Noxious Weed Survey of the U.S. Air Force Academy and Farish Outdoor Recreation Area- 2007






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TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

MAPS

EXECUTIVE SUMMARY

This report provides a summary of weed mapping efforts at the U.S. Air Force Academy ("the Academy") and the Farish Outdoor Recreation Area ("Farish") over the past five years. In 2007, distributions of 17 target species were mapped in their entirety at the Academy and Farish from June 4 through October 1. Attribute data were gathered for each infestation documenting size, number of shoots, distribution pattern, and in some cases treatment status and success.

The primary emphasis of this report is to compare data collected in 2002 and 2003, when baseline data were obtained, with those collected in 2007. Mapping the distribution of targeted noxious weeds again in 2007 has made it possible to examine the change in weed populations at the Academy and Farish over both space and time. The purpose of this report is to distill these data into a cogent and succinct picture elucidating trends in rate of spread, distribution, habitat affinities, occupied area, number of stems, and number of mapped features. These analyses are aimed at informing managers regarding the current status of the Academy's weed management program with respect to the Academy's weed management objectives.

While 2002 was the driest year on record, the 2007 growing season was relatively moist. These differences tend to exaggerate the magnitude of change in weed populations between those years.

A total of 5,654 features were mapped at the Academy and Farish in 2007. Of these, 156 were locations where infestations of spotted knapweed and Russian olive had been mapped previously but were eradicated in 2007. There were 5,328 extant weed infestations at the Academy and 170 extant weed infestations at Farish. Fifty-seven infestations of Canada thistle and yellow toadflax were mapped outside the boundaries of high priority conservation areas, leaving a total of 5,271 infestations that fell within the study area at the Academy.

The area occupied by targeted noxious weeds increased 75% between 2002 and 2007 at the Academy. Rate of spread was greatest for diffuse knapweed, followed by spotted knapweed. The magnitude of change was greatest (in descending order) for spotted knapweed, common St. Johnswort, Scotch thistle, and leafy spurge. In terms of actual acreage invaded between 2002 and 2007, diffuse knapweed was the highest at 80.31 acres invaded. Spotted knapweed invaded 53.21 acres at the Academy.

The increase in infested area increased 264% at Farish between 2002 and 2007. During that time yellow toadflax invaded 13.6 acres, musk thistle invaded 1.76 acres, and Canada thistle invaded 1.33 acres at Farish. It appears that all noxious weeds are in an earlier stage of invasion at Farish, indicating that there are still significant opportunities for preventing infestations.

Although progress has been made with some species, weed management objectives have not yet been reached for any target weed species. The Academy is closest to reaching management goals for Russian olive, which has been reduced by 62%; the management objective for this species is 90% suppression. A reduction of 90% or greater is well within reach if management practices that have been used in the past are continued.

Significant progress towards meeting management objectives has been made for common St. Johnswort, myrtle spurge, Russian knapweed, and tamarisk. Objectives could be reached relatively easily for all of these species, and also for Scotch thistle, through the strategic use of herbicide, biocontrol, and pulling.

For other species, the window of opportunity has closed somewhat since 2002. This is especially true for spotted knapweed. Ambitious herbicide treatment of this species over the next two to five years could still turn the current trend around. However, since this species has now been in a phase of rapid spread for 3 to 5 years it has become entrenched enough that reversing the trend will be relatively costly. Leafy spurge and diffuse knapweed have also become significantly more widespread over the last five years. At Farish, yellow toadflax, Canada thistle, and musk thistle are all spreading into new areas rapidly, but because of the small area involved, reversing these trends is still feasible.

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.

Mapping noxious weeds is an important step in designing a weed management program and action plan. Weed mapping provides data that can identify areas potentially subject to weed invasion and provides feedback regarding management efforts. This allows managers to maximize the effectiveness of limited financial and human resources in weed management (Cooksey and Sheley 1998).

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 and recommended weed management protocols for the Academy and Farish.

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 monitoring plots established in 2005 were resampled. A fourteenth species, myrtle spurge 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 and the monitoring program was evaluated. Recommendations for modifying the monitoring program as appropriate are offered by Anderson and Lavender (2008). Since six species include mapping and census techniques as a part of the monitoring program, there is considerable overlap between the monitoring program and the mapping project discussed in this report. Despite this overlap we made the decision to report the results of these projects separately, since the scope of these projects differed considerably. 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.

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.

Purpose of This Report

This report provides a summary of weed mapping efforts at the Academy and Farish over the past five years. A primary emphasis in this report is to compare data collected in 2002 and 2003, when baseline data were obtained, with those collected in 2007. For some species targeted in the Academy's monitoring program additional comparisons could be made with data from 2005 and 2006. Because it is now possible to examine the change in weed populations at the Academy and Farish over space and time,

it is necessary to distill the large amount of available data in order to elucidate trends in rate of spread, distribution, habitat affinities, occupied area, number of stems, and number of mapped features. These analyses are aimed at informing managers regarding the current status of the Academy's weed management program with respect to the Academy's weed management objectives. Details for each weed management target are treated separately in the Results section of this report.

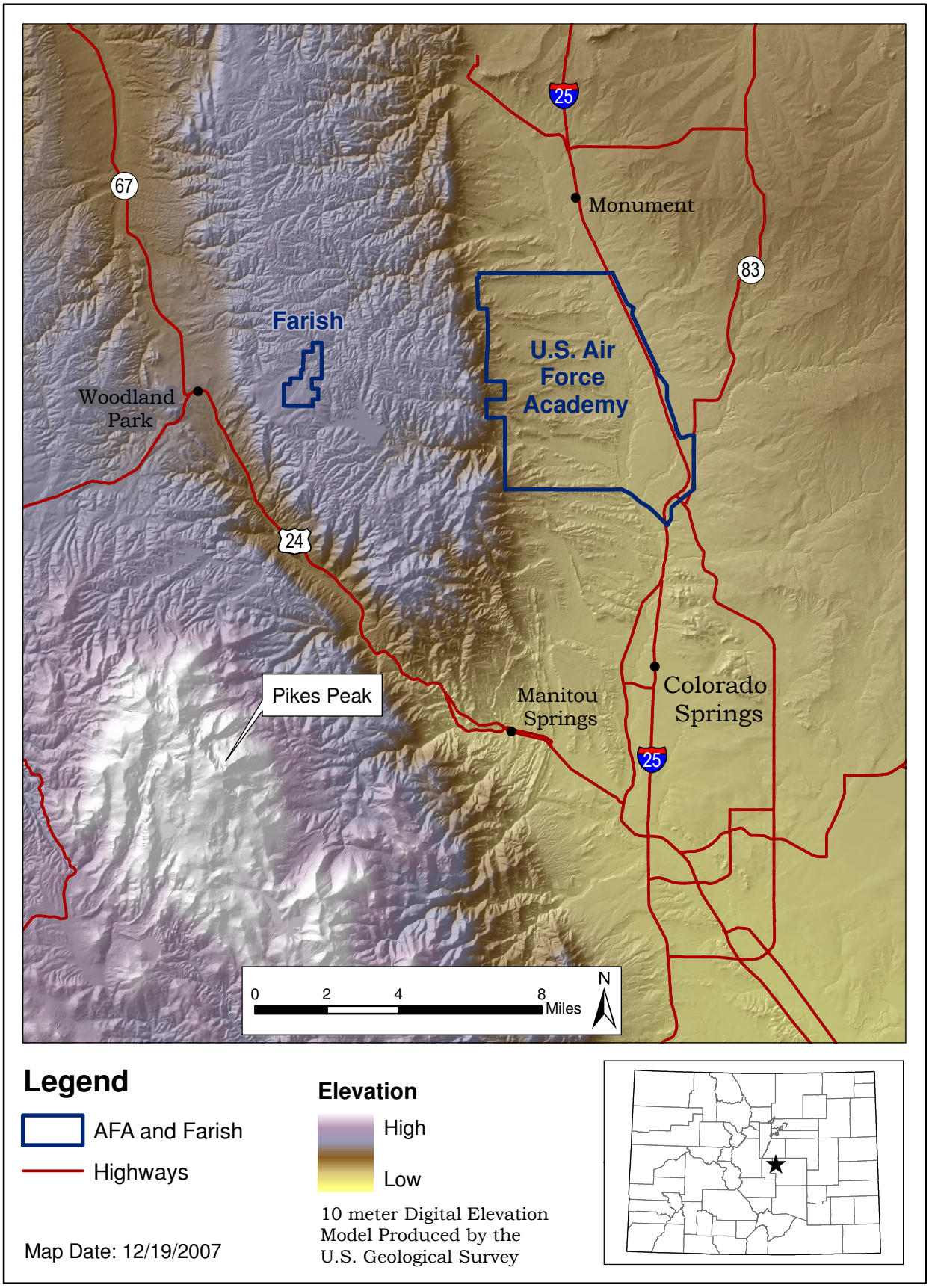

Figure 1. Vicinity map for the U.S. Air Force Academy and the Farish Memorial Recreation Area, El Paso County, Colorado.

METHODS

Sixteen noxious weed species were mapped in the study area in 2007. Additionally, diffuse/ spotted knapweed hybrids were mapped separately, for a total of 17 mapped entities in 2007. The species targeted in this study are those that were mapped in 2002, plus Russian knapweed, myrtle spurge, and diffuse/ spotted knapweed hybrids, all of which were discovered at the Academy after 2002. All species except diffuse/ spotted knapweed hybrids are included as management targets in the Integrated Noxious Weed Management Plan (Carpenter et al. 2004). Nomenclature used in this report conforms to that used by the Colorado Weed Management Association (2008) and the Colorado Department of Agriculture (2005). The complete list of mapping targets for this study is included in Table 1. Fourteen invasive plant species that have a relatively high probability of invading the Academy and Farish (Table 2) were also sought in 2007. The requirements mandated for species on these lists are interpreted in Table 3.

The data collected in the field conform to standards established by NAWMA (North American Weed Management Association 2002) and meet the needs of the Colorado Department of Agriculture's statewide weed mapping (Colorado Department of Agriculture 2008a). All attribute data 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.

It was especially important to maintain consistency in mapping methodology in 2007 to ensure that the data collected would be comparable to those collected in 2002 and 2003. CNHP conducted one week of training onsite with the field technician to ensure that field interpretation and mapping were consistent with methods used previously by Anderson et al. (2003).

All weed infestations were mapped in the field using ArcPad version 7.0.1 (ESRI 1995-2006), a portable version of GIS software that allows the user to create and edit shapefiles remotely using a personal digital assistant (PDA). ArcPad was installed on a Trimble Recon PDA with a Windows Mobile operating system, connected to a GlobalSat compact flash GPS receiver for data collection and a PC Card for data storage. The GlobalSat compact flash GPS receiver has a horizontal accuracy of 10 meters, but was found in field trials to be accurate most often to within 5 meters. All data were collected using the GPS unless otherwise noted in the comments field of the weed shapefile. In some situations, it was easier for the field technician to map an occurrence using "heads-up" digitizing, mapping directly on-screen using a 1 foot resolution digital orthophoto quad for reference; however, this was an infrequent situation, occurring less than 2% of the time. To prevent data loss, all files were stored on the PC Card and transferred to a laptop via MS Activesync at least once daily. Shapefiles collected in the field were assimilated into a file geodatabase in ArcGIS 9.2 (ESRI 1999-2006) using the autoreconciliation process for checking-in and checking-out data. Weekly, all data files were emailed directly to CNHP and backed up on University servers to ensure the integrity of the data. Weed attributes were reviewed by GIS personnel for validity and completeness.

Table 1. Targeted noxious weed species at the U.S. Air Force Academy and Farish Outdoor Recreation Area and their status on the Colorado State Noxious Weed List (Colorado Department of Agriculture 2008b).

Species	**List**
Myrtle spurge (*Euphorbia myrsinites*)	List A
Bull thistle (*Cirsium vulgare*)	List B
Canada thistle (*Cirsium arvense*)	List B
Diffuse knapweed (*Centaurea diffusa*)	List B
Fuller's teasel (*Dipsacus fullonum*)	List B
Leafy spurge (*Euphorbia esula*)	List B
Musk thistle (*Carduus nutans*)	List B
Russian knapweed (*Acroptilon repens*)	List B
Russian-olive (*Elaeagnus angustifolia*)	List B
Scotch thistle (*Onopordum acanthium*)	List B
Spotted knapweed (*Centaurea maculosa*)	List B
Tamarisk (*Tamarix ramosissima*)	List B
Whitetop (*Cardaria draba*)	List B
Yellow toadflax (*Linaria vulgaris*)	List B
Common St. Johnswort (*Hypericum perforatum*)	List C
Field bindweed (*Convolvulus arvensis*)	List C
Diffuse/ spotted knapweed hybrid	none

Table 2. Noxious weed species and other invasive plant species considered likely to invade the U.S. Air Force Academy and Farish Outdoor Recreation Area and their status on the Colorado State Noxious Weed List (Colorado Department of Agriculture 2008b.

Species	**List**	**Source**
Mediterranean sage (*Salvia aethiopis*)	List A	1
Purple loosestrife (*Lythrum salicaria*)	List A	1
Yellow starthistle (*Centaurea solstitialis*)	List A	2
Bouncingbet (*Saponaria officinalis*)	List B	1
Chinese clematis (*Clematis orientalis*)	List B	2
Common tansy (*Tanacetum vulgare*)	List B	2
Cutleaf teasel (*Dipsacus laciniatus*)	List B	2
Dalmatian toadflax (*Linaria dalmatica*)	List B	2
Dame's rocket (*Hesperis matronalis*)	List B	2
Houndstongue (*Cynoglossum officinale*)	List B	1
Perennial pepperweed (*Lepidium latifolium*)	List B	1
Common buckthorn (*Rhamnus cathartica*)	none	1
Garlic mustard (*Alliaria petiolata)*	none	1
Tartarian honeysuckle (*Lonicera tartarica*)	none	1

Source: 1= Carpenter et al. 2004, 2= this report

Table 3. Colorado Weed Ranks. Listed noxious weeds are assigned to List A, B, or C in Colorado. Management actions are required for species on these lists, as explained below (Colorado Department of Agriculture 2005).

List A	Species in Colorado that are designated by the Commissioner for eradication.
List B	Species for which the Commissioner, in consultation with the state noxious weed advisory committee, local governments, and other interested parties, develops and implements state noxious weed management plans designed to stop the continued spread of these species.
List C	Species for which the Commissioner, in consultation with the state noxious weed advisory committee, local governments, and other interested parties, will develop and implement state noxious weed management plans designed to support the efforts of local governing bodies to facilitate more effective integrated weed management on private and public lands. The goal of such plans will not be to stop the continued spread of these species but to provide additional education, research, and biological control resources to jurisdictions that choose to require management of List C species.

The autoreconciliation process allows for a relatively easy, seamless way to continue mapping weeds at the Academy and Farish as new infestations or species are identified by Natural Resource Managers. This functionality is new in ArcGIS 9.2 (ESRI 1999-2006) and thus was not available for use during the 2002 mapping project. For detailed instructions, refer to Appendix A.

Weed infestations were mapped using 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.

Attributes were ascribed to all features mapped in the field. These include weed species, date, area of infestation, and density. Area was determined by documenting the radius of point occurrences, and by adding a buffer to line occurrences. All radii and buffers were determined in the field for each weed occurrence. Then the area was calculated in ArcGIS 9.2 (ESRI 1999-2006). Density is determined either as the number of shoots counted (for small populations) or as number of shoots per square meter (for large populations). Notes were taken about an infestation where unusual or noteworthy observations were made. All of these attributes are included in the attribute tables of the shapefiles accompanying this report.

This project has benefited from Academy's noxious weed monitoring program that began in 2005. For six species (spotted knapweed, Russian olive, Russian knapweed, Scotch thistle, common St. Johnswort, and myrtle spurge), mapping and assessment have been done in 2005 and/or 2006 as a part of the monitoring program (Anderson and Lavender 2006, Anderson and Lavender 2007). The entire distribution of these species was mapped at the Academy and census data were collected to provide

management feedback. Treatment status and treatment success were documented for all infestations of these species. This was continued in 2007, and treatment status and treatment success were documented opportunistically for other target species as well. Table 4 summarizes the activities that have taken place for each target species since 2002.

Collection of weed data at the Academy and Farish was subject to limitations imposed by human resources, time, and safety. Data were collected almost entirely by only one person covering 19,000 acres from June 4 through October 1, 2007. On a daily basis, ca 300-acre areas bounded by identifiable natural and man-made features such as ridges and roads were arbitrarily defined. The goal each day was to make observations over as much of each 300 acre area as possible, and to traverse the variation of

Table 4. Summary of mapping and monitoring activities by species at the Academy since 2002. Monitoring activities (not necessarily mapping) are indicated by purple highlighting.

Common Name	Scientific Name	2002	2003	2004	2005	2006	2007
Russian knapweed	***Acroptilon repens***			Discovered	Mapped	Mapped	Mapped
Hoary Cress	***Cardaria draba***	Mapped	Mapped				Mapped
Musk Thistle	***Carduus nutans***	Mapped					Mapped
Diffuse Knapweed	***Centaurea diffusa***	Mapped					Mapped
Diffuse / spotted knapweed hybrid	***C. diffusa x maculosa***				Discovered		Mapped
Spotted Knapweed	***Centaurea maculosa***	Mapped			Mapped	Mapped	Mapped
Canada Thistle*	***Cirsium arvense***	Mapped					Mapped in part
Bull Thistle	***Cirsium vulgare***	Mapped					Mapped
Field Bindweed	***Convolvulus arvensis***	Mapped					Mapped
Fuller's Teasel	***Dipsacus fullonum***	Mapped					Mapped
Russian Olive	***Elaeagnus angustifolia***	Mapped	Mapped in part		Mapped in part		Mapped
Leafy Spurge	***Euphorbia esula***	Mapped					Mapped
Myrtle spurge	***Euphorbia myrsinites***				Discovered	Mapped	Mapped
Common St. Johnswort	***Hypericum perforatum***	Mapped			Mapped	Mapped	Mapped
Yellow Toadflax*	***Linaria vulgaris***	Mapped					Mapped in part
Scotch Thistle	***Onopordum acanthium***	Mapped			Mapped	Mapped	Mapped
Tamarisk	***Tamarix ramosissima***	Mapped					Mapped

topography and vegetation within those units. Each traverse then served as a random, stratified sample of each noxious weed target species. It must be emphasized that this methodology is best thought of as an intensive sampling procedure rather than a comprehensive inventory, since the large area of the Academy properties precluded the intensive search of every possible location for weeds.

High priority conservation areas were emphasized in this study, both because of their importance for biodiversity conservation and because the number of weed targets is greater within them. The vicinity of Monument Creek is topographically complex and heavily vegetated, making survey work more difficult there. This area is important for biodiversity conservation but is also more susceptible to invasion by weeds than other parts of the Academy. Thus, the effort required was higher for this portion of the Academy but the importance of the information obtained is also higher.

RESULTS

A total of 5,654 features were mapped in 2007 at the Academy and Farish. Of these, 156 were locations where infestations of spotted knapweed and Russian olive had been mapped previously but were eradicated in 2007. There were 5,328 extant weed infestations at the Academy and 170 extant weed infestations at Farish. Fifty-seven infestations of Canada thistle and yellow toadflax were mapped outside the boundaries of high priority conservation areas, leaving a total of 5,271 infestations that fell within the study area.

Summary data from mapping weed targets in 2002 and 2007 are presented in tables 5a, 5b, and 6. These reveal several trends of management concern, and along with the geographic distributions of the target species (Maps 1-21), give a strong indication of where greater management efforts are needed.

There are several factors that must be taken into account when comparing weed data collected in 2002 with the 2007 data. The most important of these is the difference between the 2002 and 2007 growing seasons. The apparent increase in occupied acres, number of shoots, and number of mapped features between 2002 and 2007 is almost certainly exaggerated due to the 2002 drought. 2002 was the driest year at Colorado Springs since recordkeeping started in 1948 (Western Regional Climate Center 2008). A total of only 7.9 inches of precipitation fell that year, less than half the average amount (Table 7). Precipitation in 2007 was also below average, but growing conditions were far better than when the baseline weed map was completed. A wet monsoon season and fall in 2006, and ample spring moisture in 2007 resulted in prolific flowering of native species as well as noxious weeds in 2007. Thus, when we compare the weed data collected in 2002 with 2007's data, the differences are magnified by the effects of climate variation.

Observer variability must also be taken into consideration in interpreting these results because the mapping was done by a different person each year. Observer bias is a significant problem in monitoring plant populations (Elzinga et al. 1998). Efforts were made to reduce these effects in this study, but an element of subjectivity is unavoidable in mapping exercises of this sort.

Finally, improvements in technology between 2002 and 2007 have also had a small effect on interpreting these data. Because spatial data were captured directly from the GPS, and because the GPS used in 2007 was superior, the 2007 data are more accurate than the 2002 data. There is a small amount of uncertainty in some cases whether a given infestation was mapped previously in 2002 or instead represents a new infestation. However, the technology improvements do not affect differences observed in occupied area since area is determined by the field technician in most cases.

Despite the considerations discussed above, it is clear that the distributions and populations of the targeted weed species have changed since 2002, in most cases showing considerable increases in occupied acreage, number of stems, and number of mapped features (Tables 5a, 5b, and 6). In many cases, multiple infestations mapped in 2002 spread and became one larger infestation in 2007, resulting in a decrease in mapped features but an increase in occupied area and number of shoots. The magnitude and

pattern of change, particularly in occupied acres and the range of the target species, is greater than can be readily explained as the result of climate variation alone.

Three species showed marked change in their distributions and spread into new areas of the Academy between 2002 and 2007. These are spotted knapweed, leafy spurge, and Fuller's teasel. Common St. Johnswort was also found in new locations in the vicinity of Kettle Creek but has not yet spread to other areas. Myrtle spurge was found in two new locations in 2007.

Several other species that were already widely distributed throughout the Academy were found in new locations and now show more continuous distribution patterns than they did in 2002. These species are musk thistle, diffuse knapweed, Scotch thistle, and bull thistle.

Rate of spread was greatest for diffuse knapweed, followed by spotted knapweed. The calculated rate of spread for yellow toadflax was actually greater than that of spotted knapweed, but this is probably the result of a combination of more favorable growing season conditions and increased emphasis on mapping this species in the vicinity of Monument Creek in 2007. When the magnitude of change in occupied area is expressed as percent of the area occupied in 2002, spotted knapweed is by far the highest, having increased 1,137 percent since 2002 (Table 5b). Common St. Johnswort, Scotch thistle, and leafy spurge, in descending order, also had high magnitudes of change at the Academy.

Diffuse/ spotted knapweed hybrid populations were mapped separately in 2007. These have become increasingly prevalent since 2005 at the Academy (Anderson and Lavender 2008).

No infestations of noxious weeds previously unknown from the Academy or Farish (Table 3) were found in 2007. A single individual of tamarisk was found in 2007 in a new location for this species. A single individual was also found in 2002, suggesting that vigilance is important for catching infestations of this species at an early stage.

Ranks were given to all species to elucidate trends in occupied area, number of shoots, and number of infestations, to facilitate comparisons of trends between species, and to help assign priorities for management.

Two species, yellow toadflax and Canada thistle, were not mapped basewide in 2007 at the Academy. They were the two most common species in 2002 and remain cosmopolitan at the Academy. They were given ranks of 1 and 2, respectively in 2007; although it is possible that another species has surpassed them since 2002 this was deemed unlikely due to the nature of their current distribution at the Academy.

Although the increase in infested acreage at Farish (16.7 acres) is less than the Academy (201.73 acres), the magnitude of change was far greater at Farish (a 264% increase versus 75% increase at the Academy). This suggests that there is an urgent need for increased weed control efforts at Farish. Noxious weeds have not yet infested all habitats available to them at Farish, so aggressive management now is likely to be more successful and cost less than increased efforts later, as examined by Hobbs and Humphries (1995).

Table 5a. Summary data for all mapped weed infestations at the U.S. Air Force Academy from 2002 and 2007.

		2002						2007					
Common Name	**Scientific Name**	**Occupied Acres**	**rank**	**Estimated Number of Shoots**	**rank**	**Number of mapped features**	**rank**	**Occupied Acres**	**rank**	**Estimated Number of Shoots**	**rank**	**Number of Mapped Features**	**rank**
Russian knapweed	***Acroptilon repens***	**0**		**0**		**0**		0.03	16	200	16	2	16
Hoary Cress	***Cardaria draba***	3.58	9	21,012	4	16	11	12.79	7	1,033,954	3	241	6
Musk Thistle	***Carduus nutans***	16.16	6	2,244	7	280	4	28.94	5	76,181	7	1,070	3
Diffuse Knapweed	***Centaurea diffusa***	56.41	3	141,805	3	328	3	136.72	3	411,641	4	978	4
Diffuse / spotted knapweed hybrid	***C. diffusa x maculosa***	**0**		**0**		**0**		1.80	11	2,922	12	125	10
Spotted Knapweed	***Centaurea maculosa***	4.68	8	3,485	6	54	8	57.89	4	127,803	6	323	5
Canada Thistle*	***Cirsium arvense***	75.90	2	408,061	2	357	2	90.10	2	379,168	2	542	2
Bull Thistle	***Cirsium vulgare***	5.54 **	7	596**	10	73	7	6.48	10	4,412	11	131	9
Field Bindweed	***Convolvulus arvensis***	NA		NA		78	6	0.78	14	7,843	10	27	13
Fuller's Teasel	***Dipsacus fullonum***	18.34	5	1,693	8	35	10	10.36	8	52,154	8	181	7
Russian Olive	***Elaeagnus angustifolia***	49.79	4	1,310	9	269	5	19.09	6	633	15	114	11
Leafy Spurge	***Euphorbia esula***	1.09	10	20,914**	5	38	9	8.17	9	372,266	5	158	8
Myrtle Spurge	***Euphorbia myrsinites***	0		0		0		0.18	15	1,021	14	7	15
Common St. Johnswort	***Hypericum perforatum***	<0.10 **	12	363**	11	5	13	0.86	13	44,649	9	8	14
Yellow Toadflax*	***Linaria vulgaris***	37	1	1,001,342	1	823	1	95.80	1	3,342,459	1	1,327	1
Scotch Thistle	***Onopordum acanthium***	.17 **	11	52**	12	7	12	1.30	12	1,307	13	36	12
Tamarisk	***Tamarix ramosissima***	<0.10	13	1	13	1	14	<0.10	17	1	17	1	17
TOTAL		**268.86**		**1,602,878**		**2,364**		**471.27**		**5,858,613**		**5,271**	

*** Data are from within Potential Conservation Area Boundaries only**

**** Estimated from field notes**

Table 5b. Summary data for all mapped weed infestations at the U.S. Air Force Academy from 2002 and 2007, continued. Change from 2002 to 2007 is calculated by subtracting 2002 from 2007 data, so positive numbers indicate an increase and negative numbers indicate a decrease.

		Δ from 2002 to 2007			Δ expressed as percent			
Common Name	**Scientific Name**	**Occupied Acres**	**Estimated Number of Shoots**	**Number of Mapped Features**	**Occupied Acres**	**Estimated Number of Shoots**	**Number of Mapped Features**	**Rate of Spread (Acres/yr)**
Russian knapweed	***Acroptilon repens***	0.03	200	2	NA	NA	NA	NA
Hoary Cress	***Cardaria draba***	9.21	1,012,942	225	257	4,821	1,406	1.84
Musk Thistle	***Carduus nutans***	12.78	73,937	790	79	3,295	282	2.56
Diffuse Knapweed	***Centaurea diffusa***	80.31	269,836	650	142	190	198	16.06
Diffuse / spotted knapweed hybrid	***C. diffusa x maculosa***	1.80	2,922	125	NA	NA	NA	0.36
Spotted Knapweed	***Centaurea maculosa***	53.21	124,318	269	1,137	3,567	498	10.64
Canada Thistle*	***Cirsium arvense***	14.20	-28,893	185	19	-7	52	2.84
Bull Thistle	***Cirsium vulgare***	0.94	3,816	58	17	640	79	0.19
Field Bindweed	***Convolvulus arvensis***	NA	NA	-51	NA	NA	-65	NA
Fuller's Teasel	***Dipsacus fullonum***	-7.98	50,461	146	-44	2,981	417	-1.60
Russian Olive	***Elaeagnus angustifolia***	-30.71	-677	-155	-62	-52	-58	-6.14
Leafy Spurge	***Euphorbia esula***	7.08	351,352	120	649	1,680	316	1.42
Myrtle Spurge	***Euphorbia myrsinites***	0.18	1,021	7	NA	NA	NA	0.04
Common St. Johnswort	***Hypericum perforatum***	0.76	44,286	3	763	12,200	60	0.15
Yellow Toadflax*	***Linaria vulgaris***	58.80	2,341,117	504	159	234	61	11.76
Scotch Thistle	***Onopordum acanthium***	1.13	1,255	29	665	2,414	414	0.23
Tamarisk	***Tamarix ramosissima***	0.00	0	0	0	0	0	0
TOTAL		**201.73**	**4,247,892**	**2,907**	**75**	**266**	**123**	

*** Data are from within Potential Conservation Area Boundaries only**

Table 6. Summary data for all mapped weed infestations at Farish Outdoor Recreation Area from 2002 and 2007. Change from 2002 to 2007 is calculated by subtracting 2002 from 2007 data, so positive numbers indicate an increase and negative numbers indicate a decrease.

		2002						2007					
Common Name	**Scientific Name**	**Occupied Acres**	**Rank**	**Estimated Number of Shoots**	**Rank**	**Number of mapped features**	**Rank**	**Occupied Acres**	**Rank**	**Estimated Number of Shoots**	**Rank**	**Number of Mapped Features**	**Rank**
Musk Thistle	*Carduus nutans*	0.85	2	57	3	14	2	2.61	2	1,244	3	39	2
Canada Thistle	*Cirsium arvense*	0.23	3	3,488	2	8	3	1.56	3	14,783	2	24	3
Leafy Spurge	*Euphorbia esula*	*	4	*	4	1	4	0.03	4	113	4	1	4
Yellow Toadflax	*Linaria vulgaris*	5.25	1	99,924	1	93	1	18.85	1	399,802	1	106	1
TOTAL		**6.33**		**103,469**		**116**		**23.05**		**415,942**		**170**	

		Δ from 2002 to 2007			Δ expressed as percent			
Common Name	**Scientific Name**	**Occupied Acres**	**Estimated Number of Shoots**	**Number of Mapped Features**	**Occupied Acres**	**Estimated Number of Shoots**	**Number of Mapped Features**	**Rate of Spread (Acres/Yr)**
Musk Thistle	*Carduus nutans*	1.76	1,187	25	208	2,083	179	0.35
Canada Thistle	*Cirsium arvense*	1.33	11,295	16	577	324	200	0.27
Leafy Spurge	*Euphorbia esula*	NA	NA	0	NA	NA	0	NA
Yellow Toadflax	*Linaria vulgaris*	13.60	299,878	13	259	300	14	2.72
TOTAL		**16.70**	**312,361**	**54**	**264**	**302**	**47**	

* not quantified in 2002

Table 7. Summary data for monthly precipitation (in inches) at Colorado Springs, Colorado from 2002 through December 2007 (Western Regional Climate Center 2008).

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
2002	0.3	0.1	0.3	0.0	1.1	1.2	1.6	0.4	1.3	1.3	0.1	0.1	7.9
2003	0.0	0.6	1.0	1.0	0.9	5.1	1.1	1.9	0.6	0.1	0.0	0.1	12.4
2004	0.5	0.4	0.4	2.7	0.6	6.0	4.1	4.8	0.5	0.2	0.7	0.2	21.1
2005	0.8	0.0	1.0	1.1	0.7	2.1	1.9	2.7	0.7	0.5	0.1	0.3	11.9
2006	0.2	0.0	0.2	0.1	0.8	0.8	4.4	3.5	1.5	1.6	0.2	0.4	13.8
2007	0.3	0.2	0.7	1.9	2.4	0.9	1.7	2.7	0.3	0.3	0.2	0.4	11.9
Mean (1948-2008)	0.3	0.3	0.9	1.4	2.2	2.3	2.9	2.9	1.2	0.8	0.5	0.3	16.0

Summaries by Species

Acroptilon repens (Russian Knapweed)

Photo by David Anderson

Russian knapweed was not discovered at the Academy until 2004, so it was not mapped in the baseline study. The area occupied by Russian knapweed is currently small, at approximately .03 acres in 2007 (Table 5a, Map 3). The largest infestation is located north of the Skills Development Center, which was treated with broadleaf herbicide 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 the species has remained extant in the untreated area. High water in 2007 appears 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, where efforts to eradicate it were already underway in 2005 (Anderson and Lavender 2006). 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. On June 8, 2007 no plants were seen at this location in 20 minutes of searching. Russian knapweed was not found at any other new locations in 2007.

Cardaria draba (Whitetop)

Photo by Michelle Washebek

Whitetop is more responsive to drought conditions than many other noxious weed species at the Academy. In 2002 it was very difficult to detect during the extreme drought conditions of that year, and additional mapping was needed in 2003 to establish the extent of the infestation at the Academy. In 2003 growing conditions were more favorable and a much better understanding of the status of whitetop was gained. In 2007, acreage and estimated number of shoots had decreased since 2003 but number of mapped features had increased (Table 8). Its range along Monument Creek appears to have contracted somewhat in 2007, but additional outliers were found in the horse pasturing area (Map 4). Another outlier

was found near the north boundary of the Academy along Monument Creek in 2007. This infestation is a high priority for eradication because it could easily disperse seeds downstream and infest the upper reaches of Monument Creek.

Whitetop is not yet known from Farish; if any infestations are found there they will warrant aggressive management efforts.

Table 8. Summary data for whitetop from 2002, 2003, and 2007 at the U.S. Air Force Academy.

	2002	2003	2007
Occupied Acres	3.58	18.43	12.78
Rank	9	--	7
Estimated Number of Shoots	21,012	5,419,089	1,033,954
Rank	4	--	3
Number of Mapped Features	16	148	241
Rank	11	--	6

Carduus nutans (Musk Thistle)

Photo by Michelle Washebek

Musk thistle was abundant at the Academy in 2007. The number of infestations, occupied area, and number of individuals of musk thistle increased significantly at the Academy from 2002 to 2007 (Table 9). Whether this indicates a long-term trend or is the result of wet conditions in 2006 and 2007 is unknown. Infestations of musk thistle tend to be relatively small at the Academy. However, the average size of an infestation went from eight individuals in 2002 to 71 individuals in 2007. This trend, combined with the excellent dispersal capabilities of this species suggest that it could rapidly increase at the Academy.

In 2002, musk thistle was already found throughout much of the Academy (Map 5), but some new areas appear to have been invaded in 2007. These include the area east of Reservoir #1, the Combat Arms Range, the Jacks Valley Training Complex, and the fill area east of the athletic fields. In general there are more new infestations in the north portion of the Academy in 2007 than in the south portion. There was also considerable spread of musk thistle at Farish from 2002 to 2007 (Table 10, Maps 20 and 21).

Table 9. Summary data for musk thistle from 2002 and 2007 at the U.S. Air Force Academy.

	2002	2007	Δ from 2002 to 2007	Δ expressed as percent
Occupied Acres	16.16	28.94	12.78	79
Rank	6	5		
Estimated Number of Shoots	2,244	76,181	73,937	3,295
Rank	7	7		
Number of Mapped Features	280	1070	790	282
Rank	4	3		

Table 10. Summary data for musk thistle from 2002 and 2007 at Farish Outdoor Recreation Area.

	2002	2007	Δ from 2002 to 2007	Δ expressed as percent
Occupied Acres	0.85	2.61	1.76	208
Rank	2	2		
Estimated Number of Shoots	57	1,244	1,187	2,083
Rank	3	3		
Number of Mapped Features	14	39	25	179
Rank	2	2		

Centaurea diffusa (Diffuse Knapweed)

Diffuse knapweed had the highest rate of spread of all targeted species at 16.06 acres per year between 2002 and 2007 (Table 5b). Its occupied area more than doubled in five years and its estimated number of shoots and number of mapped features increased approximately three-fold (Table 11).

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

Photo by Michelle Washebek

Academy.

As in 2002, diffuse knapweed was found principally along the I-25 corridor and along the railroad right-of-way, and in other dry disturbed areas throughout the Academy (Map 6). It has not shown the same propensity for invading undisturbed sites that spotted knapweed has shown.

Table 11. Summary data for diffuse knapweed from 2002 and 2007 at the U.S. Air Force Academy.

	2002	2007	Δ from 2002 to 2007	Δ expressed as percent
Occupied Acres	56.41	136.72	80.31	142
Rank	3	3		
Estimated Number of Shoots	141,805	411,641	269,836	190
Rank	3	4		
Number of Mapped Features	328	978	650	198
Rank	3	4		

Centaurea diffusa x maculosa (Diffuse/ Spotted Knapweed Hybrids)

Diffuse and spotted knapweed are hybridizing along the Palmer divide (Beck personal communication 2007). Hybrids between diffuse and spotted knapweed were not known from the Academy in 2002. In 2007 hybrids were found in relatively low numbers in most areas where diffuse knapweed and spotted knapweed occur together at the Academy (Table 12, Map 7). Because hybrids are not detectable in the vegetative state, it is likely that the actual number of hybrid individuals was higher than was observed in 2007.

Photo by Michelle Washebek

Table 12. Summary data for diffuse/ spotted knapweed hybrids in 2007 at the U.S. Air Force Academy.

	2002	2007	Δ from 2002 to 2007	Δ expressed as percent
Occupied Acres	0	1.80	1.80	NA
Rank	0	11		
Estimated Number of Shoots	0	2,922	2,922	NA
Rank	0	12		
Number of Mapped Features	0	125	125	NA
Rank	0	10		

Centaurea maculosa (Spotted Knapweed)

Photo by Michelle Washebek

Spotted knapweed was mapped in 2002, 2005, 2006, and 2007 at the Academy (Table 13, Figure 2, Map 8). During this time it spread rapidly at the Academy, and detailed information regarding this progression was obtained. Spotted knapweed was relatively uncommon at the Academy in 2002, occupying only 4.68 acres, but by 2007 it occupied a total of 57.89 acres 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). The population size of spotted knapweed was 36 times greater in 2007 than it was in 2002. Unfortunately, this species has now become too common for eradication to be feasible without considerable effort.

This species has displayed a propensity for invading habitats at the Academy where human disturbance is minimal. These habitats include grassy meadows (such as the large meadow adjacent to the water treatment plant access road), oak woodlands (such as the area east of the intersection of Cross Drive and Parade Loop), and along sandy washes (such as along Deadman's Creek and where the outflow from Reservoir #3 crosses the Golf Course access road).

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 from 2002 and 2007 at the U.S. Air Force Academy.

	2002	2007	Δ from 2002 to 2007	Δ expressed as percent
Occupied Acres	4.68	57.89	53.21	1,137
Rank	8	4		
Estimated Number of Shoots	3,485	127,803	124,318	3,567
Rank	6	6		
Number of Mapped Features	54	323	269	498
Rank	8	5		

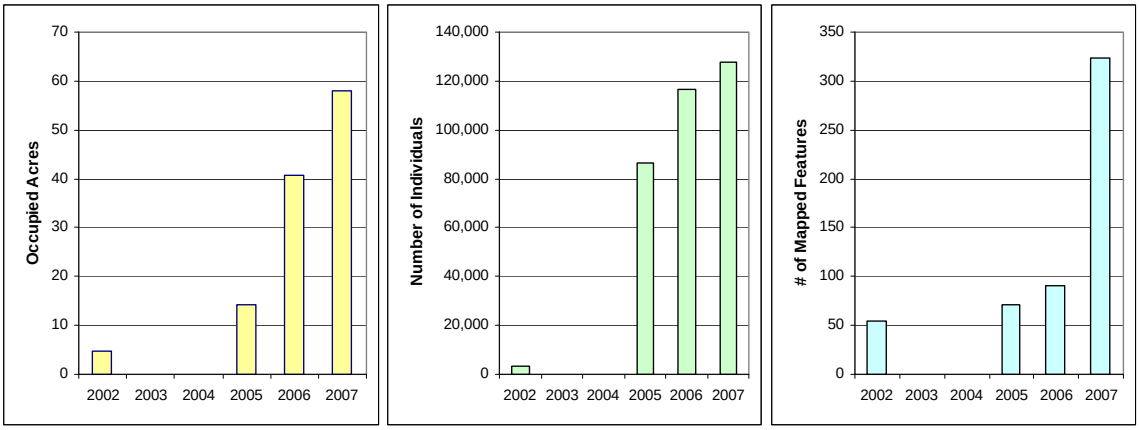

Figure 2. Summary of 2002-2007 census data for spotted knapweed at the U.S. Air Force Academy.

Cirsium arvense (Canada Thistle)

Canada thistle is abundant at the Academy, especially in the vicinity of Monument Creek, and is second only to yellow toadflax in occupied area (Table 14). Along with yellow toadflax, it is one of two species that is only targeted for management within high priority conservation areas. It is common in wetlands, riparian areas, roadsides, swales, construction sites, and many other habitats at the Academy where excess moisture is available, although it is also sometimes found in relatively dry sites as pictured here.

Photo by Michelle Washebek

Because this species has already invaded most potential habitats at the Academy, its distribution pattern did not change greatly since 2002 (Map 9). However, 19 additional acres were observed to be infested by this species in 2007, suggesting that existing infestations had spread within the high priority conservation areas along Monument Creek and its tributaries.

At Farish, it appears that Canada thistle spread considerably (Table 15) is in an earlier stage of infestation. Between 2002 and 2007 it spread into many new areas (Maps 20 and 21). This trend suggests that this species will continue to invade similar habitats that were surveyed in 2007 where Canada thistle was absent. Active management of this species now may offset more expensive control efforts in the future at Farish.

Table 14. Summary data for Canada thistle from 2002 and 2007 from within high priority conservation areas at the U.S. Air Force Academy.

	2002	2007	Δ from 2002 to 2007	Δ expressed as percent
Occupied Acres	75.9	90.10	14.20	19
Rank	2	2		
Estimated Number of Shoots	408,061	379,168	-28,893	-7
Rank	2	2		
Number of Mapped Features	357	542	185	52
Rank	2	2		

Table 15. Summary data for Canada thistle from 2002 and 2007 at Farish Outdoor Recreation Area.

	2002	2007	Δ from 2002 to 2007	Δ expressed as percent
Occupied Acres	0.23	1.56	1.33	577
Rank	3	3		
Estimated Number of Shoots	3,488	14,783	11,295	324
Rank	2	2		
Number of Mapped Features	8	24	16	200
Rank	3	3		

Cirsium vulgare (Bull Thistle)


Photo by Michelle Washebek

Bull thistle is distributed widely throughout the Academy property (Map 10). The 79 percent increase in the number of mapped features between 2002 and 2007 (Table 16) occurred mostly in new areas, suggesting that this species has spread at the Academy. However, it is possible that some infestations were not detectable in 2002 due to drought conditions. This species appears less tolerant of drought than either Scotch thistle or musk thistle, and like Canada thistle, it is typically found in areas with somewhat higher soil moisture.

Table 16. Summary data for bull thistle from 2002 and 2007 at the U.S. Air Force Academy.

	2002	2007	Δ from 2002 to 2007	Δ expressed as percent
Occupied Acres	5.54	6.48	0.94	17
Rank	7	10		
Estimated Number of Shoots	596	4,412	3,816	640
Rank	10	11		
Number of Mapped Features	73	131	58	79
Rank	7	9		

Dipsacus fullonum (Fuller's Teasel)


Photo by Michelle Washebek

As in 2002, the distribution of Fuller's teasel at the Academy was concentrated in the southern portion of Monument Creek and along Kettle Creek. Its invasion has been limited to wetlands, riparian areas, and areas kept wet by runoff or lawn watering at the Academy.

Between 2002 and 2007, Fuller's teasel appears to have invaded the reach of Monument Creek between Black Squirrel Creek and Deadman's Creek (Map 12).

The high water of 2006 disturbed much of the riparian area along Monument Creek. While it appears that numbers have declined locally as a result

of this (Table 17), the disturbance has created many opportunities for Fuller's teasel to spread. Extra management attention may be required for this species in 2008.

The summary data for this species reflect changes in the population size and distribution at the Academy. Disturbance from flooding in 2006 appears to have fragmented infestations of Fuller's teasel, resulting in a considerable increase in the number of mapped features despite the overall decline in occupied acres.

Table 17. Summary data for Fuller's teasel from 2002 and 2007 at the U.S. Air Force Academy.

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	2002	2007	Δ from 2002 to 2007	Δ expressed as percent
Occupied Acres	18.34	10.36	-7.98	-44
Rank	5	8		
Estimated Number of Shoots	1,693	52,154	50,461	2,981
Rank	8	8		
Number of Mapped Features	35	181	146	417
Rank	10	7		

Elaeagnus angustifolia (Russian Olive)

The control of Russian olive is the greatest weed management success story at the Academy. Treatment of this species in 2003 and 2004 was highly successful (Table 18, Map 13). In 2005, only 46 infestations remained extant of the 173 examined that year. Although 633 individuals remain on the Academy, most of them are along the I-25 corridor (these 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. Eradicating this species from all areas of the Academy except the I-25 corridor is possible with a relatively small amount of additional treatment and maintenance.

Photo by Michelle Washebek

Table 18. Summary data for Russian olive from 2002 and 2007 at the U.S. Air Force Academy.

	2002	2007	Δ from 2002 to 2007	Δ expressed as percent
Occupied Acres	49.79	19.09	-30.71	-62
Rank	4	6		
Estimated Number of Shoots	1,310	633	-677	-52
Rank	9	15		
Number of Mapped Features	269	114	-155	-58
Rank	5	11		

Euphorbia esula (Leafy Spurge)

Photo by Michelle Washebek

Despite aggressive management with herbicide and biocontrol, the footprint of leafy spurge at the Academy increased more than six-fold from 2002 to 2007 (Table 19). From 2002 to 2007 an average of 24 new infestations per year became established at the Academy. This species disperses readily into undisturbed habitats and is extremely difficult to eradicate. Its vegetative shoots are similar to those of yellow toadflax, and it is often found with Gambel oak where it can be very difficult to detect. Efforts to manage or eradicate infestations of this species using herbicide in the vicinity of the Combat Arms Range have met with limited success, in part because of incomplete treatment (Anderson and Lavender 2008).

Fortunately, the distribution of leafy spurge remains concentrated the northwest portion of the Academy property in the vicinity of Jacks Valley and around the cadet area (Map 14). As nodes from which this species is likely to spread in other parts of the Academy, several outlying infestations were found in 2007 that represent higher priorities for management. Leafy spurge was mapped in two areas in the southeast corner of the Academy, east of the control tower and in another site in the plantation area near the south gate. Leafy spurge was found in holes where trees were removed at these locations, suggesting that the infestations originated from contaminated soil or

machinery. New infestations were also found near the Jacks Valley Training Complex in 2007. In 2007 leafy spurge was found south of Interior Drive, where there is an opportunity to prevent the advance of this species into uninfested areas to the south. Eradication of the infestations discussed above will help contain leafy spurge and prevent the infestation of other areas.

At Farish, a small infestation of leafy spurge remained extant in 2007 (Table 20, Maps 20 and 21) but had not spread into other areas of the facility. This infestation is also a very high priority for eradication.

Table 19. Summary data for leafy spurge from 2002 and 2007 at the U.S. Air Force Academy.

	2002	2007	Δ from 2002 to 2007	Δ expressed as percent
Occupied Acres	1.09	8.17	7.08	649
Rank	10	9		
Estimated Number of Shoots	20,914	372,266	351,352	1,680
Rank	5	5		
Number of Mapped Features	38	158	120	316
Rank	9	8		

Table 20. Summary data for leafy spurge from 2002 and 2007 at Farish Outdoor Recreation Area.

	2002	2007	Δ from 2002 to 2007	Δ expressed as percent
Occupied Acres	*	0.03	NA	NA
Rank	--	4		
Estimated Number of Shoots	*	113	NA	NA
Rank	--	4		
Number of Mapped Features	1	1	0	0
Rank	4	4		

* not determined in 2002

Euphorbia myrsinites (Myrtle Spurge)

Photo by David Anderson

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. All known extant infestations of this species have been monitored in 2006 and 2007 (Anderson and Lavender 2008).

Two new infestations of myrtle spurge were found in 2007 just east of Reservoir 1 near Black Squirrel Creek and another unnamed tributary (Map 15). One of these consisted of a single individual which was pulled, but the second consists of hundreds of plants.

Several other infestations have been known since 2006 and are being managed. One of these 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.

Another infestation 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 infestation increased considerably from 2006 to 2007.

The third extant infestation 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 where it appears to have been eradicated. 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.

Hypericum perforatum (Common St. Johnswort)


Photo by Michelle Washebek

The distribution of common St. Johnswort at the Academy is limited to sites along Kettle Creek, where it is found in a wide range of habitats. These include an undisturbed site near Kettle Creek dominated by snowberry (*Symphoricarpos occidentalis*), open sites dominated by grasses, and in gravelly soil on the steep slopes and roadside of a water control structure. It is found in both shaded and open sites, and in areas varying considerably in available moisture. Its wide ecological amplitude suggests that this species has the potential to invade a wide range of sites at the Academy, as it has done elsewhere in Colorado and the U.S.

Ongoing management efforts for common St. Johnswort at the Academy have been quite effective at some infestations. In 2002, a large infestation of common St. Johnswort was mapped southeast of the Aardvark landing strip and west of the access road. This infestation was an outlier and a high priority for management. Broadleaf herbicide was applied to this infestation sometime in the summer or fall of 2005 after baseline monitoring data were obtained. No evidence of common St. Johnswort was found at this site in 2006 and 2007 (Anderson and Lavender 2008). Biocontrol insects introduced by Michels et al. (2004) have had considerable local impacts on the density of common St. Johnswort infestations in the vicinity of Kettle Creek, even resulting in the apparent eradication of some patches.

Despite these successes, additional infestations of common St. Johnswort were discovered along Kettle Creek in 2007, illustrating that this species is continuing to spread at the Academy (Map 16). The infested area has increased considerably since 2002 (Table 21), but it is still under one acre and eradication of this species remains feasible at present.

Table 21. Summary data for common St. Johnswort from 2002 and 2007 at the U.S. Air Force Academy.

	2002	2007	Δ from 2002 to 2007	Δ expressed as percent
Occupied Acres	0.10	0.86	0.76	763
Rank	12	13		
Estimated Number of Shoots	363	44,649	44,286	12,200
Rank	11	9		
Number of Mapped Features	5	8	3	60
Rank	13	14		

Linaria vulgaris (Yellow Toadflax)

Photo by Michelle Washebek

Yellow toadflax is the number one noxious weed at the Academy and Farish in occupied acreage, number of shoots, and number of mapped features (Table 22 and 23). It is present in low densities throughout most of the Academy in a wide range of habitats (Map 17). It has become entrenched at the Academy and is now impossible to eradicate. Along with Canada thistle, this species was only mapped within high priority conservation areas at the Academy in 2007. Within the study area for this species, yellow toadflax increased in infested area, number of shoots, and number of mapped features between 2002 and 2007. Because cover and density of yellow toadflax is strongly influenced by available moisture, this difference can be explained to some extent by the drought conditions of 2002.

At Farish, yellow toadflax is also very common but it appears that it has not yet spread to all available habitats. Occupied acreage of yellow toadflax increased 259 percent between 2002 and 2007, reaching 18.85 acres in 2007 (Table 6). This suggests that the window of opportunity for cost effective management of this species at Farish is closing rapidly.

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 presents a significant challenge to weed management, since the successful reduction of a target species may come at the expense of an infestation of yellow toadflax.

Table 22. Summary data for yellow toadflax from 2002 and 2007 from within high priority conservation areas at the U.S. Air Force Academy.

	2002	2007	Δ from 2002 to 2007	Δ expressed as percent
Occupied Acres	37	95.80	58.80	159
Rank	1	1		
Estimated Number of Shoots	1,001,342	3,342,459	2,341,117	234
Rank	1	1		
Number of Mapped Features	823	1327	504	61
Rank	1	1		

Table 23. Summary data for yellow toadflax from 2002 and 2007 at Farish Outdoor Recreation Area.

	2002	2007	Δ from 2002 to 2007	Δ expressed as percent
Occupied Acres	5.25	18.85	13.60	259
Rank	1	1		
Estimated Number of Shoots	99,924	399,802	299,878	300
Rank	1	1		
Number of Mapped Features	93	106	13	14
Rank	1	1		

Onopordum acanthium (Scotch Thistle)

Photo by David Anderson

The population of Scotch thistle has increased considerably from 2002 to 2007 at the Academy (Table 24, Figure 3, Map 18). It is distributed widely but because its occupied area is limited to 1.3 acres, eradication is still a realistic goal for this species.

The greatest concentration of infestations of Scotch thistle is still the area east of the athletic fields, but it has also spread to new sites along the railroad right-of-way and southwest of the cadet area. New locations were also found in the southeast corner of the Academy in 2007. The magnitude of its increase between 2002 and 2007 suggests that this species has entered a phase of rapid expansion at the Academy and warrants aggressive management.

Although there have been efforts to control this species, especially at larger infestations, the efforts have sometimes been 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 24. Summary data for Scotch thistle from 2002 and 2007 at the U.S. Air Force Academy.

	2002	2007	Δ from 2002 to 2007	Δ expressed as percent
Occupied Acres	0.17	1.30	1.13	665
Rank	11	12		
Estimated Number of Shoots	52	1,307	1,255	2,414
Rank	12	13		
Number of Mapped Features	7	36	29	414
Rank	12	12		

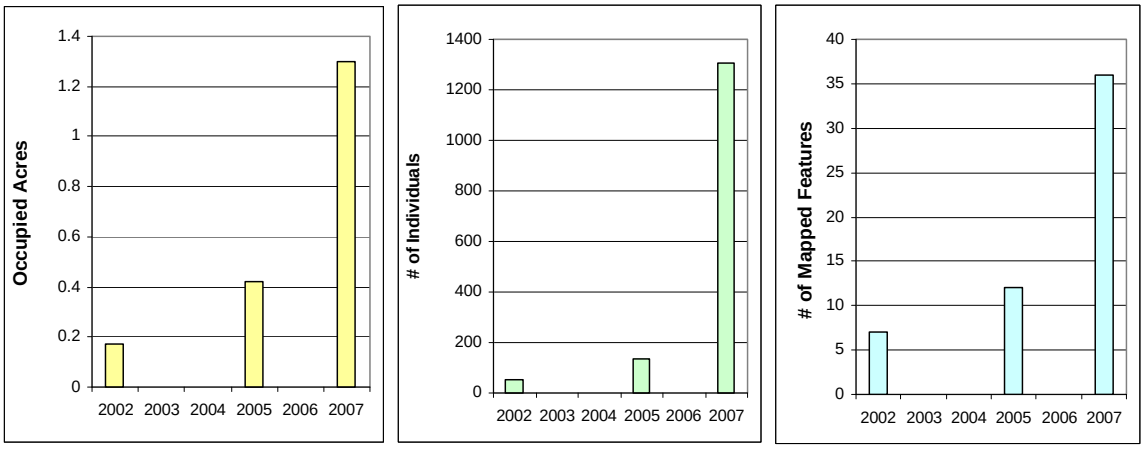
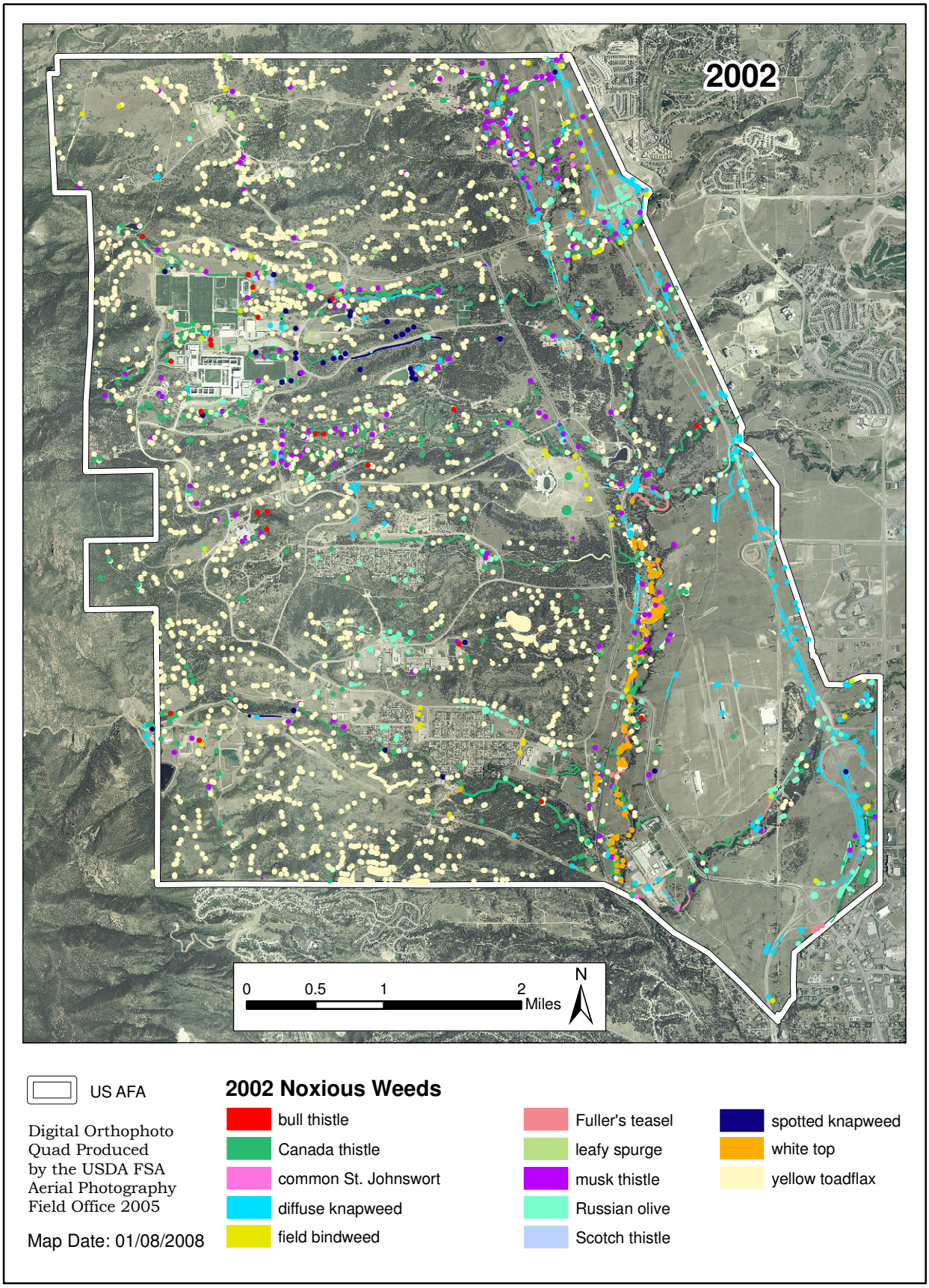


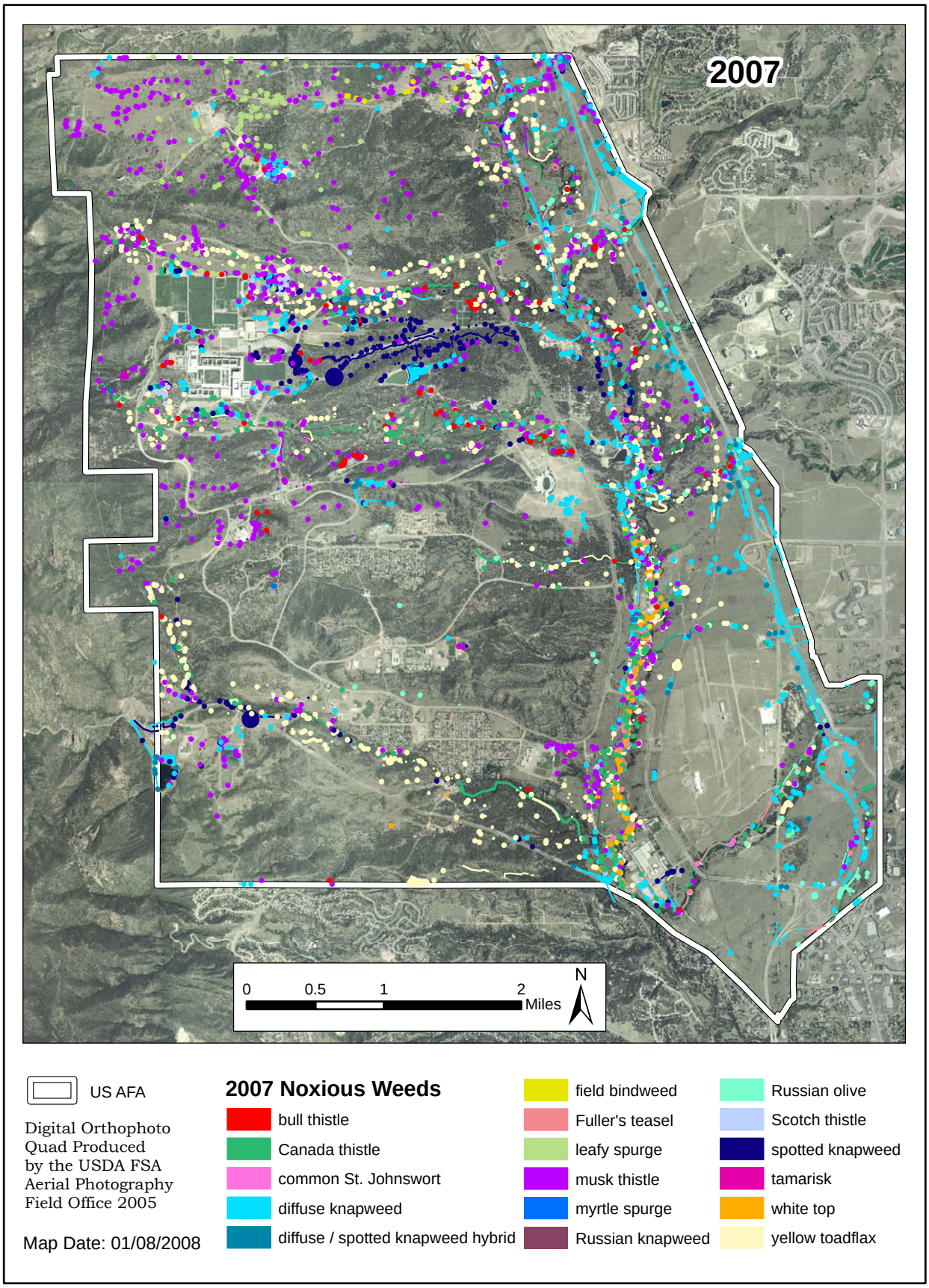
Figure 3. Summary of 2002-2007 census data for Scotch thistle at the U.S. Air Force Academy.

Tamarix ramosissima (Tamarisk)

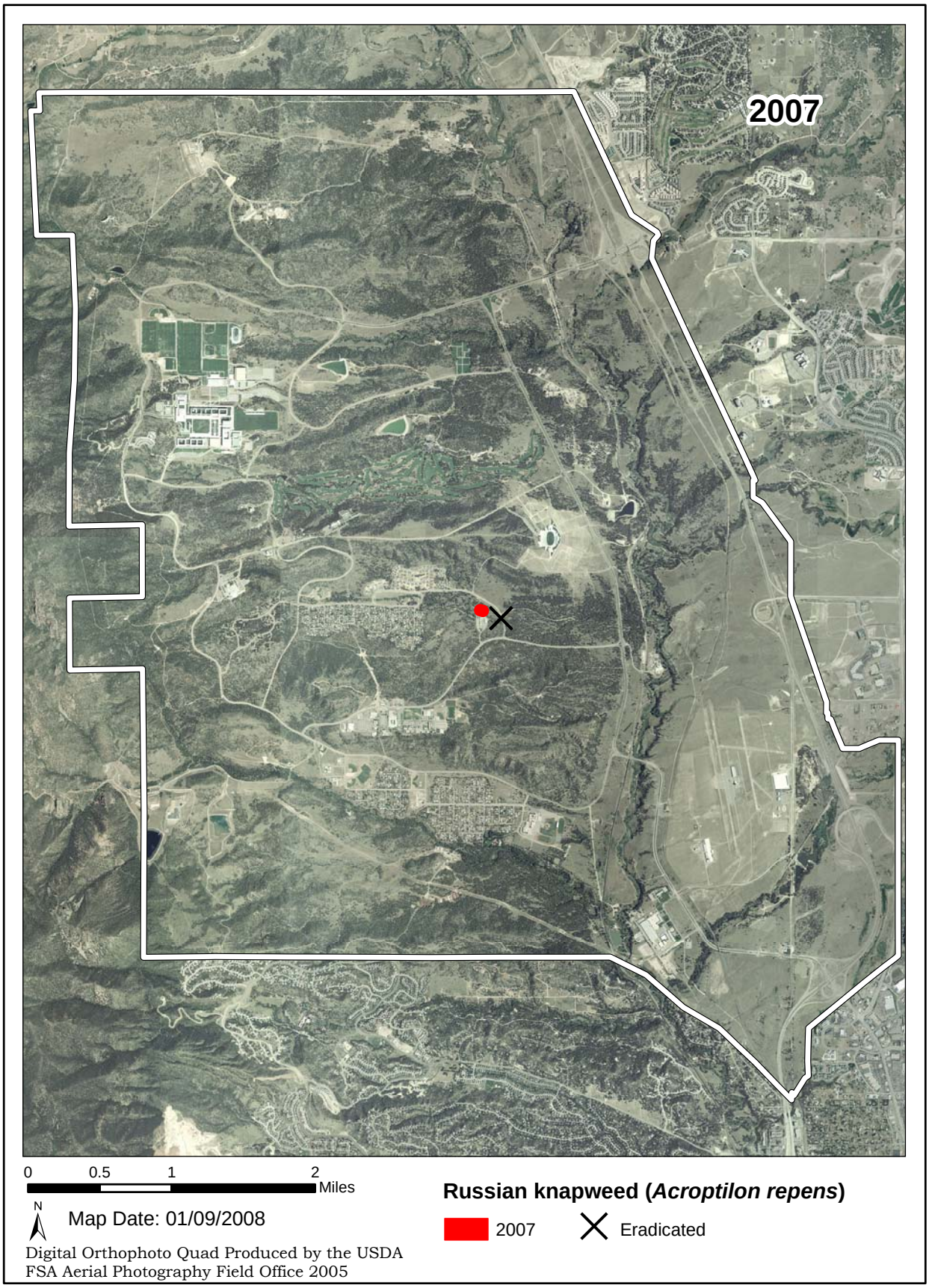
There are currently no viable populations of tamarisk at the Academy, but this species is dispersing onto the Academy property. A single tamarisk was found at the Academy in 2002 near the east boundary and Pine Creek (Map 19; Anderson et al. 2003). This plant was small and not yet reproductive, and was eradicated by Natural Resources Staff. Tamarisk was not seen at the Academy again until 2007 when another small, non-reproductive individual was found at a new site along Monument north of the sewage treatment plant. It was also pulled and the infestation is presumed to be extirpated. Continued survey efforts appear to be necessary to prevent the establishment of this species on the Academy property.



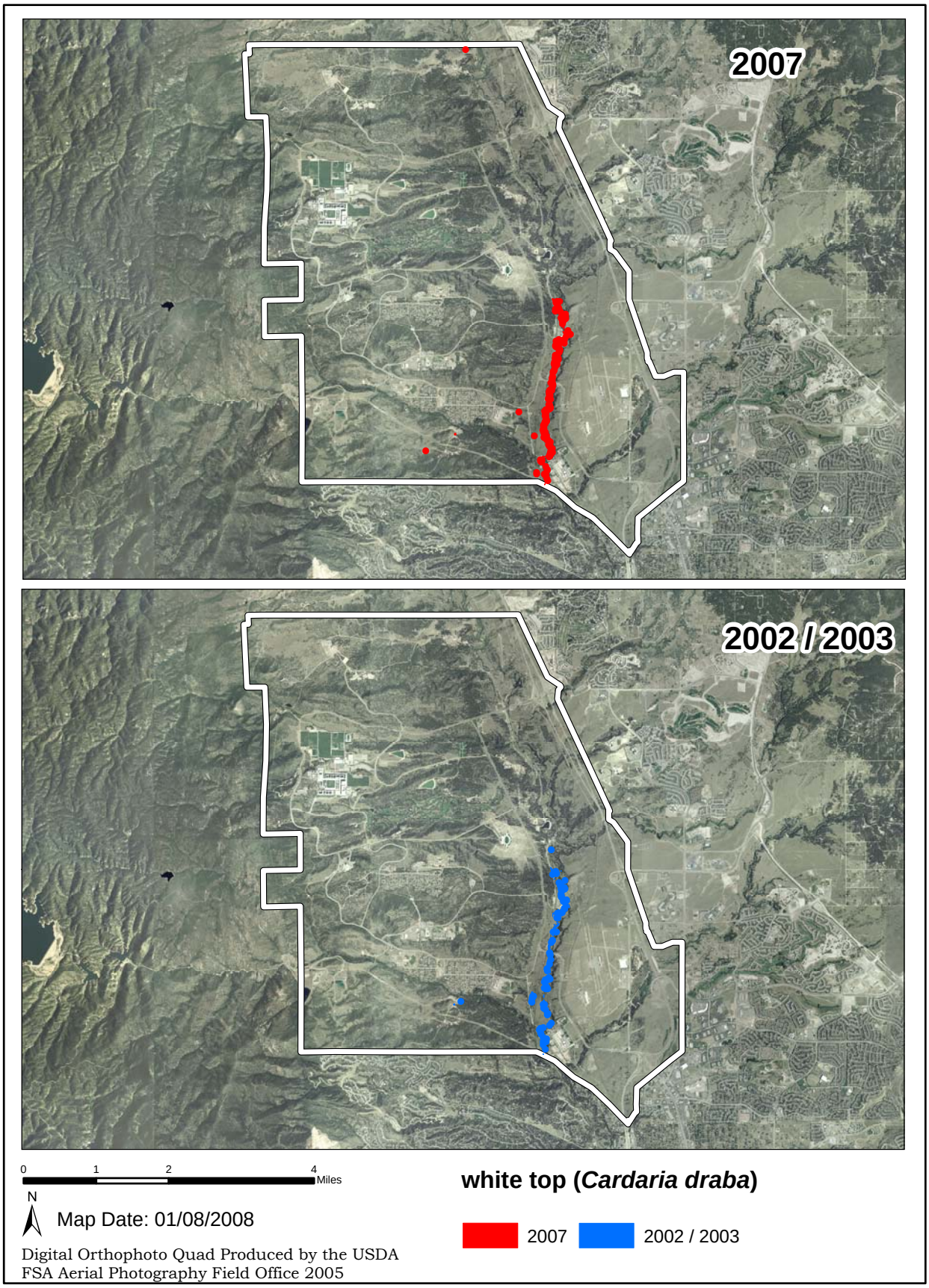
Map 1. Distribution of targeted noxious weed species at the U.S. Air Force Academy in 2002 (from Anderson et al. 2003).



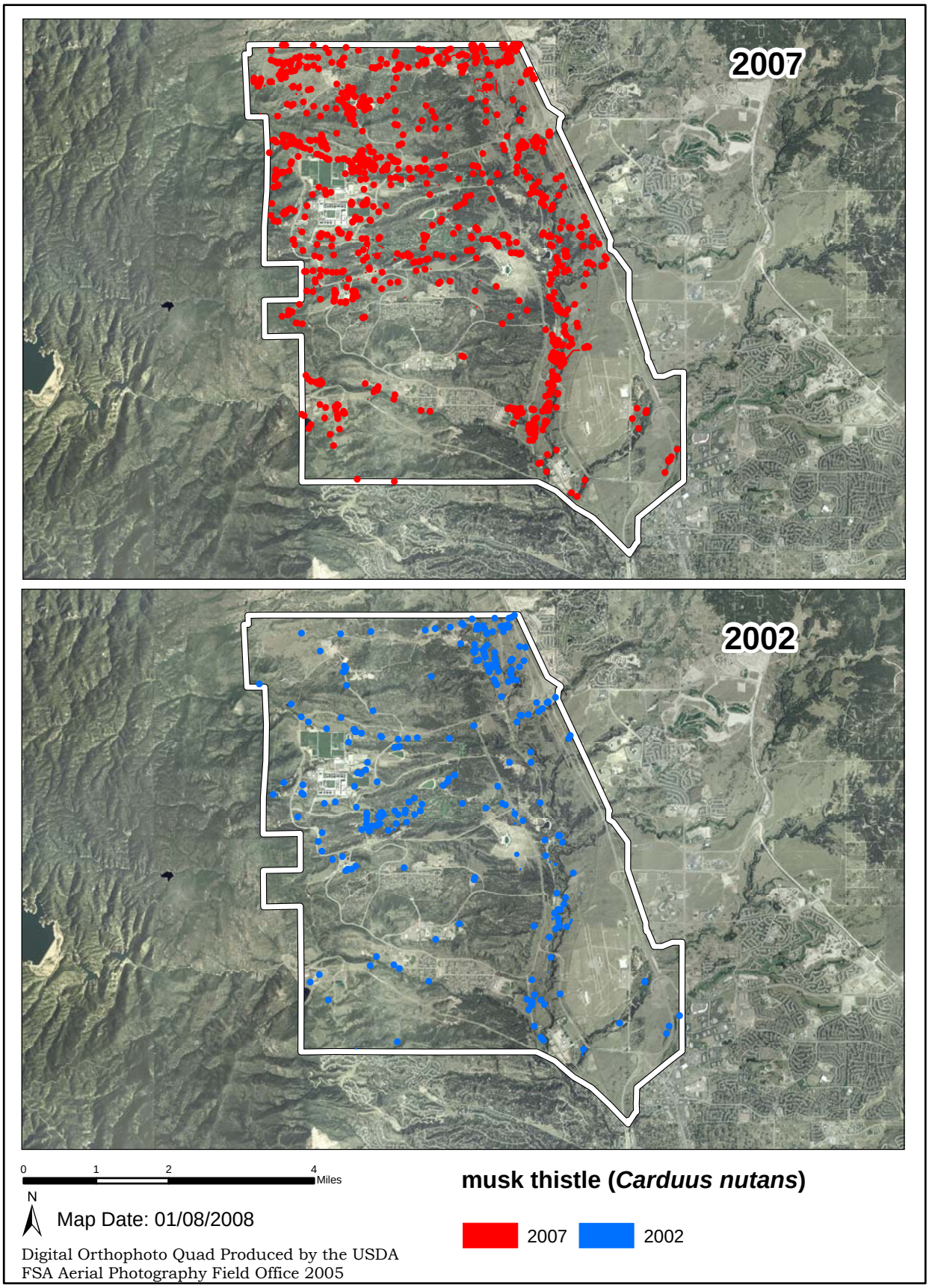
Map 2. Distribution of targeted noxious weed species at the U.S. Air Force Academy in 2007.



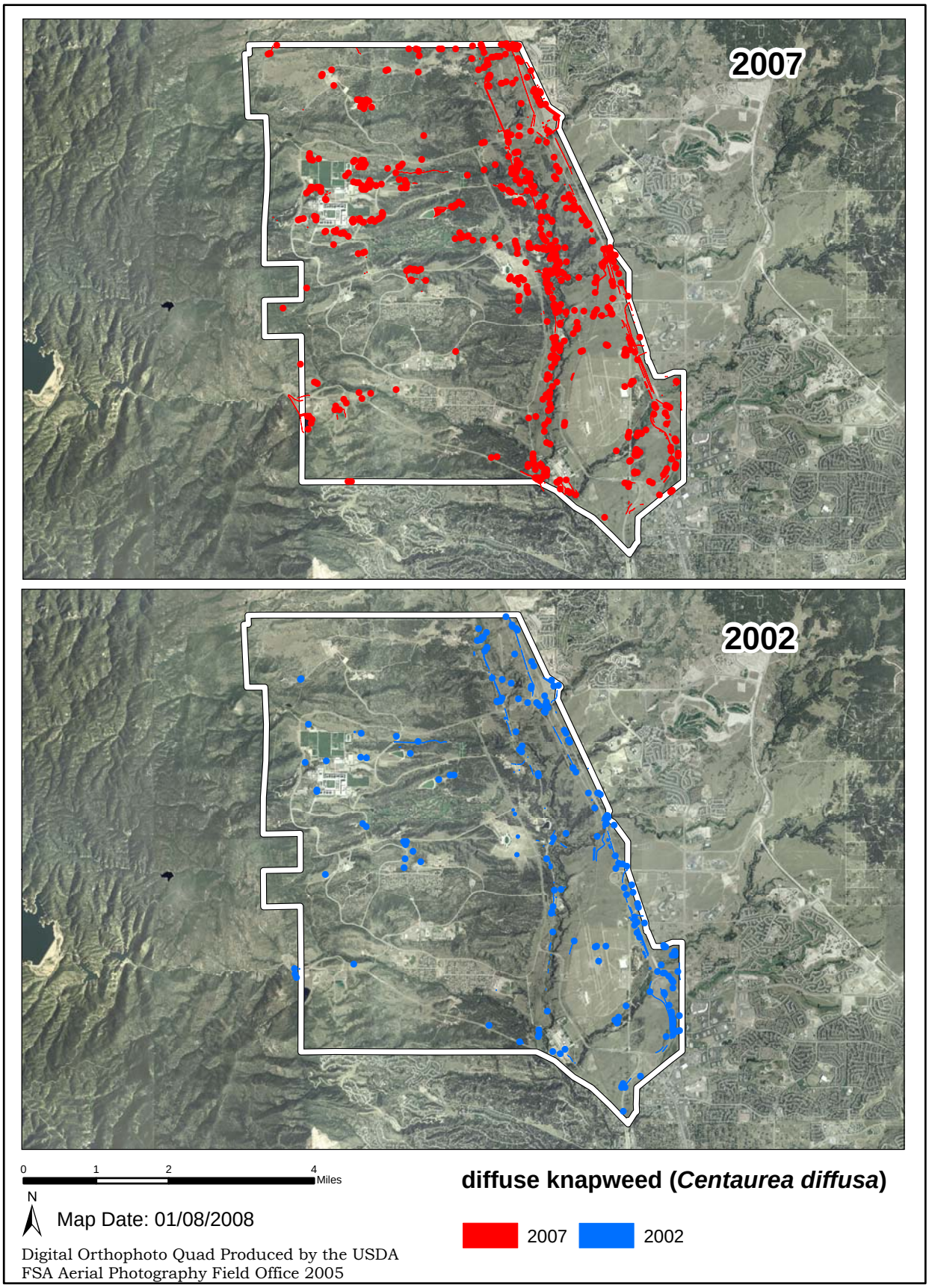
Map 3. Distribution of Russian knapweed (*Acroptilon repens*) at the U.S. Air Force Academy in 2007.



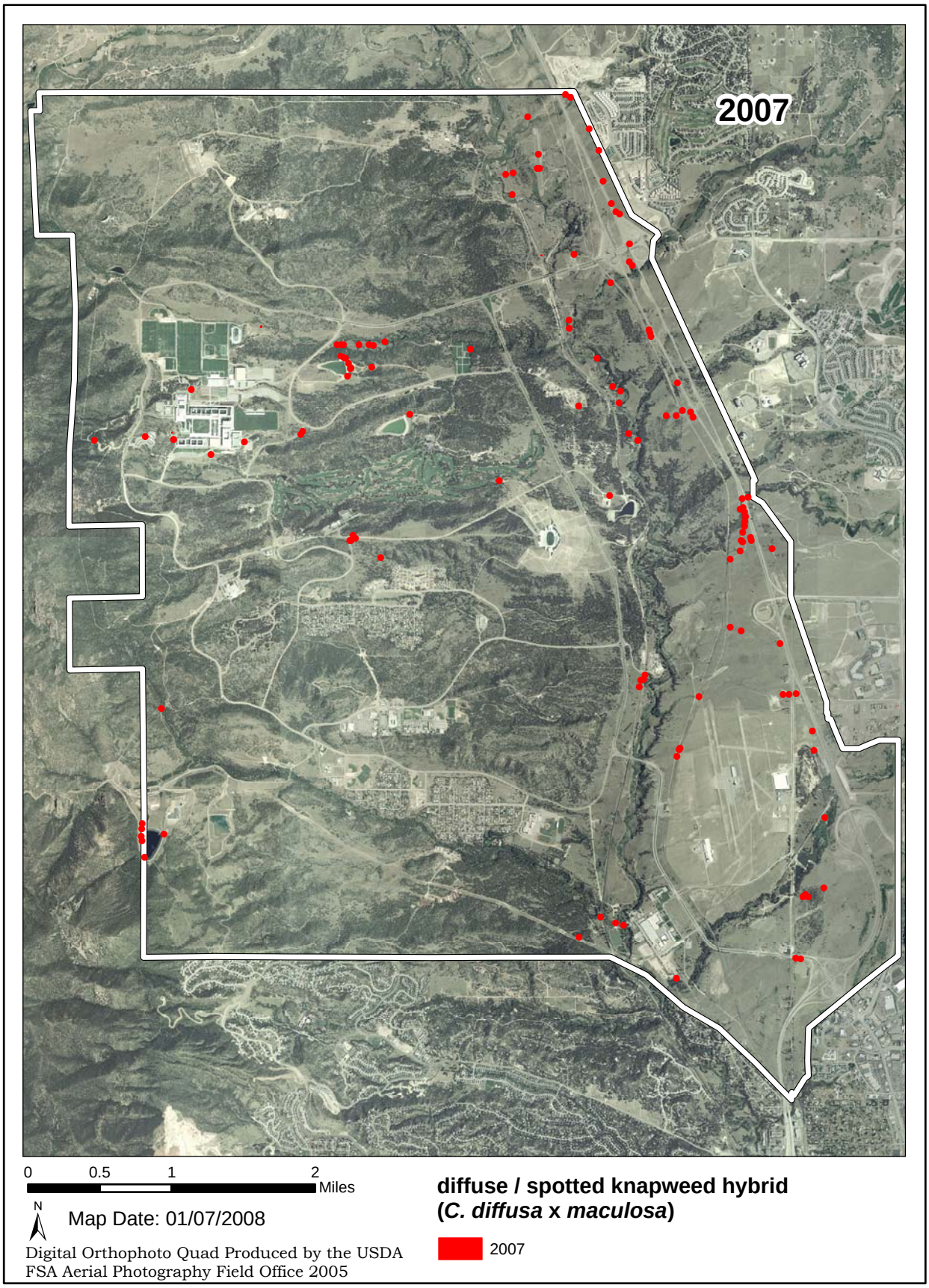
Map 4. Distribution of whitetop (*Cardaria draba*) at the U.S. Air Force Academy in 2002 / 2003 and 2007.



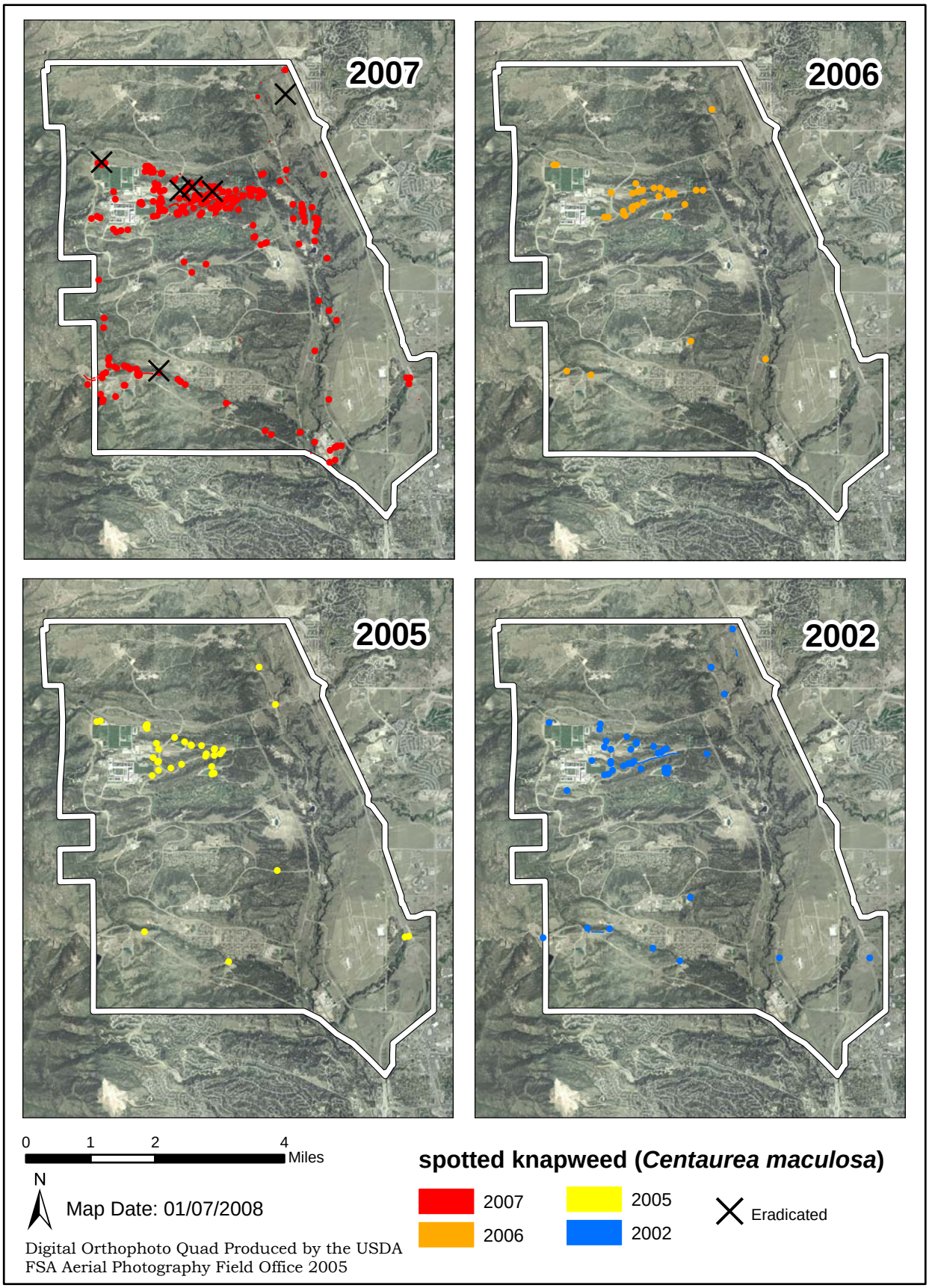
Map 5. Distribution of musk thistle (*Carduus nutans*) at the U.S. Air Force Academy in 2002 and 2007.



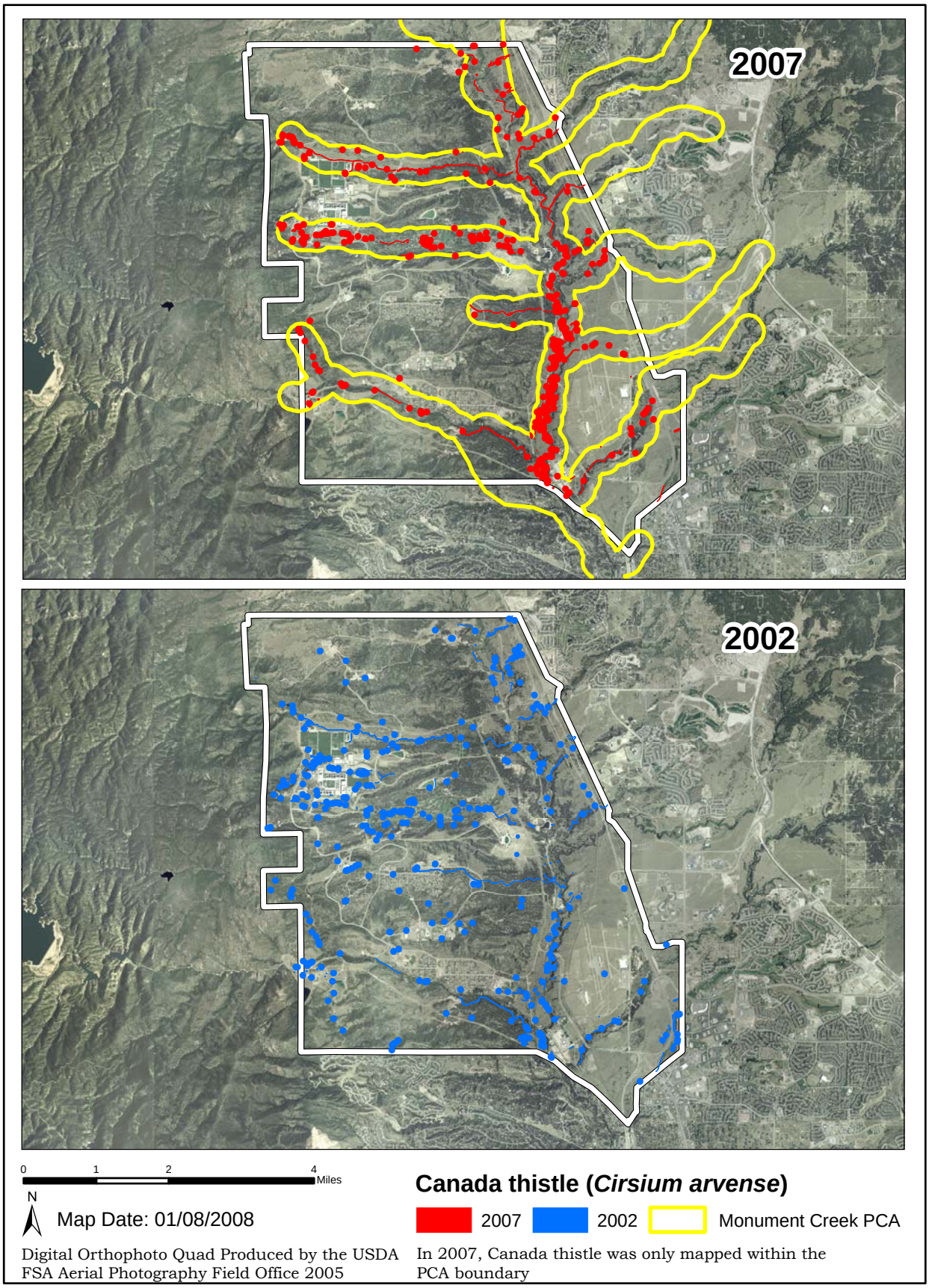
Map 6. Distribution of diffuse knapweed (*Centaurea diffusa*) at the U.S. Air Force Academy in 2002 and 2007.



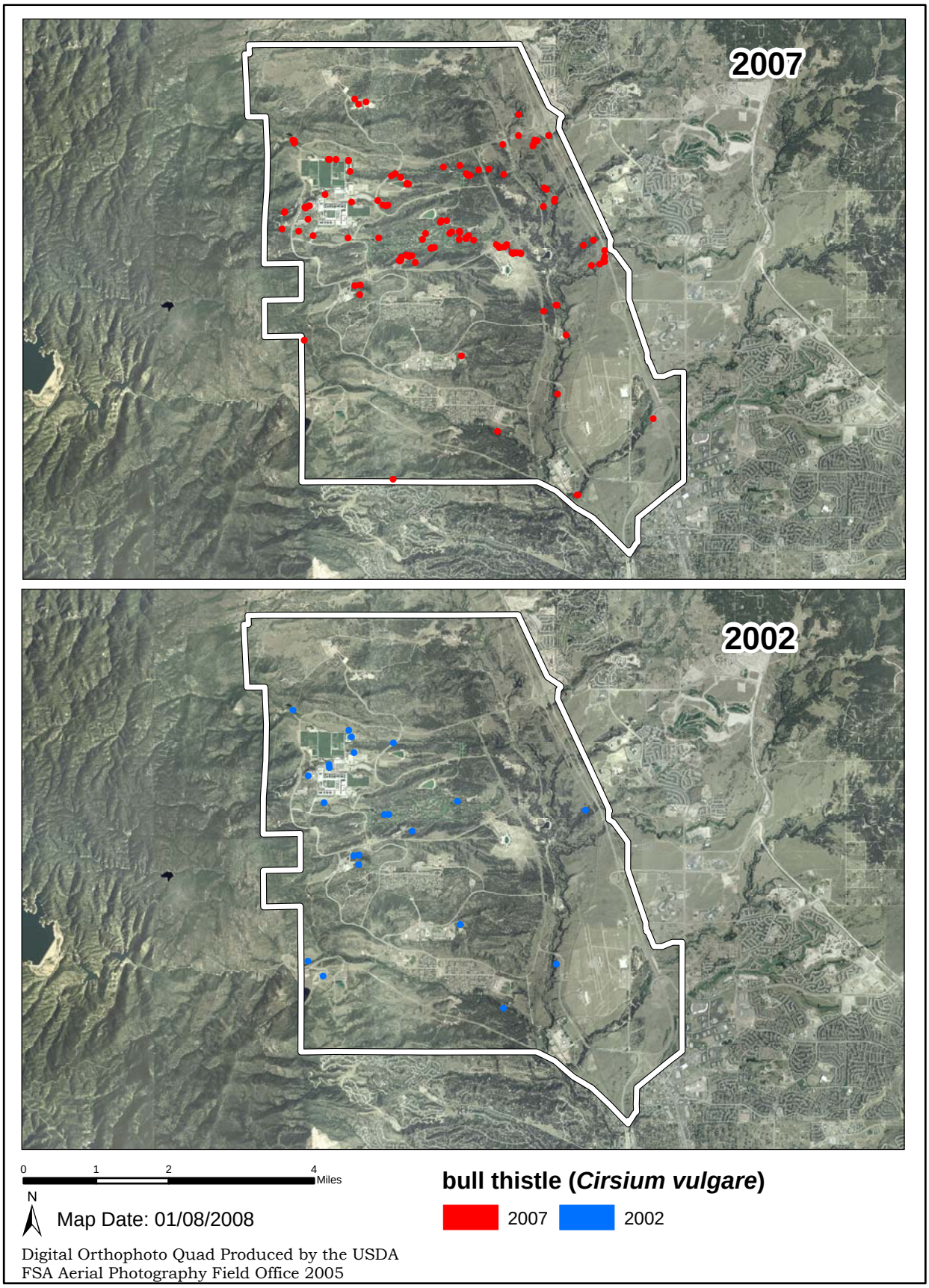
Map 7. Distribution of diffuse / spotted knapweed hybrids (*C. diffusa* x *maculosa*) at the U.S. Air Force Academy in 2007.



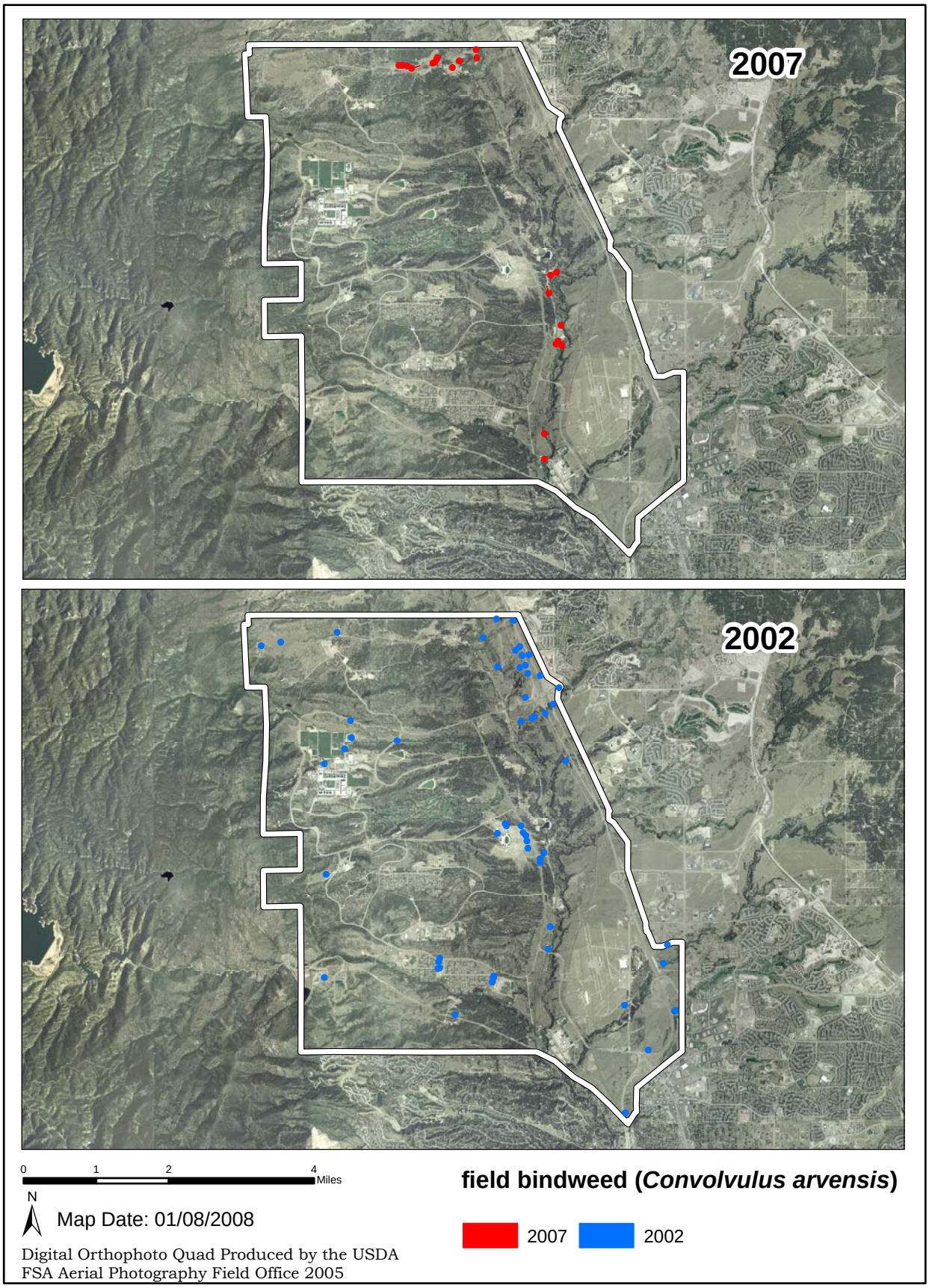
Map 8. Distribution of spotted knapweed (*Centaurea maculosa*) at the U.S. Air Force Academy in 2002, 2005, 2006, and 2007.



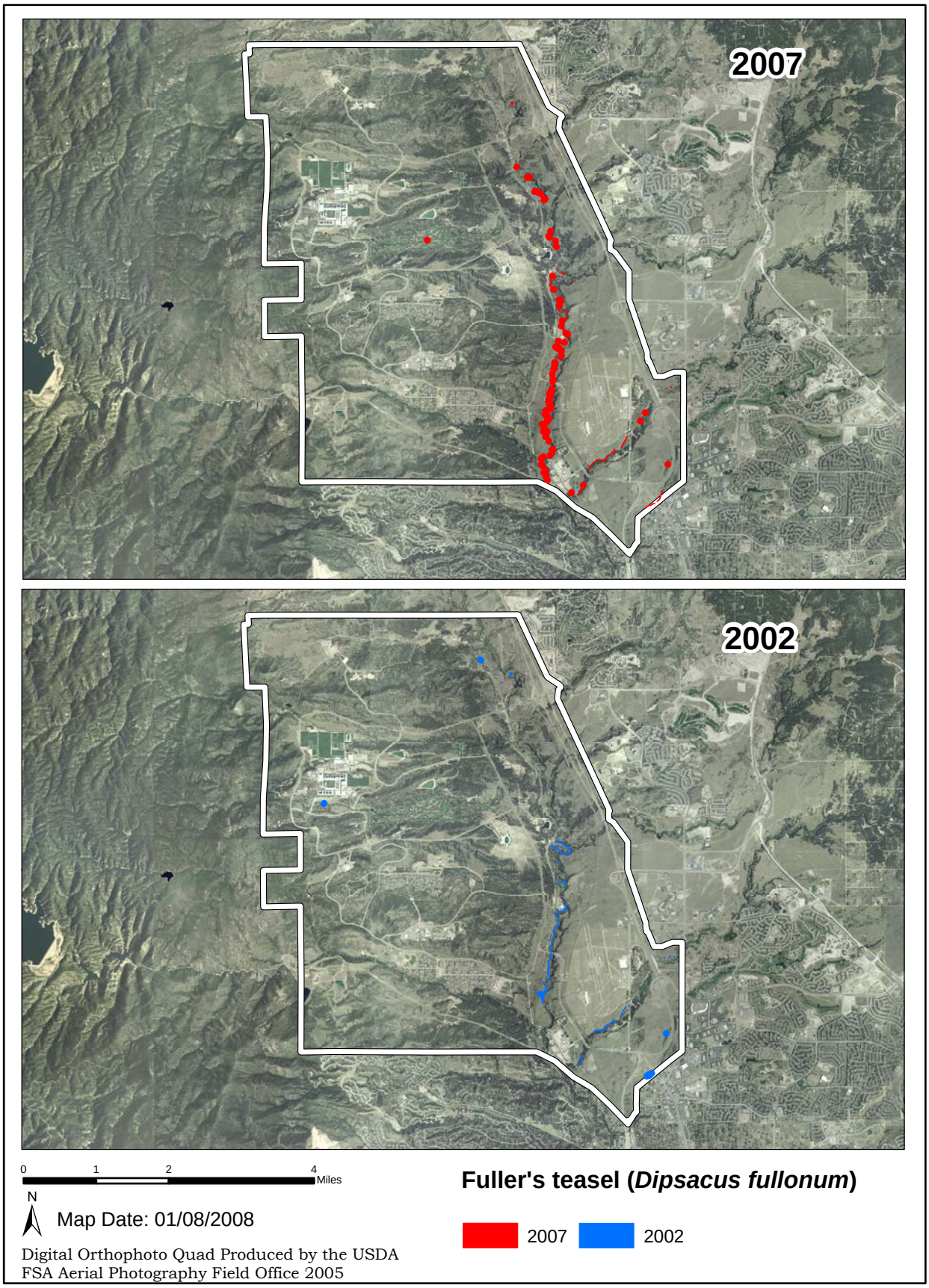
Map 9. Distribution of Canada thistle (*Cirsium arvense*) at the U.S. Air Force Academy in 2002 and 2007 (within high priority conservation areas only).



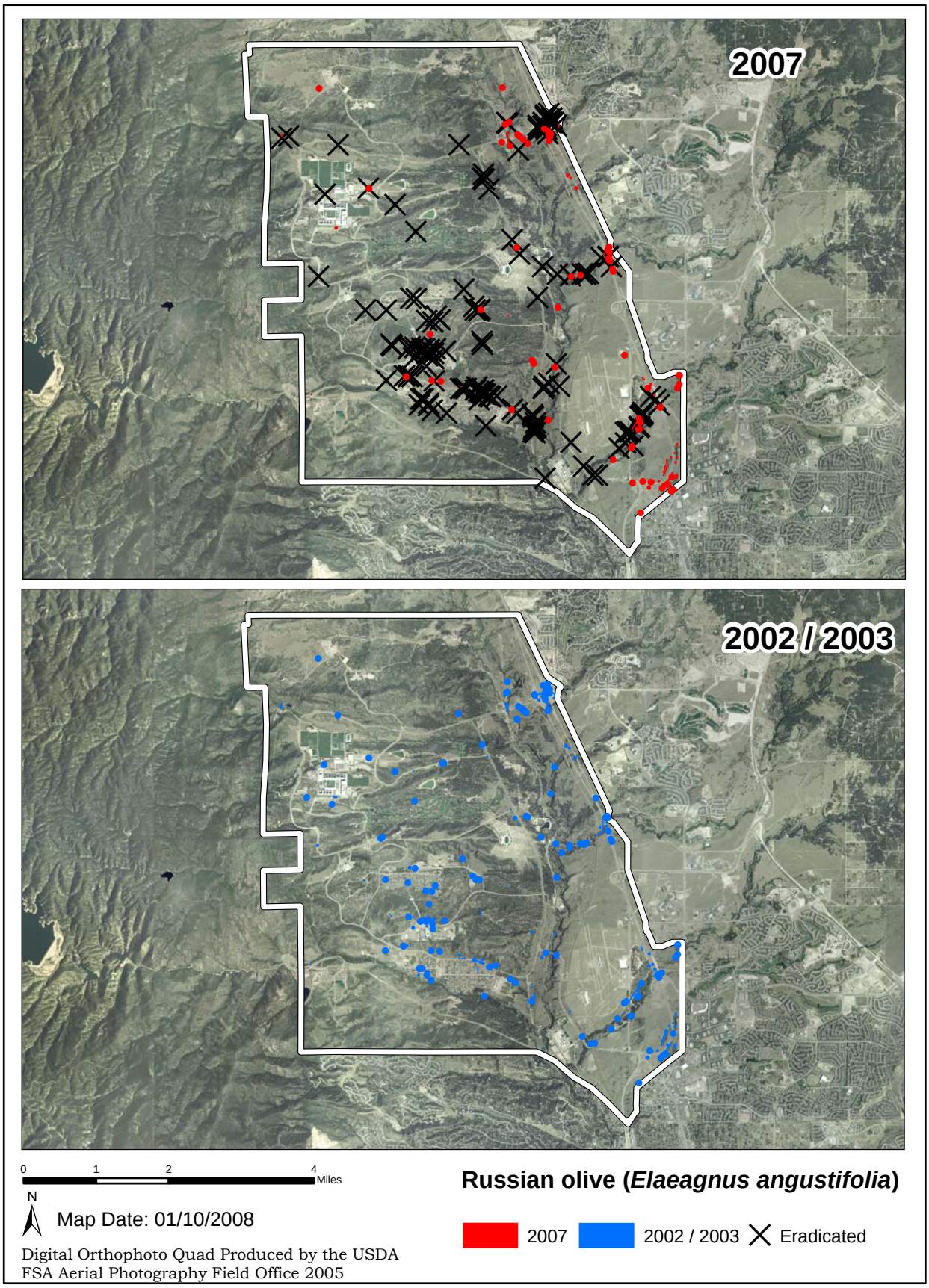
Map 10. Distribution of bull thistle (*Cirsium vulgare*) at the U.S. Air Force Academy in 2002 and 2007.



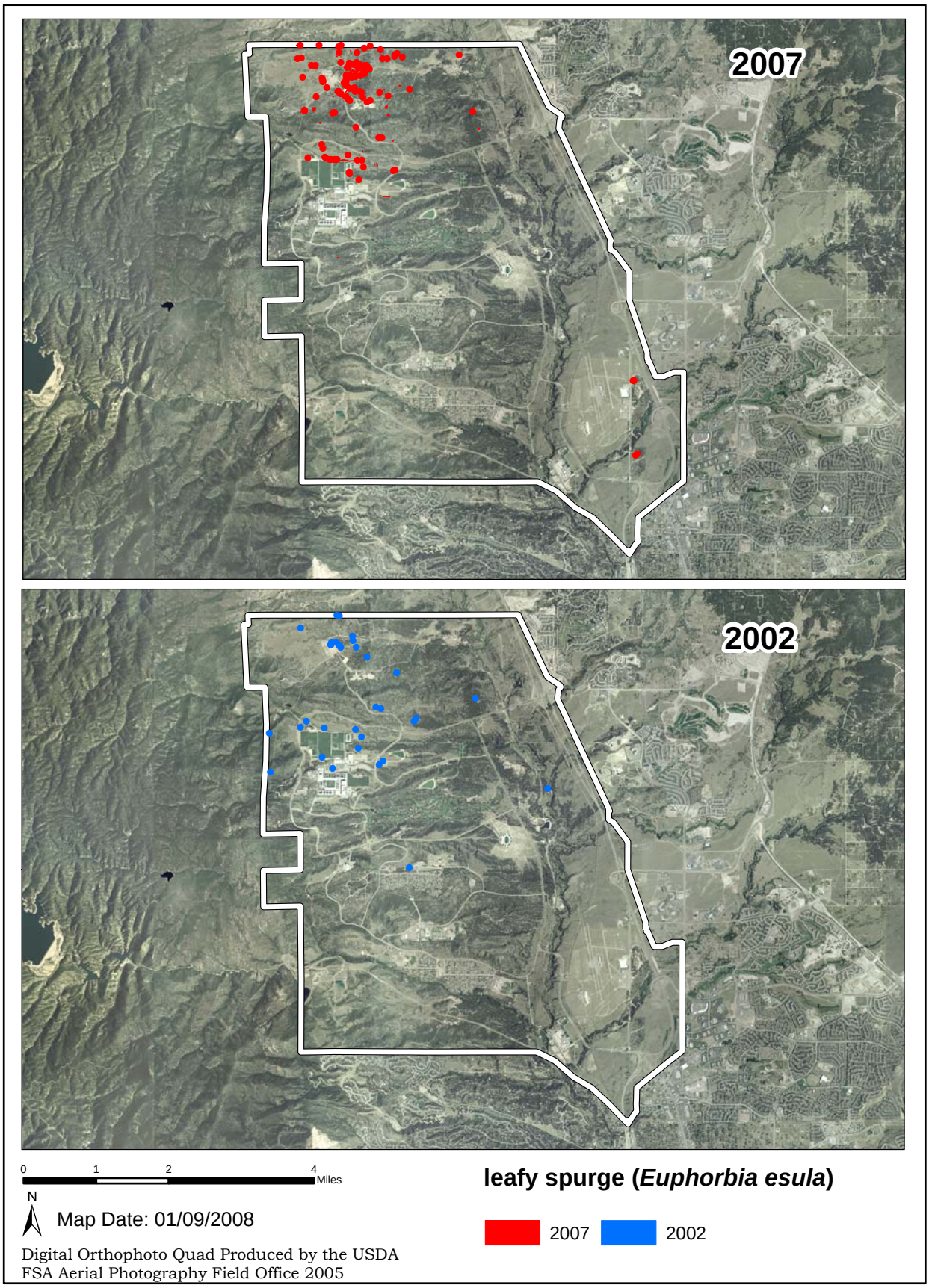
Map 11. Distribution of field bindweed (*Convolvulus arvensis*) at the U.S. Air Force Academy in 2002 and 2007.



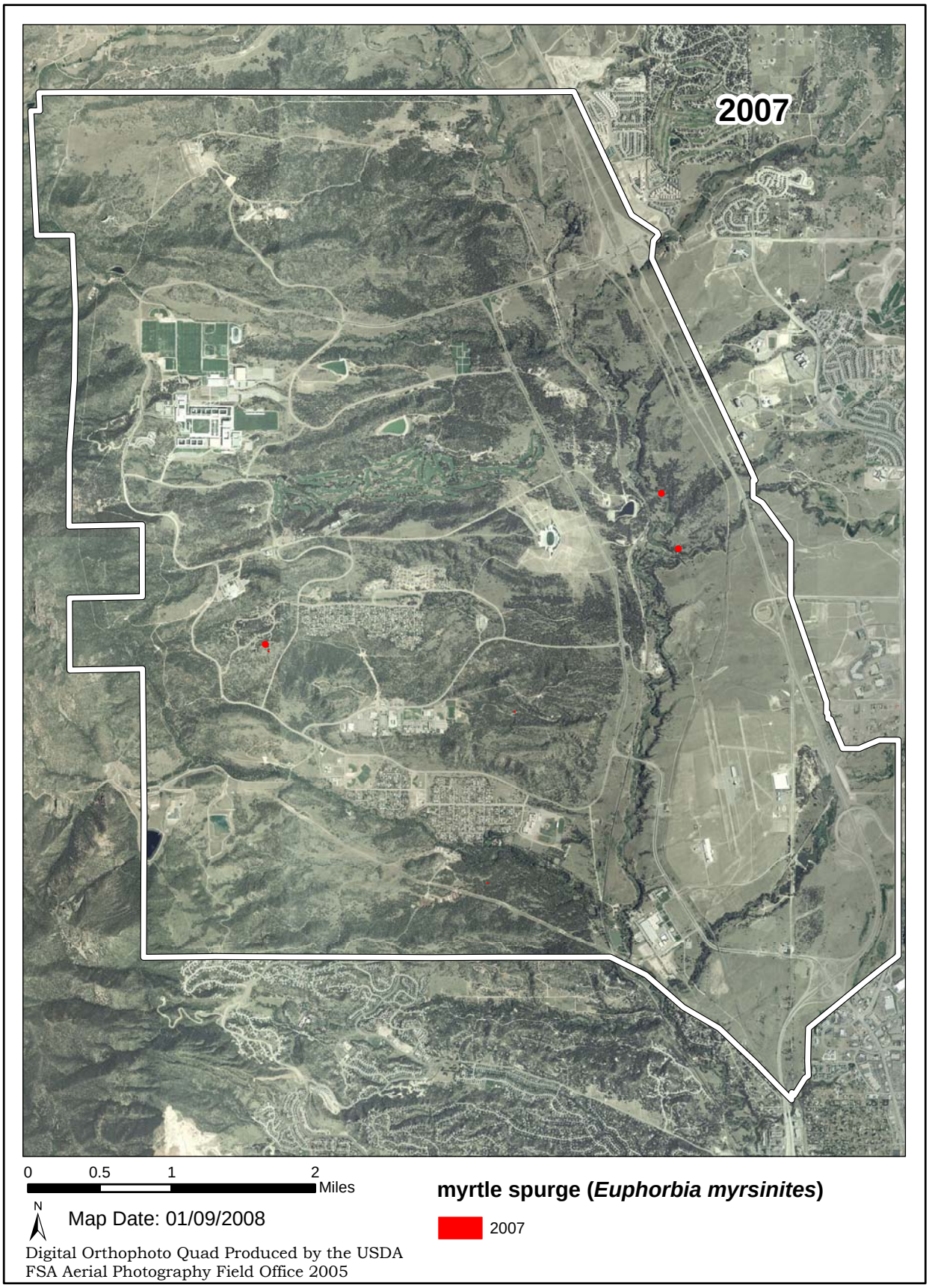
Map 12. Distribution of Fuller's teasel (*Dipsacus fullonum*) at the U.S. Air Force Academy in 2002 and 2007.



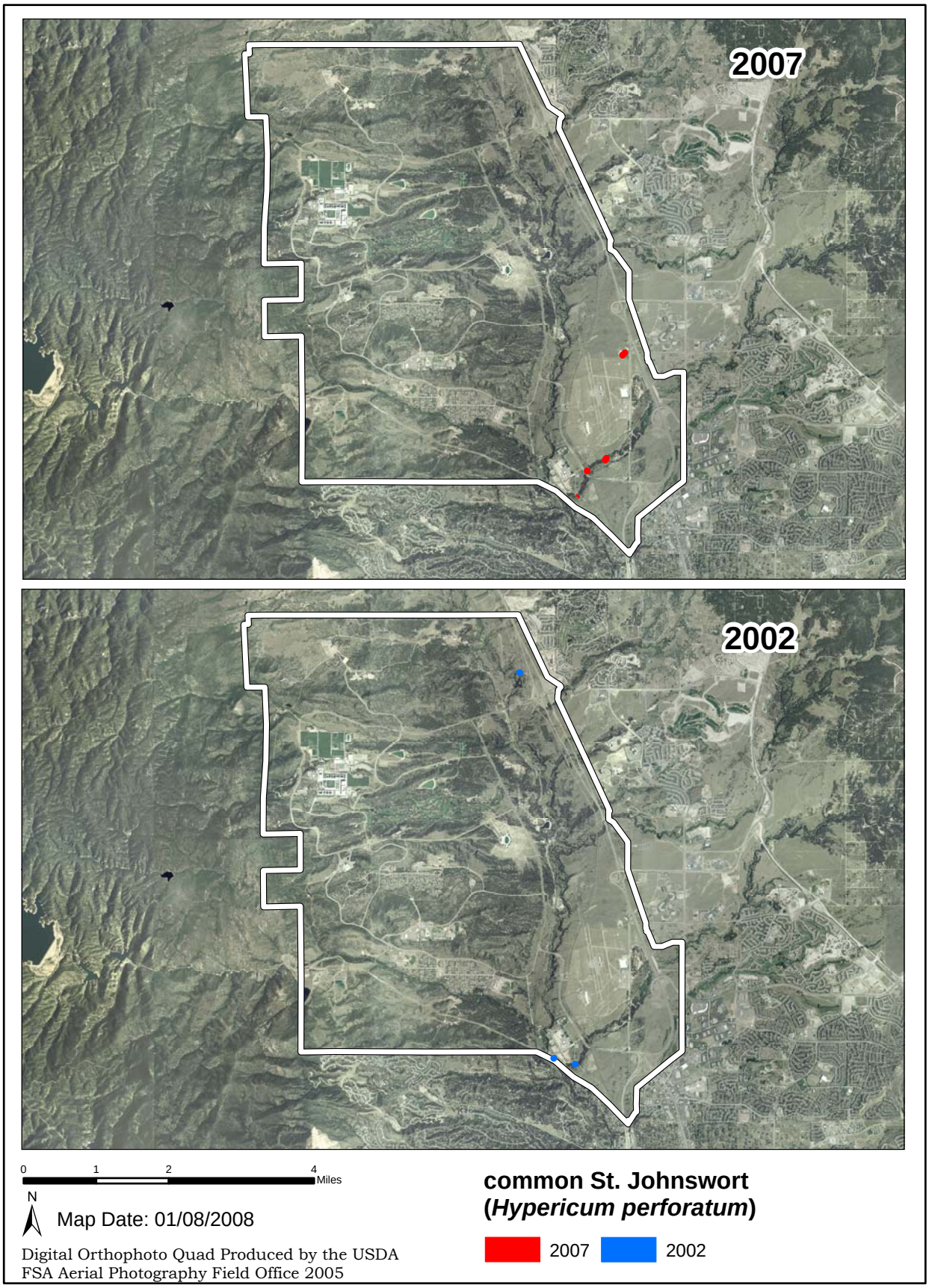
Map 13. Distribution of Russian olive (*Elaeagnus angustifolia*) at the U.S. Air Force Academy in 2002 / 2003 and 2007.



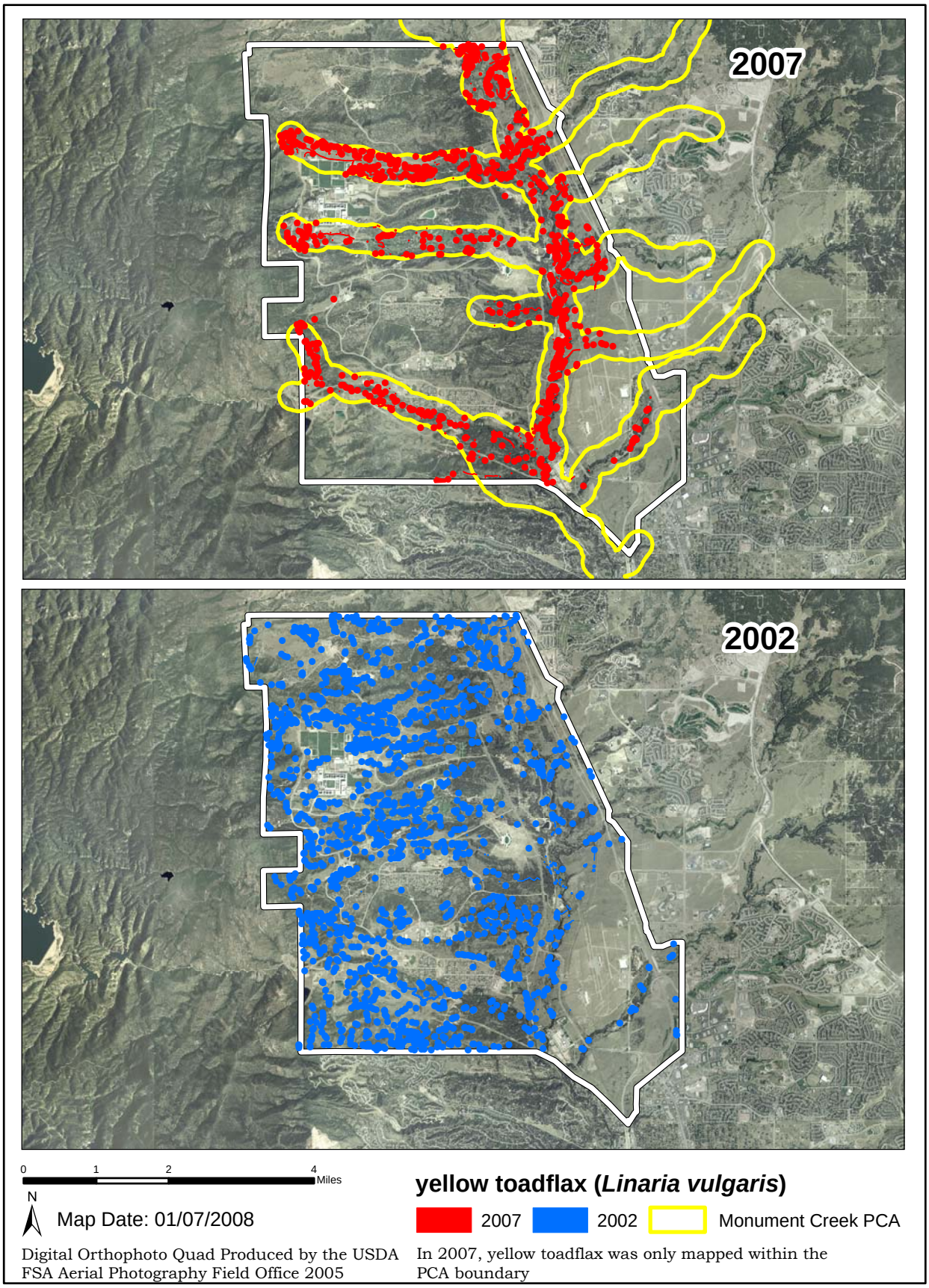
Map 14. Distribution of leafy spurge (*Euphorbia esula*) at the U.S. Air Force Academy in 2002 and 2007.



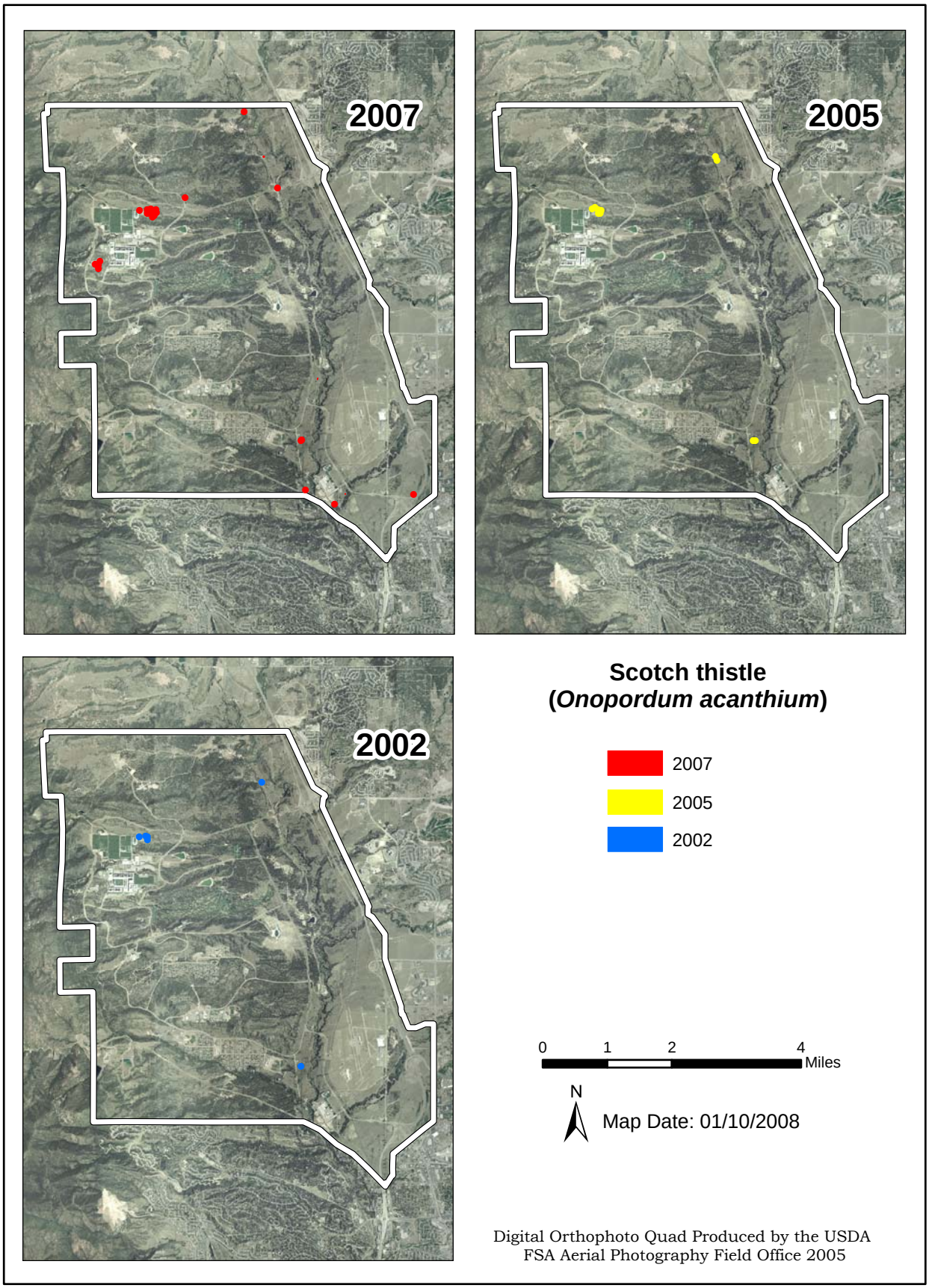
Map 15. Distribution of myrtle spurge (*Euphorbia myrsinites*) at the U.S. Air Force Academy in 2007.



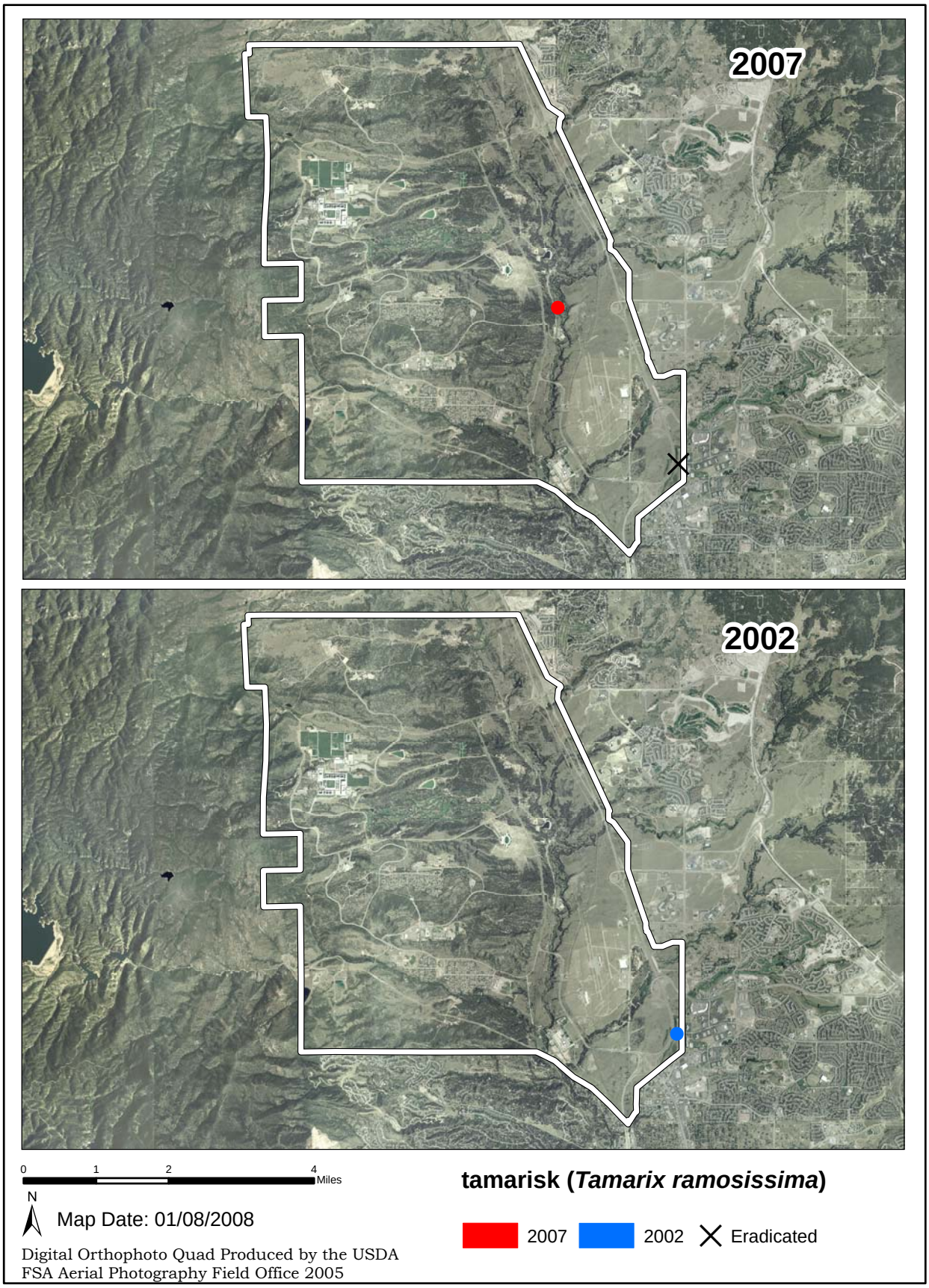
Map 16. Distribution of common St. Johnswort (*Hypericum perforatum*) at the U.S. Air Force Academy in 2002 and 2007.



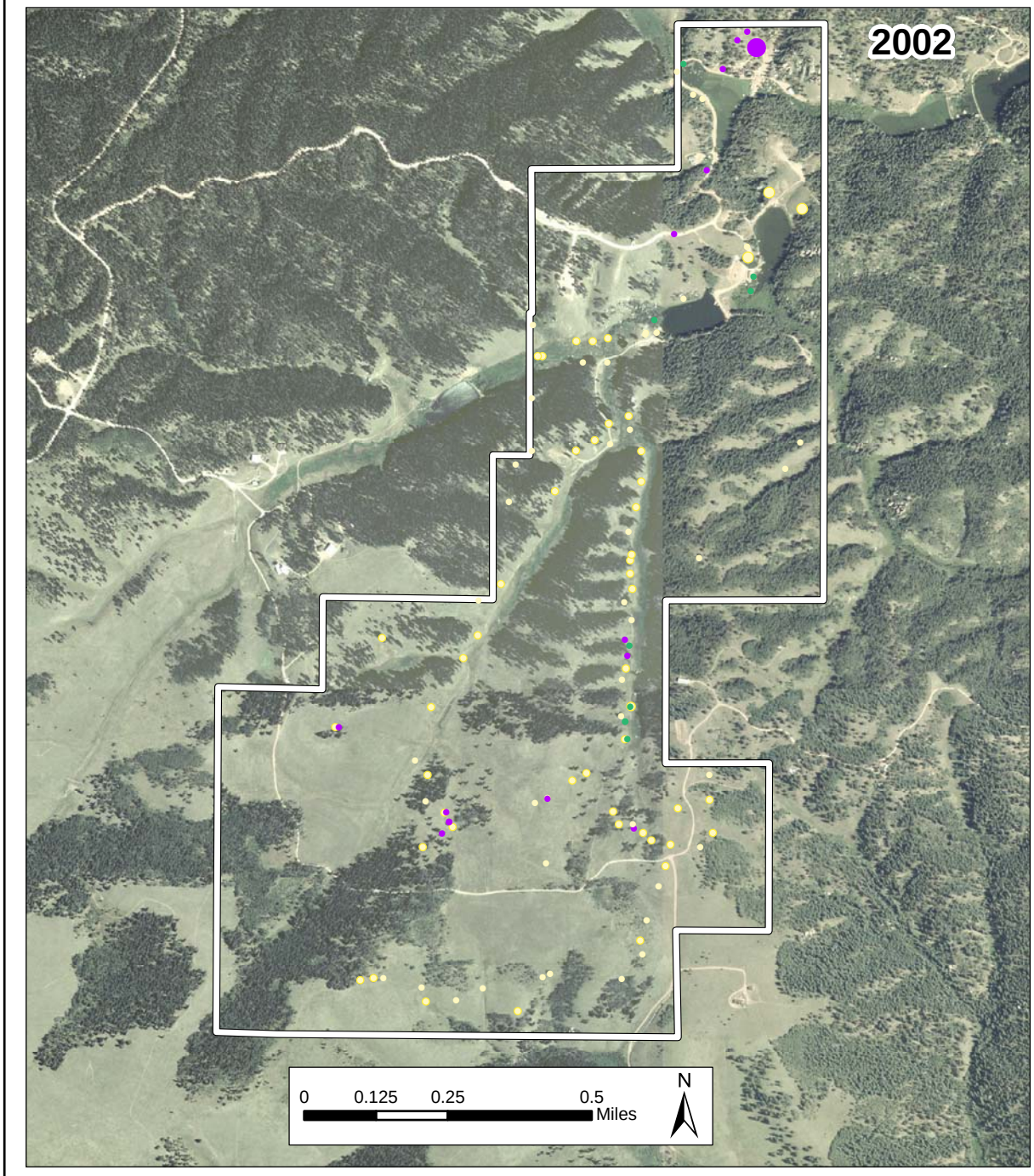
Map 17. Distribution of yellow toadflax (*Linaria vulgaris*) at the U.S. Air Force Academy in 2002 and 2007 (within high priority conservation areas only).



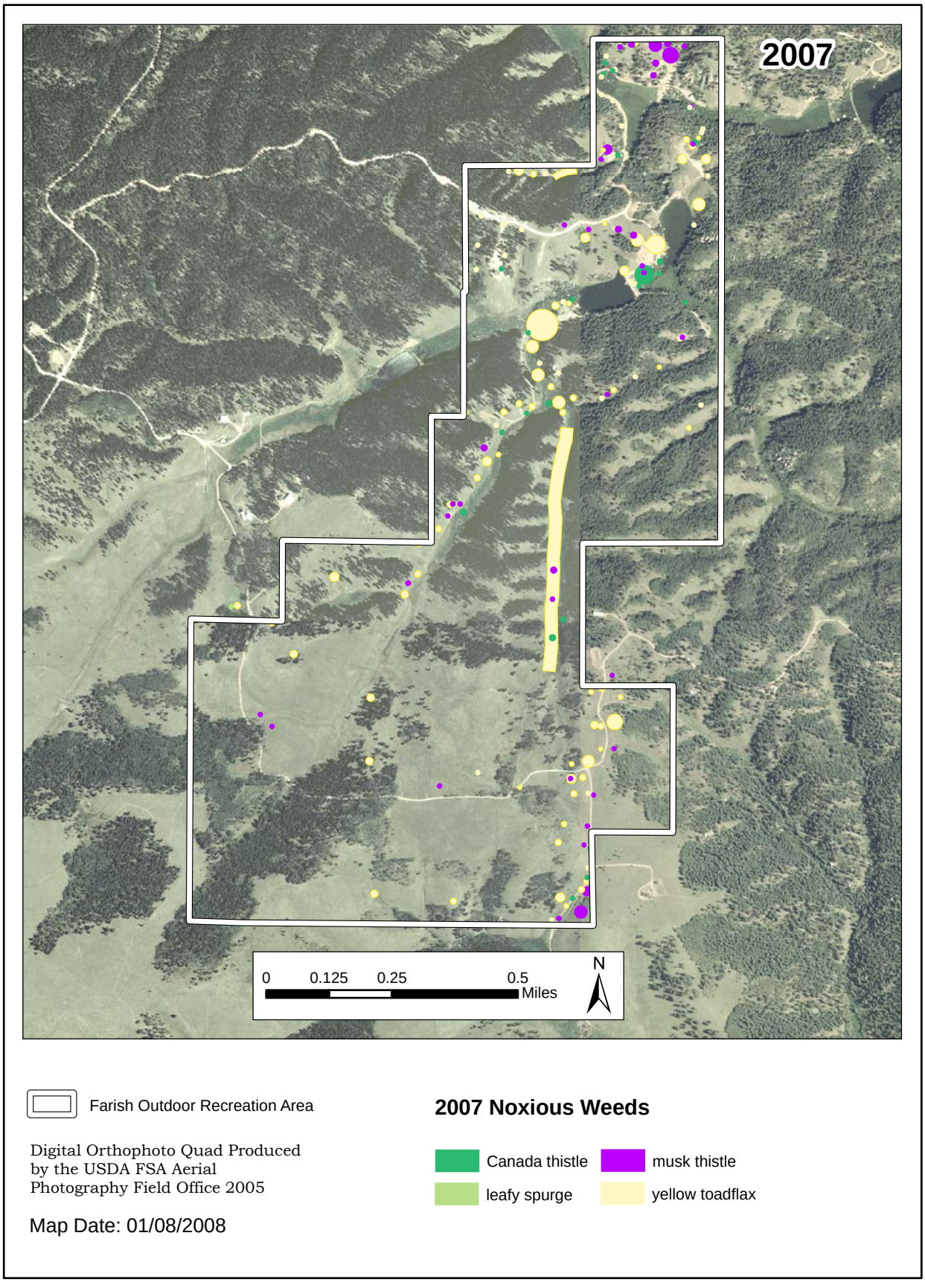
Map 18. Distribution of Scotch thistle (*Onopordum acanthium*) at the U.S. Air Force Academy in 2002, 2005, and 2007.



Map 19. Distribution of tamarisk (*Tamarix ramosissima*) at the U.S. Air Force Academy in 2002 and 2007.



Map 20. Distribution of targeted noxious weed species at Farish Outdoor Recreation Area in 2002 (from Anderson et al. 2003).



Map 21. Distribution of targeted noxious weed species at Farish Outdoor Recreation Area in 2007.

DISCUSSION

Weed map data are extremely useful for developing a weed management program (Barnett 2007). The baseline data obtained in 2002 provided critical insights into the distribution and relative size of the infestations of target species at the Academy and Farish. These data made it possible for the Natural Resources staff to accurately target weed management efforts, set goals, and develop an integrated weed management strategy. The baseline weed map has been a valuable tool for identifying opportunities for strategic weed management that maximizes the cost to benefit ratio (as discussed by Hobbs and Humphries 1995).

By mapping targeted noxious weeds again in 2007, a temporal dimension was added that greatly increases the value of the spatial and tabular data. Comparing the data from 2007 with the baseline data from 2002 offers far greater insights and provides answers to some important questions. With only a single year of map data it was not possible to draw inferences regarding trends, rates of spread, or patterns of invasion. However, it is crucial for these factors to be quantified in order for managers to measure progress towards meeting weed management goals and make strategic improvements to their weed management programs.

Assessment of Progress Towards Weed Management Objectives

By comparing 2002 and 2007's weed map data and utilizing results from the Academy's monitoring program, it is possible to measure progress towards the weed management objectives assigned by Carpenter et al. (2004). These objectives (summarized in Table 25) are ambitious but reasonable, but as weeds continue to spread, meeting these goals becomes more difficult and costly.

Although progress has been made with some species, weed management objectives have not yet been reached for any target weed species. The Academy is closest to reaching management goals for Russian olive. Russian olive has been reduced by 62%; the management objective for this species is 90% suppression. A reduction of 90% or greater is well within reach if management practices that have been used in the past are continued.

Significant progress towards meeting management objectives has been made for common St. Johnswort, myrtle spurge, Russian knapweed, and Tamarisk. Objectives could be reached relatively easily for all of these species, and also for Scotch thistle, through the strategic use of herbicide, biocontrol, and pulling.

For other species, the window of opportunity has closed somewhat since 2002. This is especially true for spotted knapweed. Ambitious herbicide treatment of this species over the next two to five years could still turn the current trend around. However, since this species has now been in a phase of rapid spread for 3 to 5 years it has become entrenched enough that reversing the trend will be relatively costly. Leafy spurge and diffuse knapweed have also become significantly more widespread over the last five years. At Farish, yellow toadflax, Canada thistle, and musk thistle are all spreading into

new areas rapidly, but because of the small area involved, reversing these trends is still feasible.

In advancing towards achieving weed management objectives, it can be challenging to minimize impacts to conservation targets. Many areas of the Academy and Farish are highly sensitive, and some would be impossible to restore within a reasonable management timeframe. One example is the wetland habitat occupied by Porter's feathergrass at Farish, where any use of herbicide would be risky. These considerations and likely conflicts between noxious weeds and conservation targets are reviewed by Spackman Panjabi and Decker (2007).

Table 25. Noxious weed management objectives for species targeted in this study (from Carpenter et al. 2004), with priority from Spackman Panjabi and Decker (2007), and estimated relative cost of achieving weed management objectives based on current distribution at the Academy and stage of invasion after Hobbs and Humphries (1995). Estimated costs of achieving objectives are somewhat subjective.

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

Mapping as a Monitoring Tool

There are many advantages to monitoring species through mapping, although there are some limitations as well (Barnett et al. 2007). As a means of quantifying the status of targets, mapping offers several benefits. Because it is a census, the data are not subject to the same risk of type I and type II errors that a random sample is subject to. It has also proven to be reliable and cost-effective, and has effectively provided data needed to manage weeds and measure progress towards weed management objectives at the Academy.

While these methods are in many ways ideal for monitoring weeds at the Academy, they are most applicable for relatively rare species that can be censused within a reasonable timeframe. Species such as Canada thistle and yellow toadflax are too abundant and widespread for the practical use of census techniques, and even within high priority conservation areas it is necessary to conceptualize their mapped distributions as rigorous samples rather than a complete census. Spotted knapweed has begun to approach a population size and distribution threshold that is fairly labor intensive, though not impossible, to census annually. While the percentage of undocumented infestations is not known, it is certainly small. Although the area surveyed is large, the stratification of the study area and ratio of area surveyed to hours in the field suggest that relatively few infestations remain undocumented. Updating the base-wide noxious weed map is deemed sufficient for monitoring yellow toadflax (within high priority conservation areas) and bull thistle. Wherever possible, we recommend that this method of monitoring weeds be continued, and we strongly support recommendations to conduct another base-wide noxious weed survey in 2012.

Data Sharing and Collection

The value of the data from this project will be maximized if they can be shared with weed management professionals at the Academy and with other weed scientists and management professionals. The dataset from 2002 and 2003 has already been showcased by the Nature Conservancy and NatureServe scientists and has been incorporated into databases maintained by the State of Colorado (Colorado Department of Agriculture 2008a) and the National Institute of Invasive Species Science (U.S. Geological Survey 2008). Data from this project are of potential interest to weed scientists worldwide.

The mobile mapping technology employed by CNHP and Natural Resources Staff at the Academy would be highly effective if utilized collaboratively 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.

ACKNOWLEDGEMENTS

The help and generosity of many experts is gratefully acknowledged. Our partners at the Academy were extremely helpful throughout this project. Brian Mihlbachler, our primary contact at the Academy, played a critical role in this project. His assistance with project logistics and with identifying study sites was extremely valuable, as was his time spent in the field orienting CNHP personnel. Greg Speights, Steve Wallace, and Diane Strohm also provided crucial logistical support and advice.

Michelle Washebek spent four months in the field through the summer of 2007 completing the mapping portion of this project. Her high quality work serves as the foundation for this report and distinguishes her as an excellent fieldworker. The work of Ron Abbott in 2002 and of Joe Stevens in 2003 were invaluable in guiding the mapping in 2007, and their experience was valuable for refining the mapping methodology employed in this project.

We received expert advice from many individuals including Janet Coles, Renée Rondeau, Alan Carpenter, Greg Newman, George Beck, Eric Lane, Kelly Uhing, and James R. zumBrunnen. The work of Gerry Michels and his colleagues has also been valuable for this project.

Bruce Roselund, Dee Dee Runner, and Andrea Vigil assisted with project management and support. Mary Olivas, Carmen Morales, and others at CSU assisted with contract administration. Melissa Landon provided editorial and technical assistance with report production.

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APPENDIX A- WEED MAPPING INSTRUCTIONS

OPEN AFA_WEEDS.MXD IN ARCMAP. MAKE SURE ARCPAD TOOLBAR IS TURNED ON (View => Toolbars => ArcPad) AND THE ACTIVE DATA FRAME IS "WGS84" (right-click on Data Frame and select "Activate")

1) Back-up the geodatabase. In Windows Explorer, copy J:_NaturalRes\Noxious Weeds\2007_CNHP_Weed_Survey\AFA_Weeds_WGS84.gdb to J:_NaturalRes\Noxious Weeds\2007_CNHP_Weed_Survey\Backups and rename with the current date (ex. AFA_Weeds_WGS84_04_14_2008.gdb)

2) In the ArcMap document, AFA_Weeds.mxd, undo any layers checked out for editing (3rd button from the left in the ArcPad toolbar). Select all and click on Undo. If this is grayed out, then there are no layers checked out for editing and you are OK to proceed.

3) Check data out by clicking on "Get Data for ArcPad 7" (4th button from the left on the ArcPad toolbar). Checkmark weed points, lines and polygons. Click on next and checkmark weed points, lines and polygons again. Click on next.

Select "The full extent of the selected layer(s)"

Uncheck "Only get features specified in layer's definition query" and "Only get fields specified as visible in layer's properties"

Use the default folder name, DataForArcPad1

Under "Where do you want this folder to be stored?", browse to J:_NaturalRes\Noxious Weeds\2007_CNHP_Weed_Survey\

Uncheck "Create an ArcPad map referencing the data".

Click on finish

4) In Windows Explorer, copy everything in the Forms folder (apls and dbfs) into the DataForArcPad1 folder. Select "Yes to All" to overwrite files in DataForArcPad1. This will replace the generic data entry forms created in ArcMap during the check-out process with AFA's custom data entry forms.

5) Transfer the entire DataforArcPad1 folder to the PDA's Storage Card using MS ActiveSync. Get Connected using Activesync and transfer the DataForArcPad1 folder to the PDA in Storage Card/Weeds.

6) Edit data in ArcPad
Point, line and polygon weed data are available for editing with custom data entry forms.

After mapping new weeds or updating existing weed shapes or attributes …

7) Copy DataforArcPad1 folder from the PDA into J:_NaturalRes\Noxious Weeds\2007_CNHP_Weed_Survey\ and overwrite the existing folder.

8) In the ArcMap document AFA_Weeds.mxd, make sure the WGS84 data frame is active and put the AFA_Weeds_WGS84 geodatabase in "edit mode". Make sure the Editor toolbar is turned on (View => Toolbar => Editor). Then go to Editor => Start Editing. If prompted, select AFA_Weeds_WGS84.gdb. If no other data layers are in the data frame, then AFA_Weeds_WGS84.gdb will automatically be in edit mode and no prompt will occur.

9) Add your edits to the geodatabase. Click on "Check in edits from ArcPad" (2nd button from the left on the ArcPad toolbar).

Select any shapefiles you edited in the field (if you modified points, but not lines and polygons then just check in the point file). This will add any new shapes, remove deleted shapes or modify changes to existing shapes in the geodatabase.

***Note: if no files are marked for check in repeat Steps 2 and 3 EXCEPT in Step 3 check data out to the folder DataForArcPad2 (instead of DataForArcPad1). Copy everything in DataForArcPad1 into DataForArcPad2, overwrite all files and try "check in" again.**

10) Stop editing and save changes (Editor => stop editing)

11) Activate the "STATE PLANE" data frame (right-click on the "STATE PLANE" data frame and select "Activate"). Open the Toolbox and scroll to AFA Weed Tools. Double-click on "Weeds Step One" and hit OK. Double-click on "Weeds Step Two", add the date to the end of the file names (ex. AFA_Weeds04_25_2008) and hit OK.

***Note: "Weed Tools" should automatically be in your ArcMap document when you open the toolbox. If for some reason it is not, turn on ArcToolbox, right-click, select "Add Toolbox" and browse to the J:_NaturalRes\Noxious Weeds\2007_CNHP_Weed_Survey\. Select "Weeds" and click on open. You should now see a category for "AFA Weed Tools" in ArcToolbox.**

12) Right-click on the newly created shapefile, click on the symbology tab and import the legend from the old weed shapefile. Once you have copied the symbology to the new file, you can remove the old file from your ArcMap document. At this point, it would be best to copy the old shapefile into the back-up folder.

13) Browse and make sure your edits were completed. Once that is confirmed, you can delete the DataforArcPad1 folder on the PDA and on your computer.