Noxious Weed Monitoring at the U.S. Air Force Academy- Year 3 Results

2005

2006

2007

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On the cover: Plot 2 of common St. Johnswort, where herbicide application appears to have eradicated this species.

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EXECUTIVE SUMMARY

This report summarizes the results of three years of population monitoring of targeted noxious weeds at the US Air Force Academy ("the Academy"), and evaluates the current monitoring program. In the summers of 2002 and 2003 the Colorado Natural Heritage Program (CNHP) mapped 14 selected noxious weeds found on the Academy and the Farish Outdoor Recreation Area ("Farish"). The project was undertaken to provide the Academy Department of Natural Resources with information on noxious weeds to serve as the basis for the development of a formal Integrated Weed Management Plan for Academy properties, and to meet the requirements of a comprehensive weed management plan.

In 2004, an Integrated Noxious Weed Management Plan was produced for the Academy. This plan designated 14 noxious weed species as targets for eradication, suppression, or containment. The plan stipulated a monitoring program to measure the effectiveness of management efforts at the Academy and to provide some measure of progress towards meeting goals for weed management and eradication.

In 2005, CNHP established a monitoring program for 13 species of noxious weeds at the Academy (Russian knapweed, hoary cress, musk thistle, diffuse knapweed, spotted knapweed, Canada thistle, bull thistle, Fuller's teasel, Russian olive, leafy spurge, common St. Johnswort, yellow toadflax, and Scotch thistle). This program was established following the guidelines provided in the Academy's Integrated Noxious Weed Management Plan. Permanent baseline monitoring plots were established for 10 of the target species (Russian knapweed, hoary cress, musk thistle, diffuse knapweed, Canada thistle, bull thistle, Fuller's teasel, leafy spurge, common St. Johnswort, and yellow toadflax). Three permanent plots were established for 11 of the 13 species (all except Russian knapweed and common St. Johnswort). The permanent plots employed combinations of photopoints, transects with quadrats, belt transects, perimeter mapping, and photopoints. The methods used were contingent upon the growth form and distribution pattern of each species.

In 2006, all permanent plots established in 2005 were resampled. Another species, myrtle spurge (*Euphorbia myrsinites*) was added to the monitoring program because it is listed on Colorado's A list (requiring eradication). Significant change was observed in most permanent plots between 2005 and 2006. This appears to be the result of climatic variation between years in most cases because most plots were not treated.

Post-hoc power analysis in 2006 indicated that power to detect the minimum detectable change required in the management plan was sufficient in all but one of the twelve permanent plots employing quadrat sampling. To improve the sensitivity of these plots to change and minimize the risk of Type II errors, the sampling intensity was doubled at these plots for the target species.

In 2007 all permanent plots were resampled a third time. The data from the first three years are analyzed and discussed in this report, and recommendations for continued monitoring are offered based on these results.

Most noxious weeds targeted in this study were strongly influenced by climate variation. Cover and density were highest in 2005 for many species, and dropped precipitously in 2006 as a result of drought conditions. Many species rebounded somewhat in 2007 after the relatively wet monsoon season of 2006 and a wet spring in 2007.

Management efforts took place at almost half (15 of 31) of the permanent plots at some time within the three year period. At 12 of the 15 treated plots, management efforts appear to have been effective in achieving weed management goals, although in some cases it is difficult to determine the degree to which the observed signal is the result of management versus climate variation. In six of the treated plots, a significant portion of the infestation remained untreated. Management efforts for common St. Johnswort and Russian olive appear to have been highly effective, while management efforts for leafy spurge and spotted knapweed have had limited success. While progress was made at some plots towards meeting weed management goals, these goals have not been achieved base-wide for any species, as indicated by the comprehensive weed map completed in 2007.

Ongoing management efforts must continue, and in some cases must be modified or increased, to meet stated weed management objectives at the Academy and Farish. We recommend continued monitoring to measure progress towards meeting these objectives, using modifications of the approaches heretofore applied in this study. The most effective monitoring has involved the use of census techniques to map and assess entire weed populations at the Academy. Continuing the quantitative vegetation sampling, perimeter mapping, and photopoint monitoring is recommended in several cases where these techniques can address specific management questions. Implementing a natural resource-based monitoring program in concert with the existing monitoring program is likely to provide valuable feedback for management.

INTRODUCTION

Weeds are known to alter ecosystem processes, degrade wildlife habitat, reduce biological diversity, reduce the quality of recreational sites, reduce the production of crops and rangeland forage plants, and poison livestock (Sheley and Petroff 1999). All of these impacts are occurring in Colorado (Colorado Department of Agriculture 2001). In recognition of their enormous detriments to our society and environment, many local governments now require public and private landowners to manage noxious weeds. The U.S. Air Force Academy (referred to herein as "the Academy") must conform to state (Colorado Department of Agriculture Plant Industry Division 2005) and county (El Paso County 2007) weed control regulations for noxious weeds. The Academy has also established management objectives for weed control in order to remain compliant with local weed regulations.

The Academy and the Farish Outdoor Recreation Area ("Farish") are near Colorado Springs, Colorado (Figure 1) and are important for biodiversity conservation locally and globally. The Academy has become increasingly insular and, like many military installations, it has become increasingly important for conservation as natural landscapes elsewhere in the area are developed and altered. In all, at least 30 plants, animals, and plant communities of conservation concern are found at the Academy and Farish, including Porter's feathergrass (*Ptilagrostis porteri*), a globally imperiled endemic of Colorado, and Southern Rocky Mountain cinquefoil (*Potentilla ambigens*), found only in Colorado and New Mexico (Spackman Panjabi and Decker 2007, Colorado Natural Heritage Program 2008). The Academy is critically important for the conservation of the listed threatened Preble's meadow jumping mouse (*Zapus hudsonius preblei*) (Colorado Natural Heritage Program 2008). Noxious weeds threaten the viability of conservation targets by competing for resources and altering the structure and function of the ecosystems they invade. They also increase the cost while diminishing the likelihood of success of restoration efforts.

History of Weed Mapping and Monitoring at the Academy

In 2002 and 2003, the Colorado Natural Heritage Program (CNHP) mapped selected noxious weeds found at the Academy and Farish (Anderson et al. 2003). The project was undertaken to provide the U.S. Air Force Academy Department of Natural Resources with information on noxious weeds to serve as the basis for development of a formal Integrated Weed Management Plan, and to meet the requirements of a comprehensive management plan. In 2002, 3,936 infestations were mapped for 14 target species at the Academy and Farish, and additional infestations were mapped in 2003.

In 2004, an integrated noxious weed management plan was developed based largely on the results of the weed mapping exercise (Carpenter et al. 2004). The purpose of this plan is to guide the management of noxious weeds at the Academy and Farish in the most efficient and effective manner. This plan supports the 2003-2008 *Integrated Natural Resources Management Plan* for the Academy. The plan set weed management objectives (Table 1) and recommended weed management protocols for the Academy and Farish. The plan also underscored the importance of monitoring weed infestations as a means of measuring the effectiveness of management practices, and recommended monitoring protocols.

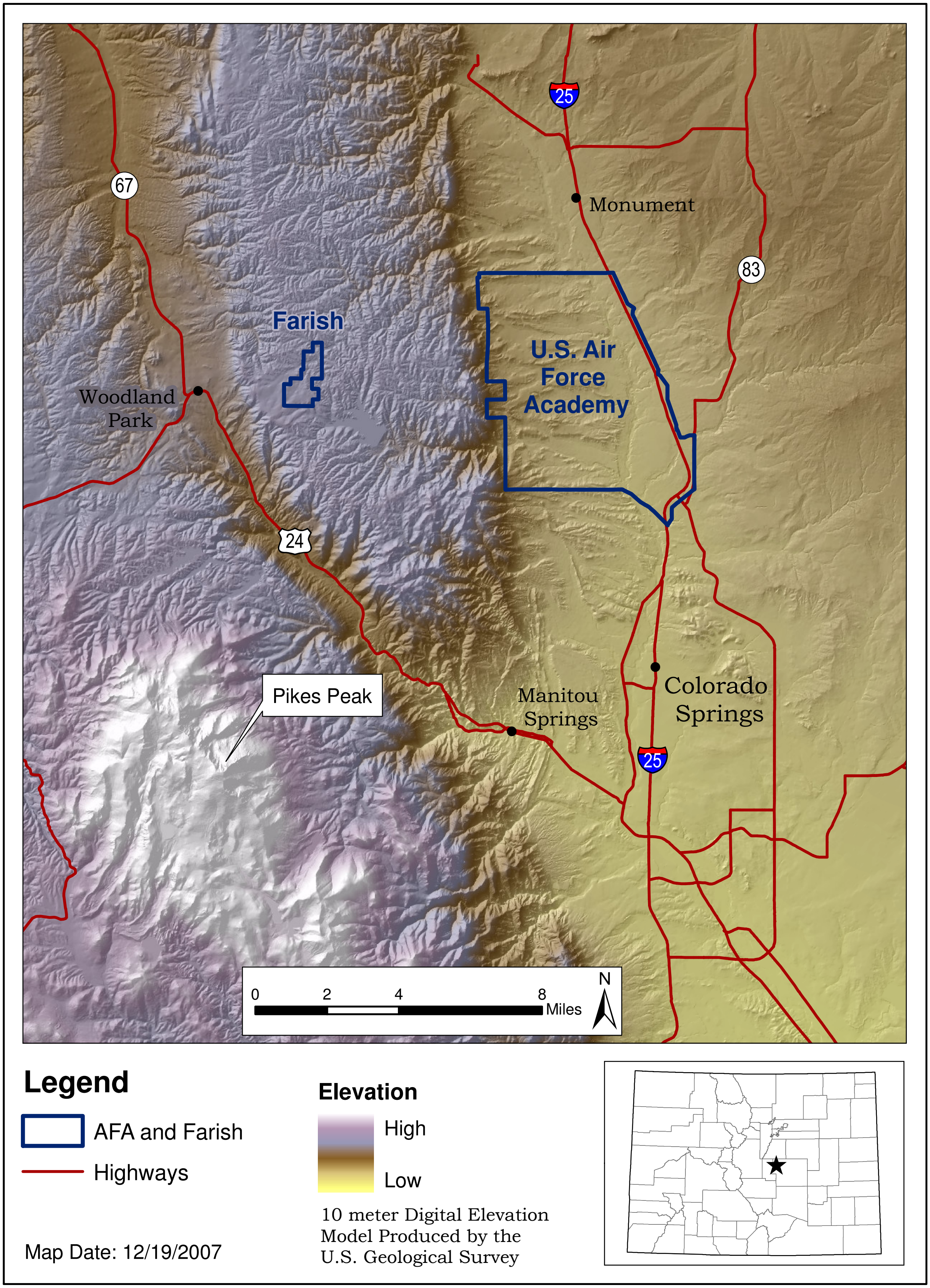

Figure 1. Vicinity map for the U.S. Air Force Academy and the Farish Memorial Recreation Area, El Paso County, Colorado.

Table 1. Noxious weed management objectives for species targeted in this study (from Carpenter et al. 2004). Myrtle spurge was not included in the management plan, but since it is on Colorado's A list of noxious weeds, eradication is required.

Species	**Weed Management Objective**	**Recommended Reduction**	**Prioritization**	**Action**
Russian knapweed	Eradicate	100%	All	Eliminate all plants
Scotch thistle	Eradicate	100%	All	Eliminate all plants
Spotted knapweed	Eradicate	100%	All	Eliminate all plants
Hoary cress	Suppress	90%	All	Reduce canopy cover
Musk thistle	Suppress	50%	All	Prevent all seed dispersal
Diffuse knapweed	Suppress	50%	All	Reduce density
Canada thistle	Suppress	50%	High Priority Areas	Reduce canopy cover
Bull thistle	Suppress	90%	All	Prevent all seed dispersal
Fuller's teasel	Suppress	50%	All	Prevent all seed dispersal
Russian olive	Suppress	90%	All	Reduce density
Leafy spurge	Suppress	90%	All	Reduce canopy cover
Common St. Johnswort	Suppress	90%	All	Reduce canopy cover
Yellow toadflax	Suppress/ Containment	50%	High Priority Areas	Reduce canopy cover
Myrtle spurge	Eradicate	100%	All	Eliminate all plants

Weed management priorities have been set for the Academy and Farish that are based primarily on four factors: 1) current status on State and County noxious weed lists, 2) current prevalence at the Academy or Farish and cost effectiveness of management, 3) potential invasiveness, and 4) the threat posed to significant natural resources (Anderson et al. 2003, Carpenter et al. 2004, Spackman Panjabi and Decker 2007). For example, myrtle spurge is given a high priority for management due to its status as a List A species, for which eradication is required by State Law. However, common St. Johnswort is also given a high priority for management; although State and County weed management statutes do not require eradication of this species, its distribution at the Academy is localized and eradication is feasible at present. This species is also a threat to significant natural resources at the Academy.

In 2005, a monitoring program for 13 species of noxious weeds (Russian knapweed (*Acroptilon repens*), hoary cress (*Cardaria draba*), musk thistle (*Carduus nutans*), diffuse knapweed (*Centaurea diffusa*), spotted knapweed (*Centaurea maculosa*), Canada thistle (*Cirsium arvense*), bull thistle (*Cirsium vulgare*), Fuller's teasel (*Dipsacus fullonum*), Russian olive (*Elaeagnus angustifolia*), leafy spurge (*Euphorbia esula*), common St. Johnswort (*Hypericum perforatum*), yellow toadflax (*Linaria vulgaris*), and Scotch thistle (*Onopordum acanthium*)) was established at the Academy. Of the 13 species targeted for monitoring in this study, 12 are species that had been mapped in 2002 and 2003. A total of 14 species were mapped in 2002 and 2003, but two species (Tamarisk, *Tamarix ramosissima*, and field bindweed, *Convolvulus arvensis*) were not targeted for monitoring. Tamarisk was not targeted for monitoring because the single plant discovered in 2002 had been destroyed and there had been no new reports of this species at the Academy. Field bindweed was not targeted for monitoring because it occurs sporadically in relatively small infestations in a limited area of the Academy, mostly near infrastructure. Russian knapweed was discovered at the Academy in 2004, so it was not mapped in 2002 and 2003 but is included as a monitoring target because of its legal status and invasiveness.

In 2006, all permanent monitoring plots established in 2005 were resampled. A fourteenth species, myrtle spurge (*Euphorbia myrsinites*) was added to this study because it is listed on Colorado's A List of noxious weeds, and eradication of this species is required under state law (Colorado Department of Agriculture 2005). It was discovered at the Academy in 2005 by Natural Resources staff. In 2007, the monitoring plots were sampled a third time. The first three years of data from this project were analyzed and are presented in this report.

Weed Mapping in 2007

In addition to the third year of noxious weed monitoring, CNHP completed a weed map of the Academy and Farish in 2007, completely revising the baseline weed survey completed in 2002 and 2003 for most target species. The results of this project are presented in a companion report (Anderson and Lavender 2008).

As defined by Elzinga et al. (1998), monitoring is the collection and analysis of repeated observations in order to evaluate changes and progress toward meeting management objectives. Therefore, the revision of the weed map can also be considered a monitoring exercise in a sense. Although there is considerable overlap between the weed map project and the weed monitoring project, we have reported the results of these projects separately. While much of the monitoring has focused on intensive study of a small number of permanent plots, the mapping has focused on the entire Academy and Farish, so we felt that reporting the results of these studies separately would help the reader by making the results of each study more accessible. However, the methods employed to monitor spotted knapweed, Russian olive, and Scotch thistle are similar to those used to map all other targeted species in 2007, so there is much overlap between the two reports for these species.

Purpose of This Report

As noted by Carpenter et al. (2004), the purpose of a weed monitoring program is to provide a rational basis for determining if weed management actions are effective in moving toward the weed management objectives. Carpenter et al. (2004) recommended annual weed monitoring and analysis of monitoring data for three consecutive years once a monitoring program is initiated. Thereafter, weed management actions for the forthcoming year can be changed, as needed, if indicated by the results of the monitoring. Those monitoring activities that are deemed relevant and most effectively and economically inform weed management activities should be continued, while those that are less valuable or relevant should be discontinued or modified. They noted that the results of the first three years of monitoring should indicate whether annual sampling was needed, or whether resampling less frequently would be sufficient for each target species, acknowledging that the needs of each species are likely to be different.

This report addresses two goals. The first is to present a summary and analysis of the first three years of monitoring data for the Academy. The second is to present an evaluation of the program and recommendations for continued monitoring based on these data, as recommended by Carpenter et al. (2004). To facilitate the readability and usefulness of this report each target species is treated in a separate section, in which a data summary, analysis, and recommendations for continued monitoring are included.

METHODS

This project was undertaken to evaluate the effectiveness of ongoing management of noxious weeds at the Academy, and to determine whether weed management objectives are being met. The recommendations for the design and deployment of monitoring plots offered by Carpenter et al. (2004) were adhered to closely in this study. The monitoring program at that Academy has utilized a combination of permanent plots and census techniques, as recommended by Carpenter et al. (2004). A total of 31 permanent plots are randomly distributed in weed infestations of 11 target species throughout the Academy (Figure 2). Because of differences in management goals (Table 1) and the habit and ecology of each target species, several different sampling methods were required (Table 2). Three other target species (spotted knapweed, Russian olive, and Scotch thistle) have been monitored without permanent plots by mapping and assessing all infestations periodically.

For five species (Canada thistle, common St. Johnswort, Russian knapweed, whitetop, and yellow toadflax), cover was quantified using $1m^2$ quadrats along permanent transects. Initially, each transect included 10 quadrats, but this number was doubled in 2006 when power analysis indicated that the risk of type II error was unacceptable at two plots (Anderson and Lavender 2007). The cover data from these plots were analyzed using paired T-tests. Because there were only 10 quadrats per plot in 2005, the 2005 data were compared with their corresponding 10 quadrats resampled in 2006, and the 2006 data were compared with all 20 quadrats sampled in 2007.

Density of diffuse knapweed was quantified at three permanent plots using belt transects in which individuals were counted. The methods used to monitor diffuse knapweed were also improved in 2006 (see Anderson and Lavender 2007).

Leafy spurge was monitored using a system of systematic survey transects and perimeter mapping at three sites to observe the rate and likelihood of spread within those sites. These sites are in or near areas where scrub oak (*Quercus gambelii*) biomass was managed with hydroax treatment.

Three species (musk thistle, bull thistle, and Fuller’s teasel) were monitored by sampling photopoints at three permanent plots for each species. Myrtle spurge was also monitored in this way, but all infestations of this species were perimeter mapped and censused annually as well.

See Anderson and Lavender (2006) and Anderson and Lavender (2007) for details regarding the selection and establishment of plots and the methodology employed for each sampling technique in this study. Sampling techniques for each target species are summarized in Table 2.

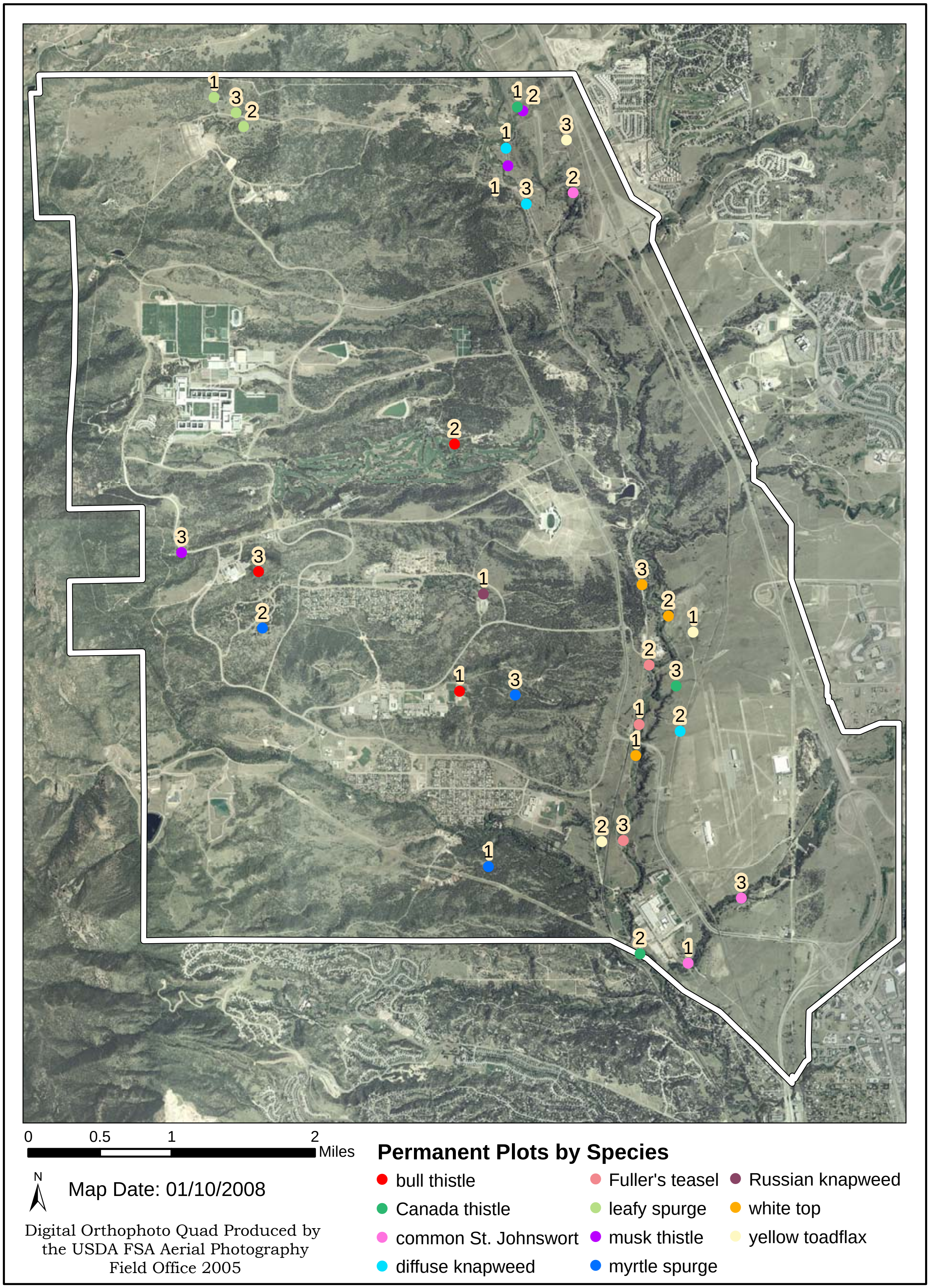

Figure 2. Locations of all permanent monitoring plots established in 2005 and 2006.

Table 2. Summary of sampling methods used at permanent plots in 2005 through 2007. Changes implemented in 2006 are indicated in bold.

Species	**Sampling Methods**	**Plot 1**	**Plot 2**	**Plot 3**
Russian Knapweed	*Transect/ photopoint/ photoplot/ perimeter mapping*	25 m transect w/ **20** quadrats, 5 photoplots, 3 photopoints	N/A	N/A
Whitetop	*Transect/ photopoint/ photoplot*	50 m transect, **20** quadrats, 5 photoplots, 2 photopoints	50 m transect, **20** quadrats, 5 photoplots, 2 photopoints	50 m transect, **20** quadrats, 5 photoplots, 2 photopoints
Musk Thistle	*Photopoint*	1 photopoint	1 photopoint	1 photopoint
Diffuse knapweed	*Belt Transects/ photopoints*	4 25 m belt transects, **each divided into five segments**, 2 photopoints	4 25 m belt transects, **each divided into five segments**, 2 photopoints	4 25 m belt transects, **each divided into five segments**, 2 photopoints
Canada Thistle	*Transect/ photopoint/ photoplot*	50 m transect, **20** quadrats, 5 photoplots, 2 photopoints	50 m transect, **20** quadrats, 5 photoplots, 2 photopoints	50 m transect, **20** quadrats, 5 photoplots, 2 photopoints
Bull Thistle	*Photopoint*	1 photopoint	1 photopoint	1 photopoint
Fuller's Teasel	*Photopoint*	1 photopoint	2 photopoints	1 photopoint
Leafy Spurge	*Perimeter mapping/ survey transects/ photopoint*	Perimeters mapped, 5 E-W survey transects spaced 20m apart, one photopoint	Perimeters mapped, 4 E-W survey transects spaced 20m apart, one photopoint	Perimeters mapped, 4 E-W survey transects spaced 20m apart, one photopoint
Common St. Johnswort	*Transect/ photopoint/ photoplot/ perimeter mapping*	2 photopoints, perimeter mapping. *Rationale:* excessive poison ivy precluded the use of transect method	25 m transect w/ **20** quadrats, 5 photoplots, 3 photopoints, perimeter mapping	25 m transect w/ **20** quadrats, 5 photoplots, 2 photopoints, perimeter mapping
Yellow Toadflax	*Transect/ photopoint/ photoplot*	25 m transect, **20** quadrats, 5 photoplots, 2 photopoints	25 m transect, **20** quadrats, 5 photoplots, 2 photopoints	25 m transect, **20** quadrats, 5 photoplots, 2 photopoints
Myrtle Spurge	***Perimeter mapping/ photopoint***	**Perimeter mapping, 1 photopoint**	**Perimeter mapping, 2 photopoints**	**Perimeter mapping, 1 photopoint**

RESULTS AND RECOMMENDATIONS

Cover and density of the target species were strongly affected by climate in this study. Total annual precipitation from 2005 through 2007 was drier than average (Table 3). In 2005, monthly growing season precipitation was 31% to 93% of the average. This was followed by a somewhat dry winter and an extremely dry spring in 2006. This had an especially noticeable impact on whitetop, which was barely detectable in parts of the three permanent plots in June of 2006 (see the whitetop section below for details). In July of 2006, conditions changed dramatically. There were frequent heavy monsoon thunderstorms in July and August of 2006 which caused flood conditions along Monument Creek (which decimated most of the monitored populations of Fuller's teasel in this study). July's total precipitation was 150% of the average in 2006. This moisture resulted in exceptional wildflower displays in late summer of 2006, and especially in the spring of 2007. Many noxious weed monitoring targets at the Academy responded to these conditions by showing high cover/ density in 2005, followed by extremely low cover/density in 2006, and a rebound in 2007. Results specific to each species are summarized in the following sections.

Treatments were applied sporadically and unpredictably to the permanent plots (Table 4). Almost half of the plots (15 of 31) received some sort of treatment between 2005 and 2007. In six of the treated plots, a significant portion of the infestation remained untreated. Only one of the infestations monitored at a permanent plot was eradicated due to management efforts (common St. Johnswort plot 2), although some other plots showed significant success in decreasing density, especially the two treated Canada thistle plots.

Table 3. Summary data for monthly precipitation (in inches) at Colorado Springs, Colorado from 2005 through September 2007 (Western Regional Climate Center 2008).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
2005	0.8	0	1	1.1	0.7	2.1	1.9	2.7	0.7	0.5	0.1	0.3	11.86
2006	0.2	0	0.2	0.1	0.8	0.8	4.4	3.5	1.5	1.6	0.2	0.4	13.84
2007	0.3	0.2	0.7	1.9	2.4	0.9	1.7	2.7	0.4	nd	nd	nd	11.06
Mean (1948-2007)	0.3	0.3	0.9	1.4	2.2	2.3	2.9	2.9	1.2	0.8	0.5	0.3	16.08

Table 4. Summary of treatments applied at the permanent monitoring plots from 2005 through 2007. Herbicide treatments are coded yellow, biocontrol treatments are coded blue, pulling is coded orange, and mowing is coded green. Affected quadrat numbers are in parentheses where a plot sampled for cover was partially treated.

	plot 1			plot 2			plot 3		
	2005	**2006**	**2007**	**2005**	**2006**	**2007**	**2005**	**2006**	**2007**
Acroptilon repens **(Russian Knapweed)**	herbicide (4-10)	no Tx	no Tx	x	x	x	x	x	x
Cardaria draba **(Whitetop)**	no Tx	no Tx	no Tx	no Tx	no Tx	no Tx	no Tx	no Tx	no Tx
Cirsium arvense **(Canada Thistle)**	no Tx	herbicide	no Tx	no Tx	herbicide (1-9)	no Tx	no Tx	no Tx	no Tx
Hypericum perforatum **(Common St. Johnswort)**	biocontrol	biocontrol	biocontrol	herbicide	no Tx	no Tx	biocontrol	biocontrol	biocontrol
Linaria vulgaris **(Yellow Toadflax)**	no Tx	no Tx	no Tx	no Tx	no Tx	no Tx	no Tx	no Tx	no Tx
Centaurea diffusa **(Diffuse Knapweed)**	no Tx	no Tx	no Tx	no Tx	no Tx	no Tx	no Tx	no Tx	mowing (in part)
Carduus nutans **(Musk Thistle)**	no Tx	herbicide	no Tx	no Tx	herbicide	no Tx	herbicide	no Tx	herbicide
Cirsium vulgare **(Bull Thistle)**	no Tx	no Tx	no Tx	no Tx	no Tx	no Tx	no Tx	no Tx	no Tx
Dipsacus fullonum **(Fuller's Teasel)**	no Tx	affected by flood	affected by flood	no Tx	affected by flood	affected by flood	no Tx	affected by flood	affected by flood
Euphorbia esula **(Leafy Spurge)**	no Tx	no Tx	no Tx	herbicide	no Tx	herbicide	no Tx	no Tx	herbicide (in part)
Euphorbia myrsinites **(Myrtle Spurge)**	x	pulled	no Tx	pulled (in part)	No Tx	no Tx	herbicide	no Tx	no Tx

Permanent Monitoring Plots With Transects

Acroptilon repens (Russian Knapweed)

Species	Sampling Methods	Plot 1	Plot 2	Plot 3
Russian knapweed	*Transect/ photopoint/ photoplot/ perimeter mapping*	25 m transect w/ 20 quadrats, 5 photoplots, 3 photopoints	N/A	N/A

The area occupied by Russian knapweed was approximately .03 acres in 2007 (Anderson and Lavender 2008). The area occupied decreased following the application of herbicide in 2005 and 2006 (Table 4). However, this species remains extant at the largest infestation north of the Skills Development Center where plot 1 is located (Table 5). A broadleaf herbicide was applied at plot 1 for Russian knapweed just prior to baseline sampling in 2005. However, the treatment was applied to only a portion of the infestation, leaving the rest untreated. Russian knapweed did not reappear in the treated area in 2006 or 2007 at this location, but it remained extant in the untreated area. High water in 2007 appeared to have extirpated the western portion of the infestation where it had been growing within a stand of coyote willow. In late 2005 or early 2006, restoration work was done where a road passed through the infestation. New topsoil was added and a seed mix was applied consisting of native and non-native grasses. No Russian knapweed was detected within the restored area in 2007.

Russian knapweed was also observed in small numbers along Douglass Drive prior to this study. Efforts to eradicate this infestation were already underway in 2005. Approximately ¼ mile of the road was surveyed in the area in 2005-2007 to monitor the status of this infestation. Plants were observed in 2005 and 2006, and evidence of treatment with herbicide was observed in both years (Figure 3 and 4). On June 8, 2007 no plants were seen at this location in 20 minutes of searching.

Table 5. Summary data for the Russian knapweed permanent plot in 2005-2007. P values are for paired T-tests comparing 2006 with 2005 and 2007 with 2006.

	2005	**2006**	**2007**
average % cover	3.35	4.9	2.5
sd	5.17	8.93	4.27
P		0.650	0.079

Figure 3. Withered stems of Russian knapweed following application of herbicide. This patch was observed adjacent to the west guard rail along Douglass Drive on June 4, 2005. Plants were not seen at this location in 2006 and 2007.

Figure 4. This photo, taken June 8, 2007, shows a site along Douglass Drive where Russian knapweed was detected in 2005 and 2006. Herbicide was applied to the infestation in late 2006 or early 2007 (note the dead smooth brome and coyote willow at center frame), and appears to have been successful.

Recommendations for Russian Knapweed:

Further monitoring of all Russian knapweed sites is needed to ensure that this species is eradicated from the Academy. There is no need to continue sampling the transect at Plot 1. Annual surveys and perimeter mapping will provide the information needed to eradicate this species from the Academy given the current status of this species. If this species spreads into other areas or its population begins to increase rapidly, the monitoring needs for this species will need to be reassessed.

Cardaria draba (Whitetop)

Species	Sampling Methods	Plot 1	Plot 2	Plot 3
Hoary cress	*Transect/ photopoint/ photoplot*	50 m transect, 20 quadrats, 5 photoplots, 2 photopoints	50 m transect, 20 quadrats, 5 photoplots, 2 photopoints	50 m transect, 20 quadrats, 5 photoplots, 2 photopoints

May and June were extremely dry in 2006, which had obvious effects on most species that year (Figure 5). However, whitetop cover was less affected than cover of some other native species at the three permanent plots, many of which were not seen in 2006 (e.g., *Achillea lanulosa*) or were only measurable in trace amounts (e.g., *Hesperostipa comata*).

No treatment with herbicides occurred at any monitored infestation of whitetop between 2005 and 2007 (Table 4). Therefore, the change in population size observed at these sites is entirely due to annual climatic variation and other ecological factors. Percent cover of whitetop declined in all three plots in 2006, and increased again in 2007 (Figure 6, Table 6).

Figure 5. Photoplot #4 at whitetop plot 3 in 2006 and 2007. In the 2006 photo, whitetop is visible next to the pinecone in the upper right.

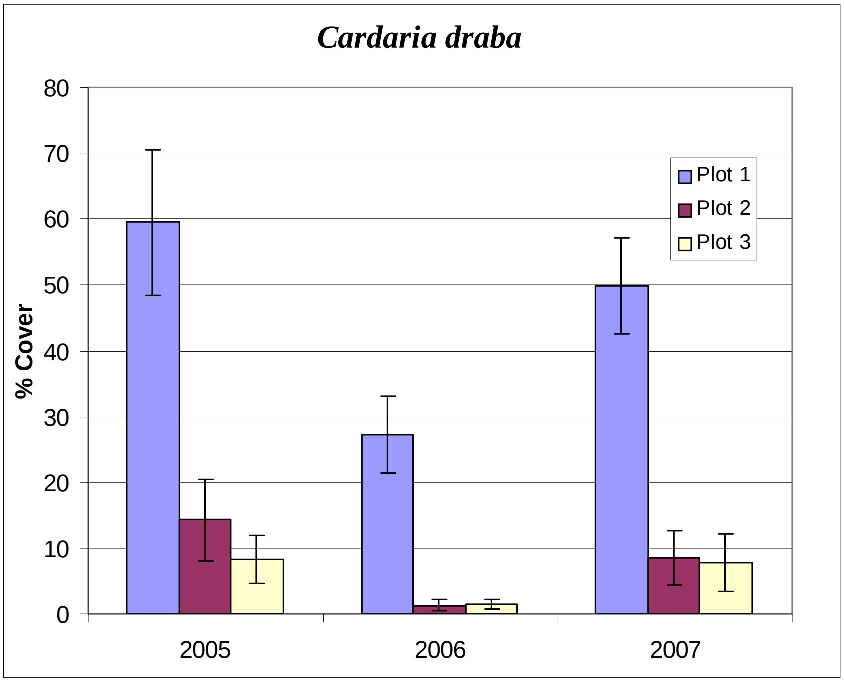

Figure 6. Average percent cover of whitetop in 2005-2007 at the three permanent plots. Error bars are 90% confidence intervals around the mean.

Table 6. Summary data for the three whitetop plots in 2005-2007. P values are for paired T-tests comparing 2006 with 2005 and 2007 with 2006.

		2005	2006	2007
Plot 1	**average % cover**	59.5	27.3	49.9
	sd	21.18	11.20	13.94
	P		<0.001	<0.001
Plot 2	**average % cover**	14.3	1.3	8.525
	sd	11.97	1.74	7.84
	P		0.007	0.001
Plot 3	**Average % cover**	8.2	1.375	7.85
	sd	7.00	1.44	8.45
	P		0.009	0.001

Recommendations for Whitetop:

1. Begin herbicide treatment in the vicinity of plots 1 and 2 in 2008, leaving plot 3 untreated.

2. Resume annual monitoring in 2009 to assess the effectiveness of treatment applications.

Centaurea diffusa (Diffuse Knapweed)

Species	Sampling Methods	Plot 1	Plot 2	Plot 3
Diffuse knapweed	*Belt Transects/ photopoints*	4 25 m belt transects, each divided into five segments, 2 photopoints	4 25 m belt transects, each divided into five segments, 2 photopoints	4 25 m belt transects, each divided into five segments, 2 photopoints

In 2007 density (plants/m^2) of diffuse knapweed was extremely high in places, with small juvenile plants forming almost a turf in some infestations. It appears that recent climate patterns have allowed density to increase and have caused this species to spread at the Academy. Anderson and Lavender (2008) illustrate the degree to which this species has increased over the last five years. At plots 1 and 2, density increased in 2007, but density declined at plot 3 (Figure 7, Table 7). Plots 1 and 2 were not treated between 2005 and 2007. A strip along the west side of plot 3 was mowed prior to sampling in 2007, which evidently resulted in a considerable reduction of density at this location compared with 2006 (Figure 8). Mowing, though impractical for most knapweed infestations, may be an effective means of managing this species at the Academy along the railroad right-of-way and roadsides. The railroad appears to be a major corridor for the dispersal of diffuse knapweed throughout the Academy, so intensive management of infestations there may provide benefits base-wide.

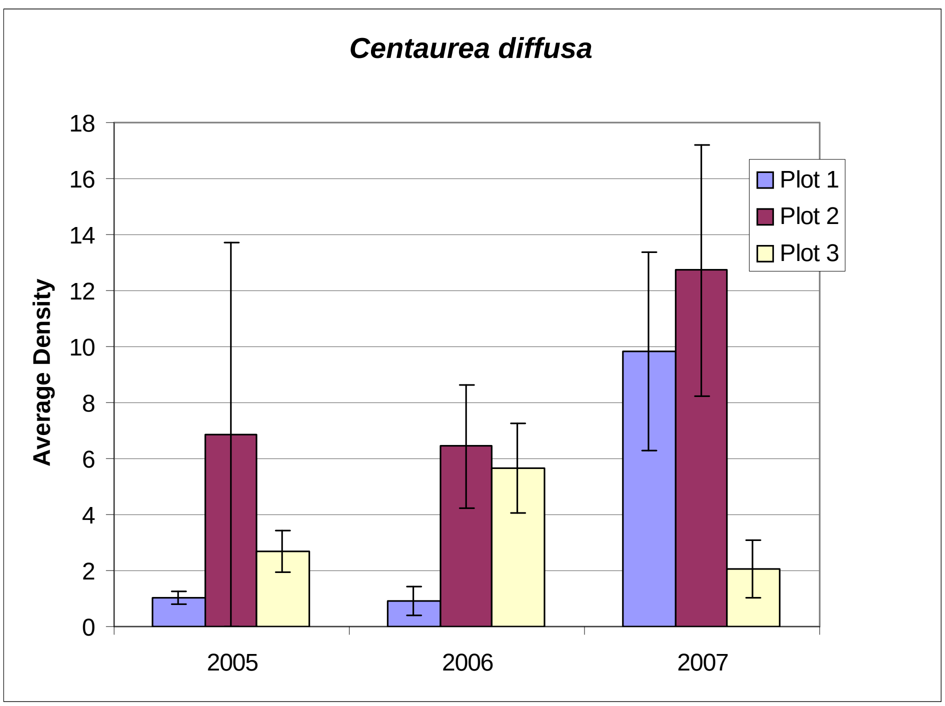

Figure 7. Average density of diffuse knapweed in 2005-2007 at the three permanent plots. Error bars are 90% confidence intervals around the mean.

Table 7. Summary data from permanent monitoring plots for diffuse knapweed.

		2005	2006	2007
Plot 1	**average density (plants/m^2)**	1.02	0.92	9.83
	SD	0.29	1.41	9.59
	N (*C. diffusa*)	153	138	1475
	N (Hybrids)	0	19	24
Plot 2	**average density (plants/m^2)**	6.85	6.44	12.73
	SD	8.32	5.98	12.16
	N (*C. diffusa*)	771	966	1909
	N (Hybrids)	0	92	160
Plot 3	**average density (plants/m^2)**	2.68	5.68	2.05
	SD	0.89	4.35	2.77
	N (*C. diffusa*)	302	809	292
	N (Hybrids)	0	27	1

Figure 8. Monitoring photo from plot 3 for diffuse knapweed, illustrating the effectiveness of mowing in reducing cover and removing seed. Diffuse knapweed density was very low in the mowed area to the right of the meter tape.

Recommendations for Diffuse Knapweed:

More targeted treatment is needed to control this species at the Academy. An appropriate mowing regime along rights-of-way may help mitigate the spread of this species to other areas of the Academy. Mowing higher up the railroad cuts might decrease the cover along railroad rights-of-way.

Because mowing appears to decrease diffuse knapweed density, we recommend taking the opportunity to investigate the effectiveness of this practice on managing this species along railroad right-of-ways at the Academy. If mowing can be done along the railroad rights-of-way north of Northgate Boulevard in the summer of 2008, plots 1 and 3 can be compared with plot 2 in 2009 to assess the effectiveness of this management practice in achieving management goals.

Centaurea diffusa X maculosa (Diffuse/ Spotted Knapweed Hybrids)

Diffuse and spotted knapweed are hybridizing along the Palmer divide (Beck personal communication 2007). The prevalence of hybrid plants increased from 2002 to 2007 at the Academy. Hybrids were observed in low numbers in the vicinity of the three permanent plots for diffuse knapweed in 2005, but none were found within plots that year (Figure 9). However, they were observed in 2006 and 2007. Because hybrids were not detectable in the vegetative state, it is likely that the actual density of hybrids was higher at the three permanent plots.

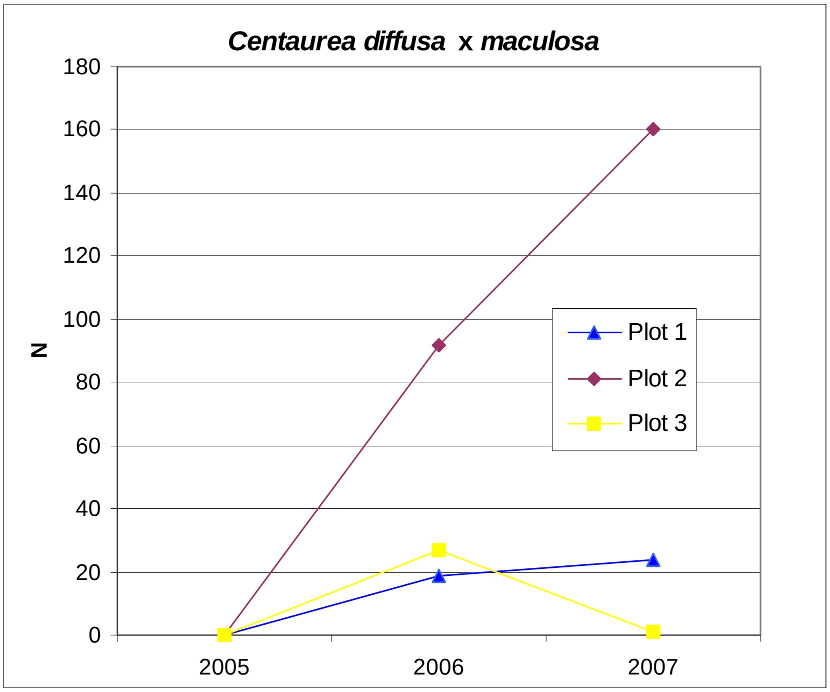

Figure 9. Number of hybrid knapweeds observed at each permanent plot in 2005-2007.

Recommendations for Diffuse/Spotted Knapweed Hybrids:

Continue to measure the prevalence of hybrids at the permanent plots for diffuse knapweed, and document their presence when observed elsewhere as a part of the monitoring for spotted knapweed. It is not known whether biocontrols for diffuse and spotted knapweed are effective against the hybrids. It may be possible to observe the response of hybrids to biocontrols in plots established by Michels et al. (2004) at the Academy.

Cirsium arvense (Canada Thistle)

Species	Sampling Methods	Plot 1	Plot 2	Plot 3
Canada thistle	*Transect/ photopoint/ photoplot*	50 m transect, 20 quadrats, 5 photoplots, 2 photopoints	50 m transect, 20 quadrats, 5 photoplots, 2 photopoints	50 m transect, 20 quadrats, 5 photoplots, 2 photopoints

Canada thistle is abundant at the Academy, especially in the vicinity of Monument Creek, and is second only to yellow toadflax in occupied area (Anderson and Lavender 2008). Along with yellow toadflax, it is one of two species that is only targeted for management within high priority conservation areas.

A decline was seen following control efforts at two of three permanent plots for this species. Cover in all three plots declined during the study, but the decline was greatest in plots 1 and 2 (Table 8), which were treated with herbicide in 2006 (Table 4). While significant reductions in cover resulted from the treatments, ramets of Canada thistle remained in many quadrats after treatment (frequency at plot 1 declined from 100% to 40% after treatment, and declined from 100% to 10% at plot 2 after treatment). Seedlings were observed at plot 1 in 2007, suggesting that this site may be reinfested by emergence of plants from the resident seedbank in the future.

Table 8. Summary data from the three permanent monitoring plots for Canada thistle. P values are for paired T-tests comparing 2006 with 2005 and 2007 with 2006.

		2005	**2006**	**2007**
Plot 1	**average % cover**	33.5	17.05	0.3
	sd	19.27	14.17	0.62
	P		0.003	<0.001
Plot 2	**Average % cover**	24.7	5.35	2.15
	sd	8.60	8.20	6.95
	P		<0.001	0.058
Plot 3	**Average % cover**	33.5	14	8.2
	sd	25.46	9.21	8.72
	P		0.004	0.061

Recommendations for Canada Thistle:

It is fortunate that two of the three permanent plots were treated in 2006. This represents an opportunity to measure the effectiveness of the treatment applications. Although this species is a relatively low management priority at the Academy, it may be worthwhile to take advantage of this opportunity. Therefore, we recommend revisiting the three permanent plots for this species in 2008. Future monitoring will provide insights into the success of herbicide applications in 2006. Resampling these plots in 2008 will help determine whether the treatments are resulting in lasting declines in cover, or if the remaining plants are rebounding.

Euphorbia esula (Leafy Spurge)

Species	Sampling Methods	Plot 1	Plot 2	Plot 3
Leafy spurge	*Perimeter mapping/ survey transects/ photopoint*	Perimeters mapped, 5 E-W survey transects spaced 20m apart, one photopoint	Perimeters mapped, 4 E-W survey transects spaced 20m apart, one photopoint	Perimeters mapped, 4 E-W survey transects spaced 20m apart, one photopoint

The approach taken to monitoring leafy spurge at the Academy was different than the approaches taken for all other species (See Anderson and Lavender 2006 for a description of the methods used). The primary purpose of the leafy spurge monitoring program is to measure the effectiveness of ongoing herbicide treatment application in the Jacks Valley area. However, two other questions addressed by this monitoring by revisiting survey transects are:

1. How fast is leafy spurge spreading at the Academy?
2. How likely is it that uninfested oak woodlands that were recently hydroaxed will become infested with leafy spurge in the next three to five years?

At plot 2, herbicide was applied aggressively every year to control leafy spurge. From 2005 to 2007, leafy spurge spread rapidly into uninfested areas at this site (Figure 10). Efforts to spray it were locally effective here, but in any given year many stems had evaded herbicide treatment and these became nodes from which the species spread in subsequent years. Overall, the area occupied and number of stems increased continuously from 2005 through 2007 despite treatment efforts (Table 9).

Herbicide was also applied to the largest infestation at plot 3 in 2007. Most of the ramets detected at this site had been treated but a significant portion of the infestation had been missed by the herbicide. The small infestation at plot 1 was not treated in 2005-2007.

Data from the survey transects make it possible to estimate the rate of spread of leafy spurge at the Academy. The total area of plots 1 and 3 is 27,520m^2. One new infestation was observed per year in the combined area of these plots in 2006 and 2007 (1 infestation per 27,520m^2 per year). At this rate, there would be 2,715 founder infestations per year on the Academy. This is very likely an overestimate based on the results of mapping this species at the Academy in 2008 (Anderson and Lavender 2008), but within the area of Jack's Valley and Deadman's Creek where leafy spurge is currently spreading rapidly, this rate may be accurate.

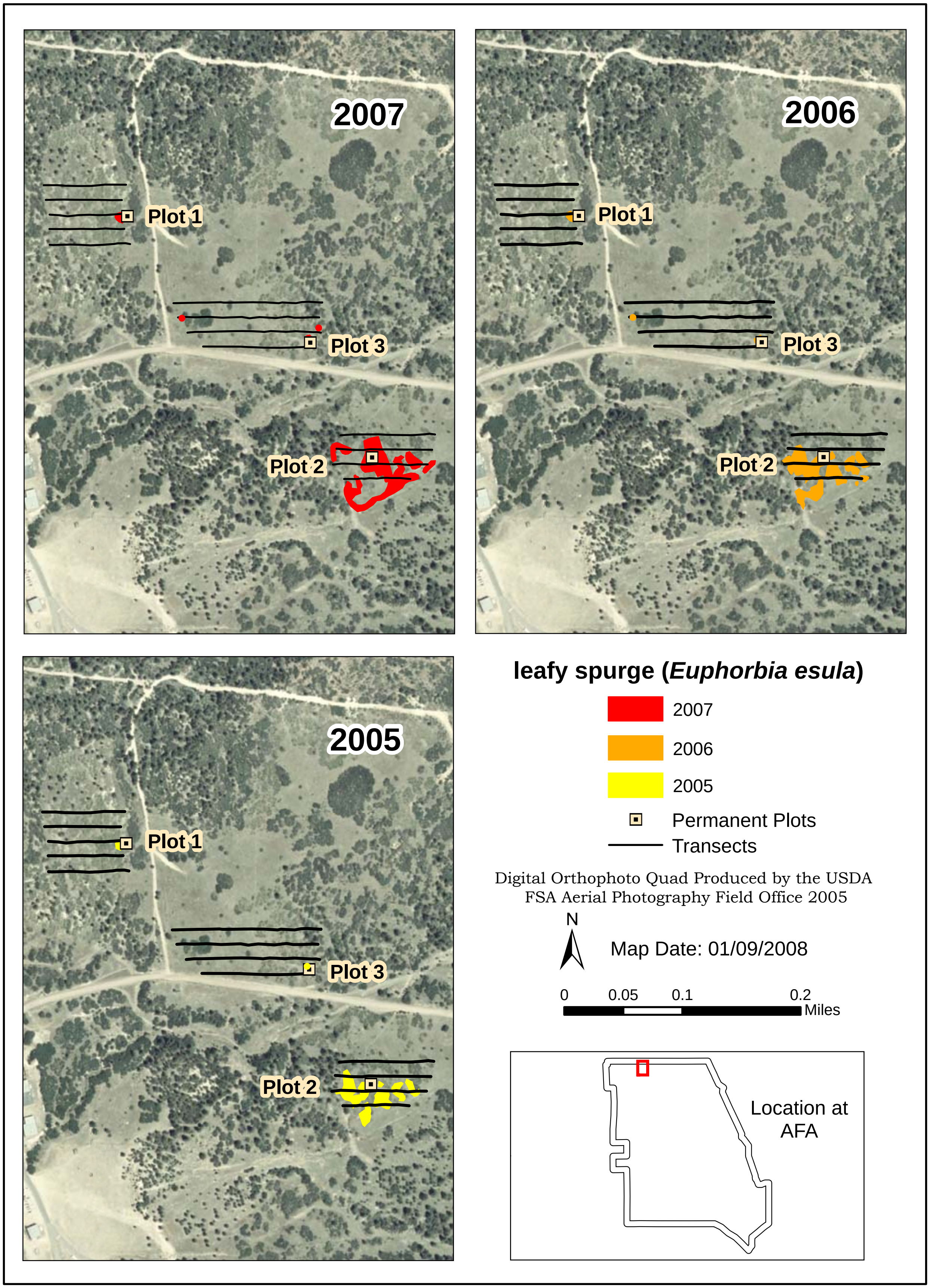

Figure 10. Distribution of leafy spurge at the three permanent plots in 2005-2007.

Table 9. Summary data from the three permanent plots for leafy spurge.

		Occupied Area (m^2)	N (ramets)	# patches
Plot 1	**2005**	78	234	1
	2006	146	5840	1
	2007	129	5149	1
Plot 2	**2005**	2340	6097	6
	2006	3193	11130	7
	2007	4214	18156	4*
Plot 3	**2005**	79	393	1
	2006	97	970	2
	2007	108	545	3

* In 2007, several smaller patches grew and amalgamated into four larger patches at plot 2.

Recommendations for Leafy Spurge:

Monitoring leafy spurge has yielded valuable information and it is not labor intensive (requiring one full day to sample all three plots). Therefore, we recommend continuing to monitor this species using perimeter mapping and survey transects every year.

The photopoints for this species are not particularly informative because it is very difficult to see ramets of leafy spurge in the photos. Pinflags were used to mark patches of plants in the photos, but it was not possible to mark them all, and many patches remained concealed by oaks or topography. Therefore, the value of this monitoring is low and we do not recommend continuing it for leafy spurge.

Hypericum perforatum (Common St. Johnswort)

Species	Sampling Methods	Plot 1	Plot 2	Plot 3
Common St. Johnswort	*Transect/ photopoint/ photoplot/ perimeter mapping*	2 photopoints, perimeter mapping. *Rationale:* excessive poison ivy precluded the use of transect method	25 m transect w/ 20 quadrats, 5 photoplots, 3 photopoints, perimeter mapping	25 m transect w/ 20 quadrats, 5 photoplots, 2 photopoints, perimeter mapping

Some ongoing management efforts for common St. Johnswort at the Academy appear to have been quite effective. At plot 2, broadleaf herbicide was applied sometime in the summer or fall of 2005 after the baseline data were obtained at this site. No evidence of common St. Johnswort was found at this site in 2006 and 2007 (Table 10, Figure 11). Broadleaf herbicide resulted in a dramatic change in the flora of this site- after 2005 the floristic composition of this site was almost exclusively grasses and sedges. In 2006 only native graminoids were detected, but in 2007 Kentucky bluegrass (*Poa pratensis*) was observed. Photopoints of this plot are shown on the cover of this report.

At plots 1 and 3, biocontrol insects introduced by Michels et al. (2004) have had considerable local impacts on the density of common St. Johnswort (Figure 12).

Additional infestations of common St. Johnswort were discovered along Kettle Creek in 2007, illustrating that this species is continuing to spread at the Academy (see Anderson and Lavender 2008 for details).

Table 10. Summary data for plots 2 and 3 of common St. Johnswort in 2005-2007. P values are for paired T-tests comparing 2006 with 2005 and 2007 with 2006.

		2005	2006	2007
Plot 2	**average % cover**	27.1	0	0
	sd	19.54	0.00	0.00
	P		0.002	NA
Plot 3	**average % cover**	21.3	11.875	17.75
	sd	13.70	12.69	17.87
	P		0.056	0.005

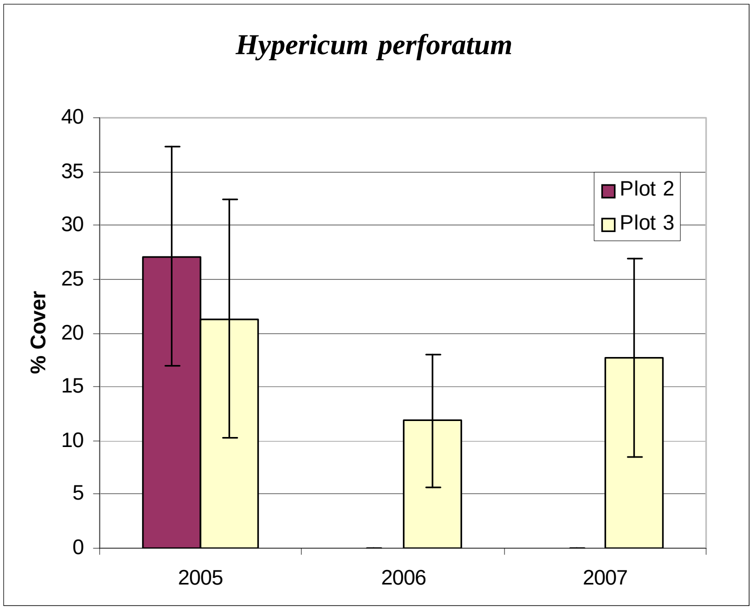

Figure 11. Average percent cover of common St. Johnswort in 2005-2007 at plots 2 and 3. Error bars are 90% confidence intervals around the mean.

Recommendations for Common St. Johnswort:

While biocontrol insects appear to have been highly effective in some areas at the Academy, it is uncertain whether they alone can achieve the management goals for this species. Additional efforts, such as herbicide spraying, may be necessary since St. Johnswort has spread to other locations along Kettle Creek between 2002 and 2007 (Anderson and Lavender 2008). Continuing perimeter mapping and photopoint monitoring of this species in 2008 will be valuable in assessing the success of ongoing management, with resampling of transects in 2009. Continued monitoring of plot 2 (where it appears that common St. Johnswort was eradicated by application of broadleaf herbicide) is needed in case there is a recurrence. Annual perimeter mapping of the newly discovered infestations along Kettle Creek is also needed to ensure that management is effective.

Figure 12. Photopoint 1a, showing progress in managing common St. Johnswort with biocontrol insects from 2005-2007. No common St. Johnswort was detected here in 2007.

Linaria vulgaris (Yellow Toadflax)

Species	Sampling Methods	Plot 1	Plot 2	Plot 3
Yellow toadflax	*Transect/ photopoint/ photoplot*	25 m transect, 20 quadrats, 5 photoplots, 2 photopoints	25 m transect, 20 quadrats, 5 photoplots, 2 photopoints	25 m transect, 20 quadrats, 5 photoplots, 2 photopoints

Initially, it proved to be challenging to find infestations of yellow toadflax where size and heterogeneity were appropriate for quantitative vegetation sampling. Despite considerable effort to find suitable sites, high variability within plots for this species has made it difficult to detect change in cover from year to year (Table 11, Figure 13). Post-hoc power analysis on the first two years' data indicated that sampling intensity needed to be increased for this species (Anderson and Lavender 2007). Therefore, the sampling intensity was doubled in 2006 and 2007.

No treatments were applied to plots for yellow toadflax in 2005-2007 (Table 4). Anecdotal observations at the Academy suggest that yellow toadflax sometimes increases in density after herbicide is applied. The reduction of a targeted species through herbicide application may open a site for colonization by other weeds, and yellow toadflax appears to take advantage of these opportunities. This observation is not yet supported by quantitative data from permanent plots, but it may take more time since application of herbicide for this effect to manifest itself. Plot 2 appears to be a site where yellow toadflax increased following herbicide application sometime before 2005.

Table 11. Summary data for yellow toadflax in 2005-2007. P values are for paired T-tests comparing 2006 with 2005 and 2007 with 2006.

		2005	**2006**	**2007**
Plot 1	**average % cover**	9.5	4.9	5.7
	sd	4.45	4.12	5.60
	P		0.002	0.422
Plot 2	**average % cover**	32.0	10.9	7.5
	sd	9.87	8.03	6.72
	P		<0.001	0.046
Plot 3	**average % cover**	11.0	5.1	3.7
	sd	9.81	4.65	5.95
	P		0.070	0.240

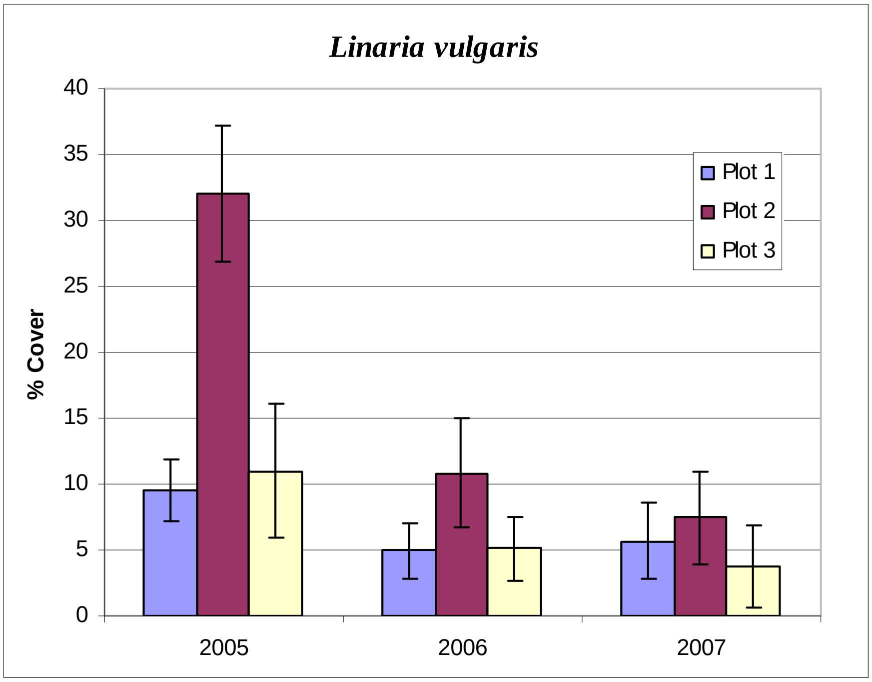

Figure 13. Average percent cover of yellow toadflax in 2005-2007 at the three permanent plots. Error bars are 90% confidence intervals around the mean.

Recommendations for Yellow Toadflax:

We recommend that monitoring for this species not continue on an annual basis for many reasons. Yellow toadflax is a low priority for management, is managed somewhat opportunistically, and is already widely distributed base-wide. The value of the monitoring data for management purposes has been limited so far. We believe it would be better to focus efforts on species about which monitoring can be more informative regarding weed management activities at the Academy.

Perhaps the best approach to managing this species is to identify high priority conservation areas on the Academy where yellow toadflax is absent, and work to keep them that way. This is a considerable challenge because this species is present in low densities almost everywhere on the Academy. It is uncertain whether benefits will be realized if herbicide treatment is used to attempt to achieve management goals for this species, since it appears that yellow toadflax often moves into areas after herbicide application. Also, the biological impacts of herbicide use within or near conservation areas may outweigh any benefits if not applied with the utmost care.

Permanent Monitoring Plots Without Transects

Carduus nutans (Musk Thistle)

Species	Sampling Methods	Plot 1	Plot 2	Plot 3
Musk thistle	*Photopoint*	1 photopoint	1 photopoint	1 photopoint

Musk thistle was abundant at the Academy in 2007 (Anderson and Lavender 2008). The number of infestations, occupied area, and number of individuals of musk thistle increased dramatically at the Academy from 2002 to 2007 (Anderson and Lavender 2008). Whether this indicates a long-term trend or is the result of wet conditions in 2006 and 2007 is unknown.

Despite the observations base-wide, the number of individuals at the three permanent plots declined between 2005 and 2007 (Figure 14). This is due to herbicide treatments that reduced density at each of the permanent plots. Plots 1 and 2 were sprayed in late 2005 or early 2006, while plot 3 was sprayed in late 2005 (immediately after the baseline data were collected) and again in early 2007 (Table 4). No musk thistles were seen at any of the permanent plots in 2006, but they had returned to all three plots in 2007.

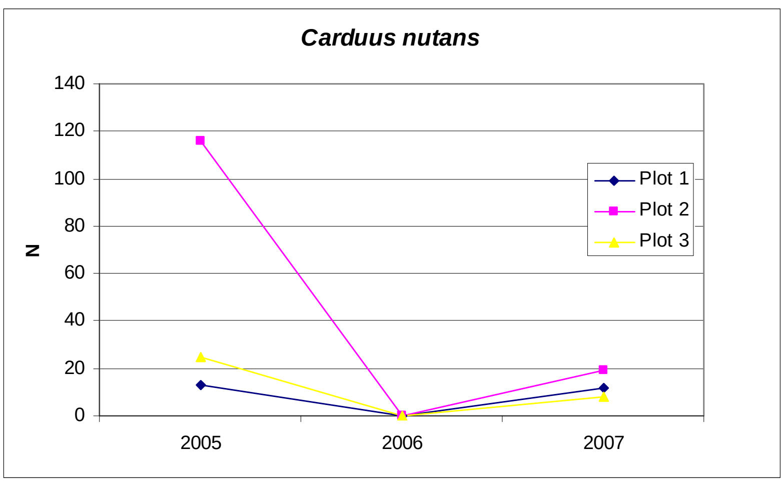

Figure 14. Census data for the three musk thistle monitoring plots in 2005-2007, obtained from photopoints.

Recommendations for Musk Thistle:

Given the trend observed base-wide for musk thistle over the past five years, and the ongoing management of the three musk thistle infestations currently being monitored, it is advisable to revisit the monitoring plots for this species in 2008. We also recommend setting up seven additional randomly selected photopoints for this species and obtaining baseline data for them in 2008. Subsequently, the plots could be resampled every other year, unless the plots indicate that the current population trend is continuing, in which case it would be advisable to continue annual resampling of the monitoring plots. This in conjunction with a base-wide noxious weed survey every five years, is likely to provide sufficient feedback to managers regarding this species.

Cirsium vulgare (Bull Thistle)

Species	Sampling Methods	Plot 1	Plot 2	Plot 3
Bull thistle	*Photopoint*	1 photopoint	1 photopoint	1 photopoint

None of the bull thistle plots were treated in 2005-2007. Plot 1 is adjacent to the athletic fields at the Community Center, where several plants have matured every year in a small spillway. Plot 2 is located adjacent to the golf course in a site that receives overspray from the sprinklers. At plot 3, bull thistle abundance declined sharply in 2007 (Figure 15) while Canada thistle (and also musk thistle to a lesser extent) increased. Only a single bull thistle was observed in the plot, and six were seen in the entire clearing where there had been many tens of plants in 2006. It appears that greater surface runoff from the hospital area upslope has changed the hydrology of this site, leaving it more suitable to Canada thistle.

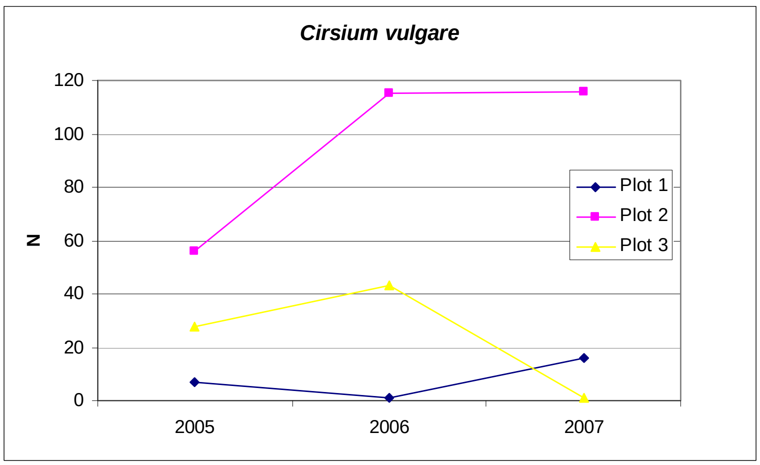

Figure 15. Summarized census data for the three bull thistle monitoring plots in 2005-2007, obtained from photopoints.

Recommendations for Bull Thistle:

Bull thistle has been only moderately invasive at the Academy thus far (Anderson et al. 2003). Although its population has increased at the Academy since 2002, its occupied area has not increased greatly since then (Anderson and Lavender 2008). Broadening the scope of the bull thistle monitoring program by adding additional photopoints would provide a more comprehensive picture of the effectiveness of base-wide management for this species. However, mapping bull thistle through a comprehensive base-wide noxious weed survey every five years is probably sufficient for measuring the success of management practices, unless a change in population trend is observed indicating a need for greater vigilance in its management.

Dipsacus fullonum (Fuller's Teasel)

Species	Sampling Methods	Plot 1	Plot 2	Plot 3
Fuller's teasel	*Photopoint*	1 photopoint	2 photopoints	1 photopoint

The most common habitats occupied by teasel at the Academy are riparian areas adjacent to Monument Creek and its tributaries. These habitats are chronically disturbed, and an exceptional flood season in late summer of 2006 altered the creekbed considerably and disturbed all three of the permanent plots for this species. This disturbance impacted the populations of Fuller's teasel at the permanent plots (Figure 16), and it probably decreased the population base-wide, but it is likely that populations will rebound from this disturbance in the future. There was no evidence of treatment at any of the permanent plots for Fuller's teasel from 2005-2007.

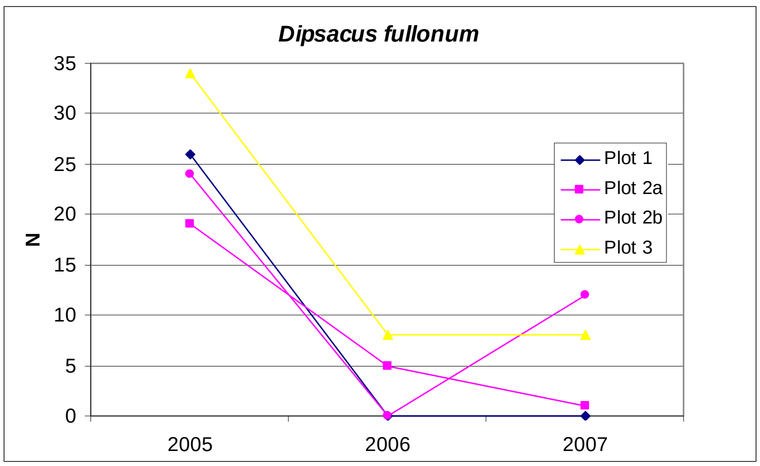

Figure 16. Summarized census data for the three Fuller's teasel monitoring plots in 2005-2007, obtained from photopoints.

Recommendations for Fuller's Teasel:

Because this species may be increasing following the flood event of 2006, it is worthwhile to resample the monitoring plots for this species in 2008. In the future, broadening the scope of the Fuller's teasel monitoring program by adding additional photopoints would provide a more comprehensive picture of the effectiveness of base-wide management for this species. However, mapping Fuller's teasel through a comprehensive base-wide noxious weed survey every five years is probably sufficient for measuring the success of management practices, unless a change in population trend is observed indicating a need for greater vigilance in its management.

Euphorbia myrsinites (Myrtle Spurge)

Species	Sampling Methods	Plot 1	Plot 2	Plot 3
Myrtle spurge	*Perimeter mapping/ photopoint*	Perimeter mapping, 1 photopoint	Perimeter mapping, 2 photopoints	Perimeter mapping, 1 photopoint

Myrtle spurge is the only noxious weed species at the Academy with List A status, mandating the eradication of this species wherever it is found (Colorado Department of Agriculture, Plant Industry Division 2005). Fortunately, Natural Resources Staff at the Academy identified the presence of myrtle spurge at an early stage of its invasion, and progress is being made towards its eradication. The three permanent plots for this species are located in the only known extant infestations on the Academy.

Plot 1 is located east of the stables in a dense stand of ponderosa pines that is being thinned. Aggressive measures were taken in 2005 and 2006 to eradicate this infestation by pulling and excavating plants. This reduced the density but many small plants were found in 2007 that may be sprouting from seeds or from rootstock that remained underground after the 2006 treatment.

Plot 2 is located at the southwestern edge of the housing in Douglass Valley behind 4176 Douglass Way, where two large patches are present. There was no evidence of treatment at this plot in 2006 or 2007. In 2006, myrtle spurge was found in a rockgarden adjacent to the two large patches where the resident said they had dug up four plants from behind their house and planted it; the resident voluntarily removed the plants after realizing it is a noxious weed. In 2007, another lone individual was found between two houses just east of the northernmost patch; the plant was pulled. The number of individuals at this plot increased considerably from 2006 to 2007 (Table 12).

Plot 3 is located in the Archery Range area near Sumac Drive. It was treated with herbicide in 2005. This was somewhat successful, but again there were numerous small plants sprouting from seed or rootstock in 2007 and additional treatments are needed.

Myrtle spurge was known from three other areas at the Academy in 2005 and 2006. It was found at two sites along Douglass Creek adjacent to Douglass Drive in 2005, and 20-30 plants were pulled at that time. On June 8, 2006 the site was revisited, and another three plants were found and pulled. It was also found at Kettle Lake in 2005, where it was pulled that year. One plant was seen at the Kettle lake location on June 8, 2006 and was pulled; this site was revisited in 2007 and no plants were seen. The third site, along the Santa Fe trail, was apparently eradicated in 2005; no plants were seen at this site in 2006 or 2007.

Recommendations for Myrtle Spurge:

It is likely that founder infestations of myrtle spurge will continue to crop up at the Academy. Continued annual monitoring is needed for this species to maintain vigilance and ensure that it is eradicated. The current monitoring program for this species is effective and is not labor intensive, requiring no more than one day in the field to complete.

Table 12. Summary data for permanent plots for myrtle spurge.

		Area (m^2)	**N (ramets)**	**# patches**
Plot 1	**2006**	160	142	1
	2007	87	97	1
Plot 2	**2006**	477	72	3
	2007	443	122	3
Plot 3	**2006**	57	25	1
	2007	150	41	1

Mapping and Assessment

Three species (spotted knapweed, Russian olive, and Scotch thistle) were monitored by mapping and censusing the population at the Academy annually (or every two years for Russian olive) and assessing the status of all known infestations.

Centaurea maculosa (Spotted Knapweed)

Spotted knapweed was mapped in 2002, 2005, 2006, and 2007 at the Academy, dramatically illustrating its rapid spread (Table 13, Figure 17). The population size of spotted knapweed was 36 times greater in 2007 than it was in 2002. Although it was relatively uncommon at the Academy in 2002, it occupied a total of 57.89 acres in 2007 and had the fourth largest footprint of all the targeted noxious weeds at the Academy, superseded only by diffuse knapweed, yellow toadflax, and Canada thistle (Anderson and Lavender 2008). The eruption of this species at the Academy is centered at the water treatment plant and stables, and the Parade Loop area, suggesting that founder populations may have been located in these areas. The I-25 corridor and Monument Creek have also become infested.

Table 13. Summary data for spotted knapweed at the Academy from 2002-2007.

	Occupied Acres	N	Number of Mapped Features
2002	4.68	3,485	54
2005	14.19	86,392	71
2006	40.61	116,455	91
2007	57.89	127,803	323

Recommendations for Spotted Knapweed:

Continuing the annual mapping is advised if these data can be used to inform aggressive management of this species. However, this has already become considerably more labor intensive than it was in 2005 when the monitoring program was started, and will now require several days in the field to complete.

Aggressive management of this species is needed to prevent further spread. Because most infestations are small and scattered, herbicide treatment is likely to be a more effective means of controlling this species base-wide than biocontrols. However, continuing the ongoing biocontrol program in conjunction with herbicide treatment is advisable given the rapid rate of spread of this species.

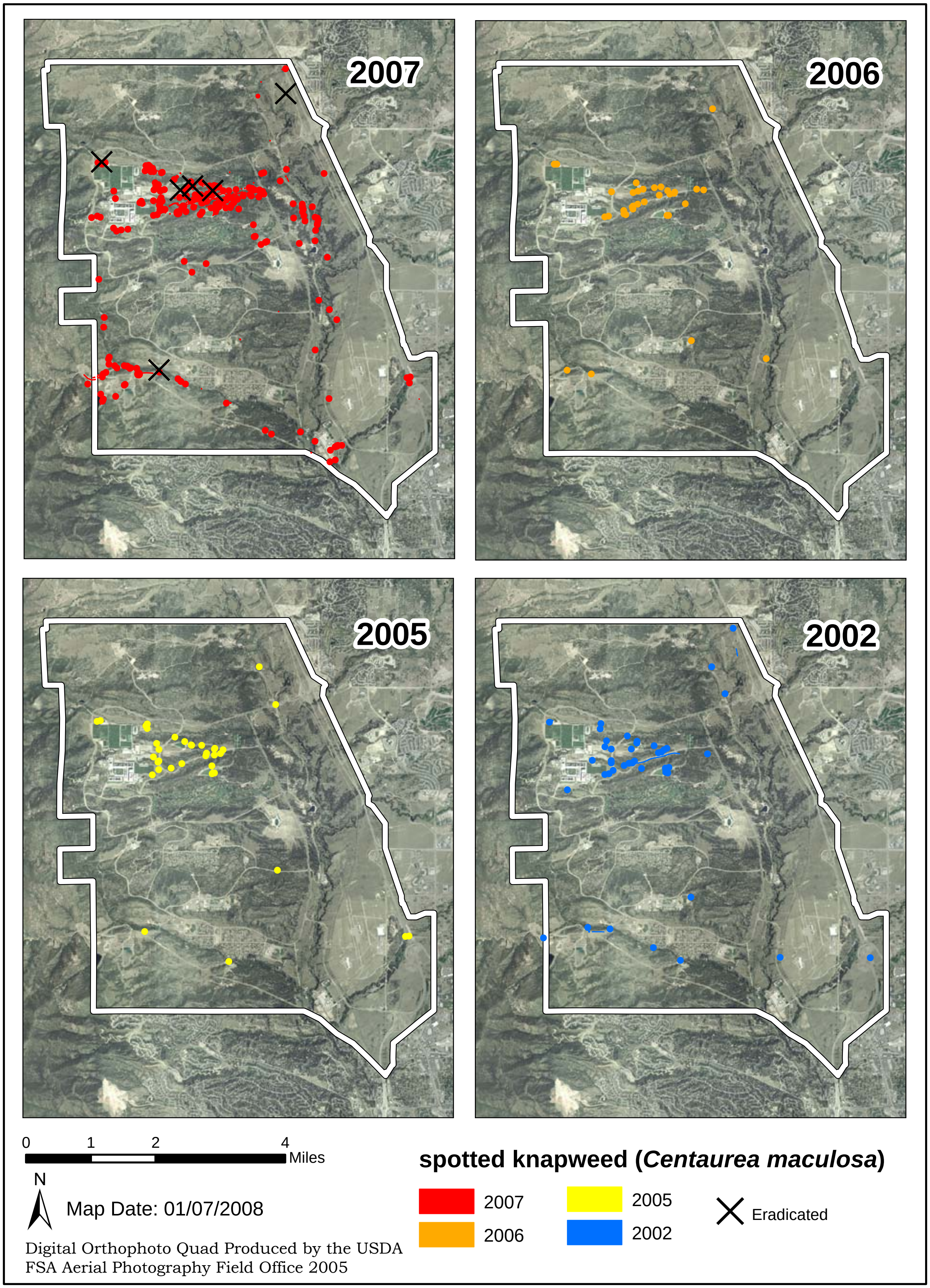

Figure 17. Extent of spotted knapweed at the Academy in 2002-2007.

Elaeagnus angustifolia (Russian Olive)

The control of Russian olive is one of the greatest weed management success stories at the Academy. Treatment of this species in 2003 and 2004 was highly successful (Table 14, Figure 18). In 2005, only 46 infestations remained extant of the 173 examined that year. Although 633 individuals remain on the Academy, most of the remaining trees are along the I-25 corridor which were not examined in 2005 since there had been no control efforts for them. This species has been nearly eradicated in most areas of the Academy.

Table 14. Summary data for Russian olive at the Academy from 2002-2007.

	Occupied Acres	Number of Individuals	Number of Extant Infestations
2002	49.79	1,310	269
2007	19.08	633	114

Recommendations for Russian Olive:

The monitoring program for this species has been effective in measuring the impact of management efforts on this species. Continuing periodic censusing and assessment of the Russian olive population at the Academy is recommended to measure progress towards management goals for this species if further control efforts are planned. In 2005 and 2007, all trees examined were scored as extant (untreated), sprouting (unsuccessfully treated) or eradicated (successfully treated). We recommend repeating this after further control efforts are undertaken (2009 at the soonest).

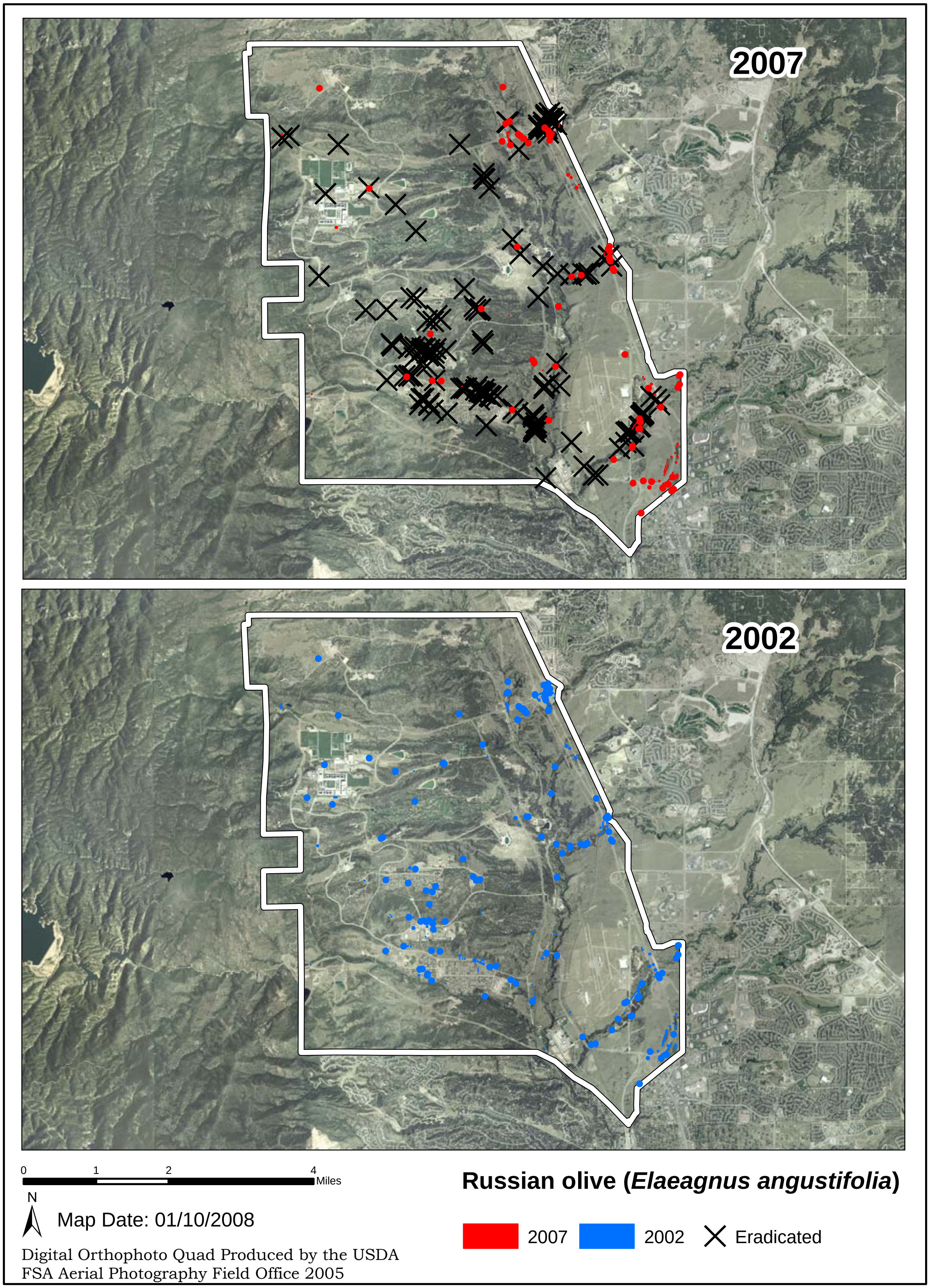

Figure 18. Extent of Russian olive at the Academy in 2002-2007 and status of infestations

Onopordum acanthium (Scotch Thistle)

The population of Scotch thistle has increased considerably from 2002 to 2007 at the Academy (Table 15, Figure 19). Monitoring this species using census techniques is challenging because it disperses widely and can erupt almost anywhere at the Academy. Every year this species has turned up in areas where it was not previously observed, making it difficult to map base-wide annually. Although there was an apparent tenfold increase from 2005 to 2007, it is likely that the actual population in 2005 was higher but plants were missed because a comprehensive base-wide survey was not conducted that year. Nonetheless, the magnitude of the increase since 2002 shows that this species is in a phase of rapid expansion at the Academy and warrants aggressive management at this time.

Although there have been efforts to control this species, especially at larger infestations, the efforts are often incomplete. For example, at the Jack's Valley Gaging Station, plants were sprayed along the railroad right-of-way near the road but not on the east side of the tracks, so this infestation has remained extant from 2005 through 2007.

Table 15. Summary data for Scotch thistle at the Academy from 2002-2007.

	Occupied Acres	**Number of Individuals**	**Number of Mapped Features**
2002	0.17	52	7
2005	0.42	137	12
2007	1.30	1,307	36

Recommendations for Scotch Thistle

Despite the challenges discussed above, continuing to monitor this species with census techniques annually or every two years is probably the least labor intensive but data-rich means of providing the information necessary to manage it. Returning to infestations mapped in previous years to assess the effectiveness of management, and opportunistically mapping any additional infestations encountered, will inform managers of priority treatment areas for this species. Although this species has spread considerably in the past five years it can still be censused relatively rapidly at the Academy, due in part to the fact that this species is easily spotted.

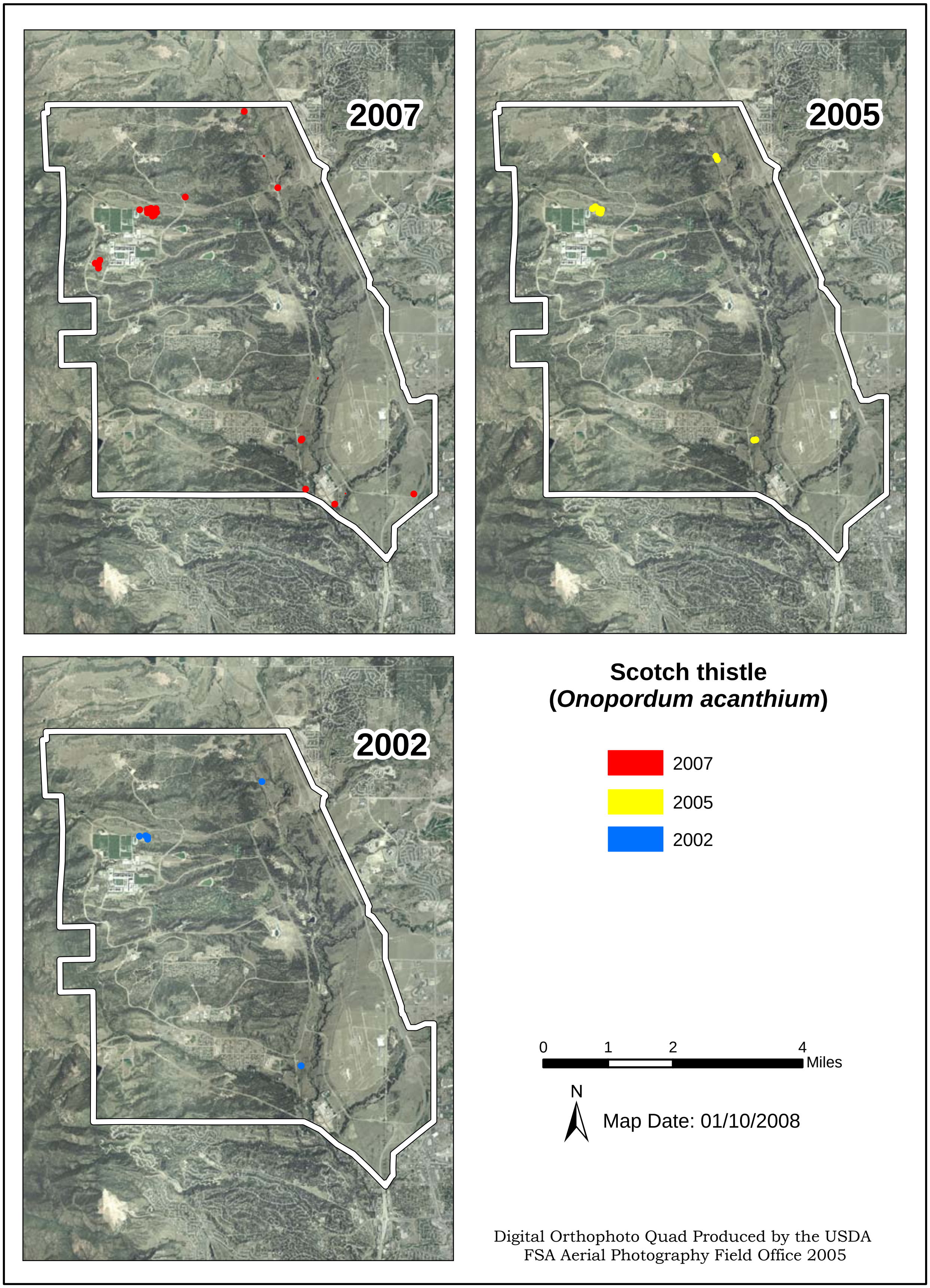

Figure 19. Extent of Scotch thistle in 2002, 2005, and 2007 at the Academy.

DISCUSSION

As is typical of a newly established monitoring program, some adjustments are needed to ensure that the goals of this project continue to be met in the future, and that the project's results are in step with the Academy's management needs. The following discussion addresses the relative virtues of the sampling methods employed in this monitoring program, offering general recommendations for future monitoring. Specific recommendations are included with the results for each species in the previous section.

Quantitative Vegetation Sampling for Cover and Density

The use of quantitative vegetation sampling in monitoring weeds is appropriate for some purposes at the Academy, but it is complicated by several factors. The methods established in 2005 have proven to be effective, providing detailed insights into the impacts of weed management on some target species and on plant community composition. The design of the plots is flexible enough to allow for adjustments of sampling intensity to increase power. The use of cover and density appears to provide a reliable metric for measuring management success without requiring an unreasonable amount of labor intensity. The data lend themselves well to analysis and statistical inference.

Estimating cover for all species at some plots has been a valuable exercise because it provides broad insights into the effects of weeds and management on species composition, species richness, and relative cover. This gives us insights not only regarding the effectiveness of management but on the broader ecological impacts of management on the plant communities of the Academy.

One limiting factor is that it was not possible to design a study with control and treatment plots. Control efforts have been ongoing for many years, and in many areas the history of management efforts is uncertain.

The randomly selected sites used as plots in this study are highly variable in species composition over small spatial scales. We believe these sites were representative of the kinds of sites infested by the target species. To achieve power that is sufficient to detect the changes recommended in the management plan, sampling intensity must be high. However, this increases the time and labor required to sample a given site. In some cases, this could be ameliorated by using longer, narrower sampling units, but plots using long, narrow quadrats can be time consuming to set up. More importantly, the size of even the largest contiguous infestations at the Academy is usually too small or narrow to fit such a plot. The large amount of time required to sample each site using this method means that it is difficult to monitor a large number of sites. And ironically, the closer one gets to achieving a management goal, the more difficult it is to rest assured that this is indeed the case because it becomes increasingly difficult to detect the target species as they become less common. These complications lead us to recommend that future monitoring efforts emphasize the approaches discussed below for most monitoring purposes at the Academy.

Continuing the use of quantitative vegetation sampling using the methods discussed above would be best suited to an experimental design with control and treatment plots. A less labor intensive approach to utilizing this sampling design could be to sample only the target species, which may save enough time to permit additional monitoring plots to be set up. However, the value of such a modification will still be limited unless there is some degree of coordination between weed treatment applications and monitoring efforts.

For species targeted for suppression and management, sampling more plots using a combination of census, mapping, and photopoints may provide more valuable feedback to managers without requiring the deployment of a study involving control and treatment plots. We feel that a monitoring program with a more extensive and less intensive approach may be better suited to the nature of weed management activities at the Academy.

Photopoints

Photopoints are not labor intensive, illustrate trends, facilitate comparison between sites and years, and are informative for weed management and other purposes. The use of photopoints in monitoring at the Academy has been worthwhile, and the continuation of this program is recommended. Photopoints do not readily provide data that are amenable to statistical analysis, but this is not necessarily needed for informing management. When sampled in conjunction with perimeter mapping and census techniques they increase the illustrative power of the data (see the cover of this report for an example) and are a means of double checking quantitative data.

Mapping and Assessment

The mapping and assessment portion of the monitoring program has been extremely successful. It has been cost effective in that it has not required extensive time or human resources, and it has provided valuable data for weed management. It is the ideal way to quantify the status of targets because it is a census, not a sample. Thus, the data from this portion of the project are not subject to the same risk of type I and type II errors that a random sample is subject to. However, these methods are only applicable for relatively rare species that can be censused within a reasonable timeframe. Spotted knapweed has begun to approach a population size and distribution that is fairly labor intensive to census annually. Wherever possible, this method of monitoring weeds should be continued.

These methods have been a highly effective means of providing feedback on the management of spotted knapweed, Russian olive, myrtle spurge, and Russian knapweed. They did not work as well for Scotch thistle, probably because the spread of this species was not contagious; a base-wide survey may be necessary to obtain a rigorous census of this species at the Academy. Nonetheless, annual monitoring of known infestations is still worthwhile if they are being actively managed.

Arguably the most effective and informative form of monitoring at the Academy has been the follow-up of the weed mapping exercise. This has been extremely effective and has generated a dataset that is of great value for weed management at the Academy and Farish. This dataset also has great potential utility to weed scientists worldwide. The baseline data have already been showcased by the Nature Conservancy and NatureServe scientists and have been incorporated into databases maintained by the State of Colorado (Colorado Department of Agriculture 2008) and the National Institute of Invasive Species Science (U.S. Geological Survey 2008). We highly recommend another base-wide noxious weed survey in 2012.

A census every five years through updating the base-wide noxious weed map is deemed sufficient for monitoring lower priority species such as Fuller's teasel and bull thistle, and for yellow toadflax within high priority conservation areas. However, reassessment more frequently would be worthwhile if the data could be used to provide feedback leading to more successful treatment and retreatment by weed management professionals.

Tamarisk

A single tamarisk was found at the Academy in 2002 (Anderson et al. 2003), and this plant was eradicated by Natural Resources Staff. One plant was found at a new site in 2007 (Anderson and Lavender 2008). Spackman Panjabi and Decker (2007) recommend this species as a high priority for monitoring at the Academy. For these reasons we recommend adding this species to the existing monitoring program. Unless more plants are found, monitoring would involve checking the sites where it was found in 2002 and 2007 and assessing the effectiveness of treatment annually for three years. If additional plants are found, they would be mapped and assessed using the methods applied to spotted knapweed, Russian olive, and other species in this study.

Data Sharing and Collection

The value of the data from this monitoring program will be maximized if they can be shared with weed management professionals at the Academy, especially for those species that have been censused and reassessed base-wide (spotted knapweed, Scotch thistle, Russian olive, common St. Johnswort, myrtle spurge, and Russian knapweed). Weed spraying contractors will need to work closely with Natural Resource Staff to implement some of the recommendations presented in this report. Future monitoring activities proposed in this report (especially for whitetop and diffuse knapweed) will require collaborative efforts for their implementation.

The mobile mapping technology employed by CNHP and Natural Resources Staff at the Academy would be highly effective if utilized by weed management professionals. The high level of precision and detail of the monitoring and mapping data collected over the last five summers at the Academy and Farish could be used to lead weed management professionals to areas needing treatment, increasing the effectiveness of the weed management program while decreasing the time required to relocate mapped infestations. Weed management professionals could also use the geodatabase created for the weed mapping project to document treatment applications and treatment success. This would facilitate cooperation towards achieving weed management goals and would add transparency to the weed treatment activities at the Academy.

Natural Resource-Based Noxious Weed Monitoring

In addition to monitoring randomly identified weed infestations, it may also be beneficial to begin a weed monitoring program focused on known occurrences of significant natural resources at the Academy. One possible sampling design would be to census and map all noxious weed targets within a given radius (i.e., 100 meters) of occurrences periodically. In conjunction with assessments of the significant species or communities themselves, such a program would provide managers with a more direct measure of the impacts of noxious weeds and their management on conservation targets than the current program offers.

Spackman Panjabi and Decker (2007) list 27 significant species and communities and cite known and likely threats from noxious weeds. Of the species targeted for monitoring at the Academy, all but four (bull thistle, myrtle spurge, Scotch thistle, and Russian knapweed) occur within ¼ mile of an occurrence of a significant species or community. This analysis provides an excellent starting point for initiating a natural resource-based noxious weed monitoring program.

Summary of Recommendations by Species

Bull Thistle (*Cirsium vulgare*)	Monitor through base-wide noxious weed survey every five years.
Canada Thistle (*Cirsium arvense*)	Resample all three permanent plots in 2008, then reevaluate; probably begin monitoring every second or third year afterward.
Common St. Johnswort (*Hypericum perforatum*)	Perimeter mapping and photopoint monitoring of all infestations in 2008, resample transects in 2009.
Diffuse Knapweed (*Centaurea diffusa*)	Resample belt transects in 2009 if railroad right-of-way is mowed north of Northgate Boulevard.
Fuller's Teasel (*Dipsacus fullonum*)	Monitor through base-wide noxious weed survey every five years.
Hybrid Knapweed (*C. diffusa* x *maculosa*)	Continue to measure the prevalence of hybrids at the permanent plots for diffuse knapweed, and document their presence when observed with spotted knapweed. Document the response of hybrids to biocontrols if possible.
Leafy Spurge (*Euphorbia esula*)	Continue annual monitoring of permanent plots, terminate photopoint monitoring.
Musk Thistle (*Carduus nutans*)	Monitor 3 existing photopoints in 2008, add 7 more randomly selected photopoints in 2008, monitor every other year after 2008.
Myrtle Spurge (*Euphorbia myrsinites*)	Continue annual census, photopoints, mapping and assessment of all locations.
Russian Knapweed (*Acroptilon repens*)	Continue perimeter mapping and census annually, end quantitative vegetation sampling, photopoints, and photoplots.
Russian Olive (*Elaeagnus angustifolia*)	Conduct another census after additional management steps have been taken (2009 at the soonest).
Scotch Thistle (*Onopordum acanthium*)	Continue annual mapping and assessment of all infestations.
Spotted Knapweed (*Centaurea maculosa*)	Continue annual census and mapping of all infestations if the data can be used immediately, otherwise wait until 2009 to remap.
Tamarisk (*Tamarix ramosissima*)	Add this species to the monitoring program since it was found once again in 2007. Map and assess all infestations annually.
Whitetop (*Cardaria draba*)	Begin herbicide treatment in the vicinity of plots 1 and 2 in 2008, leaving the area of plot 3 untreated. Resume annual monitoring in 2009 to determine whether treatment was effective.
Yellow Toadflax (*Linaria vulgaris*)	Terminate the existing monitoring program, identify high priority areas on the Academy where yellow toadflax is absent and work to prevent their infestation.

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