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Utilization of Low Grade Wood for Use as Animal Bedding: A Case Study of Eastern Hemlock

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The hemlock woolly adelgid (HWA) (*Adelges tsugae*) is causing widespread mortality of eastern hemlock (EH) (*Tsuga canadensis* [L.] Carrière) across its range. Unless ecological or cultural considerations are accounted for, few forest managers would find it economical to manage the HWA. However, new markets for EH may increase incentives to manage the HWA or at least bring more value to this low-grade tree species. Our research explores the feasibility of using EH as animal bedding, by comparing water absorption, microbial growth, and wood shaving production factors with eastern white pine (EWP) (*Pinus strobus* L.). Results showed that when dried to 10 percent and 30 percent moisture content, EH absorbed 281 percent and 176 percent of its weight in water, which was significantly lower than EWP, which absorbed 361 percent and 243 percent respectively. However, no difference was found between tree species when comparing the growth of pathogenic bacteria in bedding samples. Furthermore, no difference in volume of produced bedding was found when using a wood shaving machine. These findings suggest that EH is suitable for animal bedding, especially if the substantially lower stumpage value of the wood resource, as compared with EWP and other species within its range, compensates for the reduced moisture absorbing capability.

Keywords: Eastern hemlock, hemlock woolly adelgid, animal bedding, utilization of low grade wood, woody animal bedding

Over the past century, forests in the Northeastern United States have experienced increased infestations and outbreaks of introduced pathogens and pests (Orwig et al. 2002). One such pest is the hemlock woolly adelgid (HWA) (*Adelges tsugae*), an aphid-like insect that feeds on the sap of eastern hemlock (EH) (*Tsuga canadensis* [L.] Carrière) (Finzi et al. 2014). The HWA was first introduced to the United States from Japan in the 1950s and has been spreading throughout the range of EH ever since. To date, there are no cost-effective controls preventing the spread of the HWA, causing serious concern for the future of this tree species (Ellison et al. 2005). Once a tree is infested, it will typically succumb within four to ten years (Orwig et al. 2002).

To reduce the economic losses associated with the HWA, some forest managers are conducting presalvage harvests to obtain the highest value for the wood before infestation occurs (Kizlinski et al. 2002). However, even with presalvage harvests, EH does not have high economic value, with regional stumpage values hovering around $50/mbf (Evans 2017, Jacobson 2017, Maine Department of Agriculture, Conservation and Forestry [MDACF] 2017, New York State Department of Environmental Conservation [NYDEC] 2017, Vermont Department of Forests, Parks and Recreation [VDFPR] 2017, Wisconsin Department of Natural Resources [WDNR] 2017, UMass Amherst Cooperative Extension [UMass] 2018). The low stumpage value is because of unfavorable wood characteristics, which include ring shake, uneven grain texture,

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low resistance to splitting, low resistance to decay, and difficulty to work with (Howard et al. 2000). As such, forest managers will typically make only marginal returns selling the wood for bark mulch, pulpwood, fuel chips, low-grade timber (rough framing, subflooring, and beams), and more recently mat logs for logging operations (Howard et al. 2000, Howard 2017, pers. commun.). However, an additional and potentially more valuable market exists that may be able to absorb large volumes of EH that will become available as the HWA spreads: animal bedding.

Currently, most woody animal bedding in the Eastern United States comes from one or several different pine species, with eastern white pine (EWP) (*Pinus strobus* L.) being the most common. Eastern white pine is used because of its desirable animal bedding attributes, such as high moisture absorption, regional availability, and the capacity to inhibit the growth of pathogenic bacteria through its resin acids, terpenes, and phenolic compounds (Zehner et al. 1986). In contrast, little is known about the suitability of EH as a bedding source. Filling this knowledge gap is important, as not all trees are suitable for bedding. For instance, bedding made from hardwoods are often avoided in the dairy industry, as they have been found to support higher populations of mastitis-causing bacteria when compared with softwoods (Zehner et al. 1986). Therefore, the primary goal of this study is to assess whether EH is suitable for use as animal bedding, with EWP serving as a reference standard. We compared the two species on the following points: 1) physical and chemical characteristics (moisture absorption, wood shaving particle size, and organic fraction), 2) growth of pathogenic bacteria known to cause environmental mastitis (*Escherichia coli*, *Klebsiella* spp., and *Streptococcus* spp.) on EH only, EWP only, and a 50:50 EH + EWP bedding mix, and 3) volume output of bedding from each species using a commercial wood shaving machine.

Methods

Study Site

This study was conducted during the fall of 2017 at the University of New Hampshire's Organic Dairy Research Farm in Lee, New Hampshire. The research farm milks 50 organic Jersey cows and uses EWP wood shavings for bedding in the bedded pack system. The farm also has a 120-acre woodlot (49 hectares), which was used to obtain the EH and EWP wood for this study.

Bedding Sample Production and Wood Shaving Machine Output by Species

Eastern hemlock and EWP bedding samples were produced using the farm's wood shaving machine (Tremzac 248T). The machine operates by filling an 8-foot (2.4 meters) hopper box with logs up to 24 inches (61 centimeters) in diameter (Figure 1) (Smith et al. 2017a). The hopper box passes over a set of rotating planer knives, which planes the log one-eighth to one-half inches (3–13 millimeters) per pass. The logs used for this study came from 10 EH and 10 EWP trees, which were 10–12 inches DBH (25–31 centimeters) and ranged in age from 60–75 years (Eisenhaure 2016). All logs were cut into 8-foot sections (2.4 meters), debarked, and put through the wood shaving machine using a one-eighth-inch (3 millimeters) shaving thickness. The quality of the trees used in the study was low for both species, with EH being in a small size class and the pine having poor form because of weeviling.

Upon wood shaving, bedding was discharged from the wood shaving machine conveyor onto a clean tarp, ensuring the material would not become contaminated with soil. Separate bedding piles were made for each tree species. Following wood shaving, each pile was mixed using a tractor bucket to ensure the composite piles were thoroughly mixed. Following mixing, a one-cubic-yard (0.76 cubic meters) composite sample for each tree species was collected and stored in one-cubic-yard (0.76 cubic meters) grain storage bags for use in the study. From the one-cubic-yard (0.76 cubic meters) composite sample, roughly 5 cubic feet (0.14 cubic meters) of wood shavings per species were removed and kiln-dried to 10 percent moisture content, using methods described in Kalra and Maynard (1991). The kiln-dried shavings were stored in large airtight plastic bags for use in the microbial growth, absorption, and particle-size portions of the study.

While bedding was being generated for the study, wood shaving machine efficiency for each tree species (i.e., amount of time to generate one cubic yard [0.76 cubic meters] of bedding) was also recorded. Bedding that was discharged from the wood shaving machine was filled into the storage bins, with the amount of time required to fill one cubic yard (0.76 cubic meters) recorded. The wood shaving machine was paused in between replicates to ensure an accurate time for each replicate.

Physical and Chemical Characteristics of EH and EWP

Absorbency of Wood Shavings. The ability of EH and EWP to absorb moisture was determined for kiln-dried bedding at 10 percent moisture content and air-dried bedding at 30 percent moisture content. Absorbency for each replicate was determined by submerging 0.04 ounces (1 gram) of bedding material into 1 fluid ounce (30 milliliters) of deionized water for 1 hour. After 1 hour, the water was removed from the sample container, and a bedding wet weight was recorded. Absorbency was calculated using the following formula from Zehner et al. (1986):

Management and Policy Implications

The hemlock woolly adelgid (HWA) is causing widespread mortality of eastern hemlock (EH) across its range. Unfortunately, current control mechanisms are cost-prohibitive for wide-scale use, raising the question of what market will absorb the large volumes of low-grade EH wood that will become available as trees succumb to infestation. Our research investigates a new market for EH, by assessing whether it is suitable for livestock animal bedding. The specific factors studied were moisture absorption, ability to support pathogenic bacteria, and rates of animal bedding production using a commercial wood shaving machine. Results were compared with eastern white pine, the standard bedding selection in the northeastern United States. Our results show that EH is suitable for animal bedding and could serve as a new market to absorb wood from this low-valued tree species. Importantly, our methods can be used to assess the suitability of other tree species for use as animal bedding. This replicability is important, as this type of market may be a sound management option for forest managers, harvesting contractors, and buyers of animal bedding trying to find the highest economic value for wood that is no longer suitable for timber because of damage from pests or pathogens.

Figure 1. University of New Hampshire wood shaving machine.

$$\text{Formula 1: \%Absorbency} = \left[\begin{array}{l}(\text{wet weight} - \text{ambient weight})/\\ \text{ambient weight}\end{array}\right] * 100$$

Particle Size and Quality of Wood Shavings. The rate of moisture absorption for woody bedding has been attributed to particle size in some studies (White and McLeod 1989, Pearson et al. 2000). Particle size was assessed in this study using methods described in Pearson et al. (2000). Kiln-dried bedding samples for each tree species were placed in an 8.5-ounce (250 milliliters) beaker and weighed (20 replicates per tree species). Bedding samples were then screened through one-half, one-fourth, and one-eighth inch (13, 6, and 3 millimeters) screens, recording the weight of the material passing through each screen size. Weight of material screened by size class was converted to percent to obtain percent size of shavings by weight, as described in Pearson et al. (2000). Wood shaving quality between EWP and EH was also assessed qualitatively during this experiment, by inspecting wood shaving texture, color or appearance, and odor.

Organic Fraction of Bedding Material. Because rates of absorbency between different woods can be partially explained by the percentage of organic fraction of lignin, cellulose, and hemicellulose (Hubbe et al. 2013), bedding samples of EH and EWP were sent to DairyOne (Ithaca, New York) for analysis of organic fraction. Lignin was measured using ANKOM Technology Method 9—Method for Determining Acid Detergent Lignin in the DaisyII Incubator (ANKOM 2018a). Cellulose was measured using ANKOM Technology Method 5—Acid Detergent Fiber in Feeds—Filter Bag Technique for A200 (ANKOM 2018b). Hemicellulose was measured using ANKOM Technology Method 6—Neutral Detergent Fiber in Feeds—Filter Bag Technique for A200 (Van Soest et al. 1991, ANKOM 2018c).

Microbial Analyses

Overview. Growth of select bacteria was assessed for bedding/manure combinations: EH + manure, EWP + manure, and a manure control. A 50:50 mixture of EH and EWP was also tested, as some animal bedding producers sell a mixture of softwood species, usually a combination of pine with spruce or fir. Furthermore, a mix was selected to assess whether the two species have any type of combined effect on microbial growth, as different softwood species contain different resin acids, terpenes, and phenolic compounds that are toxic to bacteria (Zehner et al. 1986). A bedding mixture using EWP was also included, as EWP is the most common woody animal bedding in the Northeastern United States, where the study was conducted. In addition to knowing whether EH is suitable by itself, animal bedding producers would also find it useful to see whether EH could be blended into EWP bedding mixes. This would provide more flexibility in generating bedding, since there is less concern on separating tree species that may not differ from a microbial standpoint.

The microbial species and groups selected for this study were *Escherichia coli*, *Klebsiella* spp., and *Streptococcus* spp. These microbes were selected following a detailed literature review of pathogens that can cause environmental mastitis in dairy cows (Zehner et al. 1986, Grohn et al. 2004, Harrison et al. 2008). Microbial analysis for each bedding type was conducted over three separate study periods during October and November 2017. Each study period lasted three days, with microbial counts occurring at 0 hours, 24 hours, 48 hours, and 72 hours. A three-day sampling period was selected because it corresponds to the frequency of fresh bedding application at the research dairy farm and is the standard for most dairy farms with bedded pack systems.

Sample Preparation for Microbial Analysis. For each sampling period, fresh manure was collected from the bedded pack barn using a randomized grid design and a random number generator. Fifteen different manure samples were collected using a small scoop (≈ 0.50 pounds or 225 grams of manure per sample) and placed in a large aluminum tray. This composite sample was thoroughly mixed with the sampling scoop to ensure homogeneity of the composite sample. Following manure collection, bedding samples were prepared by placing 0.04 pounds (20 grams) of kiln-dried EH, EWP and the 50:50 mixture in separate trays. From here, 0.33 pounds (150 grams) of manure was spread over the top of each bedding mixture and left to sit for 6 hours. For reference, a 6-hour timeframe for bedding/manure incorporation was used because it corresponds to the average amount of time manure is left on bedding at the research farm before removal. Following the 6-hour bedding/manure incorporation period, the manure was removed from the top layer of the bedding. Bedding samples, which comprised three replicates per bedding type and manure control (≈0.04 pounds or 1 gram each), were collected and put in sterile conical tubes and immediately brought to the lab for baseline plate counts (time 0 hour). Bedding/manure samples were collected from these same trays for time 24, 48 and

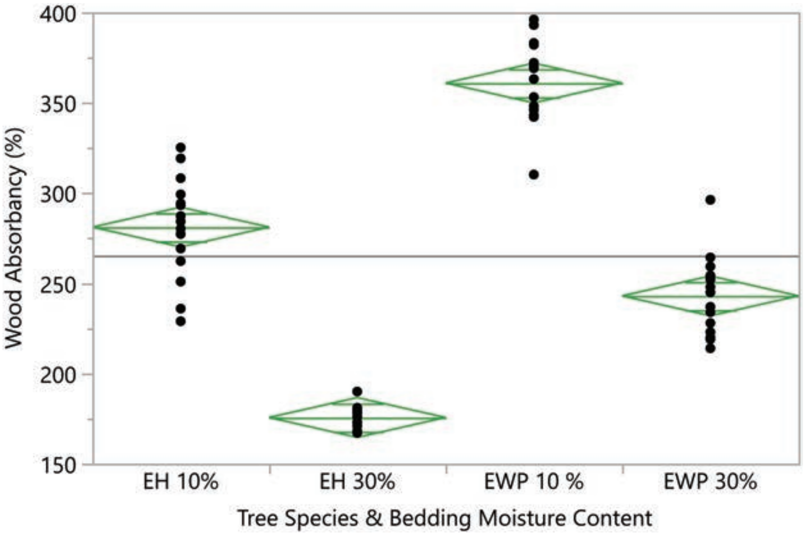

Figure 2. Bedding moisture absorbency between eastern hemlock and eastern white pine at 10 percent and 30 percent moisture content.

72 hours to assess microbial growth over time.

Microbial Growth Analysis. A piece of wood bedding (approximately 0.16 square inches or 1 square centimeter) for each replicate was placed into 0.003 fluid ounces (0.1 milliliter) of MacConkey broth (MC), LB broth (LB), and Brain Heart Infusion broth (BHI) (all from Sigma Aldrich). All liquid cultures were incubated on a shaking platform at 98.6°F (37°C) for 24 hours. Following incubation, tubes were mixed by vortexing, and appropriate dilutions of MC, BH and LB were made (10^{-3}, 10^{-5}, 10^{-7}). A total of 0.003 fluid ounces (0.1 milliliter) of each dilution were plated onto species-selective chromogenic agar plates: MC on Klebsiella ChromoSelect agar with added Klebsiella Selective Supplement (Sigma Aldrich) to select for *Klebsiella* spp., LB on Rapid'E.coli2 agar (Bio-RAD) to select for *Escherichia coli* and other coliforms, and BHI on Columbia CNA Blood Agar (Fisher Scientific) to select for *Streptococcus* spp. Plates were incubated at 98.6°F (37°C) for 24 hours. Bacterial groups were identified based on the color of the colonies according to manufacturer's instructions. On Klebsiella ChromoSelect, *Klebsiella* will form pink colonies. On Rapid E. coli 2 agar, *E. coli* will form blue colonies, and other coliforms form green colonies. On Columbia CNA Blood Agar, different species of *Streptococcus* will form colonies of different colors, and hence our counts included all *Streptococcus* species. The number of colony-forming units (CFU) for each bacterial group were counted. In total, there were 540 samples, consisting of 180 samples per study period.

Statistical Analyses

The ability of each tree species to serve as a bedding source was assessed by the relationship with the following dependent variables: 1) bedding moisture absorption, 2) wood shaving particle size, 3) growth of pathogenic bacteria, and 4) wood shaving output. The relationship between tree species to bedding moisture absorption, wood shaving particle size, and wood shaving output were analyzed using JMP Pro 13.2 (SAS Institute Inc., Cary, NC). Because of relatively small sample size of bedding moisture absorption (n = 60), wood shaving particle size (n = 40), and wood shaving output (n = 36), a Shapiro-Wilk test was first used to assess whether the data were normally distributed, using a significance level of 0.05. Following confirmation of normality, ANOVA was used to test significance at 0.05 for all models. The relationship between tree species and microbial CFUs was analyzed using R 3.4.1. (R Foundation for Statistical Computing, Vienna, Austria). ANOVA was used to test significance at 0.05 for all models. A post hoc Tukey test was then used to make pairwise comparisons between samples across all sampling times.

Results and Discussion

Physical and Chemical Characteristics of EH and EWP

Results showed that tree species has a significant effect on water absorbency, with EH absorbing less moisture than EWP at both moisture content levels ($p < 0.0001$). More specifically, at the 10 percent and 30 percent moisture levels, EH absorbed 281 percent and 176 percent of its weight, respectively, versus EWP, which absorbed 361 percent and 243 percent of its weight in water (Figure 2).

There are several reasons for the potential difference in moisture absorption between EH and EWP, which include 1) the ratio of lignocellulosic material (cellulose, hemicellulose, and lignin) (Hubbe et al. 2013), 2) wood density (Siau 1984), 3) the presence of water repellent extractives

Table 1. Chemical and physical characteristics of eastern hemlock and eastern white pine.

Chemical or Physical Characteristic	Eastern Hemlock	Eastern White Pine	Reference
Moisture content green (%)	111	65	Miles and Smith 2009
Density of wood (lbs/ft^3)	50	35	Miles and Smith 2009
Specific gravity	0.38	0.34	FLP 1999
Heartwood decay class	Slightly or nonresistant	Moderately resistant	Howard 2000
Cellulose (%)	43.50	48.10	Measured
Hemicellulose (%)	11.16	11.24	Measured
Lignin (%)	29.42	29.32	Measured
Texture of wood shaving	Slightly Coarse	Smooth	Measured
Color/appearance of wood shaving	Light reddish brown	Pale yellow	Measured
Odor of wood shavings	None	Slightly Resinous	Measured

Table 2. Percent size of wood shavings by weight.

Wood Shaving Size Class (in)	Eastern Hemlock (%)	Eastern White Pine (%)
>0.50	31.63	26.92
0.25–0.50	42.06	41.11
0.125–0.25	22.29	24.65
<0.125	4.02	7.31

Table 3. Absorbency of various bedding materials.

Bedding Material	Absorbency (%)
Recycled manure solids[2]	422
Chopped newspaper[2]	379
Eastern White Pine[4]	**361**
Recycled manure solids[3]	343
Western redcedar[1]	328
Chopped straw[2]	285
Paper[3]	282
Eastern Hemlock[4]	**281**
Chopped straw[3]	281
Chopped corn stalks[2]	277
Pine shavings[2]	263
Softwood sawdust[3]	251
Douglas-fir[1]	215
Western juniper[1]	214
Hardwood chips[3]	142
Sand[2]	27

[1] Pearson et al. 2000, [2] Misselbrook and Powell 2005, [3] Zehner et al. 1986, [4] Present study

(Vestol and Sivertsen 2011), 4) heartwood content (Vestol and Sivertsen 2011), 5) water diffusivity of the wood (porosity and reactivity of chemical components) (Khazaei 2008), and 6) the particle size/surface area of the wood shavings themselves (Pearson et al. 2000). Additional factors that affect the quantity of absorbed water from bedding, but were held constant and not a factor in this study, include quantity of bark, initial moisture content of the material, thickness of material, and type of wood bedding (shaving, sawdust, or chip) (Pearson et al. 2000).

When assessing the ratio of cellulose, hemicellulose, and lignin, our results showed no significant difference between EH and EWP (Table 1). However, particle size of bedding between species varied significantly, with EH having a greater proportion of bedding larger than one-half inch (>13 millimeters) ($p = 0.0190$) and a smaller proportion of bedding less than one-eighth inch (<3 millimeters) ($p = 0.0019$) (Table 2).

These findings are consistent with Pearson et al. 2000, who reported that moisture absorption increased with a decrease in particle size. A second potential explanation for the lower moisture absorption of EH—and a possible reason for the larger particle size—is because of wood density, with EH having an average wood density 43 percent higher than EWP (Table 1). Vestol and Sivertsen (2011) also reported the ability of higher-density wood to resist diffusion of water into inner layers.

In relation to other bedding materials with absorption values reported in the literature (Zehner et al. 1986, Pearson et al. 2000, Misselbrook and Powell 2005) (Table 3), EWP was the most absorbent woody bedding, while EH was third out of eight woody bedding materials. When comparing EWP and EH to nonwoody bedding materials, EWP ranked third most absorbent, while EH was eighth (Table 3). Having high moisture absorption is especially important for dairy cows, as increased contact with wet and contaminated bedding has been shown to increase the risk of environmental mastitis (Hogan et al. 1989).

Bacterial Growth of Mastitis-Causing Pathogens on EH and EWP Bedding

The growth of mastitis-causing bacteria for the three bedding treatments (EH, EWP, and EH + EWP) varied by tree species, pathogen, and time since the bedding was contaminated with manure (Figure 3). Bacterial growth for most treatment combinations was also higher than the general recommended bacterial load for bedding (10^6 CFU/milliliter) (Reneau 2001). The one exception was the first few days of *Klebsiella* spp., which were below the threshold and below values reported by Godden et al. (2008) for wood shavings on dairy farms.

In assessing whether tree species affected the growth of pathogenic bacteria, significance was found for 66 of the 336 pairwise comparisons. However, when removing the reference bedding samples, where no manure was added (no growth of pathogenic bacteria), significance was found for only six pairs. On day zero, microbial counts of *Streptococcus* spp. were lower for

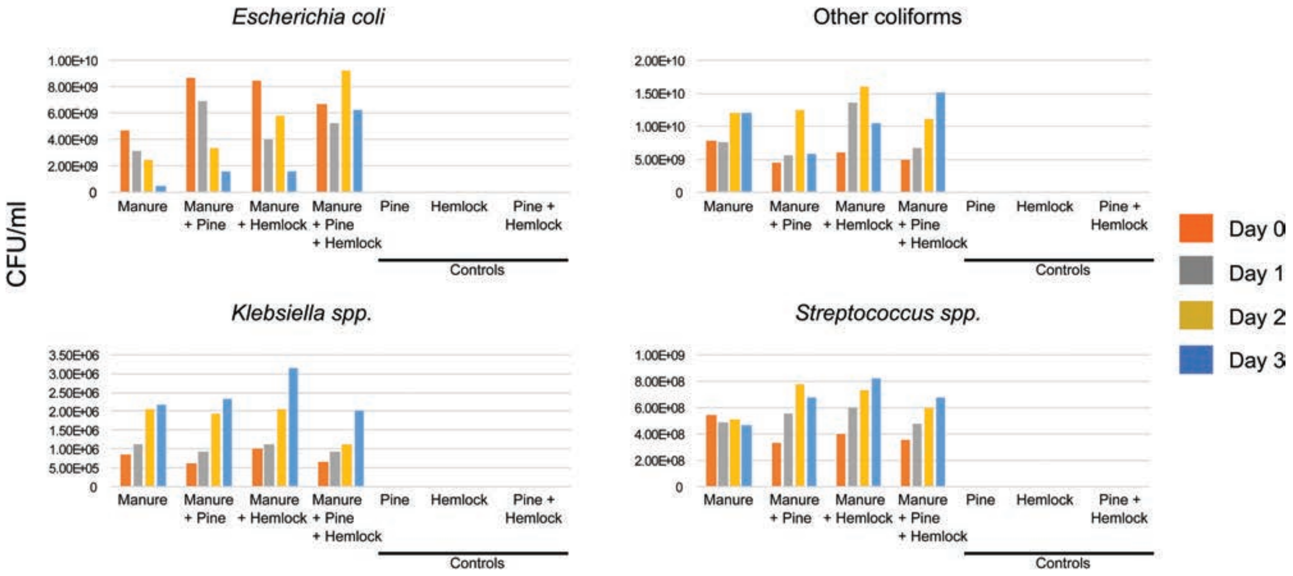

Figure 3. Bacterial counts in eastern hemlock and eastern white pine bedding by time since contamination.

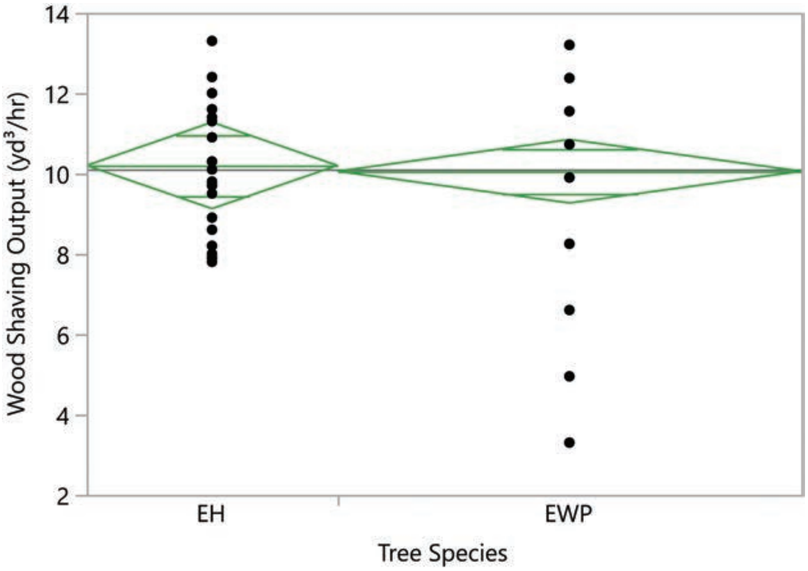

Figure 4. Wood shaving output between eastern hemlock and eastern white pine.

the EH + EWP + manure bedding samples than manure alone (p = 0.04). Bedding combinations of EWP + manure were also lower than manure alone (p = 0.02). On day one, significance was not found for any pairs, when comparing the three bedding combinations with one another. On day two, bacterial counts of *E.coli* were higher on bedding comprised of EH + EWP + manure, when compared with bedding comprised of EH + manure (p = 0.05), manure (p = 0.03) and EWP + manure (p = 0.03). On day three, microbial counts of *Streptococcus* spp. were higher on bedding samples of EH + manure, when compared with manure alone (p = 0.02) (Figure 3).

The overall lack of effect between tree species and the growth of pathogenic bacteria is encouraging. This is especially true given that no significant effect was found between treatments comparing the two tree species with one another (EH + manure versus EWP + manure), indicating no increased risk of using EH over EWP from the perspective of bedding pathogens. This finding is interesting, given that EWP is known to inhibit the growth of pathogenic bacteria in animal bedding through its resin acids, terpenes, and phenolic compounds (Zehner et al. 1986), while EH is a non-resinous softwood (Baumgras et al. 2000) lacking this ability. Eastern hemlock also has a poor heartwood decay class of slightly to nonresistant (Howard 2000), indicating increased susceptibly to microbial attack.

The 50:50 bedding mixture of EH + EWP also had encouraging results, with bacterial counts being higher for only one combination (day two, *E. coli*), while being lower for another (day zero, *Streptococcus* spp.). Variation in the growth of different mastitis-causing bacteria among different types of bedding materials is consistent with results from previous studies. For example, Godden et al. (2008) reported differences in the growth of environmental bacteria among four different bedding types (wood shavings, clean sand, recycled sand, and digested manure solids) in dairy farms. Zdanowicz et al. (2004) reported similar findings when comparing sand and sawdust bedding on dairy farms, with *Klebsiella* bacteria being more prevalent on sawdust, while *Streptococcus* spp. bacteria was more prevalent on sand.

Figure 5. EWP wood shaving log illustrating bulging around cut limb.

Volume Output of Bedding Using a Wood Shaving Machine

In comparing EH to EWP in relation to volume output of bedding produced from a wood shaving machine, there was no significant difference (P = 0.83), with output values of 10.20 and 10.06 cubic yards per hour (7.80 and 7.72 cubic meters) for EH and EWP, respectively (Figure 4).

While machine output was not statistically significant, EH was more consistent in relation to output per hour (Figure 4). The observed consistency was likely because of differences in tree form and subtle differences associated with removal of limbs. Eastern hemlock typically has a straight bole, while EWP can vary, especially if it has a history of weeviling. The EWP used in this study grew in a former pasture, resulting in heavy weeviling. Even over an 8-foot (2.4 meter) section, some of the EWP logs had substantial taper (>1 inches) (2.5 centimeters). With the wood shaving machine removing one-eighth of an inch (3 millimeters) of wood per pass, a taper of 1 inch (2.5 centimeters) could mean eight passes over the planer knives until the entire log is shaved. Likewise, inconsistently cut limbs or bulging around limbs can cause a similar issue, where the knives cut down the bulge before contacting the entire log. This issue was more prevalent with the EWP logs, which tended to bulge where a whorl of branches was located (Figure 5). The combination of weeviling and differences in limb removal may partially explain the more variable machine output for EWP (Figure 4). It is likely that output for EWP would increase if using straighter, non-weevilled logs. However, the obvious tradeoff is that straighter logs may have more value as lumber than as wood shavings.

Table 4. Eastern hemlock net volume of standing timber in the United States in 2017.

State	Million (ft^3)[1]
New York	2,288
Maine	1,821
Pennsylvania	1,750
New Hampshire	963
Vermont	950
Michigan	858
Massachusetts	698
Wisconsin	451
West Virginia	299
Tennessee	262
Kentucky	209
North Carolina	198
Connecticut	191
Virginia	156
Georgia	45
Ohio	33
Alabama	21
New Jersey	17
Maryland	16
South Carolina	13
Rhode Island	12
Total	**11,252**

[1]Adapted from Oswalt et al. (2018)

Availability of EH as a Bedding Source

The availability of EH on timberland in the United States is strong, as the species has been allowed to grow, primarily because of weak markets for its wood (Howard et al. 2000) and because the species often grows in difficult and more costly areas to harvest (ridgetops, steep hillsides, and narrow valleys) (Orwig et al. 2002). As of 2017, the current volume of EH growing stock is 11,252 million cubic feet (319 million cubic meters) (Table 4).

In addition to regional availability, the economic value of the species is low, with stumpage prices declining or remaining stagnant over the past two decades (Figure 6). We also found that EH either had the lowest or second lowest value in stumpage when compared with all other species listed on state stumpage reports. The low value is attributed to its poor lumber quality, which is known for ring shake, brittleness, density variations, and uneven texture (Baumgras et al. 2000, Howard et al. 2000). However, for the case of animal bedding production, these undesirable characteristics are not relevant.

With the value of EH being low, there is potential for the development of a new market to produce animal bedding. One of the benefits of this market is the lack of competition for EH wood. Furthermore, the resource is in large supply, with most stands being in the sawtimber size class (McWilliams and Schmidt 2000), which makes it ideal for processing though a wood shaving machine. While this market would not likely warrant more intensive management of EH for future economic gain, it may result in higher payments per volume of harvested wood. This type of market would also help absorb some of the EH that is expected to be salvage harvested, as the HWA continues to spread. Higher payments for EH may even help incentivize more rigorous management for the control of HWA.

Beyond economic benefits to those in the forest industry, farmers using woody bedding may also benefit as well. A survey study of New England dairy farmers by Smith et al. (2017b) found that the real cost of woody animal bedding increased by 70 percent from 2003–13. The primary reasons for increased cost were mill closures reducing woody byproduct (sawdust and planer shavings), increased mill efficiency reducing the amount of byproduct, reuse of wood byproduct by mills to fire-drying kilns, and increased competition for clean wood waste by the pellet manufacturing industry. However, should a new market open for wood shavings produced from EH, it would likely reduce the shortage of animal bedding that is driving up costs for farmers in the region where EH is most prevalent. Furthermore, a follow-up study by Smith et al. (2017a) on the economics of producing animal bedding using a wood shaving machine and EWP found that the venture could be quite profitable. More specifically, the most likely candidates for such a venture would be a collaborative of locally clustered small farms sharing a trailer-mounted wood shaving machine, a large farming operation with a bedding demand of over 2,500 cubic yards (1,900 cubic meters), or more likely, a milling operation that would already have the necessary wood resource, equipment (debarker, grapple for log loading into the wood shaving machine, trucks for bedding deliveries, etc.), and infrastructure (dry kilns, storage building).

Finally, because the present study used the same wood shaving mill, parameters, and equipment as those reported in Smith et al. (2017) and wood shaving output between EWP and EH were the same, the only difference in production costs between the two studies is the input cost of the wood resource itself. Consequently, lower input costs of the wood resource, as indicated by stumpage, would reduce the cost of producing bedding from EH trees in relation to EWP. However, an important question to be addressed in a future study is whether lower production costs would be offset by lower prices for the finished product, should the lower moisture absorption capability of EH be considered.

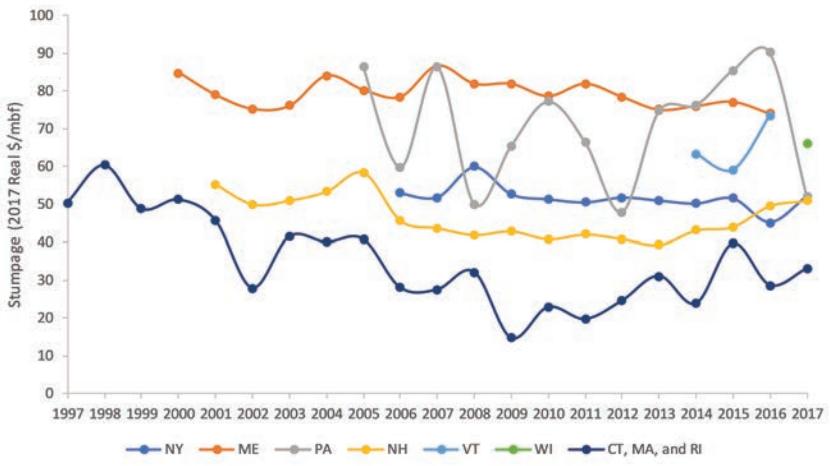

Figure 6. Stumpage prices for eastern hemlock over time throughout its range. References for each state: New Hampshire (Evans 2017), Vermont (VDFPR 2017), Maine (MDACF 2017), New York (NYDEC 2017), Pennsylvania (Jacobson 2017), Wisconsin (WDNR 2017), Southern New England (UMass 2018).

Conclusion

This study assessed the feasibility of using EH as a bedding source, comparing moisture absorption, wood shaving particle size, growth of mastitis-causing bacteria, and volume of produced bedding using a wood shaving machine with EWP. Eastern hemlock was capable of absorbing 281 percent and 176 percent of its weight in water when dried to 10 percent and 30 percent moisture content, respectively. While these rates compare favorably to other bedding types, absorption was significantly lower than EWP, which absorbed 361 percent and 243 percent of its weight at 10 percent and 30 percent moisture content, respectively. Regarding growth of mastitis-causing bacteria, no significant effect was found between treatments comparing the two tree species with one another (EH + manure versus EWP + manure). The 50:50 bedding mixture of EWP and EH also performed well, with bacterial counts being higher for only one combination (day two, *E. coli*) and lower for another combination (day zero, *Streptococcus* spp.). When producing animal bedding using a commercial wood shaving machine, output was 10 cubic yards per hour (7.6 cubic meters per hour) for both species. Based on these results, EH is comparable to EWP from a microbial and production of bedding standpoint but absorbs less moisture. However, with EH having one of the lowest stumpage values of all tree species within its range, lower wood shaving production costs associated with reduced wood cost may allow for the sale of less expensive bedding to compensate for reduced moisture absorption.

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