributions. Proc Acad Nat Sci Phila. 112: 25–40.

Costello, S. L., J. F. Negrón, and W. R. Jacobi. 2008. Traps and attractants for wood-boring insects in Ponderosa pine stands in the Black Hills, South Dakota. J Econ Entomol. 101: 409–420.

Crespi, E. J., L. J. Rissler, and R. A. Browne. 2003. Testing Pleistocene refugia theory: phylogeographical analysis of Desmognathus wrighti, a high-elevation salamander in the southern Appalachians. Mol Ecol. 12: 969–986.

Crook, D. J., J. A. Francese, K. E. Zylstra, I. Fraser, A. J. Sawyer, D. W. Bartels, D. R. Lance, and V. C. Mastro. 2009. Laboratory and field responses of the emerald ash borer (Coleoptera: Buprestidae), to selected regions of the electromagnetic spectrum. J Econ Entomol. 102: 2160–2169.

Daily, G. C., S. Alexander, P. R. Ehrlich, L. Goulder, J. Luchenco, P. A. Matson, H. A. Mooney, S. Postel, S. H. Schneider, D. Tillman, et al. 1997. Ecosystem services: benefits supplied to human societies by natural ecosystems. Issues Ecol. 2: 1–16.

de Groot, P., and R. Nott. 2001. Evaluation of traps of six different designs to capture pine sawyer beetles (Coleoptera: Cerambycidae). Agric Forest Entomol. 3: 107–111.

Desender, K., and J. P. Maelfait. 1986. Pitfall trapping within enclosures: a method for estimating the relationship between the abundances of coexisting carabid species (Coleoptera: Carabidae). Holarctic Ecol. 9: 245–250.

Dodds, K. J., and D. W. Ross. 2002. Relative seasonal abundance of wood borers (Buprestidae, Cerambycidae) and Cucujidae trapped in Douglas-fir beetle pheromone-baited traps in northern Idaho. Pan-Pac Entomol. 78: 120–131.

Dodds, K. J., G. D. Dubois, and E. R. Hoebeke. 2010. Trap type, lure placement, and habitat effects on Cerambycidae and Scolytinae (Coleoptera) catches in the northeastern United States. J Econ Entomol. 103: 698–707.

Domingue, M. J., Z. Imrei, J. P. Lelito, J. Muskovits, G. Janik, G. Csóka, V. C. Mastro, and T. C. Baker. 2014. Trapping of European buprestid beetles in oak forests using visual and olfactory cues. Entomol Exp Appl. 148: 116–129.

Dutcher, J. D., J. A. Payne, and J. K. Sharpe. 1986. Monitoring adult pecan weevil (Coleoptera: Curculionidae) emergence with a Malaise trap. J Econ Entomol. 79: 1397–1400.

Ferro, M. L., and C. E. Carlton. 2011. A practical emergence chamber for collecting Coleoptera from rotting wood, with a review of emergence chamber designs to collect saproxylic insects. Coleopterists Bull. 65: 115–124.

Ferro, M. L., M. L. Gimmel, K. E. Harms, and C. E. Carlton. 2009. The beetle community of small oak twigs in Louisiana, with a literature review of Coleoptera from fine woody debris. Coleopterists Bull. 63: 239–263.

Francese, J. A., D. J. Crook, I. Fraser, D. R. Lance, J. A. Sawyer, and V. C. Mastro. 2010a. Optimization of trap color for emerald ash borer (Coleoptera: Buprestidae). J Econ Entomol. 103: 1235–1241.

Francese, J. A., I. Fraser, M. L. Rietz, D. J. Crook, D. R. Lance, and V. C. Mastro. 2010b. Relations of color, size, and canopy placement of prism traps in determining capture of emerald ash borer (Coleoptera: Buprestidae). Can Entomol. 142: 596–600.

Francese, J. A., I. Fraser, D. R. Lance, and V. C. Mastro. 2011. Efficacy of multifunnel traps for capturing emerald ash borer (Coleoptera: Buprestidae): effect of color, glue, and other trap coatings. J Econ Entomol. 104: 901–908.

Francese, J. A., I. Fraser, D. R. Lance, V. C. Mastro, J. B. Oliver, N. Youssef. 2005. Studies to develop an emerald ash borer survey trap: II. Comparison of colors, pp. 62. *In* V. C. Mastro and R. Reardon (eds.), Emerald ash borer research and technology development meeting, FHTET-2004-15. USDA Forest Service, Morgantown, WV.

Francese, J. A., J. B. Oliver, I. Fraser, D. R. Lance, N. Youssef, A. J. Sawyer, and V. C. Mastro. 2008. Influence of trap placement and design on capture of the emerald ash borer (Cleoptera: Buprestidae). J Econ Entomol. 191: 1831–1837.

Francese, J. A., M. L. Rietz, D. J. Crook, I. Fraser, D. R. Lance, and V. C. Mastro. 2013a. Improving detection tools for the emerald ash borer (Coleoptera: Buprestidae): comparison of prism and multifunnel traps at varying population densities. J Econ Entomol. 106: 2407–2414.

Francese, J. A., M. L. Rietz, and V. C. Mastro. 2013b. Optimization of multifunnel traps for emerald ash borer (Coleoptera: Buprestidae): influence of size, trap coating, and color. J Econ Entomol. 106: 2415–2423.

Gotelli, N. J., R. K. Colwell. 2010. Estimating species richness, pp. 39–54. *In* A. E. Magurran and B. J. McGill (eds.), Frontiers in measuring biodiversity. Oxford University Press, New York, NY.

Greenslade, P. J. M. 1964. Pitfall trapping as a method for studying populations of Carabidae (Coleoptera). J Anim Ecol. 33: 301–310.

Halsall, N. B., and S. D. Wratten. 1988. The efficiency of pitfall trapping for polyphagous predatory Carabidae. Ecol Entomol. 13: 293–299.

Hanula, J. L. 1990. Monitoring adult emergence, ovary maturation, and control of the black vine weevil (Coleoptera: Curculionidae). J Entomol Sci. 25: 134–142.

Hanula, J. L., M. D. Ulyshen, and S. Horn. 2011. Effect of trap type, trap position, time of year, and beetle density on captures of the redbay ambrosia beetle (Coleoptera: Curculionidae: Scolytinae). J Econ Entomol. 104: 501–508.

Hespenheide, H. A. 2009. Two new weevils (Coleoptera: Curculionidae: Conoderinae) from Cocos Island, Costa Rica. Coleopterists Bull. 63: 333–339.

Hodkinson, B. P. 2010. A first assessment of lichen diversity for one of North America's 'biodiversity hotspots' in the Southern Appalachians of Virginia. Castanea. 75: 126–133.

Hwang, Y. S., M. S. Mulla, and H. Axelrod. 1978. Attractants for synanthropic flies. Ethanol as attractant for *Fannia canicularis* and other pest flies in poultry ranches. J Chem Ecol. 4: 463–470.

Imrei, Z., Z. Kováts, T. B. Toshova, M. Subchev, K. Harmincz, I. Szarukán, M. J. Domingue, and M. Tóth. 2014. Development of a trap combining visual and chemical cues for the alfalfa longhorn beetle, *Plagionotus floralis*. Bull Insectol. 67: 161–166.

Kirk, R. E. 1995. Experimental design: procedures for the behavioral sciences, 3rd ed, pp. 928. Brooks/Cole, Pacific Grove, CA.

Klingeman, W. E., J. A. Hansen, J. P. Basham, J. B. Oliver, N. N. Youssef, W. Swink, C. A. Nalepa, and D. C. Fare. 2015. Seasonal flight activity and distribution of metallic woodboring beetles (Coleoptera: Buprestidae) collected in North Carolina and Tennessee. Fla Entomol. 98: 579–587.

Ledig, F. T., B. Bermejo-Velázquez, P. D. Hodgskiss, D. R. Johnson, C. Flores-López, and V. Jacob-Cervantes. 2000. The mating system and genic diversity in Martínez spruce, an extremely rare endemic of México's Sierra Madre Oriental: an example of facultative selfing and survival in interglacial refugia. Can J Forest Res. 30: 1156–1164.

Leggett, J. E., and H. W. Cross. 1978. Boll weevils: the relative importance of color and pheromone in orientation and attraction to traps. Environ Entomol. 7: 4–6.

Lelito, J. P., I. Fraser, V. C. Mastro, J. H. Tumlinson, and T. C. Baker. 2008. Novel visual-cue-based sticky traps for monitoring of emerald ash borers, *Agrilus planipennis* (Col., Buprestidae). J Appl Entomol. 132: 668–674.

Lemieux, L. P., and B. S. Lindgren. 1999. A pitfall trap for large-scale trapping of Carabidae: comparison against conventional design, using two different preservatives. Pedobiologia. 43: 245–253.

Leskey, T. C. 2006. Visual cues and capture mechanisms associated with traps for plum curculio (Coleoptera: Curculionidae). J Entomol Sci. 41: 97–106.

Levesque, C., and G. Y. Levesque. 1994. Abundance and seasonal activity of weevils (Coleoptera: Curculionidae) in a raspberry plantation and adjascent sites in southern Quebec (Canada). Great Lakes Entomol. 27: 23–37.

Macias-Samano, J. n.d. Field assessment of bark and borer insects captured in baited coloured multiple-funnel traps near Merritt, BC, pp. 4. Synergy Semiochemicals Corp. Research, Burnaby, BC, Canada.

McIntosh, R. L., P. J. Katinic, J. D. Allison, J. H. Borden, and D. L. Downey. 2001. Comparative efficacy of five types of trap for woodboreres in Cerambycidae, Buprestidae and Siricidae. Agric Forest Entomol. 3: 113–120.

Meyers, N. 1989. Threatened biotas: "Hotspots" in tropical forests. Environmentalist. 8: 1–20.

Meyers, N. 1990. The biodiversity challenge: expanded hotspots analysis. Environmentalist. 10: 243–256.

Meyers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. B. da Fonseca, and J. Kent. 2000. Biodiversity hotspots for conservation priorities. Science. 403: 853–858.

Microsoft. 2013. Microsoft Excel [software]. Microsoft Corporation, Redmond, WA.

Miller, D. R., and C. M. Crowe. 2011. Relative performance of Lindgren multiple-funnel, intercept panel, and colossus pipe traps in catching Cerambycidae and associated species in the southeastern United States. J Econ Entomol. 104: 1934–1941.

Montgomery, M. E., and P. M. Wargo. 1983. Ethanol and other host-derived vlatiles as attractants to beetles that bore into hardwoods. J Chem Ecol. 9: 181–190.

Morrill, W. L., D. G. Lester, and A. E. Wrona. 1990. Factors affecting efficacy of pitfall traps for beetles (Coleoptera: Carabidae and Tenebrionidae). J Entomol Sci. 25: 284–293.

Nam, Y., S. H. Koh, D. S. Won, K. K. Kim, and W. I. Choi. 2013. An empirical predictive model for the flight period of *Platypus koryoensis* (Coleoptera: Platypodinae). Appl Entomol Zool. 48: 515–524.

Niemelä, J., E. Halme, and Y. Haila. 1990. Balancing sampling effort in pitfall trapping of carabid beetles. Entomol Fennica. 4: 233–238.

Noguera, F. A., J. A. Chemsak, S. Zaragoza-Caballero, Rodgíguez-Palafox, E. Ramírez-García, González-Soriano, and R. Ayala. 2007. A faunal study of Cerambycidae (Coleoptera) from one region with tropical dry forest in México: San Buenaventura, Jalisco. Pan-Pac Entomol. 83: 296–314.

Nordlander, G. 1987. A method for trapping Hylobius abietis (L.) with a standardized bait and its potential for forecasting seedling damage. Scandinavian J of For Res. 2: 199–213. DOI: 10.1080/02827588709382458.

Ohsawa, M. 2008. Different effects of coarse woody material on the species diversity of three saproxylic beetle families (Cerambycidae, Melandryidae, and Curculionidae). Ecol Res. 23: 11–20.

Oliver, J. B., D. C. Fare, N. Youssef, W. Klingeman. 2003. Collection of adult flatheaded borers using multicolored traps, pp. 193–199. *In* J. B. Oliver (eds.), SNA Research Conference Proceedings, Southern Nursery Association, Acworth, GA.

Oliver, J. B., Y. Youssef, D. Fare, M. Halcomb, S. Scholl, W. Klingeman, P. Flanagan. 2002. Monitoring buprestid borers in production nursery areas, pp. 12–13. *In* G. Haun (ed.), Proceedings of the 29th Annual Meeting of the Tennessee Entomological Society. 10–11 October Nashville, TN.

Otis, G. W., M. E. Young, G. Umphrey. 2005. Effects of colored objects and purple background on emerald ash borer trapping, pp. 31–32. *In* V. C. Mastro and R. Reardon (eds.), Emerald ash borer research and technology development meeting, FHTET-2004-15. USDA Forest Service, Morgantown, WV.

Peatrice, T. R., and R. A. Haack. 2014. Biology of the European oak borer in Michigan, United States of America, with comparisons to the native two-lined chestnut borer. Can Entomol. 146: 36–51.

Peatrice, T. R., and R. A. Haack. 2015. Comparison of different trap colors and types for capturing adult *Agrilus* (Coleoptera: Buprestidae) and other buprestids. Great Lakes Entomol. 48: 45–66.

Peatrice, T. R., R. A. Haack, and T. M. Poland. 2013. Attraction of *Agrilus planipennis* (Coleoptera: Buprestidae) and other buprestids to sticky traps of various colors and shapes. Great Lakes Entomol. 46: 13–30.

Pearson, D. L. , C. B. Knisley, and C. J. Kazilek. 2006. A field guide to the tiger beetles of the United States and Canada. Identification, natural history, and distribution of the Cicindelidae, pp 227. Oxford University Press, New York, NY.

Petersen, R. H. 1976. The southern Appalachian Mountains as a refugium for tropical basidiomycetes, pp. 287–295. *In* B. C. Parker and M. K. Roane (eds.), The distributional history of the biota of the Southern Appalachians. Part IV. Algae and fungi. University Press of Virginia, Charlottesville, VA.

Poland, T. M., and D. G. McCullough. 2014. Comparison of trap types and colors for capturing emerald ash borer adults at different population densities. Environ Entomol. 43: 157–170.

Raffa, K. F., and D. W. A. Hunt. 1988. Use of baited pitfall traps for monitoring Pales weevil, *Hylobius pales* (Coleoptera: Curculionidae). Great Lakes Entomol. 12: 123–125.

Rassati, D., E. P. Toffolo, A. Roques, A. Battisti, and M. Faccoli. 2014. Trapping wood boring beetles in Italian ports: a pilot study. J Pest Sci. 87: 61–69.

Raworth, D. A., and M.-Y. Choi. 2003. Determining the number of active carabid beetles per unit area from pitfall-trap data. Entomol Exp Appl. 98: 95–108.

Reddy, G. V. P., and A. Raman. 2011. Visual cues are relevant in behavioral control measures for *Cosmopolites sordidus* (Coleoptera: Curculionidae). J Econ Entomol. 104: 436–442.

Redfearn, P. L. Jr. 1986. Bryogeography of the Interior Highlands of North America: taxa of critical importance. The Bryologist. 89: 32–34.

Riley, D. G., and D. J. Schuster. 1994. Pepper weevil adult response to colored sticky traps in pepper fields. Southwestern Entomol. 19: 93–107.

Roach, S. H., H. R. Agee, and L. Ray. 1972. Influence of position and color of male-baited traps on captures of boll weevils. Environ Entomol. 1: 530–532.

Robison, H. W., R. T. Allen. 1995. Only in Arkansas: a study of the endemic plants and animals of the state, pp. 121. The University of Arkansas Press, Fayetteville, AR.

Ruiz-Sanchez, E., F. Rodriguez-Gomez, V. Sosa. 2012. Refugia and geographic barriers of populations of the desert poppy, *Hunnemannia fumariifolia* (Papaeraceae). Organ Divers Evol. 12: 133–143.

Sabu, T. K., R. T. Shiju. 2010. Efficacy of pitfall trapping, Winkler and Berlese extraction methods for measuring ground-dwelling arthropods in moist-deciduous forests in the Western Ghats. J Insect Sci. 10: 1–17. (insectscience.org/10.98).

Sabu, T. K., R. T. Shiju, K. V. Vinod, S. Nithya. 2011. A comparison of the pitfall trap, Winkler extractor, and Berlese funnel for sampling ground-dwelling arthropods in tropical montane cloud forests. J Insect Sci. 11: 1–19. (insectscience.org/11.28).

Sakalian, V. P., M. Langourov. 2004. Colour traps a methods for distributional and ecological investigations of Buprestidae (Coleoptera). Acta Soc Zool Bohemicae. 68: 53–59.

Sakalian, V. P., V. I. Dimova, G. C. Damianov. 1993. Utilization of color traps for faunistic investigation on beetles (Insecta: Coleoptera), pp. 47–52. *In* Second Nacional Scientific Conference of Entomology, 25–27 October, Sofia Publishing Group, Richmond, British Columbia, Canada.

Sakchoowong, W., S. Nomura, K. Ogata, J. Chanpaisaeng. 2007. Comparison of extraction efficiency between Winkler and Tullgren extractors for tropical leaf litter macroarthropods. Thai J Agric Sci. 40: 97–105.

Sama, G., N. Jansson, M. Avci, O. Sarıkaya, M. Coşkun, T. Kayış, H. Özdikmen. 2011. Preliminary report on a survey of the saproxylic beetle fauna living on old hollow oaks (*Quercus* spp.) and oak wood in Turkey (Coleoptera: Cerambycidae). Munis Entomol Zool J. 6: 819–831.

Samuels, M. L., J. A. Witmer. 2003. Statistics for the life sciences, 3rd ed, pp. 724. Pearson Education, Inc., Upper Saddle River, NJ.

Sanderson, M. W., and A. Miller. 1941. A new species of ground beetle of the genus Rhadine from an Arkansas cave (Coleoptera: Carabidae). Proceedings of the Arkansas Academy of Science 1:39–40.

Setyo Leksono, A., K. Takada, S. Koji, N. Nakagoshi, T. Anggraeni, K. Nakamura. 2005. Vertical and seasonal distribution of flying beetles in a suburban temperate deciduous forest collected by water pan trap. J Insect Sci. 12: 199–206.

Shipman, N. M. 2011. Role of color and odor on the attraction of insect visitors to spring blooming Trillium, pp. 76. M.S. thesis, Western Carolina University, Cullowhee, NC.

Skvarla, M. J., D. M. Fisher, K. E. Schnepp, A. P. G. Dowling. 2015a. Data from: terrestrial arthropods of Steel Creek, Buffalo National River, Arkansas. I. Select beetles (Coleoptera: Buprestidae, Carabidae, Cerambycidae, Curculionoidea excluding Scolytinae). Dryad Digital Repository. doi:10.5061/dryad.4h40n.

Skvarla, M. J., D. M. Fisher, K. E. Schnepp, A. P. G. Dowling. 2015b. Terrestrial arthropods of Steel Creek, Buffalo National River, Arkansas. I. Select beetles (Coleoptera: Buprestidae, Carabidae, Cerambycidae, Curculionoidea excluding Scolytinae). Biodivers Data J. 3: 1–42.

Skvarla, M. J., J. D. Holland. 2011. Nontarget insects caught on emerald ash borer purple monitoring traps in western Pennsylvania. Northern J Appl Forestry. 28: 219–221.

Skvarla, M. J., J. L. Larson, A. P. G. Dowling. 2014. Pitfalls and preservatives: a review. J Entomol Soc On. 145: 15–43.

Smart, L. E., M. M. Blight, A. J. Hick. 1997. Effect of visual cues and a mixture of isothiocyanates on trap capture of cabbage seed weevil, *Ceutorhynchus assimilis*. J Chem Ecol. 23: 889–902.

Sosa, V., E. Ruiz-Sanchez, F. Rodriguez-Gomez. 2008. Hidden phylogeographic complexity in the Sierra Madre Oriental: the case of the Mexican tulip poppy *Hunnemannia fumariifolia* (Papaveraceae). J Biogeography. 36: 18–27.

Spence, J. R., J. K. Niemelä. 1994. Sampling carabid assemblages with pitfall traps: the madness and the method. Can Entomol. 126: 881–894.

The Nature Conservancy, Ozarks Ecoregion Assessment Team. 2003. Ozarks ecoregional conservation assessment, pp. 52. The Nature Conservancy Midwestern Resource Office, Minneapolis, MN.

Ulyshen, M. D., J. L. Hanula, S. Horn. 2005. Using Malaise traps to sample ground beetles (Coleoptera: Carabidae). Can Entomol. 137: 251–256.

Ulyshen, M. D., J. L. Hanula. 2007. A comparison of the beetle (Coleoptera) fauna captured at two heights above the ground in a North American temperate deciduous forest. Am Midland Nat. 158: 260–278.

Vance, C. C., K. R. Kirby, J. R. Malcon, S. M. Smith. 2003. Community composition of longhorned beetles (Coleoptera: Cerambycidae) in the canopy and understory of sugar maple and white pine stands in south-central Ontario. Environ Entomol. 32: 1066–1074.

Waage, B. E. 1985. Trapping efficiency of carabid beetles in glass and plastic pitfall traps containing different solutions. Fauna Norvegica B. 32: 33–36.

Walker, M. J., A. K. Stockman, P. E. Marek, J. E. Bond. 2009. Pleistocene glacial refugia across the Appalachian Mountains and coastal plain in the millipede genus Narceus: evidence from population genetic, phylogeographic, and paleoclimatic data. BMC Evol Biol. 9: 1–11.

Ward, D. F., M. Larivière. 2004. Terrestrial invertebrate surveys and rapid biodiversity assessment in New Zealand: lessons from Australia. N Z J Ecol. 28: 151–159.

Wickings, K., A. S. Grandy. 2011. The oribatid mite *Scheloribates moestus* (Acari: Oribatida) alters litter chemistry and nutrient cycling during decomposition. Soil Biol Biochem. 43: 351–358.

Wiedenmann, R. N., P. L. Larrain, R. J. O'Neil. 1992. Pitfall sampling of ground beetles (Coleoptera: Carabidae) in Indiana soybean fields. J Kansas Entomol Soc. 65: 279–291.

Wilson, B. H., N. P. Tugwell, E. C. Burns. 1966. Attraction of tabanids to traps baited with dry ice under field conditions in Louisiana. J Med Entomol. 3: 148–149.

Work, T. T., C. M. Buddle, L. M. Korinus, J. R. Spence. 2002. Pitfall trap size and capture of three taxa of litter-dwelling arthropods: implications for biodiversity studies. Environ Entomol. 31: 438–448.

Yanega, D. 1996. Field guide to northeastern longhorned beetles (Coleoptera: Cerambycidae), pp. 174. Manual 6. Illinois Natural History Survey, Champaign, IL.

Yen, A. L., R. J. Butcher. 1997. An overview of the conservation of non-marine invertebrates in Australia. Environment Australia, Canberra.

Zaiontz, C. 2015. Real Statistics Resource Pack (Release 3.8). (http://www.real-statistics.com/)

Zhou, J., R. A. Goyer, G. J. Lenhard. 1993. Seasonal occurrence of *Callidea viridipennis* (Say) and *Plochonius timidus* Haldeman (Coleoptera: Carabidae), predators of the fruittree leafroller *Archips argyrospila* (Walker), in Louisiana. J Entomol Sci. 28: 254–262.