An Experimental Approach to Testing the Efficacy of Management Treatments for Glossy Buckthorn at Seney National Wildlife Refuge, Upper Michigan

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ABSTRACT

Glossy buckthorn (*Frangula alnus*) is an exotic invasive shrub within many Midwestern wetlands and adjacent ecotones, including those found in several National Wildlife Refuges. Where glossy buckthorn becomes established, it can form a dense homogenous monoculture, outcompete native shrubs, and alter other ecosystem processes. Active management of glossy buckthorn is critical to minimize the spread of this species, and to restore or rehabilitate those areas presently impacted. We tested the efficacy of herbiciding and scorching on glossy buckthorn survival. Treatments were implemented in concert with management efforts currently practiced at Seney National Wildlife Refuge in Upper Michigan. One year after applying 20% glyphosate to cut buckthorn stumps, we found no difference in resprout density between this concentration of herbicide applied by sponge to stumps, scorching stumps with a propane torch, or untreated controls ($p > 0.05$). Additional low-volume spraying of 5% glyphosate to resprouts the following year significantly ($p < 0.001$) reduced resprout density as compared to scorching and controls, with no difference between scorch treatments and the controls. Low-volume herbicide spraying reduced seedlings by 96% and 91% one and two years following treatment, with no difference in seedling density between scorching treatments and controls. The most effective management option for reducing glossy buckthorn appears to be repetitive herbicide application, possibly for more than two years.

Keywords: glossy buckthorn (*Frangula alnus*), herbicide, invasive species, Seney National Wildlife Refuge, wetlands

The deleterious impacts of exotic invasive species on natural ecosystem patterns and processes have provoked an increase in research and management efforts, and have even led to Presidential Executive Orders (National Strategy and Implementation Plan for Invasive Species Management 2004) that guide many federal land management agency practices. Exotic plant invasions have been implicated in the loss of many native plant species and the degradation of entire ecosystems (Chornesky et al. 2005). Recent studies have shown that besides limiting the establishment and growth of native plant species through competition for nutrients, water, and sunlight (Heidorn 1991, Houlahan and Findlay 2004), exotic invasive plants can also adversely impact soil moisture, soil pH, carbon and nitrogen cycles, and soil microbial activity (Heneghan et al. 2004).

In order to meet the requirements of the National Wildlife Refuge System Improvement Act of 1997 (Public Law 105-57), National Wildlife Refuges must minimize the impacts of exotic invasive species. However, the efficacy of specific management actions on target species has not often been quantified, and in many places invasive species management guidelines are lacking.

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Glossy Buckthorn

Glossy buckthorn (*Frangula alnus*) is an exotic invasive shrub that originates from Eurasia and northern Africa (Barnes and Wagner 1981). On many private and public lands in the Midwest (including many National Wildlife Refuges), glossy buckthorn has become a major invasive plant in the ecotone between upland and wetland habitats, and within sedge (*Carex* spp.) and shrub-dominated wetland communities growing on organic soils. Where glossy buckthorn becomes established, it typically forms a homogenous monoculture, outcompetes native shrubs (e.g., *Alnus*, *Betula*, *Prunus*, *Viburnum*, and *Salix* species), and thwarts the establishment of other woody species (Frappier et al. 2003, 2004).

Glossy buckthorn prefers sunny wetland areas, but is also found in shady areas and on a variety of soil types (Reinartz 1997, Possessky et al. 2000). Generally, the plant leafs out earlier in the spring, retains its leaves and drupes for a longer time, and grows faster than many native plant species (Richburg et al. 2002, Sanford et al. 2003). The entire shrub may grow as tall as 6.7 m, with many stems branching from the base. In older shrubs, base stems can be as large as 25.4 cm in diameter (Voss 1985).

The plant's rapid growth rate and ability to form dense monocultures have promoted its use in hedgerows and for other landscaping purposes. An effective competitor, glossy buckthorn reproduces primarily through prolific seeding, but can also vigorously stump sprout. This species also spreads through consumption and distribution of its drupes by several native bird species, including American robins (*Turdus migratorius*), Bohemian waxwings (*Bombycilla garrulus*), cedar waxwings (*Bombycilla cedrorum*), and rose-breasted grosbeaks (*Pheucticus ludovicianus*) (Catling and Porebski 1994).

The spread of any one dominant species, especially an exotic invasive species, may have a number of implications for wildlife habitat management (With 2002). For instance, wetlands invaded by glossy buckthorn monocultures often seem to be compositionally and structurally more homogenous than wetlands not invaded by the shrub (Possessky et al. 2000). This lack of heterogeneity may reduce the diversity and abundance of food resources (soft mast) for migrating birds made available at different times by different species (e.g., *Viburnum, Prunus*) because of phenological variation. Consequently, shrub wetlands infested by glossy buckthorn may provide fewer food resources over a more limited time frame (Corace pers. obs.).

Previous studies of glossy buckthorn invasions have shown decreased abundance and diversity of both woody and herbaceous plant species in some cases (Frappier et al. 2003, 2004), but not others (Houlahan and Findlay 2004). The reason for the incongruity of results among research projects is unknown, but likely resides in site-specific characteristics of infested areas, and the responses of individual plants to these conditions. Consequently, because of potential geographic variation in the response of a species to different management strategies, land managers often require ecoregional-specific research on the efficacy of different management options.

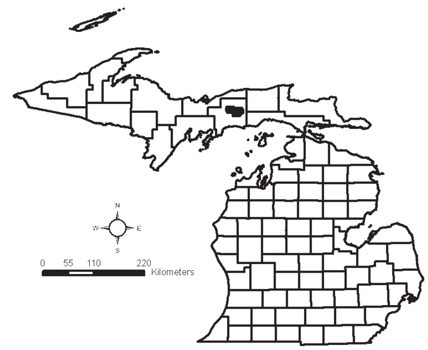

Figure 1. Counties of Michigan and the location of Seney National Wildlife Refuge in the Upper Peninsula.

Management of Glossy Buckthorn at Seney National Wildlife Refuge

To manage glossy buckthorn, staff at Seney National Wildlife Refuge in the Upper Peninsula of Michigan have mainly relied on cutting stems and applying a 20% active ingredient (ai) glyphosate solution to the cut stem, with some spraying of sprouts and small plants with a 5% ai glyphosate solution. This approach, which has been at least initially substantiated by recent research (Pergams and Norton 2006), is informed by the general experience and advice of colleagues from the Michigan State Department of Natural Resources, The Nature Conservancy, and member organizations of the Michigan Invasive Plant Council.

In concert with this ongoing management of glossy buckthorn at Seney National Wildlife Refuge, we used an experimental approach to quantify and compare the efficacy of mechanical (cutting), chemical, and heat (propane torch scorching) treatments on the survival of glossy buckthorn resprouts, and seedlings growing on refuge road edges adjacent to wetlands also impacted by glossy buckthorn. We monitored these treatments for up to three years. The objectives of these experiments were to 1) compare the effectiveness of herbicide (glyphosate), scorching, and control treatments of glossy buckthorn stumps to reduce resprouting; 2) compare the effectiveness of these treatments to reduce resprouting when applied one year after the stumps had been treated with 20% glyphosate; and 3) compare the effectiveness of these treatments in reducing the density of glossy buckthorn seedlings following removal of the glossy buckthorn overstory.

Seney National Wildlife Refuge (SNWR) is located in the eastern Upper Peninsula of Michigan between Lake Superior to the north and Lake Michigan to the south (Figure 1). SNWR encompasses 38,545 ha, of which approximately 2,832 ha are comprised of man-made impoundments (pools) of shallow open water and submergent vegetation (Corace et al. 2006b). Beginning in the 1930s, refuge pools were created for waterfowl. The pools are surrounded by retaining dikes, which serve as refuge roads and separate sedge and shrub-dominated wetlands from the pools and upland cover types. Functionally, dikes at SNWR serve as ecotones between wetlands and upland cover types.

Overall, glossy buckthorn is found on nearly 2,000 ha of SNWR in either dense monotypic stands or as scattered individuals on dikes or in wetlands that support a mix of species including sedges (*Carex* spp.), bluejoint grass (*Calamagrostis canadensis*), other grasses (Poaceae), cattails (*Typha* spp.), alder (*Alnus* spp.), willow (*Salix* spp.), birch (*Betula* spp.), *Prunus* spp., *Viburnum* spp., and tamarack (*Larix* *laricina*). Approximately two-thirds of SNWR is wetland and one-third is upland. The mosaic of wetland and upland cover types that characterize SNWR provides for a diversity of habitats for many wildlife species, including migratory and nonmigratory bird species (Crozier and Niemi 2003, Corace et al. 2006a).

The climate of SNWR is strongly influenced by Lake Michigan and Lake Superior. Precipitation is fairly evenly distributed throughout the year, annually averaging 84 cm. Dominant soils at SNWR are organic mucks and peats or sands (Albert 1995). Most lands immediately adjacent to SNWR are state-owned and managed by the Michigan Department of Natural Resources.

Table 1. Summary of treatments used in three experiments. Complexes are multiple live glossy buckthorn stems arising from the same locus.

Experiment	Year	*n*	Treatment
1. Single application	2004	35	a) control—cut complexes only
		35	b) cut + 20% glyphosate application to stumps
		35	c) cut + scorching with propane torch
2. Initial application	2003	75	cut complexes + 20% glyphosate application to stumps
1-y follow-up treatment	2004	25	a) control—no follow-up treatment
		25	b) low-volume broadcast application of 5% glyphosate
		25	c) scorching with a propane torch
3. Seedling treatments	2004	13	a) control—no treatment
(1-m² quadrats)		13	b) low-volume broadcast application of 5% glyphosate
		13	c) scorching with a propane torch

Experimental Treatments

Three experimental treatments were implemented in July 2004 to test the efficacy of growing season treatments commonly used at SNWR (and elsewhere in Michigan) to manage glossy buckthorn (Table 1). For Experiments 1 and 2, which compared treatments to prevent resprouting from cut stems, we identified "complexes," (multiple live glossy buckthorn stems arising from the same locus), and assigned a treatment (herbicide, scorch, or control, respectively) to every third complex we encountered. Complexes were measured prior to application of any treatments, and ranged from 3 to 25 stems with an average (± SE) of 7.2 (± 0.4) stems per complex. Experiment 3 investigated the efficacy of treatments on seedlings that emerged after the buckthorn overstory had been removed.

Experiment 1

The first experiment assessed initial, one-year, and two-year responses to a single application of a wetland-approved, surfactant-free herbicide (common name "Rodeo," active ingredient glyphosate) with scorching using a propane torch. A total of 105 glossy buckthorn complexes were cut between May and August of 2004, with three treatments each applied to 35 complexes: a) control, stems were cut and no other treatment applied; b) 20% glyphosate stump application via sponge immediately following cutting of stems; and c) scorching immediately after cutting stems (30 seconds of blue flame per stump complex).

Stump complexes were surveyed for the number of stump sprouts at the end of the growing season in 2004, and in July of 2005 and 2006. A stump sprout was defined as an individual arising from any previously cut member of the complex, excluding growth less than 2.5 cm in length.

We also measured the number of seedlings that emerged from the ground after treatment. Because seedlings were so abundant after being "released" through the cutting of the adult plants, we only counted the number of seedlings within a 15-cm radius of each stump complex.

Experiment 2

Experiment 2 involved follow-up treatments on complexes that had been cut and then treated with 20% glyphosate during the May–September field season of 2003. We measured stump sprouts in early summer 2004 prior to follow-up treatments. Sprouts ranged from 3 to 18 with an average (± SE) of 6.4 (± 0.4) per stump complex. In July 2004, we applied three additional treatments (n = 25 each): a) control, untreated beyond the initial cut and 20% glyphosate stump application in 2003; b) low-volume broadcast application of 5% glyphosate to stump sprouts arising from the stump complex; and c) scorching with a propane torch (30 seconds of blue flame per stump complex) to stump sprouts arising from the stump complexes. Based on the advice of colleagues in Michigan we used a lower concentration of glyphosate for the foliar treatment to sprouts, because the sprouts were smaller in diameter than the original cut stems, and to minimize negative effects of the herbicide. We remeasured the complexes for the number of sprouts at the end of the growing season in 2004 and in July of 2005. We also counted the number of one-year seedlings within a 15-cm radius of each stump complex.

Experiment 3

The third experiment investigated the efficacy of treatments on seedlings and was implemented in July 2004 in an area with a high density of glossy buckthorn seedlings < 10 cm in height. These seedlings colonized the area from the existing seed bank and were "released" from sunlight competition by the previous removal of a glossy buckthorn overstory. We installed 39 1-m² quadrats, with one of three treatments randomly assigned and applied to seedlings in 13 quadrats each: 1) no treatment control; 2) 5% low-volume broadcast glyphosate application; and 3) scorching with a propane torch (30 seconds of blue flame per quadrat). We counted the number of glossy buckthorn seedlings in each quadrat prior to treatment, and 14 days, 60 days, one year, and two years subsequent to treatments. In July of 2006 (two years post-treatment), quadrats were surveyed for numbers and diversity of plant species. No pretreatment species-level information was collected as the site was almost a pure monoculture of dense glossy buckthorn.

Data Analysis

Means and standard errors were calculated for each group of treatments within each experiment for each time period. One-way analysis of variance (ANOVA) followed by Tukey's pairwise comparisons (Zar 1999) was used to test the significance of differences ($\alpha = 0.05$) between treatments for each measurement period. A multivariate repeated measures ANOVA was used to test for trends over time for given treatments. Species richness (S, number of taxa), Shannon's Diversity Index (H), and Buzas and Gibson's evenness (e^H/S) were computed from the quadrat data collected in year two for Experiment 3 (seedling treatment). We examined differences in glossy buckthorn density, species richness, and evenness using one-way ANOVA followed by Tukey's pairwise comparisons. SYSTAT Version 8.0 (SPSS, Inc.) was used for all statistical analyses.

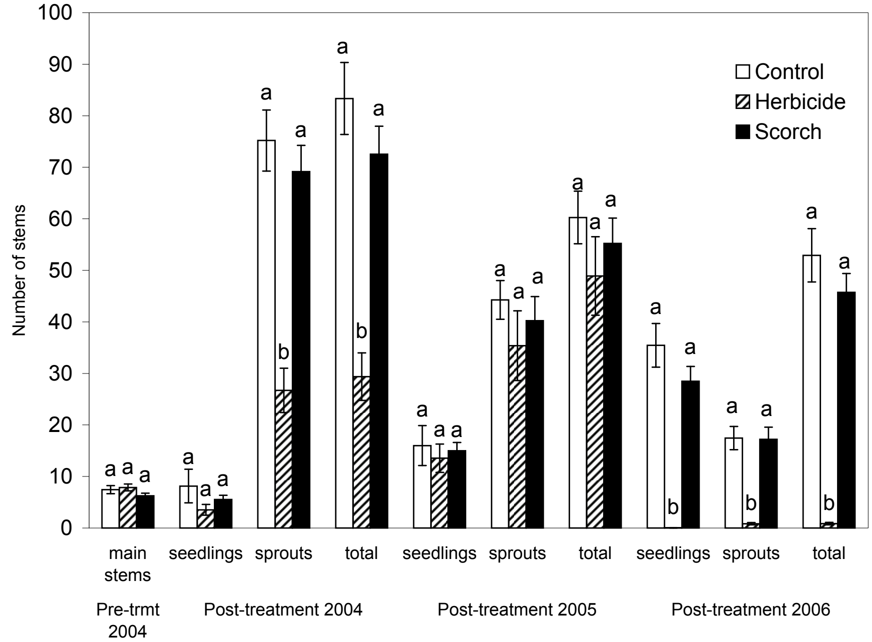

Figure 2. Effects of treatments on glossy buckthorn (*Frangula alnus*) complexes (Experiment 1) in terms of adjacent seedlings ($F_{4,202} = 8.0$, $p < 0.001$) and stump sprouts ($F_{4,202} = 9.1$, $p < 0.001$). Letters that are different within each group of three bars represent significant differences at $\alpha = 0.05$.

Results

Experiment 1

There was no difference in the number of main stems within each stump complex prior to the single application of treatments in 2004 (Figure 2); however, there was a significant effect of time (total stems: $F_{4,202} = 8.0$, $p < 0.001$) within each treatment, with seedlings generally increasing over time. One exception was the 20% glyphosate stump treatment, with both stump sprouts and seedlings tending to first increase after treatment, then generally decline. There was a significant reduction in the number of sprouts from stumps treated with 20% glyphosate during the initial year ($F_{2,102} = 23.9$, $p < 0.001$) and two years following treatment ($F_{2,102} = 40.8$, $p < 0.001$), with no difference in the number of seedlings between the treatments and the controls in the initial year of treatment and the year following treatment. Also in 2005, we found no significant differences in the number of stump sprouts between any of the treatments and the controls (Figure 2).

Experiment 2

Testing the effects of treatments in 2004 following a 20% glyphosate stump application in 2003, we found no significant differences in sprouts or seedlings following the initial treatments and prior to the second round of treatments in 2004 (Figure 3). There was a significant effect of time within each treatment (total stems: $F_{4,144} = 14.4$, $p < 0.001$). After the follow-up treatment in 2004, herbicide-treated stump complexes had significantly fewer stump sprouts as compared to the controls and the scorching treatments. Stumps treated with 20% glyphosate showed significantly fewer seedlings in the second year as compared to control and scorch treatments, with no significant differences between the scorch treatment and the controls for any measurement period.

Experiment 3

There were no differences in the pretreatment number of seedlings in the 1-m² quadrats (Figure 4). There was a significant effect ($F_{8,144} = 9.6$, $p < 0.001$) of time within each treatment with a general increase in number of seedlings 60 days after scorching as well as in the controls, then declining with time; the herbicide treatment showed a slight increase in the latter two measurement periods. Low-volume broadcast application of 5% glyphosate significantly reduced the number of glossy buckthorn seedlings compared to initial conditions ($F_{2,36} = 23.8$, $p < 0.001$), with no significant reduction within the control or the scorch treatments. The herbicide reduced seedling density by 99% within 14 days of treatment, and the effect persisted for at least 60 days post-treatment. One year post-treatment, seedling density was 4% of initial conditions, averaging 10 (± 4.6) per square meter; at two years, seedling density was 9% and averaged 22 (± 5.6). The controls and scorch treatments averaged 387 (± 58.6) and 367 (± 48.4) seedlings per square meter, respectively, one year after treatment, and 217 (± 14.9) and 211 (± 22.0) two years after treatment.

Species richness, diversity, and evenness were greater for the 5% low-volume broadcast glyphosate treatments than the control and scorch treatments (Table 2). Species composition in seedling quadrats differed according to treatment after two years. The controls and scorch treatments were dominated by glossy buckthorn, whereas only 36% of individual plants found in the herbicide-treated quadrats were glossy buckthorn. Unlike the control and scorch treatments, the density of other non-native plants was similar to buckthorn seedling density in the herbicide treatment. These species included bull thistle (*Cirsium vulgare*), hemp nettle (*Galeopsis* spp.), common mullein (*Verbascum thapsus*), oxeye daisy (*Leucanthemum vulgare*), spotted knapweed (*Centaurea stoebe*), and St. Johnswort (*Hypericum perforatum*).

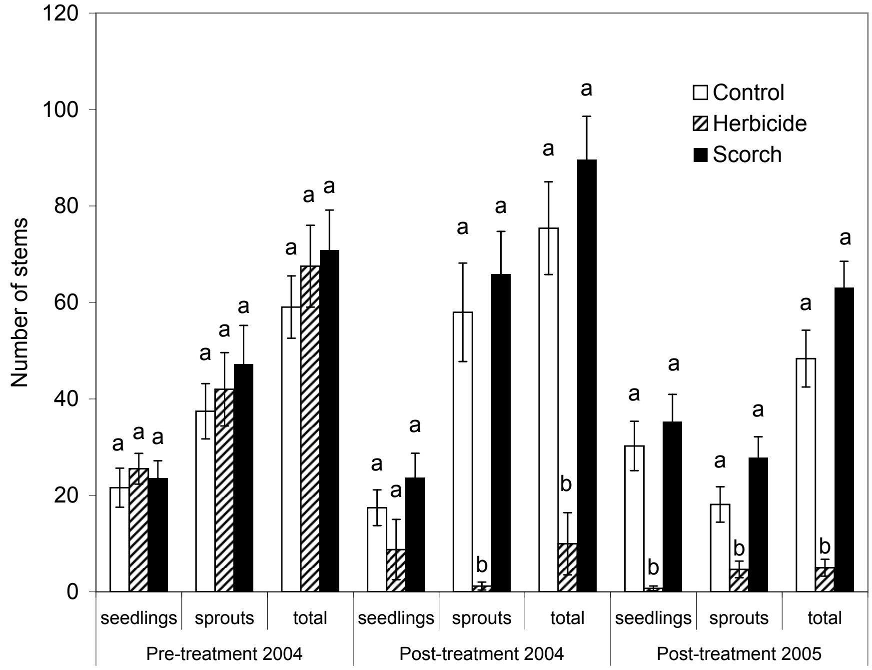

Figure 3. Effects of follow-up treatments on glossy buckthorn (*Frangula alnus*) (Experiment 2). Letters that are different within each group of three bars represent significant differences at α = 0.05; by 2005 the herbicide treatment significantly decreased the number of adjacent seedlings ($F_{2,72}$ = 17.9, $p < 0.001$) and stump sprouts ($F_{2,72}$ = 10.7, $p < 0.001$).

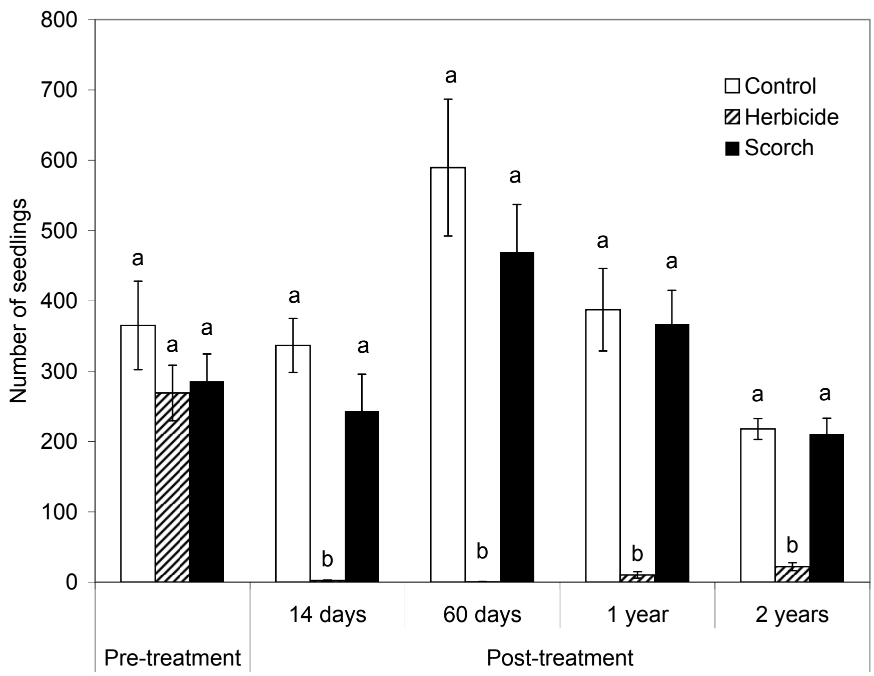

Figure 4. Effects of treatments on glossy buckthorn seedlings (Experiment 3). Letters that are different within each group of three bars represent significant differences at α = 0.05.

Discussion and Management Implications

Once established, glossy buckthorn and the related European buckthorn (*Rhamnus cathartica*) have proved difficult to manage and eradicate (Archibold et al. 1997, Reinartz 1997, Pergams and Norton 2006). Previous research has illustrated the differential responses of various herbicides in managing European buckthorn (Glass 1994, Pergams and Norton 2006), and the poor response of glossy buckthorn to fire (Post and Klick 1989, Boudreau and Willson 1992). Of the herbicide and scorching treatments that we compared, we showed that the only effective treatments of glossy buckthorn during the growing season were those involving low-volume spraying of 5% glyphosate as a follow-up to a 20% glyphosate stump treatment, or as a stand-alone treatment on seedlings. Seedlings were unaffected by stump application of 20% glyphosate, but did show a significant reduction after spraying of 5% glyphosate in the follow-up year. Even so, we did not

Table 2. Measures of mean biological diversity (± SE) and density (percentage of total stems) of buckthorn (*Frangula alnus*) and other non-native plants after 2004 control treatments in seedling quadrats.

	Control	Herbicide	Scorch	*F*	df	*p*
Species richness (*S*)	4.6 (0.67)	6.5 (0.54)	4.3 (0.50)	5.9	2,36	0.006
Diversity (*H*)	0.33 (0.10)	1.36 (0.12)	0.32 (0.10)	45.0	2,36	< 0.001
Evenness (e^H/S)	0.38 (0.07)	0.64 (0.05)	0.35 (0.03)	14.1	2,36	< 0.001
Buckthorn density	93	36	94			
Other non-natives	4	37	2			

achieve complete eradication of glossy buckthorn seedlings or elimination of recurring stump sprouting, suggesting that even these treatments may slowly yield to the prevalence of glossy buckthorn or other non-native species in the absence of follow-up measures. In all of the seedling control quadrats, non-native species dominated the vegetation in the refuge roadside ecotone where we conducted most of our work, with glossy buckthorn being the most prevalent.

The most effective treatment was low-volume broadcast spraying of 5% glyphosate to sprouts arising from stumps or to seedlings. Our work must be placed in the context of other possible management impacts, however. Treatments using glyphosate in sedge- and shrub-dominated wetlands, for example, must be informed by research by Relyea (2005) suggesting that herbicides containing surfactants (such as many formulations of glyphosate, although not the one we used) may have deleterious effects on the populations of anurans and other wildlife species. Work at SNWR has also addressed whether glyphosate concentrations < 5% may be effective in foliar spray treatments of small (< 2.5 cm diameter breast height) glossy buckthorn resprouts. Results suggest that 1.25% or 2.5% glyphosate concentrations used during the growing season may be as effective as the 5% concentration we used in this study (Corace et al., this issue).

Our research supports previous findings of Post and Klick (1989), who found that prescribed fire alone had little long-term effect on glossy buckthorn eradication. Burned plants tended to resprout vigorously within two years. Although our research did not show scorching to be an effective treatment, prescribed fire is still an important management tool in an integrated framework of ecosystem and exotic invasive species management (DiTomaso et al. 2006). Where shrub encroachment due to fire suppression has altered the composition of historically sedge-dominated wetlands (as it has in SNWR), glyphosate treatments followed up by prescribed fire may help to not only reduce glossy buckthorn, but also restore other wetland ecosystem patterns. Killing glossy buckthorn plants through the methods described above should aid in the broader goal of wetland restoration by allowing for the growth and development of herbaceous plants that comprise the finer fuels necessary to sustain prescribed fire over a wetland. Once a dense, homogenous monoculture of glossy buckthorn is cut and the sprouts and seedlings are mitigated, the resulting herbaceous vegetation can be managed more effectively by prescribed fire.

Because open wetlands are found commonly at SNWR and many other public lands in the Midwest (including other refuges in the National Wildlife Refuge System, Scott et al. 2004), our findings regarding the efficacy of glossy buckthorn management techniques may be especially relevant to many other regional land managers. Owing to geographic variability in the response of some species to management, our findings may have relevance in some areas and not others. Future research could address this issue by conducting a similar study in other Midwestern ecoregions.

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