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Bat Activity in Woodland Vernal Pools

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Abstract

A major interest in bat conservation is identifying, understanding, and protecting key resources and habitats. This project sought to understand the dependence of bats on 17 woodland vernal pools and 2 outgroups in northern Wisconsin and the Michigan Upper Peninsula. Bat species use was documented with mist nets and the Anabat II detection system. Bat relative activity was compared to the available invertebrate prey base, as measured by UV light traps. Of the 55 bats captured in 5 rounds of mist-netting (190 mist-net-nights), little brown bats (*Myotis lucifugus*) dominated the captures (41 individuals) and Anabat calls (7814). Northern myotis (*M. septentrionalis*, 13 individuals captured, 753 calls) and big brown bats (*Eptesicus fuscus*, 1 individual captured, 94 calls) also were documented at multiple sites. Bat activity was at a maximum ca. 30-60 minutes after sunset. Weak yet significant relationships revealed that big brown and little brown bat use of woodland vernal pools decreased as the pools dried up. Although the total number of invertebrates captured across rounds and sites were closely tied to temperature, no clear relationships were discovered between bat activity and invertebrate abundance (in sum or across orders). This work shows the importance of woodland vernal pools to several bat species throughout the summer months, which spend a considerable amount of time foraging at these sites. Continued Anabat and mist-netting surveys in summer 2005 will help elucidate trends in bat activity, and further refine call identification in these oftentimes structurally cluttered habitats.

Introduction

Recent studies have emphasized the importance of woodland vernal pools to herpetofauna (Preisser et al., 2000; Zelder, 2003), invertebrates (Brooks, 2000), and small

terrestrial mammals (Brooks and Doyle, 2001). However, the use of woodland vernal pools by bats largely has been overlooked. Given the abundance of prey items at these sites, it is likely that bats use these sites for feeding and drinking during late spring and summer when the pools hold water. But questions arise as to which species utilize these habitats and estimating their degree of dependence on them over time.

Despite numerous bat studies in the Great Lakes region by Kurta (e.g., Kurta, 1982; Kurta et al., 1989; Foster and Kurta, 1999; Kurta, 2000) and others (e.g., Whitaker, 1992; Whitaker and Rissler, 1992; Carter et al., 2002), information is lacking on bat activity in the Upper Peninsula (UP) of Michigan and northern Wisconsin. Previous chiropteran studies in the region have concentrated on bat hibernacula (e.g., Kurta, 1980; Whitaker and Rissler, 1992; Kurta, personal communication) or southern sites (e.g., Indiana, Michigan Lower Peninsula; Kurta et al., 1989; Whitaker, 1992; Martinus and Kurta, 2001) that host a number of species whose range does not extend to northern Wisconsin and the Michigan UP (Kurta, 1995). Given the limited number of species that potentially inhabit this area (seven; Kurta, 1995), it is unknown whether habitat preferences noted further south hold true. It is also unclear whether eastern pipistrelles (*Pipistrellus subflavus*), a species of concern in Michigan and Wisconsin, use this area during the summer months, as they have been found sparingly hibernating in old mines in the far eastern and western portions of the Michigan UP (Kurta and Teramino, 1994; Kurta, personal communication).

Preliminary mist-netting in the Gogebic Co., Michigan in summer 2003 (Francl, unpublished data) recorded the presence of multiple species, including the abundant little brown bat (*Myotis lucifugus*), and, less commonly, the northern myotis (*M. septentrionalis*), big brown bat (*Eptesicus fuscus*), and red bat (*Lasiurus borealis*).

Given the importance of open water (von Frecknell and Barclay, 1987; Francl, 2003) and forest canopy gaps (Chrome and Richards, 1988; Grindal and Brigham, 1995; Grindal and Brigham, 1999) to bats, it is plausible that vernal ponds may play an important role in bat foraging activities during late spring and summer. Indeed, a recent small-scale survey of wooded vernal pools and beaver swamps in central Massachusetts (Ford and Brooks, unpublished data) suggested interspecific competition minimization: northern myotis frequented woodland vernal pools, while little brown bats preferred to forage over beaver swamps. Presumably, the “openness” (canopy measures) of an area and bats’ morphological adaptations play an integral role in this separation. More field-intensive, large-scale studies like this current work might solidify Brooks’ and Ford’s conclusions.

Monitoring woodland vernal pools as they gradually desiccate will help to determine the true habitat needs for each bat species. That is, by temporally measuring bat activity, I ascertained whether they are attracted to vernal ponds because they provide necessary open water (available late spring and early summer), or because they are simply a forest canopy gap with more maneuverability for feeding.

In these bat surveys, I expected to find the woodland vernal pools visited primarily by those who frequently feed over water, like little brown bats. I expected those sites that are more structurally “cluttered” by woody vegetation to be frequented by forest-dwelling gleaners, like northern myotis. By monitoring the physical characteristics of the vernal ponds throughout the summer, I hypothesized that bat activity would decrease in relation to area of open water, as it likely reflects insect abundance (Brooks, 2000). However, I didn’t predict the diversity of invertebrate species to be as influential to bat activity as the availability of bugs within a consumable size range.

Methods

Site selection

Seventeen woodland vernal pools were selected for this study, based on accessibility (ability to locate open water in early May) and the largest diversity of pond characteristics (e.g., area and depth of ponds, canopy closure, surrounding forest type; Figure 1). Eleven sites were located at the University of Notre Dame Environmental Research Center (UNDERC; Vilas Co., Wisconsin and Gogebic Co., Michigan), which contains over 50 woodland vernal pools and 550 ha of aquatic habitats on its 3035-ha area. The remaining six sites were located on the adjacent Ottawa National Forest, which encompasses nearly 1 million acres of land in the Michigan UP. Of the 17 ponds, seven are currently part of a cooperative long-term herpetofaunal study between UNDERC (PI: Sunny Boyd) and the USDA Forest Service. The remaining 10 sites were paired geographically, with one small pool with a closed canopy, and the paired site being markedly larger and, consequently, more open-canopied. If canopy differences were not apparent, sites were paired according to area and depth parameters (shallow, large pools versus smaller, deeper pools). Two additional outgroup sites were monitored at UNDERC, one permanent beaver pond (Figure 1—white triangle) and one perennial stream (Tenderfoot Creek; Figure 1—black triangle).

Pond physical characteristics

Maximum water depth and water surface area was measured at each woodland vernal pool at 2-week intervals. A portable YSI meter recorded water chemistry parameters (pH, DO, temperature), once in late May and once in early July, if water persisted. Percent tree canopy cover was estimated with a spherical densiometer at these times, as well. From water's edge,

four readings, one in each cardinal direction were averaged. Estimated date of drying (when no visible water exists on the surface) also was recorded.

To compare rates of desiccation among vernal pools of different initial sizes and depths, pool volume was measured proportionately throughout the season. That is, “full” (100% capacity) pond volume was at its maximum for the June 7 readings, and, and all remaining volume measures were calculated relative to this full pond volume. Drainage patterns also were compared among sites, based on soil classifications by ELTP soil maps (draft form provided by USDA Forest Service, Bessemer Ranger District, Gogebic Co., Michigan).

Bat surveys

Each of the 19 sites (17 woodland vernal pools, 2 outgroup sites) were sampled approximately one night every 14 days, depending on suitable netting weather (temperature remained at or above 10°C [50° F] until midnight, and rain events or strong winds were not occurring). By sampling on *every* suitable evening from 1 June- 5 August, five rounds were completed. Two mist nets (6 m, 9 m, or 12 m) were set at 60°-90° angles from one another, maximizing greatest spanning across open water. Nets were open from dusk (ca. 2030-2100) until midnight or later (if bats were captured near midnight). Upon capture, bats were placed in individual soil sample bags (5” x 7”; ca. 13 x 18 cm) for one hour, to allow time for defecation (pellet analysis to be completed in future studies). All captured bats were identified, weighed, measured (forearm length), sexed, and aged (juvenile versus adult, by examining degree of epiphyseal diaphyseal fusion; Anthony, 1988). A small section (ca. 1 cm²) of fur was shaved on the dorsal surface of the bat to document recaptures. Upon release, the individual bat was recorded with Anabat II detector equipment for as long as it was within range.

Throughout the mist-netting effort, an Anabat II detector and ZCAIM unit were stationed on the pond edge, pointed above and across the water to maximize bat recognition over the vernal pool. Time of first call was noted. Recorded echolocation calls were filtered prior to analysis (Anabat default filters 6-9 or Britzke and Murray, 2000), and identified to species using Anabook 4.7j and Analyze 2.3 software (Corben, 1999b; Jolly, 1999). Only calls with ≥ 3 individual call pulses were analyzed (Johnson et al., 2002). Because bat detectors do not distinguish among individual calls, I did not use this data to estimate abundance; rather, I noted species presence and relative activity levels among sites, and compared species presence to mist-netting efforts (Zimmerman and Glanz, 2000).

Bat calls were identified using a modified key for potential species in the region (A. Menzel, unpublished data; K. Francel, unpublished data). This key was fine-tuned according to call characteristics of hand-released bats from this summer's work and calls shared among researchers working in Michigan (M. Wund, unpublished data; L. Kruger, unpublished data).

Call times were standardized to the time of sunset, and patterns were examined at 30-minute intervals throughout the sampling effort. To standardize call times across sampling periods, only calls recorded up to 4 h after sunset were analyzed. To correlate with bat activity, temperature and relative humidity were documented on-site every 30 minutes, using a Kestrel 3000 (Nielsen-Kellerman, Boothwyn, PA).

Invertebrate sampling

Flying insects were sampled with ultra-violet (UV) blacklights, set concurrently with mist-netting at a site. Blacklights have been used in multiple bat feeding studies (e.g., Lacki et al., 1995; Carter et al., 1998; Lee and McCracken, 2002), and, despite their recognized biases, have proven sufficient in such studies.

The apparatus was set up within 10 m of the water's edge (at maximum pool volume), while maximizing distance from the mist nets, to minimize bias to bat movement or capture. For vernal pools that were within 20 m of one another, and not separated by a road (VP J & K, VP M & N), a single blacklight collection system was set up between the sites, and insect data was shared between the pairs. In this system, a UV blacklight was draped over a king-size white sheet, suspended by rope and reaching ca. 0-2 m above the ground. Invertebrates were collected via sweep-netting of this sheet. Insects were swept into bins of soapy water stationed directly beneath the sheet for temporary storage, and preserved in 70% ethanol at the end of the evening. Those individuals within size range to be consumed by bats (2–25 mm; Carter et al., 1998) were identified to order, and, occasionally, suborder or family.

Invertebrate diversity was estimated for each evening's collections using the Shannon-Weiner index of diversity (MacArthur and MacArthur, 1961). Diversity was compared across sites and across rounds to determine if insect diversity influenced bat activity levels.

Statistical analyses

All statistical analyses were performed using Systat 10.2 (SPSS, Inc.2000b) or SAS 9.1.2 (SAS Institute, 2004). Figures were created in SigmaPlot 2000 6.1 (SPSS Inc., 2000a) or Arcview 3.2 (ESRI,1999).

Results

Pond physical characteristics

Maximum pond area ranged from 61-1318 m², while maximum volume varied from 71-1002 m³. Drying dates ranged from 28 June to 20 August (Table 1). Generally, the larger (surface area) pools tended to be relatively shallow, containing more trees within the perimeter.

Smaller pools were that were initially deeper often persisted later into the season. However, an examination of ELTP soil maps did not provide insight into differing drainage patterns among pools, primarily because of the scale of the maps; more often than not, these pools were classified according to the soils of the surrounding uplands.

Bats surveys

Of the 55 adult bats captured in 5 rounds of mist-netting (190 mist-net-nights), little brown bats dominated the captures (41 individuals) and Anabat calls (7814; Table 3, 4). Northern myotis (13 individuals captured, 753 calls) and big brown bats (1 individual captured, 94 calls) also were documented at multiple sites. In examining recapture data, a little brown bat was caught twice in the same net, approximately 30 minutes after release. No other marked individuals were recaptured across rounds or sites.

When examining bat captures over time, 71% (39/55) of bats were captured within the first 60 minutes after sunset, and 84% (46/55) were netted within the first 90 minutes (Table 3). The number of recorded bat calls followed a similar temporal pattern, in which 46% of all calls were recorded within the first 60 minutes after sunset (Figure 2). A repeated measures ANOVA examining calls across 30-minute intervals revealed significant differences among the intervals ($F = 40.116$, $p < 0.001$; Figure 2).

Comparisons of bat use at the outgroup sites and the 17 woodland vernal pools did not reveal any significant differences, likely due to the wide range in activity levels across the pools and the low species richness across all sites.

Invertebrate sampling

Over the collecting period at all 19 sites, 186922 individuals within consumable size for bats (2-25mm) were counted and identified to order. Two dipteran families (Culicidae,

Tipulidae) were clearly identifiable, and sorted as such. In examining invertebrate trends at the 17 vernal pools, dipterans dominated the collections: 37299 individual culicids (mosquitoes), 2992 tipulids (craneflies), 27695 other flies were counted (representative sites in Figure 2; a full list of collections is available upon request). Moths (lepidopterans, 37758 individuals) also were well-represented. Several other orders were common but less abundant across all sites, and included beetles (Coleoptera), mayflies (Ephemeroptera), and caddisflies (Trichoptera).

Although the invertebrates collected at the Beaver Pond were rather similar to the vernal pools, captures at Tenderfoot Creek were markedly different. Of note were multiple netting periods in which dipteran (16121 and 21948 individuals in two separate nights) and ephemeropteran (7799 and 5025 individuals in two nights) emergences had recently taken place, as documented by the large numbers collected.

A nested ANOVA examined invertebrate counts (total number collected per evening, nested to account for clear differences among sites) in relation to temperature measures (measured on-site at 2200) across rounds. The number of invertebrates collected at a particular site was strongly tied to changes in temperature across rounds ($F=3108$, $p<0.0003$). Additionally, species diversity across all sites showed a clear trend, increasing with time ($F=18.471$, $p<0.001$; Table 5).

Bat activity and habitat/pool characteristics

Pearson's correlations examined bat species activity and various pond characteristics (Table 6). Little brown bats preferred to forage at sites with fewer total trees standing in the pool and a lower total density of trees. Additionally, they were found more often at sites that were closer to large, permanent bodies of water. In examining trends across rounds, a weak relationship was found, showing that little brown bat activity decreased as the proportion of open

water decreased at each site. However, the total area of open water across sites was not an influential factor for this species. In examining big brown bats, correlations found that this species is attracted to vernal pools with greater areas of open water (both the maximum area and area of water remaining over time), as well as less canopy coverage. No trends were found in an analysis of northern myotis and habitat features (Table 6).

Relationships among bats, invertebrates, and site features

Nested ANOVAs examining invertebrate abundance (no. collected per evening), and temperature (standardized across sites to 2200) found that invertebrates abundance (within sites) varies significantly across sites and among temperature readings within sites. When relating bat activity to these invertebrate and temperature trends, however, no significant relationships were discovered. Pearson's correlations of bat activity (by species or in sum) revealed no clear, significant patterns when compared to single invertebrate orders or total invertebrate abundance, at any temporal or spatial scale. This was concretized by nested ANOVAs, indicating that bats responded neither to temperature across rounds nor insect abundance.

Discussion

Despite the low species richness across sites (three of potentially seven species in the region), the use of woodland vernal pools for bats should not be discounted. Relative bat activity, as estimated by the Anabat recordings, was comparable to our outgroup sites, which contained permanent water bodies. This indicates that bat use around temporary waterbodies like these pools can be very important to bats, despite the highly dynamic system.

The presence and relative activity levels for each species is not surprising, given their morphology and known habitat preferences. Little brown bats, a small, highly-maneuverable

species, used all vernal pools regardless of the pools' initial area. However, relative activity within sites was higher earlier in the season, when the pools held more water. The reason for this is two-fold: first, these pools might have been a draw for bats for drinking purposes, as well as feeding. Secondly, although statistical evidence did not show any obvious relationships between bats and invertebrates, the trends in insect abundance indicate a temporal bell-shaped curve for many sites. It's possible that bats did respond to insect emergences from the pools, but our surveying methods were not detailed enough to detect this trend. Additionally, the trend towards higher activity at sites closer to permanent bodies of water meant that the highly-mobile bats were probably feeding at those larger sites as well, and moving across the landscape to continue feeding. Nearness to road did not significantly affect this bat species' relative activity, but it is likely that little brown bats used it as a less obstructed corridor for travel. Indeed, corridors like these roads may explain why little browns, known to use roads for travel, were ubiquitous across all sites. Personal observations throughout the surveying season noted bats flying at dusk, following the road/corridor, and occasionally "dropping in" to feed at the pools. In some cases, the bats predictably circled—doing laps around the pond and out to the road—and repeating.

Whereas little brown bats apparently are attracted to sites based on the *presence* of open water or open habitats—less "clutter," fewer trees, big brown bats showed slightly different preferences. Big browns used sites only with a relatively large amount of open water, which corresponded to open-canopied areas. These trends agree with the species' morphological adaptations for open habitats (high wing-loading, low wing aspect ratio). This species did not show a preference for site use, whether or not water was actually present. Essentially, big brown bats are likely choosing sites for the *open space*, not necessarily the open water. Not surprisingly,

big brown bat capture success was very low (one bat captured), as they had been visually observed to fly well above the mist-nets, focusing on feeding in the range of the canopy.

Northern myotis did not show any habitat preferences, likely because they were not necessarily choosing to forage at these sites across the landscape. As gleaners, it is likely that they are foraging in surrounding forested habitats, and “dropping in” at many of the sites not for foraging bouts but for drinks of water. Perhaps future studies of this bat might provide data to support or refute this theory.

One large caveat in these analyses is the acknowledgement that Anabat call identification is not an exact science. Furthermore, it can be especially troublesome in cluttered habitats like the woodland vernal pools. To be consistent, if there was a questionable call between little brown bats and northern myotis, I defaulted to little browns (based on greater capture rates). Thus, it is possible, and even likely, that northern myotis are under-represented. In future studies at UNDERC, I will continue to build a more accurate call library so that these identification concerns may be assuaged. Additionally, it is possible that additional species may have been present but undetected (or misidentified). For example, red bats likely used the sites as well, but two issues—the failure to capture an individual and its similarity in call to little brown bats in cluttered habitats—led me to identify borderline calls as little brown bats. It is even possible that an occasional eastern pipistrelle may have used the woodland vernal pools this summer. But without proof by capture, I defaulted to known species’ calls.

Capture success (55 bats in 190 mistnet nights) was small compared to other survey studies conducted across wetlands in recent years. In comparison, Huie (2002) captured 362 bats in 62 mistnet nights in Kentucky, and Carter et al. (1998) captured 132 in 5 weeks (~150 mist-net nights) of surveys on Sapelo Island, Georgia. I speculate that capture success and total

activity are related to a combination of factors—regional summer temperatures, the abundance of alternative water sources across the landscape, and the lower species richness and diversity compared to these surveys further south. I have little doubt that weather played a highly influential role in the success of this project. Local long-term residents stated that summer 2004 was markedly cooler and wetter than the average in the Michigan UP. As invertebrate activity nearly halts around 10°C (50°F), and bat activity is strongly tied to feeding on these invertebrates, it is commonly accepted that bat surveys at temperatures near or below this threshold are rarely successful. In 33% of the survey nights, the temperature dropped below 13°C (55.4°F) by midnight. Bat activity obviously tapered off long before 10°C was reached.

Given the combination of limitations presented in Summer 2004 (relatively cooler weather, need for fine-tuning of Anabat call analysis and creation of a reliable key to bat calls), I plan to continue surveying a subset of these vernal pools in Summer 2005. The pools (5, P, 6, 7, L, J, K, M, N, E, G) are sites in which one or more bats were captured via mistnets. By affixing fluorescent glow-sticks to released bats, Anabat can accurately record individuals for a longer time. Once the call range of multiple individual can be assessed, future studies may be able to implement stronger, more reliable keys to call identification.

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Table 1. General information for 17 vernal ponds (indicated as “VP”), a beaver pond, and a creek crossing, which were sampled for bats and invertebrates in summer 2004.

Site	UTM N	UTM E	Elevation	Max Surface Area (m ²)	Max Volume (m ³)	Dry Date	pH
VP 10	5122945	304149	522	487	244	7/17	5.4
VP 5	5122326	303859	517	262	128	7/18	6.0
VP 6	5122397	303987	519	1318	1002	7/17	4.3
VP 7	5122403	304014	519	408	519	7/17	4.8
VP 9	5122705	304177	524	950	342	7/17	5.2
VP A	5127335	306917	523	61	18	6/28	6.1
VP B	5127239	306902	523	632	240	6/28	6.1
VP E	5125116	303015	515	483	325	7/20	5.7
VP F	5125050	303007	515	375	84	7/3	5.7
VP G	5125041	302778	517	224	168	8/1	5.8
VP H	5125094	302689	521	1088	374	7/11	5.6
VP J	5123712	306379	522	312	187	7/31	5.8
VP K	5123746	306394	518	382	405	8/20	5.7
VP L	5119935	308764	522	314	273	8/12	5.6
VP M	5122280	306352	525	129	71	7/5	6.0
VP N	5122321	306327	518	265	244	8/12	5.9
VP P	5122326	303799	498	675	338	8/12	5.6
Beaver Pond	5124943	307749	515	7825	~11700	None	5.4
Tenderfoot Creek	5125757	304723	501	N/A	N/A	None	7.6

Table 2. Forest attributes within and surrounding woodland vernal ponds surveyed in summer 2004. Listed are the number of trees located within or on the edge of open water, measures of DBH (diameter at breast height) and tree density, percent canopy as measured by a densiometer, volume of “open” flying space above the pond, as measured to the top of the tree canopy and the bottom (where leaves become dense, hindering open flight) of the canopy.

Site	No. trees	Total DBH	Avg. DBH	% Canopy	Volume (up canopy; m ³)	Volume (low canopy; m ³)	Trees/m ²
VP 10	25	245.1	9.8	99.2	8991	1875	0.051
VP 5	0	0	0	100	5527	1694	0
VP 6	18	156.5	8.7	24.5	12430	2039	0.014
VP 7	0	0	0	95.8	7633	2612	0
VP 9	49	709.0	14.5	85.4	19142	4575	0.051
VP A	0	0	0	98	878	371	0
VP B	127	1056.8	8.3	98.7	9936	2522	0.201
VP E	1	41.1	41.1	98.4	10429	1482	0.002
VP F	9	202.3	22.5	93.8	3887	1879	0.024
VP G	0	0	0	95.8	5123	2333	0
VP H	69	1322.7	20.3	88.8	22235	10740	0.063
VP J	25	403.5	16.1	91.1	6893	2591	0.080
VP K	6	25.1	4.2	97.4	5910	1503	0.016
VP L	5	95.6	19.1	98.2	5408	3116	0.016
VP M	5	129.0	25.8	98.7	2600	1411	0.039
VP N	3	62.5	20.8	99	4636	2887	0.011
VP P	0	0	0	65.4	3973	3944	0

Table 3. Bat species captured by date surveyed. Time captured also listed. Dates with asterisks indicate that vernal pool was dry.

Date	Site	Species	Number Captured	Time Caught (minutes after sunset)
3-Jun	VP 5	MYLU	5	43 - 48
19-Jun	VP 5	MYLU	1	24
8-Jul	VP 5	MYLU	2	16, 20
18-Jul	VP 5	MYLU	3	19 - 26
6-Jun	VP 7	EPFU	1	69
6-Jun	VP 7	MYLU	1	221
6-Jun	VP 7	MYSE	1	211
21-Jun	VP 7	MYLU	1	69
9-Jul	VP 7	MYLU	2	37, 43
8-Jun	VP E	MYSE	2	68
22-Jun	VP E	MYLU	1	39
10-Jul	VP E	MYLU	5	34 - 44 (4), 89 (1)
1-Aug	VP F	MYSE	1	40
10-Jun	VP G	MYSE	3	58, 64, 148
11-Jul	VP G	MYLU	1	49
11-Jul	VP G	MYSE	1	49
21-Jul	VP G	MYLU	1	57
2-Aug	VP G	MYSE	1	211
2-Aug	VP H	MYSE	1	210
17-Jun	VP J	MYLU	1	70
2-Jul	VP K	MYLU	4	30 - 40
16-Jul	VP K	MYLU	5	36 - 51 (4), 121 (1)
28-Jul	VP K	MYLU	1	50
4-Jun	VP L	MYLU	1	60
20-Jun	VP L	MYLU	1	49
15-Jul	VP L	MYLU	1	26
15-Jul	VP L	MYSE	1	29
27-Jul	VP N	MYSE	1	198
5-Aug	Beaver	MYSE	1	40
29-Jun	Tenderfoot	MYLU	1	184
14-Jul	Tenderfoot	MYLU	1	62
25-Jul	Tenderfoot	MYLU	1	136
5-Aug	Tenderfoot	MYLU	1	50

Table 4. Anabat calls by date. Any other way to better present this? Figure examples of 4

Date	Site	EPFU	MYLU	MYSE
1-Jul	Beaver	2	55	5
14-Jul	Beaver	0	65	16
26-Jul	Beaver	0	105	1
5-Aug	Beaver	0	156	40
13-Jun	Tenderfoot	0	110	24
29-Jun	Tenderfoot	32	63	7
14-Jul	Tenderfoot	4	100	11
25-Jul	Tenderfoot	16	32	4
5-Aug	Tenderfoot	1	129	59
14-Jun	VP 10	0	48	7
27-Jun	VP 10	0	68	0
13-Jul	VP 10	0	18	1
24-Jul	VP 10	0	23	0
4-Aug	VP 10	0	1	13
3-Jun	VP 5	0	113	3
19-Jun	VP 5	0	122	13
8-Jul	VP 5	0	116	4
18-Jul	VP 5	1	164	10
29-Jul	VP 5	0	90	6
6-Jun	VP 6	13	122	2
21-Jun	VP 6	0	57	12
9-Jul	VP 6	64	211	1
19-Jul	VP 6	3	123	0
31-Jul	VP 6	0	146	2
6-Jun	VP 7	0	113	38
21-Jun	VP 7	0	65	7
9-Jul	VP 7	0	148	4
19-Jul	VP 7	0	97	0
31-Jul	VP 7	0	21	6
14-Jun	VP 9	0	16	0
27-Jun	VP 9	0	79	9
13-Jul	VP 9	0	26	5
24-Jul	VP 9	0	57	1
4-Aug	VP 9	0	5	16
12-Jun	VP A	0	0	1
28-Jun	VP A	0	0	0
12-Jul	VP A	0	0	0
22-Jul	VP A	0	0	2
8-Aug	VP A	0	0	5
12-Jun	VP B	0	108	0
28-Jun	VP B	0	18	5
12-Jul	VP B	0	2	0
22-Jul	VP B	0	109	0
8-Aug	VP B	0	8	5
8-Jun	VP E	0	210	3
22-Jun	VP E	0	40	5
10-Jul	VP E	0	207	16
20-Jul	VP E	0	40	1
1-Aug	VP E	0	74	15
8-Jun	VP F	0	74	11
22-Jun	VP F	0	44	15
10-Jul	VP F	0	19	4
20-Jul	VP F	0	43	2
1-Aug	VP F	0	251	16
10-Jun	VP G	0	244	22
26-Jun	VP G	0	156	3
11-Jul	VP G	0	106	32
21-Jul	VP G	0	107	24
2-Aug	VP G	0	246	46
10-Jun	VP H	13	18	0
26-Jun	VP H	0	69	20
11-Jul	VP H	0	41	4
21-Jul	VP H	0	64	4
2-Aug	VP H	0	138	4
2-Jun	VP J	0	17	3
17-Jun	VP J	0	140	5
2-Jul	VP J	0	36	8
16-Jul	VP J	0	20	3
28-Jul	VP J	0	17	4
2-Jun	VP K	0	12	1
17-Jun	VP K	0	142	26
3-Jul	VP K	0	161	23
16-Jul	VP K	0	17	15
28-Jul	VP K	0	139	11
4-Jun	VP L	0	153	3
20-Jun	VP L	0	229	33
1-Jul	VP L	0	58	4
15-Jul	VP L	0	162	1
26-Jul	VP L	0	59	0
1-Jun	VP M	0	154	1
5-Jul	VP M	0	38	5
17-Jul	VP M	0	97	3
27-Jul	VP M	0	44	1
1-Jun	VP N	0	36	2
16-Jun	VP N	0	83	2
5-Jul	VP N	0	51	5
17-Jul	VP N	0	210	12
27-Jul	VP N	0	78	15
3-Jun	VP P	0	92	1
19-Jun	VP P	0	218	0
8-Jul	VP P	0	118	0
29-Jul	VP P	0	112	0

Table 5. Shannon-Weiner index of diversity, calculated for invertebrates collected each evening, sampled over five rounds. Vernal pools J & K and M & N pooled because these neighboring sites shared a common blacklight set-up.

Site	Round 1	Round 2	Round 3	Round 4	Round 5
VP 10	0.377	0.821	1.044	0.854	0.741
VP 5	0.547	0.530	0.754	1.371	1.060
VP 6	0.664	0.377	0.905	1.284	1.173
VP 7	0.933	0.685	1.115	1.511	1.154
VP 9	0.651	0.656	0.948	0.824	0.842
VP A	0.648	0.734	1.102	1.046	1.100
VP B	0.887	0.637	1.172	0.981	0.954
VP E	0.842	0.754	0.767	1.068	0.988
VP F	0.481	0.846	0.965	1.046	1.082
VP G	0.669	0.735	1.056	0.802	0.687
VP H	0.449	0.654	1.126	0.890	1.085
VP J&K	0.886	0.594	0.856	1.001	1.094
VP L	0.893	1.316	0.871	1.137	1.207
VP M&N	0.809	0.628	0.776	1.072	1.213
VP P	0.416	0.379	0.671	1.047	1.131
Beaver Pond	0.665	0.868	0.855	1.181	0.779
Tenderfoot Creek	0.369	0.411	0.559	1.327	1.307
Average	0.658	0.684	0.914	1.085	1.035

Table 6. Pearson's product-moment correlations (r ; p -value in parentheses) comparing bat species measures and habitat measures for 17 woodland vernal pools. Bats measure above dotted line is the average number of Anabat calls per round, while below dotted line examines bat calls for each specific round as the presence and area of open water changes. Significant ($p < 0.10$) correlations in bold.

	EPFU	MYLU	MYSE
Area of open water (maximum)	0.668 (0.003)	-0.012 (0.963)	-0.222 (0.391)
Canopy coverage (densiometer)	-0.890 (0.001)	-0.240 (0.353)	0.307 (0.230)
No. Trees	0.022 (0.934)	-0.451 (0.070)	-0.290 (0.259)
Trees/m ²	-0.093 (0.723)	-0.482 (0.050)	-0.312 (0.223)
DBH (average)	-0.065 (0.804)	0.031 (0.906)	-0.132 (0.613)
Volume to lower canopy	0.027 (0.917)	0.001 (0.996)	-0.075 (0.774)
Volume to upper canopy	0.280 (0.276)	-0.207 (0.426)	-0.026 (0.920)
Distance to road	-0.075 (0.776)	0.159 (0.541)	0.295 (0.250)
Distance to permanent water	-0.102 (0.697)	-0.714 (0.001)	0.051 (0.846)
Persistence of water (days)	-0.112 (0.668)	-0.187 (0.472)	-0.315 (0.218)
Open water present (m ²)	0.296 (0.007)	0.090 (0.419)	0.023 (0.837)
Open water remaining (area, %)	0.042 (0.711)	0.191 (0.085)	0.099 (0.377)

Figure 1. Map of 17 woodland vernal pools surveys in Summer 2004, represented by grey triangles. Outgroup sites represented by black triangle (creek) and white triangle (beaver pond). Boundaries represent those of UNDERC property. Sites outside of UNDERC are located on Ottawa National Forest.

Figure 2. Numbers of individuals from eight major invertebrate orders collected for each round of sampling at four representative sites: (A) VP 5, a relatively small, deep pool at UNDERC; (B) VP B, a large, shallow pool amidst an ash-dominated stand on the Ottawa National Forest; (C) VP 6, a large open bog-like site at UNDERC; and (D) Tenderfoot Creek, an outgroup site at UNDERC, demonstrating the influence of vast mayfly (Ephemeroptera) emergences on invertebrate collections. *Note the extreme differences in scale (y-axis) across sites.*

Figure 3. Average number of bat calls across 30 minute-intervals for all evenings. Times are seasonally adjusted to hours past time of sunset. Despite the great variability among sites (as indicated by confidence intervals), a significant trend indicated highest activity within the first hour after sunset.





