

# Reproductive Failure in Largeleaf Wild Indigo in a Restored Prairie in Southeastern Minnesota

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**ABSTRACT** Native prairie restorations in many regions of the United States have been hindered by various herbivores consuming plant reproductive parts or products. I conducted field studies of a population of largeleaf wild indigo (*Baptisia lactea*) on a restored prairie in southeastern Minnesota during the growing seasons of 2010–2012 to determine the cause(s) of repeated reproductive failure. I assessed plants for browsing damage caused by white-tailed deer (*Odocoileus virginianus*) during the period of flowering and with a deer exclosure experiment involving caged and non-caged plants. I compared reproductive output (numbers of seed pods, viable seeds) of caged plants to non-caged plants at the end of the growing season. I conducted surveys for Say's blister beetles (*Lytta sayi*) during plant flowering in June, and for indigo weevils (*Apion rostrum*) in seed pods at the end of the wild indigo growing season. Deer browsing damaged 46% of wild indigo plants, destroying 14% of the flowers of the indigo population during June. Neither the numbers of seed pods nor viable seeds differed significantly between caged and non-caged plants in October. Blister beetles were present and consumed wild indigo flowers only during June 2011, but numbers exceeded 25 beetles/wild indigo plant. High weevil abundances ( $\bar{x} = 3.1$  weevils/seed pod,  $SD = 2.3$ ) in 2010 ( $n = 88$ ) and 2011 ( $n = 27$ ) resulted in heavy seed predation and high seed pod abortion. Overall seed production averaged  $<2$  viable seeds/plant during 2010 and 2011, with more than 80% of plants not producing a single viable seed. Taken together, browsing by deer, herbivory by blister beetles and weevils, and pollination failure reduced potential reproductive output of the Kramer Ridge wild indigo population by  $>99\%$  during the study period.

**KEY WORDS** *Apion rostrum*, *Baptisia lactea*, deer browsing, indigo weevils, largeleaf wild indigo, *Lytta sayi*, *Odocoileus virginianus*, pod abortion, Say's blister beetles, seed production

After losing the majority of pre-settlement tallgrass prairies from the North American landscape during the past century (Samson and Knopf 1994, Steinauer and Collins 1996, Robertson et al. 1997), prairie restoration efforts have expanded dramatically in recent decades (Skold 1989, Mlot 1990, Samson and Knopf 1994, Dobson et al. 1997, Borsari and Onwueme 2008). Techniques for prairie establishment and management have been tested and refined for a wide variety of conditions and habitats (Schramm 1992). Restorations have been undertaken to be “complete,” establishing species in abundances and composition similar to native communities, or “functional,” preventing soil erosion and improving soil nutrient levels and water quality, but lacking species diversity (Camill et al. 2004). Ongoing restoration efforts by government and private organizations continue to slowly expand the footprint of tallgrass prairies in the midwestern United States and increase our knowledge and understanding of the important functions of this unique ecosystem (Dobson et al. 1997, Tilman et al. 1997, Lal et al. 1999, Knops and Tilman 2000, Camill et al. 2004).

Legumes (Leguminosae) play an integral role in the nutrient dynamics of prairie ecosystems, fixing nitrogen in symbiosis with soil bacteria and metering fixed nitrogen to associated non-nitrogen fixing plants (Piper and Gernes 1989, Graham et al. 2008). When legumes are absent or suppressed, growth of other prairie plants is reduced, maintenance of diversity is challenged, and overall prairie develop-

ment is delayed (Graham et al. 2008). In prairie restorations, inclusion of a variety of legumes and appropriate bacterial inocula is critical to successful prairie development (Graham et al. 2008).

Both large and small herbivores can limit success of legumes in restored prairies. For example, white-tailed deer (*Odocoileus virginianus*) are common herbivores in tallgrass prairies in the Midwestern United States (Englund and Meyer 1986, Ritchie and Tilman 1995, Anderson et al. 2001, 2005, 2006). Deer densities in this region can be high ( $>30$  deer/km<sup>2</sup>; Anderson et al. 2005), and their browsing can have significant effects on the growth, diversity, and abundances of tallgrass prairie forbs (Englund and Meyer 1986, Ritchie and Tilman 1995, Anderson et al. 2005, 2006, 2007). In particular, restored prairies exposed to heavy deer browsing suffer from reduced plant community quality (Anderson et al. 2007) and suppressed growth and reproduction (Ritchie and Tilman 1995). Browsing by deer appears to be especially harsh for legumes (Englund and Meyer 1986, Ritchie and Tilman 1995, Anderson et al. 2001), even though several species have chemical defenses to discourage herbivores (Crammer and Turner 1967). In an Illinois restored prairie, deer browsed on nearly half of the wild indigo (*Baptisia*), reducing total reproductive units (flowers, seed pods) on browsed plants by  $>60\%$  (Anderson et al. 2001).

Small insect herbivores also can have a significant effect on legume reproductive success. Numerous studies

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have reported significant reductions in reproductive output of legumes in native tallgrass prairies, restored prairies, and commercial seed production fields. Reproductive losses have resulted from consumption of flowers by various blister beetles (Coleoptera: Meloidae) and seed pod abortion and/or seed consumption by various weevils (Coleoptera: Curculionidae) and moths (Lepidoptera: Olethreutidae; e.g., Evans et al. 1989, Petersen 1989, 1990, Evans 1990, Mundahl and Plucinski 2010). Losses of *Baptisia* reproductive tissues exceeding 80% are common (e.g., Haddock and Chaplin 1982, Evans et al. 1989, Horn and Hanula 2004).

Repeated attempts to gather seed from largeleaf wild indigo (*Baptisia lactea* var. *lactea* (Raf.) Thieret, synonymous with *B. alba* var. *macrophylla* (Larisey) Isely and *B. leucantha* Torr. and A. Gray) on a small, restored prairie in southeastern Minnesota to plant on other restored prairie sites failed due to lack of seed production (J. Cole, Minnesota Department of Natural Resources [MNDNR], personal communication). Field observations suggested that a combination of browsing by white-tailed deer, flower destruction by blister beetles, and seed and seed pod losses to weevils caused these reproductive failures. My objective in this study was to examine the potential effects of herbivores on reproductive output of largeleaf wild indigo in this restored prairie. I used a white-tailed deer exclosure experiment and field observations of plant reproductive efforts and insect abundances during three growing seasons to assess the roles of these herbivores in causing poor seed production in *Baptisia*.

## METHODS

### Study Site

Kramer Ridge (44° 06' 08" N, 91° 58' 13" W) is a portion of the Whitewater Wildlife Management Area (WWMA, managed by the MNDNR) in Winona County in southeastern Minnesota. Native prairie vegetation has been restored on various sites within the ridge, with mixed grasses and forbs and cool season grasses planted on 37.4 ha within 13 plots scattered across five township sections. I conducted this study on one, 3-ha plot on the extreme eastern edge of the WWMA. The MNDNR estimated a pre-fawn white-tailed deer density of 7 deer/km<sup>2</sup> for this area in 2010 (MNDNR 2010), and I observed deer at the site during each visit.

The study plot was restored to native forbs and grasses in June 1996. Prior to restoration, the site was in agricultural production on a 5-yr rotation of corn-corn-oats-hay-hay for approximately four decades. After restoration, the site was managed with controlled burns in April 1999 and May 2005. In October 2008, the plot was leased to a neighboring farmer who mowed and pelletized the dry biomass to use as fuel to heat a commercial greenhouse operation.

The restored prairie had a diversity of forbs and grasses. Common species included big bluestem (*Andropogon*

*gerardii*), compass plant (*Silphium laciniatum*), goldenrods (*Solidago* spp.), gray-headed coneflower (*Ratibida pinnata*), wild bergamot (*Monarda fistulosa*), golden alexanders (*Zizia aurea*), prairie spiderwort (*Tradescantia occidentalis*), wild black raspberry (*Rubus occidentalis*), largeleaf wild indigo, partridge pea (*Chamaecrista fasciculata*), and purple prairie clover (*Dalea purpurea*). The latter three species were the dominant nitrogen-fixing plants in the plot.

### *Baptisia* Density Survey

I used transects to estimate densities of *Baptisia* at the study site during the first week of June 2010. I calculated plant densities for individual transects (four 50-m, non-overlapping transects) with the King method for line transects (Brower et al. 1998). I measured perpendicular distances from a transect line to all *Baptisia* plants on both sides of transects; I then used these distances to determine the areas surveyed by transects and the densities of *Baptisia* plants.

### Deer Browsing Damage Assessments

I made estimates of deer browsing damage during the peak flowering season for *Baptisia* in June 2012; no estimates were made during 2010 or 2011 due to time spent conducting a deer exclusion study (2010) and a blister beetle outbreak on *Baptisia* plants during 2011. I selected 48 *Baptisia* plants at random from the population and examined them for evidence of deer browsing (e.g., browsed branches or flower racemes). I counted the number of flower racemes on each plant and the number of racemes damaged by deer browsing. I also counted flowers on a single, randomly selected raceme on each of 25 non-browsed plants, and the total numbers of flowers remaining on all browsed racemes.

I made comparisons between the reproductive potential of *Baptisia* plants with and without browsing damage. I used a simple *t*-test to compare numbers of racemes per plant between browsed and non-browsed plants. I estimated numbers of flowers per plant and numbers lost to browsing per plant and my estimates were used to quantify the loss in reproductive potential both in browsed plants and in the *Baptisia* population.

### Deer Exclusion Cage Experiment

At the beginning of the flowering period during the first week of June 2010, I randomly selected eight *Baptisia* plants and enclosed them in cylindrical cages (1.8 m high, 2.5 × 2.5 cm or 5.0 × 10.0 cm mesh, diameter variable based on plant size) to prevent browsing by deer while allowing access to insect pollinators (Fig. 1). Cages remained in place for four months, encompassing the period of flowering, pollination, seed pod inflation, and seed maturation and pod drying.

During late June, I selected five plants at random from

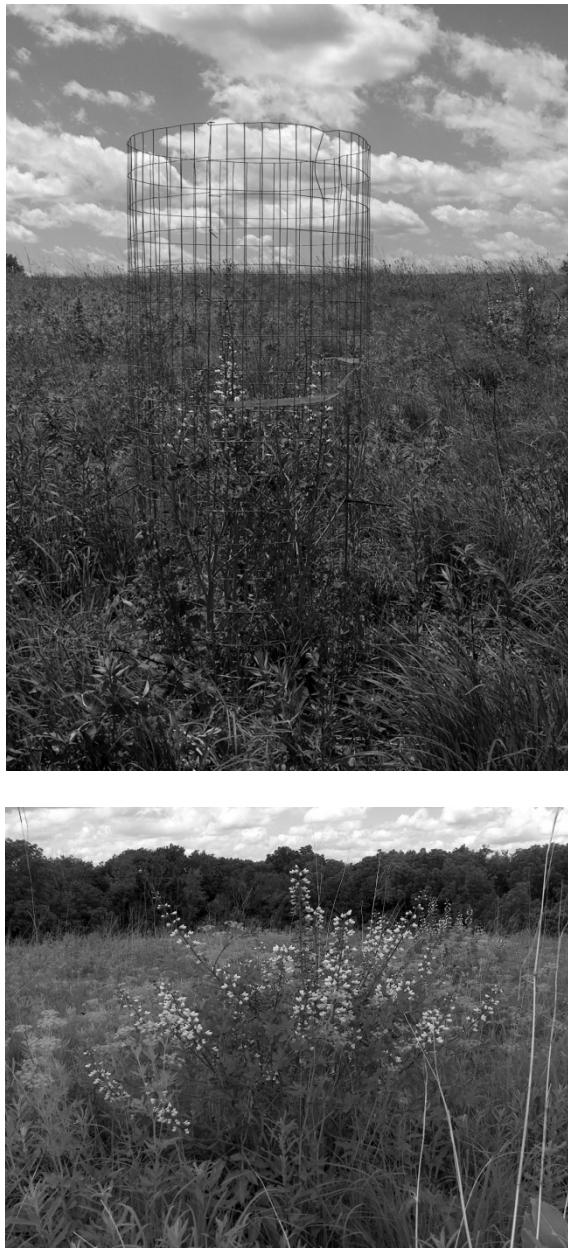


Figure 1. Caged (top) and non-caged (bottom) *Baptisia lactea* during flowering in June 2010 at the Kramer Ridge restored prairie.

the non-caged population and I enumerated the numbers of racemes (flower shoots) on each plant and inflated seed pods on each raceme (see Fig. 2 for an illustration of racemes and inflating seed pods on a caged plant). These counts served as a baseline to assess the potential proportional loss of pods to deer browsing on non-caged plants or losses to other causes on both caged and non-caged plants. In early October, I removed cages from around *Baptisia* plants and enumerated the numbers of racemes per plant and intact, mature seed pods per raceme. For comparison, I also counted racemes and seed pods on 16 non-caged *Baptisia* plants.

I compared the reproductive potential of non-caged *Baptisia* plants in late June and the final reproductive output of plants in early October by using simple *t*-tests to compare numbers of racemes per plant, inflated pods per raceme, and pods per plant between the two sampling periods. Additionally, I compared these same three variables, as well as the numbers of seeds produced per plant (*t*-tests) between caged and non-caged plants in October to assess the potential effects of deer browsing on the reproductive output of non-caged plants.



Figure 2. Inflating seed pods on racemes extending above a caged *Baptisia lactea* on the Kramer Ridge restored prairie, late June 2010.

### Insect Grazers on *Baptisia*

During June 2011, I observed adult Say's blister beetles (*Lytta sayi* LeConte) feeding on *Baptisia* flowers and buds at Kramer Ridge. Blister beetles were not present during either 2010 or 2012, so observations could not be made during those years. I collected several individual beetles from different plants to confirm species identification, and I enumerated beetles feeding on flowers on *Baptisia* racemes. Aggregations of blister beetles were present on many individual plants, but absent from others. The portion of *Baptisia* plants within the population that was impacted by these aggregations on the date of observation was unknown, as counts of plants with and without aggregations were not made. I made no additional visits to the study site during the time period when blister beetles were aggregating. Consequently, direct assessment of the impact of feeding by blister beetles on *Baptisia* flowers could not be made. Three months after observing blister beetles feeding on *Baptisia* flowers at Kramer Ridge, I assessed plants for reproductive output by counting the numbers of racemes, mature pods, and pods per raceme on each of 55 *Baptisia* plants.

At the end of the 2010 and 2011 growing seasons, I collected mature seed pods from plants to estimate the abundance of the seed predator, the wild indigo weevil (*Apion rostrum* Say). I harvested all intact, pre-dehiscent pods from each of 24 plants in 2010 and 55 plants in 2011 and placed the

pods into bags designated for each plant. I opened the pods in the lab and counted the number of viable seeds in each pod. I also tallied the number of adult wild indigo weevils within each pod. All statistical analyses were conducted using VassarStats (Website for statistical computation; <http://vassarstats.net/>).

### RESULTS

#### *Baptisia* Densities

I estimated *Baptisia* density at the study site to be 188 plants/ha (1 plant/53 m<sup>2</sup>; SD = 94 plants/ha). I surveyed >100 *Baptisia* plants along the four transects to produce the density estimate. These plants ranged in size from young, single-stem plants to individuals with 8 to 10 stems in a cluster. *Baptisia* were located on the eastern portion of the restoration site on high ground adjacent to a brushy fence line bordering an agricultural field.

#### Deer Browsing Damage

I found that approximately 50% of the *Baptisia* plants examined (22 of 48 plants, 46%) displayed browsing damage caused by deer (Fig. 3). Browsing by deer damaged an average of 6 racemes/plant (SD = 6, range = 1 to 22 racemes), affecting >27% of all racemes on these plants (range = 3 to



Figure 3. Flowering *Baptisia lactea* displaying browsing damage from white-tailed deer at the Kramer Ridge restored prairie, June 2012.

76%). Including non-browsed plants, deer damaged 3 ( $SD = 5$ ) racemes/plant (13% [ $SD = 21\%$ ] of racemes/plant). Plants with and without browsing damage did not differ significantly in the number of flower racemes/plant ( $t_{46} = 1.48$ ,  $P = 0.14$ ), averaging 19 racemes/plant ( $SD = 13$ , range = 1 to 48).

Browsing by deer had a large impact on potential reproductive output of *Baptisia* at Kramer Ridge. While non-browsed racemes contained an average of 76 ( $SD = 29$ ) flowers/raceme ( $n = 25$ , range = 22 to 118 flowers/raceme), browsed racemes averaged only 2 ( $SD = 6$ ) flowers/raceme ( $n = 105$ , range = 0 to 44 flowers/raceme), a loss of 97% of the reproductive potential of browsed racemes. An average, non-browsed plant in this population could produce 1,444 flowers (19 racemes/plant  $\times$  76 flowers/raceme). In contrast, an average browsed plant could produce 1,000 flowers ([13 non-browsed racemes/plant  $\times$  76 flowers/raceme] + [6 browsed

racemes/plant  $\times$  2 flowers/browsed raceme]), a loss of 30.7% of reproductive potential. With browsed plants comprising 46% of the *Baptisia* population at Kramer Ridge, deer browsing on flower racemes reduced potential reproductive output of the *Baptisia* population by 14%.

#### Deer Exclusion Cage Experiment

Four weeks after flowering began, I found that *Baptisia* plants averaged 83 inflated seed pods per plant (range = 20 to 190) borne on an average of 15 racemes (range = 4 to 23; Table 1). Seed pods per raceme ranged from 0 to 25, but only 17% of racemes held 10 or more pods (Fig. 4). The vast majority of racemes held only a few pods, with an average of 5 and a median of 2 pods per raceme (Fig. 4, Table 1).

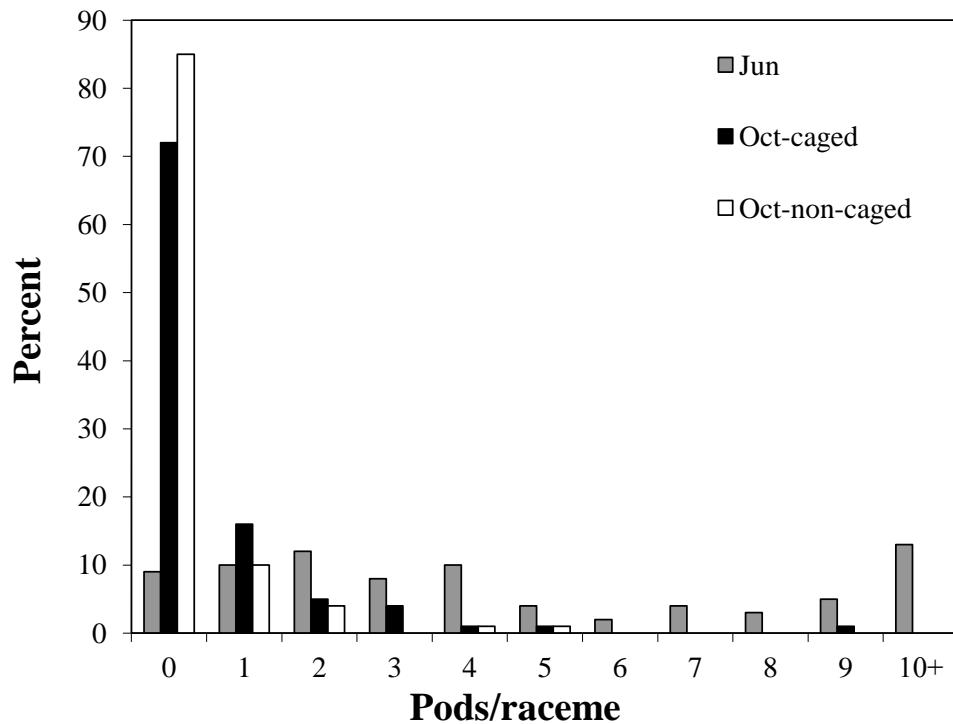


Figure 4. Frequency distribution of seed pod abundance on racemes of *Baptisia lactea* at Kramer Ridge restored prairie after pod inflation in late June ( $n = 78$ ) and after pod maturation in October (caged [ $n = 81$ ] and non-caged [ $n = 155$ ] plants), 2010.

Table 1. Reproductive output measures of *Baptisia lactea* and infestation levels of *Baptisia* seed pods by *Apion rostrum* in a Kramer Ridge restored prairie, 2010. Values are means ( $\pm$ SD) with sample sizes below. Results of *t*-tests comparing June and October values and caged and non-caged plants are reported as *t*-value (*P*-value).

Variable	Late Jun	Oct caged	Oct non-caged	Statistical comparisons		
				Jun vs. Oct-caged	Jun vs. Oct-non-caged	Caged vs. non-caged
Racemes/plant	15.6 (7.1)	10.3 (2.8)	9.7 (3.8)	1.94 (0.08)	2.46 (0.02)	0.37 (0.72)
	5	8	16			
Pods/plant	83.6 (70.6)	6.0 (10.6)	2.3 (4.9)	3.14 (0.01)	4.86 (<0.01)	1.20 (0.24)
	5	8	16			
Pods/raceme	5.4 (5.1)	0.6 (1.4)	0.2 (0.7)	8.08 (<0.01)	12.26 (<0.01)	2.70 (<0.01)
	78	81	155			
Seeds/plant	---	2.5 (5.5)	0.3 (0.9)	---	---	1.63 (0.12)
		8	16			
<i>Apion</i> /pod	---	2.8 (2.0)	3.5 (2.7)	---	---	1.20 (0.23)
		59	29			

At the end of the reproductive season, *Baptisia* plants had significantly fewer racemes and pods per plant and fewer pods per raceme than did plants immediately after pod inflation (Table 1). The most significant declines (85 to 95%) were in the numbers of pods present. The vast majority (>70%) of racemes held no seed pods in early October, with only five of 236 racemes (2%) having more than three pods (Fig. 4).

Caged and non-caged plants did not differ in the numbers of racemes or pods per plant in October, although caged plants had significantly more pods per raceme than non-caged plants (Table 1). Caged and non-caged plants also did not differ in the number of viable seeds produced per plant (Table 1). Only 25 viable seeds were found in the 88 pods collected from 24 *Baptisia* plants in early October. Most (80%) of these seeds were collected from caged plants. All of the viable seeds collected were produced by just two caged (15 and 5 seeds each) and two non-caged (3 and 2 seeds each) plants.

### Insect Grazers on *Baptisia*

On 18 June 2011, I observed adult blister beetles aggregating on many *Baptisia* plants at Kramer Ridge and feeding heavily on flowers and unopened flower buds. Many racemes had been stripped of nearly all flowers and buds, but numbers of racemes affected to this extent were not tallied. Counts of beetles on 29 racemes from 10 plants averaged 10 beetles/raceme (SD = 5, range = 3 to 22 beetles/raceme). I made no attempt to identify the sex of beetles or to determine numbers engaged in eating versus mating.

*Baptisia* seed pods at Kramer Ridge were heavily infested by *Apion* during September and early October. Over 80% of pods contained live adult weevils, with an average of 3 *Apion*/pod in both 2010 and 2011 (Table 2). The majority (68%) of weevils were collected from seed pods containing four or more weevils, with one pod containing 10 adult *Apion* (Fig. 5). Seed production by *Baptisia* was low during both

years, averaging only 1 seed/plant (Table 2).

Seed consumption by developing *Apion* produced dramatic reductions in the numbers of seeds in pods by autumn. Seed pods without *Apion* averaged 11 (SD = 7) seeds/pod in 2011, whereas all seed pods averaged 0.3 seeds/pod in 2010 (97% reduction in seed number) and 2.6 seeds/pod in 2011 (76% reduction; Table 2).

### Collective Impact of Herbivores on *Baptisia*

At Kramer Ridge, the average *Baptisia* plant had the potential to produce >15,500 seeds (19 racemes/plant  $\times$  76 flowers/raceme  $\times$  11 seeds/seed pod = 15,884 seeds/plant). Deer browsing during flowering reduced potential reproductive output of the *Baptisia* population by 14% (see above). Although not directly assessed in the present study, pollination success of *Baptisia lactea* and other *Baptisia* spp. averages only ~60% (= ~40% pollination failure; Table 3). Taken together, pollination failures and deer browsing may have reduced seed production in the *Baptisia* population by 54%. With seed production of only 1 seed/plant in 2010 and 2011, the Kramer Ridge *Baptisia* population suffered a reproductive loss of 99.99%. By subtraction, blister beetles and weevils together reduced *Baptisia* seed production by ~46%.

### DISCUSSION

The *Baptisia* population on the restored prairie at Kramer Ridge suffered a near complete reproductive failure during 2010 and 2011. My findings suggested that these failures were influenced strongly by herbivory by two different species of beetles and white-tailed deer feeding on flowers, flower racemes, and seeds. Each of these herbivores was capable of significant damage to *Baptisia* reproductive output, but collectively they produced nearly 100% reproductive failure.

Browsing by white-tailed deer can have significant, nega-

Table 2. Characteristics of *Baptisia lactea* and *Apion rostrum* on a Kramer Ridge restored prairie, 2010 and 2011. Values are totals or means (with SD in parentheses).

Variable	2010	2011
<i>Baptisia</i> plants examined	24	55
Racemes/plant	9.9 (3.5)	7.0 (4.1)
Total seed pods	88	27
Seed pods/plant	3.5 (7.3)	0.5 (2.5)
Total seeds	25	70
Seeds/seed pod	0.3 (1.0)	2.6 (4.8)
Seeds/plant	1.0 (3.2)	1.3 (6.8)
Total <i>Apion</i>	267	80
<i>Apion</i> prevalence	82%	85%
<i>Apion</i> /pod	3.1 (2.3)	3.0 (2.3)

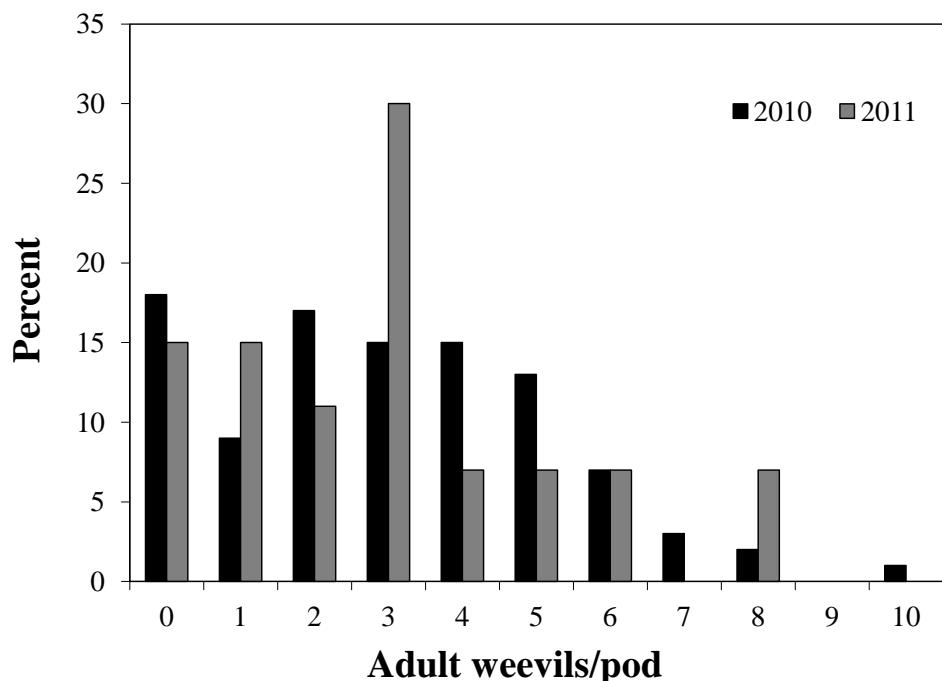


Figure 5. Frequency distribution of adult weevil (*Apion rostrum*) abundance in mature *Baptisia lactea* seed pods at Kramer Ridge restored prairie, September and October 2010 ( $n = 88$ ) and 2011 ( $n = 27$ ).

Table 3. Pollination success (percent of flowers producing inflated seed pods) of *Baptisia lactea* and other *Baptisia* species as reported in literature.

Species	Pollination success (%)	Source
<i>Baptisia lactea</i>	46	Peterson et al. 2010
	62	Peterson et al. 2010
	47	Peterson et al. 2010
	46	Peterson et al. 2010
	73	Peterson et al. 2006
	100	Haddock and Chaplin 1982
<b><i>B. lactea</i> average</b>	<b>62</b>	
<i>Baptisia leucophaea</i>	66	Peterson et al. 2000
	95	Peterson et al. 2000
	69	Peterson et al. 2000
	10	Haddock and Chaplin 1982
<b><i>B. leucophaea</i> average</b>	<b>60</b>	
<i>Baptisia bracteata</i>	46	Peterson et al. 2006
<i>Baptisia lanceolata</i>	17	Horn and Hanula 2004
<b>Overall average</b>	<b>56</b>	

tive effects on tallgrass prairie forbs (Englund and Meyer 1986, Ritchie and Tilman 1995, Anderson et al. 2001, 2005, 2007). When this browsing activity impacts nitrogen-fixing legumes, the long-term success of a prairie restoration may be compromised (Graham et al. 2008). In my study, deer browsing damaged 46% of *Baptisia* plants at Kramer Ridge and caused a loss of 30% of reproductive tissues in these browsed plants. By comparison, deer on an Illinois prairie browsed on a similar proportion (48%) of *Baptisia* plants, but caused twice as much (60%) loss of reproductive tissues (Anderson et al. 2001). Higher deer densities in Illinois (30 to 42 deer/km<sup>2</sup>) compared to southeastern Minnesota (7 deer/km<sup>2</sup>) may have contributed, in part, to increased severity of browsing damage to individual plants, though not to prevalence of damage. Although such browsing likely has little effect on the present nitrogen-fixing activities of these plants, it could affect recruitment of new plants to the population and thereby limit prairie nutrient dynamics (Piper and Gernes 1989, Graham et al. 2008) in future years.

Blister beetles can be highly destructive to flowering plants, especially to legumes, where losses of flowers and developing seed pods can exceed 80% (Evans et al. 1989, Evans 1990, Whiles and Charlton 2006, Swanson and Neff 2007). The blister beetle infestation on wild indigo plants in the Kramer Ridge prairie was high compared to previous reports of their abundances on prairie legumes. At Kramer Ridge, blister beetles were three times more abundant (>270 beetles/10 plants) than the maximum abundance (90 beetles/10 plants) reported on *Baptisia* plants at four sites in a native tallgrass prairie in Kansas (Evans et al. 1989). In addition, 14% of individual, wild indigo flower racemes at Kramer Ridge had blister beetle counts (18 to 22 beetles) higher than the total beetle count (17 beetles) on the entire, most heavily infested plant in Kansas (Evans 1990). The infestation of *Baptisia* by blister beetles on Kramer Ridge in 2011 likely contributed to the nearly complete lack of intact seed pods (0.5 seed pod/plant) at the end of the growing season.

Reproduction failure resulting from weevil infestation appears to be common for several species of *Baptisia* (Haddock and Chaplin 1982, Petersen and Slepoda 1994, Horn and Hanula 2004, Mundahl and Plucinski 2010). Average weevil counts in seed pods of *B. lactea* on Kramer Ridge during two successive years (3 weevils/pod) were among the highest ever reported for *A. rostrum* (0.5 to 2.7 weevils/pod; Petersen 1989, Petersen and Slepoda 1994, Horn and Hanula 2004, Petersen et al. 2006, 2010, Mundahl and Plucinski 2010), which consequently resulted in direct seed loss via consumption by weevils and seed pod abortion (and subsequent seed loss) by plants infested by weevils (Petersen 1989, 1990, Petersen and Slepoda 1994). Infestation levels as low as 1.0 weevil/pod have resulted in plants aborting (abscising) infested seed pods (Petersen 1989), although heavier infestations usually are needed to induce the highest rates of pod abortion (Petersen 1989, 1990). However, no previous

studies have reported so few seeds (<2 mature seeds/plant) produced by a population of *B. lactea* infested by *Apion*.

Restored prairies may be managed to improve the success of legumes such as *Baptisia*. In the years since it was restored in 1996, the Kramer Ridge prairie has been burned twice, the latest 5 years prior to the study period. Burning may benefit reproductive output of *B. lactea* (Carter et al. 2000, Petersen et al. 2010), but this management tool may have no effect on weevil or blister beetle infestation rates (Evans et al. 1989, Petersen et al. 2010). The most successful reproductive years for *Baptisia* usually coincide with atypically cold temperatures (e.g., late spring frosts), suggesting that seed predators like *Apion* may be susceptible to poor weather conditions (Haddock and Chaplin 1982). However, late spring frosts can destroy early season flowers and buds, which typically are those most likely to escape predation by blister beetles (Evans et al. 1989).

## MANAGEMENT IMPLICATIONS

The wild indigo population on the Kramer Ridge restored prairie has suffered from repeated reproductive failures resulting from deer browsing on flower racemes, blister beetles eating flowers, and weevils eating seeds and contributing to seed pod abortion. Together, these herbivores virtually eliminated seed production in the entire wild indigo population during two successive years. However, based on plant densities and the mix of small, medium, and large plants in the population, reproduction in recent years (previous 5 to 8 years) appears sufficient to sustain the population at this location. Further research is needed to better quantify the ultimate impacts of deer, blister beetles, and weevils on seed production in this population of wild indigo.

## ACKNOWLEDGMENTS

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