Response of Pale Swallow-wort (*Vincetoxicum rossicum*) to Triclopyr Application and Clipping

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Pale swallow-wort is a nonnative vine, invading natural areas across much of the northeastern United States and southeastern Canada. Control of this clump-forming herbaceous perennial has been difficult. We conducted a 2-yr study (2005–2006) in a heavily infested site in Chaumont, NY to assess the response of swallow-wort to triclopyr applied once as a foliar treatment (1.9 kg ae/ha) (2005 only) alone or in combination with clipping 4 wk later, followed by a single clipping in 2006. We also evaluated the response of swallow-wort to one or two clippings during each of the 2 yr. Two yr after treatments began, swallow-wort cover was lower in plots treated with triclopyr (20 ± 5%) compared with plots subjected to clipping-only (56 ± 6%) or unmanaged controls (76 ± 6%). Stem densities were also lower in triclopyr-treated plots (25 ± 5 stems/m^2) than in clipping-only (188 ± 9 stems/m^2) and control (178 ± 10 stems/m^2) plots across three different sample dates. Seedling densities were lower in triclopyr-treated plots (160 ± 50 seedlings/m^2) relative to clipping-only (1,120 ± 180 seedlings/m^2) and control (960 ± 50 seedlings/m^2) plots after the 2005 growing season. The cover of other plant species was negatively correlated with swallow-wort cover and was higher in triclopyr-treated plots (75 ± 3%) than in clipping-only (5 ± 1%) and control (7 ± 4%) plots in 2006. Across both years, swallow-wort in control and clipped plots produced follicles, but not in triclopyr-treated plots. Regardless of clipping frequency, clipping in June or July was not effective in reducing swallow-wort stem density, cover, or follicle production. Although a single application of triclopyr provided considerable suppression of swallow-wort after two growing seasons, application of triclopyr in subsequent years is likely required to achieve long-term control.

Nomenclature: Triclopyr, butoxyethyl ester; Pale Swallow-wort, *Vincetoxicum rossicum* (Kleopow) Barbar., syn. *Cynanchum rossicum* (Kleopow) Borhidi.

Key words: Dog-strangling vine, invasive species, natural areas, weed control.

To protect natural habitats from the detrimental effects of invasive plant species, there is an urgent need to develop effective and sustainable management programs. The control of invasive species generally requires an integrated approach to limit their growth and reproduction, because a single strategy often might not be effective and/or sustainable (van Wilgen et al. 2000). The invasive nonnative perennial vine, pale swallow-wort [*Vincetoxicum rossicum* (Kleopow) Barbar]. Apocynaceae, formerly in the Asclepiadaceae) is a troublesome invasive species that likely will require the use of several management approaches to achieve effective long-term control. Black swallow-wort [*V. nigrum* (L.) Moench] is a closely related invasive congener and is more widely distributed in North America, but *V. rossicum* is considered more aggressive (Sheeley and Raynal 1996). The swallow-worts are increasingly becoming problematic in numerous habitats of northeastern North America, including natural areas, woodlands, pastures, Christmas tree plantations, roadsides, and old fields (DiTommaso et al. 2005). Hereafter, pale swallow-wort is referred to as swallow-wort.

Swallow-wort is native to the Ukraine and southwestern parts of European Russia and was intentionally introduced into New York State in the late 1800s and into Eastern Ontario, Canada in the early 1900s as an ornamental plant (Sheeley and Raynal 1996). This species occurs throughout the northeastern United States, but is especially abundant in the Lower Great Lakes Basin of the United States and Canada (DiTommaso et al. 2005). Swallow-wort is an herbaceous, clump-forming, perennial vine that reproduces via seed, but can also expand vegetatively from buds on the root crown. Swallow-wort seeds are comose, which allows

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Interpretive Summary

Pale swallow-wort (*Vincetoxicum rossicum*) is a climbing herbaceous perennial that has become invasive in many natural areas in the northeastern United States and adjacent Canada. Control of this vine has been difficult and challenging. Current methods of control have produced inconsistent results. Consequently, there is an urgent need to determine effective management strategies for this plant. In this field study in Chaumont, NY, we determined that one application of triclopyr, regardless if followed by clipping, successfully suppressed swallow-wort growth for two growing seasons. A single foliar application of triclopyr (1.9 kg ae/ha [1.7 lb ae/ac]) in mid-June 2005 resulted in significantly lower swallow-wort cover and density even by late summer the following year (August 2006). There was a concomitant increase in the cover of other vegetation with the reduction in swallow-wort cover in triclopyr-treated plots. Although the nonswallow-wort vegetation at the field site is comprised mainly of other (mostly naturalized) nonnatives, these species are not as aggressive as swallow-wort and pose little threat to the nearby protected and unique alvar community.

We also assessed the effects of clipping vegetation once (mid-June) and clipping vegetation twice (mid-June and mid-July) on swallow-wort cover and stem and seedling densities. All these parameters (as well as cover of other plant species) did not differ for plants subjected to either of these clipping treatments relative to the untreated control. Thus, although repeated clipping (i.e., mowing) might eventually exhaust belowground carbohydrate reserves of swallow-wort, it is not as effective as applying triclopyr in suppressing swallow-wort infestations. Moreover, despite carrying out one or two clippings a season, some mature seeds were produced by the end of the season. Conversely, in the triclopyr-treated plots, no seeds were produced. Although further research is necessary, even a single foliar application of triclopyr could offer more effective management of swallow-wort than mowing. Nonetheless, more timely clipping to minimize the likelihood of seeds maturing could also be an effective means of reducing swallow-wort infestations and expansion. Lastly, our seedbank results suggest that if no active restoration of our field site occurs following the control of swallow-wort, nonnative (mostly naturalized), but much less aggressive plant species (e.g., common mullein, *Festuca* spp.) will dominate the site and pose less of a threat to the nearby alvar community than does swallow-wort.

for effective long-distance wind dispersal. Individual plants can grow up to 3 m in one season, smothering surrounding vegetation and forming dense monospecific stands in affected areas (DiTommaso et al. 2005).

Swallow-wort tolerates a wide range of moisture regimes and typically grows in areas with full sun, although it can also colonize heavily shaded forest understories (Sheeley 1992; DiTommaso et al. 2005). The adaptability of swallow-wort places many ecosystems and plant communities at risk. For instance, swallow-wort threatens the globally-rare and imperiled alvar communities, which are composed of a unique mixture of sparsely vegetated rock, grassland, and savanna barrens that develop on thin soils over glaciated limestone or dolostone bedrock. These communities, which comprise almost 5,000 ha (12,355 ac) in the Lower Great Lakes Basin of the United States and Canada, have already been negatively impacted by rapidly expanding swallow-wort populations (Bonanno 1999). Swallow-wort is competitively displacing native plants and, consequently, is deleteriously affecting local fauna and flora. Six rare animal species and 23 rare plant species are now threatened by swallow-wort invasion in northern New York alone (S. E. Bonanno, unpublished data). Furthermore, Ernst and Cappuccino (2005) observed that the displacement of resident plants by swallow-wort in old-field communities significantly reduced arthropod diversity in these habitats. Swallow-wort also can have harmful effects on the native monarch butterfly (*Danaus plexippus* L.) due to its competitive displacement of the native old-field herb, common milkweed (*Asclepias syriaca* L.) (DiTommaso and Losey 2003; Mattila and Otis 2003). Swallow-wort also serves as a population sink for monarch butterflies by attracting and stimulating oviposition, despite the unsuitability of this plant for development of monarch larvae (Casagrande and Dacey 2007; DiTommaso and Losey 2003; Mattila and Otis 2003). Dense monospecific populations of swallow-wort deter grassland birds from nesting and also prevent predation by raptors of small rodents who might take refuge under the dense senesced plant material during the winter (DiTommaso et al. 2005).

Control of swallow-wort has been challenging. Individual stems produce large numbers of seeds; for example, Smith et al. (2006) found that each stem produces an average of 250 seeds. Seedling survivorship is high, varying from 71 to 100% (Ladd and Cappuccino 2005) and, because swallow-wort is self-compatible, a single propagule can initiate a new population (St. Denis and Cappuccino 2004). Seeds of this species can also be polyembryonic, a condition in which single seeds are capable of producing more than one seedling (DiTommaso et al. 2005). Polyembryonic seeds in swallow-wort most often comprise two embryos, although up to eight embryos have been observed in a single seed (Smith et al. 2006). Until a longer-term sustainable management program can be established (e.g., biological control), a combination of chemical and mechanical tactics may be the most effective means of minimizing the spread of swallow-wort in affected areas.

Several studies have investigated the effects of herbicides on swallow-wort, but results have been inconsistent. Lawlor and Raynal (2002) compared the effects of triclopyr and glyphosate, applied as foliar sprays or to cut stems, on swallow-wort populations in central New York. Foliar applications of the butoxyethyl ester formulation of triclopyr (1.9 kg ae/ha [1.7 lb ae/ac]) and glyphosate (3.1 and 7.8 kg ae/ha) were more effective in reducing swallow-wort cover and biomass than cut-stem applications of the triethylamine salt of triclopyr (1.4 kg ae/ha) and glyphosate (3.1 kg ae/ha). Among the foliar-spray treatments, there

Table 1. Mean (± SE) swallow-wort stem and seedling densities in May 2005 in Chaumont, NY before treatments were applied (*n* = 7).[a]

	Stem density	Seedling[b] density
Treatment	Stems/m^2	Seedlings/m^2
Control (no herbicide or clipping)	98 ± 10 a	1,040 ± 70 a
Triclopyr	90 ± 20 a	890 ± 90 a
Triclopyr + clipping 4 wk later	110 ± 10 a	960 ± 120 a
Clipping once	95 ± 10 a	1,010 ± 130 a
Clipping twice	97 ± 10 a	1,110 ± 110 a

[a] Treatment means with the same letter in a column are not statistically different at the alpha = 0.05 significance level, according to a Student's *t* means comparison test.

[b] Seedlings < 10 cm in height were included in assessment.

were no significant differences between the herbicides. In a different study, performed on Grenadier Island, NY, glyphosate (1.79 kg ae/ha) was shown to be more effective than triclopyr (butoxyethyl ester formulation; 2.24 kg ae/ha) and each of these herbicides was more effective than a triclopyr-2,4-D mixture (butoxyethyl ester formulation; 1.12 : 2.24 kg ae/ha) (F. M. Lawlor, unpublished). Anecdotal evidence from Christmas tree growers and land managers of natural areas suggests that herbicidal control of swallow-wort has been inconsistent and that repeated herbicide treatments are necessary to achieve long-term control (Lawlor and Raynal 2002). Herbicide application combined with clipping or mowing is an alternative management strategy for swallow-wort that could increase the efficacy of control.

If properly timed, clipping or mowing of swallow-wort plants can be effective in preventing seed production and limiting regrowth within a growing season (DiTommaso et al. 2005). For instance, McKague and Cappuccino (2005) determined that a single clipping of plants at soil level in late June was the optimal timing for controlling the spread of swallow-wort in an old-field/forest edge habitat in Ottawa, Canada. This timing was late enough in the season to ensure that plants did not resprout and produce mature seeds. Alternatively, clipping plants too early in the growing season (e.g., before mid-June) can provide ample time for the accumulation of resources to compensate for the lost plant tissue and for plants to reproduce (Bergelson and Crawley 1992; Bergelson et al. 1996; Lennartsson et al. 1998; Maschinski and Whitham 1989; Mutikainen et al. 1994).

The effects of either clipping or herbicide applications on swallow-wort control reported to date, have been inconsistent and inconclusive. Furthermore, the integration of these two strategies for the management of swallow-wort has received limited attention. In our 2-yr study, we evaluated a foliar application of triclopyr, either alone or in combination with clipping of aboveground tissue, and clipping once or twice in each of two growing seasons on stem density and cover of swallow-wort in a heavily infested old field in northern New York. We used triclopyr rather than glyphosate because it showed better efficacy at label rates in preliminary work (F. M. Lawlor, personal communication) and because its selectivity for broadleaf plants conserves grasses. Our hypothesis was that the combination of an herbicide application and clipping would be more effective in reducing swallow-wort cover and density than either tactic used alone.

Materials and Methods

Study Site. The field experiment was conducted in 2005 and 2006 in Chaumont, New York (44°06′N, 76°04′W) within the Chaumont Barrens, an area well-known for its globally-rare alvar communities. The study area was dominated by swallow-wort with mean densities of 98 ± 5 stems/m^2 and 1,003 ± 54 seedlings/m^2 (Table 1); however, percentage cover of swallow-wort was low (18 ± 1%) at the start of the study in early May 2005 (Figure 1A). The study site was a ~0.2 ha old field on a shallow Farmington loam soil (mixed, active, mesic Lithic Eutrudept). The soil had 8% organic matter content, determined by loss on ignition (Storer 1984), and pH 5.3. Extractable soil nutrients, including phosphorous (1.5 mg/kg), potassium (77. 8 mg/kg), calcium (932.9 mg/kg), and magnesium (68.9 mg/kg) were measured using Morgan's extraction method (Morgan 1941). Other plant species found in the study area included sulfur cinquefoil (*Potentilla recta* L.), oxeye daisy (*Chrysanthemum leucanthemum* L.), bird vetch (*Vicia cracca* L.), goldenrod species (*Solidago* spp.), fescue species (*Festuca* spp.), timothy (*Phleum pratense* L.), mouse-ear chickweed (*Cerastium vulgatum* L.), and creeping buttercup (*Ranunculus repens* L.) (Table 2). Of the 41 plant species identified at the site, 71% were nonnative.

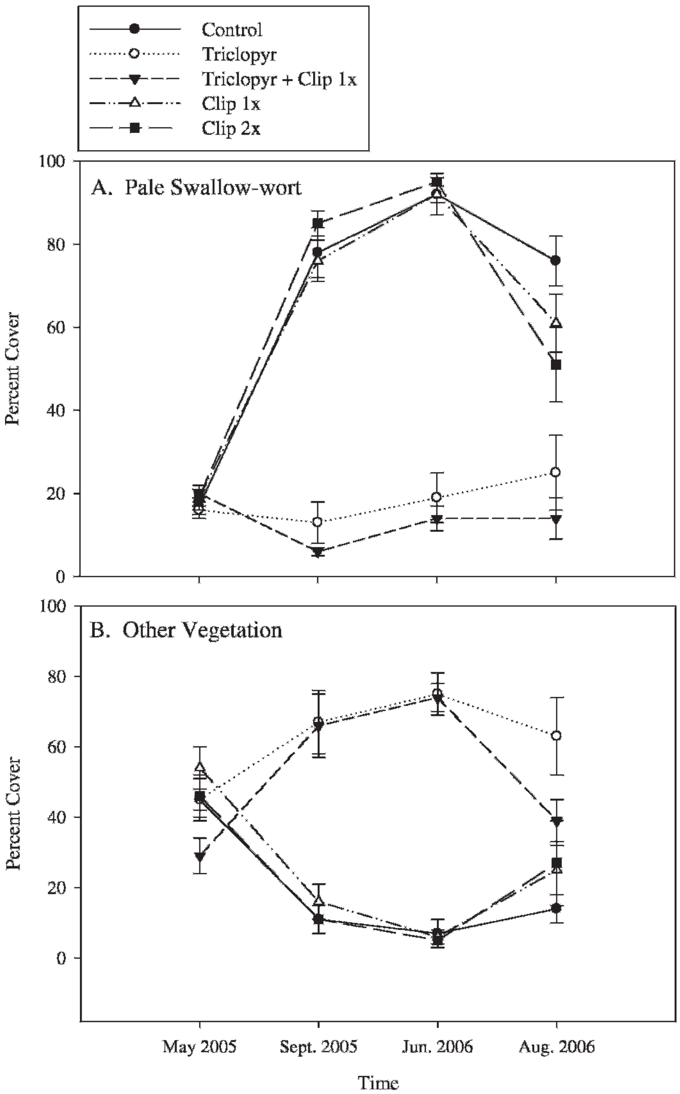

Figure 1. Observed post-treatment means (± SE) for (A) swallow-wort and (B) other vegetation percentage cover before treatments were applied (May 2005) and at three time points following treatment applications in Chaumont, NY ($n = 7$).

Experimental Design and Treatments. In late May 2005, 35 1-m^2plots were established with at least 1 m separating each plot. A completely randomized design was employed with five treatments and seven replications. Prior to the application of treatments, we visually estimated the percentage cover of swallow-wort and other vegetation in each plot. We also recorded the number of swallow-wort stems in each plot (excluding stems $<$ 10 cm in height) and the seedling density (seedlings $<$ 10 cm in height) in each of two 100-cm^2 subplots within each plot. Subplots were located 10 cm inside two diagonal corners of the 1-m^2 plots. These initial surveys revealed no differences between treatment plots in the percentage cover of swallow-wort and the mature stem and seedling densities (Figure 1; Table 3). However, the percentage cover of other vegetation varied between treatments.

The five treatments included: (1) a triclopyr application in June 2005, (2) a triclopyr application in June 2005 followed by a clipping 4 wk later and clipping alone in July 2006, (3) a clipping in June 2005 and in June 2006, (4) two clippings per year, in June 2005 and another clipping 4 wk later and in June 2006 and another clipping 4 wk later, and (5) a weedy control. The butoxyethyl formulation of triclopyr[1] was sprayed at the label-recommended rate of 1.9 kg ae/ha on June 10, 2005. Although our intent was to apply triclopyr during both years of the study (i.e., treatments 1 and 2 above), no herbicide was applied in 2006 because the private landowner of our study site would not allow it. Clippings were still conducted in both years on June 2 and July 12 in 2005 and on June 29 and July 27 in 2006 (i.e., treatments 2, 3, and 4 above). Application of triclopyr during only the first year of the project is relevant because landowners and natural areas managers are often guarded about applying herbicides in or near sensitive habitats (e.g., woodlands, near waterways, in the vicinity of endangered native plant species) (A. DiTommaso, personal communication). Also, even though spraying might be more cost-effective than mowing, unless volunteers are employed for mowing, herbicide costs for treating large areas can be prohibitive.

Herbicide treatments were applied with a low volume hand-pump Field King® backpack sprayer[2] using an adjustable cone nozzle. Pressure was maintained at approximately 110 KPa and the spray volume was ~140 L/ha (~91.4 gal/ac). Applications were made at the early fruiting stage of swallow-wort as per the label recommendation for the triclopyr butoxyethyl ester. To prevent herbicide drift onto adjacent plots, plots that were not sprayed were covered with heavy plastic sheeting during herbicide application. In clipped treatments, all above-ground plant material was cut by hand to a height of 8 cm using metal hand clippers.

We also collected the same data as done prior to treatment applications (i.e., percentage cover, swallow-wort stem and seedling density) at three sample dates during the 2-yr study: September 27, 2005; June 29, 2006, and August 10, 2006. To prevent further spread of swallow-wort, especially into the adjacent alvar communities, we removed swallow-wort follicles before they matured from plants in all plots during each of the two growing seasons.

Seedbank Assessment. On May 26, 2005, we collected soil at the study site to determine the plant species composition of the seedbank prior to initiation of treatments. Samples (3.5×10^{-3} m^3) were randomly collected from the top 10 cm of soil in the alleyways adjacent to the experimental plots. Each sample was combined in a 2 : 1 mixture with "Cornell Mix" (a

Table 2. Frequency of vegetation other than pale swallow-wort recorded in the 35 experimental plots in Chaumont, NY in May 2005.

Scientific name	Common name	Frequency
Potentilla recta L.*	Sulfur cinquefoil	34
Chrysanthemum leucanthemum L.*	Oxeye daisy	18
Vicia cracca L.*	Bird vetch	15
Solidago spp.	Goldenrods	12
Festuca sp.	Fescue	9
Phleum pratense L.*	Timothy	8
Cerastium vulgatum L. *	Mouse-ear chickweed	6
Ranunculus repens L.*	Creeping buttercup	6
Agrostis stolonifera L.	Creeping bentgrass	4
Achillea millefolium L.	Common yarrow	2
Bromus ramosus Huds.*	Hairy-brome	2
Brassica spp.	Mustards	1
Daucus carota L.*	Wild carrot	1
Echium vulgare L.*	Blueweed	1
Lonicera tatarica L.*	Tatarian honeysuckle	1
Poa spp.	Bluegrasses	1
Ranunculus acris L.	Tall buttercup	1
Taraxacum officinale G. H. Weber ex Wiggers	Dandelion	1
	Other grasses	1

* Indicates a nonnative species.

2 : 2 : 1 mixture of peat, vermiculite, and perlite), spread in flats to a depth of 2.5 cm, and placed in a controlled greenhouse environment for 4 mo. Greenhouse conditions included a 14-h photoperiod and an alternating day/night temperature regimen of 24/21 C (75/70 F). Flats were watered as required and were fertilized biweekly with 200 ml of a 21–5–20 N–P–K solution. Emerged seedlings were identified, counted, and removed from flats monthly. After 4 mo, flats were placed in 4 C cold storage for 3 mo. Flats were subsequently returned to the greenhouse under the same growing conditions described above. Seedling emergence data were collected as described above for 3 additional mo.

Data Analysis. An ANOVA was used to evaluate the main effect of treatment on the baseline data collected in May 2005. To assess the main effect of treatment, we analyzed the posttreatment data using analyses of covariance

Table 3. P values and degrees of freedom (df) for treatment effects from analyses of covariance (ANCOVAs), which were performed for percentage cover swallow-wort and other vegetation and for stem and seedling densities for each date. Also shown are results from repeated measures ANCOVAs for posttreatment data (after May 2005), performed to analyze overall effects of treatment and month.

		Cover		Swallow-wort density	
Date	Source	Swallow-wort	Other vegetation	Stems	Seedlings
May 2005	Treatment effect (4 df)	0.69	0.04	0.70	0.77
September 2005	Pretreatment effect (1 df)	0.11	0.16	0.04	0.03
	Treatment effect (4 df)	< 0.0001	< 0.0001	< 0.0001	< 0.0001
June 2006	Pretreatment effect (1 df)	0.02	0.37	0.02	0.43
	Treatment effect (4 df)	< 0.0001	< 0.0001	< 0.0001	0.17
August 2006	Pretreatment effect (1 df)	0.13	0.02	0.11	0.08
	Treatment effect (4 df)	< 0.0001	0.0006	< 0.0001	0.12
Overall	Pretreatment effect (1 df)	0.04	0.03	0.01	0.05
	Month effect (2 df)	< 0.0001	0.95	0.03	< 0.0001
	Treatment effect (4 df)	< 0.0001	< 0.0001	< 0.0001	0.0004
	Treatment × month (6 df)	< 0.0001	< 0.0001	0.007	0.0003

Table 4. Average monthly temperatures and total precipitation for 2005 and 2006 and 30-yr averages (1976 to 2006) for the Watertown International Airport, Dexter, NY, 6 km from the field site. Average monthly temperatures and total precipitation for the growing season and average yearly temperatures and precipitation are also shown.

Month	Temperature			Precipitation		
	2005	2006	30-yr average	2005	2006	30-yr average
	C			mm		
January	−9.2	−1.2	−7.1	46.7	88.9	68.5
February	−6.4	−6.3	−6.0	45.5	58.9	54.0
March	−3.2	−0.8	−0.7	24.4	28.2	58.0
April	6.6	7.3	6.5	98.0	71.9	74.1
May	10.8	13.8	12.7	22.1	58.7	78.3
June	20.4	18.1	17.4	45.2	113.8	73.6
July	21.8	22.1	20.4	106.9	40.1	64.2
August	20.9	19.6	19.4	163.1	30.0	83.4
September	17.1	14.3	15.1	155.7	124.5	98.8
October	9.9	8.7	8.9	123.7	164.1	88.9
November	5.2	5.6	3.4	158.8	85.9	92.3
December	−4.9	1.6	−3.3	69.9	108.2	73.4
Growing season total (April to October)	15.3	14.8	14.3	714.8	603.0	561.4
Monthly average	7.4	8.6	7.2	88.3	81.1	75.6

(ANCOVAs) with the baseline data serving as the covariate. We also evaluated the main effects, treatment and month, and their interaction, using repeated measures ANCOVAs, with treatment as a between-plot fixed effect, month as a within-plot fixed effect, and plot as a random effect. Treatments were compared using the Student's *t* test for pairwise comparisons (Steele and Torrie 1980). The JMP 6.0 program (SAS Institute 2005) was used for all statistical analyses.

Results and Discussion

Although annual and growing season precipitation in 2005 and 2006 exceeded the 30-yr averages, May and June 2005 and May 2006 had lower monthly precipitation than the averages (Table 4). This low water availability appeared to delay swallow-wort growth and development early in the season in both years on these relatively shallow soils, resulting in the wilting of plants (particularly in 2005). However, this early water stress did not appear to affect the growth of plants later in the season, perhaps because of the excess rainfall in the following 3 mo.

Our site had a relatively low pH (5.3) compared with other shallow, calcareous soils that swallow-wort is typically associated with in the Lower Great Lakes Region. In central NY, Sheeley (1992) reported a mean soil pH of 6.7 in a swallow-wort-infested forest understory and a pH of 7.0 in an open site. Lawlor (2000) found soil pH levels ranging from 5.9 to 7.2 in several central NY study sites and a pH of 8.0 at dredge fill sites. Clearly, swallow-wort has the ability to colonize and thrive in soils having a wide range of pH and this feature might, in part, explain its invasive success and expanding distribution.

At each sampling date following treatment applications, plots subjected to the triclopyr treatments differed significantly from plots receiving the clipping treatments and from the unmanaged control plots for all parameters measured, even after accounting for baseline data variation (Figure 1; Tables 3, 5). There were no differences between the triclopyr-only and the triclopyr + clipping treatments or between the single clipping treatment and the double clipping treatment at any of the three post-treatment collection dates for all parameters measured. Thus, our results did not support our original hypothesis that a combination of control methods would be more effective than either clipping or herbicide alone. Additionally, no differences were found between the clipping treatments and the unmanaged control in the percentage cover of swallow-wort or other vegetation, or in swallow-wort seedling densities. Although follicle production of swallow-wort was not quantified, follicles were produced by plants in all plots except those treated with triclopyr. In the unmanaged control plots, follicle production was high. Smith et al. (2006) reported that over 1,600 follicles/m^2) were produced by swallow-wort plants in a nearby heavily infested and unmanaged old-field site with stem densities ranging from 126 to 142 stems/m^2. Even in plots where vegetation was clipped twice during each growing season, some follicles were produced. However, regardless of clipping frequency, plants from clipped plots produced

Table 5. Observed post-treatment swallow-wort means (± SE) for stem and seedling densities after treatments were applied May 2005 (n = 7, unless otherwise noted).[a,b]

Date	Treatment	Swallow-wort density	
		Stems/m²	Seedlings/m²
September 2005	Control (no herbicide or clipping)	170 ± 20 b	960 ± 70 a
	Triclopyr	14 ± 10 c	210 ± 100 b
	Triclopyr + clipping 4 wk later	0 ± 0 c	110 ± 50 b
	Clipping once	180 ± 20 ab	1,210 ± 340[d] a
	Clipping twice	210 ± 10 a	1,030 ± 150 a
June 2006	Control (no herbicide or clipping)	170 ± 10 a	340 ± 70 a
	Triclopyr	40 ± 20 b	210 ± 120 ab
	Triclopyr + clipping 4 wk later	38 ± 6 b	40 ± 20 b
	Clipping once	200 ± 20 a	320 ± 120 a
	Clipping twice	200 ± 10 a	210 ± 50 ab
August 2006	Control (no herbicide or clipping)	190 ± 20 a	510 ± 190 ab
	Triclopyr	30 ± 10 b	290 ± 140 ab
	Triclopyr + clipping 4 wk later	NA	180 ± 50 b
	Clipping once	150 ± 20[d] a	660 ± 180 a
	Clipping twice	NA	610 ± 60 ab

[a] For each month, treatment means with the same letter in a column are not statistically different at the alpha = 0.05 significance level, according to a Student's t means comparison test.

[b] Abbreviations: NA, data not available.

[c] Seedlings < 10 cm in height were included in assessment.

[d] n = 6.

substantially fewer follicles than plants from the unmanaged plots.

Swallow-wort Cover and Stem Density. Although the effect of treatment on percentage cover varied by month ($P < 0.0001$) (Table 3), individual ANOVAs show that swallow-wort cover was 81% lower in plots treated with triclopyr compared with plots not receiving the herbicide ($P < 0.0001$ for each date) (Figure 1; Table 3). Similarly, at the end of another 2-yr study in central NY, the mean cover of swallow-wort in plots receiving foliar applications of triclopyr (1.9 kg ae/ha) was 72% lower than cover in nontreated control plots (Lawlor and Raynal 2002).

Stem density also varied by treatment and month ($P < 0.0001$) and the same trend that distinguished triclopyr-treated plots from those that did not receive a triclopyr application was observed (Tables 3, 5). Triclopyr-treated plots had 86% lower stem densities than nontriclopyr-treated plots. In September 2005, swallow-wort stem densities were greater in the twice-clipped plots than in the unmanaged control plots, a possible result of vegetative overcompensation by plants following the removal of a substantial portion of aboveground tissue (Benner 1988; Maschinski and Whitham 1989; Naber and Aarssen 1998). Unfortunately, because of logistical problems, swallow-wort stem density data for the double clipping and triclopyr + clipping treatments for the last sample date (August 2006) are not available. However, based on data from September 2005 and June 2006 and from personal observation of the first author (KMA), clipping was not likely to have substantially affected stem density levels relative to levels found 2 mo earlier (June 2006).

Christensen (1998) found that, although repeated mowing of swallow-wort during one growing season near Toronto, ON reduced average stem height, percentage cover was not affected because plants resprouted from root crown buds. The extensive, fibrous root system of swallow-wort is likely to persist for several years despite repeated removal of aboveground tissue via clipping or mowing (Christensen 1998). Thus, this management tactic when used alone will necessitate a long-term and substantial investment in labor, especially if the infestation is large. Although repeated clipping of swallow-wort during several growing seasons might eventually diminish its below-ground carbohydrate reserves, clipping is not an effective means of rapidly reducing swallow-wort cover or stem density. Based on our findings, treating plants with triclopyr, even if only once, can be a more effective strategy for decreasing swallow-wort cover and stem density than clipping.

Swallow-wort Seedling Density. An interaction effect was found between treatment and month for swallow-wort seedling density ($P < 0.0003$, repeated measures analysis; Table 3). Seedling densities in September 2005 were 85% lower in plots treated with triclopyr than in plots not receiving a triclopyr application (Table 5). However, the ANCOVA seedling density results for June and August 2006 showed no treatment effect (Table 3), despite some significant differences in means comparisons (Table 5). Plots treated with triclopyr + clipping had lower seedling densities in June than plots clipped once or the control plots, and lower densities in August than plots clipped once (Table 5). Clipping alone did not reduce seedling densities; seedlings might have regrown or dormant embryos in polyembryonic seeds might have been stimulated to germinate by the removal of aboveground tissue. Triclopyr used alone killed most plants, including seedlings, but, because of its low residual activity, other swallow-wort seeds might have germinated because of increased light availability. The lower seedling density for the triclopyr + clipping treatment could reflect the mortality of some newly emerged seedlings following clipping. That few differences in seedling densities were observed during the second year of the study is not surprising given that triclopyr is highly mobile in soil and has limited persistence (Cox 2000).

Overall, the management treatments reduced swallow-wort seedling densities by an average 54%. This result was expected because during both years of the study, all follicles were removed from plants in the experimental plots (including unmanaged control plots) to minimize the spread of seeds into a nearby sensitive and protected alvar community. Also, during the 2005 season, much of the area surrounding our field site was treated with triclopyr by Nature Conservancy personnel to suppress swallow-wort and minimize seed dispersal into the alvar community. Thus, the lower posttreatment swallow-wort seedling densities might have reflected this reduction in the seed rain and the limited supply of swallow-wort seeds in the seedbank. Swallow-wort seeds have been estimated to survive only about 4 yr in the soil (DiTommaso et al. 2005), thus further limiting the availability of viable seeds to the seedbank.

Interestingly, seedling densities were 60% higher at the end of each growing season than at the beginning of the second (2006) growing season. Spatial gaps created by vegetation control in the triclopyr treatments or a more open leaf canopy in the clipped treatments, resulting in increased light availability, might have stimulated swallow-wort seed germination during the growing season. Conversely, Smith et al. (2006) observed that swallow-wort seedling densities decreased during the growing season in an unmanaged site. This decrease was likely in response to density-dependent mortality (Harper 1977), because densities (up to 4,800 seedlings/m^2) attained carrying capacity for the site. Given that swallow-wort seedling densities were likely not near the carrying capacity at our study site, the increase in seedling density during the growing season likely was due to increased germination of seeds.

Other Vegetation Cover. There was a treatment by month interaction ($P = 0.006$) on the percentage cover of nonswallow-wort vegetation within plots (Figure 1; Table 3). In September 2005 and in June 2006, the percentage cover of other vegetation was 87% greater in triclopyr-treated plots than in plots not treated with triclopyr. However, in August 2006, this trend was not as clear. The percentage cover of other vegetation was 65% greater in plots treated with triclopyr alone than in plots not treated with triclopyr, but cover in the triclopyr + clipping plots did not differ from that in plots subjected to the two clippings. That recruitment of other species was lower in clipped plots relative to triclopyr treated plots suggests clipping might not be as an effective management strategy as triclopyr application, especially if restoration efforts are dependent on recruitment of favorable species from the existing seedbank. Generally, the increase in the percentage cover of other vegetation was correlated with a decrease in the cover of swallow-wort for approximately 1 yr after a single application of triclopyr in the absence of clipping. Thus, temporary dominance by other plants is likely to occur on sites where both swallow-wort density and coverage are reduced. Our finding is corroborated by observations from previous studies in New York and Ontario, assessing the efficacy of several herbicides to control swallow-wort. In these studies, the frequency and abundance of native and naturalized herbaceous species increased following the application of the most effective herbicides, including triclopyr (DiTommaso et al. 2005; Lawlor 2000).

Of the 41 species that emerged from soil samples collected in May 2005, 76% were herbaceous dicots and of the species identified, 62% were perennials (Table 6). Seedlings of the biennial herb, common mullein (*Verbascum thapsus* L.), comprised a large percentage (33%) of seedlings that emerged; other dominant species included sulfur cinquefoil (*Potentilla recta* L.) (14%), black medic (*Medicago lupulina* L.) (14%), swallow-wort (10%) and a fescue species (*Festuca* sp.) (8%). It is common to observe nonnative, often naturalized, plant species dominate inhospitable sites having low nutrient levels or shallow soils, such as at our site (e.g., Bastl et al. 1997; Pickett 1982). Nonnative plants constituted 77% of species identified from the seedbank samples and 71% were nonnative prior to the application of treatments in May 2005 (Table 6). Despite swallow-wort's relatively small presence in the seedbank, the percentage cover and dominance was high at this site. This observation is in accordance with swallow-wort being a highly aggressive competitor and possibly being able to alter the soil

Table 6. Mean (± SE) number of emerged seedlings and percentage of total emerged seedlings from soil collected at Chaumont, NY in May 2005 prior to the start of treatments ($n = 19$).

Life History	Species	Seedlings/m^3 (seedlings/ft)	% of total
Annual dicot	*Medicago lupulina* L.*	5,800 ± 500	14
Annual dicot	*Portulaca oleracea* L.*	800 ± 400	2
Annual dicot	*Erigeron annuus* (L.) Pers.	700 ± 100	1.6
Annual dicot	*Stellaria* sp.	500 ± 200	1.3
Annual dicot	*Stellaria media* (L.) Vill.*	200 ± 100	< 1
Annual dicot	*Capsella bursa-pastoris* (L.) Medik.*	150 ± 50	< 1
Biennial dicot	*Verbascum thapsus* L.*	14,000 ± 2,000	33
Biennial dicot	*Daucus carota* L.*	400 ± 100	< 1
Biennial dicot	*Barbarea vulgaris* Ait. f.*	120 ± 80	< 1
Biennial dicot	*Conyza canadensis* (L.) Cronq.	60 ± 30	< 1
Perennial dicot	*Potentilla recta* L.*	6,100 ± 600	14
Perennial dicot	*Vincetoxicum rossicum* (Kleopow) Barbar.*	4,100 ± 600	9.8
Perennial dicot	*Rumex acetosella* L.*	800 ± 500	2
Perennial dicot	*Cerastium vulgatum* L.*	500 ± 100	1.3
Perennial dicot	*Potentilla argentea* L.*	300 ± 90	< 1
Perennial dicot	*Trifolium repens* L.*	300 ± 80	< 1
Perennial dicot	*Hypericum perforatum* L.*	200 ± 90	< 1
Perennial dicot	*Solidago* sp.	200 ± 100	< 1
Perennial dicot	*Echium vulgare* L.*	100 ± 100	< 1
Perennial dicot	*Linaria vulgaris* P. Mill.*	90 ± 60	< 1
Perennial dicot	*Chrysanthemum leucanthemum* L.*	60 ± 30	< 1
Perennial dicot	*Rhus typhina* L.	15 ± 15	< 1
Perennial dicot	*Rumex obtusifolius* L.*	15 ± 15	< 1
Perennial dicot	*Taraxacum officinale* G. H. Weber ex Wiggers	15 ± 15	< 1
Perennial dicot	*Trifolium pratense* L.*	15 ± 15	< 1
Other dicot	Lamiaceae sp.	400 ± 100	< 1
Other dicot	Unidentified sp. 1	400 ± 400	< 1
Other dicot	Unidentified sp. 2	200 ± 100	< 1
Other dicot	*Chrysanthemum* sp.	140 ± 50	< 1
Other dicot	*Brassica* sp.	90 ± 40	< 1
Other dicot	*Verbena* sp.	50 ± 20	< 1
Annual monocot	*Panicum capillare* L.	1,200 ± 500	2.8
Perennial monocot	*Phalaris arundinacea* L.	200 ± 100	< 1
Perennial monocot	*Phleum pratense* L.*	110 ± 60	< 1
Perennial monocot	*Elytrigia repens* (L.) Desv. ex Nevski*	80 ± 40	< 1
Other monocot	*Festuca* sp.	3,200 ± 400	7.7
Other monocot	*Poa* sp.	500 ± 200	1.3
Other monocot	Unidentified grass	60 ± 6	< 1
Other monocot	Unidentified sedge 1	30 ± 20	< 1
Other monocot	*Panicum* sp.	15 ± 15	< 1
Other monocot	Unidentified sedge 2	15 ± 15	< 1

* Indicates a nonnative species.

microbial community (Greipsson and DiTommaso 2006; Smith et al. unpublished). Because yearly applications of the herbicide triclopyr likely would be necessary to suppress swallow-wort in heavily infested areas, these multiple applications could negatively impact nontarget plants in the treated area. Therefore, spot herbicide applications might be more appropriate in these areas to minimize the impact on nontarget plants.

Future Swallow-wort Control. It would be valuable in future swallow-wort research to include additional treatments that more accurately reflect current management practices, such as clipping followed by triclopyr application, or attempting to determine the optimal timing for mowing infested areas. Herbicide applications are generally made several weeks to months after mowing to allow for target plant regrowth (Beck and Sebastian 2000; Hunter 1996; Mislevy et al. 1999; Monteiro et al. 1999). Our aim in applying triclopyr prior to clipping in this study was to control for the effects of treatment timing. In future experiments, clipping treatments that precede herbicide applications should also be included. Additionally, the most appropriate time for mowing species such as swallow-wort that reproduce primarily by seed is just prior to seed maturation. Although our clipping treatments did not reduce swallow-wort cover or plant density relative to the unmanaged control treatment, a more appropriately timed clipping treatment has the potential to substantially minimize swallow-wort seed output. The viability of swallow-wort seeds collected at various stages of follicle development during the growing season has not been studied extensively, but a single mowing in late June is likely to reduce the probability that seeds produced after mowing have enough time to mature (McKague and Cappuccino 2005).

Active restoration of native plants at our site would be necessary to significantly change the current species composition and dominance following the successful control of swallow-wort. It is likely that if such steps are not taken, other resident nonnative species will rapidly occupy gaps created by the removal of swallow-wort. However, most of the nonnative species present at the site should be less problematic than not controlling the swallow-wort population.

Sources of Materials

[1] Garlon 4®, Dow AgroSciences LLC, 9330 Zionsville Rd., Indianapolis, IN 46268.

[2] Field King® backpack sprayer, The Fountain Group, Inc., D. B. Smith & Co., Inc. (Affiliate), Utica, NY 13501.

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