ENVIRONMENTAL AND ECONOMIC RESEARCH AND DEVELOPMENT PROGRAM

An Assessment of Woody Biomass Harvests in Northern Wisconsin

Final Report
December 2013

PREPARED BY:

Dr. KARL MARTIN[1]
Dr. TRACY RITTENHOUSE[2]
CHRISTINE ANHALT[1]
Dr. TRICIA KNOOT[1]
Dr. DAVID MACFARLAND[1]
Dr. BAISHALI BAKSHI[3]
Dr. TIM VAN DEELEN[4]

[1]WISCONSIN DEPARTMENT OF NATURAL RESOURCES,
BUREAU OF SCIENCE SERVICES, MADISON, WI 53716

[2]UNIVERSITY OF CONNECTICUT,
DEPARTMENT OF NATURAL RESOURCES AND THE ENVIRONMENT, STORRS, CT 06269

[3]UNIVERSITY OF MINNESOTA,
NATURAL RESOURCES SCIENCE AND MANAGEMENT, ST. PAUL, MN 55108

[4]UNIVERSITY OF WISCONSIN-MADISON,
DEPARTMENT OF FOREST AND WILDLIFE ECOLOGY, MADISON, WI 53706

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This report was funded through the Environmental and Economic Research and Development Program of Wisconsin's Focus on Energy.

EXECUTIVE SUMMARY

Increased public interest in utilizing alternative energy sources has spurred attention by those in industry and state agencies to explore greater utilization of wood material from timber harvests. Current forest management practices can be modified to include increased removal of post-harvest material, which has traditionally been left on the forest floor and can serve as regenerative material or habitat for biodiversity. As a result, many states, including Wisconsin, have developed guidelines to ensure that removal of additional woody material does not compromise the long-term productivity of forestland (Herrick et al. 2009). As biomass harvest becomes more common, additional tools will be needed to increase the ease of guideline implementation and monitoring. Moving forward, research is also needed to better evaluate the potential ecological and economic impact of such harvesting methods. To this end, this project includes three main objectives: 1) quantification and analysis of downed woody material from aspen stands of variable harvest types (Rittenhouse et al. 2012), 2) examination of small mammal response to woody debris levels (Rittenhouse et al. In prep), and 3) net potential revenue gained through harvest of residual woody biomass (Bakshi et al. In prep). We measured coarse and fine woody debris at aspen stands of variable harvest types and found that roundwood harvested stands contain the most downed wood (125.71 ± 20.79 m^3/ha), followed by whole-tree harvest (75.54 ± 23.70 m^3/ha), and mature, unharvested aspen stands (40.90 ± 11.6 m^3/ha). We demonstrated that the volume of fine woody debris could be estimated from coarse woody debris, potentially making guideline implementation and monitoring significantly more efficient. In a subset of stands measured for biomass material, we sampled for small mammal abundance using Sherman and pitfall traps. We found evidence that downed wood is not equally important to small mammals targeted in this study. Only voles' abundance corresponds to volume of downed wood. Additional taxa specific data will be important to understand wildlife response to increased removal of woody material. As a management practice, maintaining brushpiles would provide habitat heterogeneity, supporting a diversity of mammal species. This project has resulted in a successful peer-reviewed publication (Rittenhouse et al. 2012), with additional manuscripts in preparation. Findings from this project will contribute to review and potential refinements of state agency standards.

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All photographs credit T. A. G. Rittenhouse

ACKNOWLEDGEMENTS

The authors wish to thank J. Bocek, D. Ferguson, T. Pearson, J. Thompson, and B. Werner for assistance with collecting the field data and C. Murray for statistical advice. We thank S. Polasky, F. Isbell and H. Van Vleck for useful comments on the economic aspects of the project and references and A. Amato, J. Bockheim and J. Orrock for answering questions on forest management, relation of nutrients with timber productivity and small mammal responses to woody debris. We thank K. Wilhelm and B. Rathsack for their pertinent theses on nutrient responses to harvest intensity, T. Mace and S. Radcliffe of TimberMart North for information on Aspen timber prices, and S. Chatterjee for collaboration on improving p-values of mixed effects models. Support for this work was provided through the Wisconsin FOCUS ON ENERGY Program, Wisconsin Department of Natural Resources, the Division of Forestry, and with additional funding from Federal Aid in Wildlife Restoration Project W-160-P funds.

INTRODUCTION

A variety of interacting factors in the United States, including rising fossil fuel costs, emphasis on energy independence and homeland security, and concerns about climate change and interest in reducing carbon emissions have ignited interest in utilizing alternative and renewable energy sources. Such interest has resulted in legislation (e.g., Energy Policy Act of 2005, Energy Independence and Security Act of 2007) aimed at increasing investment in alternative sources of energy, including woody biomass. The potential resulting markets from such initiatives have spurred attention by those in industry and state agencies to explore greater utilization of wood material from timber harvests. Potential strategies include expansion of harvesting of traditionally non-marketable forest stands, the intensification of harvests in managed forests through more frequent harvests and increased removal of harvest residues, and an increase of short-rotation woody crops in the landscape (Janowiak and Webster 2010).

Intensification of timber harvests has the potential to immediately impact forest systems, as current forest management can be modified to include increased removal of post-harvest residues, i.e. woody material such as branches, treetops, and twigs (coarse and fine woody debris) that remain following a commercial timber harvest. The post-harvest residues are considered to be the largest, and least expensive, source of already unused woody biomass material in the Lake States Region (Peterson 2005, Becker et al. 2009). This woody debris can then be converted to wood chips and transported to an end user of the material. Traditionally this material is left on the forest floor and can serve as regenerative material or habitat for biodiversity after harvests (Rittenhouse et al. 2012). An increase in demand for traditionally low-value woody material from forest stands could lead to changes in forest stands (e.g., soil conditions, site productivity, hydrology, biodiversity) and the composition of the landscape as well (Janowiak and Webster 2010). In particular, the impact of more intensive harvests on soil nutrients and long-term sustainability on sites considered nutrient-poor is of significant concern (Evans and Perschel 2009).

As a result many states, including Wisconsin, have developed guidelines to ensure that removal of additional woody biomass material does not compromise the long-term productivity of forestland (Evans et al. 2013). Wisconsin Biomass Harvesting Guidelines provide recommendations to retain coarse woody debris already present prior to harvest and to retain 10% of tree top and limbs on site following harvest. More specific guidelines are provided with the goal of protecting species of greatest conservation need, sensitive ecosystems, and protecting sites at risk of nutrient depletion (Herrick et al. 2009). Continued research, however, is needed to better understand availability of biomass material following various types of harvest operations and site conditions and the potential ecological and economic impact of such harvesting methods. Such information can inform the continued development and refinement of biomass harvesting guidelines and sustainable bioenergy investments.

To this end, this project includes three main objectives:

1) Quantification and analysis of downed woody material from aspen stands of variable harvest types (see published article, Rittenhouse et al. 2012);
2) Examination of small mammal response to woody debris levels (Rittenhouse et al. In prep); and
3) Assessment of the potential revenue gained through harvest of residual woody biomass (Bakshi et al. In prep).

Harvest operations in aspen provide a good model for this study, as they could be easily modified to accommodate increased demand for biofuels via intensification of timber harvest. Further, they have been known to provide suitable habitat for small mammal communities within dry northern forests (Oaten and Larsen 2008). We focus on small mammals as they may be a good indicator for wildlife response to woody biomass removal. Small mammal response to coarse woody debris has been documented through both correlative and experimental studies; yet these studies demonstrate both positive and negative association of small mammals with woody debris (Riffell et al. 2011). Further, small mammals are known to respond to habitat variability at both large landscape and smaller stand-level scales (Barrett and Peles 1999, Martin and McComb 2002). Understanding small mammal response within a stand will aid managers in determining how much fine and coarse woody debris is needed to support biodiversity. Furthermore, given the interest in expanding the use of post-harvest wood residue, we estimate the potential revenue gained through the collection of material available from aspen study sites. However, we recognize that challenges remain concerning operational feasibility as related transportation costs and current value of the biomass material that could limit expansion of the post-harvest wood residue use (Becker et al. 2011).

METHODOLOGY AND ANALYSIS

Study site description

Study sites were located in Burnett, Oneida, Marinette, and Douglas counties. These counties are distributed across northern Wisconsin and are typified by sandy soils. Nutrient depletion has been cited as a potential effect of forest biomass harvest and therefore we specifically targeted sandy soils on the basis that they are more susceptible to nutrient depletion than other soil types (Janowiak and Webster 2010, Pare et al. 2002).

Aspen stand selection

We selected previously harvested aspen stands on county and state forest land from the online database Wisconsin Forest Inventory & Reporting System (WisFIRS), which is designed to track timber sales on public and private land.

Stands were selected on the basis of four criteria: (1) aspen listed as the primary species, (2) 35-100 acres in size, (3) approximately circular in shape with minimal edge (in order to reduce edge effects), and (4) harvested between 2007 and 2010 or between 1960 and 1970. We confirmed date, season of harvest, and harvest type with local foresters.

Quantification and analysis of downed woody material from variable harvest types

Between September 2009 and July 2010, we sampled 41 replicate aspen stands in four counties ($N_{\text{Burnette}} = 14$, $N_{\text{Douglas}} = 7$, $N_{\text{Oneida}} = 14$, and $N_{\text{Marinette}} = 6$). Stands sampled were of three harvest types ($N_{\text{Roundwood}} = 14$, $N_{\text{Whole-tree}} = 17$, $N_{\text{Control}} = 10$) defined as:

1) **Roundwood harvest**: traditional 4 inch bole harvest, where the boles are removed and limbs are left on site

2) **Whole-tree harvest**: trees are cut at the base, brought to a staging area and the entire tree, including limbs, is fed through a chipper or grinder on site

3) **Control**: unharvested, mature aspen stands between 40 and 50 years of age

Harvest types were distributed throughout each county. There is replication of all treatment combinations of harvest type and county, except that only one stand was classified as whole-tree harvest in Marinette County. Whole-tree harvest is less common in this county and this stand was the only stand that fit the other criteria.

To sample the volume of downed woody material, we used a line intersect sampling technique. Within each stand we placed 10 points at random, which were ≥ 40 m from the stand edge and > 80 m from each other. We measured coarse woody debris (CWD) and fine woody debris (FWD) along 5 radiating transects. Transects were 40 meters in length, and from the point radiated out at 0, 72, 144, 216, and 288 degrees (Fig. 1).

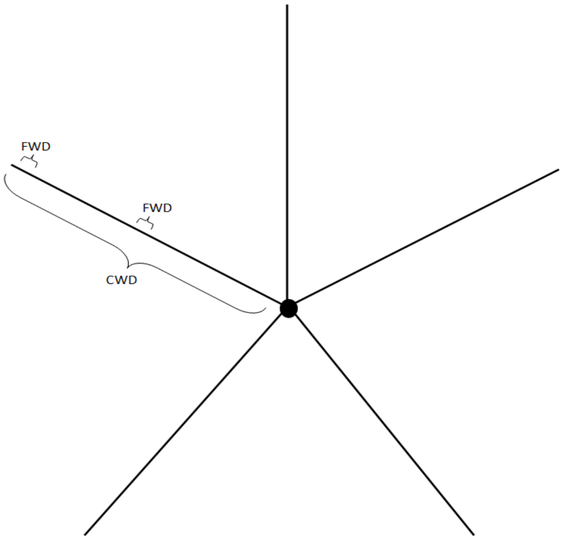

Fig. 1. Woody debris was measured along five radiating transects at each point (adapted from Rittenhouse 2012)

CWD was defined as pieces of wood ≥7.62 cm in diameter at the location where the wood intersected transects, while FWD was pieces of wood < 7.62 cm in diameter. We counted and measured the diameter of all CWD at the point where the piece of wood intersected transects. We tallied FWD at two 4 m portions of the larger 40 m transect. We classified FWD into three class sizes: small (≥0.64 cm), medium (0.64-2.54 cm), and large (2.55-7.62), as defined by the Forest Inventory and Analysis program of the Forest Service (Woodall and Menleon 2008).

We calculated the total volume of woody debris per hectare and the volume of FWD in each size class using previously published equations and squared diameters for aspen (Marshall et al. 2000, Woodall and Monleon 2008). Using ANOVA, we then compared volume of woody debris by harvest type and county. In order to provide managers with information about the effect of harvest prescriptions on volume of FWD, we also compared FWD volume by season and year since harvest.

For each harvest type, we quantified the relationship between FWD and CWD volumes using mixed linear regression models. We developed and ranked candidate models that predict the volume of fine woody debris from volumes of coarse woody debris and other characteristics of the site including county, season, soil, and year since harvest. Stand was included as a random effect to account for lack of independence among sites within a stand. Models were then ranked using Akaike's Information Criterion and Akaike weights. We made predictions based on the AIC optimal model and plotted the predicted values and confidence intervals of FWD volume for the CWD volumes measured in the study.

Small mammal response to woody debris levels

To evaluate the impact of biomass harvest on small mammals, we sampled in 16 aspen stands, a subset of the stands sampled for woody debris volume. Sampling took place during August and September 2010. Stands were of 3 harvest types ($N_{Roundwood} = 7$, $N_{Whole\text{-}tree} = 7$, $N_{Control} = 4$) and in 3 counties ($N_{Burnette} = 5$, $N_{Douglas} = 5$, $N_{Oneida} = 6$).

Each week of the study period, we simultaneously trapped two aspen stands of different harvest types for four consecutive days. We ensured that stands of different harvest types were spread throughout the study period. At each stand, traps were arranged in 10 sampling grids, with the center of the grid corresponding to the radial transect used to measure volume of downed woody debris. We placed 16 traps per grid arranged 4 X 4 with 15 m spacing, giving a total of 160 traps per stands (Fig 2). In each stand, 6 grids were set with Sherman traps (large aluminum, 7.6 X 8.9 X 22.9 cm) and 4 grids were set with pitfall traps (20 cm diameter X 38 cm height, with lids held 20 cm off the ground). At one stand, due to logistical constraints, we were only able to set 8 grids, giving a total sample of 153 grids.

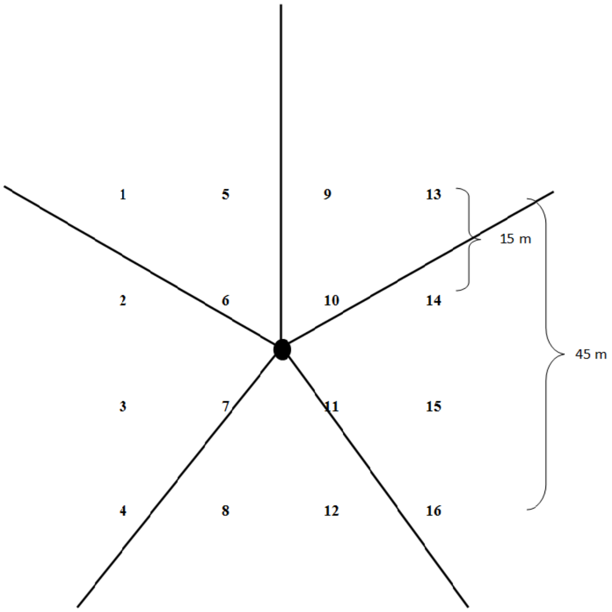

Fig. 2. Traps were arranged in 10-4X4 sampling grids, with the center of the grid corresponding to the center of the radial transect.

Traps were baited with peanut butter and polyester batting was provided if temperatures fell below 7.2 °C. Animals captured were identified to species, weighed, and sexed. Targeted species (mice, shrews, and voles) were uniquely marked with paint pens and released at point of capture (Pauli et al. 2006).

In addition to FWD and CWD data collected prior, additional habitat variables were measured at 8 of the 16 trap locations within each grid. Soil moisture, tree density, and groundcover variables were measured during either the week of or the week following small mammal trapping. We calculated soil moisture from the average of 3 readings of volumetric water content measured using soil moisture probes. We excluded readings within 24 hours of a large rain event (>1.3 cm).

In order to capture information about the presence or absence and make up of a brush pile, we recorded the number of pieces of woody material that crossed the center point of a 1 m^2 quadrant and measured the diameter of the largest piece of woody debris. To quantify regeneration, we recorded the number and height of all tree species within each quadrant. We visually estimated ground cover to the nearest 5% in the following categories: bare soil, rock, litter, FWD, CWD, vegetation, and stems.

Due to the limited number of recaptures in each time period at each grid, we were unable to examine the effects of downed wood using a mark recapture model. Alternately, we developed a set of candidate models representing competing hypotheses regarding habitat features which affect small mammal abundance within a stand. These models were expressed as Poisson regression models with mixed effects and the minimum number known alive as the response variable. Models were then ranked using Akaike's Information Criterion and Akaike weights.

Potential revenue from biomass harvest

To estimate the net revenue that is obtainable from converting woody biomass material to bioenergy, we estimated the market value of the biomass available (residual material) within our study sites. In order to estimate the market value of the biomass available, we first utilized the data collected on CWD and FWD availability on all study sites, in addition to other variables collected such as soil, acres, and season. We used a generalized linear mixed effects (GLM) econometric model to predict the total volume of biomass available across the 41 sites, with site treated as a random effect. We tried several different model specifications for the estimation of total volume of biomass. In terms of covariates the following model, Model 1 was best for the fixed effects by the AIC criterion:

Model1:~ soil*county+county*treat+county*soil+treat*soil (any interaction a*b denotes a+b+ab)

However results of Model 1 are difficult to interpret owing to its complexity. So we evaluated several reduced form models that were simpler while maintaining performance. We identified Model2 as preferred utilizing AIC criterion: Model2:~ county+treat

We then ran the following two models and added their predicted values as our total biomass volume (sum of fitted CWD values and fitted FWD values) given by the following equations:

Vol.Coarse~ county+treat

Vol.Fine~Vol.Coarse+county+treat

Predicted plot-wise total=Fitted Values of Vol.Fine with Vol.Course as a predictor+Fitted values of Vol.Course.

In summary, the regressors in Model 2, i.e. treat and county are plausible explanatory variables as shown by the fit of the predicted values shown in Figure 3.

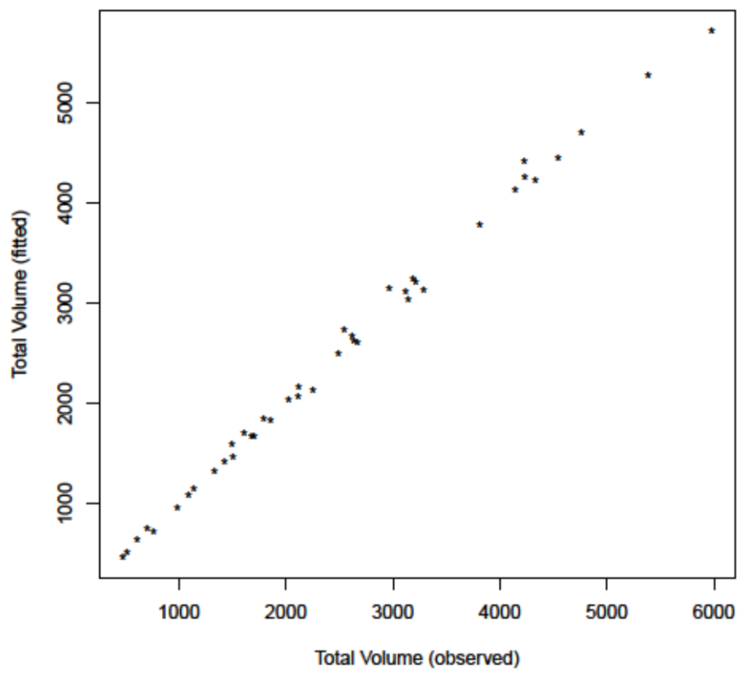

Fig. 3. Predicted values of total biomass volume against observed volume.

We then combined the results from the econometric model with an estimate of the price of woody biomass in the region, which we set at $2.14/dry ton of material (Terry Mace, personal communication, Peterson 2005).

FINDINGS

Quantification and analysis of downed woody material from variable harvest types

We found that the estimate of CWD and FWD volume differed significantly by harvest type and county (all $P < 0.0001$; Fig. 4, Appendix A).

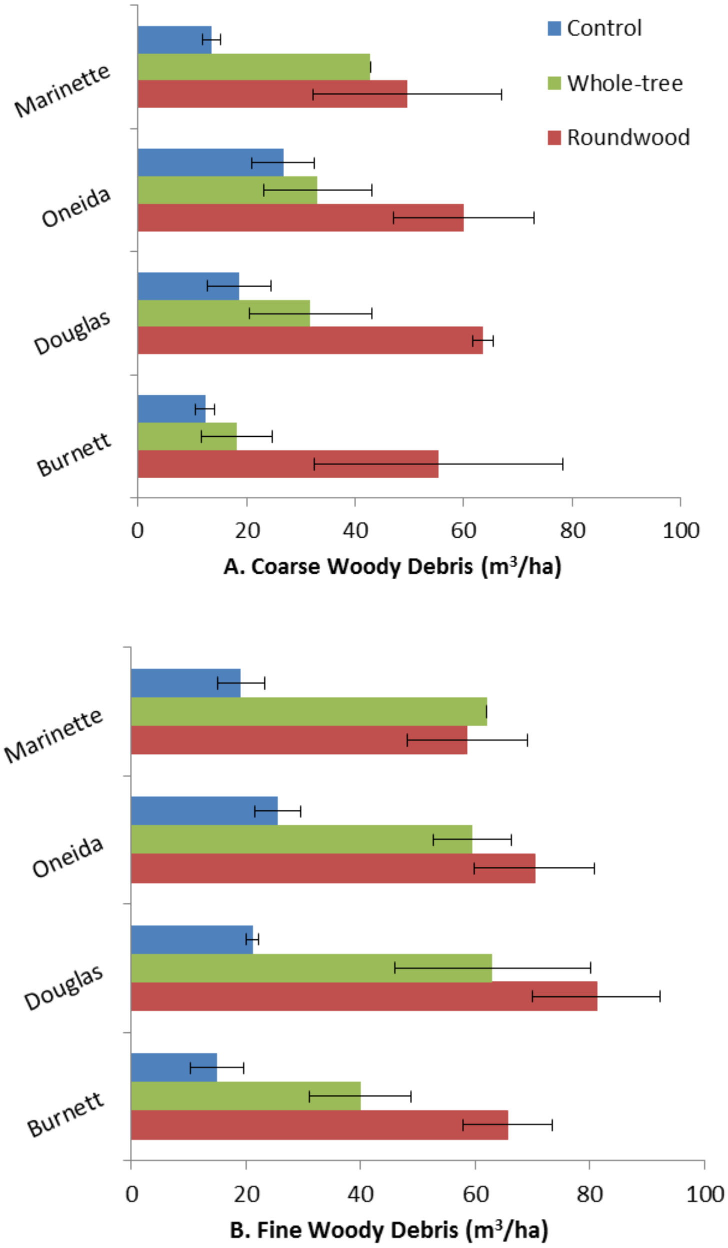

Fig. 4. Volume and standard deviation of CWD (A) and FWD (B) within the 4 counties for the 3 harvest types (adapted from Rittenhouse 2012)

In addition, we found that volume of FWD was affected by an interaction of season and harvest type (Fig. 5A). Specifically, the volume of FWD is greater following a winter harvest than summer harvest in whole-tree stands, but not roundwood stands. We also found that for both harvest types, volume of FWD decreases with time since harvest, which indicates that FWD decomposes rapidly (Fig. 5B).

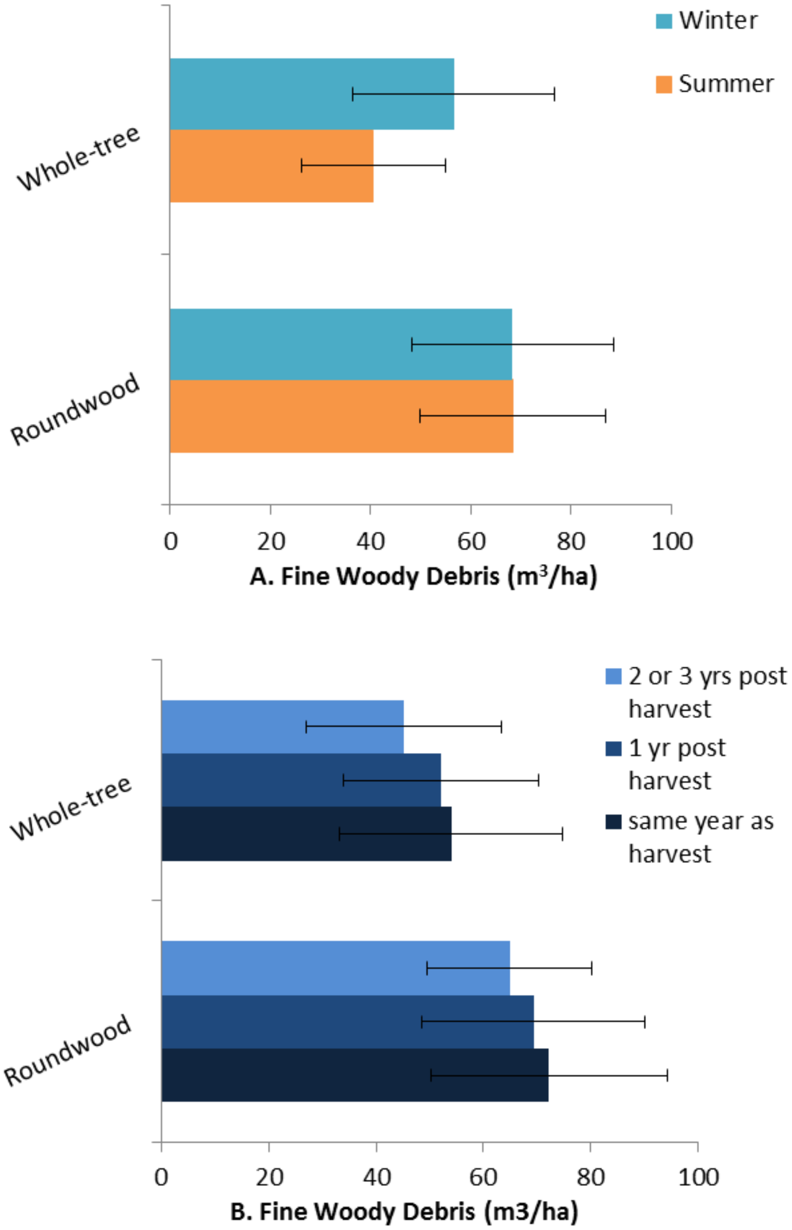

Fig. 5. Volume and standard deviation of FWD (A) within roundwood and whole-tree harvests for the summer and winter season and volume and standard deviation of FWD (B) within roundwood and whole-tree harvests for years since harvest (adapted from Rittenhouse 2012)

Across all 3 size classes of FWD, we found the volume to be greater for both roundwood and whole-tree harvest stands compared to control stands (Fig. 6).

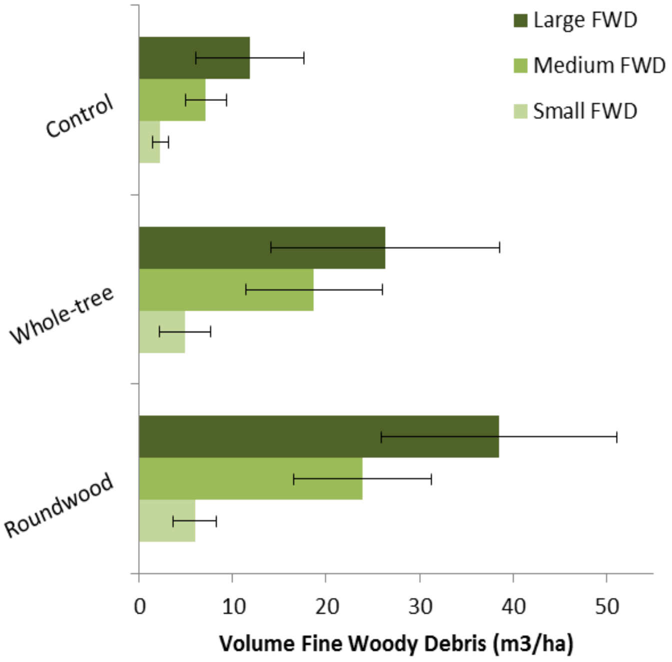

Fig. 6. Volume and standard deviation of FWD within the 3 harvest types for the 3 size classes (adapted from Rittenhouse 2012)

Through our AIC model selection approach, we found that the relationship between volume of FWD and CWD was best explained by the model containing volume of coarse woody debris, harvest type, and county (Appendix B). For this model, the variance that was attributed to the random effect of stand indicated that there is significant variation amongst sample points within a stand, but that variation is still less than the variability among stands. In the optimal model, estimates of the fixed effect parameters indicated that more FWD is found at stands where roundwood harvest had been conducted as compared to whole-tree harvest. Control stands had the lowest volumes of FWD. For each harvest type we plotted theses predicted volumes of FWD and their confidence intervals for the range of CWD that was measured (Fig. 7). The volume of FWD (where X is the volume of CWD in m^3/ha and Y is the volume of FWD in m^3/ha for treatment *i*) can be estimated as follows:

Volume of FWD in a roundwood harvest stand ($Y_{Roundwood}$; m^3/ha) can be estimated as:

$$Y_{Roundwood} = (6.69395 + 0.022331 * \sqrt{X})^2$$

Volume of FWD in a whole-tree harvest stand ($Y_{Whole\text{-}tree}$; m^3/ha) can be estimated as:

$$Y_{Whole\text{-}tree} = (6.20722 + 0.022331 * \sqrt{X})^2$$

Volume of FWD in a mature aspen stand ($Y_{Control}$; m^3/ha) can be estimated as:

$$Y_{Control} = (3.73515 + 0.022331 * \sqrt{X})^2$$

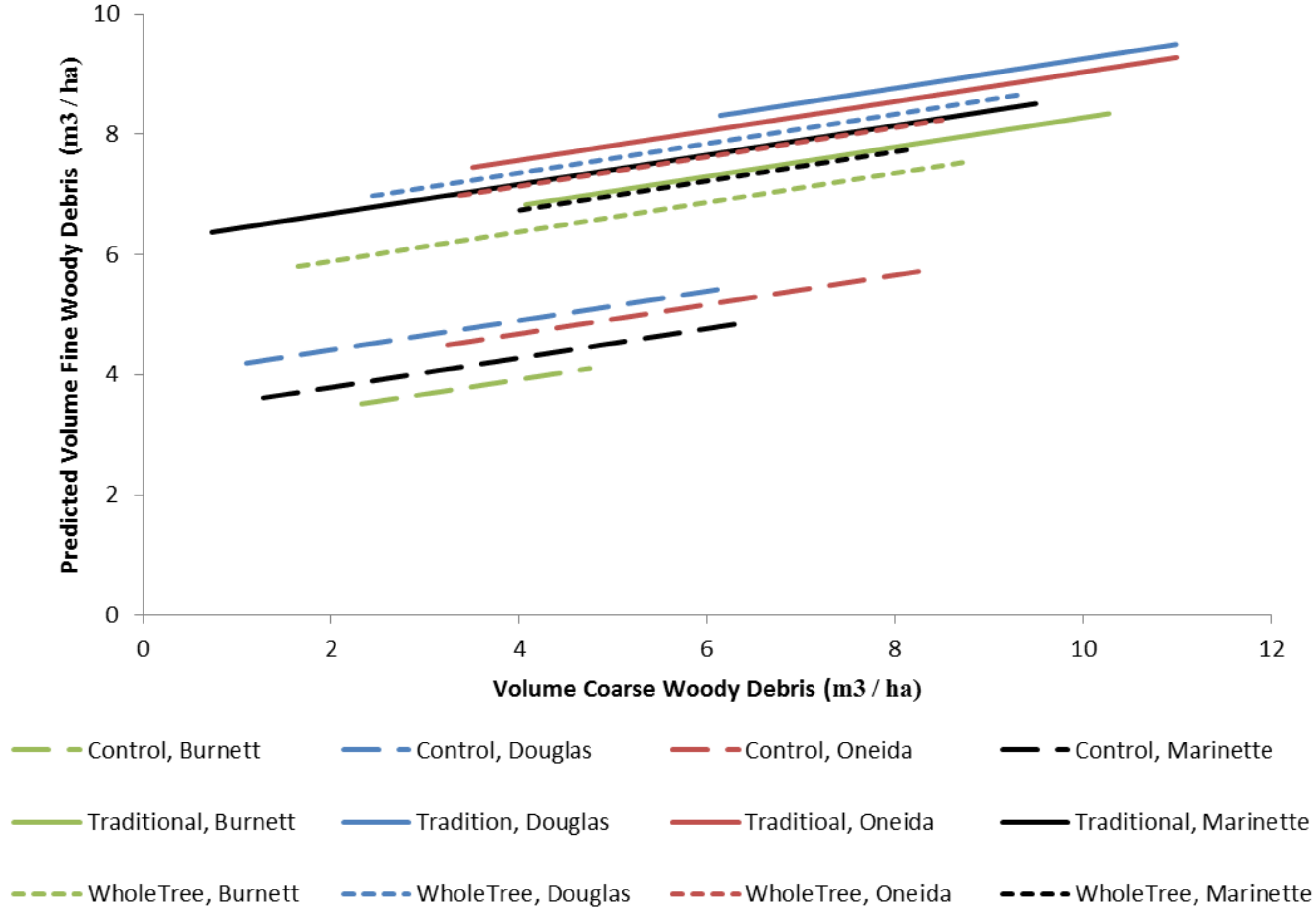

Figure 7. Predicted volumes of FWD for range of CWD volumes observed (adapted from Rittenhouse 2012)

Small mammal response to woody debris levels

We captured a total of 1961 unique individuals during 9792 trap nights. We grouped species into three categories: **Voles** (n = 74) which included red-backed voles (*Clethrionomys gapperi*) and meadow voles (*Microtus pennsylvanicus*); **Mice** (n = 560) consisting of white-footed mice (*Peromyscus leucopus*) and deer mice (*Peromyscus maniculatus*); **Shrew** (n = 538) consisting of masked shrew (*Sorex cinereus*), pygmy shrew (*Sorex hoyi)*, and short-tailed shrew (*Blarina brevicauda*).

Trap type greatly influenced species captured. Mice were caught in grids consisting of Sherman traps, while voles and shrews were caught in pitfall traps (for all species categories P < 0.0001). There was not a clear pattern among harvest treatments or counties, however comparison of candidate models did reveal some abundance differences within stand.

For mice, AIC model selection suggests that abundance is best explained by the model containing all of the ground cover variables and the measurement of soil moisture, which was an important variable in the model (B = -

0.04755, SE = 0.01249, P = 0.0001; Appendix C). Specifically, mice abundance decreased as soil moisture increased.

For shrews, three candidate models were competing (within 2 AIC units). The best model, according to AIC selection, contained only the measurement of soil moisture (Appendix C). The competing models contained the measurement of soil moisture and one additional variable. Model averaging results indicated that the additional variables likely provide little biological meaning. We therefore made all inference based on the model containing only the measurement of soil moisture. Specifically, we found that shrew abundance increased as soil moisture increased.

For voles, AIC model selection suggests that abundance is best explained by the model containing an interaction of volume of CWD with the volume of FWD (Appendix C). Specifically abundance of voles is highest when the volume of both CWD and FWD is high (Fig. 8). However, abundance also is high at sites where there are low volumes of CWD and moderate volumes of FWD. It is important to note that sites with low volumes of CWD and high volumes of FWD were not detected in this study.

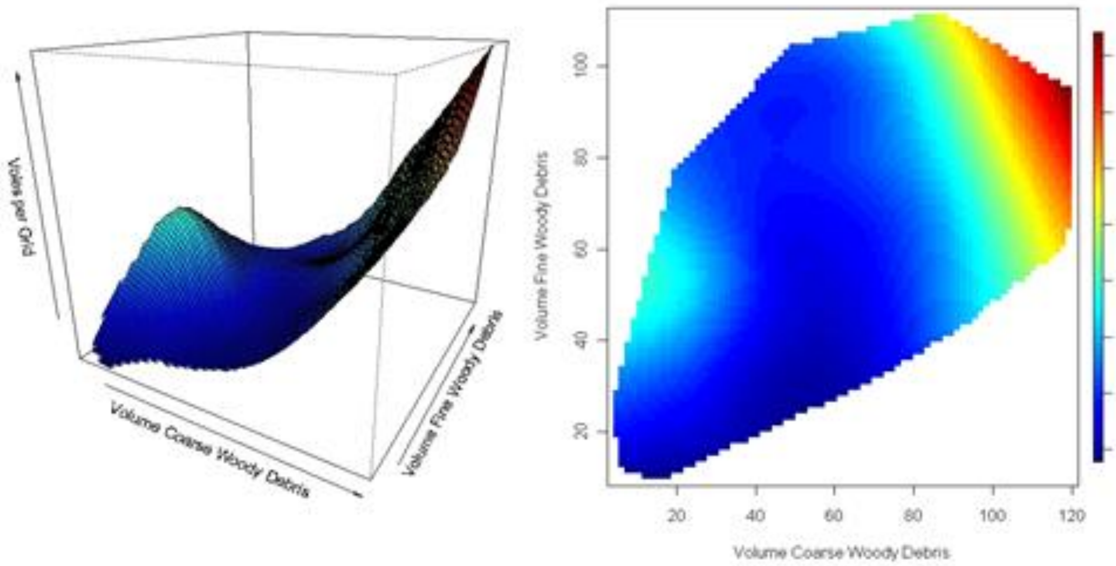

Fig. 8. Abundance of voles is affected by an interaction of volume of CWD and volume of FWD (adapted from Rittenhouse In prep)

Potential revenue from biomass harvest

The value estimates reflect the potential for additional revenue gained through harvesting the woody biomass material (FWD and CWD) from all sites at the time of study. From our final econometric model, the total volume of biomass measured within the total acreage considered (3030 acres) is 102,424.27 cubic meters or 33,859.26 dry tons. Using standard conversion factors between cubic meters, green tons, dry tons and the above price, the potential revenue that could be obtained by landowners for this additional volume of timber is $72,458.82, for CWD and FWD biomass across all sites.

IMPLICATIONS

In quantifying the volume of woody material remaining after aspen harvest, we found substantial variation among sites (range of 42.24 - 159.72 m^3/ha). Aspen stands following roundwood harvest contained more downed wood (125.71 ± 20.79 m^3/ha) than stands with whole-tree harvest (75.54 ± 23.70 m^3/ha), while mature, unharvested aspen stands contained the least downed wood (40.90 ± 11.6 m^3/ha). Notably stands for both harvest types contained more FWD (58.31 ± 15.86 m^3/ha) than CWD (39.89 ± 20.48 m^3/ha). Such results indicate that there is significant potential for increased removal of FWD on recently harvested sites for use in biomass markets, but also that substantial amounts of FWD have historically served as a nutrient input and wildlife habitat following harvest.

On harvested sites, both season of harvest and years since harvest impact the amount of FWD. We identified larger volumes of FWD on winter harvested stands compared to summer harvested stands, possibly from frozen conditions leading to increased breakage of limbs (Rittenhouse et al. 2012). We also found that the volume of FWD decreased with each year since harvest. Stands continue to contain more FWD than CWD for the three years following harvest, suggesting that decomposition of FWD may be an important nutrient input during that time period.

With respect to the potential for woody biomass removal to impact small mammals, we found evidence that downed wood is not equally important to the small mammal species targeted in this study. We found that vole abundance corresponds positively to the volume of downed wood. For mice, ground cover and soil moisture were better predictors of abundance than volume of downed wood; the abundance of mice was negatively associated with soil moisture. While for shrews, soil moisture was positively associated with abundance. Our findings were consistent with previous literature which documents a positive relationship between voles and downed wood (Vanderwel et al. 2010). Notably, we found that voles respond also to an interaction between CWD and FWD. Specifically, voles were found at sites with both high CWD and FWD, but secondarily voles were found at sites with low CWD and moderate volumes of FWD, indicating that voles may seek out FWD at sites where very low volumes of CWD are found. These sites may provide cover from predators, in addition to low levels of competition (Rittenhouse In prep). These important distinctions between taxonomic groups support the idea that small mammals are specialists tied to resources at small spatial scales (Manning and Edge 2004).

Our study sites covered a range of downed wood volume, and we did not detect a minimum threshold volume of woody material at which small mammals are absent. However, all sites sampled were imbedded within a forested landscape where high quality small mammal habitat is abundant on neighboring stands. We did not verify that survival rates and birth rates within sites with low levels of down wood are adequate to maintain populations within the stand if the surrounding forest is not present to provide immigration into the site. It is possible that small mammals travel through sites with little down wood, but populations cannot persist within these sites. Additional taxa specific data will be important to understand wildlife response to increased removal of downed wood. As a management practice, maintaining brushpiles would provide habitat heterogeneity supporting a diversity of mammal species (Rittenhouse In prep).

Applied insights and future monitoring needs

The effort required to quantify the volume of FWD on a site is substantial. Thus, as an important applied implication of our study, we demonstrated that the volume of FWD could be estimated from the volume of CWD present, potentially making guideline implementation and monitoring significantly more efficient. In Wisconsin, compliance with the Woody Biomass Harvesting Guidelines is directly linked to forest certification, and is also mandatory on state lands. The results of this study could be used in the development of an accessible tool for managers to be used in the field. This would provide managers with a reliable method to verify the amount of material remaining after a harvest and therefore would provide an opportunity for managers to adjust practices to meet site goals as set by guideline standards (i.e., tonnage of material remaining on a site following harvest) while meeting other goals that may benefit from woody biomass removal, such as revenue generation.

Woody biomass harvest is not defined by the procedures used to harvest trees, but rather by the end product. As a result, identifying these biomass harvest sites is difficult because logging operations typically do not specify the end product. If removal of downed wood present on site prior to harvest was occurring, we would expect that mature stands (those used as controls in our study) would contain more CWD than whole-tree harvest stands. In our study, we found that mature stands contained less CWD than either of the harvest types, indicating that there is likely no or little removal of downed wood present of site prior to whole-tree or roundwood harvests on county and state lands. Woody biomass is considered a low-value material, with multiple limiting factors thought to constrain biomass utilization, including lack of a guaranteed supply of material, presence of a wood products industry infrastructure, transportation costs, and the value of biomass, among others (Becker et al. 2011). However, if these constraints were removed (i.e., the price of woody biomass increased), we would expect increased interest in available woody biomass and potential intensification of the removal of downed wood material (Dirkswager et al. 2011), possibly beyond what we found in our study. Thus, as demand for woody biomass potentially changes, we would recommend the continued monitoring of the harvest intensity of biomass across site conditions and the types of harvest operations and evaluation of resulting economic and ecological impacts.

CONCLUSION

This project has resulted in a successful peer-reviewed publication (Rittenhouse et al. 2012), with additional manuscripts in preparation (Rittenhouse et al. In prep, Bakshi et al. In prep *a, b.)*. Findings from this project are currently contributing to the Council on Forestry Advisory Committee's Review of Wisconsin's Woody Biomass Harvesting Guidelines process and potential refinements of state agency standards. Findings from this project can also be translated into a tool for direct use by forest managers to verify the amount of woody material remaining after a harvest; a potential use being explored by staff within the Wisconsin DNR, Bureau of Sciences Services.

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Rittenhouse, T.A.G., D.M. MacFarland, K.J. Martin, and T.R. Van Deelen. 2012. Downed wood associated with roundwood harvest, whole-tree harvest, and unharvested stands of aspen in Wisconsin. Forest Ecology and Management 266:239-245.

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Bakshi, B., et al. In prep *a*. Ecological impact of biomass harvesting in Wisconsin Aspen forests: the case of small mammals

Bakshi, B., et al. In prep *b.* Economic impact of biomass harvesting in Wisconsin Aspen forests

ABSTRACTS AND PROCEEDINGS

The Wildlife Society Indiana Chapter, Salem, IN 2012 Invited Seminar**:** *Maintaining wildlife populations in intensively managed forests*

Alfred University, Alfred, NY 2012 Invited Seminar**:** *Maintaining wildlife populations in intensively managed forests*

The Wildlife Society Wisconsin Chapter, Wisconsin Dells, WI 2011 Plenary: *Small mammal and amphibian response to early successional silvicultural practices*

71th Midwest Fish and Wildlife Conference, Mpls, MN 2010 Paper**:** *Biomass harvest in Wisconsin forests: Changes to woody debris levels and small mammal communities*

The Wildlife Society Wisconsin Chapter, Wausau, WI 2010. *Reduced Woody Debris Volume Associated with Biomass Production.*

Appendix A. Results of ANOVA analysis comparing volume of fine woody debris (FWD) and volume of coarse woody debris (CWD) (Adapted from Rittenhouse 2012).

Response Variable	**Source of Variation**	**df**	**F value**	**P value**
FWD	COUNTY	3	33.2186	< 0.0001
	HARVEST	2	386.4046	< 0.0001
	COUNTY*HARVEST	6	5.5638	< 0.0001
	Residuals	397		
CWD	COUNTY	3	21.0029	< 0.0001
	HARVEST	2	169.2741	< 0.0001
	COUNTY*HARVEST	6	5.3808	< 0.0001
	Residuals	397		

Appendix B. Candidate models ranked by change in AIC value for estimating the volume of FWD (Adapted from Rittenhouse 2012). See variable descriptions below. All models contained site as a random effect.

Model	**AIC**	**loglik**	**Delta AIC**	**W**
COARSE, HARVEST, COUNTY	1130	-556	0	0.6875
COARSE, HARVEST, COUNTY, HARVEST*COUNTY	1132	-550.8	2	0.2529
COARSE, HARVEST	1136	-562	6	0.0342
COARSE, SEASON	1137	-562.4	7	0.0208
COARSE, YEARSINCE	1140	-562.8	10	0.0046
COARSE	1184	-587.8	54	0.0000
COARSE, COUNTY	1186	-586	56	0.0000
COARSE, SOIL	1187	-586.3	57	0.0000

COARSE: volume of coarse woody debris (m^3/ha)

HARVEST: type of timber harvest (whole tree, roundwood, or control)

COUNTY: Douglas, Burnett, Marinette, or Oneida

SEASON: season of harvest (control, summer, winter)

YEARSINCE: year since harvest (control, year 0, year 1, year 2, or year 3)

SOIL: soil type (sand, loamy sand, sandy loam or sandy clay, and loam or silt).

Appendix C. Candidate models ranked by change in AIC value for estimating target small mammal abundance (Adapted from Rittenhouse 2012. See variable descriptions below. All models contained site as a random effect. Only the top seven candidate models are included in the table. Mice is a combination of *Peromyscus leucopus* and *Peromyscus maniculatus* species. Shrews include *Sorex cinereus, Sorex hoyi, Blarina brevicauda.* Voles include *Clethrionomys gapperi* and *Microtus pennsylvanicus.*

	Model	**logLik**	**AIC**	**delta AIC**	**W**	**BIC**	**Deviance**
Mice	SOIL, ROCK, LITTER, FWD, CWD, LOWVEG, STEMS, MOIST	-94.57	209.1	0	0.9561	234.5	189.1
	Global Model	-89.87	215.7	6.6	0.0353	261.3	179.7
	SOIL, ROCK, LITTER, FWD, CWD, LOWVEG, STEMS	-100.4	218.8	9.7	0.0075	241.6	200.8
	SOIL, ROCK, LITTER	-106.9	223.9	14.8	0.0006	236.6	213.9
	SOIL, CWD, LOWVEG, LITTER	-106.2	224.3	15.2	0.0005	239.5	212.3
	HARVEST, SOIL, CWD, LOWVEG, LITTER	105.9	227.7	18.6	0.0001	-248	211.7
	CWD, LOWVEG	-111.5	231.1	22	0.0000	241.2	223.1

HARVEST: Type of timber harvest classified as whole tree chip, traditional, or control

COARSE: Volume of coarse woody debris (m3/ha)

FINE: Volume of fine woody debris (m3/ha)

BRUSHHEIGHT: Height of brushpile (m), brushpile defined by 3 or more pieces of stacked woody material

BRUSHDIAMETER: Diameter of largest piece of woody material in brushpile (m)

ASPENNO: Number of aspen trees

ASPENHEIGHT: Average height of aspen trees (m)

MOIST: Soil moisture (units)

SOIL: Percent cover that is bare soil

ROCK: Percent cover that is rock, stumps or standing water

LITTER: Percent cover of dead and decaying leaves, pine needles, and plant matter

FWD: Percent cover of fine woody debris

CWD: Percent cover of coarse woody debris

LOWVEG: Percent cover of grasses, forbs, or woody plants less than knee height.

STEMS: Percent cover that is tree trucks or base of growing vegetation greater than knee height

SITE: Aspen stand

	Model	logLik	AIC	delta AIC	W	BIC	Deviance
Shrews	MOIST	-63.77	133.5	0	0.2787	139.8	127.5
	MOIST, BRUSHHEIGHT	-63.56	135.1	1.6	0.1252	143.5	127.1
	MOIST , COARSE	-63.75	135.5	2	0.1025	143.9	127.5
	HARVEST, MOIST	-62.87	135.7	2.2	0.0928	146.2	125.7
	MOIST, COARSE, BRUSHHEIGHT	-63.55	137.1	3.6	0.0461	147.6	127.1
	LITTER	-65.62	137.2	3.7	0.0438	143.5	131.2
	SITE	-66.69	137.4	3.9	0.0396	141.6	133.4

HARVEST: Type of timber harvest classified as whole tree chip, traditional, or control

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STEMS: Percent cover that is tree trucks or base of growing vegetation greater than knee height

SITE: Aspen stand

	Model	logLik	AIC	delta AIC	W	BIC	Deviance
Voles	COARSE, FINE, COARSE*FINE	-64.15	138.3	0	0.4164	148.8	128.3
	COARSE, FINE, COARSE*FINE, BRUSHHEIGHT, BRUSHDIAMETER, ASPENNO, ASPENHEIGHT	-61.48	141	2.7	0.1079	159.8	123
	FINE	-67.96	141.9	3.6	0.0688	148.2	135.9
	FINE, ASPENNO	-66.96	141.9	3.6	0.0688	150.3	133.9
	COARSE, FINE	-67.27	142.5	4.2	0.0510	150.9	134.5
	ASPENNO	-68.39	142.8	4.5	0.0439	149.1	136.8
	SITE	-69.64	143.3	5	0.0342	147.5	139.3

HARVEST: Type of timber harvest classified as whole tree chip, traditional, or control

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LOWVEG: Percent cover of grasses, forbs, or woody plants less than knee height.

STEMS: Percent cover that is tree trucks or base of growing vegetation greater than knee height

SITE: Aspen stand