



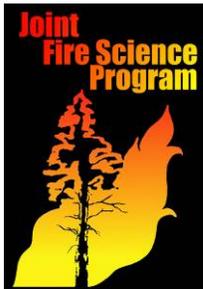
# To Burn or Not to Burn Oriental Bittersweet: A Fire Manager's Conundrum

## First Progress Report September 30, 2009

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For

The Joint Fire Science Program



## Project Justification

Oriental bittersweet (*Celastrus orbiculatus*) is a highly invasive liana (woody vine) that occurs throughout the Eastern United States. This twining plant can blanket and girdle adjacent vegetation, affecting succession and damaging trees. In areas where prescribed fire is a management tool, the response of Oriental bittersweet to fire needs to be quantified, rather than relying on anecdotal evidence. Currently, in areas already infested with this species, there are no strategies for prioritizing pre- or post-fire treatments on Oriental bittersweet. This largely results from a lack of understanding of the nature of post-fire resprouting by this species. Sprouting of bittersweet can at least double with fire and sprouts appear to respond to fire with an increase in growth rate (Pavlovic and Young pers. obs.). Beyond this basic need to understand the interaction between fire and Oriental bittersweet resprouting, we need to investigate how fire may interact with light, soil moisture, litter and other environmental factors to either increase or decrease abundance of this species. Finally, it is unknown how fire regimes influence the distribution of Oriental bittersweet on the landscape; thus we need to model the distribution of Oriental bittersweet in a fire impacted landscape. If we determine through our research that fire enhances the spread of this species, modification of fire suppression tactics and potential fire exclusion zones may be necessary. Thus we will be able to provide land managers throughout the Eastern US with data-driven decision support tools for more successful management of this species in fire dependent and invaded areas.

## Background

Oriental bittersweet is an exotic woody vine, or liana, introduced from Asia as a horticultural plant into the northeastern United States in the 1860s. It is present in many habitats, including open dry foredunes, forest understories, oak savannas, “edge” habitats (Pavlovic and Young, pers. obs.), and eastern deciduous forests. This species continues to spread westward from the east coast of the US, and now can be found from Maine to Georgia and west to Minnesota, Iowa, Arkansas, and Missouri. Oriental bittersweet is of great concern to land managers because of its ability to completely blanket the vegetation that it uses as support for climbing, to overtop neighboring vegetation, girdle trees, weigh down tree limbs resulting in wind and ice damage, and to alter successional trajectories (Fike and Niering 1999). Vine diameters can reach as much as 18 cm after reaching canopy tree crowns (Leicht-Young et al. 2007). This species is particularly threatening because of its ability to invade high quality habitats and mature forests with low light levels at the ground layer (Leicht-Young et al. 2007, Leicht-Young and Pavlovic, pers. obs.). Land managers of public lands such as Indiana Dunes National Lakeshore (INDU) wish to control Oriental bittersweet before it dominates as it has in much of the northeastern and mid-Atlantic regions of the United States, and to slow its westward expansion (McNab and Loftis 2002). The unknown effect of fire on Oriental bittersweet adds another layer of complexity to an already challenging species to manage.

The spread of Oriental bittersweet even further west than its current distribution is likely because of its wide light and moisture tolerances, including an ability to grow in very dry conditions (Leicht-Young et al. 2007) and because of long-distance seed dispersal by birds. Finally, when one examines the native range of Oriental bittersweet in China, it has not yet reached the same latitudinal extent in the United States (Zheng et al. 2004).

There have been few published studies examining the effects of fire on invasive non-native plant species in the Eastern US (Richburg et al. 2004, Dibble et al. 2007, Glasgow and Matlack 2007). Most studies on fire in this region focus on the response of native species to fire (Elliott et al. 1999). Glasgow and Matlack (2007) made the observation that since many native species experience increased recruitment and growth in response to fire, there is no reason to believe that non-native invasive species would not respond in the same way.

Fire can promote recruitment of seedlings by removal of litter (Glasgow and Matlack 2007), enhancing nutrients and decreasing canopy cover (Elliott et al. 1999). Previous research has shown that fire increases germination of Japanese stiltgrass (*Microstegium vimineum*) and multiflora rose (*Rosa multiflora*) in Eastern forests (Glasgow and Matlack 2007). Oriental bittersweet seeds require cold stratification for germination, but little is known about fire temperature effects on these seeds. While Leicht-Young et al. (2007) demonstrated that Oriental bittersweet seedlings can survive and grow under a broad range of light levels, establishment from seeds across gradients in light and soil chemistry have not been examined. Whether fire creates groundlayer light and soil conditions that increase the susceptibility of habitats to bittersweet establishment is unknown as well. Therefore we propose to examine burning and post fire effects on the germination, establishment and growth of Oriental bittersweet.

Fire may also enhance the spread of Oriental bittersweet by causing plants to sprout from root crowns, root fragments, and runners (Howard 2005). While prescribed fire is limited to sandy regions of the Northeast and mid-Atlantic region, it is a prevalent management tool for habitat restoration in the Midwest, Great Lakes region, and Southeast. This presents a potential conflict between using fire as a community restoration tool and promoting the spread of Oriental bittersweet. Howard (2005) states “there is no literature suggesting that fire can be used as a management tool to control Oriental bittersweet... However, wildfire that removes much of Oriental bittersweet's aboveground biomass may provide opportunities for other control measures.” While sprouting in shrubs has been studied (Richburg et al. 2004, Gurvich et al. 2005), sprouting of vines such as Oriental bittersweet has been little documented except in tropical forests. Understanding how to manage vines in a more general sense is of increasing importance since researchers report that vines are increasing worldwide (Wright et al. 2004). Gerwing (Gerwing 2001) found that vines in the Amazon have significant effects on tree growth and that cutting was more effective in reducing vine impact than burning. Bebawi and Campbell (2002) determined that the season of fire had differing effects on mortality of the invasive rubber vine (*Cryptostegia grandiflora*) in Australia. Both studies showed that vines of different size classes experienced different levels of mortality when burned. Resource managers need critical information that quantifies resprouting ability of Oriental bittersweet at both the population and individual levels and determines which combinations of cutting and season of fire are most effective for its control.

Sprouting characteristics are ecologically and evolutionarily important trait that assist in understanding vegetation structure, function, and dynamics (Bond and Midgley 2001). After top killing, resprouting in plants occurs from the root crown, root caudex or roots. Research has shown that total nonstructural carbohydrates (TNC) in roots influences seasonal resprout growth rate and that burning when TNC reserves are low can increase mortality (Richburg et al. 2004, Gurvich et al. 2005). Thus, we will investigate the influence of fire on resprouting ability and on TNC by examining how these two factors may influence post-fire regeneration of Oriental bittersweet. We hypothesize that growing season burns (June) will have a greater negative effect on Oriental bittersweet than dormant season burns. Since soil productivity influences resprouting in woody plants (Iwasa and Kubo 1997), we will investigate how soil productivity influences Oriental bittersweet resprouting.

Landscape scale models have predicted Oriental bittersweet occurrence based on land use history and strength of association between correlated environmental and habitat variables. In the Appalachian Mountains, mesic forests tended to be invaded (McNab and Loftis 2002), whereas upland flats were more invaded in southern Illinois (Pande et al. 2007). Neither of these studies, however, examined how past and current fire regimes may influence Oriental bittersweet distribution on the landscape. Studies on other non-native invasive species have used fire regime as an explanatory variable. Floyd (2006) showed that depending on the habitat and soil characteristics, a location could be more prone to invasion after burning than if had not burned. We propose to model the relationship among fire regime, habitat and soil, and Oriental

bittersweet distribution. As a result of the lack of systematically collected data on Oriental bittersweet, our research will make a major contribution to the problem of invasive non-native plant species in the Eastern US.

## **Project Objectives**

We hypothesize that fire is an important facilitator of the spread and growth of Oriental bittersweet on the landscape. We will test this general hypothesis on Oriental bittersweet life history stages at scales up to the landscape level. More specifically, in our study we propose to:

1. Examine fire effects on the different life stages of Oriental bittersweet, and determine how fire modifies the susceptibility of habitats to invasion by Oriental bittersweet.
2. Quantify the rate of Oriental bittersweet resprouting caused by fire compared to cutting to determine whether fire response is equivalent and whether both in combination can reduce reserves.
3. Determine if growing season cutting or burning are more effective at controlling bittersweet when root reserves may be low compared to cutting or burning during the dormant season.
4. Model the presence and abundance of Oriental bittersweet in a fire mosaic landscape.

From this project we will be able to identify the positive and negative interactions of fire with bittersweet life history and how that may translate into its distribution on the landscape.

The information derived from our proposed research will determine:

1. If fire affects recruitment of Oriental bittersweet from seed
2. If fire affects the growth rate of Oriental bittersweet
3. If pre-fire cutting or fire seasonality can reduce the positive response of Oriental bittersweet to fire
4. If past and current fire histories influence the current distribution of Oriental bittersweet on the landscape

These studies are presented below with the following headings:

- I Temperature effects on seed viability
- II Fire and the susceptibility of invasion experiment
- III Fire effects on established plants of Oriental bittersweet
- IV Predicting bittersweet presence and abundance in a fire mosaic landscape

## **Study Site**

The Indiana Dunes National Lakeshore (INDU), a unit of the National Park Service (NPS), is a 6,000 hectare natural area at the southern tip of Lake Michigan, known for its high native biological diversity. INDU is a mosaic of upland and wetland vegetation from dunes along the shore to wetlands and glacial moraine forests. Soils range from sands of low productivity to rich morainal clay soils. The dominant oak savanna-woodland complex is largely fire dependent, but large portions have tracts that have experienced decades of fire suppression. This landscape is being invaded by Oriental bittersweet. Research burns commenced in 1986 and prescribed management burns have increased in frequency and coverage since 1992. Fire history is known for the 20<sup>th</sup> century derived from tree core analyses (Henderson and Long 1984). Historical fire maps for 25 years commencing in 1982 are available on GIS. While present in the landscape for at least 40 years (Pavlovic, pers. obs.), the highly invasive Oriental bittersweet is currently beyond the lag phase of invasion and is invading all units of the park. Therefore, the period of invasion matches the period for which detailed fire records are available permitting model development of fire effects history on Oriental bittersweet distribution.

## **I Temperature effects on seed viability I – Lab Experiment:**

### Methods:

We examined fire temperature effects on seed viability in the lab by exposing seeds and fruits to critical temperatures for specific durations. Fruit of oriental bittersweet were collected in late October 2008 from selected sites at Indiana Dunes. Arilate fruit and seed removed from fruits were exposed to ambient temperature prior to the experiment. For the moist heat experiment, 25 fruits and 25 seeds were exposed to three different volumes of boiling water (10, 50, and 100 mL) until it reached room temperature (Vivar-Evans et al. 2006). Water was brought to a boil and seeds or fruit were immediately immersed in the water without further heating. This resulted in the fruit and seeds experiencing different durations of exposure to heat. We used thermocouples to monitor the water temperature (Fig 1).

For the dry heat experiment, 25 fruits with seeds and 25 seeds were exposed to temperatures ranging from 60 °C to 140 °C in 20 °C intervals for periods of 1, 3, and 5 minutes. For both the moist heat and the dry heat experiment, there were four replicated sets of 25 fruits or seeds for each treatment, including a control that was not exposed to heat. Thus for the moist heat experiment we had 400 fruits or seeds (4 reps x 3 volumes + 1 control x 25 fruits or seeds), and for the dry heat experiment we had 1,600 fruits or seeds (4 reps x 5 temperatures x 3 durations x 25 fruits or seeds + 100 control). Seeds and one seed extracted from each fruit were tested for seed viability using the tetrazolium test (Peters and Lanham 2000) (Figure 2). Preliminary data were analyzed using simple linear regression and ANOVA followed by a Tukey's b post hoc test where appropriate for both the moist and dry heat experiments.



Figure 1. Fruits receiving the moist treatment 100 mL volume.



Figure 2. Tetrazolium treated seeds of oriental bittersweet. Total pink indicates the seed is viable, while non-pink indicates unviable seed.

For the moist heat experiment, we had nearly 100% mortality for the greatest volume and the highest duration for both the fruit and the seeds (Figure 3). There was a tight relationship between maximum temperature and duration for both the fruit and the seeds (Figures 3 A and B). When we looked at the relationship between the volume of water and percent viability, we saw that the higher volume of water resulted in lower viability. Using volume as a variable takes both temperature and duration into account because the higher the volume, the greater the maximum temperature sustained by the fruit and seeds as well as longer duration. Overall, volume had a significant effect on both the seeds from the fruit ( $F_{3,12} = 193.8, P = 0$ ) and the seeds alone ( $F_{3,12} = 70.5, P < 0.001$ ). The Tukey's b test indicated for both the fruit and the seeds, there was no significant difference between the control and the 20 mL volume. For the seeds in the fruit, there were significantly fewer viable seeds in the 50 and 100 mL volumes (Fig 4A). The same was true for the seeds alone, but with significantly fewer viable seeds in the 100 mL volume compared to the 50 mL volume (Fig 4B).

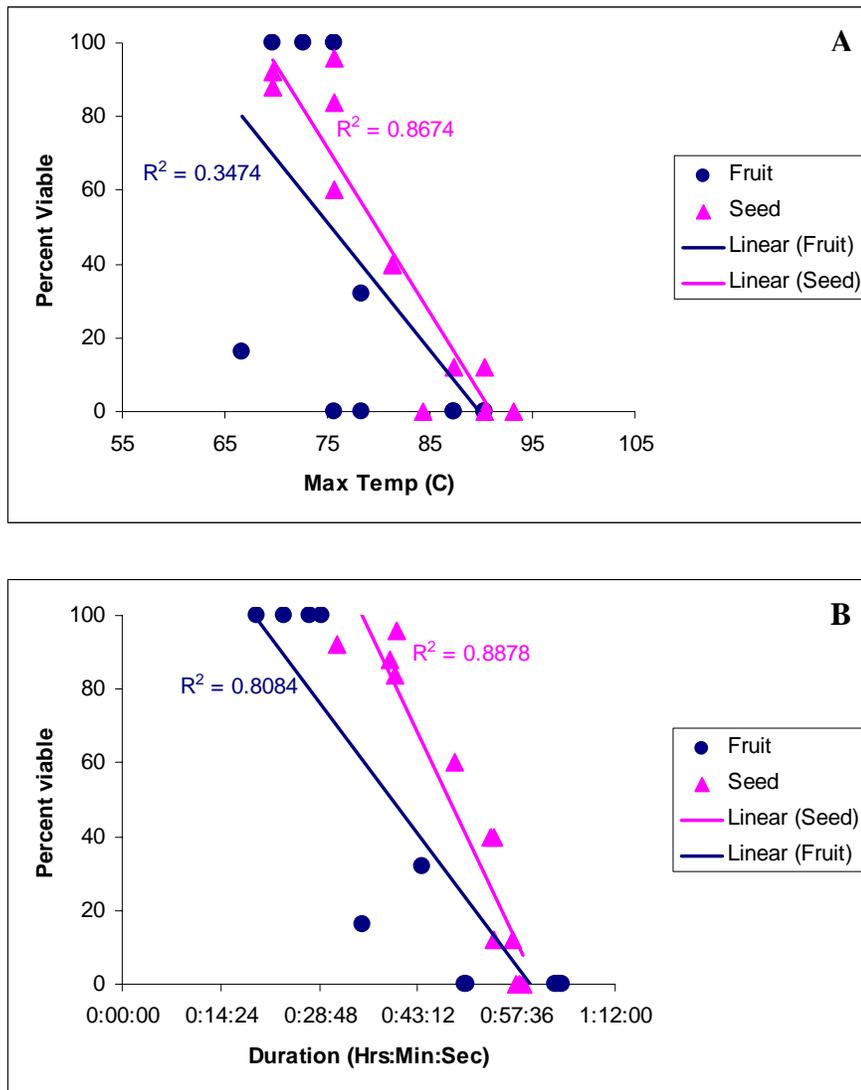


Figure 3. Regression of percent of viable fruit and seed vs. (A) maximum temp and (B) duration.

In the dry heat experiment, for the seeds contained in fruits, both temperature ( $F_{4,47} = 27.9, P = 0$ ), duration ( $F_{2,47} = 24.7, P < 0.001$ ) and the temperature x duration interaction were significant ( $F_{8,47} = 8.05, P = 0$ , Fig 5A). The same results held true for the seeds with temperature ( $F_{4,48} = 145.5, P = 0$ ), duration ( $F_{4,48} = 46.9, P < 0.001$ ) and temperature x duration ( $F_{8,48} = 11.7, P < 0.001$ , Fig 5B). As a result of the significant two-way interactions, we could not perform post hoc tests, although the graphs indicate both the importance of the temperature itself as well as how long the seeds were exposed to that temperature.

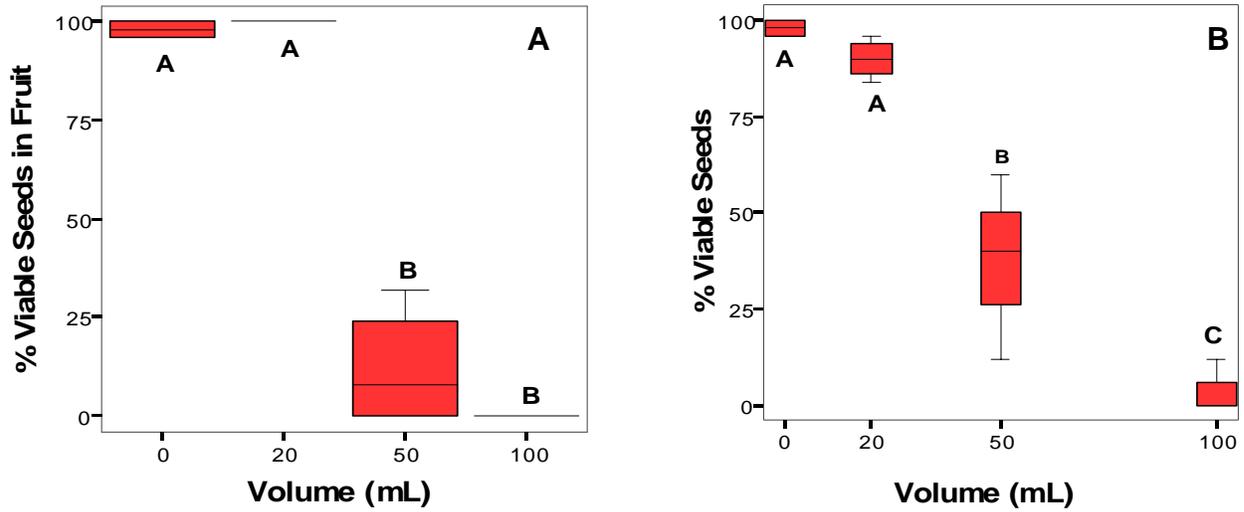


Figure 4. Percentage viable (A) seeds treated in fruit and (B) percent of isolated viable seed after being subjected to different volumes of boiling water. The 0 volume corresponds to the control treatments. Different letters indicate significant differences at the  $\alpha = 0.05$  level using Tukey's b test.

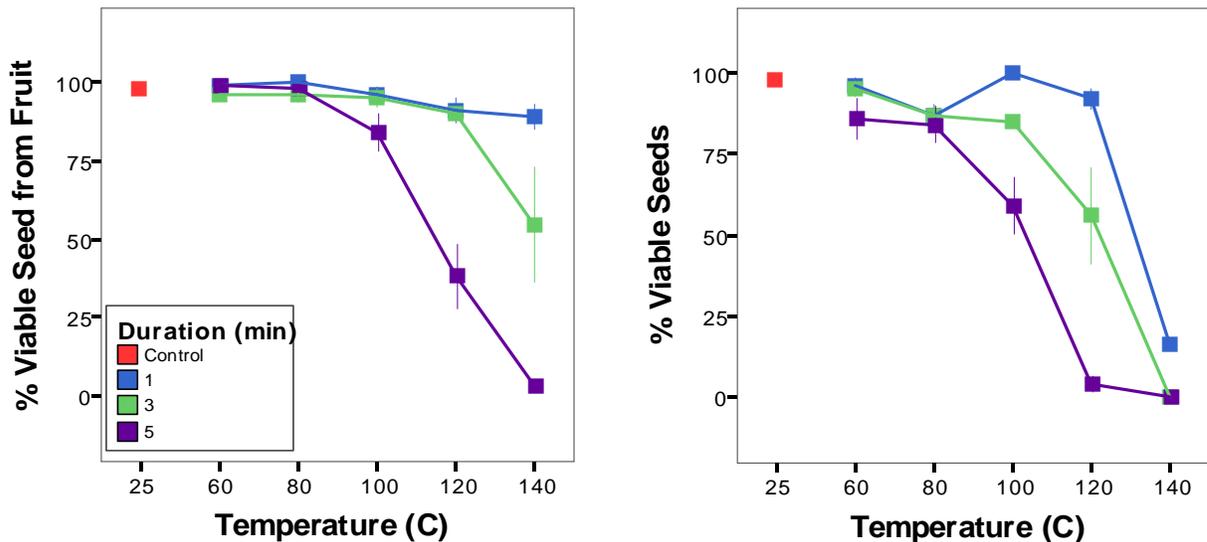


Figure 5. The percentage viable seeds extracted from (A) fruit and (B) seeds alone after being subjected to dry heat. Values are mean  $\pm$  SE. Blue lines are 1 min duration, green is 3 min and purple is 5 min. The red represents the control.

## **Temperature effects on seed viability II – Field Experiment:**

### **Methods:**

We took aluminum screen packets with 25 arillate fruits and 25 seeds and placed them on the litter, under the litter, and 6 inches above the ground on our temperature monitoring stakes. These were conducted in prairie and savanna habitats during prescribed burns to assess the impact of fire. Temperatures within each bag were assessed using aluminum tags with temperature sensitive paint. After the burn, we collected the bags and assessed seed viability. The weather conditions in 2009 and logistic constraints resulted in only one prescribed fire being conducted at INDU by the NPS. To supplement data from that burn, we used the burns from our susceptibility of invasion experiment to obtain data from a prairie site (Mnoke Prairie). We hope to conduct additional experiments over the next two years.

### **Results:**

The oak woodland and prairie fires were high intensity and all seed of Oriental bittersweet were charred and killed. The damage to seeds was extensive, so that tetrazolium tests were unnecessary (Figure 6). In the prairie burns, the average temperature was 399 °C above the litter and 357 °C below the litter. For the oak woodland prescribed burn, the average temperature above the litter was 472 °C and 379 °C under the litter.



Figure 6. Remains of seed packet after being subjected to fire. Note the upper aluminum tag is partially melted.

### **Summary of lab and field temperature experiments:**

The lab experiments showed that temperature and duration important in determining seed viability. The moist heat overall, had a higher kill rate for the seeds at the 100 mL volume than the dry heat did at 140 °C. This is most likely a result of heat transferring more effectively from the liquid water to the solid fruits and seeds than from the transfer of heat from the air in the dry heating experiment. Also the seeds cool down more rapidly after being removed from dry heat than from the moist heat because the heat is lost to the air more rapidly than the water. We were still surprised that any seed survived with the dry heat at the highest temperature of 140 °C. It is also somewhat evident that the seed contained in the fruit had some additional protection from

lethal temperatures. The overall viability level for the seed from the fruit was higher in the dry heat experiment.

The field experiment, however, indicated that seeds and fruit subjected to actual fires on the ground are most likely going to be destroyed by the intense heat. The temperatures the plants were subjected to in the field were on average almost 4 times higher than those in the lab. And the maximum temperatures in the field were much higher than those in the lab. We plan to conduct additional experiments in which we will place the fruit at different levels along a pole to simulate fruit in trees on the vines. We would expect that fruit at greater heights in the tree would be more protected from flame damage and could survive to propagate after a fire.

## II Fire and the susceptibility of invasion experiment:

### Methods:

To test the extent to which fire makes different habitats susceptible to invasion by Oriental bittersweet, we sowed seeds in sand or moraine prairie, oak savanna, oak hickory forest, beech maple forest, and sand forest in 12 randomized blocks in each community type (Table 1). A permit from INDU was obtained for this study with assurances that we would remove and kill the introduced plants at the termination of the study.

Blocks were selected in each area that lacked infestations of Oriental bittersweet. Most blocks were more than 50 m from each other when they occurred in the same habitat type and patch. Each block was 6 X 6 m with four 2 X 2 m nested treatment plots separated by 2 m buffer zones. Randomized treatments consisted of low intensity burn, high intensity burn, litter removal, and intact litter (6 habitats \* 12 blocks \* 4 plots = 288, Figure 7).

Extreme winter weather and snow cover prevented us from establishing the plots until April 2009. The first snowfall arrived November 18, 2008 and the ground was frozen until late March. With the rapid onset of the fire season and the closure of burning on April 15 at the Heron Rookery and Mnoke Prairie we were unable to burn the oak hickory and beech maple plots in spring of 2009. The Heron Rookery and Mnoke Prairie were closed by the U.S. Fish and Wildlife Service to prevent fire impacts on the endangered Indiana Bat (*Myotis sodalis*). We will conduct the burns in the oak hickory, beech maple, and oak forest in the fall of 2009, when leaf litter is dry, undecomposed, and flammable. Seeds will be sown in the spring of 2010 as similarly as in 2009 and monitored monthly.

	Sand Prairie	Moraine Prairie	Sand Oak Savanna	Moraine Oak Hickory	Moraine Beech Maple Forest	Sand Forest
Howes Prairie	6		4			
Mnoke Prairie		12		12		
Inland Marsh	6		4			
Miller Woods			4			
Headquarters Woods & Bailly					6	
Heron Rookery					6	
West Beach Burn Unit						6
Cowles Burn Unit						6

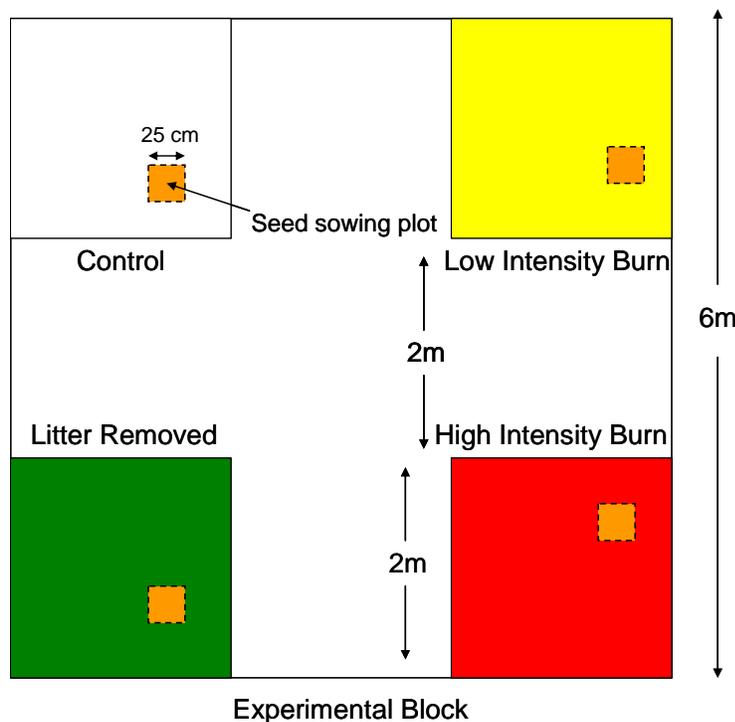


Figure 7. Layout of susceptibility of invasion experimental block.

In late March and early April, the susceptibility plot blocks were established in Miller Woods, Inland Marsh, Howes Prairie and Mnoke Prairie areas. Fuel from the litter removal plot was placed on the high intensity plot to increase its fuel load. On the day of the low-intensity and high-intensity burns, a 0.25 by 0.25 m litter sample was taken to assess fuel loads and moisture content. Ten centimeter deep soil samples were taken from the low and high intensity burn plots prior to the burning as well, to assess soil composition prior to the burns. The two meter buffers were weed whipped and raked prior to the burns as well. Burns at Miller Woods were conducted on April 8, Inland Marsh April 8, and 9, Howes Prairie in April 9 and 23, and Mnoke Prairie on April 17. On the day of the burn, litter was sampled from the low and high litter treatment plots in a 0.25 by 0.25 m frame. Litter was removed from the random sampling location, placed in a preweighed plastic bag, reweighed. Transferred to a preweighed paper bag, for drying at 70 °C for 12 hours. Dry weight was measured and these data were used to calculate litter biomass and percentage litter moisture. In each, plot temperature sensitive paint tags were deployed on a stake at 0, 0.5, 1, 1.5, 2.5, 3.5, 4.5 feet above the ground (Cole et al. 1992). Temperature paints were 250 °F (121 °C), 300 (149 °C), 400 (204 °C), 500 (260 °C), 600 (316 °C), 700 (371 °C), 800 (427 °C), 900 (482 °C), 1000 (538 °C), 1200 (649°C). During the burns rate of fire spread, flame height (minimum, maximum, and average), and wind speed and direction were recorded (Figure 8- 10).

We planted 25 seeds in each of the four subplots on April 28, 2009 within a randomly placed 25 cm x 25 cm plot. Within these plots we created a 5 x 5 grid with cells of 1 cm each to place each seed for easier relocation. Germinants were monitored on May 28, June 23 and 24,

July 24 and 27, August 19 and 20 and the end of September (Figure 8). Number of live seedlings and height of plant from the ground to the apical meristem were measured. Preliminary analyses were conducted using the maximum percent germination across the three months in which there were germinants. The fire treatment effect on percent germination was conducted using an ANOVA followed by a post-hoc Tukey's b test. A t-test was used to compare the impacts of habitat and soil alone on percent germination.



Figure 8. Grid for monitoring germination of oriental bittersweet seedlings. Seedling is circled.

During the course of the growing season, we collected additional environmental data on each of the four subplots. We took canopy photographs, photosynthetically active radiation (PAR) readings and soil moisture readings at the Miller Woods, Inland Marsh, Howes Prairie and Mnoke Prairie locations. These variables will be used in our final analysis of the susceptibility of different habitats to invasion by oriental bittersweet.

### **Results:**

The savanna and sand prairie plots had greater litter biomass than the moraine prairie ( $F_{2,66} = 7.3$ ,  $P < 0.001$ : 46 versus 71 grams). The savanna and sand prairie litter also had three times more moisture on the day of the burn than the prairie litter ( $F_{2,66} = 25.5$ ,  $P < 0.001$ : 7% versus 21%). Fire temperatures averaged 719 °F (382 °C) in the low litter treatment and 806°F (430 °C) in the high litter treatment ( $F_{1,66} = 6.3$ ,  $P=0.015$ ), but did not differ among communities ( $F_{2,66} = 2.4$ ,  $P = 0.095$ ). The increase in minimum and mean flame height from low to high litter treatments was statistically significant, but was greatest for the moraine prairie. Maximum flame heights were lowest in the savanna, highest in the moraine prairie, and intermediate in the sand prairie (Table 2). Spread of fires were significantly faster in prairie (moraine and sand) than in the savanna ( $F_{2,66} = 9.2$ ,  $P < 0.001$ ), representing different fire behavior in graminoid fuels versus oak leaf litter. Average rate of spread of prairie fires was 0.012 m s<sup>-1</sup> and 0.007 m s<sup>-1</sup> in the savanna.

We determined that oriental bittersweet germination occurred in all of the habitat types at low percentages (Table 3), although there were a few subplots that reached close to 50% germination in the moraine prairie. The percentage of total germination increased with time in all habitat types.

**Table 2. Means of minimum, average, and maximum flame heights in inches in susceptibility plots by habitat and fuel loads. Within each flame height category, means lacking common superscript letters are statistically significantly different at the  $\alpha = 0.05$  level.**

Flame Height (in):	Fuel load	Habitat		
		Savanna	Sand Prairie	Moraine Prairie
Maximum	---	15 ± 2 <sup>A</sup>	28 ± 5 <sup>B</sup>	43 ± 3 <sup>C</sup>
Mean	Low	7 ± 1 <sup>A</sup>	13 ± 2 <sup>B</sup>	20 ± 3 <sup>C</sup>
	High	15 ± 2 <sup>B</sup>	23 ± 4 <sup>C</sup>	42 ± 3 <sup>D</sup>
Minimum	Low	7 ± 1 <sup>A</sup>	9 ± 2 <sup>AB</sup>	15 ± 3 <sup>C</sup>
	High	10 ± 2 <sup>BC</sup>	14 ± 2 <sup>C</sup>	36 ± 3 <sup>D</sup>

**Table 3. Mean ± SE and the maximum percent germination of *C. orbiculatus* seeds as of August 2009.**

	Mean ± SE			Maximum		
	Prairie		Savanna	Prairie		Savanna
	Moraine	Sand	Sand	Moraine	Sand	Sand
June %						
Germination	5.7 ± 1.1	2.8 ± 1.1	1.6 ± 0.5	28	36	16
July %						
Germination	11.3 ± 1.5	2.9 ± 1.2	2.7 ± 0.7	44	36	20
August %						
Germination	13.9 ± 1.7	3.5 ± 1.4	2.2 ± 0.6	48	40	16

When we examined just the effect of habitat and soil type on maximum percent germination, we found that there was no significant difference between the sand prairie (3.8 ± 1.4) and sand savanna (4.3 ± 0.8), while the moraine prairie had the highest maximum percent germination (14.6 ± 1.7,  $t = 3.3$ ,  $P = 0.001$ ). When we looked at fire treatment and habitat type, we found that there was a significant difference in germination for habitat type ( $F = 5.5$ ,  $P = 0.021$ ) and a marginally significant difference due to treatment ( $F = 2.122$ ,  $P = 0.1$ ). However, the post-hoc test indicated that the control treatment had the greatest percent germination, was not significantly different from the low and high intensity burns, but was significantly different from the litter removal plot (Table 4).

**Table 4. Mean ± SE maximum percent germination for the four treatments.**

	Control	High Intensity	Low Intensity	Litter Removed
Maximum % Germination	11.9 ± 2.3 <sup>a</sup>	7.3 ± 1.6 <sup>ab</sup>	6.3 ± 1.4 <sup>ab</sup>	4.6 ± 1.3 <sup>b</sup>

**Summary of fire and the susceptibility of invasion experiment:**

By manipulating the amount of litter in the plots, we were able to successfully create a high fire intensity treatment that was significantly different than the low intensity treatment. We also saw differing fire behaviors in the prairie vs. savanna habitats. In terms of germination, we saw an increase in the number of germinating seeds from June to August. In our examination of the maximum percent germination, we found that sand prairies and sand savannas were similar in their germination percentages while the moraine prairie had much higher germination rates. This is most likely due to the richer soils and higher moistures of these moraine prairies vs. those habitats located on sand. It will be interesting to compare these values to our forested habitats results this coming season. We also determined that it is possible that fire may not necessarily make prairie and savanna habitats more susceptible to invasion from seed of oriental bittersweet. We found that the control plots had the highest maximum percentage of germination suggesting that the litter provided some shelter from drying out and excessive insolation in the early stages of germination. The two burned plots had intermediate percent germination compared to the control and litter removal plots, probably because fire did not remove all the litter whereas raking did. In the next growing season, we will be able to determine if growth rates and overall survival differ between burn treatments and habitats.



Figure 9. NPS fire crew black lining moraine prairie susceptibility plots in March 25, 2009 to protect unburned plots from prescribed fire.



Figure 10. Noel Pavlovic sampling litter prior to burning of sand prairie plots.



Figure 11. Burning high (foreground) and low fuel (background) susceptibility plots.

### III Fire effects on established plants of Oriental bittersweet:

**Methods:** Eight experimental blocks, split between sand and moraine soils, were located in major infestations of Oriental bittersweet to test effects of combinations of cut and burn treatments on vine resprouting in the spring of 2009. Our original intent was to balance these blocks between sand versus moraine soils and burned and unburned sites; however we were unable to find a second burned moraine sites (Table 5). We tried to maintain a 5 meter buffer between treatment plots, but in some cases this was not possible given the spatial arrangement between the bittersweet patches. Treatments were allocated randomly among blocks: control, dormant season burned, growing season burned, dormant season cut, growing season cut, dormant season cut + burned, and growing season cut + burned (Figure 4). At five of the block sites we added two additional treatments at the request of the NPS: cut and herbicide, and burn and herbicide. The burn plus herbicide treatments will be conducted in the spring of 2010. We will compare these to the responses of the controls in our main design. Each treatment plot is 10 X 10 m. and has a meter-wide buffer around the periphery. We placed four random 1 X 1 m subplots with in each quadrant of the plot where the population response will be quantified (Figure 3). We presampled the subplots for abundance of Oriental bittersweet in July of 2009.

**Table 5. Sites by substrate type and fire history for conducting fire effects experiments at Indiana Dunes National Lakeshore.**

Substrate type	Fire history	
	Previously burned	Previously Unburned
Sand	Kintzel Dunes - 9	Kemil Rd. (Furnessville) - 9
	Marquette Trail - 9	Mineral Springs Rd - 7
Moraine	Mnoke Prairie - 7	Bailly Picnic Area - 7
		Learning Center - 9
		Chellburg Farm - 9

**a) Population response** – In each subplot, we measured Oriental bittersweet stem density and cover, litter cover, PAR, and soil moisture. In each experimental plot, canopy cover was quantified from a hemispherical photograph taken at the plot center in August and September of 2009.

**b) Individual response** – We measured the basal diameter of four individual Oriental bittersweet shoots from each plot with one located randomly in each subplot. The individuals were marked with a wire flag and tagged with a copper tag so they can be relocated for remeasurement. In 2010 we will conduct our treatments and we will measure the survival, basal diameter, and number of resprouts and their lengths. After burning, we will assess fire intensity on these stems based on the following burn classification: unburned, light intensity - < 50% circumference burned, moderate intensity - > 50% circumference burned, and heavily burned – bark consumed with wood partially exposed. For each stem its position (coppice, root sucker or aerial shoot) and number of resprouts will be quantified. Leader (i.e., new growth) growth rates will be measured post-treatment and twice during the growing season, in May and in September. Growth will be expressed as increment length divided by days between samplings.

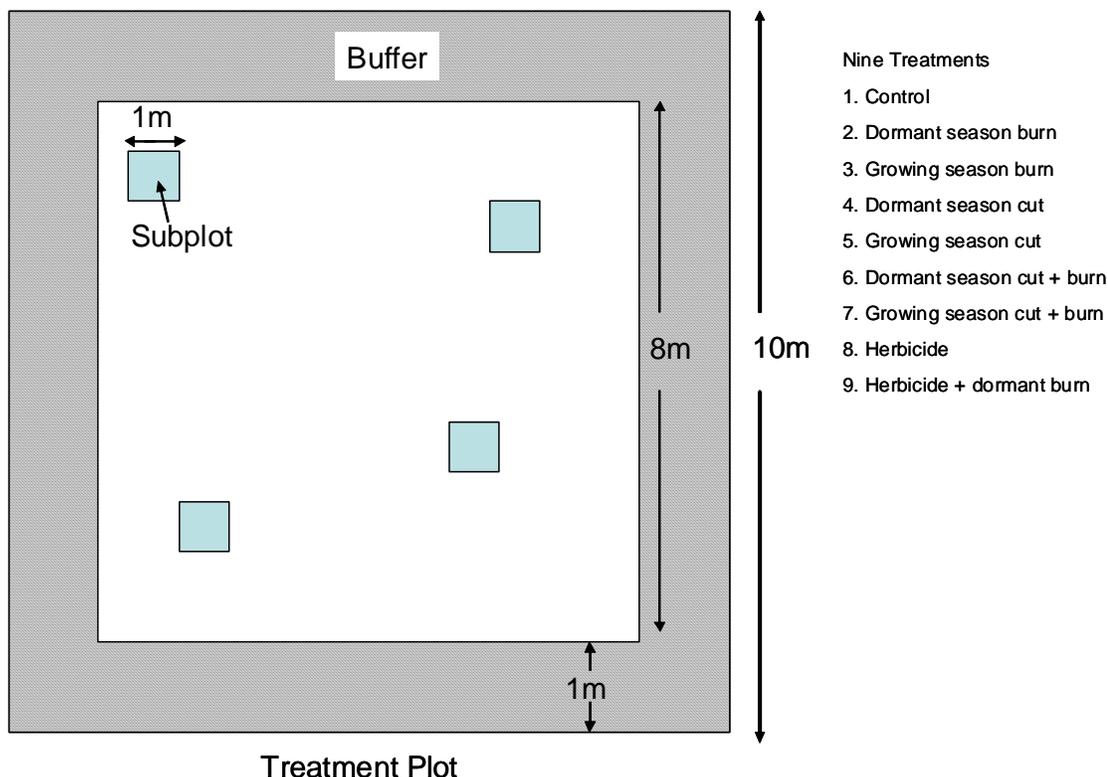


Figure 3. Example of plot layout with sampling subplots. Not indicated are the randomly located individuals within each quadrant.

We discovered that previously burned plots lacked larger individuals representing the larger of the six size categories: seedlings, > 0.25 m self supporting, and < 5 mm, 5-10 mm, 10-15 mm, > 15 mm climbing (modified from Gerwing 2001). To better capture their survival and resprouting, we will tag and measure individuals in the control, spring burn, spring cut, and burn and cut in spring plots in October 2009 at five of the sites (Bailly, Chellburg, Furnessville, Learning Center, and Mineral Springs). We will measure the basal diameters of the stems and diameter at 1.3 m along the stem if long enough. After burning, we will assess fire intensity on these stems based on the following burn classification: unburned, light intensity - < 50% circumference burned, moderate intensity - > 50% circumference burned, and heavily burned - bark consumed with wood partially exposed. For each stem its position (coppice, root sucker or aerial shoot) and number of resprouts will be quantified. Leader (i.e., new growth) growth rates will be measured pre- and post-treatment and twice during the growing season, in May and in September. Growth will be expressed as increment length divided by days between samplings.

**c) Total nonstructural carbohydrate study** – In each treatment plot we will harvest six separate root samples (approximately 1 by 10 cm) every four weeks from May to September (5 blocks by 2 soil types by 6 replicates = 60 samples per treatment) to quantify carbohydrate reserves starting between the dormant and growing seasons (early May) of 2010 and 2011. Root samples will be collected as widely spaced as possible to ensure they are from separate individuals. Once soil has been removed, the roots will be dried to constant weight at 70° C, ground in a coffee grinder to pass through a 40 mesh screen and dried for an hour at 70° C. Total nonstructural carbohydrates (TNC) will be extracted from three subsamples of 10 mg of ground material. We will use the methods described in Kobe (1997) and Cruz and Moreno (2001) that allow us to characterize the

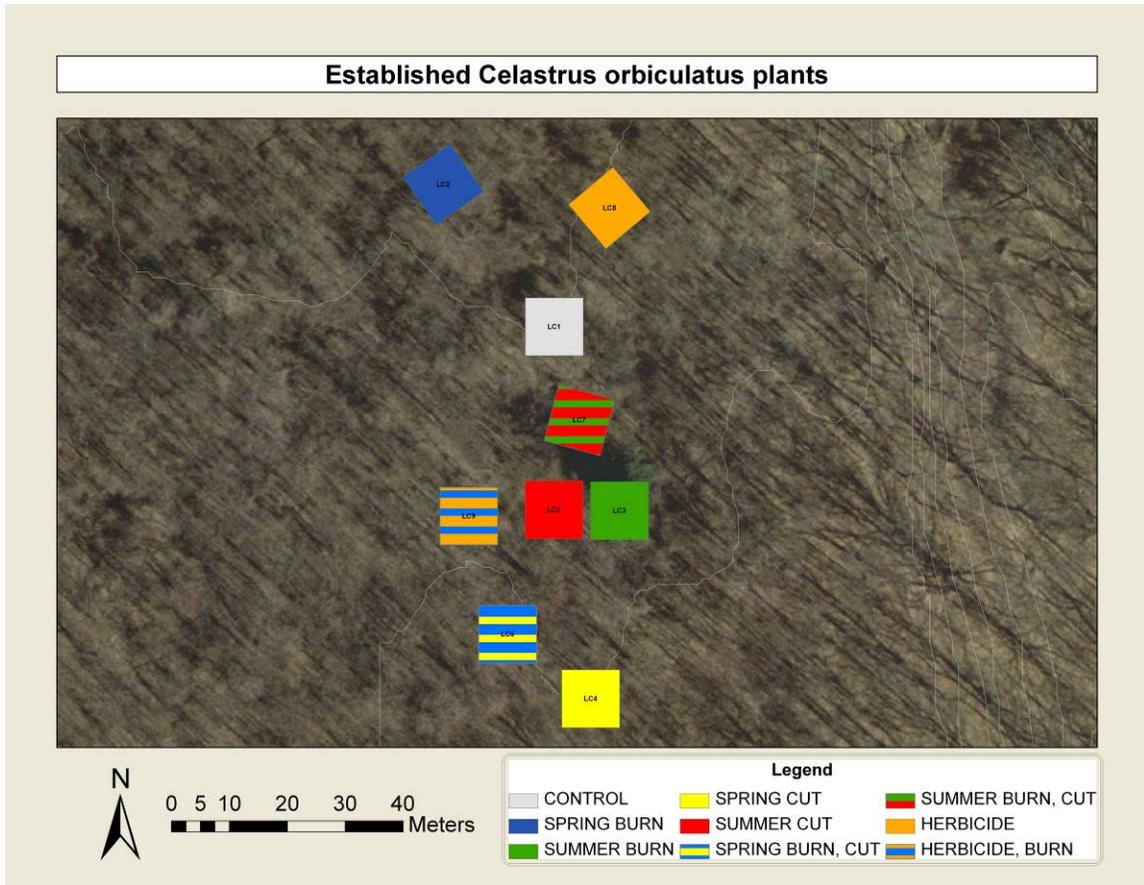


Figure 5. Layout of experiment treatment plots at the Chellburg Farm block.

different TNC fractions: monosaccharides, disaccharides, and starch. We have recently successfully tested the protocol.

**Results:**

The block sites varied considerably in quality. On the moraine, Bailly, Chellburg Farm, and Indiana Dunes Learning Center had low native species cover and had low quality groundlayer plant richness. The sites are adjacent to former farm lands, were disturbed, and have undergone succession. Mnoke Prairie was also forested, but unlike the others has been prescribed burned. Nevertheless, the groundlayer flora at this site is also depauperate.

The Mineral Springs and Furnessville sandy sites were similarly disturbed in the past and have undergone considerable succession and have low diversity of herbs. Marquette Trail and Kintzele Ditch sites both have been recently invaded by Oriental bittersweet, have dense infestation patches, but also have good representation of oak savanna/woodland flora.

Preliminary analysis shows that sandy sites have higher cover of Oriental bittersweet than do moraine sites, 54% compared to 30% ( $F_{1,64} = 20.8, P < 0.001$ ); however, the substrate types do not differ in density; respectively 14 and 16 stems  $m^{-2}$  ( $F_{1,64} = 0.36, P = 0.55$ ).

## IV Predicting bittersweet presence and abundance in a fire mosaic landscape:

### Methods:

We have acquired the most recent fire maps from the NPS and Indiana Dunes State Park, thus we have a complete fire history from 1982 to September 2009. We have not yet selected the 400 points to be sampled, but these will be selected using either ArcMap or a sampling protocol that is employed in the distance sampling program (DISTANCE <http://www.ruwpa.st-and.ac.uk/distance/>). We will employ these maps to identify patches of landscape that have experienced differing fire regimes. Fire patches will be characterized by time since last fire and fire frequency. Chi-squared analysis of years since last fire and fire frequency will be used to categorize this fire regime state space and determine sample sizes per regime combinations. Once classified, these will be randomly sampled from the GIS layer. We will upload waypoints into the GPS, and then sample at these points to generate data for creation and validation of the landscape models of bittersweet presence and abundance as a function of fire history. A total of 400 plots (10 m radius) will be sampled with 300 used model development and 100 for model validation.

We have developed the following criteria for the sample selections:

- a) There will be equal representation among fire histories to benefit subsequent data analysis.
- b) We will also sample near and far from roads to understand the interaction between fire and disturbance along roads on the invasion of Oriental bittersweet.

We have developed a data dictionary modified from the protocol used in the Invasive Plant Atlas of the NorthEast (IPANE) (Table 6).

**Table 6. Data fields for landscape scale sampling**

Variable	Options
Plot number	
Canopy closure with densiometer	
Slope (degrees)	
Aspect (compass)	
Soil type	Sand, loam, muck, clay,
Habitat	Edge (upland/wetland, Field/forest, Lake edge, roadside: Forests (oak/pine. Oak woodland, oak savanna, Floodplain forest, Mixed hardwoods, Oak/hickory, Dune forest, Mesophytic forest): Miscellaneous (Foredune, Secondary dune, Open field, Old field, Stream bank, Abandoned lot/homesite)
<i>Celastrus</i> abundance	Single plant, <20, 20-99, 100-999, >1000
<i>Celastrus</i> distribution	Single plant, Evenly sparse, Single patch, Multiple patches, Dense throughout
<i>Celastrus</i> diameter at 130 cm above the ground	Five largest stems.
<i>Celastrus</i> cover (%)	<1%, 1-5%, 6-25%, 26-50%, 51-75%, 76-100%
Abundance, distribution and cover of the woody exotic species present within the plot	Species include: <i>Acer platanoides</i> , <i>Ailanthus altissima</i> , <i>Berberis thunbergii</i> , <i>Celastrus scandens</i> , <i>Elaeagnus umbellata</i> , <i>Euonymus</i>

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*alatus, Lonicera tatarica, Lonicera tatarica*  
*hybrids, Lonicera japonica, Lonicera maackii,*  
*Robinia pseudoacacia, Rosa multiflora, Ulmus*  
*pumila and Viburnum opulus*

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### **Results:**

We will commence sampling of the plots in late June of 2010 and will sample more than 200 plots that year and complete the sampling in 2011.

### **Summary:**

We have demonstrated in the lab that seed of Oriental bittersweet are sensitive to wet and dry heat whether or not they are in fruit. Viability is sensitive to temperature and duration and begins to decline at 100 °C with exposures from 1 to 5 minutes. In two prescribed burns the seed were killed and scorched which is good news for land managers, although we have yet to experiment in mesophytic habitats where fire temperatures may be lower. Preliminary results from the susceptibility of invasion suggest that a small percentage of seeds germinate and establish in the spectrum of habitats studied. There is a hint that there is greater germination on richer soils. Fire appears to create germination conditions less favorable than controls but better than litter removed plots. We will have more to say about the growth and survival conditions of the plants in the future. We have initiated the established plants experiment and fire effects in the landscape study, but results will wait until next year.

## **Project Duration, Timeline, and Progress**

This project started on September, 2008 and will be completion in December of 2011. The progress per the proposal is indicated below and in Table 7 by the red text.

### *Post-Award/Prefunding Period (September 2008)*

- Temperature effects on seed viability: we will collect seed and fruits of Oriental bittersweet for this and the susceptibility experiment. **Completed**
- Susceptibility Experiment: layout of plots in park. **Completed**
- Resprout Experiment: setup 8 blocks. **Completed**

### *First Funding Year (2009)*

- Temperature effects on seed viability: conduct lab experiment during winter. **Completed**
- Susceptibility Experiment: conduct burns, rake litter, sow seeds and fruit in late winter (March/April), and assess emergence and response during the growing season. **Beech-maple, oak-hickory, and sand forest plots to be burned fall 2009 and seeds sown in the spring.**
- Resprout Experiment: presample population, individual, and environmental variables. **Completed**
- Fire Regime Study: identify paired sites in proposed prescribed burns for late fall and late winter burn seasons. **In progress**
- Progress Summary due in September. **Completed**

### *Second Funding Year (2010)*

- Susceptibility Experiment: follow second year growth rates and disassemble experiment, commence analysis and paper writing.
- Resprout Experiment: apply burn and cut treatments and sample population, individual, and environmental variables.

- Predicting Bittersweet Abundance/Growth in fire mosaic: Analyze fire mosaic, locate random sampling points, and commence sampling. **In progress.**
- Progress Summary due in September.

*Third Funding Year (2011)*

- Resprout Experiment: sample population, individual, and environmental variables.
- Resprout Experiment: apply burn treatments and sample population, individual, and environmental variables.
- Predicting Bittersweet Abundance/Growth in fire mosaic: Complete sampling and develop models.
- Final report due December 31, 2011.

Table 7. Deliverable, Description and Delivery Dates

<b>Deliverable Type (See Format Overview, Section VIII)</b>	<b>Description</b>	<b>Delivery Dates</b>
Refereed Publication	Paper titled: Roles of fire intensity, disturbance, habitat, and environmental variables in the susceptibility of Oriental bittersweet establishment	July 2010
Refereed Publication	Paper titled: Experimental and prescribed fires: their effect on the growth and spread of Oriental bittersweet	Dec 2011
Refereed Publication	Paper titled “Burning questions in managing Oriental bittersweet”	
Field Demonstration/Tour	Public display at Bailly experimental plots. Tours will be given to the public twice per year with the National Park Service.	Starting 2009 <b>In progress</b>
Workshop	Midwest Manager workshop to be held at the Indiana Dunes Environmental Learning Center	2011
Conference Symposia	Symposium on Fire and Exotic Plant Management in the Eastern US at Ecological Society of America/Natural Areas Conference	August/October 2010 <b>Postponed to 2011 when we have results to discuss.</b>
JFSP Annual Conference	Presentation on project progress	2009, 2010, 2011
Non-refereed publication	USGS Fact Sheet Concerning Fire and Oriental Bittersweet: paper and web based.	2011
Non-refereed publication	Progress Summaries	Sept. 30, 2009-2010
Non-refereed publication	Final Report and educational multimedia DVD	Dec. 31, 2011

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