Noxious Weed Monitoring at the U.S. Air Force Academy- Year 1 Results

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Knowledge to Go Places

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

EXECUTIVE SUMMARY

In the summers of 2002 and 2003 the Colorado Natural Heritage Program (CNHP) mapped 14 selected noxious weeds found on the U.S. Air Force Academy ("the Academy") and the Farish Outdoor Recreation Area ("Farish"). 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 the development of a formal Integrated Weed Management plan for U.S. Air Force 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.

The Colorado Natural Heritage Program 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). Permanent baseline monitoring plots were established for 10 of these species (Russian knapweed, hoary cress, musk thistle, diffuse knapweed, Canada thistle, bull thistle, Fuller's teasel, leafy spurge, common St. Johnswort, and yellow toadflax) in 2005. Three permanent plots were established for each species (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 pattern of distribution of each species. Two hundred and sixty eight infestations of four species (Russian knapweed, spotted knapweed, Russian olive, and Scotch thistle) were revisited in 2005 and their status was assessed. Reassessment included quantifying population size and success of any treatments. All newly discovered infestations of these species were also mapped and assessed.

Two occurrences of rare plants (plains ironweed, *Vernonia marginata* and Southern Rocky Mountain cinquefoil, *Potentilla ambigens*) were visited and documented, and the threats to those occurrences from noxious weeds were assessed. Three new suboccurrences of Southern Rocky Mountain cinquefoil were discovered in 2005. Two native plant species were found in 2005 that had not previously been documented at the Academy (St. Johnswort, *Hypericum formosum* and sleepy silene, *Silene antirrhina*).

Preliminary analyses of baseline data from the permanent plots suggests that current sampling intensities are sufficient for detecting meaningful changes in abundance of all target species except Russian knapweed. However, since this species is known only from two small locations at the Academy, the mapping and assessment will provide a reliable evaluation of the status of this species with respect to management efforts. More robust statistical analyses will be possible after the monitoring plots are resampled in 2006. Tabular and GIS plot data from this study are included on a CD that accompanies this report.

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 2005) weed control regulations for noxious weeds. The Academy has also established management objectives for weed control to remain compliant with local weed regulations.

In 2002 and 2003, the Colorado Natural Heritage Program (CNHP) mapped selected noxious weeds found at the Academy and the Farish Outdoor Recreation Area ("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 that will 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 (Figure 1).

In 2004, an integrated noxious weed management plan was developed based on the results of the weed mapping exercise (Carpenter and Perce 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.

As noted by Carpenter and Perce (2004), the purpose of monitoring is to provide a rational basis for determining if weed management actions are effective in moving toward the weed management objectives. Carpenter and Perce (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. After the first three years of monitoring, the data may show that less frequent or less intensive monitoring is acceptable for certain weed species.

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 and Perce (2004) were adhered to closely in this study. To determine whether the weed management objectives set by Carpenter and Perce (2004) are being met, this monitoring study needs to detect a minimum change of between 50% and 90% in cover, density, or seed production.

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 (*Eleagnus 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 has been destroyed and there have 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.

This report presents methods and baseline findings from the first year of noxious weed monitoring at the Academy. One purpose of this report is to document the methods employed to facilitate future monitoring efforts. The baseline findings presented here will facilitate management efforts for these species in 2006, particularly those for which all infestations were revisited.

Table 1. Noxious weed management objectives for species targeted in this study (from Carpenter and Perce 2004).

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

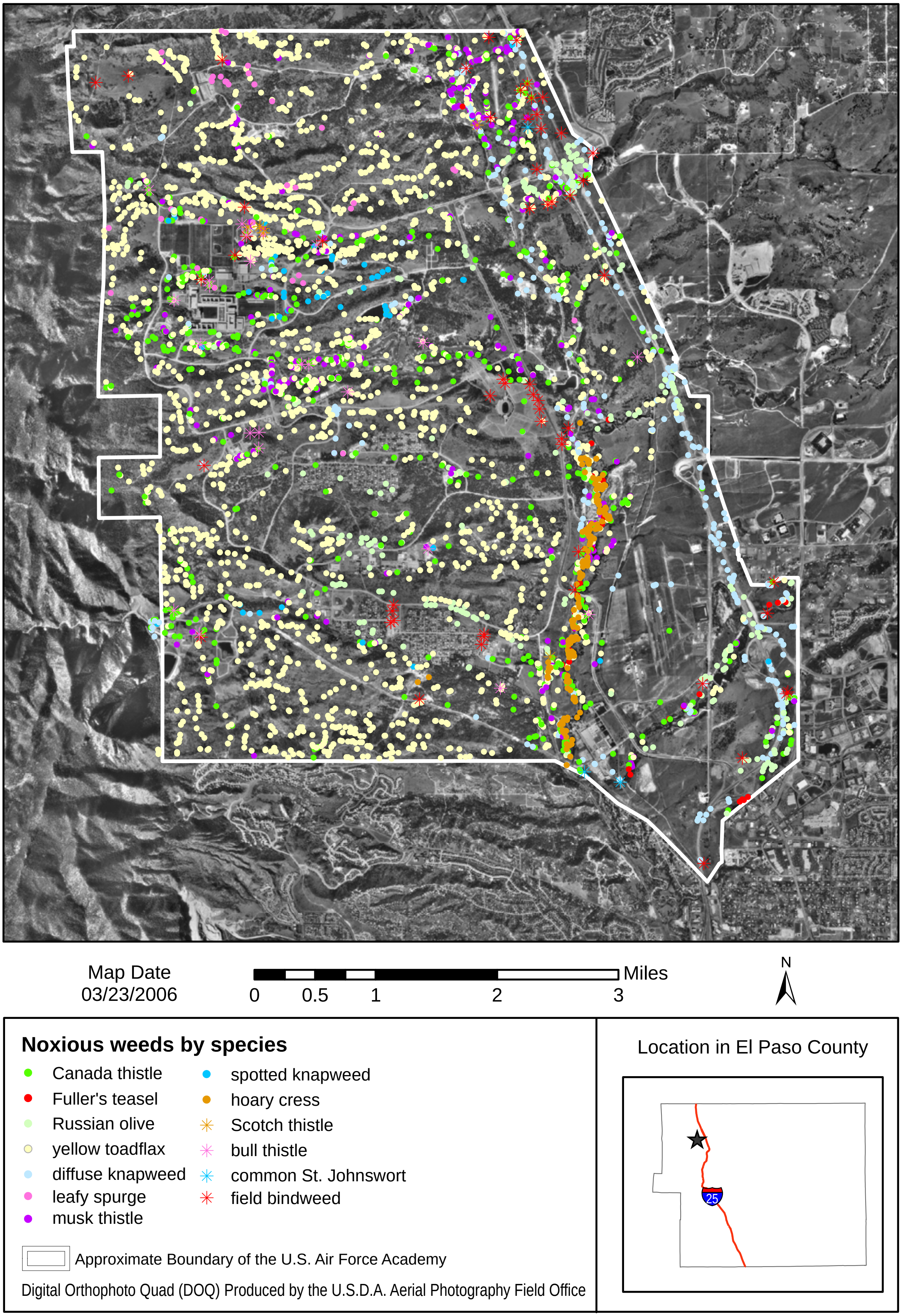

Figure 1. Noxious weed infestations of 13 species mapped in 2002 and 2003. Tamarisk is extirpated and not included on this map.

METHODS

Methods recommended by Carpenter and Perce (2004) were employed for monitoring and assessing the 13 noxious weed species targeted in this study.

Mapping and Assessment

Infestations of four noxious weed species (Russian knapweed, spotted knapweed, Russian olive, and Scotch thistle) were visited and assessed to determine their status in 2005, and any newly discovered infestations of these species were also mapped. Due to current management needs, it was decided that monitoring for these species would consist of annual revisits during which the status of every infestation would be reassessed to determine the effectiveness of ongoing integrated weed management strategies. For Russian olive, the Academy has made significant progress towards eradicating this species through targeted efforts. Crews have cut the trees and applied herbicide to the stumps throughout most of the Academy property. Spotted knapweed is on the "B list" of the Colorado State Noxious Weed List, for which management efforts are recommended. However, the El Paso County Forestry and Noxious Weed Division of the Environmental Services Department requires that managers eradicate this species (El Paso County 2005). Thus, each infestation was revisited to measure progress towards that goal. Russian knapweed and Scotch thistle are both uncommon at present at the Academy, so it was feasible to revisit all occurrences of these species and assess their status. Eradication of these species is a realistic goal for the Academy at present.

The data collected in the field conforms to standards established by NAWMA (North American Weed Management Association 2002) and weed documentation is compliant with Federal Geographic Data Committee Content Standards for Digital Geospatial Metadata (version of June 8, 1994). All attributes specified in the Montana Noxious Weed Survey Protocol (Cooksey and Sheley 1998) were gathered for each weed occurrence. The methodology specified in this mapping system was modified to suit the mobile device used to gather data for the project.

All weed infestations were mapped in the field using ArcPad version 6.0.1 (ESRI 1995-2003), a portable version of ArcView GIS software that allows the user to create and edit shapefiles remotely. This software was installed on a 64MB Compaq iPAQ Pocket PC (model H3670) equipped with a dual PC card expansion pack. For data security, all digital files were saved on a PC card and downloaded from the iPAQ to a laptop PC at least once daily. Shapefiles generated in the field were edited and quality controlled nightly. A Teletype PC card GPS unit was installed in a PC card slot on the iPAQ and provided locational data in ArcPad. This GPS unit is accurate to within 20 meters, but was found in field trials to be accurate most often to within 5 meters, even under heavy tree canopy.

The information collected at each infestation is summarized in Table 2. These data were collected in the field and are included in the attribute tables of the shapefiles accompanying this report.

Table 2. Summary of data collected for each infestation of the four species targeted for mapping and assessment.

Criterion	Description
Date	Date of assessment or reassessment
Species	Russian knapweed/ Spotted knapweed/ Russian olive/ Scotch thistle
Feature Type	New/ Mapped (newly discovered or previously mapped in 2002 or 2003).
Feature ID	Numeric ID of feature mapped in 2002 or 2003- links the new information to features in the shapefiles of all weed infestations at USAFA
Status	Extant, eradicated, sprouting, other
Treatment Success	Good, Poor, Not Treated
Percent Cover	Ocular estimate of percent cover of the target species within the infestation.
Pattern	Continuous or Patchy
Number of Individuals	A count of the number of genets (for nonrhizomatous species) or ramets (for rhizomatous species) in the infestation.
Density	Number of plants per square meter within the infestation (used when impossible to determine number of individuals).
Radius	The radius of the infestation in meters; used to generate polygon shapefiles from points which can then be used to determine the area (in square meters) of the infestation.
Comments	Any comments (including any unusual or noteworthy observations) about the infestation were noted in the field.

Weed infestation mapping exceeded the tolerances recommended by Cooksey and Sheley (1998). Large infestations (typically 5 or more acres) were mapped as polygons. Linear infestations, such as those following railroad tracks, roads, and lakeshores, were mapped as lines. All other infestations, which make up the majority of the infestations encountered in the study area, were mapped as points.

Permanent Plots

Permanent plots were established for ten targeted noxious weed species (Russian knapweed, hoary cress, musk thistle, diffuse knapweed, Canada thistle, bull thistle, Fuller's teasel, leafy spurge, common St. Johnswort, and yellow toadflax). Different sampling methods were employed depending on the distribution patterns and habit of the target species. Suggestions for sampling methods that were offered by Carpenter and Perce (2004) were closely adhered to in this study. Photopoints were established at permanent plots for all target species. For non-rhizomatous species with low density, scattered populations (bull thistle, musk thistle, Fuller's teasel) only photopoints were employed. For rhizomatous, densely distributed species (Russian knapweed, hoary cress, common St. Johnswort, and yellow toadflax), quadrats along permanent transects were employed, and were augmented by photoplots. Diffuse knapweed, a non-rhizomatous species, was sampled using belt transects. Permanent plots for monitoring leafy spurge were established in which perimeter mapping and photopoints were used, along with systematic survey transects to observe any possible spread of the infestations. The methods employed for each of these types of plots are summarized in Table 3, and described in detail below.

Table 3. Summary of sampling methods used at permanent plots in2005.

Species	**Sampling Methods**	**Plot 1**	**Plot 2**	**Plot 3**
Russian knapweed	***Transect/ photopoint/ photoplot/ perimeter mapping***	25 m transect w/ 10 quadrats, 5 photoplots, 3 photopoints	Census, GPS, photographs. *Rationale:* small, localized population	Photos, GPS. *Rationale:* no plants were found at this site for this species in 2005.
Hoary cress	***Transect/ photopoint/ photoplot***	50 m transect, 10 quadrats, 5 photoplots, 2 photopoints	50 m transect, 10 quadrats, 5 photoplots, 2 photopoints	50 m transect, 10 quadrats, 5 photoplots, 2 photopoints
Musk thistle	***Photopoint***	1 photopoint	1 photopoint	1 photopoint
Diffuse knapweed	***Belt Transects/ photopoints***	4 25 m belt transects, 2 photopoints	4 25 m belt transects, 2 photopoints	4 25 m belt transects, 2 photopoints
Canada thistle	***Transect/ photopoint/ photoplot***	50 m transect, 10 quadrats, 5 photoplots, 2 photopoints	50 m transect, 10 quadrats, 5 photoplots, 2 photopoints	50 m transect, 10 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/ 10 quadrats, 5 photoplots, 3 photopoints, perimeter mapping	25 m transect w/ 10 quadrats, 5 photoplots, 2 photopoints, perimeter mapping
Yellow toadflax	***Transect/ photopoint/ photoplot***	25 m transect, 10 quadrats, 5 photoplots, 2 photopoints	25 m transect, 10 quadrats, 5 photoplots, 2 photopoints	25 m transect, 10 quadrats, 5 photoplots, 2 photopoints

Plot locations were selected randomly. From the GIS data of weed distributions mapped in 2002 and 2003, a subset of potential sites for plots was selected based on infestation size. Only infestations greater than 50 meters in diameter in at least one dimension were selected in order to maximize the probability that they would be sufficiently large to accommodate the sampling design. From this subset, two sets of three plots each were randomly selected for each target species using the random point generator extension (version 1.3) in ArcView (ESRI 1992-2000). The first set of points generated by this method was designated as the top priority for establishment of plots. The second set was designated as a backup in case any of the plots selected in the first set turned out to be unsuitable for establishing a permanent plot.

Random sampling allows the use of robust statistical data analysis. Plot data gathered in 2005 will be compared with data from each plot collected in 2006 to determine population trend of the infestation. The goal is to detect a minimum change of at least a 50% in cover, density, or number of individuals, depending on what data were gathered at a given plot, based on Carpenter and Perce (2004). This minimum detectable change threshold exceeds the stated management goals for many species at the Academy (Table 1). The statistical analysis may employ a two-tailed Paired *t*-Test after obtaining the second year of data to compare mean percent cover or mean number of ramets/genets between the two years if the data meet assumptions of normality. Similar comparisons will be made in the third year and in future years if possible, but a repeated measures analysis of variance (ANOVA) test (or an analogous non-parametric test if necessary) will be used to model changes in correlation over time. To make inferences regarding population trend, tests may be used to assess the linear or quadratic effects of time and treatment on trend, or a linear regression will be fitted to the data.

Quadrat Sampling

Rhizomatous species (hoary cress, Canada thistle, common St. Johnswort, Russian knapweed, and yellow toadflax*)* were sampled using a series of quadrats along a transect to estimate cover. Percent cover was chosen as the metric for these species because they tend to occur in dense populations where numbers of ramets cannot be easily quantified.

A 1.42 x .71m quadrat (1m^2) was used to estimate cover. This design was recommended by Dr. George Beck at CSU (Beck personal communication 2005). It is subdivided with elastic into 20 sections, each equating to 4% of the total cover within the quadrat (Figure 2). This greatly augments the accuracy and repeatability of the cover estimate and reduces observer bias.

At each site, 10 quadrats were sampled along a transect. The largest transect possible was employed for each target species. For hoary cress and Canada thistle, a 50 meter transect was used because infestations were frequently larger in diameter than 50 meters in at least one dimension. Three species (common St. Johnswort, Russian knapweed, yellow toadflax) required the use of a 25 meter transect because these species typically occur in smaller infestations at the Academy where a 50 meter transect would not fit. At plot 1 for Russian knapweed, the entire population was only 33 m long in its longest dimension so the transect design described above was shortened to 25 m with quadrats spaced every 2.5 m.

To identify the starting point for the first quadrat along the transect a random number between 1 and 5 was generated. For 50 meter transects this number became the location along the transect at which the first quadrat was placed, and subsequent quadrats were positioned every 5 meters from the first along the tape. For 25 meter transects, the random number was divided by two to determine the placement of the first quadrat and quadrats were spaced 2.5 meters apart. Each quadrat was positioned along the right side of a transect, with the distance measured along the transect to the lower left corner of the quadrat (Figure 3). Transects were marked at both ends using a 2 foot rebar stake leaving approximately ¼ protruding from the ground surface. Each stake was marked using a copper tag on which the plot number was written.

Within each quadrat, the percent cover of the target species and all other species present in the quadrat was estimated. The cover of non-target species was estimated because as management theoretically results in a decrease of cover of the target species, other species will replace it. It will be possible to observe whether changes in the percent cover of the target species results in increases of desirable (native) or undesirable (non-native) plant species at these sites. However, the primary goal of quadrat sampling is to measure percent cover of the target species and of other species of interest.

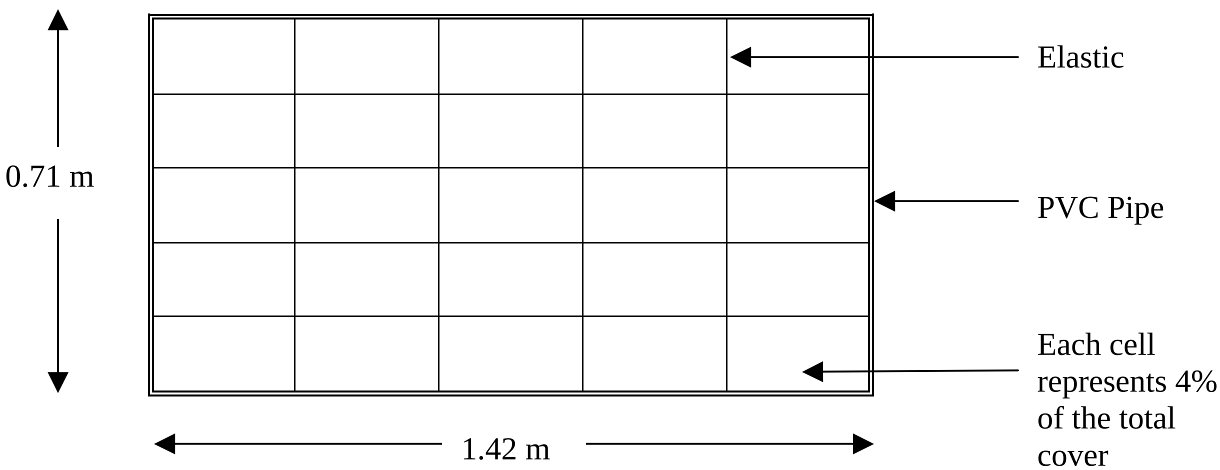

Figure 2. The design of the quadrat frame used for estimating cover.

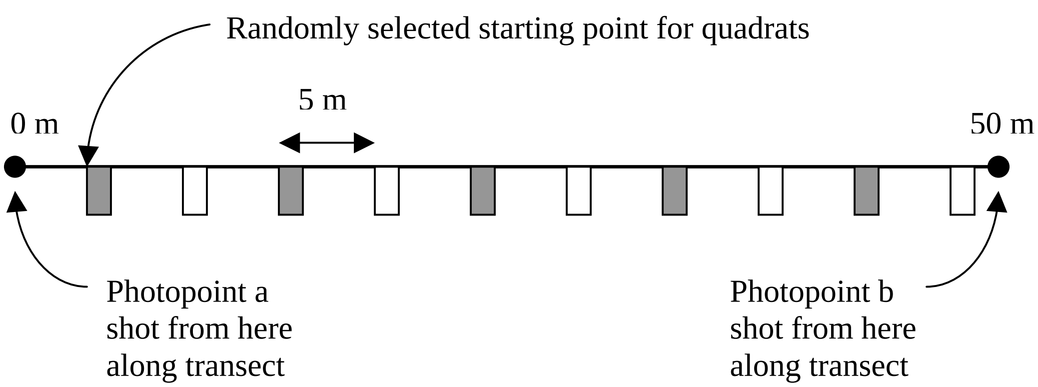

Figure 3. The layout of plots in which a 50-meter transect was used. Photoplots were sampled at shaded transects

Photoplots

Photoplots are photos taken of a subsample of a plot, and often consist of close-up photos taken of the ground within a quadrat. The goal of photoplot sampling in this project is to verify trends seen in quantitative data and to illustrate those changes. It is hoped that it will provide an effective documentation of change in cover of both the target species and of non-target species, and may help elucidate trends in vegetation change resulting from noxious weed management treatments or lack thereof.

The methods used in setting up and documenting the photoplots follows recommendations in Elzinga et al. (1998) and Hall (2002). Photoplots were taken at every other quadrat location in the sampling design described for quadrat sampling (Figure 3). Photoplots were monumented using a large galvanized stake placed in the lower left corner of the photoplot to facilitate relocation using a metal detector in subsequent years. The subdivided quadrat frame was placed over the photoplot to mark the boundary. Each photoplot included 60% of a quadrat. All photoplots were shot on 100 ASA Fuji Reala print film at a focal length of 28mm. The widest aperture possible was used to maximize the depth of field in the photos.

Belt Transects

Diffuse knapweed was sampled using 25 x 1.5m belt transects (Figure 4). The width of 1.5 m was determined through experimentation with different widths, and was determined to be the maximum width that could be reliably censused in a single pass. A meter tape was outstretched on one side of each belt transect, and a 1.5 m long pole was used to determine whether plants at the distal side of the belt fell within the transect. At each of the three plots, four transects were sampled (Figure 5). All plants rooted within the belt transects were counted using a tally counter. Plants were not counted if the canopy projected into the transect but the individual was not rooted in the transect.

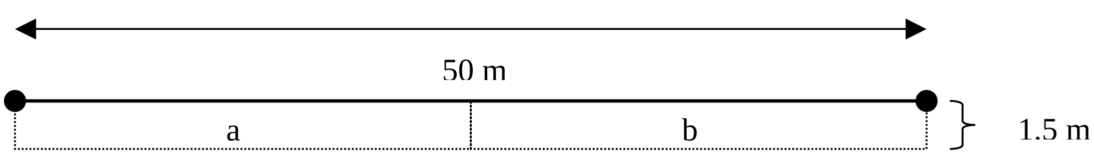

Figure 4. Detail of a single belt transect used for measuring density of diffuse knapweed at permanent monitoring plots.

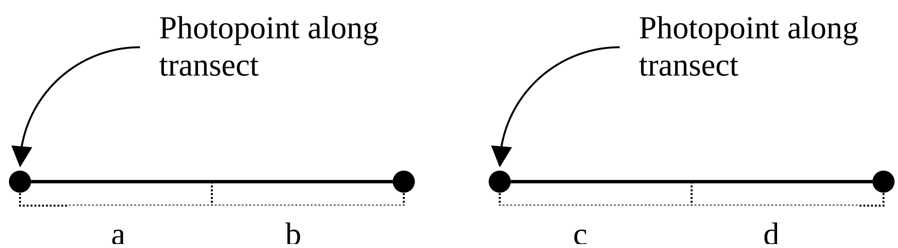

Figure 5. Layout of belt transects used for measuring density of diffuse knapweed at permanent monitoring plots.

Photopoints

Photopoints are pictures that are retaken from the same position at each observation, and are typically taken to help elucidate changes to a plot. They are usually taken towards the horizon, rather than at the ground as is done for photoplots. Photopoints were established at all permanent plots. The camera was positioned directly above rebar monumentation marking the photopoint (Figure 6). At plots using quadrats (Figure 3) and belt transects (Figure 5) at least two photopoints were sampled at each permanent plot. Photos were shot using a tripod such that the lens aperture was 1.5 m above the surface, and such that the sky occupied no more than ¼ of the photo. All photopoints were shot on 100 ASA Fuji Reala print film at a focal length of 28mm. The widest aperture possible was used to maximize the depth of field in the photos. Table 4 provides details on data that were collected for each photopoint. A drawing of each photo was also made in the field to use for verification later in collating the baseline data, following the recommendations of Hall (2002).

Photopoints were used as the primary tool for monitoring musk thistle, bull thistle, Fuller's teasel, and at plot 1 of common St. Johnswort. Photos of these species will be used to quantify the number of bolted plants and/or observe changes in the extent of the infestation over time. For all other species, the goal of the photopoint monitoring is similar to that of photoplots. It will provide an alternate means of verification for trends that become apparent in quantitative data and can provide a means of illustrating those trends. It may also provide insight into factors not considered at the outset of the monitoring project. The photopoints could be valuable for deducing possible effects on the vegetation within the plot that are the result of things happening outside the plot.

Figure 6. Setup used for sampling photopoints.

Table 4. Summary of data collected in the field for each photopoint.

Criterion	**Description**
Species	Scientific name of the target species
Plot#	Plot number (1-3)
Subplot#	Indicates position of photopoint within the plot
Plot Type	Quadrat, belt transect, photopoint,
Date	Date of photograph
Time	Time of photograph in 24:00 format
Observer(s)	Observer(s)
Feature ID	Numeric ID of feature mapped in 2002 or 2003- links the new information to features in the shapefiles of all weed infestations at USAFA. Some photopoints are at features not previously mapped.
Focal Length	The focal length of the lens for 35 mm film (always 28mm)
ASA	Film speed
Film Type	The brand and type of film
Roll#	Each roll of film shot in the project was given a sequential number
Aperture	F stop- all photos were shot at the smallest possible aperture (or largest F stop) to maximize depth of field.
Shutter Speed	Shutter speed
Bearing	Compass bearing of the center of the photograph
Datum	The datum used for recording the precise location of the photo (NAD 83)
UTM E	Easting coordinate in Universal Transverse Mercator System
UTM N	Northing coordinate in Universal Transverse Mercator System
Description	Description of the photo
Comments	Comments regarding when to take the photo, where to park, etc.

Perimeter Mapping

Perimeter mapping was used in monitoring Russian knapweed, leafy spurge, and common St. Johnswort. Perimeter mapping was used at all known infestations of Russian knapweed and common St. Johnswort at the Academy, and it was used at the three permanent plot sites for leafy spurge. Where perimeter mapping was used in this study, features were mapped broadly to include all individuals. This decision was made under the assumption that any individual is capable of multiplying through cloning or seed dispersal. Thus, including all individuals within the map features is the only way to ensure that managers are fully informed of where actions are required. Where outliers were found, a separate polygon was mapped if the distance between the patches would be resolvable at the sensitivity of the GPS (approximately 5 meters). In all cases, the target species were found in fairly discrete populations where there was seldom difficulty in identifying the edge of the occurrence.

Perimeter mapping was used for leafy spurge in favor of quadrat sampling for two reasons. The infestations of leafy spurge at the Academy are discontinuous and very patchy, which would lead to results with a very low coefficient of variance. Thus, a high sampling intensity would be needed to achieve the desired minimum detectable change. Also, most infestations of leafy spurge are small (less than 25 meters in diameter along their longest axis), so the sampling design used for all other quadrat sampling at the Academy would not be suitable.

Systematic Survey Transects

In order to monitor the possible spread of leafy spurge into surrounding areas, survey transects were used to verify the current status of each of the three infestations monitored at the Academy. At each monitoring site, four or five survey transects were sampled in the vicinity of the known infestations of leafy spurge at each plot. The transects are oriented east-west, and follow UTM northing lines every 20 meters. Each transect was walked slowly in an east or west direction, using the GPS unit to remain on the transect line. Each transect can be thought of as a 10 meter wide belt transect, since the presence of leafy spurge was be detectable within approximately five meters of the observer on either side of the transect. Perimeter mapping was used to record any infestations of leafy spurge found within the transect. The transects will be resampled annually to determine whether leafy spurge is spreading into adjacent uninfested areas.

RESULTS

Mapping and Assessment

Known sites were revisited and assessed, and new sites were mapped when found for the four targeted species (Table 5). A total of 268 infestations were mapped and assessed in 2005 (Figure 7). Of these, 217 were mapped in 2002 and revisited in 2005, while 50 were newly identified in 2005. Table 5 provides a summary of the results of mapping and assessment.

Table 5. Summary of 2005 baseline assessment for four noxious weed species at the U.S. Air Force Academy.

Species	**Revisits**	**New Infestations**	**Extant in 2005**
Scotch thistle	6	3	8 of 9
Russian olive	170	3	46 of 173
Russian knapweed	0	3	2 of 3
Spotted knapweed	41	42	79 of 83
TOTAL	217	51	135 of 268

Spotted knapweed

Spotted knapweed appears to have become more abundant within the areas where it was mapped in 2002, and seems to have spread to many new locations since 2002 (Figure 8). Current management efforts are apparently having little impact on this species. In 2002 it was mapped at 51 locations (10 of these were not visited in 2005). Of the 41 infestations revisited in 2005, only four appeared to have been extirpated. Most of the occurrences mapped in 2002 were found to be extant in 2005, where it was often evident that population sizes had grown considerably. Spotted knapweed was also found at 42 additional locations in 2005 where it had not been documented in 2002 (Figure 9). Most alarming is its affinity for sites that are not disturbed and are dominated by native plant species (Figure 10). It was found in open settings and also under partial canopy closure, suggesting that it has a broad ecological amplitude at the Academy and the potential to invade in many vegetation types. Because of its apparent rapid spread, and its propensity for invading undisturbed sites dominated by native plant species, it is a formidable threat at the Academy. The known behavior of this species in Montana (where it is the most problematic noxious weed in the state, Rees 1996), coupled with these and other observations of this species in Colorado suggest that this species is capable of spreading widely throughout the Academy and elsewhere in Colorado.

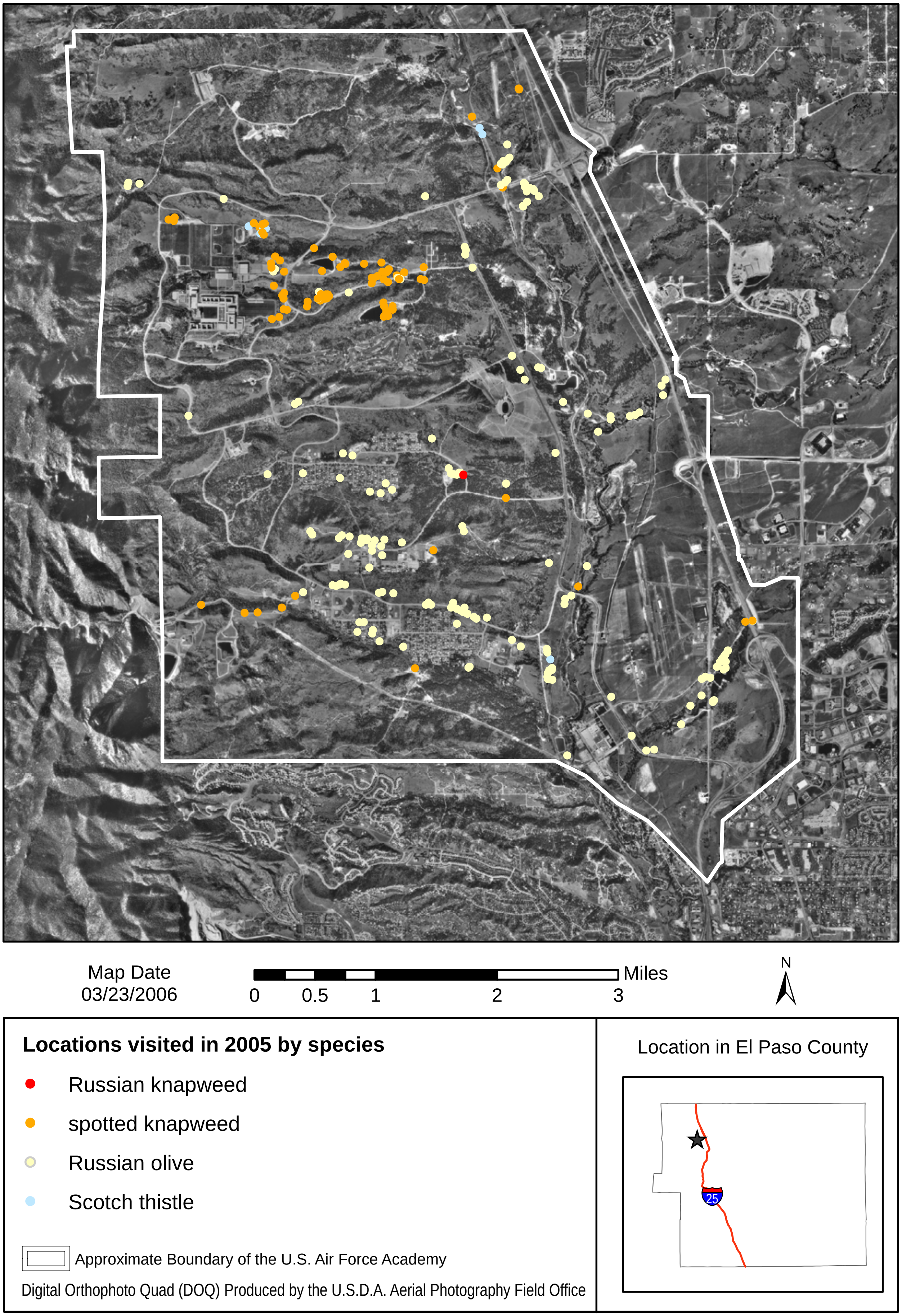

Figure 7. All mapping and assessment locations at the Academy visited in 2005 by species.

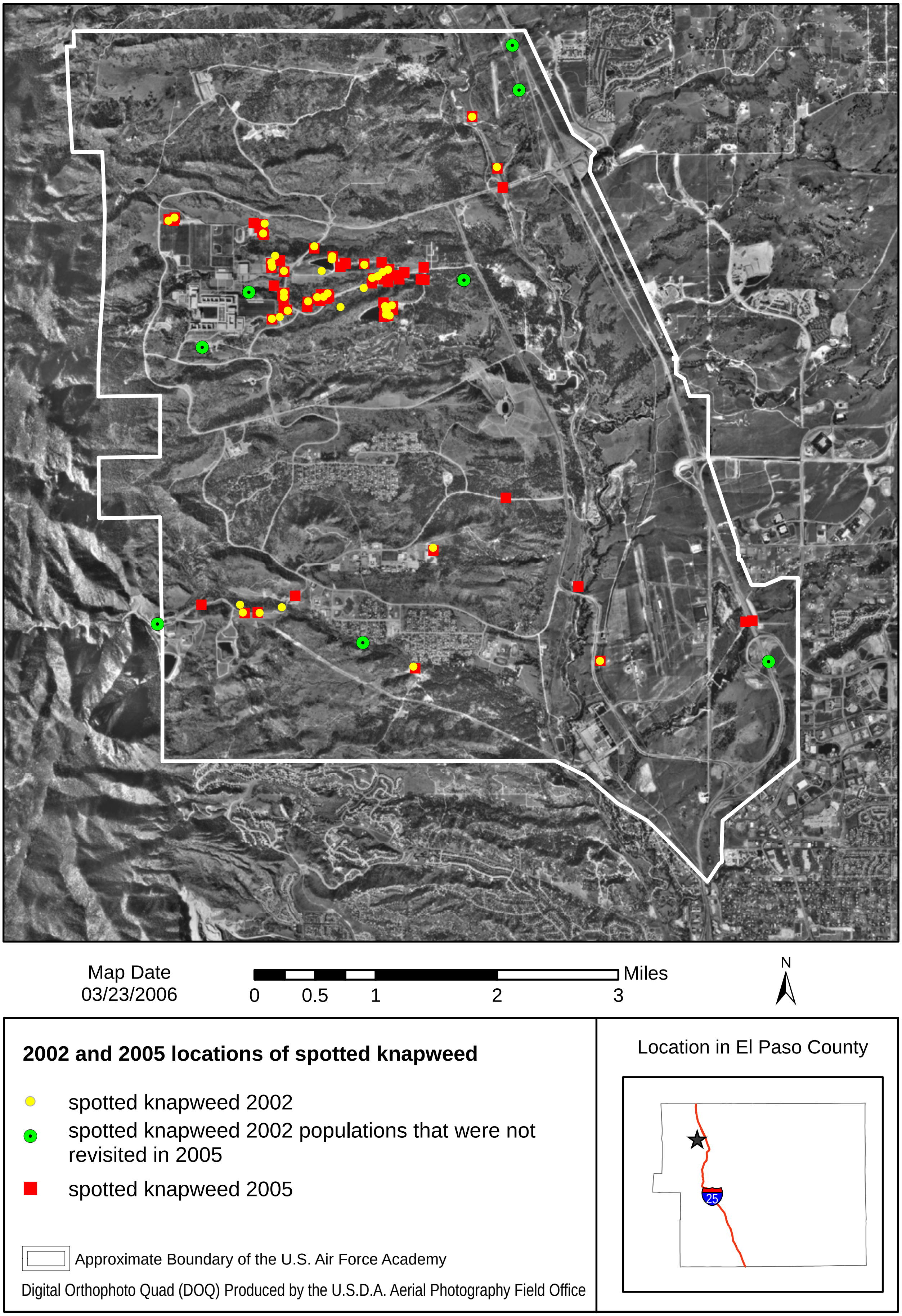

Figure 8. Distribution of spotted knapweed as it was mapped in 2002 compared with its distribution in 2005.

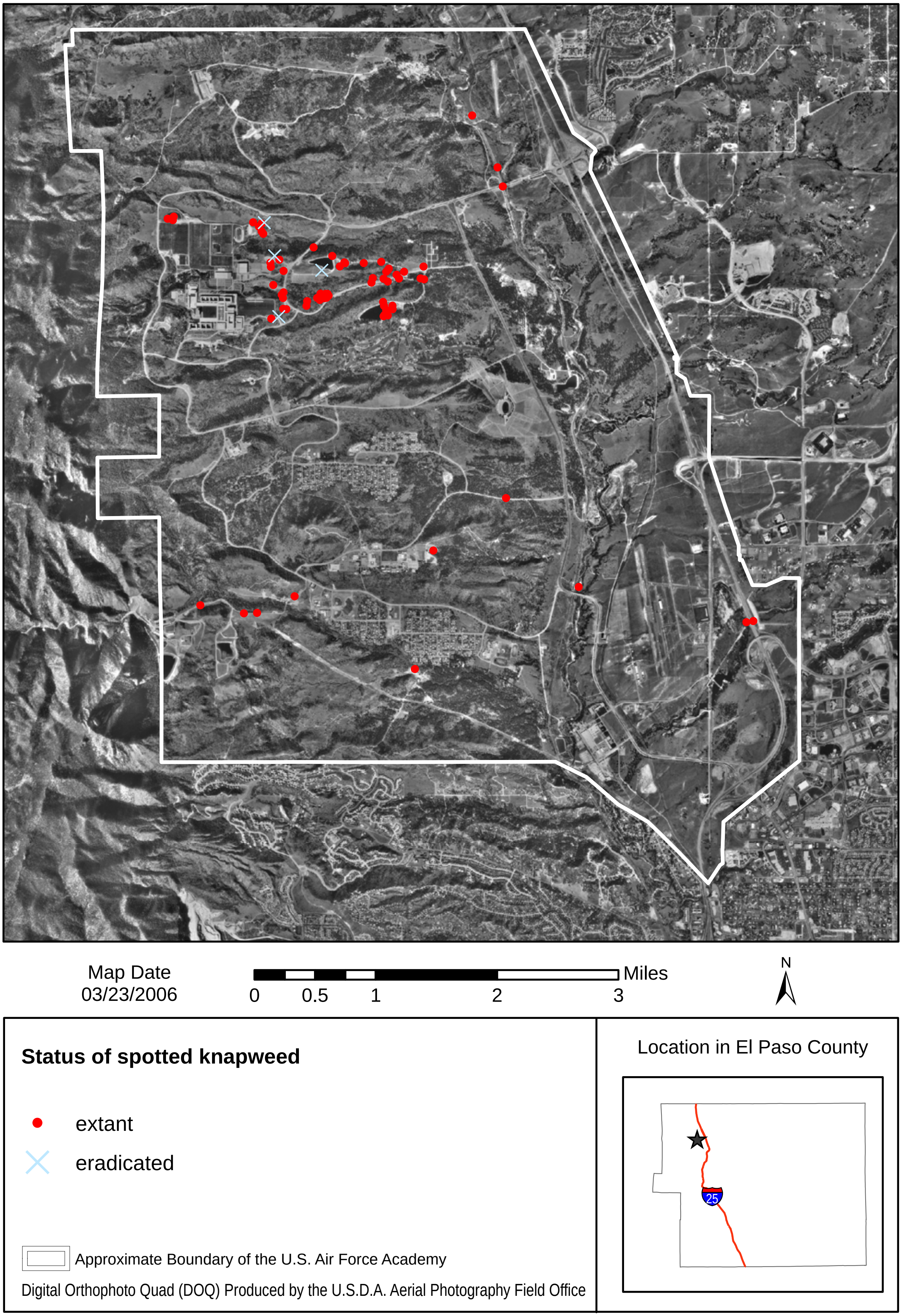

Figure 9. Map of all known infestations of spotted knapweed at the Academy and their status in 2005.

Figure 10. Invasion of a meadow adjacent to the Water Treatment Plant Road by spotted knapweed.

Russian olive

In contrast to spotted knapweed, the ongoing efforts to suppress Russian olive at the Academy appear to have been highly successful (Table 5, Figure 11). 127 of the 173 infestations revisited in 2005 appeared to have been eradicated through cutting trees and treatment of stumps with herbicide (Figure 12). Sprouting from stumps was observed at 24 of the infestations (Table 6). Two previously unknown infestations were identified in 2005.

Table 6. The status of Russian olive at the Academy in 2005 (does not include individuals near I-25 that were not surveyed).

	Status
Extant (untreated):	22
Sprouting from treated stump:	24
Eradicated:	127
TOTAL:	173

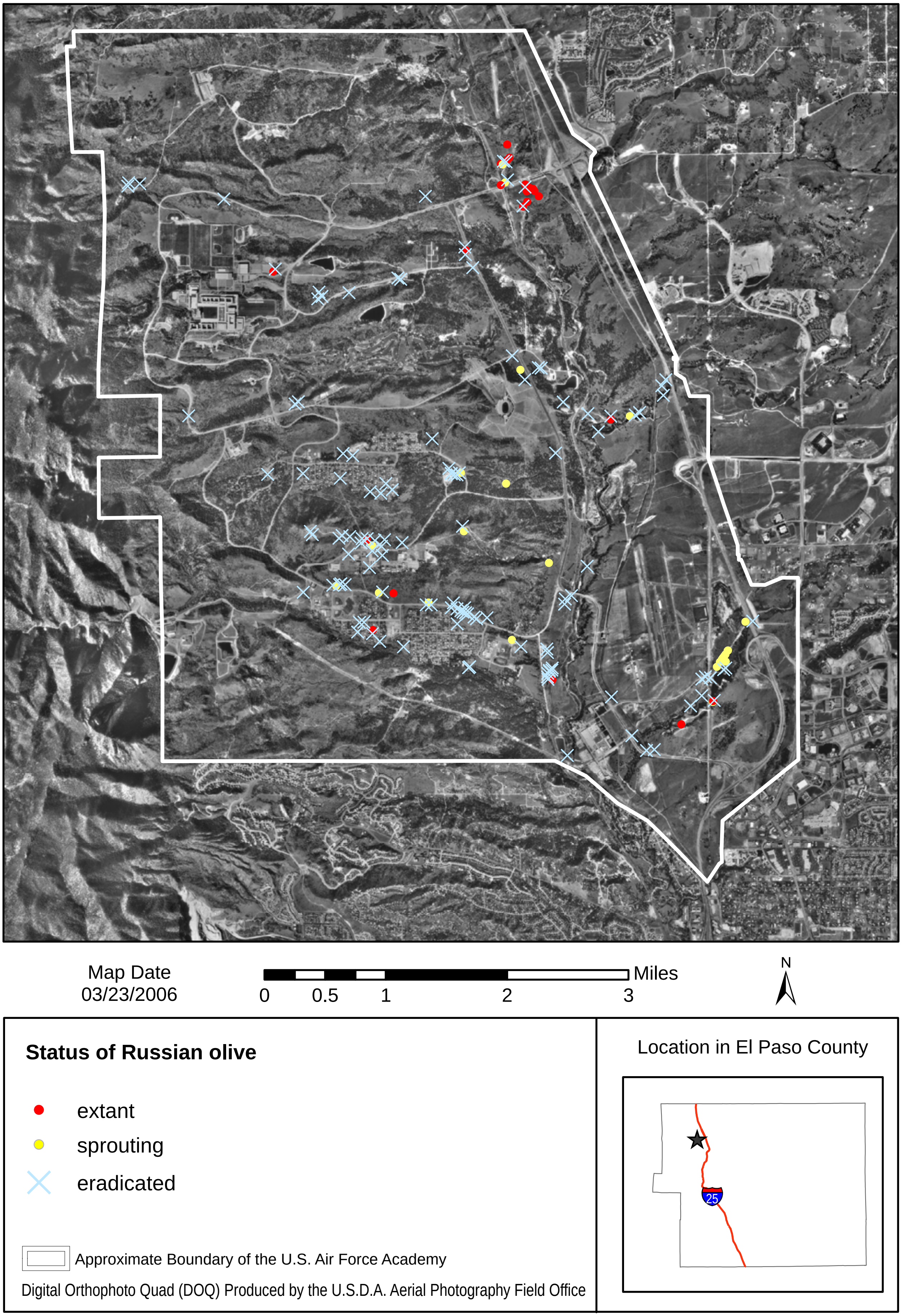

Figure 11. Map of all known infestations of Russian olive at the Academy and their status in 2005.

Figure 12. A successful treatment of Russian olive.

Scotch thistle

Most of the infestations of Scotch thistle observed in 2005 had been treated at least partially (Figure 13). In some cases untreated individuals were discovered at treated sites in areas that are more difficult to access. For example, at the Jack's Valley Gaging Station, plants near the road had been sprayed but those on the east side of the railroad tracks were untreated. Figure 14 shows the status of Scotch thistle at the Academy in 2005.

Figure 13. Treated individuals of Scotch thistle near the power substation along the Water Treatment Plant Road.

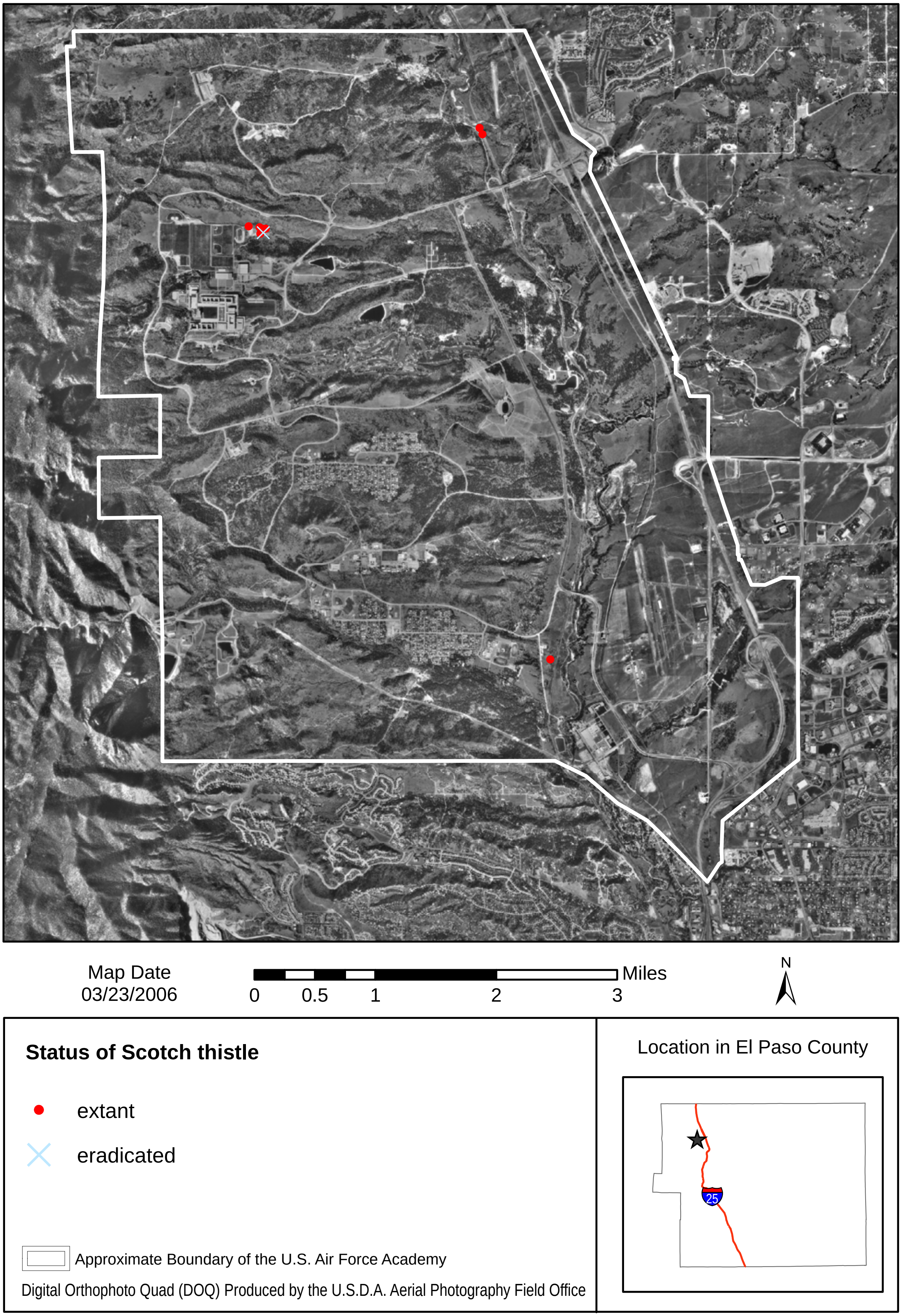

Figure 14. Map of all known infestations of Scotch thistle at the Academy and their status in 2005.

Russian knapweed

Russian knapweed has been known from three infestations at the Academy. Two of these were found to remain extant in 2005, although both had been treated in 2005 prior to the establishment of the monitoring plots. A permanent transect was established at the largest infestation, where the infestation had been treated with herbicide but many ramets had been missed in the treatment among taller willows at the east end of the infestation. At the other extant site the infestation was mapped and censused. The third infestation had been reported along I-25 west of the Kettle Lake Detention Basin. This area was searched in 2005 but Russian knapweed was not found at this location. However, spotted knapweed and diffuse knapweed were found abundantly at this site. This area will be searched again in 2006.

Permanent Plots

A total of 28 permanent plots were established for 10 target species (Table 3). The locations of these plots are presented in Table 7 and Figure 15. Detailed results for each type of permanent plot are discussed below.

Quadrat Sampling

Quadrat sampling was completed at twelve plots (Table 1). The coefficient of variance was below 1.0 in all plots except Russian knapweed plot 1 (Table 8). However, given the small size of this infestation it is not possible to add more quadrats without risking an unacceptable level of autocorrelation, as discussed by Carpenter and Perce (2004).

Photoplots and Photopoints

Baseline photoplots were sampled at every other quadrat at plots for Russian knapweed, hoary cress, Canada thistle, common St. Johnswort, and yellow toadflax. Five photoplots were sampled at each transect, for a total of 60 (only five photoplots were sampled for Russian knapweed and 10 for common St. Johnswort). A total of 47 photopoints were sampled, with at least one photopoint at each permanent plot. Duplicate bracketed photos were taken at many of the photopoints and photoplots.

Belt Transects

Four belt transects were sampled at each of the three diffuse knapweed plots. Preliminary analysis of the belt transect data for diffuse knapweed suggest that the current sampling intensity is sufficiently robust (Table 8).

Table 7. Coordinates and summary information for all permanent plots established in 2005. All UTM coordinates are projected in NAD 83 CONUS. Feature ID matches the unique identifier used in the weed map for the Academy; a zero value indicates that this feature was not mapped in 2002 or 2003.

Species	PLOT #	Feature Type	Feature ID	Date	UTM E	UTM N
Russian knapweed	1	Mapped	4019	6/4/2005	512802	4315638
Hoary cress	1	Mapped	3887	6/2/2005	514512	4313828
Hoary cress	2	Mapped	3912	6/3/2005	514879	4315391
Hoary cress	3	Mapped	3909	6/4/2005	514582	4315743
Musk thistle	1	Mapped	3397	7/5/2005	513079	4320431
Musk thistle	2	Mapped	3701	7/5/2005	513245	4321049
Musk thistle	3	New	0	7/6/2005	509415	4316102
Diffuse knapweed	1	Mapped	3510	7/5/2005	513055	4320631
Diffuse knapweed	2	Mapped	3385	7/6/2005	515028	4314151
Diffuse knapweed	3	Mapped	3526	7/8/2005	513284	4320006
Canada thistle	1	New	0	7/7/2005	513183	4321092
Canada thistle	2	Mapped	1073	7/8/2005	514559	4311610
Canada thistle	3	Mapped	3722	7/9/2005	514965	4314607
Bull thistle	1	Mapped	3988	8/8/2005	512534	4314549
Bull thistle	2	Mapped	3941	8/8/2005	512477	4317314
Bull thistle	3	Mapped	3998	8/9/2005	510280	4315888
Fuller’s teasel	1	Mapped	3600	8/6/2005	514550	4314176
Fuller’s teasel	2	Mapped	3486	8/7/2005	514661	4314843
Fuller’s teasel	3	Mapped	3449	8/7/2005	514372	4312879
Leafy spurge	1	New	0	8/8/2005	509778	4321198
Leafy spurge	2	New	0	8/8/2005	510112	4320870
Leafy spurge	3	New	0	8/9/2005	510028	4321026
Common St. Johnswort	1	Mapped	3974	7/6/2005	515099	4311501
Common St. Johnswort	2	Mapped	4003	7/7/2005	513809	4320130
Common St. Johnswort	3	Mapped	4018	7/7/2005	515697	4312232
Yellow toadflax	1	Mapped	3331	8/6/2005	515155	4315208
Yellow toadflax	2	Mapped	3313	8/7/2005	514131	4312863
Yellow toadflax	3	Mapped	3384	8/7/2005	513734	4320723

Table 8. Summary statistics (standard deviation and coefficient of variance) for all permanent plots at which quantitative data were gathered.

Species	Plot 1 SD	Plot 1 Ave	Plot 1 CoVar	Plot 2 SD	Plot 2 Ave	Plot 2 CoVar	Plot 3 SD	Plot 3 Ave	Plot 3 CoVar
Russian knapweed	4.9	3.35	1.46	--	--	--	--	--	--
Hoary cress	21.18	59.5	0.36	11.97	14.3	0.84	6.65	8.2	0.81
Diffuse knapweed	0.66	2.3	0.29	18.52	20.64	0.9	9.188	10.6	0.87
Canada thistle	19.27	33.5	0.58	8.6	24.7	0.35	25.46	33.5	0.76
Common St. Johnswort	--	--	--	19.54	27.1	0.72	13.7	21.3	0.64
Yellow toadflax	4.45	9.5	0.47	9.87	32	0.31	9.31	11	0.85

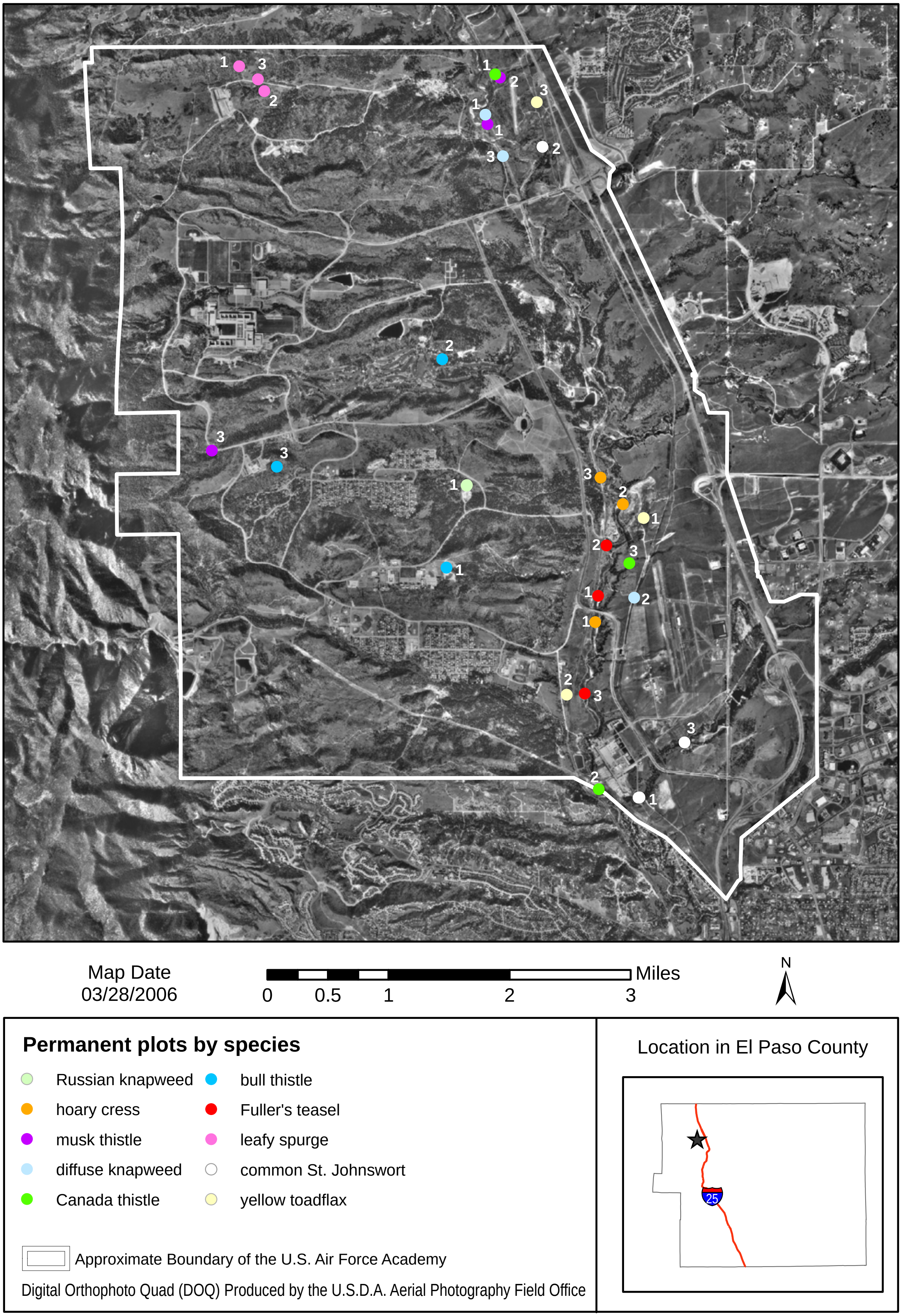

Figure 15. Location of all permanent plots established in 2005.

Perimeter Mapping and Systematic Survey Transects

Perimeter mapping was completed for all infestations of Russian knapweed and common St. Johnswort that could be found. The infestation of common St. Johnswort reported from southwest of the RV lot could not be relocated and was thus not mapped. It appeared that herbicide treatment applications may have successfully extirpated this occurrence. Attempts to verify this will be made in 2006. Perimeter mapping was completed at three permanent plots for leafy spurge in the vicinity of the Jack's Valley Training Complex (Figure 16). Systematic survey transects were also established and sampled at each permanent plot for leafy spurge (Figure 16).

Other Results

Two occurrences of rare plants (plains ironweed, and Southern Rocky Mountain cinquefoil) were visited and documented (Figure 17), and the threats to those occurrences from noxious weeds were assessed. Element occurrence records for these species were completed in the field and will be incorporated into the Biodiversity Tracking and Conservation System (BIOTICS) (Colorado Natural Heritage Program 2006).

Plains ironweed (*Vernonia marginata*, G5?S1) is a member of the aster family (Asteraceae). It is known from a single occurrence at the Academy, along Academy Drive north of the Fire Station (Figure 17), where it was originally discovered by J.D. Ripley in 1979. Roadwork taking place in this area in 2005 did not appear to be directly affecting the occurrence, probably due largely to stakes and signage placed at this location by Natural Resources Staff. Vigilance may be needed to ensure that noxious weeds do not invade from the adjacent disturbance. Plains ironweed is known from two other locations in Colorado in Baca and Cheyenne counties, where it is known only from specimens at the University of Colorado Herbarium. Its global conservation status is uncertain. It is also known from Utah, Arizona, New Mexico, Texas, Oklahoma, and Kansas (NatureServe 2006).

Three new suboccurrences of Southern Rocky Mountain cinquefoil (*Potentilla ambigens*, G3S2) were discovered in 2005 (Figure 17). One of these is within plot 2 for common St. Johnswort, where a single individual was observed (Figure 18). It was also found at two locations along Deadman's Creek west of the Cemetery, where a single plant was found at one suboccurrence and three plants at the other. Southern Rocky Mountain cinquefoil is a member of the rose family (Rosaceae). It known from at least 44 occurrences in New Mexico, Colorado, and Wyoming. Most of the population of Southern Rocky Mountain cinquefoil probably occurs in New Mexico, but its distribution is poorly understood throughout its range. The single occurrence in Wyoming has not been seen since 1900. In Colorado it is known from 26 occurrences (Anderson 2006).

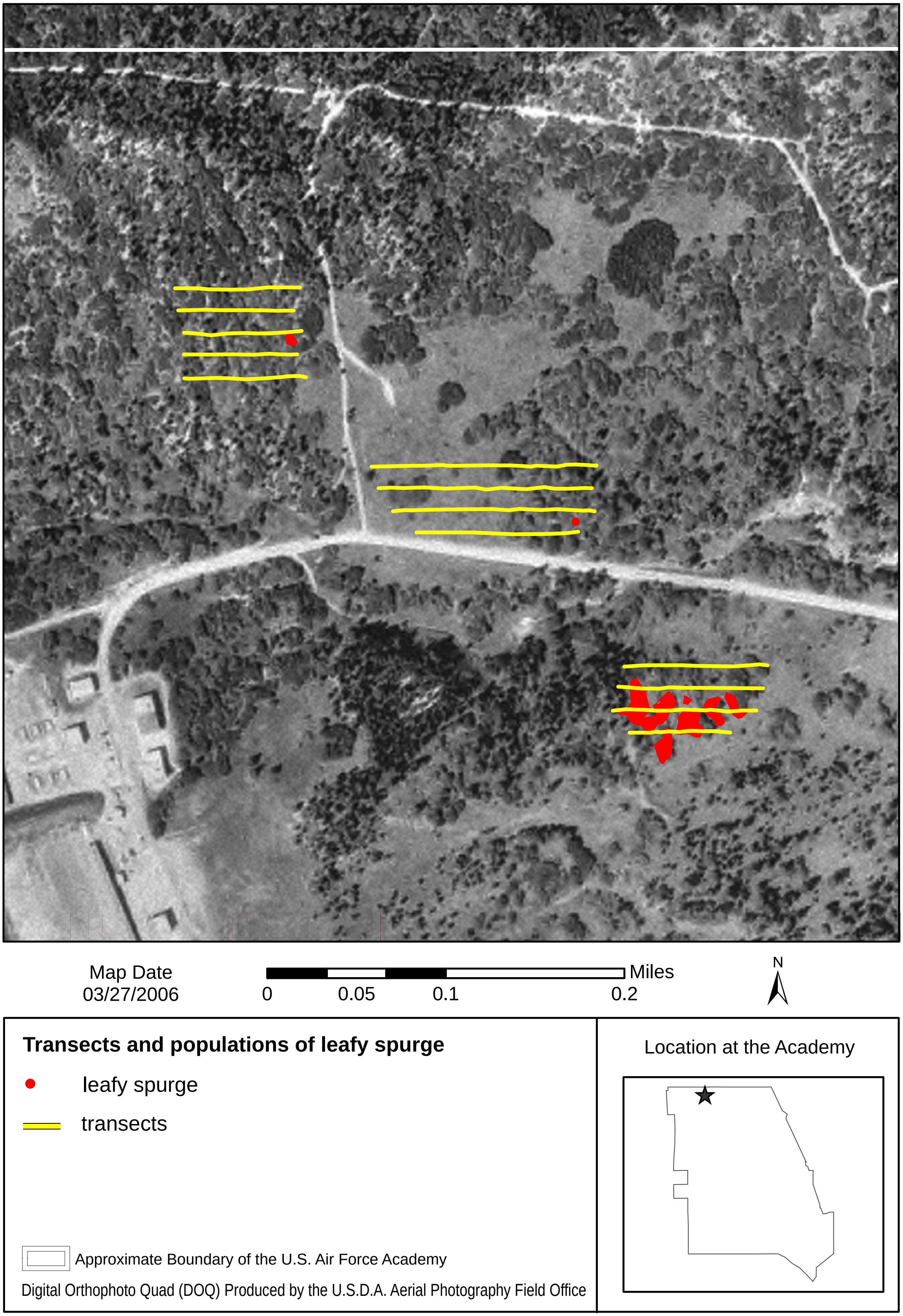

Figure 16. Perimeter mapping and systematic survey transects completed at the three permanent plots for leafy spurge.

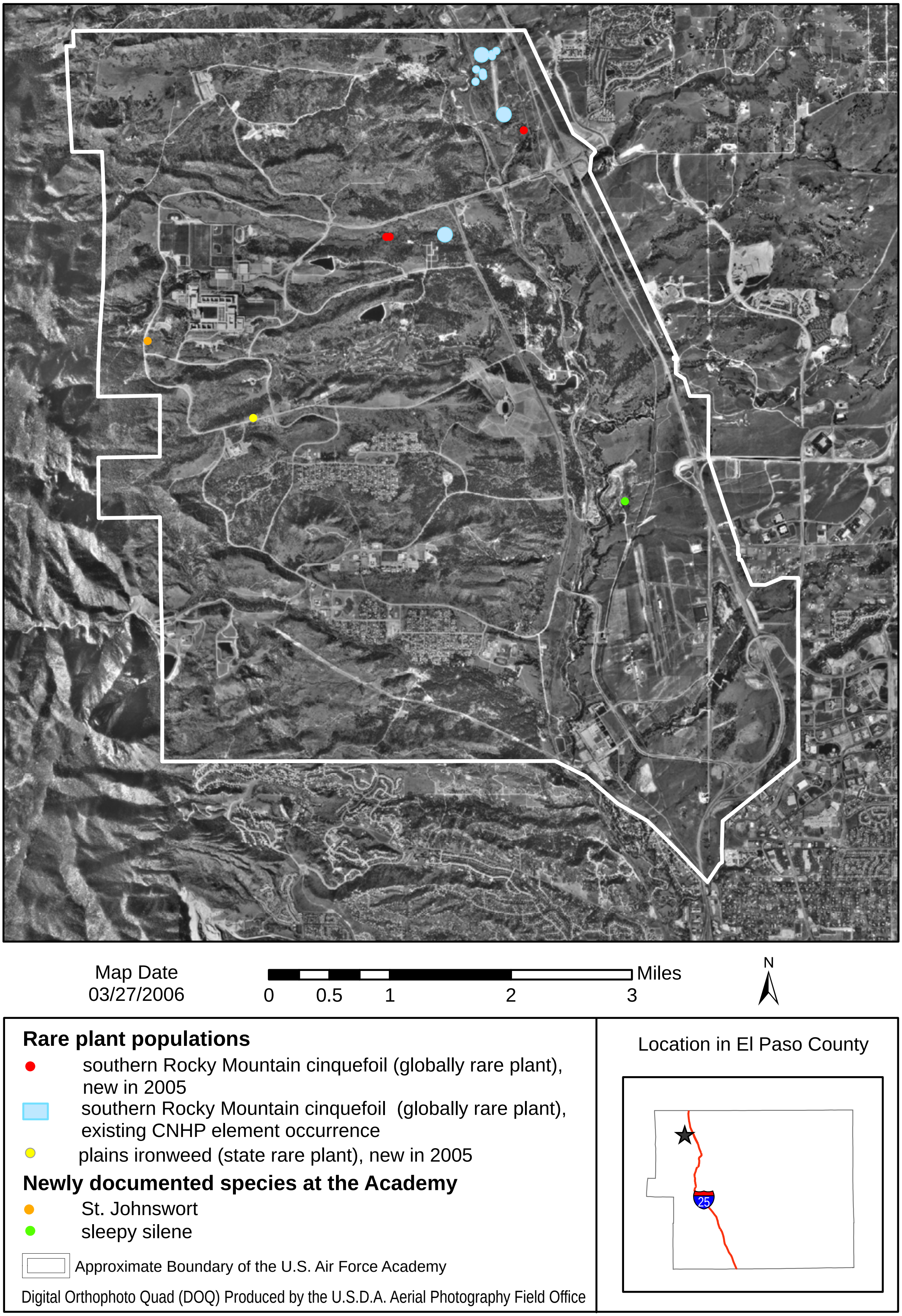

Figure 17. Occurrences of rare plants and newly documented species revisited or identified in 2005.

Figure 18. The distinctive leaf of Southern Rocky Mountain cinquefoil, on the plant observed within plot 2 for common St. Johnswort.

Two native plant species were found in 2005 that had not previously been documented at the Academy by Ripley (1994) (Figure 17). These species are St. Johnswort (*Hypericum formosum*) and sleepy silene (*Silene antirrhina*). St. Johnswort was found in a wetland immediately south of the Cadet Area. This species may be susceptible to the use of biocontrol agents that are being used to suppress common St. Johnswort at the Academy. *Chrysolina sp*., a leaf and flower-feeding beetle, has been released at three locations at the Academy to control populations of common St. Johnswort (Michels et al. 2004). The beetles were not observed on St. Johnswort in 2005. Sleepy silene was found in quadrat samples at Plot 1 for yellow toadflax.

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