Initial Response of Amphibian and Small Mammal Species to Timber and Coarse Woody
Debris Harvest in Aspen-Dominated Forests of Northern Minnesota

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Dedication

This thesis is dedicated to my mother, Theresa. Thank you for always supporting my fascination with the natural world and the creatures that inhabit it.

Abstract

Recently, there has been growing public awareness of both the finite nature and the ecological effects of using fossil fuels to generate energy. This public awareness has created an increased interest in renewable bioenergy resources, especially those produced within a nation's own borders. In light of this fact, I addressed whether the relative abundance and body condition of amphibians and small mammals varied predictably across forest plots that differ in the amount of woody biomass removal using drift-fence arrays and visual encounter surveys. Results varied between species. However, only two species (*Blarina brevicauda* and *Lithobates sylvaticus*) showed a clear negative response to harvest. These data showed that the initial effect of harvest, or harvest and green tree reserve type, appear to be important predictors for many of the amphibian and small mammal species studied. To ensure forest sustainability, further study during stand maturation will be necessary to better ascertain the long-term effects of coarse woody debris harvest on amphibian and small mammal species.

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1. Introduction

Recently, there has been growing public awareness of both the finite nature and the ecological effects of using fossil fuels to generate energy. This public awareness has created an increased interest in renewable bioenergy resources, especially those produced within a nation's own borders. One source of potential energy, which has received recent attention in Minnesota and the United States as a whole, is energy derived from woody materials (i.e., woody biomass; Evans and Finkral, 2009; Stidham and Simon-Brown, 2011). Woody biomass is defined as parts (e.g., boles, branches, twigs, stumps, and roots) of bushes, shrubs and trees, and can be harvested as *whole tree* (i.e., boles and limbs harvested as dedicated energy crop) or *coarse woody debris* (hereafter, CWD; i.e., slash that is typically left behind during traditional logging practices).

The most common forms of harvested woody biomass come from roundwood products (78%; e.g., fuel wood, pulpwood, saw logs, veneer wood) followed by the non-merchantable portion of above-ground trees (16%; e.g., limbs; Perlack et al., 2005). Dedicated energy crops such as *short rotation forests* (SRF) are increasing in popularity (Hardcastle, 2006), as is the use of the non-merchantable portion of above ground sections of shrubs (e.g., non-native understory species such as Eurasian buckthorn; Barbara Spears, MN DNR, pers. comm.). These materials are then used as a

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supplementary fuel source (i.e., mixed with coal) to generate electricity at coal-fired power plants under the assumption that the harvest of woody biomass can operate in a sustainable manner (Janowiak and Webster, 2010).

A source of contention regarding the use of woody biomass as a sustainable source of bioenergy is its potential to sequester carbon (i.e., atmospheric CO_2). Woody biomass is often proposed as a "carbon neutral" or "carbon negative" energy source (i.e., the amount of carbon released during combustion is equal to or less than the amount of carbon sequestered over the lifetime of the tree or shrub). However, because temperate and boreal forests contain a large portion of the terrestrially sequestered carbon, as both above-ground biomass and below-ground organic matter, removing above-ground biomass may impede the processes that transfer carbon into the below-ground organic realm. For example a decrease in woody materials (especially CWD) on the forest floor may result in lower below-ground sequestration potential in mature systems (Hyvönen et al., 2007). The ability to calculate robust estimates of carbon sequestration potential in temperate and boreal forests is often complex and only now becoming available (Hyvönen et al., 2007). Thus, considerable ambiguity exists as to whether energy derived from woody biomass is truly carbon neutral.

The increasing interest in the use of woody materials, especially deadwood, as a supplementary feedstock for coal-fired power plants has generated concerns regarding the ecological impact and sustainability of these practices in relation to wildlife and other ecosystem services (Fargione et al., 2009; Janowiak and Webster, 2010). While the impacts of traditional silvicultural harvest on terrestrial amphibian species (e.g.,

deMaynadier and Hunter, 1998; Yaunches, 1998; Harpole and Hass, 1999; Herbeck and Larson, 1999; Grailou et al., 2000; Semlitsch et al., 2009; Peterman et al. 2011), and small mammal species (reviewed: Kirkland, 1990) are well documented in the literature, little is known about the impacts of biomass harvesting that removes the additional woody materials typically left behind during traditional silvicultural harvest on forest floor vertebrates. Given their size and relatively low internal volume (amphibians and small mammals have high surface to volume ratios), most amphibians and small mammals are extremely susceptible to evaporative water loss (Chew and Dammann, 1961). In addition to the removal of forest canopy, the harvest of CWD and other woody materials may influence environmental H_2O availability (e.g., soil moisture) as well as other abiotic factors (e.g., soil temperature, UV-radiation, etc.), which may impact an individual's ability to regulate water loss as well as other important physiological processes. Monitoring the potential impacts of biomass harvesting on amphibian and small mammal species is imperative given that they are often used as indicator species for environmental health (Blaustein, 1994; Pearce and Venier, 2005), represent a significant portion of vertebrate biomass in these systems (i.e. energy in the form of prey for species higher on the food chain; Pough, 1980), and are important for maintaining forest health as well as tree and plant diversity (e.g., many species disperse seed and/or accelerate the decomposition of organic materials on the forest floor).

In this study, I investigate the responses of amphibians and small mammals to biomass harvesting using post-harvest capture data gathered in 2010. Specifically I address three commonly tested hypotheses: the mortality, evacuation, and retreat

hypotheses (Semlitsch et al., 2008, 2009; Peterman et al. 2011). Many studies have attempted to elucidate the mechanisms responsible for the observed species-response to timber harvest and other disturbances (Krefting and Ahlgren, 1974; Kirkland, 1990; deMaynadier and Hunter, 1998; Pearce and Venier, 2005, Semlitsch et al., 2008, 2009; Pollet et al., 2010; Peterman et al., 2011), though few have applied these three hypotheses to small mammal species. Given that I do not assume the species-specific response is unidirectional for all species (i.e., species may be positively, negatively or neutrally impacted by harvest), I modified the nomenclature for the hypotheses reviewed above (e.g., mortality − change in survival, evacuation − change in immigration or emigration and retreat − change in above-ground activity patterns; Petranka, 1993, 1994; Johnston and Frid, 2002; Semlitsch et al., 2008, 2009; Peterman et al., 2011). Using a model based approach, I included parameters in each model that could provide evidence for one or more of these hypotheses. Statistically significant differences in initial response to harvest could be viewed as either a change in survival as a result of direct harvest-induced mortality or plot-level differences in species abundance pre-harvest (Fig. 1a). Significant support for harvest by sampling period interaction parameters lends support to changes in survival, changes in immigration or emigration, or even changes in above-ground activity patterns, especially when accompanied by an inverse control by sampling period response (Fig. 1b). Here, I address whether the relative abundance and body condition of amphibians and small mammals varies predictably across forest plots that differ in the amount of biomass removed.

2. Methods

2.1. Study area

Research sites were located in temperate mixed hardwood forests in Saint Louis County, Minnesota. These areas were dominated by quaking aspen (*Populus tremuloides*), big tooth aspen (*Populus grandidentata*), and sugar maple (*Acer saccharum*). Additional species present at each site included paper birch (*Betula papyrifera*), white pine (*Pinus strobus*), balsam fir (*Abies balsamea*), as well as black and white spruce (*Picea mariana* and *Picea glauca* respectively). Sampling occurred on two 40-hectare (ha) study areas (hereafter "Site-1" and "Site-2") separated by approximately 28km. Both sites were owned and managed by Saint Louis County (Fig. 2). In cooperation with the University of Minnesota's Department of Forest Resources, sites were harvested during the winter of 2009 / 2010. Each site received three levels of biomass harvest and retention of green tree reserves in a fully factorial design (Fig. 3), along with an untreated control. Each treatment area was a minimum of 4-ha.

2.2. Environmental variables

Harvest type (i.e., harvest vs. control) and green tree reserve type (i.e., none, dispersed, clumped) for each of the 10 plots at a given site were recorded at the beginning of the study. Green tree reserves followed Minnesota Forest Resources Counsel guidelines for dispersed (6-12 per acre) and clumped (two 0.25 acre clumps per treatment) reserve type. Several additional metrics were recorded during every visit to each sampling location: start time, temperature (i.e., soil surface and soil at 15 cm), soil

moisture, and survey method (drift fence vs. visual search). Soil surface temperatures were recorded using an Extech IR Thermometer & Humidity Meter (Model: RH101) and soil temperature at 15 cm was recorded using an analog soil thermometer. Volumetric water content (i.e., soil moisture) was recorded with a Field Scout Soil Moisture Probe (Model: TDR 200). Daily high and low air temperatures and daily totals of precipitation were acquired from a local weather station located within 15km of each site (47.16539° N, 92.41526° W; Station 211840).

The volume of CWD was estimated for each of the 10 plots per site using the formula:

$$V = (\pi^2 \times \sum d^2 \div 8L) \times 10000$$

where V is the volume (m^3 / ha), d is the diameter of CWD (m), and L is the transect length (m) (adapted from Van Wagner, 1968). I estimated the volume of CWD on each of the 10 plots at each site. Measurements were taken at four random locations (same locations as each of the two drift fence arrays and time- and area-constrained quadrats), each with a transect length of approximately 45 m (i.e., 180 m per plot) using four Y-shaped transects (each with three 15 m wings). CWD debris was defined as woody materials $\geq$ 5 cm in diameter and $\geq$ 10 cm in length.

2.3. Vertebrate sampling

Sampling occurred on nine experimentally manipulated plots and an untreated control at each of the two study sites. There are a variety of accepted standard techniques for sampling amphibian and small mammal species including but not limited to box-traps

(e.g., Sherman Traps), snap-traps, and pitfall traps (with and without drift-fence arrays), visual encounter surveys, and cover board arrays (Heyer et al., 1994; Wilson et al., 1996). I selected to sample all nine plots and the control using drift-fence arrays for small mammals, and both drift-fence arrays and time- and area-constrained searches for amphibians. Each drift-fence array and time- and area-constrained search quadrat area were randomly placed at least 15m from the edge of the treatments to minimize edge effects, and at least 50 m from each other, using ArcView (v.9.0; ESRI) with the third-party Hawth's Analysis Tools extension. Sampling for amphibians and small mammals occurred during three discrete occasions from mid-June to mid-August 2010, consisting of 8, 10, and 9 consecutive days respectively. Approximately 14 days separated each of the three sampling periods.

After capture, small mammals were identified to species, and if alive, a single mark was placed on the underside of the tail to facilitate the quick and easy identification of previously marked individuals. Amphibian species were marked using a marking system corresponding to the sampling period in which they were captured, allowing groups of individuals marked during each of the three sampling periods to be distinguished from each other (Fig. 4). Individuals also received a plot-specific toe-mark, allowing the detection of between-treatment movements. Recaptured individuals found during subsequent sampling periods were given an additional mark in the location corresponding to the sampling period in which it was recaptured. At the end of the 2010 field season individuals had up to three sampling period-specific marks and a single plot-specific mark corresponding to their original capture location. Both amphibians and small

mammals were marked using visual implant elastomer (hereafter VIE; Northwest Marine Technology, Inc.; see: Nauwelaerts et al., 2000), after which they were released approximately 15m from the site of capture. Using VIE to mark amphibians is an accepted technique that has a significantly higher mark retention rate when compared to standard toe clipping practices (Davis and Ovaska, 2001). At least one study has observed individual salamanders (*Eurycea spelaea*) with visible VIE marks ≥ three years post injection (Dante Fenolio, Atlanta Botanical Garden, pers. comm.).

Incidental visually encountered amphibian species not previously captured in drift fence arrays or time- and area-constrained searches were noted and included in treatment and site-level species richness estimates, but were not marked, and were excluded from all other analyses. Aural data for anurans were excluded from all comparisons and analyses.

A representative sample of the small mammal species found dead in pitfall traps were deposited in James Ford Bell Museum of Natural History's mammal collection, University of Minnesota (Appendix 1).

2.3.1. Time- and area- constrained searches

Heyer et al., (1994) recommended that searches be conducted within 8m x 8m quadrats, allowing for easier comparison between studies. Following this recommendation, I randomly placed two 8m x 8m quadrats in each survey plot. Six time- and area-constrained searches were performed in each plot, two per plot per sampling period. These searches consisted of 20 person-minutes of searching per quadrat for a total

of 120 person-minutes per plot per year. An undergraduate field assistant and I performed low-impact visual searches (i.e., replacing objects to original positions) within each quadrat to allow for repeated sampling. Quadrats were typically sampled before 1200 hours or during preferred weather conditions (e.g., overcast skies, light rain, and/or cool temperatures) to maximize the probability that amphibians would be above-ground.

2.3.2. Drift fence arrays

Drift fence arrays were constructed using 90cm wide silt fencing, which was partially buried so that approximately 75cm was above ground. An array consisted of three wings, each approximately 7m long and spaced 120° from each other, with dark blue 19L buckets for the pitfall traps (Fig. 5; see: Gibbons and Semlitsch, 1981; Crawford and Kurta, 2000). These larger diameter pitfall traps are known to be more effective than the smaller diameter pitfall traps traditionally used in amphibian studies (Friend et al., 1989). Pitfalls were filled with approximately 2-4cm of water, and a flat rock and/or sponge to protect amphibians from desiccation and reduce the possibility of small mammal escapes. Each plot was sampled using two drift-fence arrays that were opened during each of three sampling periods. Pitfall traps were checked every other day due to the large size of sites, number of pitfall traps installed, and personnel limitations. Buckets were closed with secure-fitting lids when not in use.

2.4. Data Analyses

Given the high mortality rates associated with small mammal pitfall trapping and relatively low sample sizes for many of the amphibian and small mammal species encountered, I used initial capture data (i.e., excluding recaptures) from drift-fence captures as an index of amphibian and small mammal relative abundance (Menkens and Anderson, 1988). Index of body condition for the two species of amphibian with ≥ 50 captures were developed using "gape width" (Rogers, 2009) and mass to compare the effects of harvest on body condition during the study (methods reviewed in: Schulte-Hostedde et al., 2005). Time- and area-constrained search encounters and incidental observations were included for site-level comparisons (e.g., site-level species richness comparisons), but excluded from analyses used to model the response of captures vs. treatment effects and covariates. Shrew species (*Sorex* spp.) captured in drift fence arrays were pooled for regression analyses because of difficulties in identification and to allow easier comparison to studies using higher taxonomic rankings for analyses (e.g., soricids).

Using the software package R (v 2.14, 2011), I first determined which distribution (i.e., normal, Poisson, or negative binomial) the individual species daily count data most closely followed. These initial investigations indicated that data were both over-dispersed and contained excess zeros. Because of this, and partially due to the difficult nature of running generalized linear mixed models following a negative binomial distribution in R, capture data were aggregated across days into the 3-decrete sampling periods outlined in the survey methods. This greatly reduced the zero-inflation present in these data (Tu, 2002), and these aggregated data more closely followed a Poisson distribution. I then

tested several *a priori* models for each of the amphibian and small mammal species (or species groups) with sample size ≥ 50 (Table 1) using generalized linear mixed models (GLMMs) in R with the 'lme4' package (Bates et al., 2011). Full models considered several fixed effects as well as a single random effect of "Plot" to better account for between plot variability and repeated measures (Table 2). All models included either "Harvest" (i.e. harvested vs. unharvested control) or "Treatment" (i.e., green tree retention level vs. unharvested control) as fixed effect parameter(s) because of the important biological and experimental relevance (i.e., all models include a 'Harvest' parameter regardless of statistical support or a 'Treatment' parameter when supported by AIC). I used Akaike information criterion (AIC; Burnham and Anderson, 2002), corrected for small sample sizes (i.e., AIC_c), to evaluate model support. I then removed unsupported fixed-effect parameters one by one until either all-remaining parameters were supported statistically and/or until models were penalized via an increase in AIC_c. All models, especially those within 2 ΔAIC of the top-performing model, were examined for uninformative parameters and these models were dismissed in favor of simpler and better-supported (i.e., lower AIC_c) models (Arnold, 2010).

Models were also assessed for whether the addition of several interaction effects increased model fit. In an effort to evaluate the three hypotheses of interest (i.e., change in survival, change in immigration or emigration, and change in above-ground activity patterns), I focused most heavily on three specific parameters of interest. First, I assessed statistical support for a fixed-effect of harvest for each species; or treatment when supported by AIC_c. Statistical support for this parameter was interpreted as the *initial*

response to harvest (regardless of directionality) and likely represented a change in survival but could possibly be explained as plot-level differences in pre-harvest species abundance without support from additional parameters. Second, statistical support for temporal change between sampling periods (i.e., an increase or decrease in abundance through time) was interpreted as evidence for either an increase in survival when positive (or lack of a decrease in mortality through time) or a temporal change in above-ground activity; providing some support for the change in survival and/or change in above-ground activity patterns hypotheses. Third, statistical support for an interaction between harvest and sampling period parameters was interpreted as support for temporal changes in survival, immigration or emigration, or possibly above-ground activity patterns on harvested plots. Additional support for a change in species immigration or emigration is increasingly evident when accompanied by an inverse control by sampling period response (i.e., support for emigration from the surrounding un-harvested area into the harvested area).

3. Results

3.1. Environmental Variables

The volume of CWD in plots ranged from $52.9 – 143.9 \text{ m}^3$ / ha (mean = 97.1 m^3 / ha; n = 18 plots) for harvested plots and $42.4 – 69.0 \text{ m}^3$ / ha (mean = 55.7 m^3 / ha; n = 2 plots) for control plots. CWD volumes did not differ among experimental sites (Fig. 6). Soil moisture levels were elevated in harvested plots at Site-1 by about 14% but little effect of harvest on soil moisture levels was detected at Site-2 (Fig. 7). At Site-1, elevated soil

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moisture levels in the harvested plots remained elevated during the course of the study (Fig. 8). Soil temperature at 15cm below the surface was elevated in harvested plots at both sites but differences lacked significance.

3.2. Vertebrate Sampling

3.2.1. Time- and area- constrained searches

Time- and area-constrained visual encounter searches (VES) resulted in only 15 captures representing five species of amphibian during 40 person-hours of searching (Table 3). Red-backed salamanders (*Plethodon cinereus*) were the most commonly encountered amphibian species during VES surveys (n=6, 40.0%) followed by American toads (*Anaxyrus americanus*; n=4, 26.6%). Time- and area-constrained visual encounter surveys out-preformed drift-fence arrays with regard to *P. cinereus* and *Pseudacris crucifer* capture success but performed poorly for other amphibian species. *Pseudacris crucifer* was the only species of amphibian detected using VES surveys that was not detected using drift-fence arrays.

3.2.2. Drift fence arrays

During a single season of trapping, 3,067 captures (including recaptures) of 18 species of amphibian and small mammal resulted from 540 array-nights per site (Table 4). *Sorex* spp. were the most frequently encountered small mammals, comprising approximately 42.2% of all small mammal captures. *Microtus pennsylvanicus* and *Myodes gapperi* comprised approximately 31.5% and 13.4% of all small mammal

captures, respectively. *Anaxyrus americanus* and *Lithobates sylvaticus* comprised

approximately 82.9% and 13.2% of all amphibians captured, respectively. Recaptures for

both groups were low with only 37 recaptured amphibians and 32 recaptured small

mammals. Of the 37 recaptured amphibians, 36 (97.3%) were *A. americanus*, and a single

L. sylvaticus (2.7%). Small mammal recaptures included several species: *M.*

pennsylvanicus (n=17; 53.1%), *Sorex* spp. (n=7; 21.9%), *M. gapperi* (n=3; 9.4%), and

Zapus hudsonius (n=3; 9.4%). *Blarina brevicauda* and *Peromyscus maniculatus* were

each recaptured on a single occasion (n=1; 3.1%).

3.3. Capture associations

Using top-ranked model(s), I identified variables that best explained the relative-

abundance of individual species or species groups during the course of this study. Only

two species of amphibian (*A. americanus* and *L. sylvaticus*) were captured with sufficient

frequency to model capture associations. Both amphibian species showed a negative

initial effect of harvest on abundance, although this initial harvest effect for *A.*

americanus was weak and not supported statistically (Tables 5-6; Figs. 9-10). However,

there were significant positive clearcut (i.e., Treatment-2) by period interactions for

periods-2 and -3 indicating that *A. americanus* captures increased significantly in clearcut

plots. Additionally, there were near significant decreases in *A. americanus* abundance

through time in the un-harvested control plots as well as in harvested plots with dispersed

green tree reserves by sampling period-3 (i.e., Treatment-3 * Period-3 interaction).

Six small mammal species, or species groups (e.g., *Sorex* spp.), were captured with enough frequency to model capture associations. The initial response to harvest varied by species and included positive, negative and neutral effects. The top-ranked model for *M. pennsylvanicus* included a significant positive effect of harvest at Site-2 but no effect of harvest was detected at Site-1 (Table 7; Fig. 11). Captures of *M. pennsylvanicus* significantly increased through time in both harvested and non-harvested plots across both sites. Similarly, the top-ranked model for *M. gapperi*, lacked support for an initial effect of harvest. However there was weak support for a positive harvest by period-2 interaction (p = 0.08; Table 8; Fig. 12). However, this model included a significant parameter for mean minimum daily temperature as well as a marginally significant parameter for mean daily by-plot belowground soil temperature (p = 0.07). Two equally competitive models ranked highest for *B. brevicauda* (Table 9; Fig. 13). The first, and slightly more complex, model included a negative initial effect for harvest across all the three levels of green tree retention types as well as a marginally significant positive effect of volume of CWD. The model also indicated a positive temporal effect across all treatments and controls. The second model included a negative response to harvest (regardless of green tree reserve type) as well as a positive temporal effect (i.e., positive effect through time). However, this positive temporal effect increased in parallel between harvested and non-harvest plots through time. Two equally competitive models ranked highest for *P. maniculatus* as well (Table 10; Fig. 14). The first, and slightly more complex, model included positive non-significant initial response to harvest (p = 0.487) as well as weak non-significant interactions between harvest and periods-2 and -3, though

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the inclusion of these interaction terms were supported by AIC. Relative abundance for

P. maniculatus seemed to be influenced more heavily by abiotic conditions (i.e., mean

minimum daily temperature and mean daily precipitation) than by timber harvest. Again,

two equally competitive models ranked highest for *Z. hudsonius* (Table 11; Fig. 15). Both

models showed a positive response to harvest; however the effect of harvest lacked

significance in both models. Both models included a weak negative significant effect of

CWD volume. The top-ranked model for *Sorex* spp. was by far the most complex of the

species analyzed (Table 12; Fig. 16). The top-ranked model included positive initial

responses to harvest that included all the three levels of green tree reserves

('Treatments'). Significant positive interactions between experimental treatments by

Periods-2 and -3 were supported. Sorex captures were positively correlated with mean

daily precipitation. In addition, Sorex captures were positively correlated with below-

ground soil temperature on un-harvested plots while negatively correlated in harvested

plots.

3.4. *Effects on Amphibian Body Condition*

    Using simple linear models in R (v2.14, 2011), I compared the effects of harvest

(regardless of green tree reserve type) and harvest with respect to green tree reserve type

as well as the interaction of these parameters through time (i.e., by sampling periods) on

amphibian body condition (BC) for both *A. americanus* and *L. sylvaticus* (i.e., the two

amphibian species with sample sizes of ≥ 50).

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For *A. americanus*, the best model had a non-significant harvest effect (p = 0.17) as well as a non-significant positive temporal effect (p = 0.14) regardless of the presence of green tree reserves. For *L. sylvaticus*, the best model had a non-significant harvest effect (p = 0.61) but a significant positive temporal effect on BC (p < 0.05). While it is reasonable to suspect an increase in BC through time, interpretation is cautioned due to small sample size during sampling Period-3.

4. Discussion

These data support previous work showing that the initial effect of harvest, or harvest and green tree reserve type, appears to be an important predictor of captures for many of the amphibian and small mammal species studied (Monthey and Soutiere, 1985; Kirkland, 1990; Knapp et al., 2003). As expected, the response to harvest for many of the species tended to intensify temporally, as was evident by the statistical support for harvest by sampling-period interaction parameter(s) in many of the models generated. The significant positive clearcut (i.e., Treatment-2) by period interaction for Periods-2 and -3 indicated that *A. americanus* abundance increased significantly in clearcut plots. This observation is contrary to the results of similar studies that focus exclusively on forest dependent species (Herbeck and Larson, 1999; Knapp et al., 2003; Peterman et al., 2011), and indicated that *A. americanus* may actually benefit from harvest, specifically harvest with high-intensity disturbance. This observation, along with the decrease in *A. americanus* abundance through time in the un-harvested control plots and by Period-3 in harvested plots with dispersed green tree reserves, lends support for an increasing

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immigration rate into clearcut plots from less-disturbed plots and fails to provide support for a change in above-ground activity patterns. In addition, the lack of significant change in body condition between harvested and non-harvested sites for *A. americanus*, as well as the lack of significant change in body condition through time regardless of plot treatment, fails to provide support for changes in survivorship. However, Semlitsch et al., (2009) showed that the effects of harvest on amphibian species, specifically those with aquatic larval periods, could vary between life stages. Therefore, interpretation of these results should be done cautiously.

Conversely, *L. sylvaticus* (typically considered a forest-dependent species; Oldfield and Moriarty, 1994) showed a significant negative initial response in abundance to harvest in both supported models as well as a significant negative temporal response in abundance for both harvested and non-harvested control plots in model (see: 'LISYb' in Table 6). This was most likely a result of decreasing activity during the warmer months. However, it may also be explained by the close proximity of control and harvested plots given that *L. sylvaticus* is known to have home-range sizes on the order of 70 to 1000+ m^2 (Blomquist and Hunter Jr., 2010). The lack of significant change in initial body condition between harvested and non-harvested sites for *L. sylvaticus*, in addition to the significant positive change in body condition by period-3 regardless of green tree reserve type, failed to provide support for changes in survivorship or above-ground activity patterns. We would expect to see a significant negative effect on body condition through time in order to lend support for a negative effect on survival or support for a decrease above-ground activity. Given that body condition increased through time for *L. sylvaticus*

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they presumably experienced a net-gain in energy (i.e., prey) and therefore are most likely not spending more time than expected in refugia (i.e., retreats). Given the significant temporal decrease in abundance and positive temporal effect on body condition regardless of harvest, this observed pattern is best explained by an increase in emigration from the harvested plots and surrounding area.

Of the six small mammal groups analyzed, four showed little to no support for an effect of harvest on abundance initially or temporally (e.g., *M. pennsylvanicus, M. gapperi*, *P. maniculatus* and *Z. hudsonius*). A single species, *B. brevicauda,* showed a well-supported initial negative response to harvest, which was evident in both top-ranked models. Interestingly, Probst and Rakstad (1987) sampled similar habitat (*Populus* spp. dominated forest) in Northeastern Minnesota and the Upper Peninsula of Michigan for small mammals using baited snap-traps but their capture data differs markedly. Their research focused on three discrete stand-ages (i.e., recent clearcut – 1 to 3 years, saplings – 4 to 12 years, and mature forest – 45 to 75 years, post harvest), with their 'youngest' and 'eldest' stands closely approximating the stand-ages sampled during this study. In spite of these similarities, results differed greatly. Most notably, they captured very few *Sorex* spp. in general; the most commonly encountered small mammal species-group during my 2010 sampling season (> 1000 individuals; Table 1). This difference is most easily explained by differences in sampling methodology, which they acknowledge. Differences in sampling methodology are an important, often overlooked, consideration when trying to compare studies of this sort (Williams and Braun, 1983).

The observed decreased abundance for *B. brevicauda* in harvested plots support the findings of Probst and Rakstad (1987) and provided possible evidence for a decrease in survivorship in the harvested plots (e.g., direct mortality as a result of harvest). However, without pre-harvest data for these plots, it is difficult to conclude whether or not the observed difference in initial abundance can be attributed to the direct-effect of harvest-induced mortality. Three of aforementioned species (*M. pennsylvanicus, P. maniculatus* and *Z. hudsonius*) are typically considered to prefer habitat with sparse canopy cover, the fact that both sites were heavily wooded pre-harvest resulted in relatively small samples size for both *P. maniculatus* and *Z. hudsonius*; a possible indication of recent immigration into these sites. However, both well-supported models for *Z. hudsonius* included a near significant negative effect of CWD volume on abundance. Additionally, though supported by AIC_c, one of the two top-preforming models for *P. maniculatus* included non-significant harvest by period interaction parameters. Again, likely an artifact of small sample size for this species.

Microtus pennsylvanicus showed a weak negative non-significant initial effect of harvest at Site-1. However, statistical support for a negative harvest by Site-2 interaction parameter indicates that harvest initially affected *M. pennsylvanicus* positively at Site-2. Even though the model is lacking a significant harvest effect, the significant negative effect of belowground soil temperature on *M. gapperi* abundance is interesting because it elucidates a possible underlying abiotic condition that may result in support for changes in above-ground activity patterns.

The effect of harvest on *Sorex* spp. were overwhelmingly positive. All three experimental treatments (i.e., clearcuts, harvest with dispersed green tree reserves, and harvest with clumped green tree reserves) showed statistically significant positive initial responses to harvest in addition to significant positive interactions between harvest and sampling periods. However, there was a near significant decrease in abundance in un-harvested plots during Period-2 and -3. These results readily support the hypothesis of increased immigration into the harvested plots from the un-harvested plots.

With regard to the three hypotheses of interest, these results provide evidence for species-specific responses to harvest within and between taxonomic groups. Evidence for all three hypotheses was presented, however it is likely that observed changes in abundance or body condition are likely a result of multiple processes working in unison. That said, relatively minor changes in harvest practices and overall forest management may increase the sustainability of harvest with regard to the preservation of individual species and species communities in similar forest systems.

4.1. Conclusions

4.1.1. Considerations and limitations

As always, it is important to understand the limitations and caveats associated with data collected; especially those collected *in-situ*. Small sample sizes for many species of amphibian captured during the study limited my ability to generate models representing their response to timber and CWD harvest. Both species of amphibian included in analyses are known to be capable of dispersing over relatively large distances within

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short periods of time. Because of this, the effect of harvest is likely lessened with regard to the persistence of these species in the area through time (i.e., they are likely to immigrate into, or emigrate from, the area until more favorable conditions return). Species with reduced dispersal capabilities (e.g., plethodontid salamanders) are likely to experience an increased effect of harvest. If individuals from species with reduced dispersal capabilities fail to escape unfavorable conditions post-harvest, they are likely to be extirpated from the area until favorable conditions allow for the slow recolonization of the area, provided adequate source populations are maintained on the landscape.

Another limitation of the study was limited site-level replication. Only two sites (separated by approximately 25 km) were sampled during this study: due primarily to funding and personnel constraints. While site-level difference in species abundance are reported in many of the models generated, only *M. pennsylvanicus* showed differential effects of harvest by site. This allows the extrapolation of these results to similar forest systems in the region with some confidence. However, without sampling across multiple years, it is possible that the observed effect of harvest may in fact be better explained by natural between-year fluctuations of population dynamics (Boonstra et al., 1998; Salvidio, 2009).

Another consideration that should be acknowledged, especially when attempting to compare these results to the results from similar studies, are the differences in sampling methodology. This study used two common methods of data collection with regard to capture of amphibian species. However, visual encounter surveys preformed poorly overall and wasted time and money. Many studies that focus exclusively on small

mammals species used different sampling methodologies (Wilson et al., 1996). In lieu of using a number-10 can as the pitfall trap (typical of many small mammal trapping studies), this study opted to use large 19-L buckets in combination with partially buried fencing material in an attempt to prevent saltatory frogs from escaping.

4.2.2 Summary and management implications

The use of woody materials, especially CWD obtained during timber harvest, as a source of bioenergy has generated concerns regarding the ecological impact and sustainability of these practices in relation to wildlife and other ecosystem services. Evidence for an initial response to timber and CWD harvest for several species of amphibian and small mammals are presented above. The three hypotheses of interest (i.e., change in survival, change in immigration or emigration or change in above-ground activity patterns) are addressed, and provide evidence for species-specific responses to harvest within and between taxonomic groups. While an impact of CWD retained on-site was not detected for many of species in this study, we should be cautious about any conclusions. The volume of CWD retained on-site will likely play an important role with regard to recolonization of species that emigrated from the harvested areas as well as the carrying capacity of the system going forward. As CWD begins to decay, it will likely provide refugia for individuals moving through the harvested area, possibly counter-acting the effects of changes in soil moisture and temperature.

In an effort to increase sustainability, the dispersal abilities for species of conservation interest should be considered before harvest. Changes in the overall area of

harvest, green tree reserve type, edge effects and barriers to dispersal will likely influence the effect of timber and CWD harvest on the persistence of small vertebrate species. In addition, the impact of future climate change may influence species' ability to respond to disturbance in these forested systems, especially for species presently living near the edge of their physiological tolerances (e.g., species living at the edge of their range).

4.2.3 Future direction

To provide a more complete understanding of the temporal effects of harvest, specifically CWD harvest, on forest floor vertebrates, it would be beneficial to include a parameter in the model that accounts for temporal change in volume and decay class of retained CWD within a system. Models could include parameters for CWD input from harvest as well as from natural stand-level dynamics (e.g., tree death and wind-throw) while accounting for CWD loss (e.g., decomposition and harvest). Given that the majority of CWD retained on-site is 'new' material, its benefit is not likely to be realized until many years post-harvest. To ensure forest sustainability, further study during stand maturation will be necessary to better ascertain the long-term effects of CWD harvest on amphibian and small mammal species.

Table 1.

List of amphibian and small mammal species with samples sizes ≥ 50 (excluding recaptures) captured in drift-fences during this study in Saint Louis County, Minnesota, 2010. All species listed were captured at both sites.

Common Name	Scientific Name	Sample Size n =
American Toad	*Anaxyrus americanus*	298
Wood Frog	*Lithobates sylvaticus*	52
Short-tailed Shrew	*Blarina brevicauda*	169
Meadow Vole	*Microtus pennsylvanicus*	822
Southern Red-backed Vole	*Myodes gapperi*	353
Deer Mouse	*Peromyscus maniculatus*	77
Arctic Shrew	*Sorex arcticus*	
Masked / Pygmy Shrew	*Sorex cinereus/hoyi*	1117*
Water Shrew	*Sorex palustris*	
Meadow Jumping Mouse	*Zapus hudsonius*	73
Total		2961

* Number includes 59 unidentified *Sorex* specimens. *Sorex* spp. pooled in models.

Table 2.

Parameter definitions and abbreviations used in models.

Name	Type	Levels	Model Abbr.	Description
Harvest	Factor	2	Harvest-#	Control plots are represented by '1' and harvested plots are respresented by '2'.
Treatment	Factor	4	Treatment-Type	Control plots are represented by 'Treatment-Control', clearcuts by 'Treatment-Clearcut', harvest with dispersed green tree reserves by 'Treatment-Dispersed' and harvest with clumped green tree reserves by 'Treatment-Clumped'.
Coarse Woody Debris	Continuous	-	CWD	Volume of downed coarse woody debris (m3/ha).
Sampling Period	Factor	3	Period-#	Three discrete sampling periods.
Site	Factor	2	Site-#	Represents both sites sampled.
Precipitation	Continuous	-	Precip.	Mean daily rainfall totals (mm).
Soil Temperature	Continuous	-	Temp-Soil	Mean soil temperature at 15cm below the soil surface (C°).
Air Temperature	Continuous	-	Temp-Min.	Mean daily minimum air temperature (C°).
Soil Moisture	Continuous	-	Soil-Moist.	Volumetric water content (%).
Plot	Factor	10	Plot	Experimental plots recieving a treatment (see above definiation of treatment).

Table 3.

List of amphibians captured during visual encounter surveys (VES), Saint Louis County, Minnesota, 2010.

Common Name	Scientific Name	Site 1	Site 2	Sample Size n =
Blue-spotted Salamander	*Ambystoma laterale*	X		1
Red-backed Salamander	*Plethodon cinereus*	X		6
American Toad	*Anaxyrus americanus*	X	X	4
Wood Frog	*Lithobates sylvaticus*	X	X	2
Spring Peeper	*Pseudacris crucifer*		X	2
Total				15

Table 4.

List of amphibian and small mammal species captured by sampling method during this study in Saint Louis County, Minnesota, 2010.

Common Name	Scientific Name	Site		Survey Method	
		1	2	VES	Drift Fence
Blue-spotted Salamander	*Ambystoma laterale*	X	X	X	X
Red-backed Salamander	*Plethodon cinereus*	X		X	X
American Toad	*Anaxyrus americanus*	X	X	X	X
Green Frog	*Lithobates clamitans*	X	X		X
Northern Leopard Frog	*Lithobates pipiens*		X		X
Mink Frog	*Lithobates septentrionalis*		X		X
Wood Frog	*Lithobates sylvaticus*	X	X	X	X
Spring Peeper	*Pseudacris crucifer*		X	X	
Boreal Chorus Frog	*Pseudacris maculata*	X			X
Short-tailed Shrew	*Blarina brevicauda*	X	X		X
Star-nosed Mole	*Condylura cristata*	X	X		X
Meadow Vole	*Microtus pennsylvanicus*	X	X		X
Southern Red-backed Vole	*Myodes gapperi*	X	X		X
Deer Mouse	*Peromyscus maniculatus*	X	X		X
Arctic Shrew	*Sorex arcticus*	X	X		X
Masked / Pygmy Shrew	*Sorex cinereus/hoyi*	X	X		X
Water Shrew	*Sorex palustris*	X	X		X
Red Squirrel	*Tamiasciurus hudsonicus*	X			X
Meadow Jumping Mouse	*Zapus hudsonius*	X	X		X

Table 5.

Regression associations from the top-ranked model ($w_{ANAM} = 0.857$) for American toad (*Anaxyrus americanus*) captured in

drift-fence arrays in Saint Louis County, Minnesota, 2010.

Species	Model	Explanatory Variables	Estimate	SE	Z-Value	P > |z|	
A. americanus	ANAM	Intercept	1.600	0.434	3.68	< 0.001	*
		Treatment-Clearcut	-0.925	0.532	-1.74	0.082	
		Treatment-Dispersed	-0.423	0.518	-0.82	0.414	
		Treatment-Clumped	-0.803	0.519	-1.55	0.122	
		Precip.	-0.233	0.114	-2.04	0.042	*
		Period-2	-0.825	0.466	-1.77	0.077	
		Period-3	-0.724	0.477	-1.52	0.129	
		Treatment-Clearcut * Period-2	1.290	0.553	2.33	0.020	*
		Treatment-Dispersed * Period-2	0.207	0.516	0.40	0.688	
		Treatment-Clumped * Period-2	0.772	0.526	1.47	0.142	
		Treatment-Clearcut * Period-3	1.153	0.566	2.04	0.041	*
		Treatment-Dispersed * Period-3	-1.045	0.591	-1.77	0.077	
		Treatment-Clumped * Period-3	-0.076	0.573	-0.13	0.894	
		Treatment-Clearcut * Precip.	-0.022	0.135	-0.17	0.869	
		Treatment-Dispersed * Precip.	0.257	0.135	1.90	0.057	
		Treatment-Clumped * Precip.	0.208	0.134	1.55	0.120	

* Statistical signficance at $\alpha \leq 0.05$

Table 6.

Regression associations from the top-ranked models ($w_{LISYa} = 0.329$, $w_{LISYb} = 0.132$) for wood frog (*Lithobates sylvaticus*)

captured in drift-fence arrays in Saint Louis County, Minnesota, 2010.

Species	Model	Explanatory Variables	Estimate	SE	Z-Value	P > |z|	
L. sylvaticus	LISYa	Intercept	5.337	1.727	3.09	0.002	*
		Harvest-2	-1.583	0.775	-2.04	0.041	*
		Soil-Temp	-0.294	0.101	-2.91	0.004	*
		Site-2	-1.658	0.628	-2.64	0.008	*
	LISYb	Intercept	1.199	0.679	1.77	0.077	
		Harvest-2	-2.168	0.696	-3.11	0.002	*
		Period-2	-0.828	0.344	-2.41	0.016	*
		Period-3	-0.862	0.353	-2.44	0.015	*
		Site-2	-1.602	0.602	-2.66	0.008	*

* Statistical signficance at $\alpha \leq 0.05$

Table 7.

Regression associations from the top-ranked model ($w_{MIPE} = 0.523$) for meadow vole (*Microtus pennsylvanicus*) captured in

drift-fence arrays in Saint Louis County, Minnesota, 2010.

Species	Model	Explanatory Variables	Estimate	SE	Z-Value	P > |z|
M. pennsylvanicus	MIPE	Intercept	1.853	0.228	8.12	< 0.001 *
		Harvest-2	-0.318	0.232	-1.37	0.172
		Period-2	0.476	0.090	5.29	< 0.001 *
		Period-3	0.330	0.093	3.54	< 0.001 *
		Site-2	-1.165	0.359	-3.24	0.001 *
		Harvest-2 * Site-2	0.738	0.377	1.96	0.050 *

* Statistical signficance at $\alpha \leq 0.05$

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Table 8.

Regression associations from the top-ranked model ($w_{MYGA} = 0.476$) for southern red-backed vole (*Myodes gapperi*) captured

in drift-fence arrays in Saint Louis County, Minnesota, 201.

Species	Model	Explanatory Variables	Estimate	SE	Z-Value	P > |z|
M. gapperi	MYGA	Intercept	15.128	3.954	3.83	< 0.001 *
		Harvest-2	-0.309	0.377	-0.82	0.413
		Temp-Min	-0.865	0.264	-3.28	0.001 *
		Temp-Soil	-0.160	0.088	-1.83	0.068
		Period-2	0.342	0.474	0.72	0.471
		Period-3	0.754	0.426	1.77	0.077
		Harvest-2 * Period-2	0.693	0.396	1.75	0.080
		Harvest-2 * Period-3	-0.220	0.343	-0.64	0.523

* Statistical signficance at $\alpha \leq 0.05$

Table 9.

Regression associations from the top-ranked models (w_{BLBRa} = 0.573, w_{BLBRb} = 0.406) for short-tailed shrew (*Blarina brevicauda*) captured in drift-fence arrays in Saint Louis County, Minnesota, 2010.

Species	Model	Explanatory Variables	Estimate	SE	Z-Value	P > |z|	
Blarina brevicauda	BLBRa	Intercept	-1.460	0.450	-3.25	0.001	*
		Treatment-Clearcut	-0.999	0.312	-3.20	0.001	*
		Treatment-Dispersed	-1.266	0.360	-3.51	< 0.001	*
		Treatment-Clumped	-0.655	0.286	-2.29	0.022	*
		CWD	0.007	0.004	1.83	0.067	
		Period-2	2.141	0.372	5.76	< 0.001	*
		Period-3	2.324	0.370	6.29	< 0.001	*
		Site-2	-0.564	0.160	-3.51	< 0.001	*
	BLBRb	Intercept	-1.077	0.425	-2.54	0.011	*
		Harvest-2	-0.599	0.252	-2.38	0.018	*
		Period-2	2.141	0.374	5.73	< 0.001	*
		Period-3	2.324	0.372	6.26	< 0.001	*
		Site-2	-0.553	0.182	-3.04	0.002	*

* Statistical signficance at $\alpha \leq 0.05$

Table 10.

Regression associations from the top-ranked models (w_{PEMAa} = 0.523 and w_{PEMAb} = 0.413) for deer mouse (*Peromyscus maniculatus*) captured in drift-fence arrays in Saint Louis County, Minnesota, 2010.

Species	Model	Explanatory Variables	Estimate	SE	Z-Value	P > |z|
Peromyscus maniculatus	PEMAa	Intercept	19.955	8.789	2.27	0.023 *
		Harvest-2	0.754	1.084	0.70	0.487
		Temp-Min	-1.622	0.653	-2.49	0.013 *
		Precip.	0.201	0.105	1.91	0.056 *
		Period-2	1.346	1.324	1.02	0.310
		Period-3	1.307	1.183	1.10	0.270
		Site-2	-0.845	0.376	-2.25	0.025 *
		Harvest * Period-2	-0.048	1.297	0.04	0.970
		Harvest * Period-3	-1.923	1.204	-1.60	0.110
	PEMAb	Intercept	20.404	8.709	2.34	0.019 *
		Harvest-2	0.003	0.497	0.01	0.996
		Temp-Min	-1.605	0.652	-2.46	0.014 *
		Precip.	0.210	0.104	2.01	0.045 *
		Period-2	1.287	0.516	2.50	0.013 *
		Period-3	-0.371	0.458	-0.81	0.418
		Site-2	-0.867	0.385	-2.25	0.024 *

* Statistical signficance at $\alpha \leq 0.05$

Table 11.

Regression associations from the top-ranked models ($w_{ZAHUa} = 0.589$ and $w_{ZAHUb} = 0.383$) for meadow jumping mouse (*Zapus hudsonius*) captured in drift-fence arrays in Saint Louis County, Minnesota, 2010.

Species	Model	Explanatory Variables	Estimate	SE	Z-Value	P > |z|	
Zapus hudsonius	ZAHUa	Intercept	-2.449	0.993	-2.47	0.014	*
		Harvest-2	0.393	0.676	0.58	0.561	
		CWD	-0.014	0.008	-1.77	0.077	
		Period-2	3.235	0.731	4.42	< 0.001	*
		Period-3	1.964	0.765	2.57	0.010	*
	ZAHUb	Intercept	-2.034	0.998	-2.04	0.041	*
		Treatment-2	0.404	0.707	0.57	0.568	
		Treatment-3	1.304	0.790	1.65	0.099	
		Treatment-4	0.422	0.678	0.62	0.534	
		CWD	-0.021	0.009	-2.49	0.013	*
		Period-2	3.235	0.731	4.43	< 0.001	*
		Period-3	1.964	0.768	2.57	0.102	

* Statistical signficance at $\alpha \leq 0.05$

Table 12.

Regression associations from the top-ranked model (w_{SOREX} = 0.834) for shrews (*Sorex* spp.) captured in drift-fence arrays in Saint Louis County, Minnesota, 2010.

Species	Model	Explanatory Variables	Estimate	SE	Z-Value	P > |z|	
Sorex spp.	SOREX	Intercept	-15.094	7.828	-1.93	0.054	
		Treatment-Clearcut	13.178	8.051	1.64	0.102	*
		Treatment-Dispersed	19.925	8.114	2.46	0.014	*
		Treatment-Clumped	17.885	7.965	2.25	0.025	*
		Precipiation	0.083	0.020	4.17	< 0.001	*
		Period-2	-2.272	1.253	-1.81	0.070	
		Period-3	-2.817	1.747	-1.61	0.107	
		Site-2	0.318	0.069	4.63	< 0.001	*
		Temp-Soil	1.154	0.551	2.09	0.036	*
		Treatment-Clearcut * Period-2	3.880	1.309	2.96	0.003	*
		Treatment-Dispersed * Period-2	4.521	1.296	3.49	< 0.001	*
		Treatment-Clumped * Period-2	3.903	1.286	3.03	0.002	*
		Treatment-Clearcut * Period-3	4.449	1.798	2.47	0.013	*
		Treatment-Dispersed * Period-3	5.303	1.795	2.95	0.003	*
		Treatment-Clumped * Period-3	4.369	1.777	2.46	0.014	*
		Treatment-Clearcut * Temp-Soil	-1.048	0.564	-1.86	0.063	
		Treatment-Dispersed * Temp-Soil	-1.437	0.566	-2.54	0.011	*
		Treatment-Clumped * Temp-Soil	-1.283	0.560	-2.29	0.022	*

* Statistical signficance at $\alpha \leq 0.05$
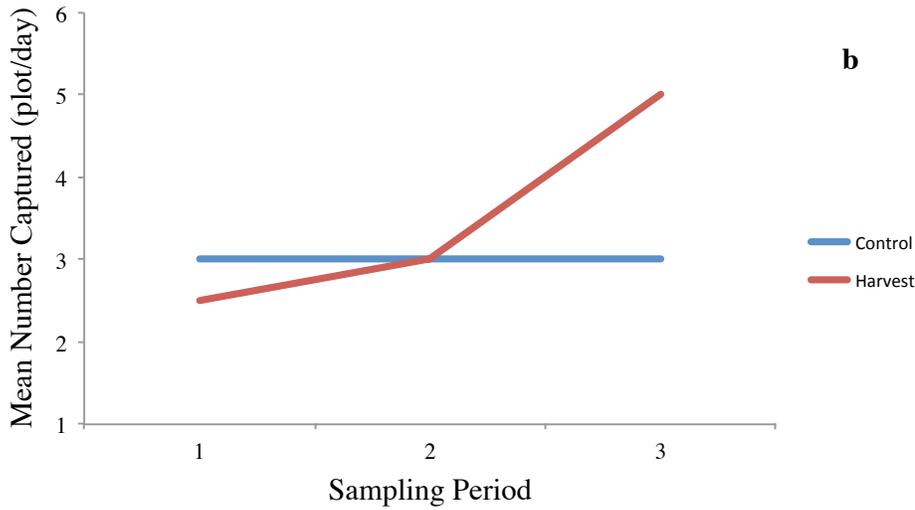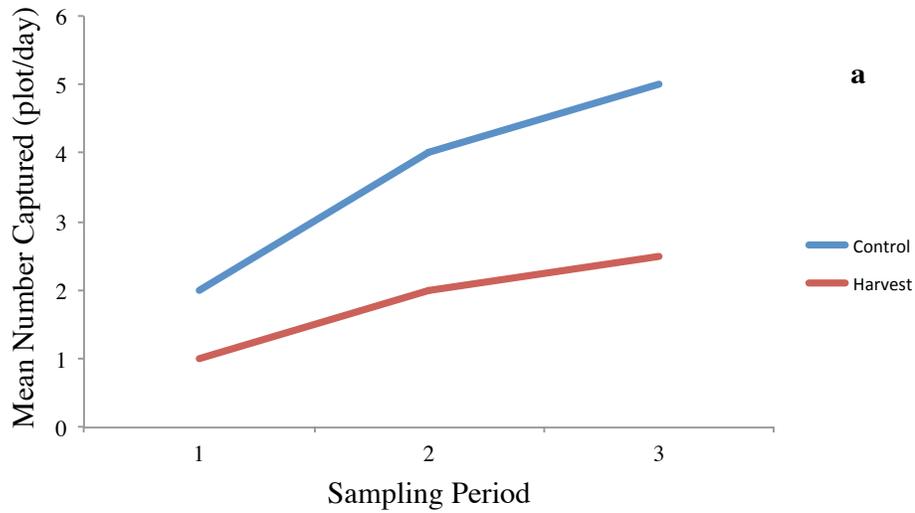
Figure 1.

Hypothetical figures illustrating plausible responses to harvest. Figure 1a depicts an initial response to harvest indicative of either a change in survival as a result of direct harvest-induced mortality or plot-level differences in species abundance pre-harvest. Figure 1b depicts a positive response to harvest via an interaction parameter without a change in control plots.
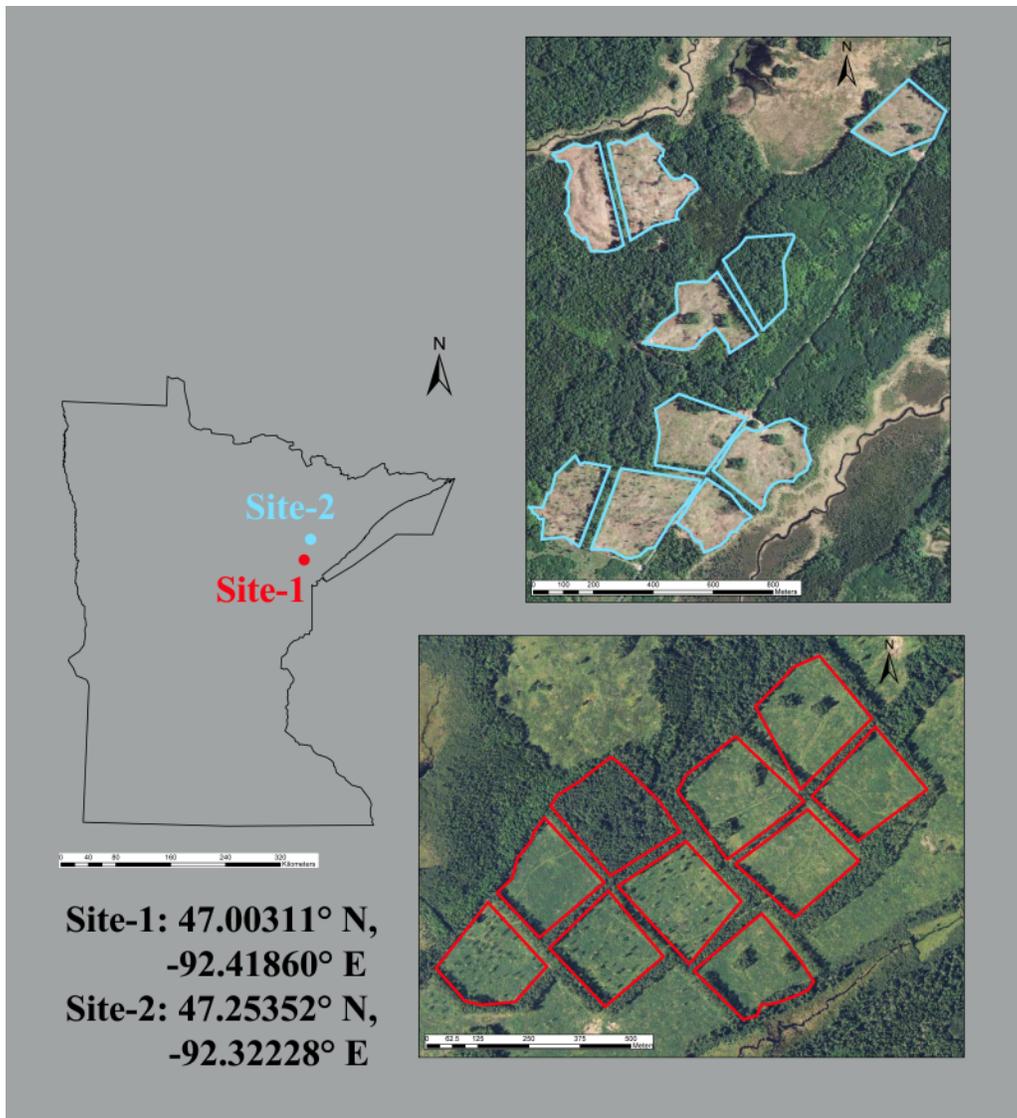
**Figure 2.**

Map of study sites in Saint Louis County, Minnesota.
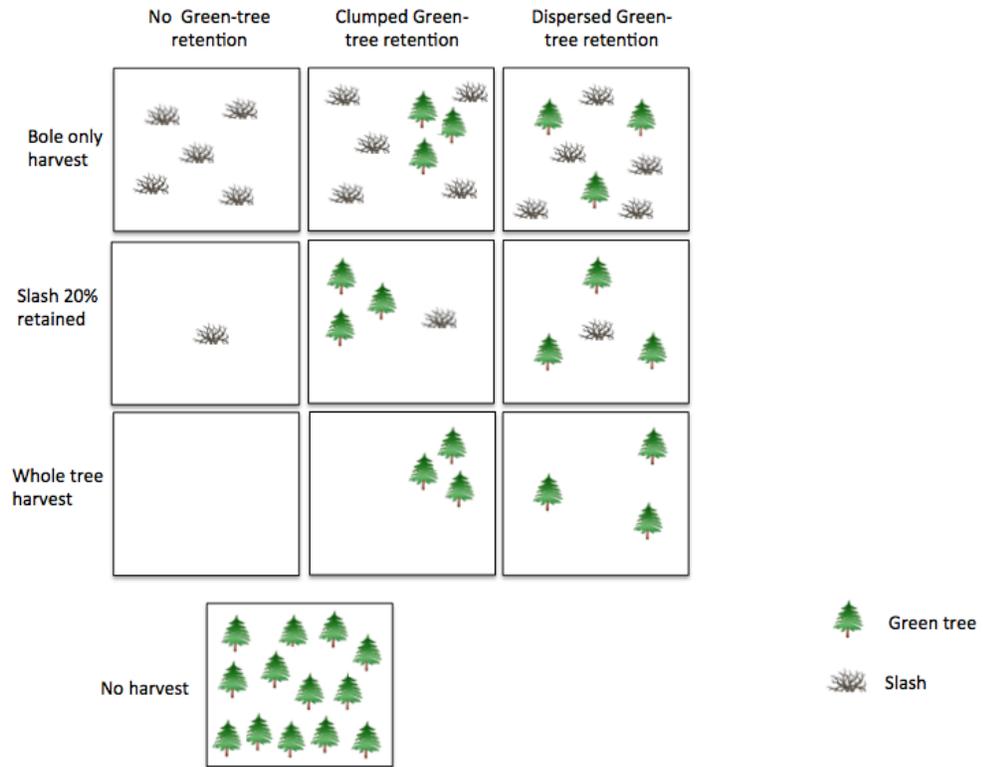
Figure 3.

Conceptual diagram depicting the nine silvicultural treatments and the control. Treatments include 3-levels of biomass harvest, 3-levels of green tree retention type, and an untreated control.
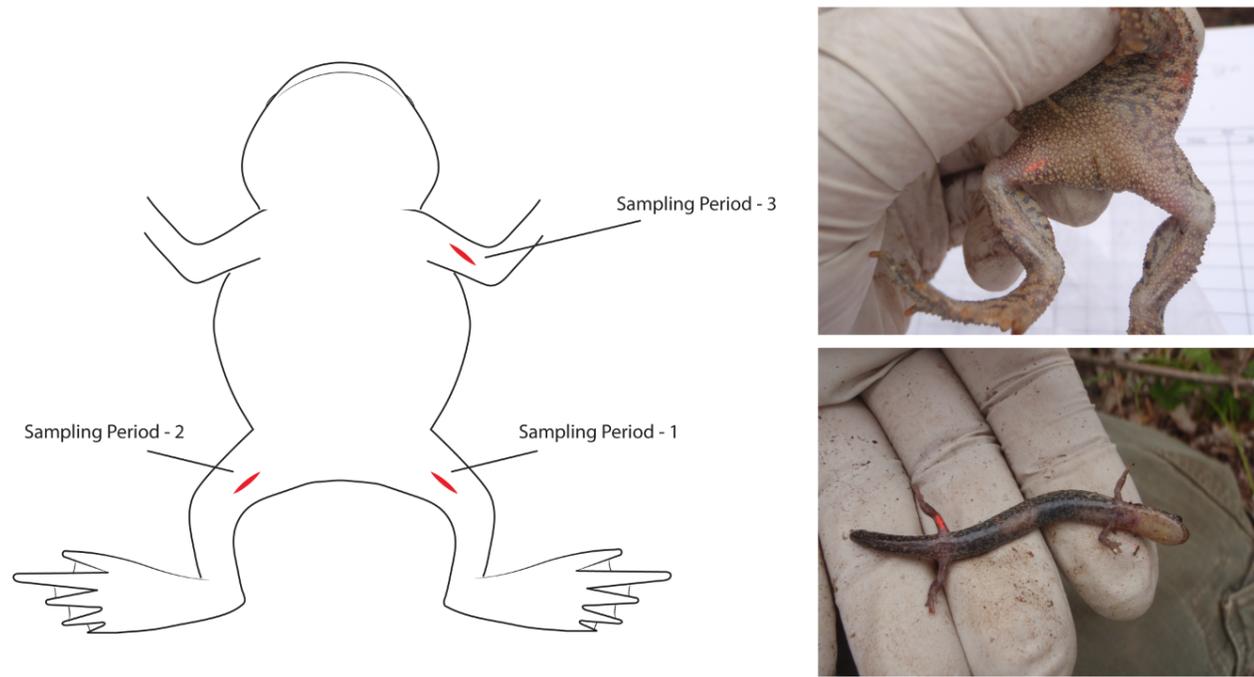
Figure 4.

Conceptual diagram and *in-situ* marks showing marking system corresponding to the sampling period in which they were captured. Top-right is *A. americanus* and bottom-right is *P. cinereus*, both captured during sampling period-2.
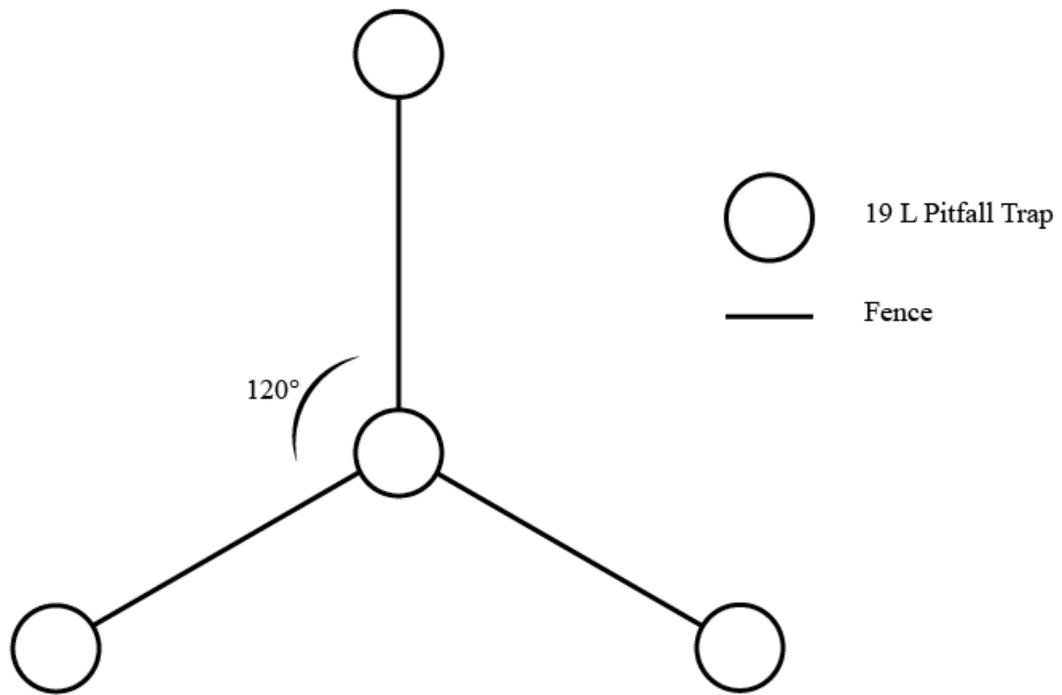
Figure 5.

Conceptual diagram depicting a drift-fence array.

Mean Volume of CWD by Site
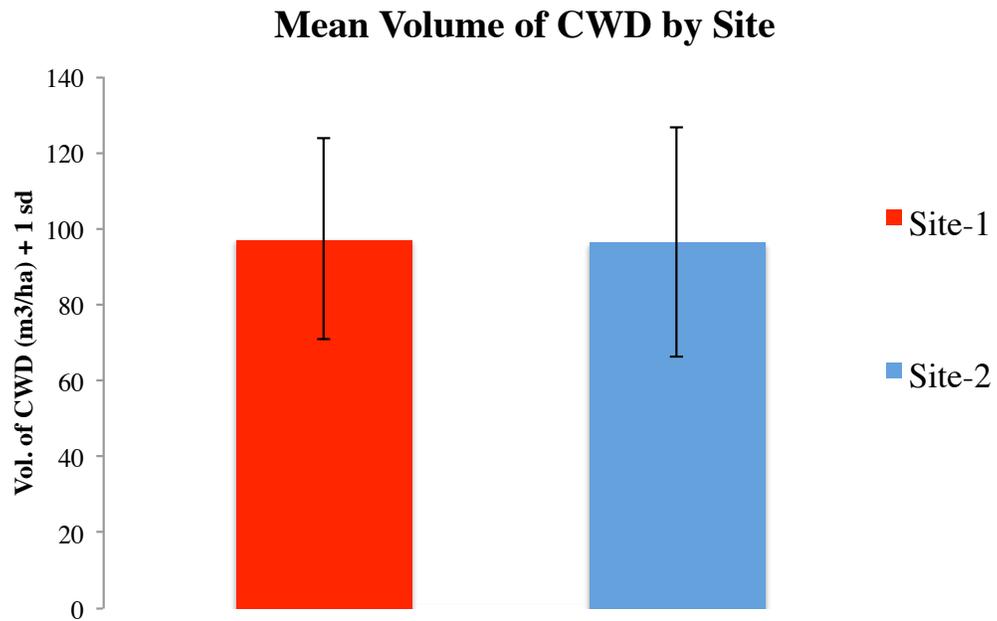
Figure 6.

Comparison of mean volume (m^3 / ha) of coarse woody debris (CWD) showing that the overall mean volume did not differ by site.

Volumetric Water Content by Site and Stand Treatment
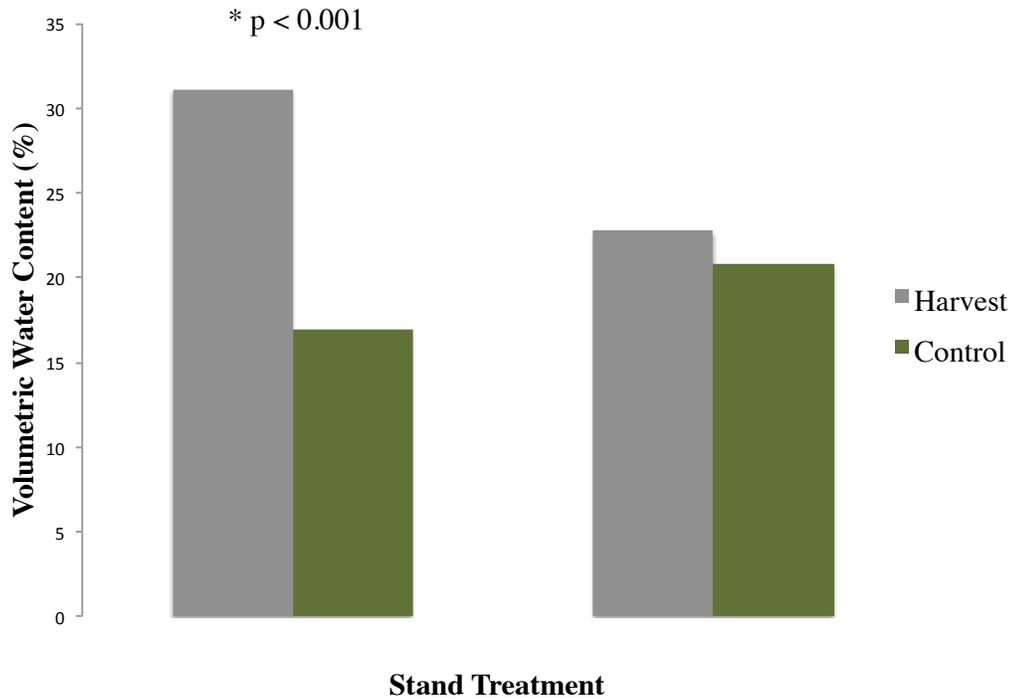
Figure 7.

Volumetric water content between stand treatments (i.e., Harvest vs. Control) by site. Statistical significance determined using Welch's t-test accounting for unequal variances.

Site-1 Soil Moisture
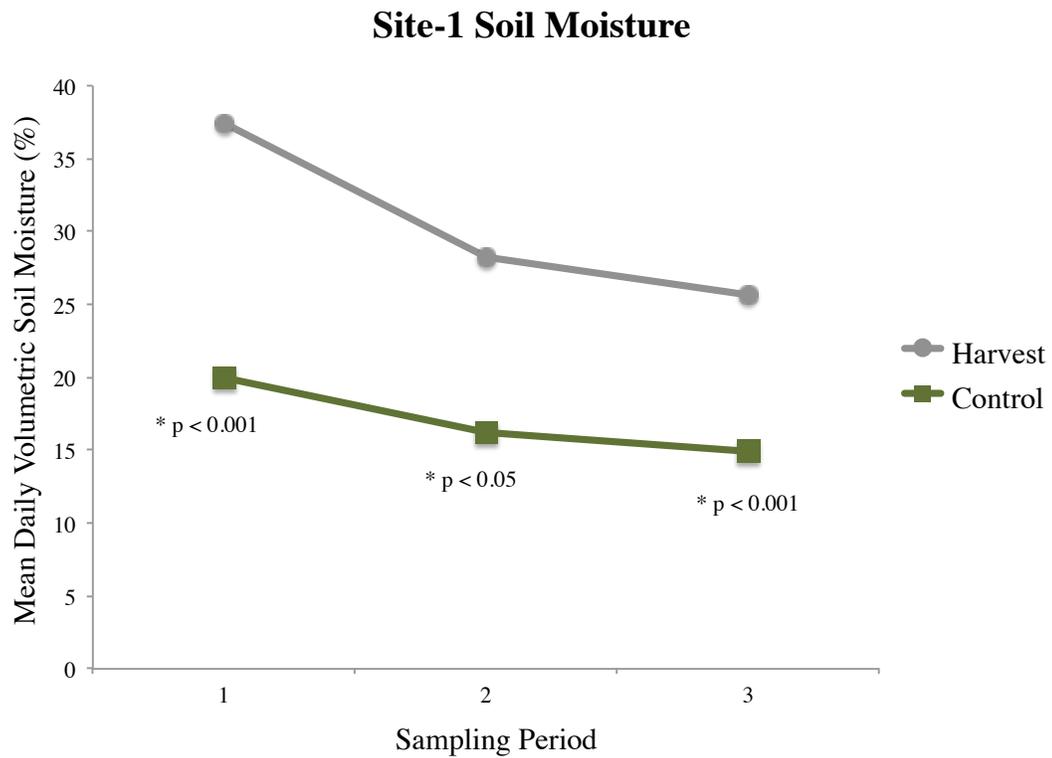
Figure 8.

Volumetric water content between stand treatments (i.e., Harvest vs. Control) at Site-1. Statistical significance determined using Welch's t-test accounting for unequal variances.

American Toad

Anaxyrus americanus
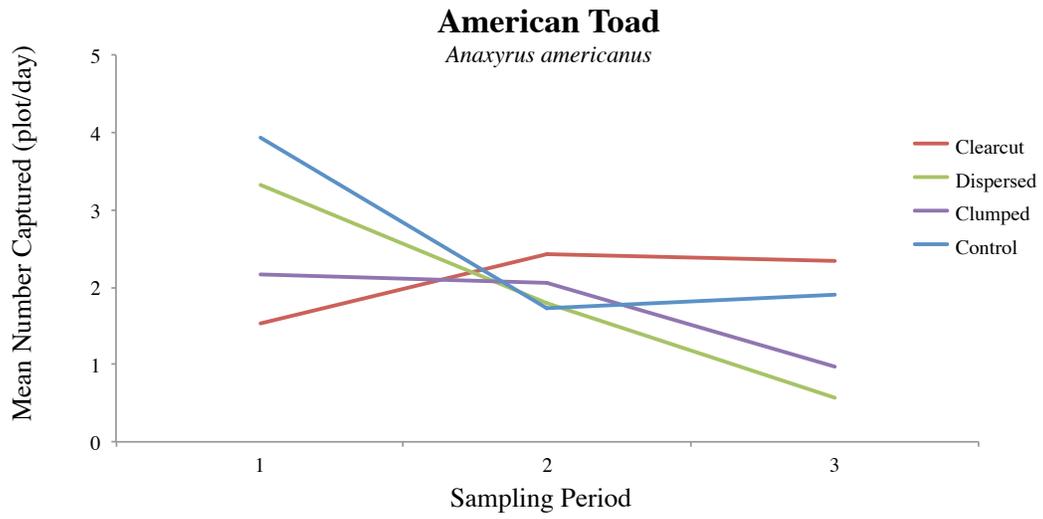
Figure 9.

Mean number of *A. americanus* captured per plot per day by treatment in Saint Louis County, Minnesota, 2010. Precipitation is held constant at overall daily mean (2.58 mm).
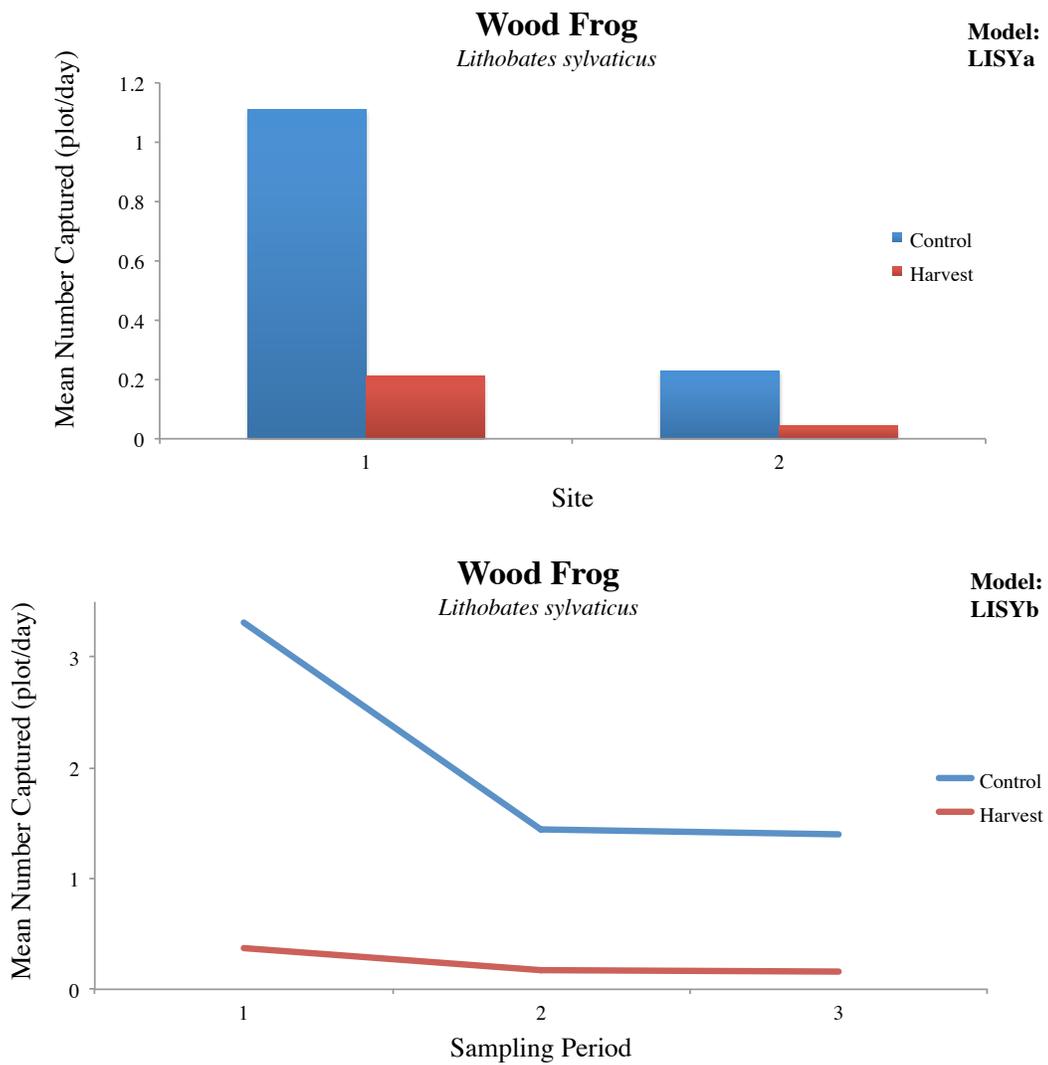
Figure 10.

Mean number of *L. sylvaticus* captured per plot per day by treatment in Saint Louis County, Minnesota, 2010. Top figure depicts output from model LISYa with below-ground soil temperature is held constant at overall daily mean (17.81 °C). Bottom figure depicts output from model LISYb. Bottom figure excludes Site-2 data, however Site-2 showed similar temporal effects but with fewer overall captures.
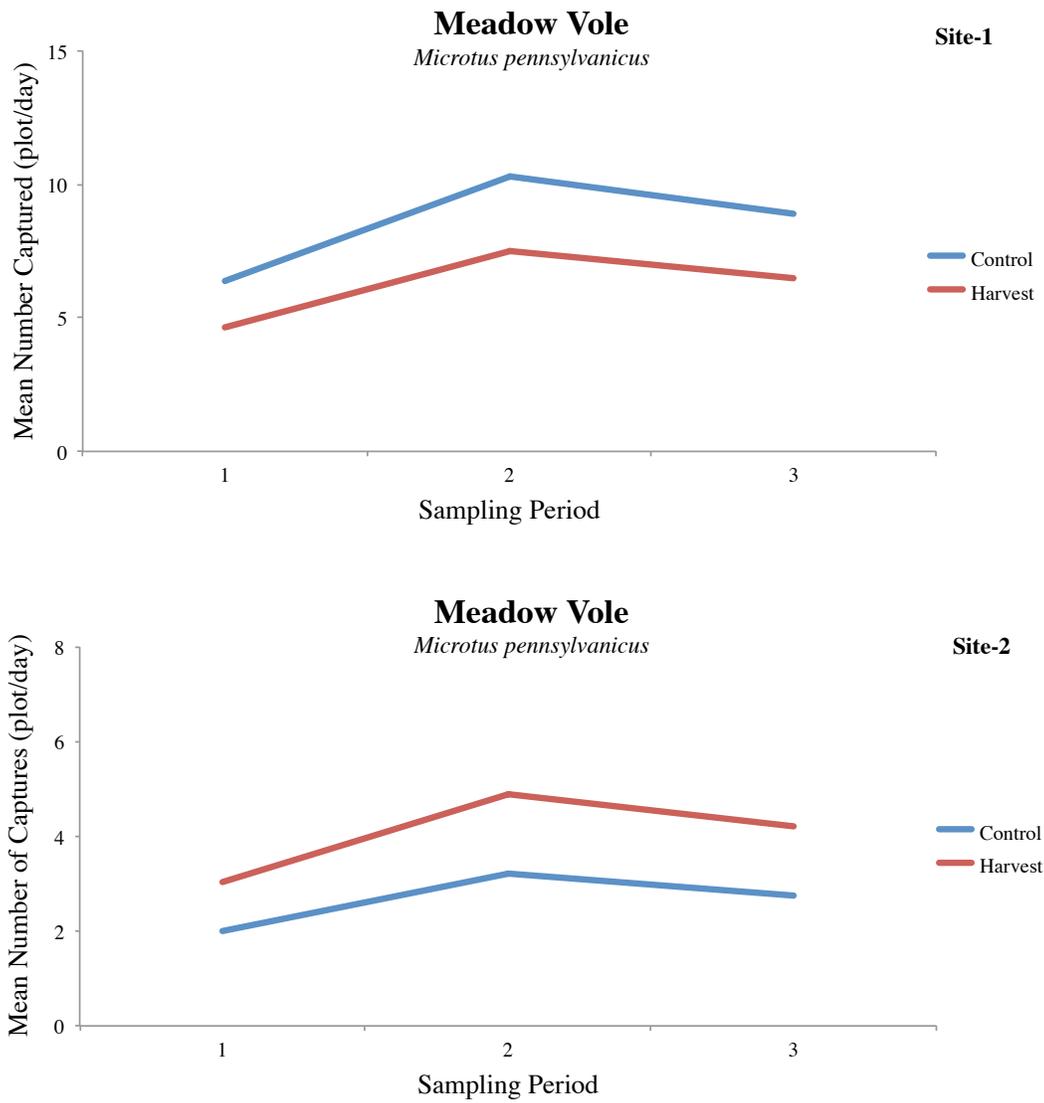
Figure 11.

Mean number of *M. pennsylvanicus* captured per plot per day by treatment in Saint Louis County, Minnesota, 2010. Top figure depicts output from Site-1, while bottom figure depicts output from Site-2.

Southern Red-backed Vole

Myodes gapperi
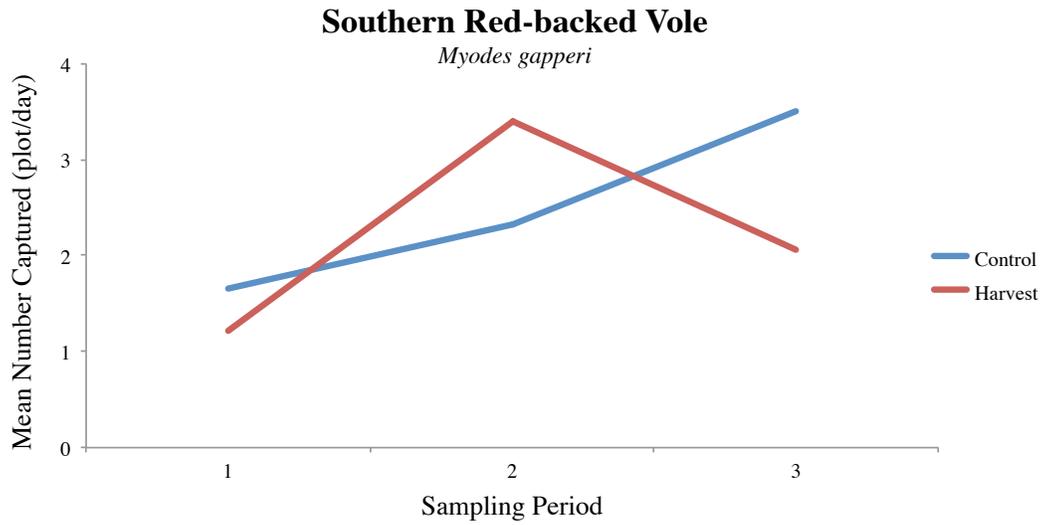
Figure 12.

Mean number of *M. gapperi* captured per plot per day by treatment in Saint Louis County, Minnesota, 2010. Site-level differences were not supported in model. Minimum air temperature and below-ground soil temperature are held constant at overall daily mean (13.61 °C and 17.81 °C respectively).
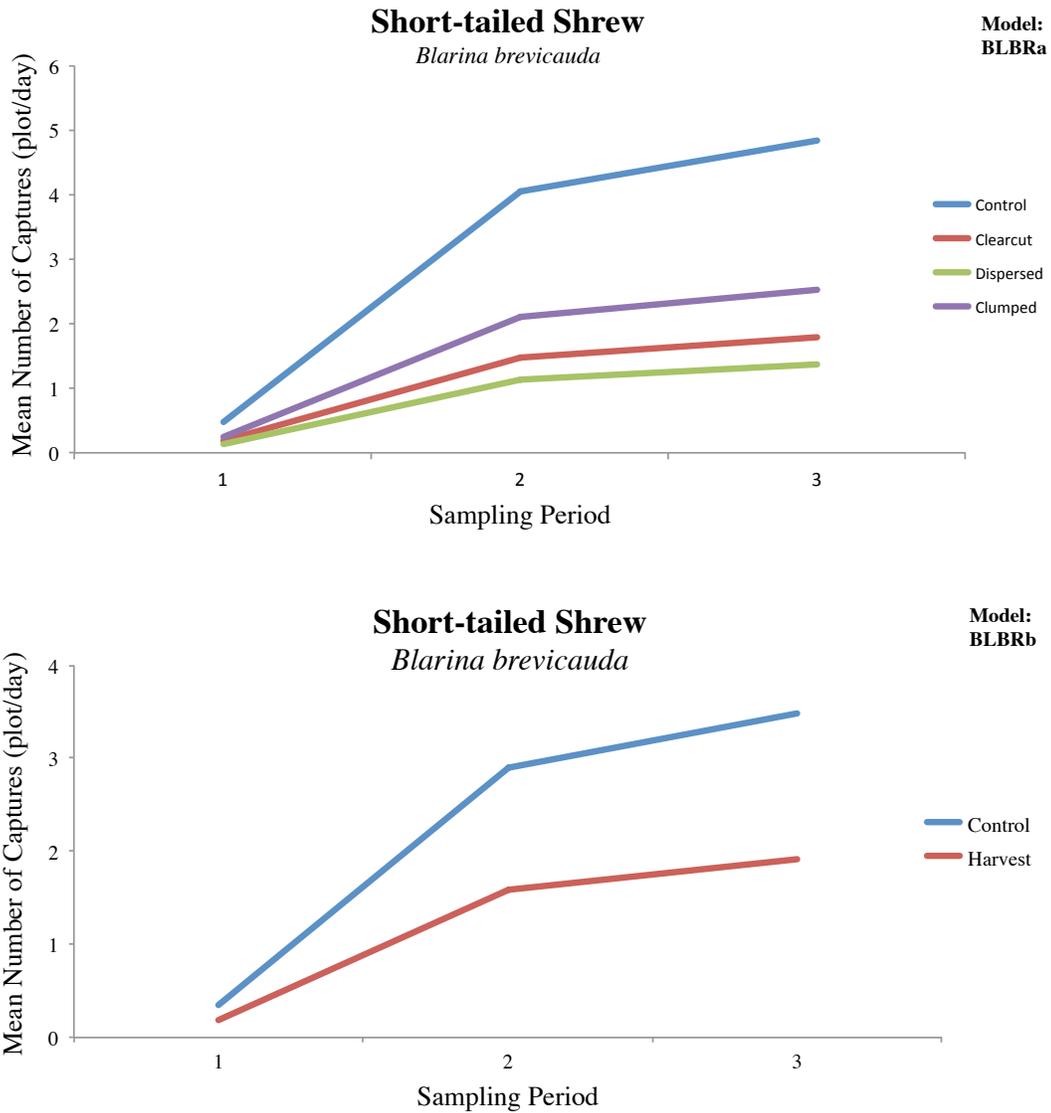
Figure 13.

Mean number of *B. brevicauda* captured per plot per day by treatment in Saint Louis County, Minnesota, 2010. Top figure depicts output from model BLBRa with volume of CWD is held constant at overall mean (96.90 m^3 / ha). Bottom figure depicts output from model BLBRb. Both figures exclude Site-2 data, however Site-2 showed similar temporal effects but with fewer overall captures.
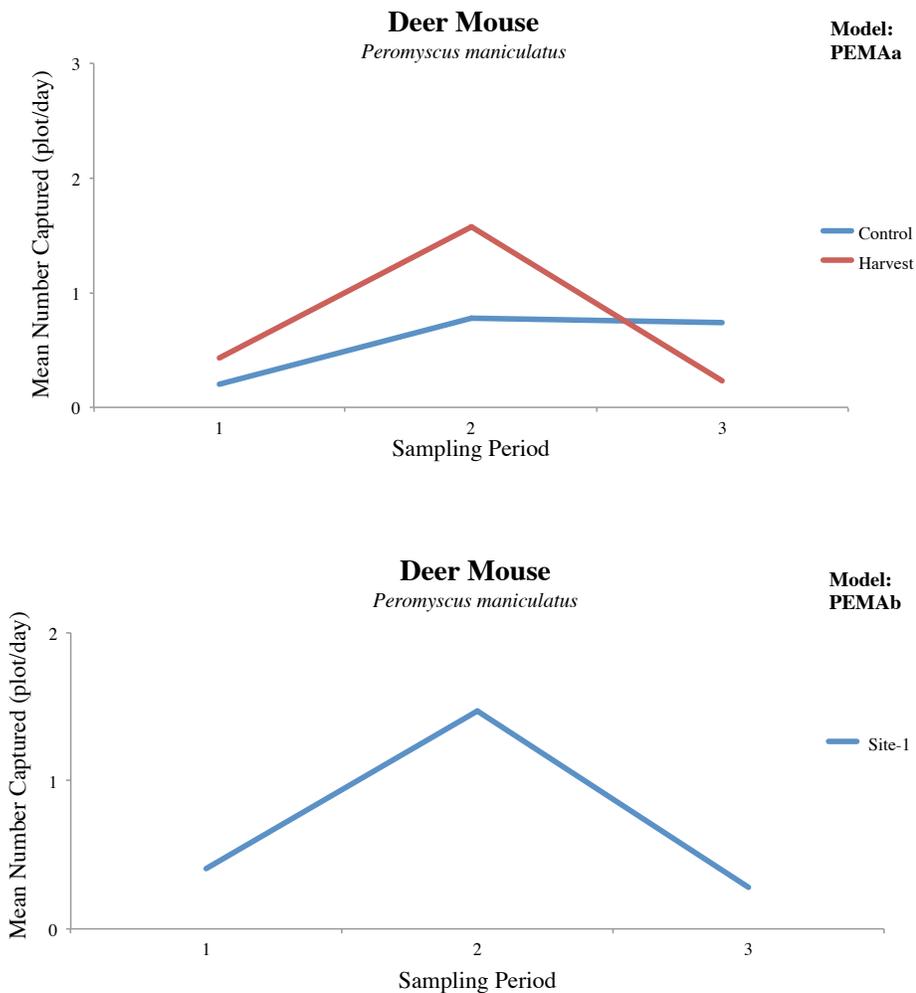
Figure 14.

Mean number of *P. maniculatus* captured per plot per day in Saint Louis County, Minnesota, 2010. Top figure depicts output from model PEMAa, while bottom figure depicts output from model PEMAb. Bottom figure excludes Site-2 data, however Site-2 showed similar temporal effects but with fewer overall captures. Model PEMAb displays a single line representing no statistical support for differences between harvest and control. For both models, minimum air temperature and precipitation are held constant at overall daily mean (13.61 °C and 2.58 mm respectively).
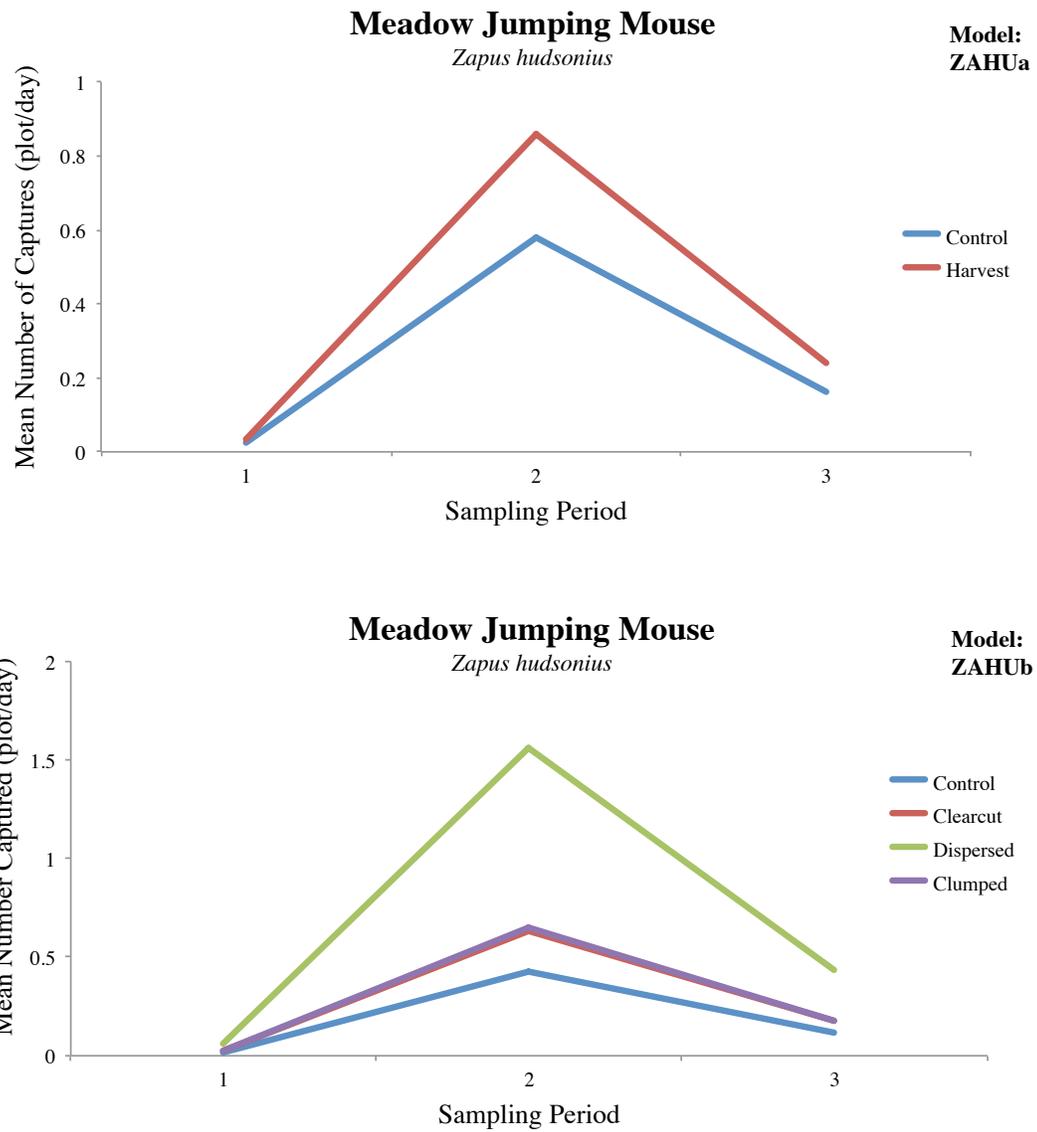
Figure 15.

Mean number of *Z. hudsonius* captured per plot per day by treatment in Saint Louis County, Minnesota, 2010. Top figure depicts output from model ZAHUa while the bottom figure depicts output from model ZAHUb. Volume of CWD is held constant at overall mean (96.90 m^3 / ha) for both.

Shrews
Sorex spp.
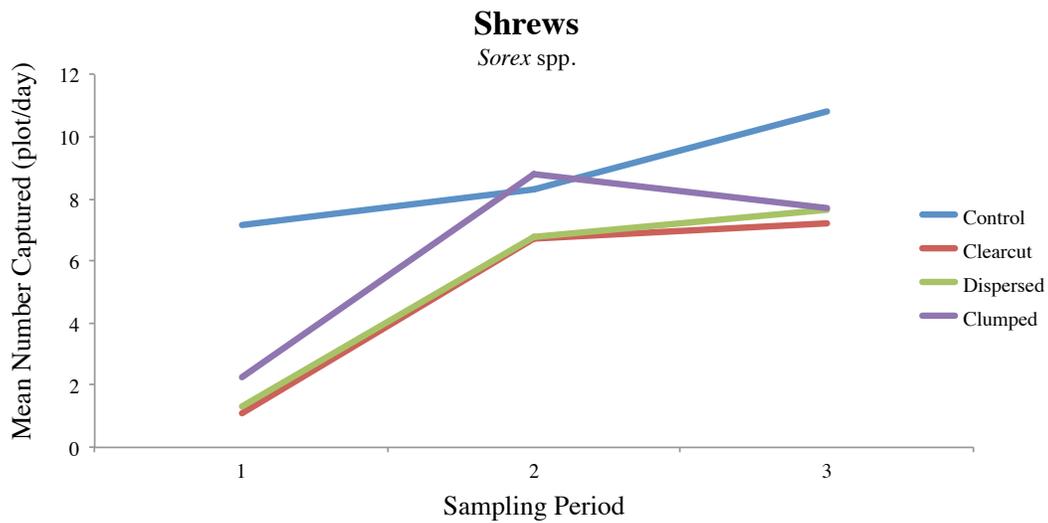
Figure 16.

Mean number of *Sorex* spp. captured per plot per day by treatment in Saint Louis County, Minnesota, 2010. Volume of CWD is held constant at overall mean (96.90 m^3 / ha) for both. Precipitation is held constant at overall daily mean (2.58 mm). Below-ground soil temperature held constant at harvest-level mean by sampling period due to model complexity to allow for better visualization of response (Sampling Period-1, control plots = 14.6 °C, harvested plots = 16.9 °C; Sampling Period-2, control plots = 16.7 °C, harvested plots = 19.0 °C; Sampling Period-3, control plots = 17.4 °C, harvested plots = 19.4 °C).

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Appendix 1

Specimens to be accessioned at Bell Museum of Natural History

Common Name	Scientific Name	Field No.
Arctic shrew	*Sorex arcticus*	CS00075
Arctic shrew	*Sorex arcticus*	CS00078
Arctic shrew	*Sorex arcticus*	CS00079
Deer mouse	*Peromyscus maniculatus*	CS00091
Meadow jumping mouse	*Zapus hudsonius*	CS00060
Meadow jumping mouse	*Zapus hudsonius*	CS00088
Meadow vole	*Microtus pennsylvanicus*	CS00050
Meadow vole	*Microtus pennsylvanicus*	CS00052
Meadow vole	*Microtus pennsylvanicus*	CS00051
Meadow vole	*Microtus pennsylvanicus*	CS00063
Meadow vole	*Microtus pennsylvanicus*	CS00076
Meadow vole	*Microtus pennsylvanicus*	CS00077
Meadow vole	*Microtus pennsylvanicus*	CS00093
Short-tailed shrew	*Blarina brevicauda*	CS00054
Short-tailed shrew	*Blarina brevicauda*	CS00085
Short-tailed shrew	*Blarina brevicauda*	CS00092
Shrew	*Sorex* spp.	CS00055
Shrew	*Sorex* spp.	CS00107
Shrew	*Sorex* spp.	CS00106
Shrew	*Sorex* spp.	CS00105
Shrew	*Sorex* spp.	CS00108
Shrew	*Sorex* spp.	CS00057
Shrew	*Sorex* spp.	CS00058
Shrew	*Sorex* spp.	CS00059
Shrew	*Sorex* spp.	CS00061
Shrew	*Sorex* spp.	CS00066
Shrew	*Sorex* spp.	CS00067
Shrew	*Sorex* spp.	CS00068
Shrew	*Sorex* spp.	CS00064
Shrew	*Sorex* spp.	CS00065
Shrew	*Sorex* spp.	CS00070
Shrew	*Sorex* spp.	CS00071
Shrew	*Sorex* spp.	CS00072
Shrew	*Sorex* spp.	CS00073
Shrew	*Sorex* spp.	CS00080
Shrew	*Sorex* spp.	CS00081
Shrew	*Sorex* spp.	CS00082
Shrew	*Sorex* spp.	CS00083
Shrew	*Sorex* spp.	CS00087
Shrew	*Sorex* spp.	CS00094
Southern red-backed vole	*Myodes gapperi*	CS00053
Southern red-backed vole	*Myodes gapperi*	CS00074
Southern red-backed vole	*Myodes gapperi*	CS00084
Southern red-backed vole	*Myodes gapperi*	CS00090
Star-nosed Vole	*Condylura cristata*	CS00048
Star-nosed Vole	*Condylura cristata*	CS00049
Star-nosed Vole	*Condylura cristata*	CS00069
Water shrew	*Sorex palustris*	CS00062
Water shrew	*Sorex palustris*	CS00086
Water shrew	*Sorex palustris*	CS00089