

Temperature Variability Between an Open Site and Beneath a Temperate Forest at the Cedarburg Bog in Southeastern Wisconsin

Taly Dawn Drezner¹ and Kim Weckerly

Department of Geography, Bolton Hall 410, P.O. Box 413, University of Wisconsin – Milwaukee, Milwaukee, WI 53201-0413.

In this study we aim to quantify subcanopy temperature and vegetation cover on two islands in the Cedarburg Bog in southeastern Wisconsin, and to link observations with the presence of the highly invasive *Rhamnus frangula* (glossy buckthorn). We collect subcanopy temperature data at six locales using dataloggers, and obtain climate data for an open field from the staff at the Cedarburg Bog. We also collect data for overstory cover using a fish-eye lens to quantify vegetation and percent sky seen from the datalogger, and we collect and quantify understory vegetation using the line method.

First, we observe that *Rhamnus* is more abundant on one island than the other. However, overstory cover and presumably receipt of insolation are similar on both islands, as is subcanopy temperature. Thus, the differences in the distribution of this invasive do not appear to be linked to overstory cover or differences in subcanopy temperature between the two islands. Second, we compare temperature under the forest canopy (cover greater than 85% in all plots) with the open site. While daily maximum temperatures are not significantly different, nighttime minimum temperatures are significantly higher in the forest on cool nights, and lower on warm nights.

Keywords: deciduous forest, fish-eye digital photography, invasive species, microclimate, Rhamnus frangula, Wisconsin

Introduction

Microclimate

Microclimate or climate at small scale – 1 cm to 1 km (Oke 1978) can vary with a host of factors including topography, canopy cover and vegetation type (Armesto and Martinez 1978; Miller et al. 1983; Drezner and Garrity 2003). Localized differences can be observed under a forest overstory, a single tree or in open areas. Solar radiation receipt can directly influence

the temperature of the subcanopy environment (De Frietas and Enright 1995) and largely determines plant growth (Pfitsch and Percy 1988; Breshears et al. 1997; Moro et al. 1997). Open sites tend to exhibit more extreme temperatures than areas under overstory cover (Drezner and Garrity 2003). In addition, temperature can affect moisture levels in the air and soil (Morecroft et al. 1998; Xu and Qi 2000) and can ultimately influence mortality rates in winter (Morecroft et al. 1998).

Extensive research on the effect of tree and forest canopies on microclimate has been conducted from arid (McAuliffe 1984a,b; Suzan et al. 1996; Gass and Barnes

¹ author of correspondence, e-mail: drezner@uwm.edu

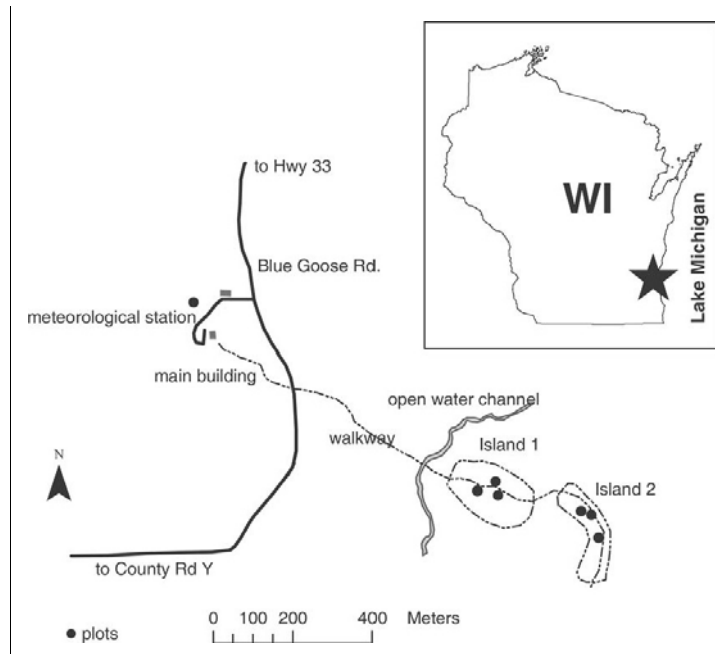


Figure 1 Location of the UWM Filed Station at the Cedarburg Bog, Wisconsin.

1998) and semi-arid landscapes (Breshears et al. 1997; Moro et al. 1997), to tropical rainforests (Chazdon and Pearcy 1991) and sub-alpine plant communities (Tappeiner and Cernusca 1996), and the plant interactions that may result are now recognized as being fundamentally important components of ecosystem dynamics (Withgott 2000). In forested areas an overstory canopy comprised of many individuals creates modified microclimate conditions that affect many species and individuals in the understory. Species under a dense overstory are adapted to very different conditions than those found in the open. Microclimate differences (soil and air temperature, wind, photosynthetically active radiation (PAR) receipt) beneath dense forest overstory cover compared to open grassland can be substantial and alter ecosystem structure and function (Davies-Colley et al. 2000).

Vegetation patterns and ecosystem processes are determined largely by the understory light environment, primarily by the overstory plant height and cover (Martens et al. 2000). Forest floors receive less light during both summer and winter than do grasslands and

open areas (Carlson and Groot 1997; Davies-Colley et al. 2000). In addition, PAR levels are reduced by shading (Geller and Nobel 1986) and vary with canopy cover as observed seasonally in deciduous forests (Morecroft et al. 1998). PAR levels are highly irregular on the forest floor, and on sunny days “sunflecks” cause sharply increased levels of light even in areas that normally experience strong shading (Chazdon and Pearcy 1991). In one study, an estimated 35% of the daily carbon gain of *Acer saccharum* seedlings in the understory of a hardwood forest in Michigan was attributed to sunflecks (Weber et al. 1985). How each of these factors affects local climate and specifically microclimate, depends on interaction with each other and with other physical environmental factors, such as soil moisture.

Environmental heterogeneity and the influence of highly local conditions and their effect on understory vegetation dynamics have been well documented. Such patterns are locally exhibited in forest gaps. Plants favoring high temperatures, light and transpiration rates grow better in large gaps, whereas species that require less light or cooler temperatures and increased moisture are more commonly found around canopy gaps (De Freitas and Enright 1995). Even placement relative to the gap is important in plant growth efficiency as insolation on the east side of the gap coincides with the warmest hours of the day creating a vapor pressure deficit great enough to slow plant growth, whereas individuals west of the gap receive direct insolation in the cooler morning hours (Barden 1996). Plants respond to these localized differences by exhibiting morphological changes over small areas or gradients (e.g. Ackerly et al. 2002). Plant morphology can vary along PAR, rainfall and soil composition gradients (Gratani 1993; Fonseca et al. 2000).

In addition, as gap size increases, greater variability in energy availability is observed (De Freitas and Enright 1995). In temperate rainforests, mean daytime understory radiation may be as low as 18% of that received in an open site (De Freitas and Enright 1995). When clear-cut, forest interiors were compared with small openings in aspen forest, for example, total irradiance values were greatest in the clearcut areas (Carlson and Groot 1997).

These differences in radiation are reflected in temperature values. In a *Populus* forest in Ontario, Canada, clearcut sites were about 5 °C cooler overnight than under forest interiors (Carlson and Groot 1997). Daytime temperatures during high sun months under a deciduous woodland canopy were as much as 3°C cooler than an open grassland site (Morecroft et al. 1998), and grasslands exhibit a more extreme range in values (Davies-Colley et al. 2000).

Another important component of microclimate is soil temperature, which decreases with increasing canopy cover (Franco and Nobel 1989; Carlson and Groot 1997). For example, cooler soil temperatures were observed in a deciduous woodland than in a grassland (Morecroft et al. 1998). Wind can alter temperature and soil moisture, and its influence can extend into a forest by as much as 240m when winds blow in towards the forest (Chen et al. 1995).

Rhamnus frangula

In Wisconsin and in many parts of North America,

Rhamnus frangula is a problematic invasive species, often establishing under forest cover. *Rhamnus frangula* tolerates a wide range of environmental conditions. It establishes successfully on soils of virtually any texture (Tansley 1968) or type (Rinzel 2000), but it is limited by high winter water levels (Godwin and Bharucha 1932). Its leaves develop early relative to other plants, and *Rhamnus* retains its leaves until later in the season (Hanson and Grau 1979, Lovely 1982). It invades open areas and shaded understory environments (Sanford et al. 2003). While it invades disturbed habitats, it also successfully invades undisturbed locales (Catling and Porebski 1994), which makes many high quality wetlands susceptible to its invasion (Catling and Porebski 1994, Rinzel 2000). Also, while it prefers alkaline soils (Leitner 1984), it will grow in acidic soils as well (Tansley 1968).

Rhamnus frangula produces fleshy black berries (Soper and Heimburger 1982, Catling and Porebski 1994) that are consumed by birds that subsequently disperse the seeds (Trial and Dimond 1979, van der Pijl, 1982). *Rhamnus frangula* is an imported ornamental plant (Possessky et al. 2000), and upon establishment, is carried from urban areas to rural areas by birds (Catling and

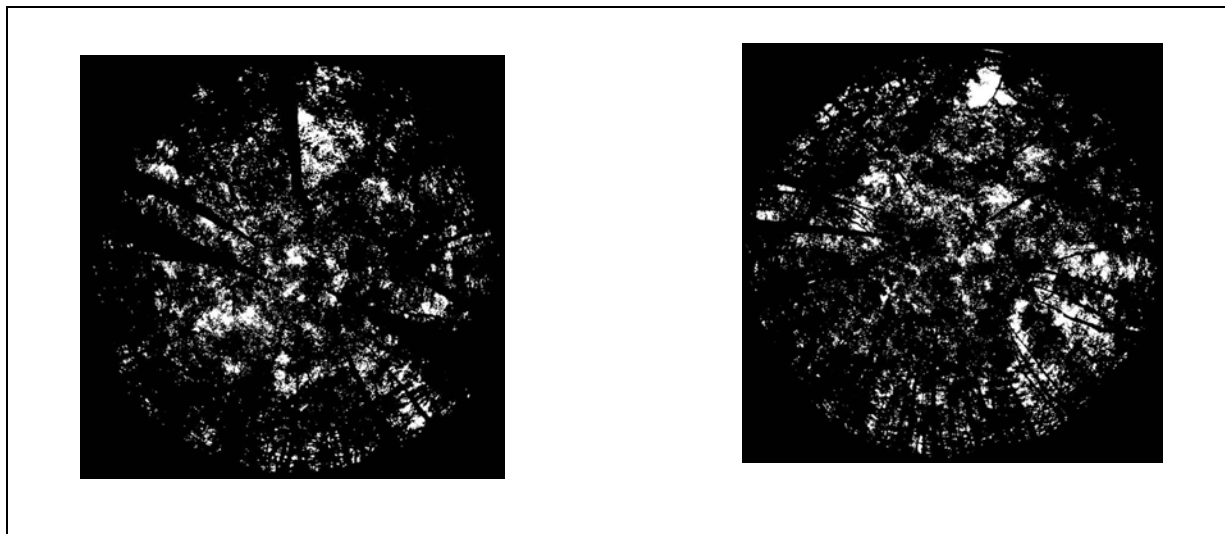


Figure 2a

Figure 2b

Figure 2 Two examples of the fish-eye digital camera lens techniques to measure overstory cover. White pixels represent the sky and black pixels represent cover. A simple ratio (black pixels to total number of pixels) provides the percent cover.

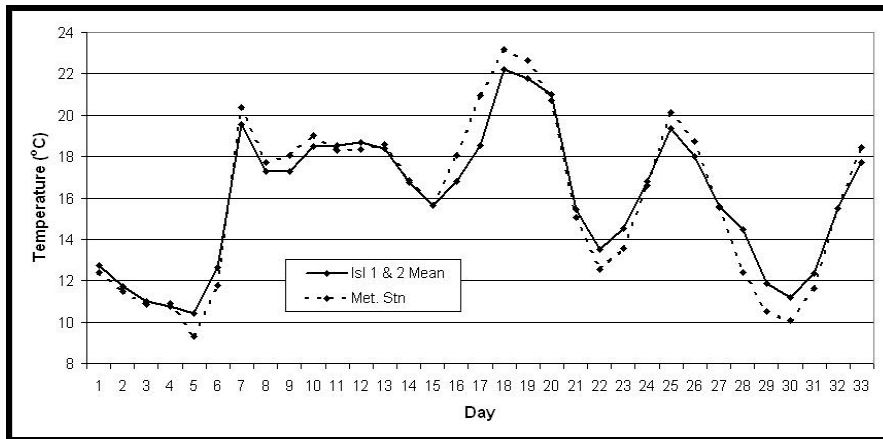


Figure 3 Mean minimum temperature over time for the meteorological station and the forested plots (average).

Porebski 1994). At the Cedarburg Bog, the opposite pattern was observed. Reinartz and Kline (1988) estimate that *Rhamnus* established at the Bog in 1955. It is believed that the Cedarburg Bog remains the primary *Rhamnus frangula* seed source for the surrounding areas (Reinartz and Kline 1988, Rinzel 2000), based in part on dating of individuals and a model of invasion (Rinzel 2000).

Purpose

The purpose of this study is twofold. First, we aim to observe microthermal variability between an open, grass dominated locale and forested communities on two islands, at the Cedarburg Bog in Wisconsin. At present, meteorological data for this site are derived solely from the single meteorological station located in the grass-covered area. In addition, we aim to quantify differences in invasive cover, namely the problematic *Rhamnus frangula*, across the forested locales, and to see if its distribution might relate to substantial differences in vegetation cover or subcanopy temperature at these locales.

Study site

The Cedarburg Bog (Figure 1) encompasses about 900 ha and is found within Wisconsin's tension zone where

northern and southern communities intermingle (Curtis 1959; Reinartz 1997; University of Wisconsin - Milwaukee 2000) It is classified as a humid continental (Köppen's Dfb) climate. Many ecological communities are found here including a variety of aquatic environments, the acidic Sapa Spruce Bog, swamp hardwood forests, old fields and the southernmost String Bog in North America (Reinartz 1997; University of Wisconsin - Milwaukee 2000). Portions of the area are owned by the University of Wisconsin

- Milwaukee (the UWM Field Station) and the Wisconsin Department of Natural Resources (University of Wisconsin - Milwaukee 2000).

Two islands were the focus of this study. The first island is (dimensions estimated from map and figure (Reinartz 1985, 11-12)) about 180 m long and as much as half that width at its widest point; the second island is long and narrow, perhaps 270 m long and 50 meters wide (Figure 1). The first (west) island has been an island for several thousand years, and shows evidence of fluctuating lake levels of perhaps two meters (Reinartz 1985). The overstory includes species such as *Prunus serotina* (black cherry), *Populus tremuloides* (aspen), *Tilia americana* (basswood), *Acer* spp. (maple) and *Taxus canadensis* (Canada yew) (Reinartz 1985). The overstory on the second (east) island includes *Prunus serotina* (black cherry), *Tilia americana* (basswood), and some *Betula papyrifera* (paper birch), and shows evidence of ice push ridges and lake terraces (Reinartz 1985).

Field methods

Plot Selection and Subcanopy Temperature Data Collection

A meteorological station is located at the Field Station in an open, grassy field. The area around the meteorological station is periodically mowed. Field Station staff provided

the daily weather data from the station. To measure temperature on the islands under the dense overstory, Onset Computer Corporation's Hobo data loggers (from this point forward these are referred to as Hobos) were used to measure ambient, near-surface temperatures (dimensions are 10.2 x 8.1 x 5.1 mm, and weigh approximately 104 grams). The accuracy of these instruments is $\pm 0.2^{\circ}\text{C}$ (Onset Computer Corporation). On each island, three plots were set up. Plot site selection was limited to locales characterized by flat and consistent topography that were not near the margin of the island, and were spatially distinct such that plots did not overlap. Within these specified constraints, each of the six Hobos was randomly placed in one of these areas. Hobos were placed directly on the ground under the dense forest canopy (see Figures 1,2). Hobos were located relatively centrally on the islands and not near the island margins. The nearest Hobo to an island edge was perhaps 25m from the edge, and the rest were considerably farther. All of the Hobos were located in areas that were representative of the forest environment. Prevailing wind direction at the meteorological station in June 2002 was from the southwest (monthly average of 214°), and 250° average in July (G. Meyer, personal communication). The islands are approximately 800 m from the meteorological station

station. Hobos recorded air temperature in five minute intervals. The Hobo marked the center of the plot. Plots were 10 X 15 m in size, except in one case where the plot was 10 X 10 m. This was due to more variable microtopography at this locale and a larger plot would have yielded less accurate results. The long axis of the plot was approximately aligned parallel to the long axis of the island. Hobo data were collected from June 13, 2002 to July 17, 2002.

Vegetation Sampling

We first quantified understory vegetation cover using the line-intercept method (Canfield 1941; Mueller-Dombois and Ellenberg 1974). The line along which sampling was conducted was the central long axis of the plot (the line was 15 m in length), where the Hobo was exactly at the midpoint of the line. All vegetative matter covering the line (whether it was a part of a leaf, the stem of a blade of grass or any other portion of the plant) was noted. Cover data were collected to an accuracy of 1 mm. Upon completion of the survey of vegetation cover on the line, the plot was thoroughly searched for any additional species not sampled on the line. The presence of these were noted as well.

Quantifying the dense and tall overstory vegetation canopy cover was problematic. Thus we decided to use a Nikon CoolPix 950 digital camera with a Nikon FC-E8 fisheye lens. This same camera model and lens were used in another study (quantifying urban canyon geometry and assessing the associated sky-view factor), which concluded that the camera and lens estimates were both accurate and objective (Grimmond et al. 2001). The image was taken approximately $\frac{1}{2}$ meter above the ground, immediately above the Hobo, with the camera pointing upwards (Figure 2). All tree species covering any portion of the plot, whether their trunk was inside or outside of the plot, were noted.

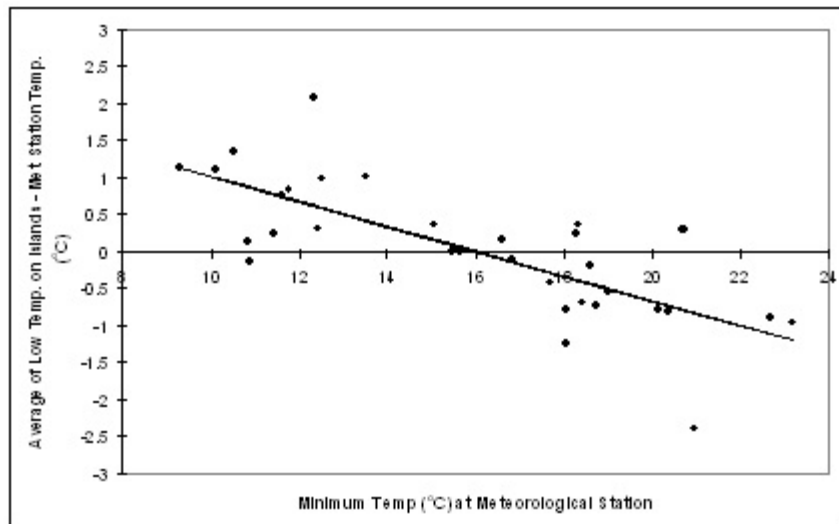


Figure 4 Regression results for the low temperature difference between the meteorological station and under the forest canopy and the minimum meteorological station temperature ($P < 0.001$).

Island/Plot#	Mean (°C)	Variance	Significance
Daily High Temperature			
Island 1			
Plot 1	27.6	21.4	
Plot 2	27.3	15.2	
Plot 3	27.1	15.8	(0.20)
Island 2			
Plot 1	26.2	15.9	
Plot 2	26.9	15.9	
Plot 3	28.8	19.4	$P < 0.001$
Island 1	27.3	16.5	
Island 2	27.3	16.5	(0.87)
Daily Low Temperature			
Island 1			
Plot 1	16.4	11.8	
Plot 2	16.1	11.3	
Plot 3	16.1	10.4	$P < 0.001$
Island 2			
Plot 1	15.5	11.2	
Plot 2	15.9	11.2	
Plot 3	15.6	11.0	$P < 0.001$
Island 1	16.2	11.1	
Island 2	15.7	11.1	$P < 0.001$
Daily Temperature Range			
Island 1			
Plot 1	11.2	9.1	
Plot 2	11.2	8.2	
Plot 3	10.9	8.0	(0.61)
Island 2			
Plot 1	10.7	7.1	
Plot 2	11.0	8.1	
Plot 3	13.1	10.0	$P < 0.001$
Island 1	11.1	7.6	
Island 2	11.6	7.8	$P < 0.01$

Table 1. Two-way ANOVA results for daily high and low temperature, and daily temperature range on and between the two islands at the Cedarburg Bog, WI.

Temperature under forest canopy and in the open

Microclimate: Data and Statistical Methods

Maximum and minimum temperatures for each day were extracted from the Hobos. Because the first and last days of data were incomplete as a result of the placement and collection of the dataloggers during the course of the day, they were excluded. For intra-island comparison, first the maximum temperature on each day ($n=33$) for each of the three Hobos on island 1 was analyzed using two-way ANOVA. This was then repeated for the second island.

The average of the three Hobos from each island was taken, and a third two-way ANOVA analysis was conducted to compare the means between islands. These procedures and analyses were then repeated for daily minimum temperature, and temperature range, for a total of nine analyses.

To determine overstory cover, the fish-eye images were imported into digital image software packages, and colors were converted to black (cover) and white (sky) pixels (Figure 2). A simple pixel count provided the number of black and white pixels in the image, which were then readily converted to percent overstory cover.

Because of the consistency of the overstory cover and the statistical results of the temperature analyses, temperature data for the two islands were averaged. Two-way ANOVA analyses were conducted for the islands (average of six plots) and the meteorological station, first for daily maximum temperature differences between the two communities, and then for daily minimum temperatures. Minimum temperatures appeared to fluctuate more at the grass site than at the forest sites (Figure 3). Thus, the mean minimum temperature at the meteorological station was

subtracted from the mean minimum temperatures on the islands giving the difference in minimum temperature between these two sites. Regression analysis was conducted for this variable and the mean minimum temperature at the meteorological station, providing information about whether temperatures at one site fluctuate more than at the other.

Microclimate: Results and Discussion

High temperature and diurnal temperature range did not vary significantly between the three plots on island 1 ($P>0.05$) (Table 1). Intra-island daily high temperature on island 2, daily minimum temperature on both islands, and diurnal temperature range on island 2 were significantly different (Table 1).

When the three Hobo readings on each island were averaged for each day, daytime high temperatures were not significantly different (Table 1). Daily minimum temperature and temperature range were significantly different, but by only 0.5°C .

The meteorological station is located in a large,

station is regularly mowed by the UWM field station staff. By comparison, the overstory cover on the islands is greater than 85% in all sampled areas. It is thus perhaps surprising that differences between daily maximum temperature between the islands and meteorological station were not significant, as been found in other temperate communities (De Fries and Enright 1995; Carlson and Groot 1997). This may be due in part to the nature of meteorological weather shelters (i.e. enclosed compartments, though ventilated) or perhaps due to sunflecks on the forest floor. Also, on days with proportionately more diffuse light and less direct insolation, temperature variations between woodland understory and grassland may disappear (Morecroft et al. 1998).

Daily minimum temperature differences between the islands and the meteorological station were also not significant. The reason for this became clear upon consideration of the graph for these 33 days (Figure 3). The conditions over the grass are more extreme than those under the dense forest overstory on the islands (Figure 3). Statistical analysis confirms that this observation is significant ($P<0.001$, Figure 4). On relatively cool nights, air temperature remains higher on the highly vegetated islands while on warm nights air temperature remains lower (Figures 3, 4). This nighttime phenomenon reflects the more extreme temperature conditions over the grass, and the more moderate temperatures under the dense overstory canopy, as has been observed diurnally elsewhere (Carlson and Groot 1997; Morecroft et al. 1998). This pattern results, in part, from the trapping of longwave radiation released from the ground at night that warms the air beneath the canopy, as well as possible effects from wind (Davies-Colley et al. 2000).

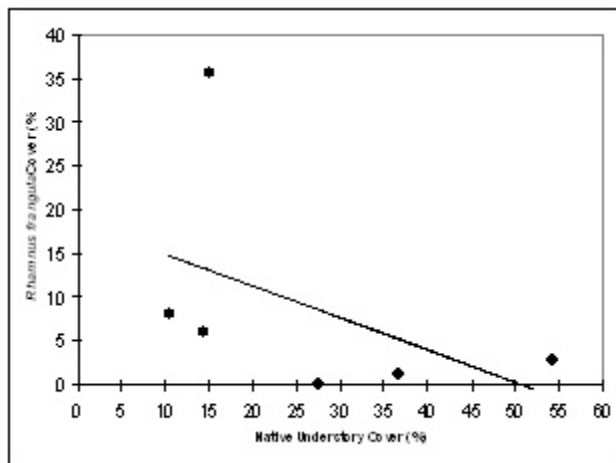


Figure 5 Regression showing the relationship between total understory native species and *Rhamnus frangula* cover ($P>0.05$).

open area with no overstory cover. The understory is almost entirely graminoid, though a few scattered invasive or early successional forbs may be found. The vegetation (i.e. grass) immediately surrounding the meteorological

RHAMNUS FRANGULA, ISLAND MICROCLIMATE, AND VEGETATION

Rhamnus: Data and Statistical Methods

Understory cover was computed for each species in each plot. The total coverage of the line by the species relative to the length of the line was computed. A species

covering 15 cm of the 15 m line would cover 1% for example (15cm/1500cm=1% cover). Species found in the plot but not on the line were arbitrarily assigned a cover of 0.01%. Regression was run to determine if *Rhamnus frangula* and invasive species were related to understory cover. To observe if there was any relationship between subcanopy temperature and understory cover, regression was run, once with mean minimum temperature and once with mean maximum temperature.

Rhamnus: Results and Discussion

A total of 65 taxa were sampled in the understory in this study (Tables 2,3). Neither mean minimum or mean maximum temperature were significantly related to understory cover. *Aster macrophyllus* was the species with the greatest cover over the 6 plots, though it was found entirely on island 1 (mean cover of 20.5% between the three plots). *Rhamnus frangula* had the second highest mean cover in the understory, particularly on island two (mean cover 16.5% on island 2), averaging only 1.3% of the understory cover on island 1. By comparison, the second most abundant taxon on island two was *Osmorhiza* spp. at 2.3% cover (Table 2). Of the 58 taxa whose status could be determined, only five taxa were invasive. *Rhamnus frangula* made up almost all of the invasive cover; the combined cover of the four other species over the six plots was less than one percent.

When the ratio of *Rhamnus frangula* cover to total understory cover for each plot was considered to control for differences in cover between plots, the average of the three ratios was 0.02 for island 1 (0, 0.04, 0.03), and 0.41 for island 2 (0.43, 0.58, 0.21). Thus, this single invasive species made up half or nearly half of the total understory cover in two of the three plots on the second island (i.e. 16.5% average *Rhamnus frangula* cover on island 2 of 33.4% total cover of all species on island 2). Overall, *Rhamnus frangula* was far more abundant on the second island. These differences are not due to management efforts at the site. In fact, the greater abundance of *Rhamnus* on the second island has resulted in preferential removal of this species on the second island (J. Reinartz, personal communication). Areas sampled on the first island have never been known to have problems with this species (J. Reinartz, personal communication). Thus, this species has not been problematic, even unchecked, on

island 1, and yet has thrived on the second island, despite management efforts there.

Because *Rhamnus* is highly tolerant of a wide range of local geomorphic, light and other environmental conditions, we considered temperature as a possible limiting factor. Daily minimum temperature on both islands were significantly different (Table 1). The daily minimum temperature differences were 0.5 °C both between the two islands, and within each island.

Thus, the actual temperature difference between the islands (and within each island) was very small. However, differences in temperature were very consistent, and consequently, statistically significant results were observed. Overall, considering the natural fluctuation in temperature over time, inter- and intra-island differences were small. We believe that such differences are unlikely to result in the observed distribution pattern of *Rhamnus frangula*.

Overstory cover was very consistent between plots and between islands. In the six plots, overstory cover ranged from 86.2% to 92.2%. Thus it is not surprising that temperature results were so consistent. *Acer* spp. and *Tilia americana* were the most abundant species. Other less abundant overstory species observed on the islands included *Cornus amomum*, *Ostrya virginiana*, *Betula papyrifera*, and *Prunus* spp. Overall, the environmental conditions, including overstory light availability, were similar in the plots on these two islands. Some of these overstory species were observed in the understory as seedlings as well.

Microclimate and shading can influence the establishment of invasive species. *Rhamnus frangula*, a

Growth Form	n	Mean Cover%
Trees	10	3.6
Shrubs	5	8.9
Forbs	32	22.4
Wood Vines	5	0.5

Table 3 Understory cover and diversity by growth form in the six forest plots. Trees include all individuals in the understory (e.g. seedlings).

Table 2. Species sampled in the forest understory on the two islands at the UWM Field Station. Status (N= native, I= invasive), growth form (GF; trees (T), shrubs (S), forbs (F), graminoids (G), woody vines (VW), and ferns), and whether the species is annual, perennial or biennial (A/B/P) are provided.

Family Species	Status	A/B/P	GF	Island 1			Mean	Island 2			Mean	Mean
				Plot1	Plot2	Plot3	Is 1	Plot1	Plot2	Plot3	Is2	All
PTERIDOPHYTA												
Ophioglossaceae												
<i>Botrychium virginianum</i>	N	P	Fern	0.01		0.01	0.01	0.01			0	0.01
Osmundaceae												
<i>Osmunda</i> sp.	N	P	Fern				0		0.01	0.01	0.01	0
Polypodiaceae												
<i>Adiantum pedatum</i>	N	P	Fern			0.01	0				0.00	0.00
<i>Athyrium filix-femina</i>	N	P	Fern				0	0.01			0.00	0.00
<i>Onoclea sensibilis</i>	N	P	Fern				0.00		0.01		0.00	0.00
GYMNOSPERMAE												
Cupressaceae												
<i>Juniperus communis</i>	N	P	S				0.00		0.01		0.00	0.00
ANGIOSPERMAE												
Aceraceae												
<i>Acer</i> sp.	N	P	T			0.1	0.03			0.01	0	0.02
Anacardiaceae												
<i>Toxicodendron radicans</i>	N	P	VW			0.17	0.06				0.00	0.03
Apiaceae												
<i>Daucus carota</i>	I	B	F		0.01		0				0	0
<i>Osmorhiza claytonii</i>	N	P	F	0.2			0.07				0.00	0.03
<i>Osmorhiza longistylis</i>	N	P	F				0			1.20	0.40	0.20
<i>Osmorhiza</i> sp.	N	P	F	0.01	0.87	1.17	0.68	2.13	0.01	3.50	1.88	1.28
<i>Sanicula</i> sp.	N	P	F				0.00			0.01	0	0
Araceae												

Table 2. Species sampled in the forest understory on the two islands at the UWM Field Station. Status (N= native, I= invasive), growth form (GF; trees (T), shrubs (S), forbs (F), graminoids (G), woody vines (VW), and ferns), and whether the species is annual, perennial or biennial (A/B/P) are provided.

Family Species	Status	A/B/P	GF	Island 1			Mean	Island 2			Mean	Mean
				Plot1	Plot2	Plot3	Is 1	Plot1	Plot2	Plot3	Is2	All
<i>Arisaema triphyllum</i>	N	P	F				0	0.37	0.4		0.26	0.13
Araliaceae												
<i>Aralia nudicaulis</i>	N	P	F		1.13		0.38				0.00	0.19
Asteraceae												
<i>Arctium minus</i>	I	B	F				0.00		0.01		0	0
<i>Aster macrophyllus</i>	N	P	F	8.23	46.19	7.10	20.51				0.00	10.25
<i>Aster</i> sp.					0.01		0.00				0.00	0
<i>Erigeron strigosus</i>	N	A	F		0.01		0.00		0.01	0.01	0.01	0.01
<i>Eupatorium rugosum</i>	N	P	F			4.20	1.40	2.63			0.88	1.14
<i>Helianthus grosseserratus</i>	N	P	F				0.00			0.01	0.00	0.00
<i>Solidago canadensis</i>	N	P	F				0.00	0.01			0.00	0.00
<i>Solidago flexicaulis</i>	N	P	F	3.77	2.73	13.99	6.83	2.43		2.60	1.68	4.25
<i>Solidago</i> sp.				0.10	0.23		0.11				0.00	0.06
<i>Taraxacum officinale</i>	I	P	F				0.00			0.53	0.18	0.09
Asteraceae unknown							0		3.35	2.80	2.05	1.03
Betulaceae												
<i>Ostrya virginiana</i>	N	P	T			0.90	0.30		3.70		1.23	0.77
Cornaceae												
<i>Cornus</i> sp.	N	P	S				0.00		0.01	0.01	0.01	0
Cyperaceae												
<i>Carex</i> sp.			G	1.73			0.58				0	0.29
Fagaceae												
<i>Quercus</i> sp.	N	P	T				0.00		0.01		0.00	0
Grossulariaceae												

Table 2. Species sampled in the forest understory on the two islands at the UWM Field Station. Status (N= native, I= invasive), growth form (GF; trees (T), shrubs (S), forbs (F), graminoids (G), woody vines (VW), and ferns), and whether the species is annual, perennial or biennial (A/B/P) are provided.

Family Species				Island 1			Mean	Island 2			Mean	Mean
	Status	A/B/P	GF	Plot1	Plot2	Plot3	Is 1	Plot1	Plot2	Plot3	Is2	All
<i>Ribes cynosbati</i>	N	P	S	0.01			0.00			0.01	0.00	0.00
<i>Ribes hirtellum</i>	N	P	S		0.01		0.00				0.00	0.00
Juglandaceae												
<i>Carya cordiformis</i>	N	P	T			0.01	0.00				0.00	0.00
<i>Carya ovata</i>	N	P	T			0.01	0.00				0.00	0
Liliaceae												
<i>Smilacina</i> sp.	N	P	F			0.02	0.01				0.00	0
<i>Smilax hispida</i>	N	P	VW			0.01	0.00	0.53		0.01	0.18	0.09
<i>Trilium grandiflorum</i>	N	P	F				0.00		0.01		0.00	0.00
<i>Uvularia grandiflora</i>	N	P	F		0.27		0.09		0.20	0.03	0.08	0.08
<i>Uvularia sessilifolia</i>	N	P	F			1.43	0.48	2.23			0.74	0.61
Liliaceae unknown							0.00		0.50		0.17	0.08
Poaceae												
<i>Panicum capillare</i>	N	A	G	0.01			0.00				0.00	0
Poaceae unknown			G		2.99	2.19	1.73	0.27	1.64	1.41	1.11	1.42
Ranunculaceae												
<i>Actaea</i> sp.	N	P	F			0.01	0.00		0.01	0.63	0.21	0.11
<i>Aquilegia canadensis</i>	N	P	F				0.00	0.01		0.67	0.23	0.11
<i>Hepatica acutiloba</i>	N	P	F		1.43	0.67	0.70			0.43	0.14	0.42
<i>Ranunculus abortivus</i>	N	B/P	F			0.01	0.00				0.00	0.00
Rhamnaceae												
<i>Rhamnus cathartica</i>	I	P	T				0.00			0.07	0.02	0.01
<i>Rhamnus frangula</i>	I	P	S		2.63	1.13	1.26	8.00	35.60	5.77	16.46	8.86
Rosaceae												

Table 2. Species sampled in the forest understory on the two islands at the UWM Field Station. Status (N= native, I= invasive), growth form (GF; trees (T), shrubs (S), forbs (F), graminoids (G), woody vines (VW), and ferns), and whether the species is annual, perennial or biennial (A/B/P) are provided.

Family Species	Status	A/B/P	GF	Island 1			Mean	Island 2			Mean	Mean
				Plot1	Plot2	Plot3	Is 1	Plot1	Plot2	Plot3	Is2	All
<i>Fragaria vesca</i>	N	P	F				0.00	0.01	0.01	1.83	0.62	0.31
<i>Fragaria virginiana</i>	N	P	F				0.00	0.01			0.00	0.00
<i>Genm canadense</i>	N	P	F				0.00			0.01	0.00	0.00
<i>Prunus serotina</i>	N	P	T				0.00	0.01			0.00	0.00
<i>Prunus</i> sp.	N	P	T	13.07			4.36			1.60	0.53	2.44
<i>Prunus virginiana</i>	N	P	T			0.01	0		0.6		0.2	0.1
<i>Rubus pubescens</i>	N	P	F				0.00		3.75	0.10	1.28	0.64
Rosaceae unknown							0.00		0.40		0.13	0.07
Rubiaceae												
<i>Galium lanceolatum</i>	N	P	F			0.01	0.00				0.00	0.00
<i>Galium trifidum</i>	N	P	F		0.01		0.00				0.00	0.00
<i>Galium triflorum</i>	N	P	F	0.25	0.34	0.03	0.2	0.01	2.6	0.01	0.87	0.54
Tiliaceae												
<i>Tilia americana</i>	N	P	T				0		1.2		0.4	0.2
Verbenaceae												
<i>Verbena hastata</i>	N	B/P	F	0.01			0.00				0.00	0
Violaceae												
<i>Viola</i> sp.	N	P	F	2.00	1.23	5.07	2.77	0.01	1.71	1.67	1.13	1.95
Vitaceae												
<i>Parthenocissus inserta</i>	N	P	VW		0.01	1.77	0.59	0.01			0	0.3
<i>Parthenocissus</i> sp.	N	P	VW				0		0.8	0.01	0.27	0.14
<i>Vitis riparia</i>	N	P	VW				0		0.01		0.00	0.00
SUM FOR PLOTS												
				29.4	60.11	40.02	43.18	18.70	56.57	24.96	33.41	38.29

European native, has invaded northeastern U.S. and Canada displacing natives (e.g. Howell and Blackwell 1977; Taft and Solecki 1990; Catling and Porebski 1994).

This species has also invaded Wisconsin, and has been especially problematic in wetlands (Heidorn 1991), including at the Field Station site in this study (Reinartz 1997). Regression results exhibit a negative relationship between *Rhamnus frangula* cover and native understory cover, however results are not significant. It is important to note that these variables represent absolute (=actual) cover, not the percentage of total cover observed in each plot. Even when the outlier is removed and the analysis re-run, the relationship is not significant ($P > 0.20$). This may be due to the small sample size, but the relationship does appear poor (Figure 5). In the six plots sampled in this study, *Rhamnus frangula* exhibited relatively high absolute cover in only one plot. With less than 10% absolute cover in five of the plots, its effects were likely not yet fully observed. *Rhamnus frangula* was less abundant on the other two plots on the second island, however native understory cover was also lower making *Rhamnus*'s relative cover in the plots high. When the relative cover of this species (*Rhamnus*/total understory cover) was correlated with total understory cover, there was no relationship ($P > 0.5$, data not shown). In addition to its observed invasiveness at the Field Station (Reinartz 1997), *Rhamnus frangula* is a problematic and highly invasive species that had invaded and dramatically altered wetlands and woodlands (Godwin, 1936). It has come to dominate the tall-shrub zone of Gavin Bog in Illinois (Taft and Solecki 1990), has been predicted to dominate open and semi-open wetlands in southern Ontario, Canada (Catling and Porebski 1994).

Despite their drastically different biotic and structural differences in composition, temperature differences were not large between the forest understory and grassland site. The invasive *Rhamnus frangula* is well established on only one of the two islands sampled, despite similarities in temperature and overstory cover. This suggests that differences in this species' abundance are due to factors other than subcanopy temperature or light availability from the overstory.

Acknowledgements

We thank Jim Reinartz for help in identifying plant specimens and for information about *Rhamnus frangula*

and the management history of the areas studied. We thank Gretchen Meyer for suggestions and support and for field station climate data.

Literature cited

- Ackerly D.D., C.A. Knight, S.B. Weiss, K. Barton, and K.P. Starmer. 2002. Leaf size, specific area and microhabitat distribution of chaparral woody plants: contrasting patterns in species level and community level analyses. *Oecologia* 130: 449-457.
- Armesto, J.J., and J.A. Martinez. 1978. Relations between vegetation structure and slope aspect in the Mediterranean region of Chile. *Journal of Ecology* 66: 881-889.
- Barden, L.S. 1996. A comparison of growth efficiency of plants on the east and west sides of a forest gap canopy. *Bulletin of the Torrey Botanical Club* 123(3): 240-242.
- Breshears, D.D., P.M. Rich, F.B. Barnes, and K. Campbell. 1997. Overstory-imposed heterogeneity in solar radiation and soil moisture in a semiarid woodland. *Ecological Applications* 7(4): 1201-1215.
- Canfield, R. 1941. Application of the line interception method in sampling range vegetation. *Journal of Forestry* 39: 388-394.
- Carlson, D.W. and A. Groot. 1997. Microclimate of clear-cut, forest interior and small openings in trembling aspen forest. *Agricultural and Forest Meteorology* 87: 313-329.
- Catling, P.M. and Z.S. Porebski. 1994. The history of invasion and current status of glossy buckthorn, *Rhamnus frangula*, in southern Ontario. *The Canadian Field-Naturalist* 108: 305-310.
- Chazdon, R.L. and R.W. Pearcy. 1991. The importance of sunflecks for forest understory plants. *BioScience* 41: 760-766.
- Chen, J., J.F. Franklin, and T.A. Spies. 1995. Growing season microclimate gradients from clear cut edges into old growth Douglas-fir forest. *Ecological Applications* 5:

74-86.

Curtis, J. T. 1959. *The Vegetation of Wisconsin*. University of Wisconsin Press.

Davies-Colley, R.J., G.W. Payne, M. van Elsijk. 2000. Microclimate gradients across a forest edge. *New Zealand Journal of Ecology* 24(2): 111-121.

De Frietas, C.R. and N.J. Enright. 1995. Microclimate differences between and within canopy gaps in a temperate rainforest. *International Journal of Biometeorology* 38: 188-193.

Drezner, T.D. and C. M. Garrity. 2003. Saguaro distribution under nurse plants in Arizona's Sonoran Desert: directional and microclimate influences. *Professional Geographer* 55(4): 505-512.

Fonseca, C.R., J.M. Overton, B. Collins, and M. Westoby. 2000. Shifts in trait-combinations along rainfall and phosphorous gradients. *Journal of Ecology* 88: 964-977.

Franco, A.C. and P.S. Nobel. 1989. Effect of nurse plants on the microhabitat and growth of cacti. *Journal of Ecology* 77: 870-886.

Gass, L. and P. Barnes. 1998. Microclimate and understory structure of live oak (*Quercus fusiformis*) clusters in central Texas, USA. *The Southwestern Naturalist* 43(2): 183-194.

Geller, G.N. and P.S. Nobel. 1986. Branching patterns of columnar cacti: influences on PAR interception and CO₂ uptake. *American Journal of Botany* 73(8): 1193-1200.

Godwin, H., F.R. Bharucha. 1932. Studies in the ecology of Wicken Fen II. The fen water table and its control of plant communities. *Journal of Ecology* 20(1): 157-191.

Godwin, H. 1936. Studies in the ecology of Wicken Fen III: The establishment and development of fen scrub (carr). *Journal of Ecology* 24: 82-116.

Grantani, L. 1993. Response to microclimate of morphological leaf attributes, photosynthetic and water relations of evergreen sclerophyllous shrub species. *Photosynthetica* 29(4): 573-582.

Grimmond, C. S. B., S.K. Potter, H.N. Zutter, and C. Souch. 2001. Rapid methods to estimate sky-view factors applied to urban areas. *International Journal of Climatology* 21: 903-913.

Hanson, E.W., C.R. Grau. 1979. The buckthorn menace to oat production. Publication Cooperative Extension programs. WS 2000; A2860, University of Wisconsin Extension, Madison, WI. 2p.

Heidorn, R. 1991. Vegetation management guideline: exotic buckthorns – common buckthorn (*Rhamnus cathartica* L.) glossy buckthorn (*Rhamnus frangula* L.), dahurian buckthorn (*Rhamnus davurica* Pall.). *Natural Areas Journal* 11:216-217.

Howell, J.A. and W.H. Blackwell, Jr. 1977. The history of *Rhamnus frangula* in (Glossy Buckthorn) in the Ohio flora. *Castanea* 42(2):111-115.

Leitner, L.A. 1984. Letter and summary of research with *Rhamnus cathartica* sent to The Nature Conservancy, Midwest Regional Office from University of Wisconsin, Milwaukee, Botany Department, 5 pp.

Lovely, D.M. 1982. Wingra Fen: 1982 report. Submitted to Friends of University of Wisconsin Arboretum, Madison, Wisconsin.

Martens, S.N., D.D. Breshears, and C.W. Meyer. 2000. Spatial distributions of understory light along the grassland/forest continuum: effects of cover, height, and spatial pattern of tree canopies. *Ecological Modeling* 126: 79-93.

McAuliffe, J.R. 1984a. Sahuaro-nurse tree associations in the Sonoran Desert: competitive effects of sahuaros. *Oecologia* 64: 319-321.

McAuliffe, J.R. 1984b. Prey refugia and the distributions of two Sonoran Desert cacti. *Oecologia* 65: 82-85.

Meyer, G. 2004. Personal communication.

Miller, P.C., D.K. Poole, and P.M. Miller. 1983. The influence of annual precipitation, topography and vegetative cover on soil moisture and summer drought in Southern California. *Oecologia* 56: 385-391.

- Morecroft, M.D., M.E. Taylor, and H.R. Oliver. 1998. Air and soil microclimates of deciduous woodland compared to an open site. *Agricultural and Forest Meteorology* 90: 141-156.
- Moro, M.J., F.I. Pugnaire, P. Haase, and J. Puigdefabregas. 1997. Effect of the canopy of *Retama sphaerocarpha* on its understory in a semiarid environment. *Functional Ecology* 11: 425-431.
- Mueller-Dombois, D. and H. Ellenberg. 1974. *Aims and Methods of Vegetation Ecology*. New York, John Wiley & Sons, Inc.
- Oke, T.R. 1978. *Boundary Layer Climates*. London, Methuen & Co. Ltd.
- Pfitsch, W.A., and R.W. Pearcy. 1988. Daily carbon gain by *Adenocaulon bicolor* (Asteraceae), a redwood forest understory herb, in relation to its light environment. *Oecologia* 80: 465-470.
- Possessky, S.L., C.E. Williams, W.J. Moriarity. 2000. Glossy Buckthorn, *Rhamnus frangula* L.: A threat to Riparian plant communities of the Northern Allegheny Plateau (USA). *Natural Areas Journal* 20(3): 290-292.
- Reinartz, J.A. 1985. A guide to the natural history of the Cedarburg Bog, Part I. *The University of Wisconsin – Milwaukee Field Station Bulletin*, 18(2).
- Reinartz, J.A. 1997. Controlling glossy buckthorn (*Rhamnus frangula* L.) with winter herbicide treatments of cut stumps. *Natural Areas Journal* 17: 38-41.
- Reinartz, J.A., J. Kline. 1988. Glossy buckthorn (*Rhamnus frangula*), a threat to the vegetation of the Cedarburg Bog. *University of Wisconsin – Field Station Bulletin* 21 (2):20-35.
- Reinartz, J.A. 2004. Personal communication.
- Rinzel, K. 2000. Factors influencing the establishment of Glossy Buckthorn (*Rhamnus frangula*) in Southeastern Wisconsin wetlands. Masters Thesis, University of Wisconsin – Milwaukee.
- Sanford, N.L., R.A. Harrington, J.H. Fownes. 2003. Survival and growth of native and alien woody seedlings in open and understory environments. *Forest Ecology and Management* 183: 377-385.
- Soper, J.H., M.C. Heimbürger, 1982. *Shrubs of Ontario*. Toronto, Canada: Royal Ontario Museum.
- Suzan, H., G.P. Nabhan, and D.T. Patten. 1996. The importance of *Olneya tesota* as a nurse plant in the Sonoran Desert. *Journal of Vegetation Science* 7: 635-644.
- Taft, J.B. and M.K. Solecki. 1990. Vascular flora of the wetland and prairie communities of Gavin Bog and Prairie Nature Preserve Lake County Illinois USA. *Rhodora* 92(871): 142-165.
- Tansley, A.G. 1968. *Britain's Green Mantle: Past, Present and Future*. London, England: George Allen and Unwin.
- Tappeiner, U. and A. Cernusca. 1996. Microclimate and fluxes of water vapour, sensible heat and carbon dioxide in structurally differing subalpine plant communities in the Central Caucasus. *Plant, Cell and Environment* 19: 403-417.
- Trial, H. Jr., J.B. Dimond, 1979. Emodin in buckthorn: a feeding deterrent to phytophagous insects. *Canadian Entomology* 111:207-212.
- University of Wisconsin – Milwaukee. 2000. 2000 Annual Report. *The University of Wisconsin – Milwaukee Field Station Annual Report*.
- van der Pijl, L. 1982. *Principles of dispersal in higher plants*, 3rd edn, p. 215. Springer Verlag, Berlin.
- Weber, J.A., T.W. Jurik, J.D. Tenhunen, and D.M. Gates. 1985. Analysis of gas exchange in seedlings of *Acer saccharum*: integration of field and laboratory studies. *Oecologia* 65: 338-347.
- Withgott, J. 2000. Botanical nursing: from deserts to shorelines, nurse effects are receiving renewed attention. *BioScience* 50: 479-484.

Drezner and Weckerly

Xu, M. and Y. Qi. 2000. Effect of spatial scale on relationship between plant species richness and microclimate in a forested ecosystem. *Polish Journal of Ecology* 48(1): 77-88.