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RESEARCH ARTICLE

Variation in Soil Temperature, Moisture, and Plant Growth with the Addition of Downed Woody Material on Lakeshore Restoration Sites

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Abstract

Downed woody material (DWM) is an important ecosystem component that performs many critical functions including influencing soil temperature and moisture, which affects plant growth and survival. Residential development along lakeshores has increased dramatically in recent decades in the northern Great Lakes region. Such development often leads to reductions in terrestrial and aquatic woody material. Although lakeshore restoration projects have occurred in the past few years in the region, there has been little effort to evaluate success. In 2007, a collaborative lakeshore restoration research project began on two lakes in Vilas County, Wisconsin. We investigated the benefits of the addition of DWM as part of these restoration projects. We randomly assigned three coverage treatments (0, 25, and 50%) of DWM on 3 × 3–m experimental plots (*n* = 10 per treatment) and monitored soil temperature and volumetric soil water content at a depth of 10 cm. All plots were planted with two native shrub species and five native understory herbaceous species. Mean maximum soil temperature, mean difference in daily high and low soil temperature, and percent change in soil moisture content were significantly lower in the 25 and 50% DWM plots. Plant canopy volume growth for snowberry (*Symphoricarpos albus*) and Barren strawberry (*Waldstenia fragaroides*) was significantly greater in the 25 and 50% DWM plots. We conclude that the addition of DWM had a significant positive effect on regulating soil temperature extremes, soil moisture, and plant volume growth for two species of native plants used for restoration projects.

Key words: **canopy volume growth, moisture content, plant survival, residential development, riparian area.**

Introduction

Downed woody material (DWM) is vital to the function and structure of healthy terrestrial and aquatic ecosystems. DWM includes fallen dead trees and large branches and is often abundant in natural forest, stream (Harmon et al. 1986), and lake ecosystems (Christensen et al. 1996; Marburg et al. 2006). Input mechanisms of DWM into a system include wind throw, insect damage, diseases, and beaver (*Castor canadensis*) (Harmon et al. 1986). DWM adds structural complexity and heterogeneity to the forest floor and soils (McComb 2008) and performs many crucial ecological functions such as providing plant habitat, nutrient storage and cycling, and sediment transport and storage (Bormann & Likens 1979; Harmon et al. 1986; France et al. 1998; Rasmussen & Whigham 1998; Hagan & Grove 1999; Reid et al. 1999). Additionally, DWM provides critical habitat for small mammals (Tallmon & Mills 1994; Ucitel et al. 2003), amphibians (Jaeger 1980), small- to mid-sized carnivores (Gilbert et al. 1997), and a variety of bird species (Maser et al. 1979), and many invertebrates, decomposer bacteria, and fungi utilize DWM as an energy and nutrient source as well as habitat (Harmon et al. 1986).

DWM also influences the abiotic environment as a moisture reservoir and by buffering fluctuations in ground surface temperatures (Harmon et al. 1986; Gray & Spies 1997). Soil temperature and moisture can affect plant and root growth (Russell 1973), nutrient uptake (Dong et al. 2001), and plant survival and productivity, which may contribute the success or failure of ecological restoration projects (Castro et al. 2002).

The effect of soil moisture content on soil temperature is complex. Moist soils conduct heat vertically more efficiently than dry soils. During a sunny day, the surface of dry soils warms more quickly by day and cools more quickly at night (Russell 1973). Therefore, drier soils should have greater daily differences in temperature. The amount of radiation received affects soil temperature (Russell 1973) and varies depending on the aspect, slope, and percent canopy cover. Thus, a south-facing slope would potentially have greater differences in daily soil temperatures than a north-facing slope due to greater sun exposure.

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Lakes, streams, and forested areas attract residential development because they provide a clean environment, opportunities for recreation, and scenery (Schnaiberg et al. 2002). Northern Wisconsin contains the third largest density of freshwater glacial lakes in the world, with more than 12,400 lakes scattered across the northern third of the state (WDNR 1996). Vacationers have been attracted to this region for decades, and more recently, increasing numbers of people are replacing small seasonal cottages with large year-round houses along lakeshores. Much of this growth has been concentrated around inland lakes (Radeloff et al. 2001; Gonzalez-Abraham et al. 2007). Since 1965, two-thirds of previously undeveloped inland lakes in northern Wisconsin (i.e. lakes with no residential housing) have become developed with homes and cottages near the shoreline (WDNR 1996).

Many studies have reported a significant reduction of trees, shrub layer, and DWM on high-development compared to low-development lakes (Christensen et al. 1996; Elias & Meyer 2003; Marburg et al. 2006). In fact, some residents equate lakeshore beauty with park-like conditions of manicured lawns and scattered trees (Macbeth 1992). Removal of DWM and vegetation structure along shorelines on high-development lakes is a common practice especially when trees fall by storm events.

The Great Lakes region is one of the most active weather zones in the northern hemisphere (Frelich 2002). In 1999, the residents of Found Lake, Vilas County, Wisconsin experienced a thunderstorm with high winds. The storm's path followed the north shoreline toppling hundreds of mature canopy trees. A similar wind storm occurred in 2005 on Statehouse Lake in Vilas County, home to the North Lakeland Discovery Center (NLDC). Following both storms, DWM was removed by residents leaving the understory vegetation exposed to increased sun, extreme temperatures, wind, precipitation, and human activity. In the years that followed, a die off of understory vegetation occurred with little regeneration and much soil erosion near the shoreline. However, where DWM was retained, some regeneration of vegetation had occurred (D. Haskell 2006, Michigan Technological University, personal observation).

In the summer (July–August) of 2007, Wisconsin Department of Natural Resources (WDNR), Michigan Technological University, Vilas County Land and Water Conservation Department (VCLWD), and Wisconsin Department of Agriculture, Trade and Consumer Protection launched a long-term ($\geq$10 years) research project investigating the potential positive impacts of lakeshore restoration on riparian and littoral communities in Vilas County, Wisconsin. This restoration project requires property owners to plant native trees, shrubs, and herbaceous plants within a 35-ft (10.7 m) buffer zone along the lakeshore and to correct erosion problems. Lakeshore restoration projects in Vilas County have been ongoing since 2000 costing \$30,000 to \$60,000 annually (C. Scholl 2006, VCLWD Conservationist, personal communication). However, little or no evaluation of these past projects has occurred to identify the factors that affect the success of restoration. Furthermore, soils in Vilas County range from loam to sandy soils (NRCS 1986) and in the past few years, the region has been in a drought with record breaking ambient temperatures (http://mrcc.sws.uiuc.edu/climate_midwest). The soil types and current weather regime could profoundly affect the success of these restoration projects.

Lakeshore restoration is a relatively new practice in northern Wisconsin and throughout North America. Prior evaluation of lakeshore restoration has focused on vegetation planting techniques (Weiher et al. 2003) but not on restoration of other attributes including ecological function and long-term plant survival and growth. To better understand the dynamics and benefits of lakeshore restoration, we added DWM to seven restoration projects with three coverage treatments and monitored the soil temperature and moisture content over the course of the growing season. We also recorded the first year survival and plant canopy volume growth of several native plant species within these treatments.

Our objectives were to (1) determine if DWM addition reduces the difference between low and high daily soil temperature and moisture on restoration sites; (2) provide first year data on plant survival and growth rates; and (3) provide a better understanding of how the presence of DWM may affect the success of lakeshore restoration. Because DWM will provide shade and retain soil moisture on disturbed, sandy soils, we hypothesized that sites with the DWM additions would show less temperature and moisture variation during the growing season. We also predicted that plant survival and growth will be greatest with the presence of DWM.

Methods

Study Area

This project was conducted on two lakes in a forested landscape on deep sands in a pitted glacial outwash landscape in Vilas County of northern Wisconsin (Stearns & Likens 2002). The first study site is located along 1,500 m of the north-northeast shoreline of Found Lake (T40N, R8E, Section 14). Found Lake is a drainage lake with a surface area of 131 ha, a maximum depth of 7 m (WDNR 2005). Found Lake was home to several fishing resorts in the past, but in recent decades, many of these resorts have been sold to developers and parceled for resale to individuals for seasonal or permanent homes. The second study site is located along 40 m of the northeast shoreline of Statehouse Lake (T42N, R5E, Section 5). Statehouse Lake is a seepage lake with a surface area of 9.3 ha, maximum depth of 6 m, and is surrounded by public lands (WDNR 2005). Statehouse Lake is home to NLDC, formerly a Youth Conservation Camp. The combination of human impact and the wind storms in the past have degraded both lakeshores. Therefore, on both study sites, regeneration of vegetation is low, and much soil erosion is occurring, making both lakeshores prime candidates for restoration. The mean daily ambient air temperature is 3.4°C, ranging from −2°C in January to 10°C in July, and the mean annual precipitation is 80.25 cm (http://mrcc.sws.uiuc.edu/climate_midwest).

Experimental Design

Restoration activities occurred on six privately owned properties on the north-northeast shoreline of Found Lake and State House Lake during the summer of 2007 (July–August). Thirty 3×3–m experimental plots were placed within these restoration areas, 24 on the shore of Found Lake and six on the shore of State House Lake. Ten sets of three experimental plots (0, 25, and 50% cover of DWM) were established. Each set of experimental plots was placed in line and parallel with the shoreline and 3 m inland from the ordinary high water mark. This placed the experimental plots in the middle of the 35-ft state mandated buffer zone (Wisconsin's Shoreland Management Program, chapter NR 115), a consistent distance from the shoreline, and far enough from the shoreline edge to minimize the risk of high wave action. The three plots were placed 0.5–1.0 m apart. A random number table was used to assign one of the three coverage densities of DWM to each experimental plot (Fig. 1): 50% of area covered by DWM ($n = 10$), 25% of area covered by DWM ($n = 10$), and 0% of area covered by DWM ($n = 10$).

We defined DWM as branches $\geq$2.5 cm and $\leq$15 cm in diameter and $\leq$3 m in length. All DWM was Northern red oak (*Quercus rubra*) acquired from a recent (within 1 year) logging site nearby. All experimental plots were protected from herbivory with 2.4 m high nylon fences erected around the perimeter of each restoration area (Haskell 2009).

In each experimental plot, we planted 3 shrubs and 25 forbs and grasses. A total of 90 shrubs and 750 ground cover individuals were planted and uniquely identified with a numbered metal tag. One snowberry (*Symphoricarpos albus*) ($n = 30$) and two Sweet fern (*Comptonia peregrine*) ($n = 60$) comprised the shrub species for each experimental plot. For each shrub, 1 L of organic compost was incorporated into the soil before shrubs were planted. We planted five of each of the following forbs and grasses: Little-blue stem (*Schizachyrium scoparium*) ($n = 150$), Barren strawberry (*Waldstenia fragaroides*) ($n = 150$), Pearly everlasting (*Anaphalis margaritacea*) ($n = 150$), Bergamot (*Monarda fistulosa*) ($n = 150$), and Large-leaved aster (*Aster marcophyllus*) ($n = 150$). Plant densities were based on recommendation from the Wisconsin Biology Technical Note 1: Shoreland Habitat (NRCS 2002). *Symphoricarpos albus* were delivered in 3-gallon nursery containers, *C. peregrine* in 1-gallon nursery containers and all ground cover species were in 2.5-in. nursery containers. A local nursery (Hanson's Garden Village, Rhinelander, WI, U.S.A.) supplied all plant material.

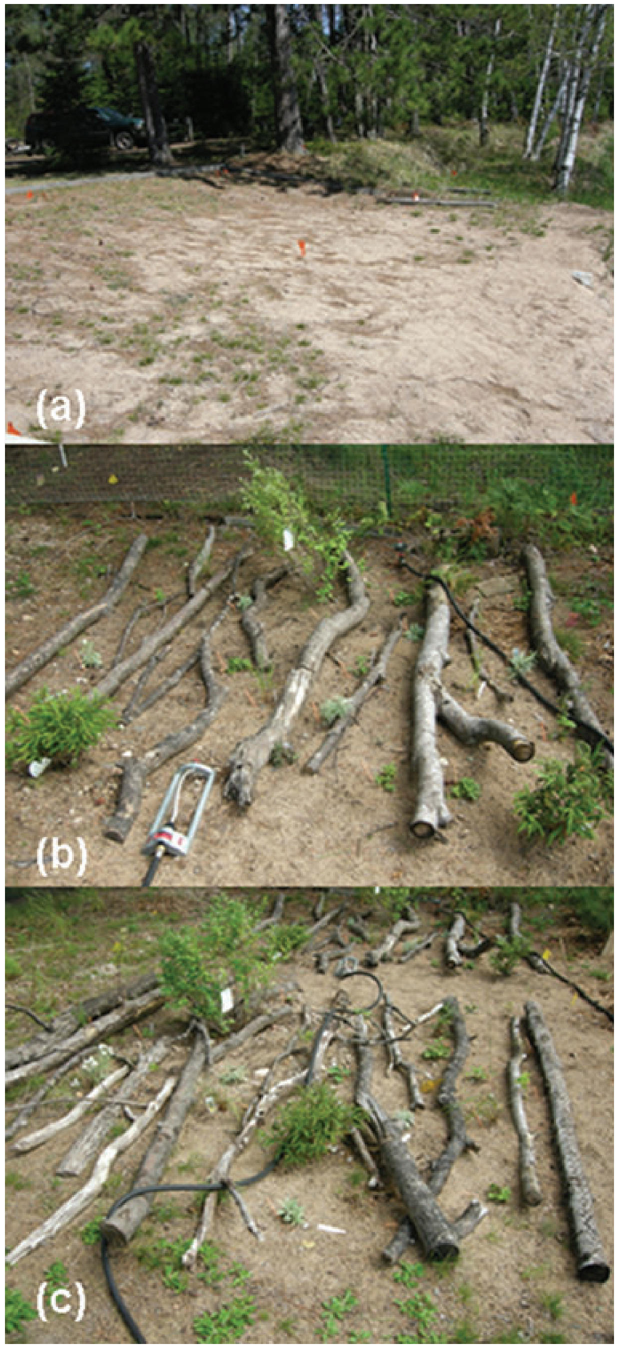

Figure 1. Represent experimental plots with downed woody material in place: (a) 0% coverage, (b) 25% coverage, and (c) 50% coverage.

Abiotic Variables

The following abiotic data were collected prior to DWM installation. Soil samples were collected from each experimental plot ($n = 30$) and analyzed for organic matter and nutrients at the Soil & Plant Analysis Lab, UW-Madison. Slope, aspect, and canopy gap fraction were measured on each plot. To quantify the gap fraction, we took a digital hemispherical photograph (Nikon Cool Pix 5000 and FC-E8 fisheye converter) at 50 cm above the ground and centered in each plot. Digital hemispherical photographs were analyzed with the software WinSCANOPY (WinScanopy 2005). Gap fraction is defined as a fraction of pixels classified as open sky in a region in the image (WinScanopy 2005).

Soil Temperature

From each plot corner, a temperature data logger (Standard Logger, KoolTrak, Inc., Palm Beach Garden, FL, U.S.A.)

was placed systematically 1 m inward at a 45° angle and at a depth of 10 cm in each plot ($n = 120$). We deployed all loggers 4–6 weeks prior to restoration, which provided data before DWM was applied. All loggers were programmed to record soil temperatures every hour during the 2008 growing season (May 6 to September 26). We computed the means and standard errors for three soil temperature variables (daily maximum, daily mean, and difference between low and high daily temperature).

Soil Moisture

Four soil moisture readings (volumetric soil water content) were measured on each plot within 5–10 cm of temperature sensor locations. Data was recorded manually using a hand held soil moisture sensor (HydroSense CS620, CD620, 12-cm probes, Campbell Scientific, Inc., Logan, UT, U.S.A.). All data were recorded 12 hour after a weekly watering event (irrigation or precipitation) and then again 24 hour after the first reading. We collected soil moisture data for 2 months during the 2008 growing season (July $n = 25$/treatment, August $n = 34$/treatment). The monthly (July–August) means of percent change between moisture readings was calculated. Rainfall and irrigated water quantities were measured with plastic rain gauges. If rainfall was not adequate (10–30 mm within a week), each plot was irrigated using a gas or electric water pump with oscillating sprinkler system.

Plant Survival and Growth

Plant measurements included height and canopy area. Height was measured from the soil surface to the highest point of the living tissue in its natural state. Plant canopy area was determined by measuring the width of the canopy at its widest point, then a second width perpendicular to the first. The mean of the two widths was used to calculate the canopy radius and circular canopy area. The height and canopy area were used to compute the cylindrical volume (m^3) for each plant (Bussler et al. 1995). The percent change in cylindrical volume (m^3) for each plant was calculated based on measurements at two time periods and was used to estimate plant growth. Shrub species were measured at the time of planting in 2007 and again in mid-August 2008. Forbs and grass species were measured in late May and again in mid-August 2008.

Plant survival (alive or dead) was recorded 1 year after planting. All shrub and ground cover individuals were included in the survival comparisons. All individual shrubs were used for growth volume analyses. Some ground cover individuals were missed during the initial measurements in May 2008 but were located in August; we excluded from ground cover volume growth analyses the missing individuals in May and all summer mortalities.

Data Analyses

The means for soil temperature variables were calculated with the software KoolTrak (KoolTrak, Inc. 2004). Monthly soil temperature and moisture data were subjected to analysis of variance (ANOVA) using a one-way procedure within SigmaStat 3.5 software (Systat Software Inc., Chicago, IL, U.S.A.) to test for differences in soil temperature and moisture across DWM treatments. We used ANOVA to compare the slope, aspect, soil organic matter, and canopy gap fraction across treatments. The Holm-Sidak method was used for all pair-wise multiple comparison tests. For ANOVA tests, we determined if all test assumptions (normality and equal variance) were met. The Kolmogorov–Smirnov test was used to evaluate the assumption of normality. We used arcsine square roots and natural logarithms to transform independent variables to meet normality assumptions. When transformation of variables was unsuccessful in producing a normal distribution, we used the nonparametric Kruskall–Wallis test. The Tukey method was used for all pair-wise multiple comparison tests for nonparametric data. All statistical tests were set at $\alpha = 0.05$.

Results

Abiotic Variables

We found no significant differences in slope ($H = 0.0126$, $df = 2$, $p = 0.994$), aspect ($H = 0.000$, $df = 2$, $p = 1.000$), soil organic matter ($F_{[2,27]} = 0.790$, $p = 0.464$), and gap fraction ($H = 1.252$, $df = 2$, $p = 0.535$) between treatments.

Soil Temperature

The soil temperature data collected prior to DWM installation in 2007 revealed no significant differences between experimental plots for the three temperatures variables. We collected daily soil temperature data during the 2008 growing season for 144 days resulting in 13,824 temperature samples (Fig. 2). We found no significant differences in the average daily temperatures (June: $F_{[2,27]} = 1.780$, $p = 0.188$; July: $F_{[2,27]} = 2.285$, $p = 0.121$; August: $F_{[2,27]} = 3.141$, $p = 0.059$) (Fig. 3). However, the average maximum daily temperature per month was significantly different (June: $F_{[2,27]} = 3.700$, $p = 0.038$; July: $F_{[2,27]} = 6.050$, $p = 0.007$; August: $F_{[2,27]} = 9.042$, $p \leq 0.001$). The 25 and 50% DWM coverage plots were 2–3°C cooler than the 0% coverage plots from June through August (Fig. 3). Daily soil temperature ranges for each month were also significantly different between DWM treatments (June: $F_{[2,27]} = 6.506$, $p = 0.005$; July: $F_{[2,27]} = 11.894$, $p \leq 0.001$; August: $F_{[2,27]} = 14.658$, $p \leq 0.001$). The difference between low and high daily soil temperatures was reduced in the 25 and 50% DWM coverage plots by over 2°C in June and 3–4°C in July and August (Fig. 3). Pair-wise multiple comparisons yielded no significant difference between 25 and 50% DWM coverage plots for both daily maximum and difference between low and high daily temperatures.

Soil Moisture

Moisture content, after a watering event, was significantly different across plots in July and August (July: $F_{[2,27]} = 58.964$,

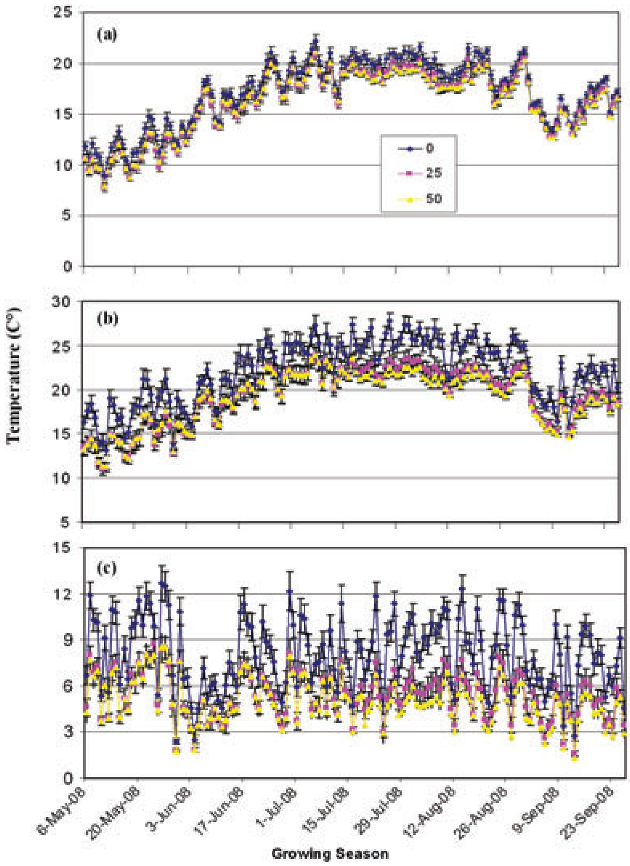

Figure 2. Three soil temperature variables (a) mean daily, (b) mean daily maximum, and (c) mean daily difference between high and low temperatures measured during the 2008 growing season with standard error bars. Temperatures were compared between three different percent coverage of downed woody material on Found and State House Lakes, Vilas County, Wisconsin.

$p \leq 0.001$; August $F_{[2,27]} = 66.511$, $p \leq 0.001$). However, pair-wise multiple comparisons found no difference between plots with DWM coverage in July, but showed significant differences between all treatments in August (Fig. 4).

Plant Survival and Growth

All 30 *Symphoricarpos albus* shrubs survived the first year after planting and 59 out of 60 *Comptonia peregrine* (99.98%) survived the first year after planting; one *C. peregrine* died in a 50% DWM cover plot. However, we did find a significant loss in *S. albus* shrub canopy volume (*S. albus* shrubs: $F_{[2,27]} = 4.961$, $p = 0.015$). *Symphoricarpos albus* shrubs in 0% DWM treatment plots experienced a 14.3% (±0.0849 SE) decline in mean canopy volume (m^3) (Fig. 5). Pair-wise multiple comparisons yielded no significant difference between 25 and 50% DWM, or between 0 and 25% DWM coverage for *S. albus* shrub canopy volume. There was no significant difference in *C. peregrine* canopy volume after 1 year ($F_{[2,27]} = 1.398$, $p = 0.264$).

Ground cover species combined had a 92.8% survival rate. *Monarda fistulosa* had the lowest survival (85.3%) rate, whereas *Waldstenia fragaroides* had the highest survival rate (98%) (Table 1). The ground cover canopy volume data revealed no significant difference for four of the five species (*Anaphalis margaritacea*: $H = 1.280$, $df = 2$, $p = 0.527$; *Aster marcophyllus*: $H = 2.191$, $df = 2$, $p = 0.334$; *M. fistulosa*: $H = 0.281$, $df = 2$, $p = 0.869$; *Schizachyrium scoparium*: $H = 2.255$, $df = 2$, $p = 0.324$). *Anaphalis margaritacea* and *A. marcophyllus* had a 2–4-fold increase in mean volume in 50% DWM plots compared to the 0 and 25% DWM plots, but variability was highest in the 50% DWM plots (Table 2). *Waldstenia fragaroides* canopy volume was significantly different ($H = 6.991$, $df = 2$, $p = 0.030$) between plots with and without DWM (Table 2). The large standard errors for canopy volume for ground cover species reveal generally high variability for this group of plants (Table 2).

Discussion

Ecological restoration efforts on disturbed sites depend on successful establishment and survival of native plant species. The effects of soil temperature and moisture are important for both herbaceous and woody plants. Bhattacharjee et al. (2008) reported that the rate of soil moisture decline was the single most important variable influencing cottonwood (*Populus deltoides*) seedling survival in sandy soils.

The addition of DWM lowered the difference between low and high daily soil temperature, maximum daily temperature, and percent change in soil moisture content relative to plots without DWM. The percent change in soil moisture content was less on the 25 and 50% DWM coverage compared to 0% DWM coverage in July and August. The mean percent change in moisture content for 0% DWM coverage plots increased 3–5-fold compared to the 25 and 50% DWM coverage plots. There was a slight increase in moisture change for the 25 and 50% DWM coverage plots in August, which correlates with an increase of ambient temperatures and drought conditions during that period (http://mrcc.sws.uiuc.edu/climate_midwest).

Several studies have investigated the ecological benefits of restoring DWM to streams and rivers (Hilderbrand et al. 1997; Larson et al. 2001; Brooks et al. 2004). No studies to our knowledge have looked at restoring DWM to lake riparian areas. Although DWM has been shown to play a number of important roles in terrestrial ecosystems and few studies have investigated how soil temperature and moisture relate to DWM coverage and how these factors affect plant survival and growth. The importance of cool and/or moist microsites for plant establishment is well-known and often mediated by vegetation. Gray and Spies (1997) compared surface temperatures and Western hemlock (*Tsuga heterophylla*) seedling survival on the north and south sides of large logs (approximately 50 cm in diameter). They found that surface temperatures were lower on the north side of logs; Western hemlock seedling survival was higher within 15 cm of the north side of logs than on the south side. They suggest that shade from large logs

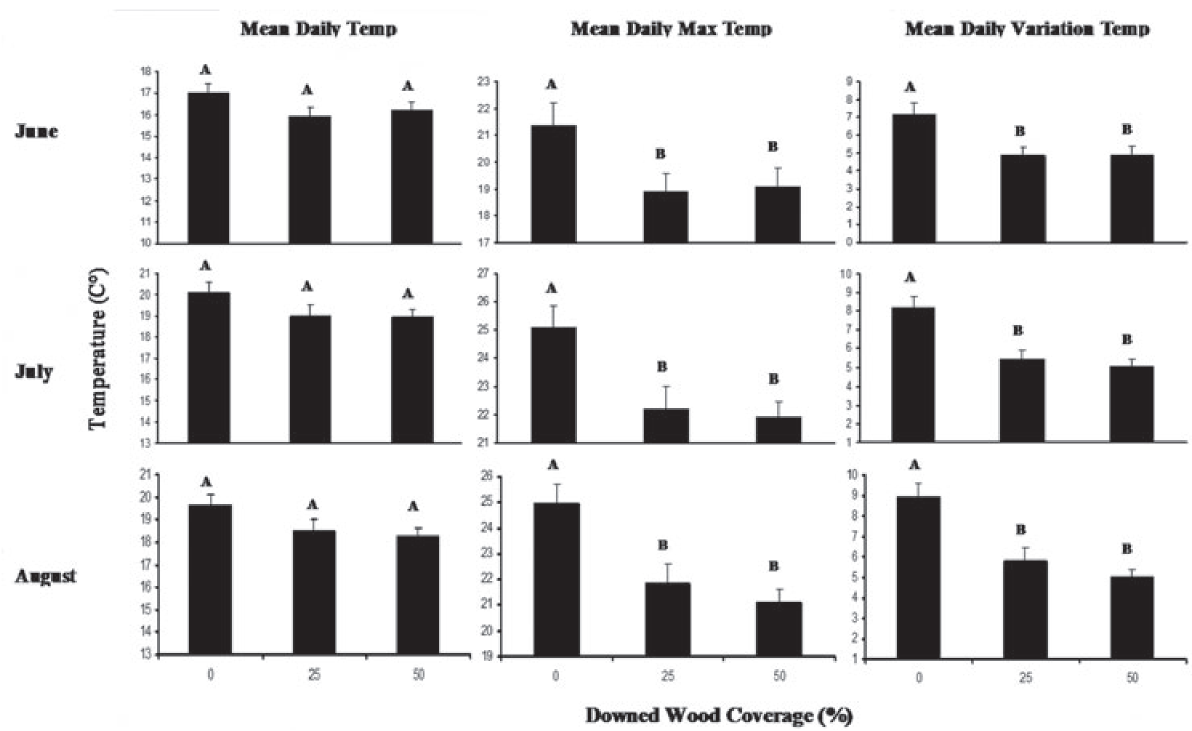

Figure 3. Mean daily, mean maximum soil temperatures, and the mean daily soil temperature variation and one standard error for 3 months in 2008 on downed woody material coverage treatments. Data collected during the summer of 2008 on Found and State House Lakes in Vilas County, Wisconsin. Bar columns with the same letter are not significantly different by Holm–Sidak pair-wise multiple comparison procedures ($p \leq 0.001$).

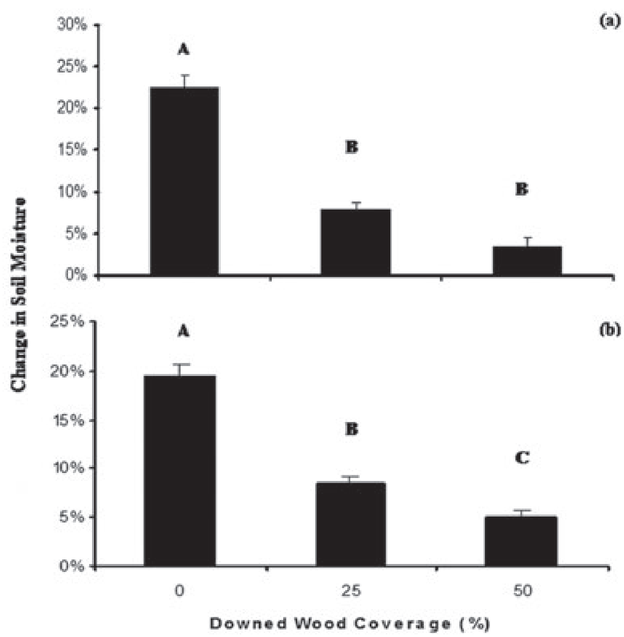

Figure 4. Mean percent change of soil moisture content from 12 to 36 hours after watering from July (a) and August (b) 2008 on three downed woody material coverage treatment. Data were collected from restoration projects on Found and State House Lakes, Vilas County, Wisconsin. Bar columns with the same letter are not significantly different by Holm–Sidak pair-wise multiple comparison procedures ($p \leq 0.001$).

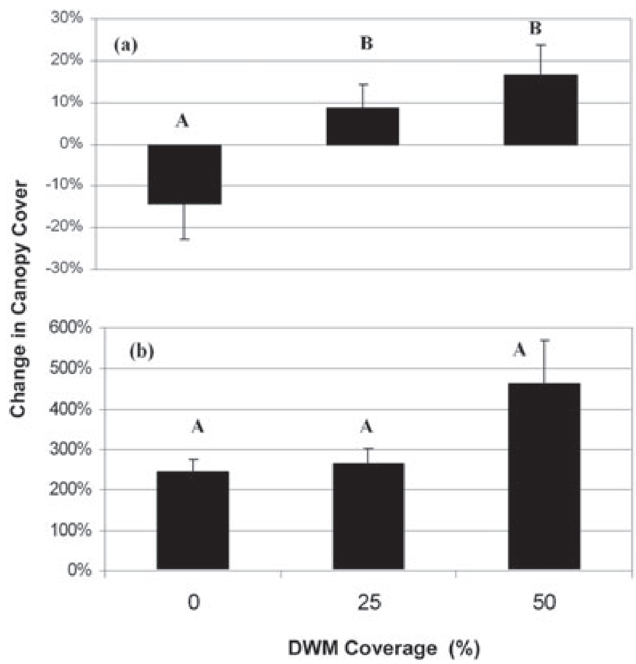

Figure 5. Percent change in canopy volume for snowberry (a) and sweet fern (b) over a 1-year period on three downed woody material coverage treatment. Data collected on Found and State House Lakes Vilas County, Wisconsin from August 2007 to 2008. Bar columns with the same letter are not significantly different by Holm–Sidak pair-wise comparison procedures ($p \leq 0.001$).

Table 1. Ground cover species survival rates for 1 year (2007–2008) after planting in three downed woody material coverage treatments.

	DWM Coverage (%)			
Species	*0*	*25*	*50*	*Total (%)*
Anaphalis margaritacea	96	98	92	95.3
Aster marcophyllus	96	96	96	96.0
Monarda fistulosa	92	82	82	85.3
Schizachyrium scoparium	90	80	98	89.3
Waldstenia fragaroides	100	96	98	98
Total	94.8	95.4	93.2	92.8

Survival rates were recorded from Found and State House Lakes' restoration projects in Vilas County, Wisconsin.

Table 2. The percent change of canopy volume for five ground cover species relative to three treatments of downed woody material coverage.

Species	*n*	*Max*	*Min*	*Mean*	*Standard Error*
Anaphalis margaritacea ($n = 132$)					
0% DWM coverage	10	269.4	3.6	49.4	26.1
25% DWM coverage	10	311.3	11.6	61.2	29.0
50% DWM coverage	10	826.9	7.0	110.7	80.0
Aster marcophyllus ($n = 135$)					
0% DWM coverage	10	66.3	4.9	26.1	6.1
25% DWM coverage	10	78.1	8.4	30.7	6.6
50% DWM coverage	10	528.2	9.8	106.9	50.6
Monarda fistulosa ($n = 128$)					
0% DWM coverage	10	148.2	3.2	29.5	13.9
25% DWM coverage	10	148.8	1.4	31.1	14.0
50% DWM coverage	10	91.5	3.6	27.2	10.7
Schizachyrium scoparium ($n = 102$)					
0% DWM coverage	10	5,256.4	102.6	871.0	493.6
25% DWM coverage	9[a]	8,083.2	61.0	1,458.6	858.0
50% DWM coverage	9[a]	19,051.6	59.8	3,536.6	2,007.3
Waldstenia fragaroides ($n = 144$)					
0% DWM coverage	9[a]	1.8	−0.7	−0.1	0.2
25% DWM coverage	10	2.8	−0.5	0.2	0.3
50% DWM coverage	8[a]	10.7	−0.3	1.4	1.1

Data were recorded in 2008 from Found and State House Lakes in Vilas County, Wisconsin.
[a] Species were missing from the DWM plots due to mortality or missing plants during the initial measurements in May 2008.

facilitated establishment of Western hemlock seedlings in large gaps exposed to direct solar radiation in a mature to old growth conifer forest. Breshears et al. (1998) looked at the influence of forest canopy density on soil characteristics and found that soil temperatures and soil evaporation rates were lower under canopy coverage compared to soils with no canopy coverage. Additionally, Callaway (1992) found that certain species of oak (*Quercus spp.*) seedlings had higher survival and root elongation rates under a shaded canopy of shrubs in southern California. A number of restoration projects have used shrubs and grasses as nurse plants to facilitate early establishment of seedlings in restoration projects in the Mediterranean region (Maestre et al. 2001; Castro et al. 2002, 2004), and in northern Africa (Aerts et al. 2007). These studies reported higher seedling survival under shrubs and grasses that reduced solar radiation exposure and slowed evaporation and seedling transpiration. However, these studies were conducted in semiarid woodlands where ambient temperatures are twice as high and precipitation is half that in northern Wisconsin.

Our soil temperature and moisture is consistent with the increase in *Symphoricarpos albus* canopy volume in the 25 and 50% DWM coverage plots. However, there was no significant difference for *Comptonia peregrine* canopy volume among treatments. As *C. peregrine* has adapted to open, well-drained soils with low to neutral pH (Hightshoe 1988; Soper & Heimburger 1994), it may be more tolerant of dry conditions than *S. albus*. Additionally, *C. peregrine* is a nitrogen-fixing plant, which is used in restoration primarily for ground cover and erosion control on steep sandy soils (NRCS 2002). *Comptonia peregrine* may tolerate transplant shock better than *S. albus*. *Symphoricarpos albus* is also thought to tolerate well-drained sandy soils (Hightshoe 1988; Soper & Heimburger 1994; Smith 2008). However, the decrease in *S. albus* canopy volume in 0% DWM coverage plots suggests that *S. albus* may have difficulty establishing in drier conditions without the presence of DWM. We observed yellowing of *S. albus* leaves among plants in all treatments, which may suggest that it lacked sufficient nutrients (D. Haskell, personal observation). There is some contradictory information in the literature about the preferred soil and moisture regimes for *S. albus*. Henderson (1987) suggests that it grows best in moist and clay soils, whereas Hightshoe (1988), Soper and Heimburger (1994), and Smith (2008) suggested it prefers drier, sandier soils. Nevertheless, both species are native to the area and are highly recommended by county conservationists and local nursery personnel for lakeshore restoration projects.

The ground cover species used in this study are adapted to moderate to dry soil conditions and are also highly recommended for use in lakeshore restoration projects. *Waldstenia fragaroides* may have lost canopy volume in the 0% DWM coverage plots between treatments because this summer green herb completes most of its life-cycle (growth, flowering, and fruiting) in the early spring. Drier soil conditions later in the year may result in plant desiccation. The 25 and 50% DWM coverage plots may have retained enough soil moisture to slow plant desiccation of *W. fragaroides*. It is also a mat forming plant that spreads by runner-like rhizomes below the ground surface. These characteristics may be beneficial in dry, sandy soils conditions, which allow the plant to take advantage of early spring soil moisture and use less energy to spread on top of or near to the soil surface. It also exhibited the highest survival rate among all ground cover species. *Monarda fistulosa* had the lowest survival rate, which may reflect its preference for more moderately moist and loamy soils (Henderson 1987). *Schizachyrium scoparium* showed the largest increase in canopy volume across all treatments. It is a warm season grass that grows slowly until mid-summer and is one of the most widely distributed native grasses in North America. It will grow on a wide variety of soils, but is well adapted to well-drained, medium to dry, low fertility soils. The plant has excellent drought and partial shade tolerance

(NRCS 2002). Because of its growth habit and adaptability to a wide range of soil conditions, *S. scoparium* may be useful as a component of lakeshore restoration projects. We found no significant difference in abiotic variables across treatments; however, some species may be more sensitive to certain variables than other species, which may explain the variability in growth patterns within treatments. Additional evaluation and measurements of abiotic factors may be necessary to fully understand species-specific mechanisms governing growth.

Restorations of lakeshores with sandy soil and a southern aspect may particularly benefit from the addition of DWM. DWM may also reduce the microclimate stress on plants during the night in early spring. As nighttime temperatures are lowest at or near bare soil surfaces causing frost and adding stress to newly planted seedlings, DWM may reduce thermal imbalance at the soil surface by absorbing and storing infrared radiation during the day and protecting fragile plants at night (Ehleringer & Sandquist 2006). In this study, DWM did show that it can stabilize soil temperature and reduce soil moisture loss throughout the growing season, which could have a positive effect on plant growth and survival in the following years.

DWM may also provide other positive functions in restoration projects such as reducing soil erosion on steep slopes (Hagan & Grove 1999). Sediment runoff from the lake shoreline can have negative effects on aquatic systems (Engel & Pederson 1998). We observed sediment accumulation on the upward side of DWM on steeper slopes indicating that the DWM was reducing sediment runoff into the lake.

Conclusion

In Vilas County during 2007, low precipitation and high ambient temperatures resulted in low lake water levels. In 2008, temperatures were relatively normal but drought conditions continued and reached severe levels in late summer months (http://mrcc.sws.uiuc.edu). The aspect, slopes, and sandy soils at these restoration sites coupled with the weather conditions can put extreme stress on recent plantings. Previous restoration projects in the area have used cedar mulch on woody plant species to minimize soil–water evaporation. However, cedar mulch has a tendency to require continuous maintenance over the summer months due to high winds or its tendency to being washed away during rain or irrigation events. This was especially problematic on steeper slopes (D. Haskell, personal observation), and if mulch is applied too heavy, it may hinder plant recruitment.

The amount of DWM available for lake riparian is related to the vegetation structure in the area (Christensen et al. 1996). Although planting trees and shrubs into restoration sites will provide DWM through natural succession, trees grow slowly and it may take decades to centuries for DWM to be replenished naturally along high-development lakes (Christensen et al. 1996). Elias and Meyer (2003) advocate the active input of DWM into restoration project.

DWM addition reduced the difference between low and high daily soil temperatures and the change in soil moisture and thus can be considered a useful technique to physically manipulate soil properties. However, longer-term monitoring of plant survival and growth may be required to fully understand the effects of DWM (Castro et al. 2004).

Implication for Practice

- The addition of DWM to restoration sites can reduce soil temperature and moisture extremes on degraded sites. Therefore, reducing stress on new plant stock.
- Because DWM positively influenced growth rates of plants used in shoreline restoration projects, and it may take decades for DWM to occur naturally on human altered sites. The addition of DWM to restoration sites should be considered when planning restoration of riparian and other restoration projects.
- As survival and growth rates of plants are crucial to the success of restoration, DWM can accelerate the success of restoration projects.
- Restoration projects with highly degraded, sandy soils and a southern aspect will benefit from the addition of DWM to sites.

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