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Management of the Invasive Shrub Amur Honeysuckle (*Lonicera maackii*) for the Endangered Perennial Wild Dill (*Perideridia americana*)

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Case Study

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Abstract

Radnor Lake State Natural Area in Nashville, TN, has cedar glades that contain the endangered perennial herb wild dill [*Perideridia americana* (Nutt. ex DC.) Rchb.] and the invasive shrub Amur honeysuckle [*Lonicera maackii* (Rupr.) Herder]. This research examined whether *L. maackii* treatment in the Radnor Lake State Natural Area cedar glades is followed by an increase in *P. americana* plants. A grid of 60 adjacent 2 m by 4 m plots was placed in five cedar glades to encompass the *P. americana* population. With great care to protect *P. americana*, the annual treatment for *L. maackii* was to pull plants ≤1-m tall from the ground; and to cut stems >1-m tall and then treat the stumps with glyphosate. The *t*-tests of means for the log natural of the number of plants in the 60 plots (significance level of P-value = 0.05) were used to compare pretreatment *L. maackii* and *P. americana* counts with posttreatment counts in 2018 and *P. americana* counts at leaf out and flowering in 2018. The *L. maackii* population was significantly smaller (P-value < 0.001) in 2018 than pretreatment at all five sites. When pretreatment in 2014 and 2015 was compared with posttreatment in 2018 for the *P. americana* populations, the increases were significant at the Cheek, Harris 2, Hideaway, and Norfleet sites, but the increase at East Hall Farm was not significant. White-tailed deer (*Odocoileus virginianus* Zimmermann) trampling was the explanation given for the decreases in *P. americana* from leaf out to flowering at all five sites in 2018. Browsing was evident only at Hideaway, which had a greater loss for *P. americana* from leaf out to flowering in 2018 than the combined losses for the Cheek, East Hall Farm, Harris 2, and Norfleet sites. The research informed the creation of adaptive management decisions regarding monitoring and treatment of the invasive species *L. maackii* for an endangered species.

Introduction

One benefit of invasive plant treatment for a land manager is the opportunity for native plants to grow in the treatment site (Boyce 2015). Of special concern are endangered species that may be particularly vulnerable to the effects of the invasive plants (Albrecht and McCue 2009). For example, invasive shrubs may be threatening the survival of populations of rare herbaceous perennial plants found in the cedar glades of the Tennessee central basin. The cedar glades are named for the eastern redcedar (*Juniperus virginiana* L.; which is not a true cedar) found in these forest openings, which also harbor a suite of grasses and herbaceous perennials adapted to full sunlight, spring flooding, summer drought, and shallow soils with extensive exposed limestone bedrock (Baskin and Baskin 2004). One of these herbaceous perennials is wild dill [*Perideridia americana* (Nutt. ex DC.) Rchb.; also called eastern Eulophus and eastern yampah], a geophyte that is state listed as an endangered species in Tennessee (Crabtree 2016). The species is also state listed as endangered in Indiana (Indiana Department of Natural Resources 2016), as threatened in Kentucky (Kentucky State Nature Preserves Commission 2011), and as extirpated in Ohio (Ohio Division of Wildlife 2015) but is not listed at the federal level (USDA 2018). In Tennessee, *P. americana* is restricted to the cedar glades in the state's central basin where Baskin and Baskin (1993) studied the species and found that *P. americana* emerges in March and shoot senescence occurs in June. The nonnative shrub Amur honeysuckle [*Lonicera maackii* (Rupr.) Herder] has invaded Tennessee central basin cedar glades (Cofer et al. 2008) and shades out early vernal native species such as *P. americana*, because it grows taller than the herbaceous perennials and its leaf out occurs before the native shrub species leaf out and at roughly the same time *P. americana* emerges (Chen and Matter 2017).

Research on *L. maackii* treatment has investigated the response of perennial herbaceous species following the treatment of *L. maackii* plants. Miller and Gorchov (2004) found greater

growth and reproduction for the spring-flowering perennial narrowleaf wild leek [*Allium burdickii* (Hanes) A.G. Jones] following *L. maackii* treatment. Christopher et al. (2014), Peebles-Spencer et al. (2017), Shields et al. (2015), and Ward et al. (2017) demonstrated that treatment of *L. maackii* was related to an increase in spring herbaceous perennials.

The overpopulation of white-tailed deer (*Odocoileus virginianus* Zimmermann) in the eastern United States has resulted in the overbrowsing of herbaceous and woody plants (Loeb et al. 2011). This effect gives rise to the possibility of *O. virginianus* causing a reduced recovery of herbaceous perennials after *L. maackii* treatments. Christopher et al. (2014) found overabundant *O. virginianus* population caused a reduction in the population of spring perennial species following *L. maackii* treatment. Ward et al. (2017) showed the response of short perennial species to *L. maackii* treatment peaked after 3 yr, and *O. virginianus* browsing reduced the population of short perennial species. In contrast, Peebles-Spencer et al. (2017) reported that *O. virginianus* did not have a significant effect on spring perennial species after *L. maackii* treatment.

Lonicera maackii treatment and endangered species management, including *P. americana,* are two Radnor Lake State Natural Area, Nashville, TN (RLSNA), land-management goals. However, *O. virginianus* population size control is not a land-management goal (Barnes 2016). Also, long-term *L. maackii* treatment efforts have been successful at RLSNA (Loeb et al. 2010). This research focuses on the response of the endangered plant *P. americana* to *L. maackii* treatments in five cedar glades located in RLSNA. The first adaptive management research question (Loeb 2011) is: Will the treatment of *L. maackii* be followed by an increase in the *P. americana* plant population when comparing pretreatment and posttreatment *P. americana* population sizes? *Odocoileus virginianus* have overbrowsed tree seedlings and saplings in RLSNA (Loeb et al. 2011, 2015) but no evidence of *O. virginianus* browsing of *P. americana* was observed before *L. maackii* treatment. The second adaptive management research question is: Does the post–*L. maackii* treatment *P. americana* plant population size change from *P. americana* leaf out to flowering?

Materials and Methods

Site Description and Perideridia americana Biology

RLSNA is located on the southern boundary of Nashville, TN (Loeb et al. 2010). Cedar glades in RLSNA are located on the Fernvale and Arnheim Limestone Formations, which are below the Fort Payne Chert and above the Chattanooga Shale (Wilson and Miller 1972). Only small parts of the Fernvale and Arnheim Formations are covered with cedar glades. As well, only seven cedar glades in RLSNA contain *P. americana* growing on some segment of the cedar glade. Two of the seven cedar glades containing *P. americana* have fewer than 10 *P. americana* plants, and these two sites were not selected for treatment. The five research sites are remote locations within the nearly 540-ha area of RLSNA. No formal trails lead to the five cedar glades. The public is not permitted to go off the formal trails in RLSNA. The names and elevations of the centers of the five research sites in RLSNA are: Cheek, 313 m; East Hall Farm, 319 m; Harris 2, 300 m; Hideaway, 313 m; and Norfleet, 297 m. Longitudes and latitudes for the research sites are not provided to protect the *P. americana* plants from being harvested. However, the authors welcome requests for a guided visit to a research site.

The only disturbance and historical information concerning *P. americana* sites in RLSNA was found in the Tennessee Division of Natural Areas Biotics Database. There were four records dated May 17, 1979. Three of the sites contained 2 or fewer plants; however, one site had about 1,000 *P. americana* plants (P Somers and L Smith, personal communication). A search for the four sites in 2013 revealed *P. americana* was not found at two sites. In contrast, Cheek is the place noted as having approximately 1,000 plants, and Hideaway is a location that had 2 plants in 1979.

Perideridia americana is a perennial herb with tuberous storage roots in a cluster of two or more radiating from the stem and slender delicate leaves that dry completely after flowering but before fruiting (Chuang 1970). In RLSNA, *P. americana* leaf out starts in early March and flowers appear by the beginning of May. Greenhouse research on *P. americana* indicates: 51% seed germination in the first year; less than 1% seed germination after the first year; only cotyledons develop in the first growing season; and flowering does not occur until the third growing season, with the vast majority of plants flowering in the fifth year (Baskin and Baskin 1993). Bidwell and Bidwell (2018) suggest *P. americana* is susceptible to *O. virginianus* browsing.

Plant Survey and Statistical Analysis

The narrow Fernvale and Arhheim Limestone Formations and small extent of *P. americana* in the cedar glades permitted the entire population of *P. americana* at pretreatment to be counted in a grid of 60 adjacent 2 m by 4 m plots laid out in six rows of 10 plots at each cedar glade, except for the Hideaway site. The Hideaway site is on the ridgeline, which left a triangle of limestone 4-m wide at the base and 8-m long to the tip of the triangle at the lower elevation boundary of the plots, and this area was not included in the research. The highest-elevation boundary of the plots was placed at the contact of the Fort Payne Chert with the Fernvale and Arhheim Limestone Formations, and the lowest-elevation row of plots encompassed the boundary of the Fernvale and Arnheim Formations and the Chattanooga Shale.

Hideaway and East Hall Farm were the first two sites discovered to contain *P. americana* in 2013. The decision to begin to conduct the research was made in the winter of 2014. Grid placement was done after leaf out in the Hideaway and East Hall Farm sites during the second week of March 2014. The grid of plots was placed at Cheek following flowering in the first week of May 2014. As additional sites were discovered, the grids were placed at Harris 2 after leaf out in the second week of March 2015 and at Norfleet following flowering in the first week of May 2015. The posttreatment counts were done in the second week of March 2018 for leaf out and the first week of May 2018 for flowering.

Prior research demonstrated that repeated *L. maackii* treatment resulted in lower counts of *L. maackii* plants than treatment in only 1 yr at RLSNA (Loeb et al. 2010). However, the prior research did not encompass the cedar glades. No research is available concerning relationships between *L. maackii* and *P. americana*. Greenhouse research showed that *P. americana* first flowers 3 to 4 yr after seed germination (Baskin and Baskin 1993); therefore, posttreatment counts were done at least 3 yr after treatment. The adaptive management research questions called for counting plants, which was performed by counting the individual root crowns to determine individual *L. maackii* and *P. americana* plants. The *L. maackii* and *P. americana* plants were counted pretreatment, which was immediately after grid placement and before the first treatment of *L. maackii* plants at each

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site. The treatment of *L. maackii* in the sites ceased after 2016. To match the timing of the pretreatment counts, the posttreatment counts for *L. maackii* and *P. americana* were in the second week of March 2018 for East Hall Farm, Harris 2, and Hideaway and in the first week of May 2018 for Cheek and Norfleet. *Perideridia americana* was also counted in the second week of March and the first week of May 2018 at all five sites for a comparison of posttreatment leaf out and flowering.

Log natural–transformed counts were used to provide normally distributed values for the statistical tests. Mixed-model analysis (P-value of 0.05 was the significance level) was done to first determine whether the five sites were similar and thus could be treated as representing the entire RLSNA. Mixed-model analysis was also used to determine whether the sites with 3 yr since treatment were different from the sites with 4 yr since treatment. The mixed model was: *Perideridia americana* = Treatment (fixed factor) + *Lonicera maackii* (fixed covariate) + site (fixed factor) + years (fixed factor) + plot (random factor). For each of the five sites as different research locations, *t*-tests (P-value of 0.05 was the significance level) were used to assess whether there were significant differences between pretreatment and posttreatment for *L. maackii* and *P. americana* and leaf out and flowering for *P. americana* in 2018. Statistics were calculated using SPSS Amos v. 25 (IBM, 1 New Orchard Road, Armonk, New York 10504-1722).

Lonicera maackii Treatment

With extraordinary attention given to not disturb the *P. americana* plants, *L. maackii* plants were pulled from the ground, except for the few shrubs > 1-m tall that were treated following the standard technique at RLSNA for larger *L. maackii* plants (Loeb et al. 2010). The stems of shrubs >1-m tall were cut with a lopper at the time the smaller plants were pulled. The day of cutting off the stems, a backpack sprayer (Solo, 5100 Chestnut Avenue, Newport News, VA 23605) was used to apply glyphosate (Rodeo®, Dow AgroSciences, 9330 Zionsville Road, Indianapolis, IN 46268) at a concentration of 20 ml L^{-1} to the *L. maackii* stumps when there was more than 4 h of direct sunlight remaining, no prediction of rain for 3 d, and the temperature exceeded 4 C. The treatment of *L. maackii* plants <1-m tall described above occurred once annually from the first treatment through 2016, but the treatment of plants >1-m tall was only needed and performed during the first treatment. Treatment was ceased in 2017 to enable posttreatment comparison. Finally, the adaptive management research question does not ask whether the treatment process had an impact on the *P. americana* plants despite the best efforts to not disturb *P. americana* plants. Instead, the adaptive management research question inquires whether the *P. americana* population increases after the *L. maackii* treatment was performed.

Results and Discussion

The mixed-model analysis found that only the East Hall Farm and Harris 2 sites were similar. The comparison of number of years of treatment, that is 3 yr versus 4 yr, also showed no significant difference. Based on these results, the following analysis will focus on the individual sites and not consider the five sites as representing the entire RLSNA. In addition, the number of years since treatment will not be used to group the five separate sites. The statistical analysis indicates the results from the five sites cannot be generalized. Therefore, comparisons with flowering perennials similar to *P. americana* and cedar glade–like environments are limited.

The means and standard deviations for: pretreatment and posttreatment counts at the five sites are presented for *L. maackii* in Table 1 and *P. americana* in Table 2; and the posttreatment comparison of *P. americana* counts at leaf out and flowering are presented in Table 3. The *t*-test comparison of means for pretreatment and posttreatment *L. maackii* counts indicate all five sites had significant (P-value < 0.001) decreases in *L. maackii* (Table 1). The largest decrease in the means for *L. maackii* plants occurred for the East Hall Farm site at 2.25 plants m^{-2} which had the largest pretreatment mean at 2.88 plants m^{-2}. The smallest decrease in the means was 0.09 plants m^{-2} which occurred for the Norfleet site that also had the smallest pretreatment mean of 0.12 plants m^{-2}. The pretreatment means for Cheek, Harris 2 and Hideaway were between 1.65 and 1.94 plants m^{-2} and the decreases ranged from 1.31 to 1.77 plants m^{-2}. The *L. maackii* treatment land management goal was achieved because there were significantly fewer *L. maackii* shrubs at posttreatment in all five cedar glades in RLSNA.

The *t*-test comparisons of means for pretreatment and posttreatment *P. americana* counts showed significant increases in Cheek, Harris 2, Hideaway, and Norfleet, but East Hall Farm had an increase that was not significant (Table 2). East Hall Farm had the smallest mean for *P. americana* at pretreatment at 0.07 plants m^{-2} and the smallest mean at posttreatment at 0.12 plants m^{-2} among the five cedar glades. Considering the change from pretreatment to posttreatment, the largest increase in *P. americana* plants occurred in Cheek at 1.74 plants m^{-2}. Cheek had the second-largest pretreatment population at 2.39 plants m^{-2}. Cheek also had the second-largest posttreatment population of *P. americana* at 4.13 plants m^{-2}. The largest pretreatment *P. americana* population was in Hideaway at 5.87 plants m^{-2}. Hideaway had the largest posttreatment population at 7.43 plants m^{-2}. The greatest percentage increase for *P. americana* (353%) occurred at Norfleet, but this increase represents only 0.76 plants m^{-2}.

In regard to the first research question, the treatment resulted in a significant decrease for *L. maackii*, and an increase of *P. americana* at all five sites in RLSNA, but the *P. americana*

Table 1. Means and standard deviations for *Lonicera maackii* plant counts in 60 plots at pretreatment and posttreatment in the Cheek, East Hall Farm, Harris 2, Hideaway, and Norfleet cedar glades located in Radnor Lake State Natural Area, Nashville, TN.[a]

	Pretreatment plants m^{-2}		Posttreatment plants m^{-2}		Comparison of pretreatment versus posttreatment
Cedar Glades	Mean	SD	Mean	SD	P-value[b]
Cheek	1.65	0.82	0.31	0.36	<0.001*
East Hall Farm	2.88	1.14	0.63	0.53	<0.001*
Harris 2	1.94	1.14	0.17	0.11	<0.001*
Hideaway	1.76	0.89	0.45	0.36	<0.001*
Norfleet	0.12	0.17	0.03	0.06	<0.001*

[a]Comparison of pretreatment versus posttreatment used a *t*-test of the log natural–transformed plant counts for the 60 plots at pretreatment and posttreatment. The dates of pretreatment and posttreatment were: Cheek pretreatment, May 2014, and posttreatment, May 2018; East Hall Farm pretreatment, March 2014, and posttreatment, March 2018; Harris 2 pretreatment, May 2014, and posttreatment, May 2018; Hideaway pretreatment, March 2014, and posttreatment, March 2018; Norfleet pretreatment, May 2015, and posttreatment, May 2018. *Lonicera maackii* treatment ceased in 2016 to provide a year for recovery before posttreatment counts.
[b]An asterisk (*) indicates a significant *t*-test comparison at 0.05 level.

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Table 2. Means and standard deviations for *Perideridia americana* plant counts in 60 plots at pretreatment and posttreatment in the Cheek, East Hall Farm, Harris 2, Hideaway, and Norfleet cedar glades located in Radnor Lake State Natural Area, Nashville, TN.[a]

	Pretreatment plants m^{-2}		Posttreatment plants m^{-2}		Comparison of pretreatment versus posttreatment
Cedar Glades	Mean	SD	Mean	SD	P-value[b]
Cheek	2.39	2.44	4.13	2.56	<0.001*
East Hall Farm	0.07	0.21	0.12	0.27	0.636
Harris 2	0.32	0.37	0.58	0.52	0.001*
Hideaway	5.87	4.30	7.43	5.59	0.046*
Norfleet	0.30	0.38	1.06	1.25	<0.002*

[a]Comparison of pretreatment versus posttreatment used a *t*-test of the log natural–transformed plant counts for the 60 plots at pretreatment and posttreatment. The dates of pretreatment and posttreatment were: Cheek pretreatment, May 2014, and posttreatment, May 2018; East Hall Farm pretreatment, March 2014, and posttreatment, March 2018; Harris 2 pretreatment, May 2014, and posttreatment, May 2018; Hideaway pretreatment, March 2014, and posttreatment, March 2018; Norfleet pretreatment, May 2015, and posttreatment, May 2018.
[b]An asterisk (*) indicates a significant *t*-test comparison at 0.05 level.

increase was not significant at East Hall Farm. These outcomes at the five sites are in agreement with the research on *L. maackii* treatment effectiveness and the response of flowering perennials post–*L. maackii* treatment conducted by Christopher et al. (2014), Miller and Gorchov (2004), Peebles-Spencer et al. (2017), Shields et al. (2015), and Ward et al. (2017).

The second research question was answered with the *P. americana* at all five sites showing decreases from leaf out to flowering during the posttreatment period, but the only significant decreases were at Cheek and Hideaway (Table 3). Hideaway had the largest mean for posttreatment leaf out at 7.43 plants m^{-2}. The largest change in the means from leaf out to flowering was a decrease of 4.48 plants m^{-2} that occurred at Hideaway. The mean at leaf out for Cheek was close to Hideaway, at 6.18 plants m^{-2}, but the decrease at Cheek of 2.05 plants m^{-2} was less than half of what occurred at Hideaway. The range of differences for the means at leaf out and flowering for East Hall Farm, Harris 2, and Norfleet was 0.11 to 0.53 plants m^{-2}.

Table 3. Means and standard deviations for *Perideridia americana* plant counts in 60 plots at posttreatment leaf out in March 2018 and flowering in May 2018 for the Cheek, East Hall Farm, Harris 2, Hideaway, and Norfleet cedar glades located in Radnor Lake State Natural Area, Nashville, TN.[a]

	Leaf out in 2018 plants m^{-2}		Flowering in 2018 plants m^{-2}		Comparison of leaf out in 2018 with flowering in 2018
Cedar Glades	Mean	SD	Mean	SD	P-value[b]
Cheek	6.18	4.02	4.13	2.56	<0.001*
East Hall Farm	1.20	2.72	0.67	1.68	0.200
Harris 2	0.58	0.52	0.47	0.41	0.180
Hideaway	7.43	4.30	2.95	1.87	<0.001*
Norfleet	1.06	1.25	0.88	1.04	0.379

[a]Comparison of leaf out versus flowering used a *t*-test of the log natural–transformed plant counts for the 60 plots at leaf out in March 2018 and flowering in May 2018.
[b]An asterisk (*) indicates a significant *t*-test comparison at 0.05 level.

The *P. americana* losses from leaf out to flowering and lack of significance for the increase from pretreatment to posttreatment at the East Hall Farm site can be explained by the conclusion of Baskin and Baskin (1993) that *P. americana* is susceptible to disturbance. One apparent cause of disturbance is *O. virginianus*, which have overbrowsed tree seedlings and saplings in RLSNA (Loeb et al. 2011). Although *P. americana* floral head browsing was found at Hideaway in 2018, *O. virginianus* trampling of the delicate *P. americana* plants appears to have caused the losses evident in comparing the leaf out to flowering results as well as the nonsignificant *P. americana* population increases at East Hall Farm. The research on the effects of *O. virginianus* following *L. maackii* treatment of Christopher et al. (2014) and Ward et al. (2017) is in agreement with decreases at the five sites in RLSNA. However, the research of Peebles-Spencer et al. (2017) did not reveal losses in perennial herbs related to *O. virginianus*. Reducing the impact of *O. virginianus* by fencing the portions of the cedar glades containing *P. americana* was not done, because the fencing would be a location signal for *P. americana* poachers. The alternative of hunting is not allowed in RLSNA. Installing fencing and reducing the *O. virginianus* population also would not be well accepted by the public (Loeb et al. 2011).

Identifying a comparable species to *P. americana* that was examined in prior research on the response of perennial species following *L. maackii* treatment (Christopher et al. 2014; Cipollini et al. 2009; Miller and Gorchov 2004; Peebles-Spencer et al. 2017; Shields et al. 2015; Swab et al. 2007; Ward et al. 2017) is a challenge. One candidate from a different taxonomic family is Canadian wildginger (*Asarum canadense* L.), which does share characteristics with *P. americana* of being a spring perennial with a tuberous root system. *Asarum canadense* is not listed as endangered at the federal level or by any state, but it is listed as threatened in Maine (Maine Natural Areas Program 2015). Jull (2001) indicates *O. virginianus* do not favor *A. canadense*. The research of Cipollini et al. (2009) reveals few effects from *L. maackii* treatment or *O. virginianus* damage on transplanted *A. canadense*. The study of Swab et al. (2007) showed higher abundance and frequency of *A. canadense* plants in sites with no *L. maackii* clearance than cleared sites. The research on *L. maackii* treatment and *A. canadense* shows the opposite response to the increases for *P. americana* after *L. maackii* treatment in RLSNA. Likewise, *P. americana* experienced losses from leaf out to flowering related to *O. virginianus* trampling, but *O. virginianus* had little effect on *A. canadense*. Although land managers may expect an increase in a native species following *L. maackii* treatment, the *A. canadense* results demonstrate that this expectation may not be met.

This research on treatment of the invasive shrub *L. maackii* in RLSNA cedar glades containing the endangered perennial *P. americana* was the first step in an iterative land-management methods assessment process (Loeb 2011). Intensive, annual *L. maackii* clearing is no longer needed, because the invasive treatment resulted in a significant reduction in *L. maackii* and was followed by an expansion of the *P. americana* population. Therefore, in the future, periodic treatment of *L. maackii* plants with glyphosate will occur before *P. americana* leaf out or after *P. americana* senescence. An alternative recommended by Cipollini et al. (2009) would be to perform basal treatment on *L. maackii* and leave dead stems standing to reduce *O. virginianus* damage. An implication of this treatment method is the *L. maackii* plants would not be treated for many years to permit the shrubs to grow to

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sufficient size to be an impediment to *O. virginianus* transit. Regardless of which *L. maackii* treatment method is selected in the future, the populations of *L. maackii* and *P. americana* will be monitored to determine whether the *P. americana* population shows a decline in more than 1 yr. If a 2-yr decline occurs, without an obvious explanation such as prolonged drought or extended cold in the spring, then *L. maackii* treatment will be implemented. If additional invasive species appear in the future, as sometimes occurs in treatment areas (Loeb 2011), then the new invasive species will be treated as well.

Land managers can benefit from a full explanation of the research basis for the adaptive management decisions made regarding treatment of the invasive species *L. maackii* for the endangered species *P. americana*. The research method implemented to measure the pretreatment versus posttreatment population changes for the endangered and invasive species was based on long-term research on *L. maackii* treatment at RLSNA (Loeb et al. 2010) and research information concerning the ecological life cycle of *P. americana* (Baskin and Baskin 1993). The key biological characteristic that led to the placement of 2 m by 4 m permanent plots is *L. maackii* shrubs will become reestablished in a treatment site despite repeated treatments. The reproductive biology of *P. americana* led to waiting at least 3 yr for the pretreatment versus posttreatment comparison, because *P. americana* requires at least 3 yr after seed germination to display flowers. The treatment method of *L. maackii* removal by pulling out the plants required giving extraordinary attention to not disturbing the individual *P. americana* plants. This focus on protecting the endangered species also was thoroughly adhered to during subsequent invasive treatments to eliminate new or reestablished *L. maackii* plants. The invasive species treatment was ended 1 yr before the posttreatment measurement to enable a pretreatment versus posttreatment comparison for the invasive species. A second benefit of permanent plots is that periodic monitoring of the endangered species as well as the invasive species can continue to be done to inform management decisions in the future, such as changing the invasive species treatment method.

Based on observations that the *P. americana* populations did not show evidence of browsing, we did not expect detrimental effects from *O. virginianus*, even though we were aware that the endangered species *P. americana* was sensitive to disturbance. We adapted the research methodology to include the comparison of plant populations at leaf out and at flowering in order to provide data on the damage caused by *O. virginianus* disturbance. Looking to the future, we are considering additional research on an invasive treatment change. This invasive management research would compare the recommendation of Cipollini et al. (2009) to perform basal treatment and leave the stems in the plot to reduce *O. virginianus* damage with our method of pulling out the plants from the plots. Implicit in testing the management change is monitoring the *P. americana* and *L. maackii* in the plots to determine whether the *P. americana* population declines as the *L. maackii* plants grow to sufficient size to serve as impediments to the *O. virginianus*.

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