Noxious Weed Survey of the U.S. Air Force Academy and Farish Outdoor Recreation Area - 2012

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Prepared For:
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Cover photos clockwise from top left: Dames rocket (Brian Mihlbachler), Yellow spring bedstraw (Wikipedia); Houndstongue (M. DiTomaso, University of California – Davis); Dalmatian toadflax (Wikipedia); Tatarian honeysuckle (Wikipedia).

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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 three sampling periods, 2002, 2007, and 2012 with a strong emphasis on changes between 2002-2007, 2007-2012, and overall trend from 2002-2012. In 2012, distributions of 22 target species were mapped at the Academy and Farish from June to October, compared to 14 and 17 species in the previous sample years. Due to the large increases in weed abundance between 2002 and 2007, it was necessary to prioritize weed mapping effort by species and area (exclusion areas), with comparison between years at the appropriate scale. No exclusion areas were necessary for the less common species. Attribute data were gathered for each infestation documenting occupied acres, number of shoots, distribution pattern, and in some cases treatment status and success.

The primary emphasis of this report is to detect trends over the three sampling years and to distill these data into a cogent and succinct picture elucidating trends in distribution, habitat affinities, occupied area, number of shoots, and number of extant 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.

The past 11 years have been drought years for the region, with the exception of the 2003-2004 water year. Annual precipitation for all sampling years was below average; however, 2007 was the least dry and 2002 the driest. Soil moisture plays a large role in weed abundance and, in general, dry years produce fewer weeds than wet years. Thus, when we documented an upward trend from 2007 to 2012 (wet to dry) we have ample reason to be concerned about the rate of spread.

Overall summary: In 2012 at the Academy and Farish, the 22 mapped weeds occupied a total of 312 acres, with over 5,300 extant mapped locations and some 4.5 million stems. While the occupied acres remained nearly stable between 2007 and 2012, the spread of weeds into new areas increased 39%, with an additional 1,480 mapped sites (Figures 1 and 2). The number of shoots also increased 87% over this same time period. Two reasons might explain the stability in acres while other indicators increased: 1)

mapping was conducted by different folks in each year and most occurrence sizes were estimated, therefore it is possible that there was an observer bias; 2) 2007 was wetter than 2012 and therefore acres occupied may be a reflection of precipitation. Potentially, both reasons may have merit. Since we have three indicators for each species, it is best to look at the preponderance of the evidence. The increase from 2002 to 2007 was greater, but that was going from an extremely dry year to a nearly average year. Therefore it is interesting to see that we still saw an overall increase from 2007 to 2012 in two of the indicators, number of shoots and extant mapped locations.

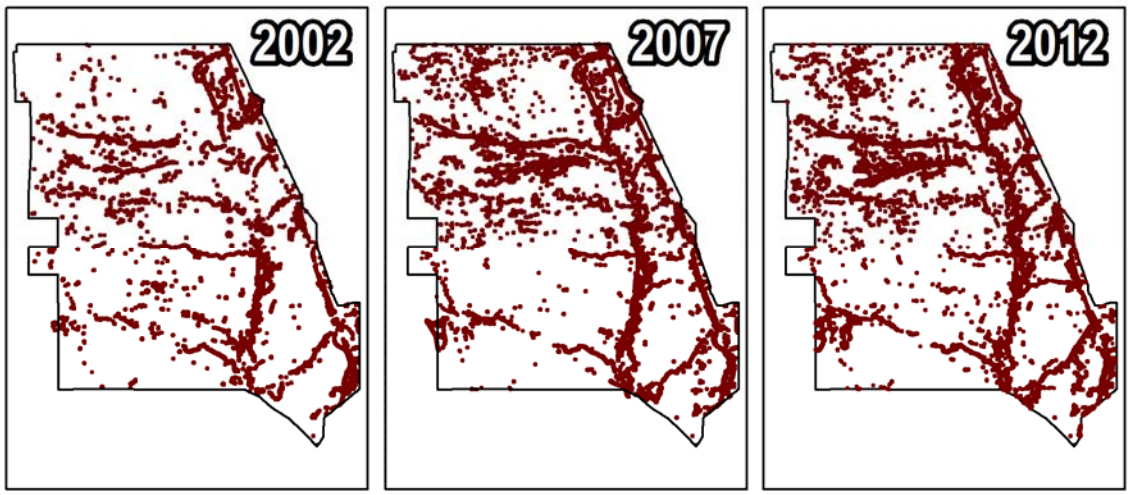


Figure 1. Distribution of known infestations at the U.S. Air Force Academy.

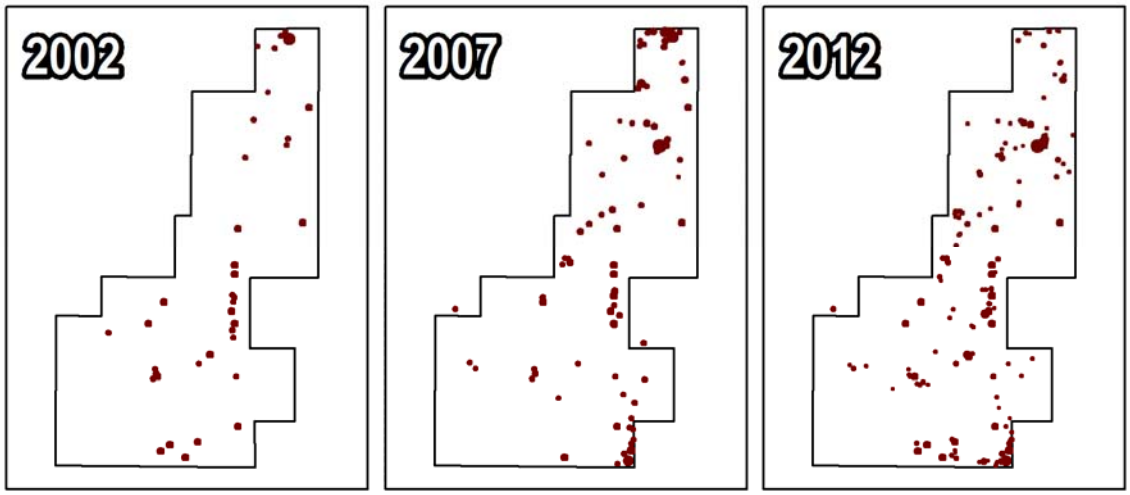


Figure 2. Distribution of known infestations at Farish Outdoor Recreation Area.

Successful Control: Natural Resource staff at the AFA successfully suppressed, maintained, or eliminated several weed species via mechanical and herbicide treatments. Due to active management, the following species occupy less than one acre/species: Russian knapweed, bull thistle, houndstongue, myrtle spurge, yellow spring bedstraw, common St. Johnswort, Dalmatian toadflax, Scotch thistle, and tamarisk. Although complete eradication is a goal for these, only Dalmatian toadflax reached this goal. The other species are still present and most have expanded their distribution since 2007 however they still have a minor presence. Russian olive has reached nearly 11 acres yet there was nearly a 72% decline since 2002. Outlier populations of whitetop were also targeted for control with a good success rate.

Less Successful Control: The combined knapweeds (diffuse, spotted, and their hybrid) were the most abundant mapped weeds in 2012, occupying nearly 160 acres, where as they only occupied 50 acres in 2002. The actual number of acres occupied in 2007 was slightly more than in 2012; however, we know that knapweeds spread into new areas in this same time period as there were 2,060 extant mapped features in 2012 compared to 1,350 in 2007, a 53% increase. In addition, the number of shoots increased 266% (up to nearly 2 million) as well.

At Farish, yellow toadflax, Canada thistle, and musk thistle are all spreading into new areas, but because of the small area involved, reversing these trends is still feasible.

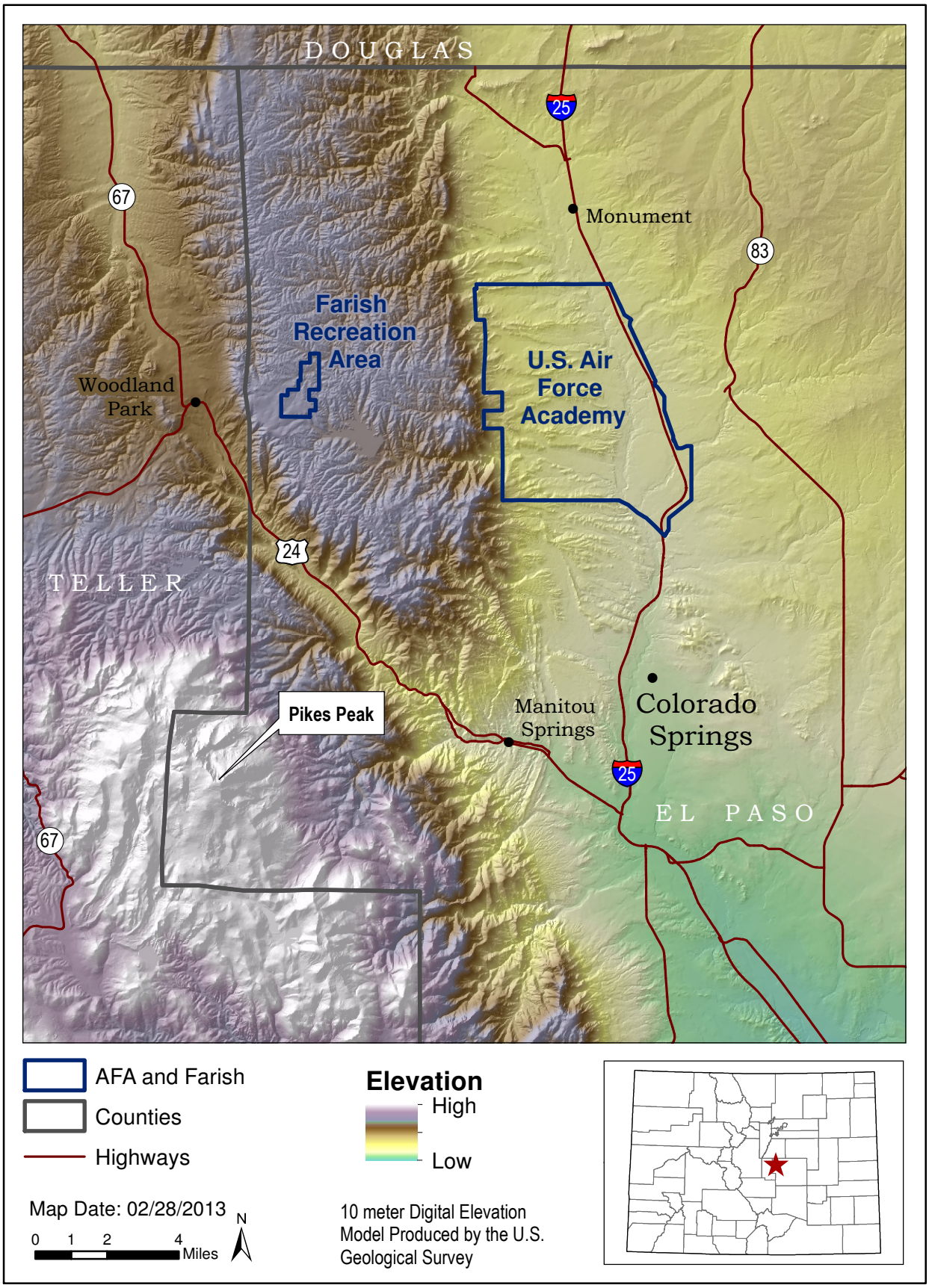
Prioritizing future weed management: Of the 22 species mapped at the Academy and Farish in 2012, we believe 11 of them should be considered high priority for future control efforts wherever they are found. These are: Dalmatian toadflax, tamarisk, yellow spring bedstraw, houndstongue, Russian knapweed, Tatarian honeysuckle, myrtle spurge, Scotch thistle, dames' rocket, common St. Johnswort, and bull thistle (ordered by least to most acreage). All of these require annual herbicide or manual extraction treatment. Several other weeds are second tiered due to their low probability of total eradication and should be prioritized in areas with high conservation value. These are: bull, Canada, and musk thistle, leafy spurge, and diffuse and spotted knapweeds.

INTRODUCTION

The U.S. Air Force Academy and Farish Outdoor Recreation Area harbor large areas of biologically intact landscapes yet weed invasions threaten to degrade these sites (Siemers et al. 2012). Nearly 30% of the known noxious weeds (75) in the State occur at the AFA and this number continues to grow with each mapping project (Anderson and Lavender 2008, and this report). In general the effects of invasive plants include a reduction in native biodiversity, changes in species composition, loss of habitat for dependent species (e.g., wildlife), changes in biogeochemical cycling, changes in ecosystem water use, and alteration of disturbance regimes (Ryan and Vose 2012). The cost of treating weeds is significant and will continue to rise.

The Academy is in a perfect zone for weed invasions as it is situated near a large urban interface and within the foothills, a zone that is extremely susceptible to weed invasion (Map 1). Also, internal and external land disturbances are frequent at the Academy, which provide an excellent avenue for weed infestations. In addition, climate change threatens to increase the abundance of weeds. Key environmental consequences of climate change are increased temperature, increased CO_2, longer growing seasons, less snow, more frequent drought, and changes in fire regimes. With climate change, new habitat, once too cold or wet, may become available, enabling plants to survive outside their historical ranges and expand beyond their current ranges. Cheatgrass, Canada thistle, and spotted knapweed have been demonstrated to increase productivity in response to elevated CO_2 levels (Dukes et al. 2011, Ziska and Dukes 2011, Ziska and George 2004).

In order to make the most out of limited resources for weed management at AFA and Farish it is necessary to know what weeds exist, where they are located, how abundant they are, and how fast their rate of spread is (Carpenter et al. 2004). This information allows for an effective weed management plan and its implementation. It is possible to suppress, contain, or eradicate weeds that are narrowly distributed and have few individuals. The best management for eradication of weeds is early detection and a rapid response.



Map 1. Vicinity map for the U.S. Air Force Academy and Farish Outdoor Recreation Area.

Due to the large increases in weed abundance between 2002 and 2007 it was necessary to prioritize weed mapping effort by species and area (exclusion areas), with comparison between years at the appropriate scale. Therefore, in 2007 and 2012, CNHP employed the use of designated mapping areas (Maps 2 and 3). No exclusion areas were necessary for the less common species. Due to different mapping areas employed throughout the years, change to detect the spread or decline of common species was only calculated within comparable designated mapping areas.

The U.S. Air Force Academy and Farish Outdoor Recreation Area are required to manage noxious weeds in order to remain compliant with Federal, State, and local weed statutes. The weed mapping and monitoring program that the Colorado Natural Heritage Program (CNHP) has been conducting since 2002 is a critical part of a successful management plan.

CNHP began mapping the distribution of noxious weed species targeted for management (suppression, containment or eradication) at the U.S. Air Force Academy and Farish Outdoor Recreation Area in 2002, followed by another year of mapping in 2007 (Anderson and Lavender 2008, Anderson et al. 2003). In 2012, CNHP conducted the third mapping survey (this report). Each subsequent sampling year has seen a rise in the number of species mapped, from 14 in 2002, to 17 in 2007, to 22 in 2012. In addition to mapping, we have been monitoring a select group of species since 2005 (Rondeau and Lavender Greenwell 2013).

Weeds now occupy over 300 hundred acres at the Academy and Farish and while it is impossible to eradicate all of the weeds on these infested acres it is possible to limit their impact. By mapping and prioritizing weed species and sites, it is possible to reach management goals. Natural Resource staff at the AFA has successfully suppressed, maintained, or eliminated several weed species and our past mapping and monitoring efforts have been an important part of controlling weeds. We are hopeful that the results of the 2012 weed mapping project will further increase the effectiveness of weed management at the Academy and Farish.

Purpose of This Report

This report provides a summary of Academy and Farish 2012 weed mapping effort over the 2002, 2007, and 2012 sample years. 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.

METHODS

CNHP mapped 21 noxious weed species and one hybrid (Table 1) within designated mapping areas at the US Air Force Academy and Farish Recreation Area. All species were mapped comprehensively except for yellow toadflax (*Linaria vulgaris*), which was sampled due to its widespread distribution (see yellow toadflax power analysis below). The species targeted in this study include all species mapped in 2002, the first baseline weed mapping project performed by CNHP (Anderson et al. 2003), all species on the state noxious weed list that have been discovered on the Academy since 2002, and Siberian peashrub, a shrub planted for wildlife cover that now appears to be expanding into wetland and riparian habitats at the Academy (Mihlbachler 2012). Sixteen invasive plant species that have a relatively high probability of invading the Academy and Farish (Table 2) were also sought in 2012. The requirements mandated for species on these lists are interpreted in Table 3.

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 2013).

Scientific Name	Common Name	State Status	El Paso Co. Control Requirements	USAFA/ Farish Management Goal
Acroptilon repens	Russian knapweed	B	Suppression/ Containment	Eradication
Caragana arborescens	Siberian peashrub	None	None	Eradication
Cardaria draba	Whitetop	B	None	Suppression- reduce by 90%
Carduus nutans	Musk thistle	B	Suppression/ Containment	Suppression- reduce by 50%
Centaurea diffusa	Diffuse knapweed	B	Suppression/ Containment	Suppression- reduce by 50%
Centaurea maculosa	Spotted knapweed	B	Eradication	Eradication
Centaurea diffusa x maculosa	Diffuse / spotted knapweed hybrid	B	Suppression/ Containment	Suppression- reduce by 50%
Cirsium arvense	Canada thistle	B	Suppression/ Containment	Suppression- reduce by 50% in High Priority Areas
Cirsium vulgare	Bull thistle	B	None	Suppression- reduce by 90%
Cynoglossum officinale	Houndstongue	B	None	Eradication
Dipsacus fullonum	Fuller's teasel	B	None	Suppression- reduce by 50%
Elaeagnus angustifolia	Russian olive	B	None	Suppression- reduce by 90%
Euphorbia esula	Leafy spurge	B	Suppression/ Containment	Suppression- reduce by 90%
Euphorbia myrsinites	Myrtle spurge	A	Eradication	Eradication
Galium verum	Yellow spring bedstraw	None	None	Eradication
Hesperis matronalis	Dames rocket	B	Eradication	Eradication
Hypericum perforatum	Common St. Johnswort	C	None	Suppression- reduce by 90%
Linaria genistifolia spp. dalmatica	Dalmatian toadflax	B	None	Eradication
Linaria vulgaris	Yellow toadflax	B	Suppression/ Containment	Suppression- reduce by 50% in High Priority Areas
Lonicera tatarica	Tatarian honeysuckle	None	None	Eradication

Scientific Name	Common Name	State Status	El Paso Co. Control Requirements	USAFA/ Farish Management Goal
Onopordum acanthium	Scotch thistle	B	None	Eradication
Tamarix ramosissima	Tamarisk	B	None	Eradication

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 2013).

Species	List	Source
Cypress spurge (*Euphorbia cyparissias*)	List A	3
Mediterranean sage (*Salvia aethiopis*)	List A	1
Orange hawkweed (*Hieracium auranticaum*)	List A	3
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
Oxeye daisy (*Chrysantheum leucanthemum*)	List B	3
Perennial pepperweed (*Lepidium latifolium*)	List B	1
Scentless chamomile (*Matricaria perforata*)	List B	3
Sulphur cinquefoil (*Potentilla recta*)	List B	3
Plumeless thistle (*Carduus acanthoides*)	List B	3
Common buckthorn (*Rhamnus cathartica*)	None	1
Garlic mustard (*Alliaria petiolata)*	None	1

Source: 1= Carpenter et al. 2004, 2= this report, 3=Colorado Department of Agriculture 2013

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 2013).

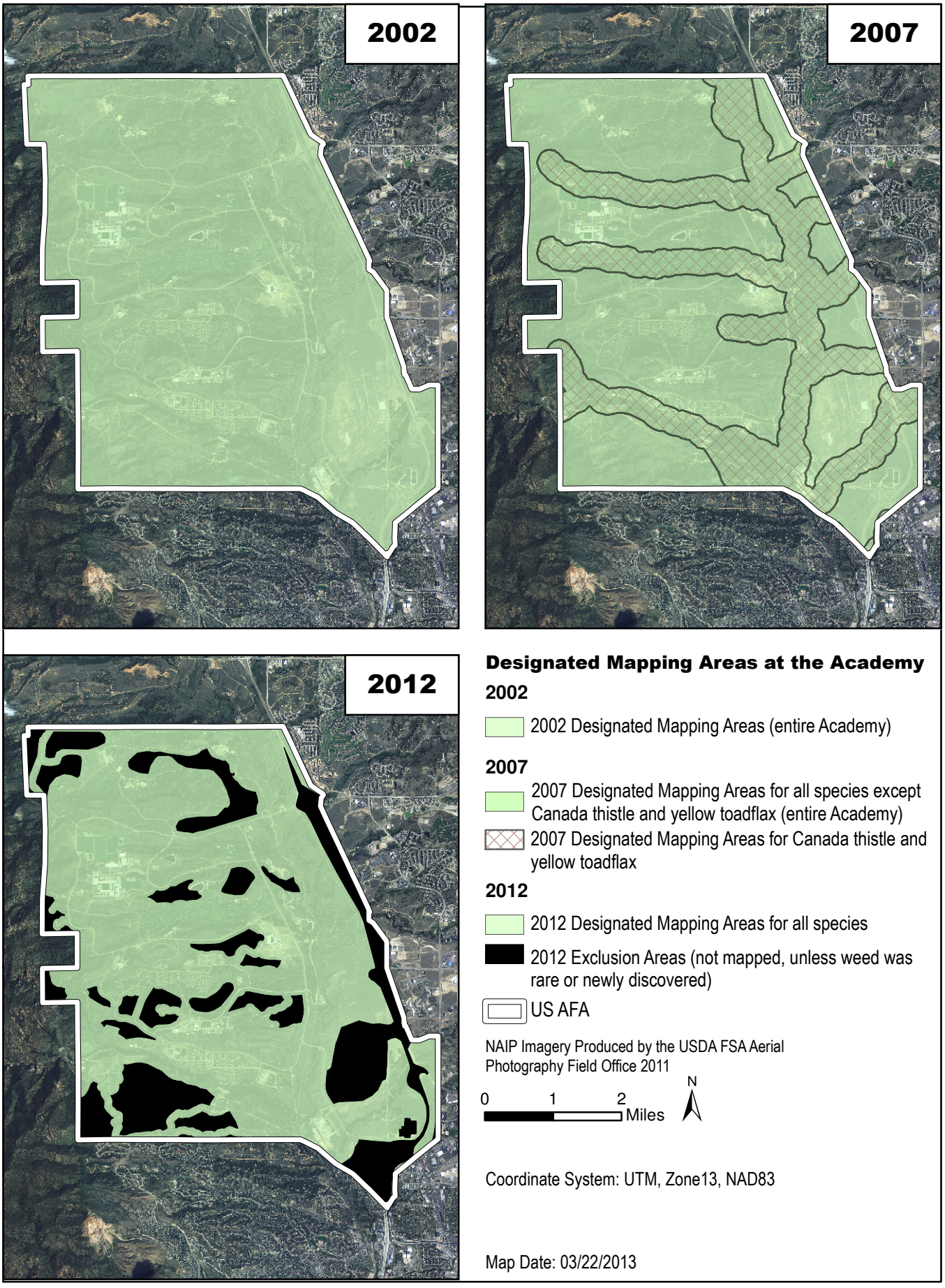
List A	Species in Colorado that are designated by the Commissioner for eradication.
List B	Species for which the Commissioner, in consultation with the state noxious weed advisory committee, local governments, and other interested parties, develops and implements state noxious weed management plans designed 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.

Since weeds at the Academy are spreading in numbers and scope (Anderson and Lavender 2008, and this report), CNHP employed the use of designated mapping areas to concentrate 2012 weed mapping efforts in biologically important areas and areas most likely to harbor weeds. Designated mapping areas at the Academy include CNHP Potential Conservation Areas (as of May 2011) and areas within 100 meters of roads (shapefile provided by Brian Mihlbachler in May 2011). Areas were then modified to include all known infestations of weeds on the annual monitoring list that use census mapping as a monitoring tool (Rondeau and Lavender 2012). Several areas were not accessible due to security reasons at the Academy and thus were not surveyed (Map 2). At Farish Recreation Area, designated mapping areas include CNHP Potential Conservation Areas (as of May 2011) and areas within 100 meters of roads. Additionally, an intermittent stream was included and buffered 100 meters because an overlay of the 2007 weed map showed significant infestations along this corridor (Map 3). This totals approximately 14,940 acres of designated mapping areas for the Academy and Farish combined, or roughly 3/4 of the entire project area, and encompasses over 90% of 2007 known weed infestations.

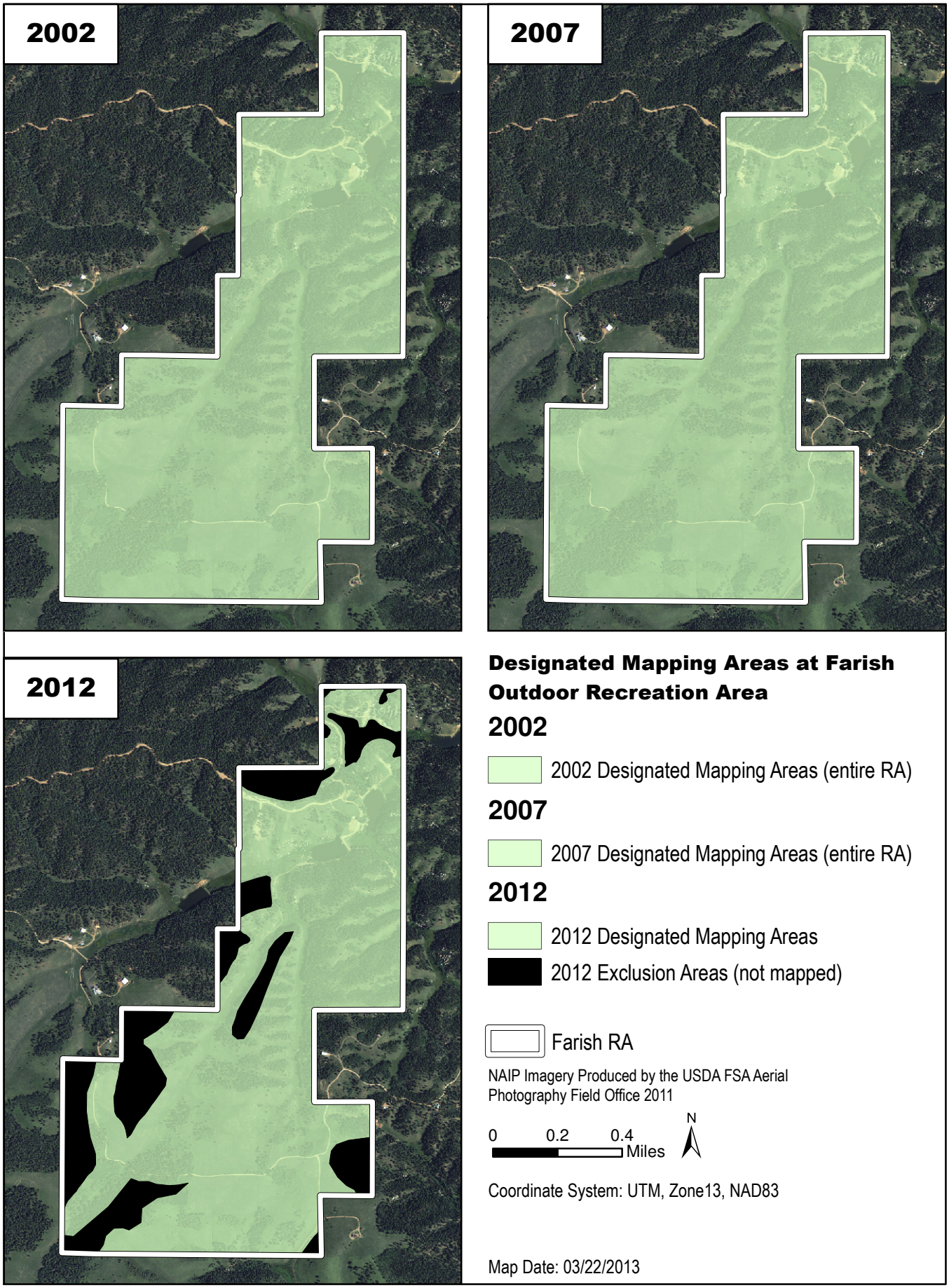
Field mapping was conducted at phenologically appropriate times in order to increase the likelihood of identifying weed infestations. The data collected in the field meet the needs of the Colorado Department of Agriculture's statewide weed mapping effort (Colorado Department of Agriculture 2013). All 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 2012 to ensure that the data collected would be comparable to those collected in 2002 and 2007. 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 and Lavender (2008). Prior to the onsite training, the field technician toured CSU greenhouses to view live specimens and reviewed recent publications on thistles and weeds in the western U.S.

All weed infestations were mapped in the field using ArcPad version 10.0.3 (ESRI 1995-2011), a portable version of GIS software that allows the user to create and edit spatial data remotely using a tablet computer. ArcPad was installed on a Trimble Yuma rugged tablet with a Windows 7 operating system and a built-in GPS receiver module. This was an improvement over the 2007 field setup, as the Yuma tablet has improved display capabilities, a rugged exterior to withstand adverse weather conditions, a stable operating system and hard drive, and a larger screen to help with navigation and data collection. The configuration of a built-in GPS receiver module prevented reoccurring loose connections that were problematic during previous weed mapping efforts. According to Trimble specifications (http://www.trimble.com/mappingGIS/yuma_rugged_tablet.aspx?dtID=technical_specs) the GPS is generally accurate to within 2-5m using SBAS (Satellite-Based Augmentation System). To ensure data accuracy during the collection process, SBAS was activated and warning systems were enabled in ArcPad to notify the user when the PDOP (Positional Dilution of Precision) exceeded 6 and the EPE (Estimated Probable Error) exceeded 8. Twenty points were averaged at each location, and 10 vertices were averaged for lines and polygons.



Map 2. 2002, 2007 and 2012 designated mapping areas at the Academy.



Map 3. 2002, 2007 and 2012 designated mapping areas at Farish Outdoor Recreation Area.

Weeds were mapped as points, lines or polygons. Linear features were mapped as lines and assigned a buffer width to estimate area. Irregularly shaped features greater than approximately 600 square meters (30m x 30m) were mapped as polygons. All other features were mapped as points and assigned a radius. Since weeds are mobile from year to year, and the GPS has inherent inaccuracies, infestations within 5 meters of each other were mapped as one feature. If previously mapped infestations were not located, they were marked as eradicated, as opposed to deleted, in order to keep track of the soil seed bank and ensure future visits to historically infested areas. Weeds tend to fluctuate based on annual weather patterns and have been found to be absent one year, only to crop up in the same location or nearby during the next growing season. All features were collected using the GPS unless otherwise noted in the attribute table. Features that were inaccessible due to natural barriers or exclosures at the Academy were digitized "heads-up" using the 2011 NAIP digital orthophoto quad for reference. Attributes were collected using customized field forms, designed to minimize user error by maximizing domain tables and field auto-population techniques. One free text field was maintained to document any observations deemed important, such as nearby significant species or difficulties incurred in a specific area (e.g., dense oak thickets affecting the ability to map features or estimate individuals). The field technician had the option to document number of individuals or density as number of individuals per square meter. If density was noted, the number of individuals was calculated in the office based on the assigned density and the size of the infestation. All of these attributes are included in the geodatabases and shapefiles accompanying this report.

Weed data were stored in a master geodatabase in ArcGIS v10 (ESRI 1999-2010). The 2011 weed map, a compilation of weeds from all CNHP mapping and monitoring projects at the Academy and Farish, was used as a starting point for the 2012 mapping effort. Each morning, weed data were exported from ArcGIS on a desktop computer to the Yuma tablet for use in ArcPad. Data were exported into an axf, a compact SQL server database format that maintains geodatabase structure within the ArcPad environment. This format facilitates the collection of advanced features such as related tables with one-to-many relationships (e.g., treatment information) and maintains the sophisticated formatting within the geodatabase. At the end of each day, the

autoreconciliation process in ArcGIS was used to seamlessly synchronize the field data into the master geodatabase. Data were copied to external hard drives each night and uploaded onto CSU servers weekly to prevent data loss. Infestations documented during the concurrent monitoring project, and those documented by USFWS personnel, were integrated into the weed map in the office post field season. For detailed instructions, refer to Appendix B.

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 one person covering 15,000 acres from June 5 through October 3, 2012. 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 topography and vegetation within those units. Each traverse then served as a random, stratified sample of each noxious weed target species. At Monument Creek, 300-acre areas were surveyed twice to capture early-flowering and late-flowering species. In addition to new infestations, over 90% of previously mapped features were revisited. Existing infestations that were not revisited were assumed to be extant. 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 precluded the intensive search of every possible location for weeds.

Aside from human limitations, weather patterns and environmental phenomena inevitably influence the results. Both 2002 and 2012 were extremely dry years, while 2007 was slightly drier than average (Figure 3). The Waldo Canyon fire also hampered weed mapping efforts during the summer of 2012. The southwest corner of the Academy burned at low intensity (Map 4) and the entire Academy was evacuated for safety reasons. Work was suspended for one week during the height of the field season, pushing more field work into late September and early October, the tail end of the growing season. Fire mitigation efforts on the west side of the Academy buried some weed infestations. It is likely that some weeds were covered in gravel and not visible to the weed mapper, but will resurface in future years.

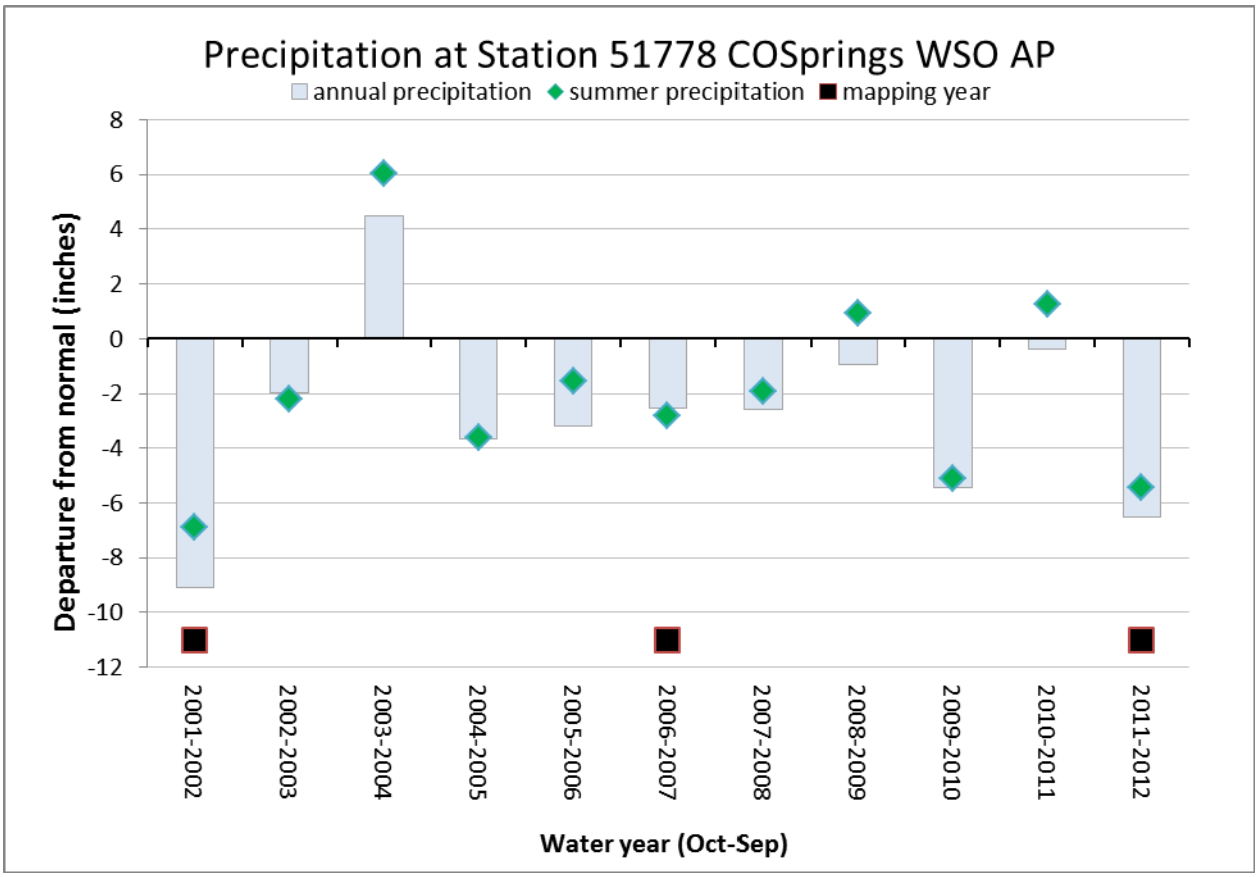
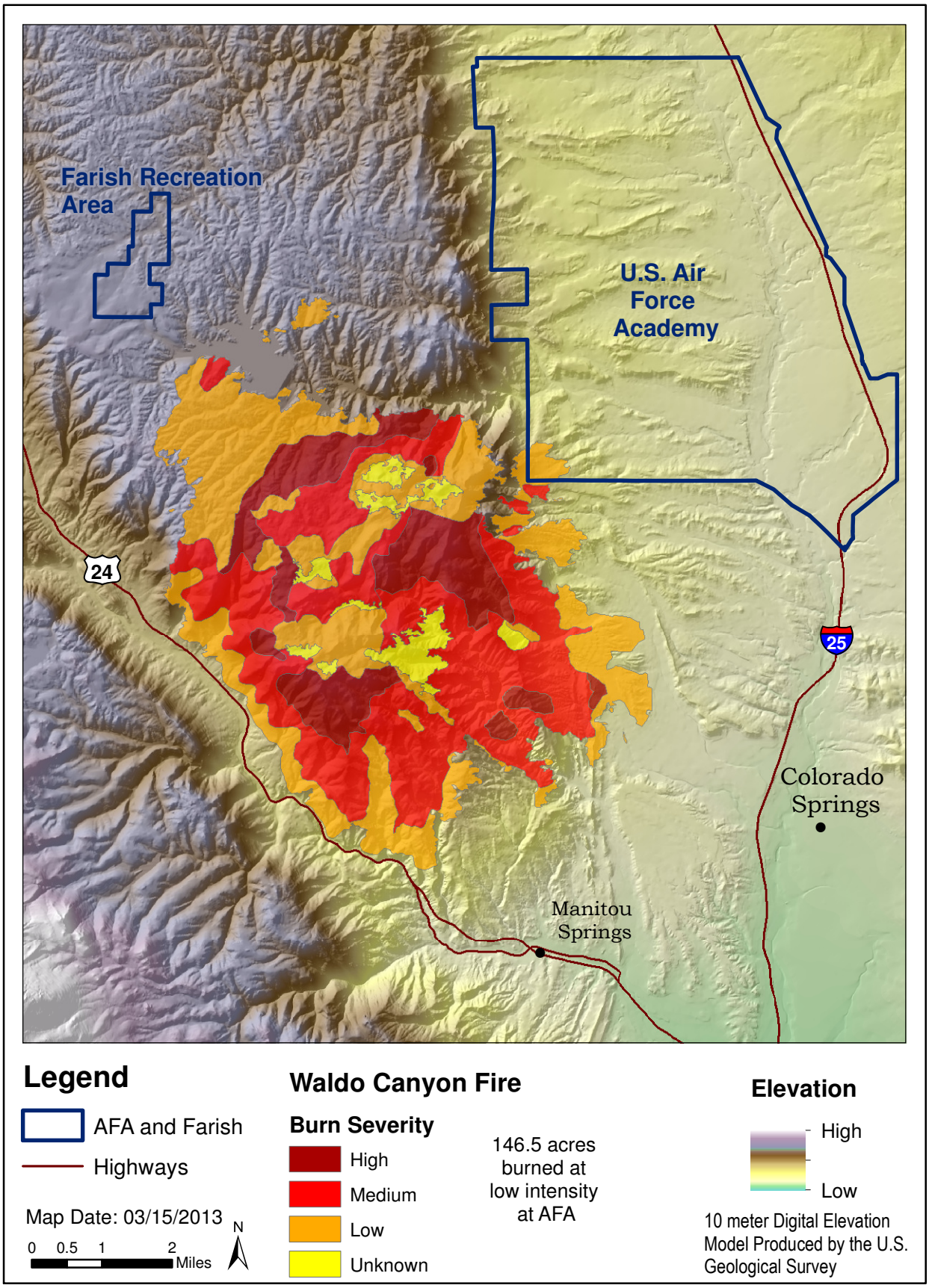


Figure 3. Summary data for monthly precipitation (in inches) at Colorado Springs, Colorado from 2002 through 2012 (Western Regional Climate Center 2013).



Map 4. Extent of the 2012 Waldo Canyon fire.

Analysis: In order to detect changes and trends for the three measures (occupied acres, number of shoots, and extant mapped features) we calculated percent change between 2002-2007, 2007-2012, and 2002-2012. For each measure we developed four categories: decrease, stable, moderate increase, high increase and color coded these from green, yellow, orange, red, respectively. The measures for all three sample years (9) were rolled up into an overall 2002-2012 trend by taking the most dominant category out of the 9 measures, (e.g., whitetop had 6 out of 9 measures that decreased and thus the overall trend was a decrease). One exception to this method occurred when occupied acres and number of shoots decreased yet the plant spread to new areas (e.g., bull thistle). Our reasoning behind this was that the spread into new areas provides a much higher probability that this species will be able to expand quickly if conditions for recruitment occur, plus it is much harder to control numerous sites.

For yellow toadflax we conducted a Fischer's Exact test on presence/absence between 2002-2007, 2007-2012, and 2002-2012.

Yellow toadflax power analysis

Yellow toadflax (*Linaria vulgaris*) is widespread at the Academy, making comprehensive mapping cost prohibitive. Due to financial limitations, and the fact that this species is not a management target, yellow toadflax was sampled throughout the Academy and Farish within 20m x 20m grids to document presence/absence. Random grids, or sample sites, were generated as a fishnet, covering the entire Academy and Farish. Then, only those grids overlapping any weed species from the 2002 survey within Potential Conservation Areas (PCAs) were selected. This focused our efforts on the most biologically important areas and guaranteed that the 2002 weed mapper had surveyed the sample site, thus allowing us to run comparisons between years. A power analysis was used to identify an appropriate sampling size. To detect a 10% change, the analysis resulted in 200 sample sites at the Academy and 20 sample sites at Farish (adjusted from the Academy's sample size based on area). Sample sites at the Academy were then stratified to ensure all biologically significant PCAs were sampled proportionally (Table 4). The size of each PCA was used to determine the number of sample sites needed within each area. Since Monument Creek is a large PCA, it was

subdivided into four units. Once the above criteria were met, the final set of sample sites was randomly selected in GIS using a minimum separation distance of 20m to prevent adjacent grids from being selected (Map 5).

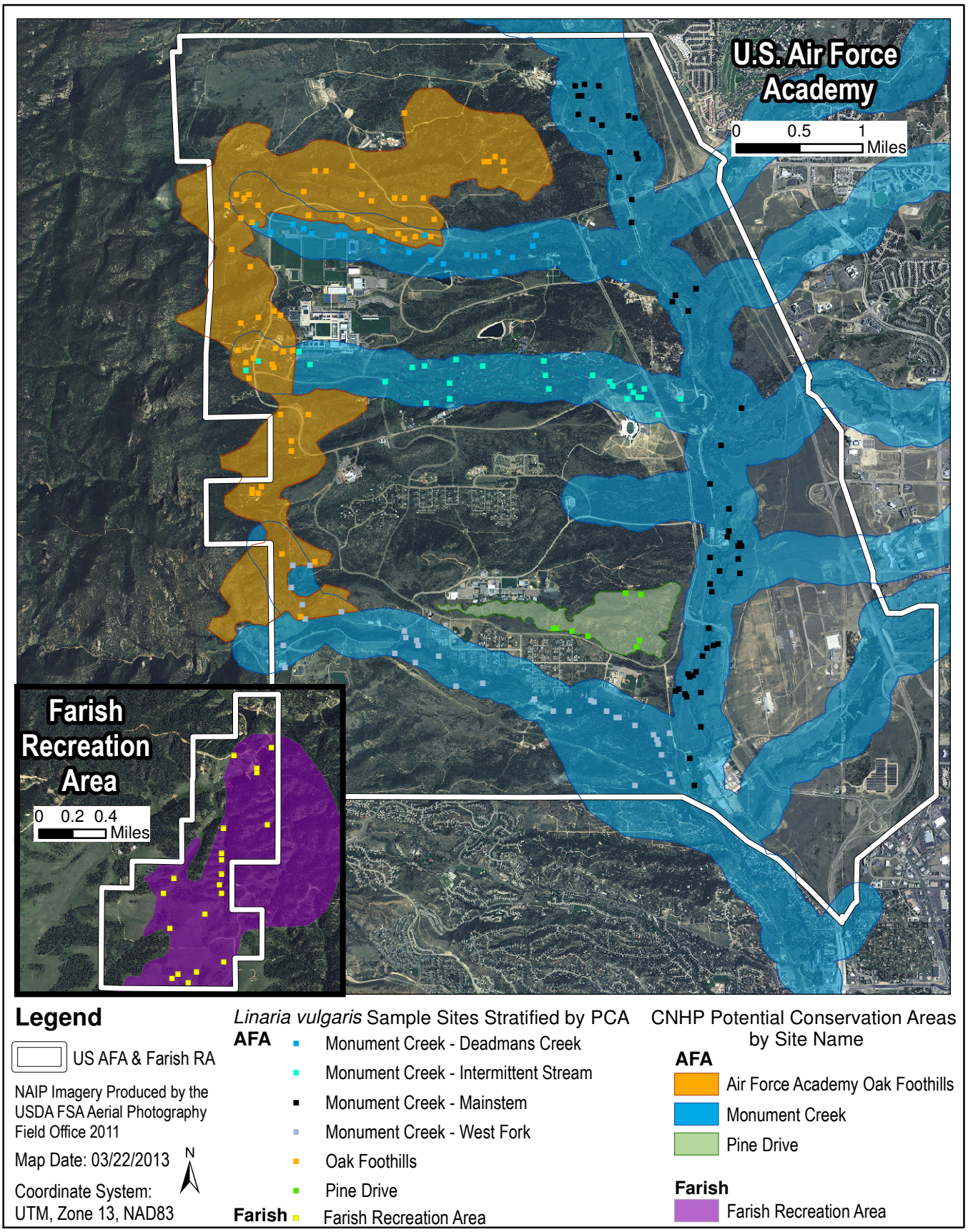
Table 4. Number of yellow toadflax sample sites within each CNHP Potential Conservation Area.

Targeted PCA	Number of Sample Sites
Monument Creek – Deadmans Creek	22
Monument Creek – Intermittent Stream	26
Monument Creek - Mainstem	52
Monument Creek - West Fork	34
Oak Foothills	58
Pine Drive	8
Farish Recreation Area	20

In order to identify an appropriate sample size, we used the free software program G*Power, Version 3.1.4 (Erdfelder et al. 1996, http://www.psycho.uni-duesseldorf.de/aap/projects/gpower/) to conduct a power analysis using data from 2002 and 2007. The difference between 2002 and 2007 was 7.3%, with 1,820 samples. A goodness-of-fit test contingency table (X^2) was input to G*Power with the following data:

	2002	2007	change
present	0.238	0.311	0.073
absent	0.762	0.689	

The calculated effect size "w" was 0.1714182 for the actual data. At an alpha of 0.05 and 90% power, 358 samples would be required to detect the same change in the future. Because this was still thought to be too many samples for the allotted field time, we conducted a sensitivity analysis for sample sizes of 100, 125, 150, and 200, holding alpha at 0.05 and calculating the effect size that would be detected under power levels from 0.40 to 0.99. Effect sizes (w) were graphed against power and change levels of 7.3, 10,



Map 5. All yellow toadflax sample sites at the Academy and Farish Outdoor Recreation Area stratified by CNHP Potential Conservation Areas.

15, and 20% as indicated on the graph. A sample size of 200 crosses the 10% change line at a power level of about 0.915 (Figure 4), while a sample size of 100 has a power of about 0.40 to detect the same size effect. The sample level of 200 was the only one capable of detecting a target change of 10% with a power of 90% or greater, and was selected as the field sample level for the Academy.

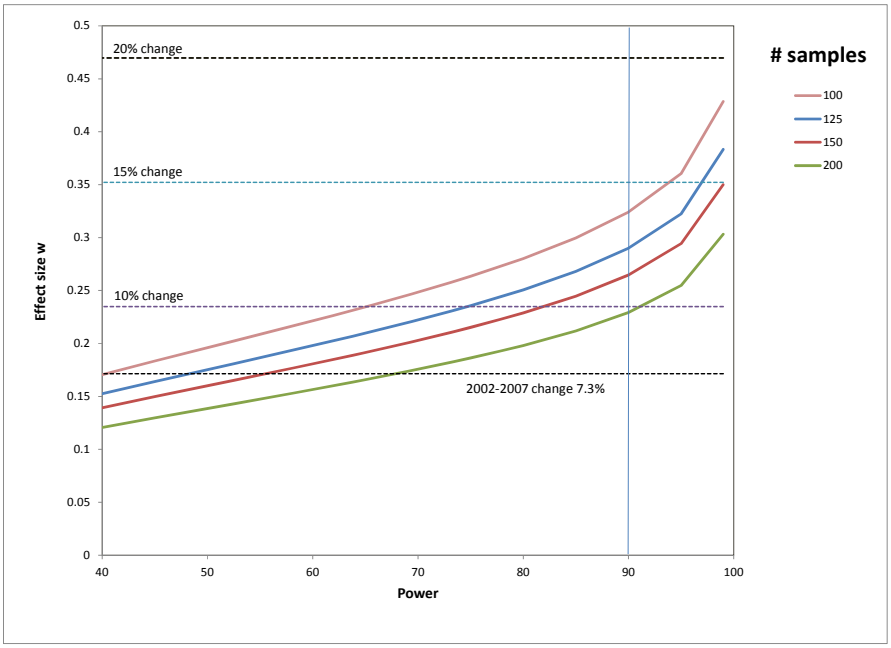


Figure 4. Sensitivity analysis for different sample sizes

RESULTS

AFA

The number of mapped species increased with each sample year; 14, 17, and 22, respectively, indicating that AFA is vulnerable to new invasions (Table 5). The species mapped in 2012 but not in the previous sample years were: Siberian peashrub (present in previous years but not mapped), houndstongue, yellow spring bedstraw, dames rocket, Dalmatian toadflax, and Tatarian honeysuckle. All but the Siberian peashrub occupy less than an acre (Table 5).

Occupied acres: The knapweed complex (diffuse, spotted, and hybrid) occupied 160 acres, over 50% of the weed acres in 2012 (Table 5). Canada thistle was the second

most numerous weed at 90 acres (29% of all weed acres), followed by musk thistle at 15 acres (5% of all weed acres) (Table 5). The largest change between 2007 and 2012 was with the diffuse/spotted knapweed hybrid, a 239% increase in occupied acres; Scotch thistle decreased the most with a 77% decrease.

Estimated number of shoots: Each sampling year saw an increase in number of shoots. There were approximately 4.5 million shoots in 2012, versus 2.4 million in 2007, an overall increase of 87%. The increase between 2002-2007 was just 8%. The diffuse-spotted-hybrid complex increased the most between 2007 and 2012 with a 6.5 fold increase, while myrtle spurge decreased the most (89% decrease).

Mapped extant features: Each sampling year saw an increase in number of mapped features (Figure 5). In 2012 there were 5,184 extant mapped features (Map 6), a 38% increase over 2007. The increase from 2002 to 2007 was even greater at 169%. Russian knapweed had the largest change from 2 to 10 mapped features (a 400% increase), while whitetop decreased the most (16% decrease; 241 to 203).

The mapping exercise discovered new locations of species that we believed to be extirpated (Russian knapweed and yellow spring bedstraw) as well as new locations for species that we use mapping as a monitoring tool: houndstongue, myrtle spurge, and Scotch thistle.

Priority species for future management: The following species occupied less than 1.25 acres/species and all have the potential to be contained, suppressed, or eradicated (in order of least to most acres): Dalmatian toadflax, tamarisk, yellow spring bedstraw, houndstongue, Russian knapweed, Tatarian honeysuckle, myrtle spurge, Scotch thistle, dames rocket, common St. Johnswort, and bull thistle. Most of these species have been targeted by the AFA Natural Resource managers and their efforts have managed to control these weeds. Nonetheless, only Dalmatian toadflax is considered eradicated at this point.

All of the other species (knapweed complex, Fuller's teasel, Siberian peashrub, leafy spurge, Russian olive, whitetop, musk thistle, Canada thistle, and yellow toadflax) occupy too many acres to be controlled base wide. We recommend that all of these species be controlled within Potential Conservation Areas, especially around rare species

and community occurrences (Siemers et al. 2012). The knapweed complex appears to be spreading faster than any other weed and will take heroic efforts to control.

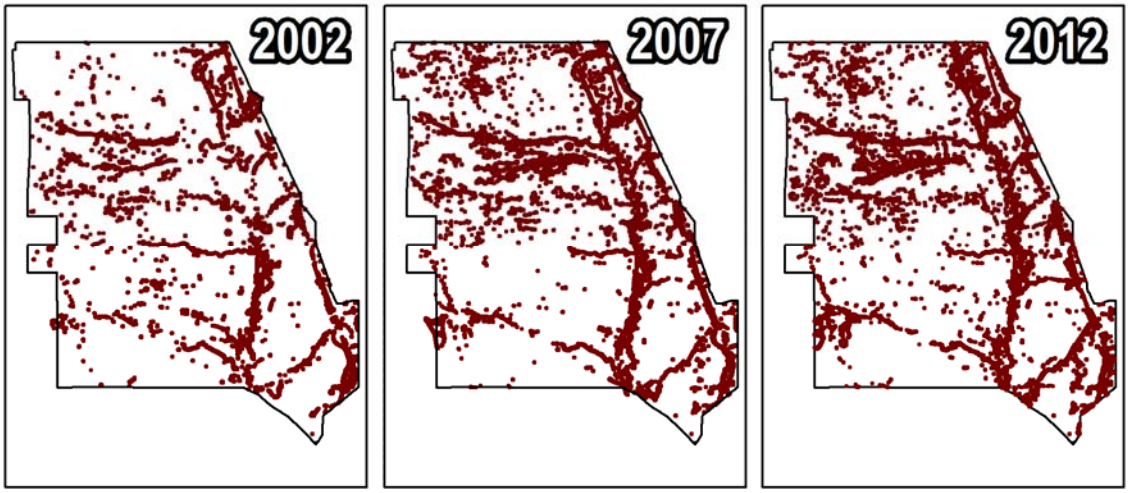


Figure 5. Distribution of known infestations at the U.S. Air Force Academy.

Farish

The number of mapped species increased from three to four between 2007 and 2012, with the addition of yellow spring bedstraw.

Occupied acres: In 2012 there were 2.4 occupied acres, primarily split evenly between musk and Canada thistle (Table 6). This was a 41% decrease over 2007 but a 129% increase from 2002 (Table 8). Leafy spurge had one occurrence just outside the boundary and yellow spring bedstraw was located at one small site.

Estimated number of shoots: Each sampling year saw an increase in estimated number of shoots. Over 27,000 shoots were estimated for all weeds in 2012, a 74% increase from 2007, which was a 337% increase over 2002. Canada thistle had the highest number, followed by musk thistle (Table 6). Musk thistle had the largest change between 2007 and 2012 (over a 10-fold increase, Table 8).

Mapped extant features: Each sampling year saw an increase in number of mapped features (Figure 6). There were 121 mapped features in 2012 (Map 7), an 83% increase over 2007, which had a 214% increase over 2002 (Table 8). Musk thistle had the largest increase (100%).

Priority species for management: Although there was a moderate increase for musk thistle, Canada thistle, and yellow toadflax between 2007-2012, the total number of

acres is still manageable and control measures for all species should be applied each year. Toadflax is much more widespread than any of the other species and may not be controllable.

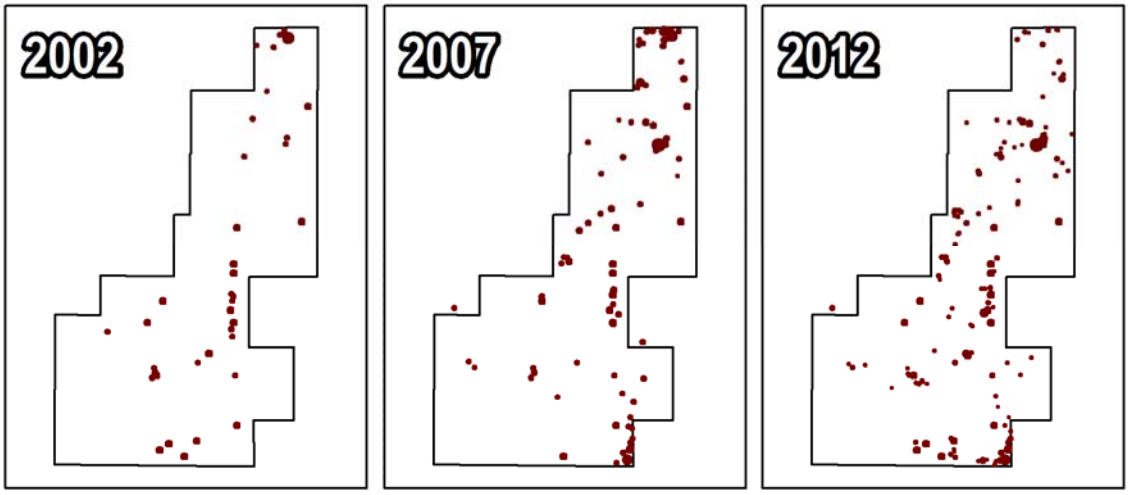
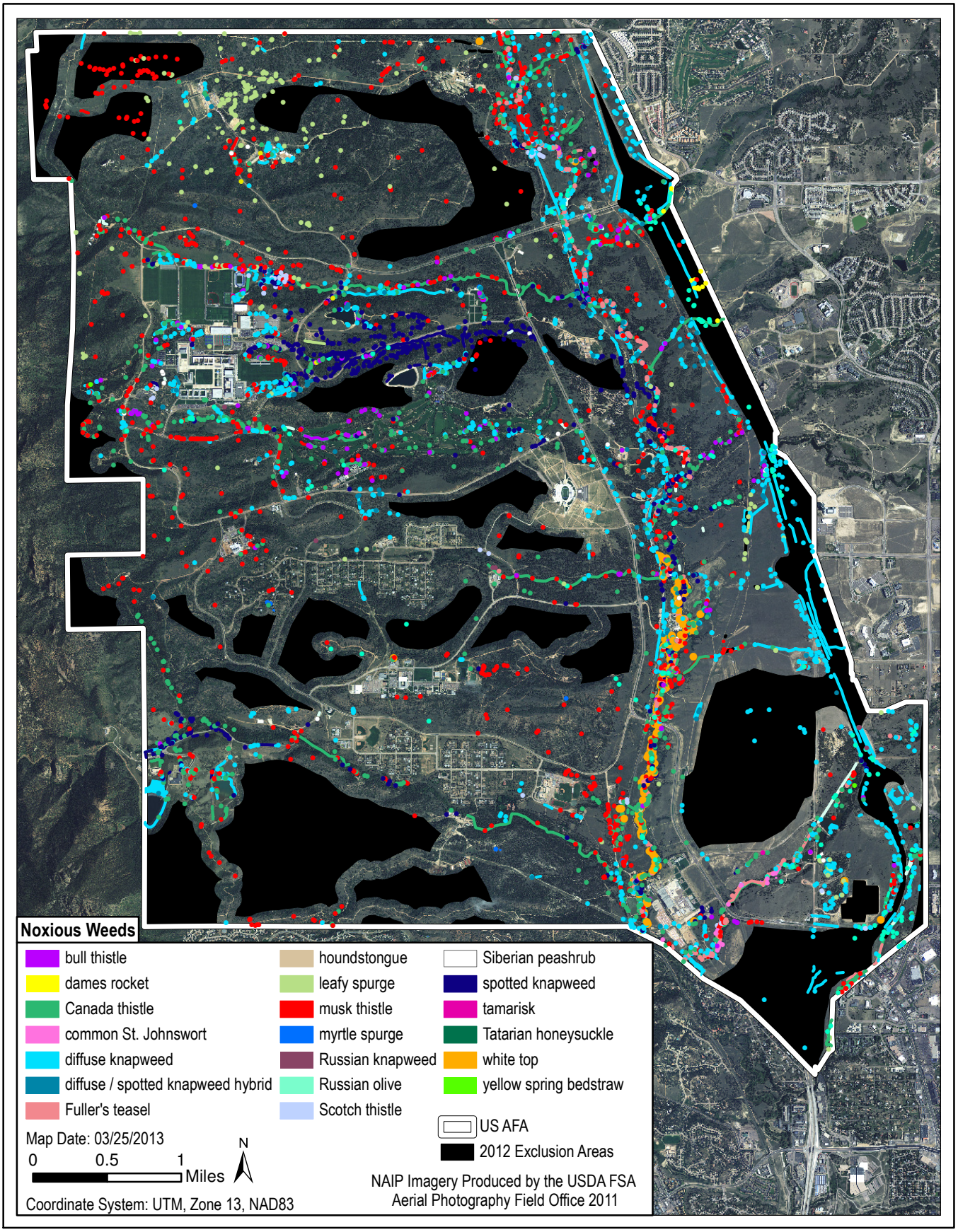
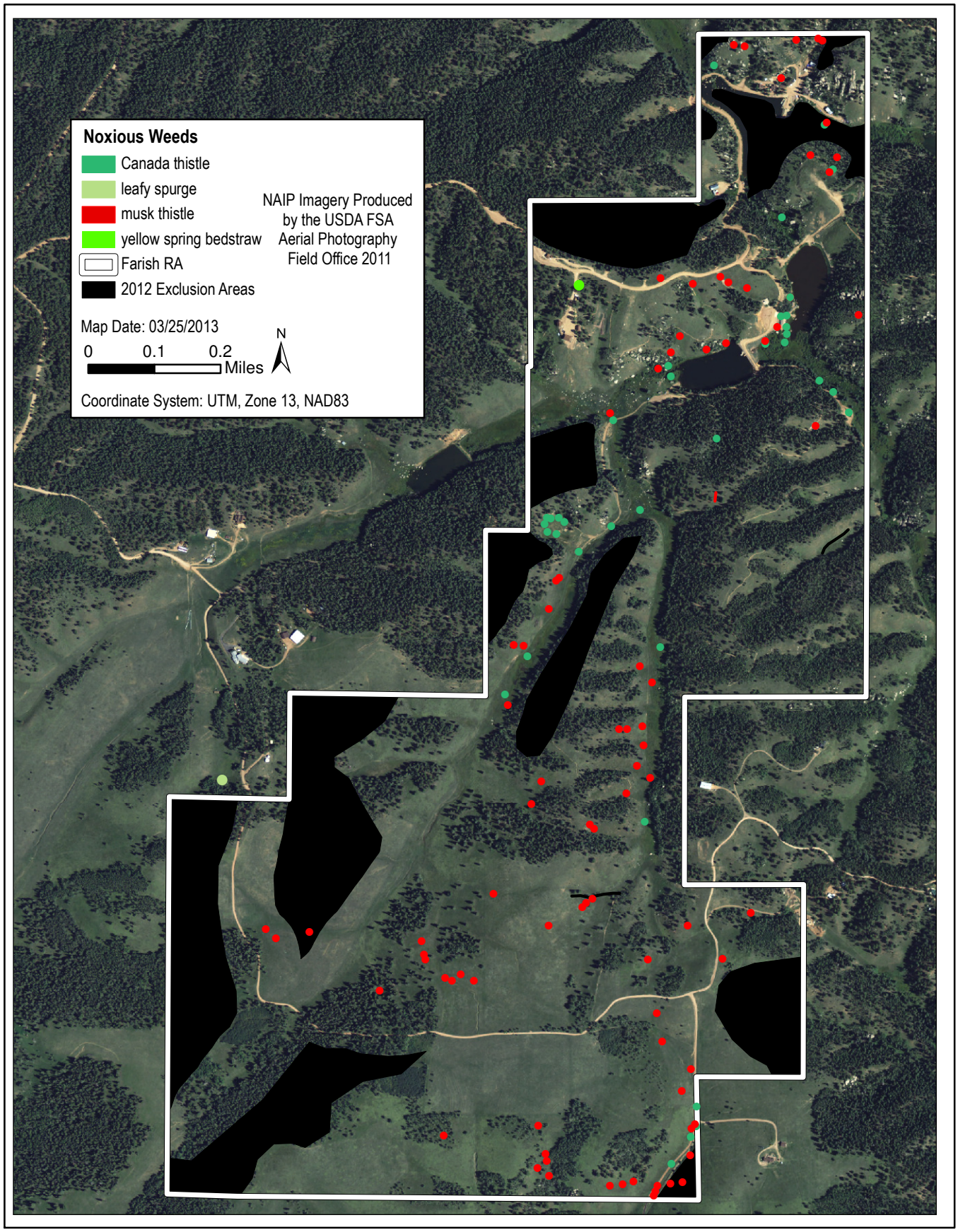


Figure 6. Distribution of known infestations at Farish Outdoor Recreation Area.



Map 6. Distribution of targeted noxious weed species at the Academy in 2012.



Map 7. Distribution of targeted noxious weed species at Farish Outdoor Recreation Area in 2012.

Table 5. Summary data for all mapped weed infestations at the U.S. Air Force Academy. Values for species in bold are all known infestations. Values for non-bold species are from comparable designated mapping areas only.

Species		2002				2007				2012			
Scientific Name	**Common Name**	**Occupied Acres**	**Estimated # of Shoots**	**# of Extant Features**	**# of Eradicated Features**	**Occupied Acres**	**Estimated # of Shoots**	**# of Extant Features**	**# of Eradicated Features**	**Occupied Acres**	**Estimated # of Shoots**	**# of Extant Features**	**# of Eradicated Features**
Acroptilon repens	**Russian knapweed**	**NA**	**NA**	**NA**	NA	**0.03**	**200**	**2**	2	**0.05**	**543**	**10**	4
Caragana arborescens	**Siberian peashrub**	**NA**	**NA**	**NA**	NA	**NA**	**NA**	**NA**	NA	**9.71**	**89,270**	**43**	NA
Cardaria draba†	**Whitetop**	**20.47**	**1,671,728**	**164**	NA	**12.76**	**1,035,489**	**241**	0	**13.08**	**828,036**	**203**	77
Carduus nutans	Musk thistle	**15.91**	**2,207**	**272**	NA	**27.03**	**49,588**	**1,020**	4	**15.20**	**125,297**	**1,082**	639
Centaurea diffusa	Diffuse knapweed	**45.42**	**130,589**	**251**	NA	**119.86**	**394,197**	**913**	0	**100.58**	**1,334,253**	**1,255**	406
Centaurea maculosa	Spotted knapweed	**4.67**	**3,485**	**54**	NA	**57.52**	**127,627**	**319**	16	**53.02**	**543,144**	**565**	156
Centaurea diffusa x *maculosa*	Diffuse / spotted knapweed hybrid	**NA**	**NA**	**NA**	NA	**1.75**	**2,810**	**118**	NA	**5.93**	**42,991**	**240**	54
Cirsium arvense	Canada thistle	***79.27**	***408,121**	***358**	NA	***90.68**	***379,992**	***543**	0	***90.17**	***1,079,070**	***776**	221
Cirsium vulgare	Bull thistle	****5.54**	****596**	****73**	NA	**6.42**	**4,347**	**128**	0	**1.19**	**4,089**	**207**	79
Cynoglossum officinale	**Houndstongue**	**NA**	**NA**	**NA**	NA	**NA**	**NA**	**NA**	NA	**0.01**	**70**	**3**	9

Species		2002				2007				2012			
Scientific Name	**Common Name**	**Occupied Acres**	**Estimated # of Shoots**	**# of Extant Features**	**# of Eradicated Features**	**Occupied Acres**	**Estimated # of Shoots**	**# of Extant Features**	**# of Eradicated Features**	**Occupied Acres**	**Estimated # of Shoots**	**# of Extant Features**	**# of Eradicated Features**
Dipsacus fullonum	**Fuller's teasel**	**18.33**	**1,693**	**35**	NA	**10.51**	**53,454**	**181**	0	**9.26**	**116,595**	**319**	65
Elaeagnus angustifolia†	Russian olive	**38.70**	**1,079**	**216**	NA	**13.30**	**531**	**89**	129	**10.80**	**557**	**154**	173
Euphorbia esula	Leafy spurge	**0.91**	**28,338**	**32**	NA	**7.58**	**336,337**	**152**	2	**10.64**	**275,713**	**204**	30
Euphorbia myrsinites	**Myrtle spurge**	**NA**	**NA**	**NA**	NA	**0.18**	**1,021**	**7**	0	**0.23**	**113**	**10**	25
Galium verum	**Yellow spring bedstraw**	**NA**	**NA**	**NA**	NA	**NA**	**NA**	**NA**	NA	**0.01**	**566**	**2**	1
Hesperis matronalis	**Dames rocket**	**NA**	**NA**	**NA**	NA	**NA**	**NA**	**NA**	NA	**0.83**	**16,871**	**14**	NA
Hypericum perforatum	**Common St. Johnswort**	****<0.10**	****363**	****5**	NA	**0.86**	**44,745**	**10**	0	**1.16**	**83,115**	**29**	10
Linaria genistifolia* spp. *dalmatica	**Dalmatian toadflax**	**NA**	**NA**	**NA**	NA	**NA**	**NA**	**NA**	NA	**0.00**	**0**	**0**	3
Lonicera tatarica	**Tatarian honeysuckle**	**NA**	**NA**	**NA**	NA	**NA**	**NA**	**NA**	NA	**0.15**	**30**	**1**	0
Onopordum acanthium	**Scotch thistle**	****0.17**	****52**	****7**	NA	**1.31**	**1,307**	**36**	0	**0.30**	**889**	**66**	73
Saponaria officinalis	**Bouncingbet**	**0.19**	**Unknown**	**1**	NA	**NA**	**NA**	**NA**	NA	**NA**	**NA**	**NA**	NA

Species		2002				2007				2012			
Scientific Name	Common Name	Occupied Acres	Estimated # of Shoots	# of Extant Features	# of Eradicated Features	Occupied Acres	Estimated # of Shoots	# of Extant Features	# of Eradicated Features	Occupied Acres	Estimated # of Shoots	# of Extant Features	# of Eradicated Features
Tamarix ramosissima	Tamarisk	<0.01	1	1	NA	<0.01	1	1	1	<0.01	1	1	4
TOTALS		**226.48**	**2,248,252**	**1,396**		**331.57**	**2,431,646**	**3,760**	**154**	**309.53**	**4,541,213**	**5,184**	**2,029**

†2002 values are sums of 2002 and 2003 mapping; * Canada thistle numbers derived from 2007 designated mapping areas, **values from field notes; not mapped in GIS

Table 6. Summary data for all mapped weed infestations at the Farish Outdoor Recreation Area. Values for species in bold are all known infestations. Values for non-bold species are from comparable designated mapping areas only.

Species		2002				2007				2012			
Scientific Name	**Common Name**	**Occupied Acres**	**Estimated # of Shoots**	**# of Extant Features**	**# of Eradicated Features**	**Occupied Acres**	**Estimated # of Shoots**	**# of Extant Features**	**# of Eradicated Features**	**Occupied Acres**	**Estimated # of Shoots**	**# of Extant Features**	**# of Eradicated Features**
Carduus nutans	Musk thistle	**0.82**	**56**	**13**	NA	**2.46**	**643**	**42**	0	**1.12**	**2,829**	**84**	20
Cirsium arvense	Canada thistle	**0.23**	**3,488**	**8**	NA	**1.55**	**14,734**	**23**	1	**1.27**	**24,082**	**35**	8
Euphorbia esula	Leafy spurge	**NA**	**NA**	**NA**	NA	**0.03**	**113**	**1**	0	**0.03**	**113**	**1**	0
Galium verum	**Yellow spring bedstraw**	**NA**	**NA**	**NA**	NA	**NA**	**NA**	**NA**	NA	**<0.01**	**3**	**1**	0
TOTALS		**1.05**	**3,544**	**21**		**4.03**	**15,490**	**66**	**1**	**2.41**	**27,027**	**121**	**28**

Table 7. Changes in weed distribution and abundance at the U.S. Air Force Academy 2002 to 2012. Positive numbers indicate an increase and negative numbers indicate a decrease. Color codes are defined as: green, < -5%; yellow, -5% to 10%; orange, 10% to 100%; red, >100%.

Scientific Name	Common Name	Occupied Acres in 2012	% change 2002 - 2007	% change 2007 - 2012	% change 2002 - 2012	Estimated # of Shoots in 2012	% change 2002 - 2007	% change 2007 - 2012	% change 2002 - 2012	# of Extant Features in 2012	% change 2002 - 2007	% change 2007 - 2012	% change 2002 - 2012	2002-2012 Trend
Acroptilon repens	Russian knapweed	0.05	NA	69%	69%	543	NA	172%	172%	10	NA	400%	400%	Increase
Caragana arborescens	Siberian peashrub	9.71	NA	NA	NA	89,270	NA	NA	NA	43	NA	NA	NA	?
Cardaria draba	Whitetop	13.08	-38%	3%	-36%	828,036	-38%	-20%	-50%	203	47%	-16%	24%	Decrease
Carduus nutans	Musk thistle	15.20	70%	-44%	-4%	125,297	2147%	153%	5577%	1,082	275%	6%	298%	Increase
Centaurea diffusa	Diffuse knapweed	100.58	164%	-16%	121%	1,334,253	202%	238%	922%	1,255	264%	37%	400%	Increase
Centaurea diffusa x *maculosa*	Diffuse/spotted knapweed hybrid	5.93	NA	239%	239%	42,991	NA	1430%	1430%	240	NA	103%	103%	Increase
Centaurea maculosa	Spotted knapweed	53.02	1131%	-8%	1034%	543,144	3562%	326%	15485%	565	491%	77%	946%	Increase
Cirsium arvense	Canada thistle	90.17	14%	-1%	14%	1,079,070	-7%	184%	164%	776	52%	43%	117%	Increase
Cirsium vulgare	Bull thistle	1.19	NA	-82%	-82%	4,089	NA	-6%	-6%	207	NA	62%	62%	Moderate Increase

Scientific Name	Common Name	Occupied Acres in 2012	% change 2002 - 2007	% change 2007 - 2012	% change 2002 - 2012	Estimated # of Shoots in 2012	% change 2002 - 2007	% change 2007 - 2012	% change 2002 - 2012	# of Extant Features in 2012	% change 2002 - 2007	% change 2007 - 2012	% change 2002 - 2012	2002-2012 Trend
Cynoglossum officinale	Houndstongue	0.01	NA	NA	NA	70	NA	NA	NA	3	NA	NA	NA	Increase (New Species)
Dipsacus fullonum	Fuller's teasel	9.26	-43%	-12%	-49%	116,595	3057%	118%	6787%	319	417%	76%	811%	Increase
Elaeagnus angustifolia	Russian olive	10.80	-66%	-19%	-72%	557	-51%	5%	-48%	154	-127%	75%	-29%	Decrease
Euphorbia esula	Leafy spurge	10.64	737%	40%	1075%	275,713	1087%	-18%	873%	204	375%	34%	538%	Increase
Euphorbia myrsinites	Myrtle spurge	0.23	NA	30%	30%	113	NA	-89%	-89%	10	NA	43%	43%	Moderate Increase
Galium verum	Yellow spring bedstraw	0.01	NA	NA	NA	566	NA	NA	NA	2	NA	NA	NA	Increase (New Species)
Hesperis matronalis	Dames rocket	0.83	NA	NA	NA	16,871	NA	NA	NA	14	NA	NA	NA	Increase (New Species)
Hypericum perforatum	Common St. Johnswort	1.16	763%	34%	1060%	83,115	12226%	86%	22797%	29	100%	190%	480%	Increase
Linaria genistifolia spp. *dalmatica*	Dalmatian toadflax	0.00	NA	NA	NA	0	NA	NA	NA	0	NA	NA	NA	Decrease

Scientific Name	Common Name	Occupied Acres in 2012	% change 2002 - 2007	% change 2007 - 2012	% change 2002 - 2012	Estimated # of Shoots in 2012	% change 2002 - 2007	% change 2007 - 2012	% change 2002 - 2012	# of Extant Features in 2012	% change 2002 - 2007	% change 2007 - 2012	% change 2002 - 2012	2002-2012 Trend
Lonicera tatarica	Tatarian honeysuckle	0.15	NA	NA	NA	30	NA	NA	NA	1	NA	NA	NA	Increase (New Species)
Onopordum acanthium	Scotch thistle	0.30	672%	-77%	77%	889	2414%	-32%	1610%	66	414%	83%	843%	Increase
Tamarix ramosissima	Tamarisk	<0.01	0	0%	0%	1	0	0%	0%	1	0	0%	0%	Stable

Table 8. Changes in weed distribution and abundance at Farish Outdoor Recreation Area 2002 to 2012. Positive numbers indicate an increase and negative numbers indicate a decrease. Color codes are defined as: green, < -5%; yellow, -5% to 10%; orange, 10% to 100%; red, >100%.

Scientific Name	Common Name	Occupied Acres in 2012	% change 2002 - 2007	% change 2007 - 2012	% change 2002 - 2012	Estimated # of Shoots in 2012	% change 2002 - 2007	% change 2007 - 2012	% change 2002 - 2012	# of Extant Features in 2012	% change 2002 - 2007	% change 2007 - 2012	% change 2002 - 2012	2002-2012 Trend
Carduus nutans	Musk thistle	1.12	199%	-54%	112%	2,829	1048%	340%	4952%	84	223%	100%	546%	Increase
Cirsium arvense	Canada thistle	1.27	577%	-18%	127%	24,082	322%	63%	590%	35	188%	52%	338%	Increase
Euphorbia esula	Leafy spurge	0.03	NA	0.00	0.00	113	NA	0.00	0.00	1	NA	0.00	0.00	Stable
Galium verum	Yellow spring bedstraw	<0.01	NA	NA	NA	3	NA	NA	NA	1	NA	NA	NA	?

Summaries by Species

Russian Knapweed (*Acroptilon repens*)

Increased in numbers and distribution but still has low enough cover to control.

Photo by David Anderson

Russian knapweed occupied 0.05 acres in 2012, a 69% increase over 2007. In 2012, 10 new locations were mapped (Map 8), totaling 543 shoots (Table 9 and Figure 7). This represents a 172% increase in number of shoots and a 400% increase in number of extant mapped features since 2007 (Table 7).

The first appearance of Russian knapweed was in 2004 and by 2007 there were two extant occurrences and 2 eradicated occurrences, all near Douglass Way (Map 8). By 2009, all of these occurrences were eradicated (Rondeau and Lavender 2012). In 2005, herbicide treatment was applied to part of the Skills Development Center and Douglass Way occurrences. The Skills Development Center was treated again in 2009. Specific details about the first two locations can be found in Anderson and Lavender (2008).

The 2012 weed mapping project was critical to finding new locations of Russian knapweed since an early response will probably control this weed. Roots from a recently established plant expand rapidly and may cover up to 12 square yards in two growing seasons and stands may survive 75 years or longer (Beck 2008). This species has the ability to greatly expand at the Academy, especially around disturbed areas; therefore, we place a high priority on controlling this species.

Table 9. All infestations of Russian knapweed at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**NA**	**0.03**	**0.05**
Estimated Number of Shoots	**NA**	**200**	**543**
Number of Extant Features	**NA**	**2**	**10**
Number of Eradicated Features	NA	2	4

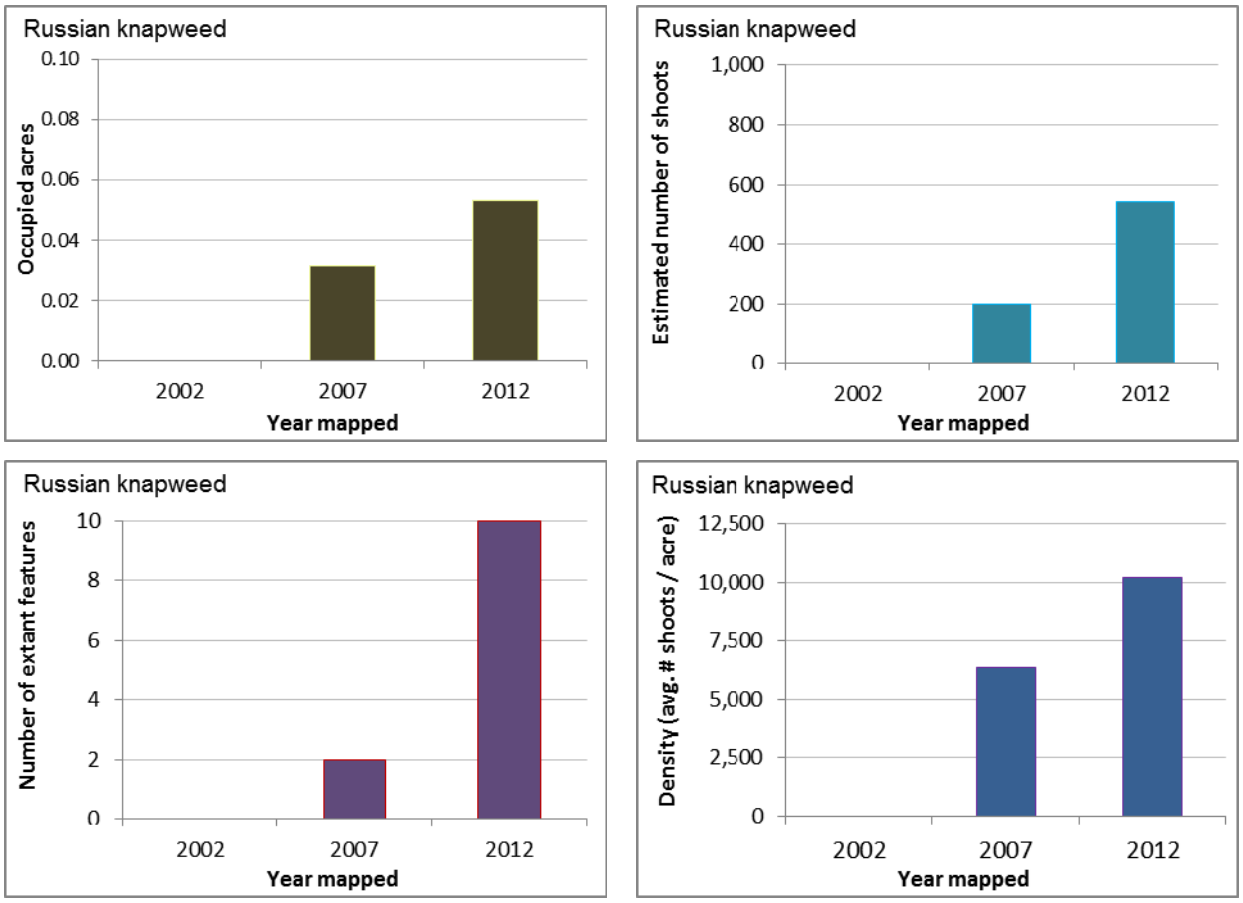
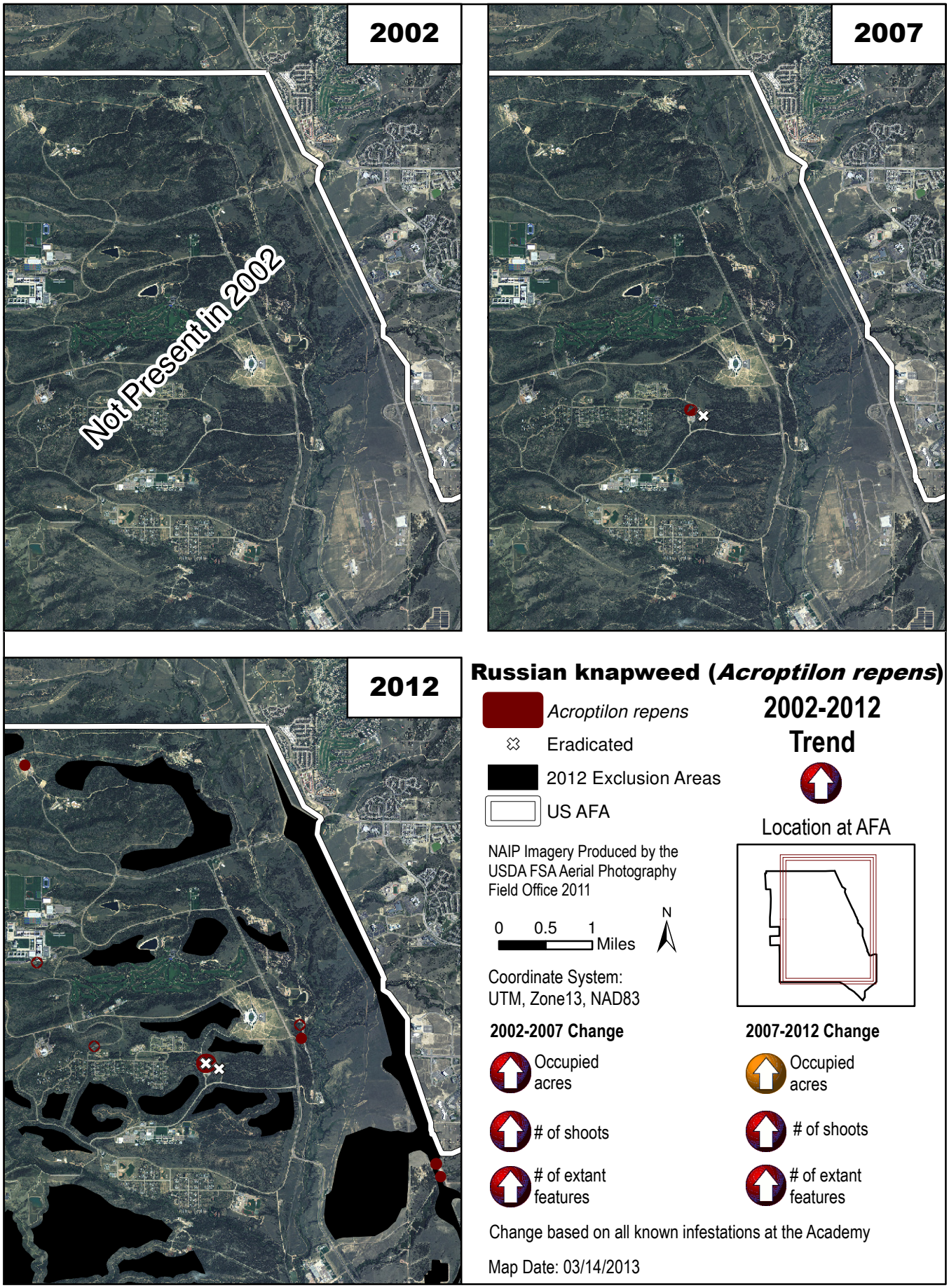


Figure 7. Russian knapweed trend, 2002-2012.



Map 8. Distribution of Russian knapweed at the Academy in 2002, 2007, and 2012.

Siberian Peashrub (*Caragana arborescens*)

?

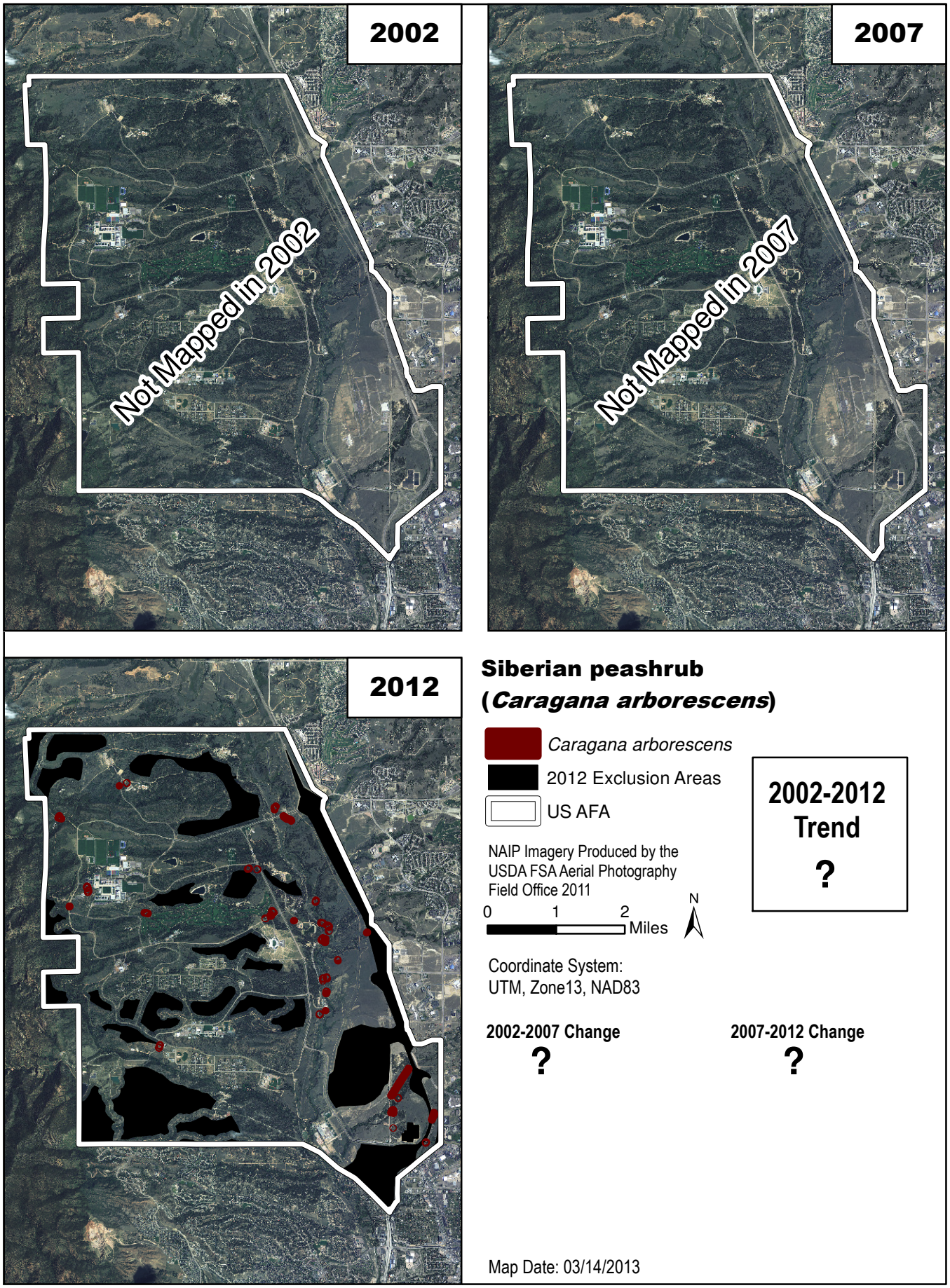
Potential expansion and possible threat to sensitive riparian areas.

Photo by Brian Mihlbachler

Siberian peashrub, an upright, deciduous shrub, was probably planted as a windbreak or for wildlife habitat. Although it was present in all the previous mapping years, 2012 was the first year that we mapped it. Nearly 10 acres were mapped with nearly 90,000 shoots counted (Table 10) at a total of 43 sites ranging from Monument Creek to roadsides (Map 9).

Table 10. All infestations of Siberian peashrub at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**NA**	**NA**	**9.71**
Estimated Number of Shoots	**NA**	**NA**	**89,270**
Number of Extant Features	**NA**	**NA**	**43**
Number of Eradicated Features	NA	NA	NA



Map 9. Distribution of Siberian peashrub at the Academy in 2002, 2007, and 2012.

Whitetop (*Cardaria draba*)

Decreasing but outliers are a concern as they have the potential to greatly expand the distribution of this weed.

Photo by Michelle Washebek

Whitetop occupied 13 acres in 2012, more or less unchanged from 2007 (Table 11). The number of extant mapped features and number of shoots decreased (16% and 20% respectively) in the same time period (Figure 8 and Table 7).

Whitetop appears to be fairly well contained along the southern portion of Monument Creek at the Air Force Academy and may also be fairly stable. 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. All of the 2007 outliers were eradicated, except possibly the northernmost infestation; however, additional outliers were located in 2012 (Map 10). Several outliers still exist on northern Monument Creek and new outliers have cropped up near the solar energy farm and the community center. All outlier infestations are a high priority for eradication efforts, with the northern ones as the highest 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 11. All infestations of whitetop at the U.S. Air Force Academy.

	2002†	2007	2012
Occupied Acres	20.47	12.76	13.08
Estimated Number of Shoots	1,671,728	1,035,489	828,036
Number of Extant Features	164	241	203
Number of Eradicated Features	NA	0	77

†2002 values are sums of 2002 and 2003 mapping

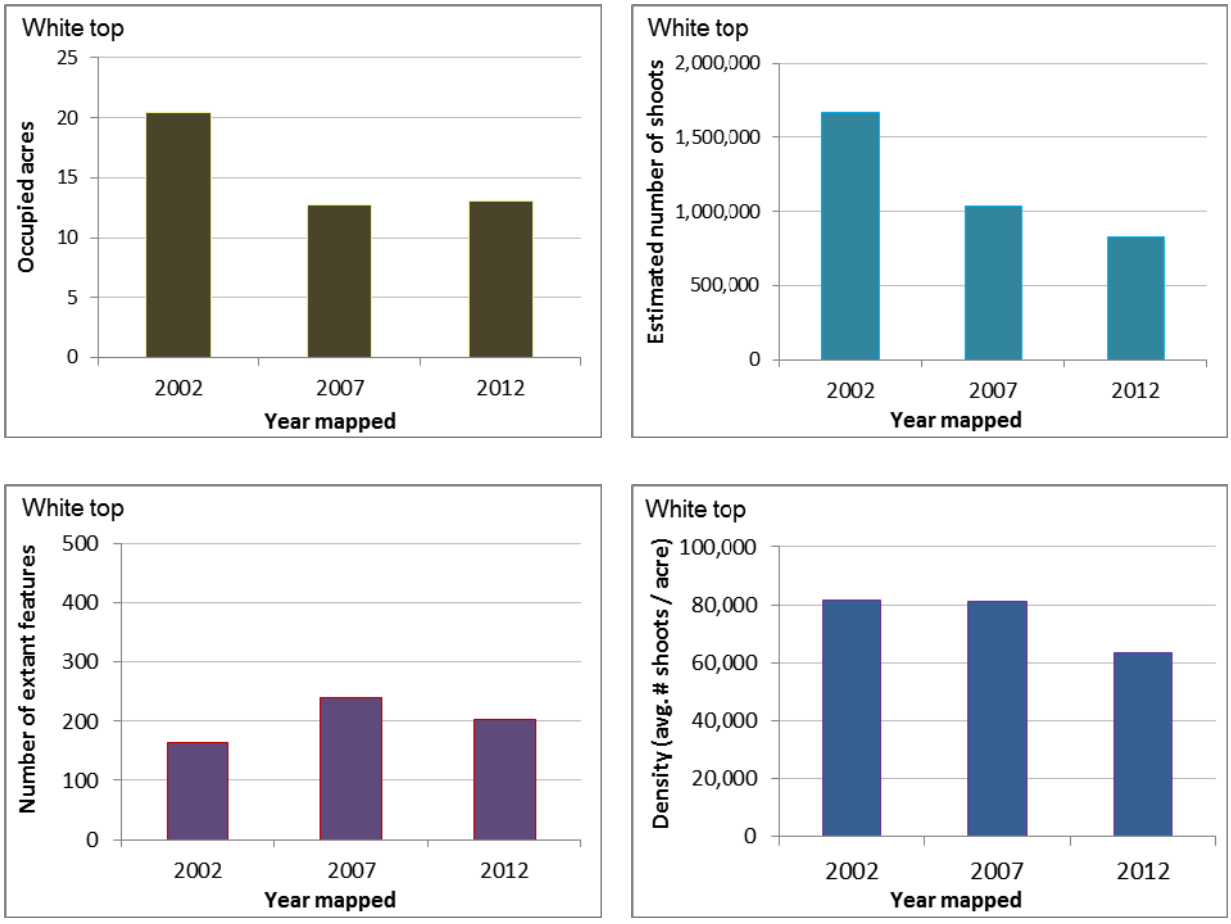
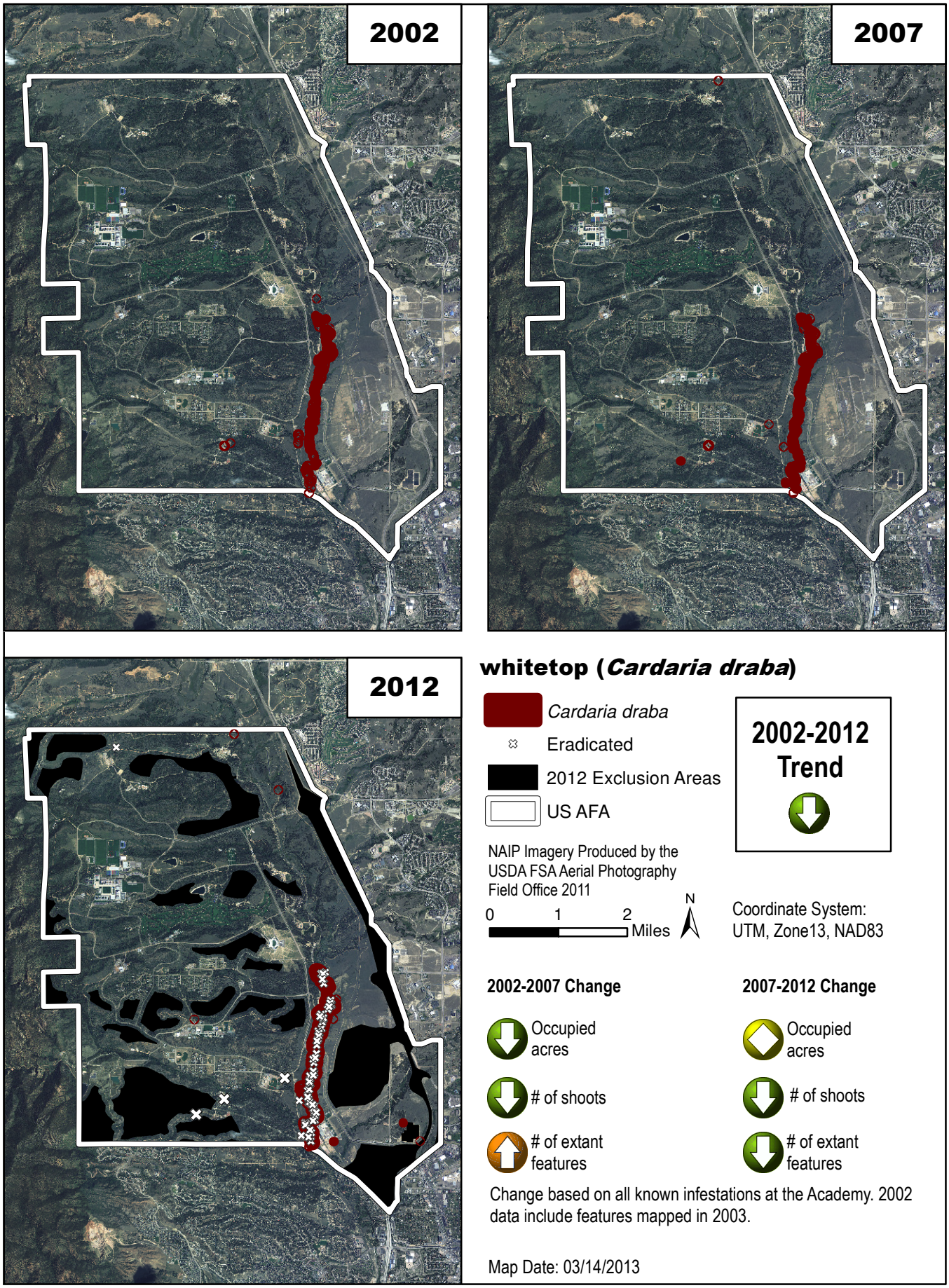


Figure 8. Whitetop trend, 2002-2012.



Map 10. Distribution of whitetop at the Academy in 2002, 2007, and 2012.

Musk Thistle (*Carduus nutans*)

Increasing and widespread. Timing of herbicide control and use of weevils may increase treatment success.

Photo by Michelle Washebek

At the Academy, musk thistle occupied 15 acres in 2012, a 44% decrease from 2007, but the number of shoots increased 153% and the number of extant mapped areas increased 6% with over 1,000 sites mapped in 2012 (Tables 7 and 12, Figure 9 and Map 11).

Most of the 2012 infestations were either identical or nearby the 2007 infestations; the one exception to this is the area north of Pine Drive, where there was only one occurrence in this area in 2007 yet in 2012 we mapped over two dozen occurrences (Map 11).

Musk thistle is a biennial weed that reproduces only from seed. The key to successful musk thistle control is to prevent seed production. Applying herbicide in the spring or fall is most effective or when it is early flower. This is an aggressive weed that establishes easily where there is bare ground. Once the plant has bolted it is more resistant to herbicide treatment. Most seed is dispersed within the immediate vicinity of the parent plant. This leads to a clumped pattern of seedling development. High quality (i.e., good condition) native plant communities are more resistant than degraded sites. The musk thistle seed head weevil, *Rhinocyllus conicus*, can reduce seed production by 50 percent on average. This weevil is no longer being redistributed because it attacks native thistles as well (Beck 2008). The *Trichosirocalus horridus* weevil attacks the crown area of musk thistle rosettes and kills or weakens the plant before it bolts. Michels et al. (2013) have successfully employed this biocontrol at select AFA sites.

Table 12. Infestations of musk thistle within comparable designated mapping areas at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**15.91**	**27.03**	**15.2**
Estimated Number of Shoots	**2,207**	**49,588**	**125,297**
Number of Extant Features	**272**	**1,020**	**1,082**
Number of Eradicated Features	NA	4	639

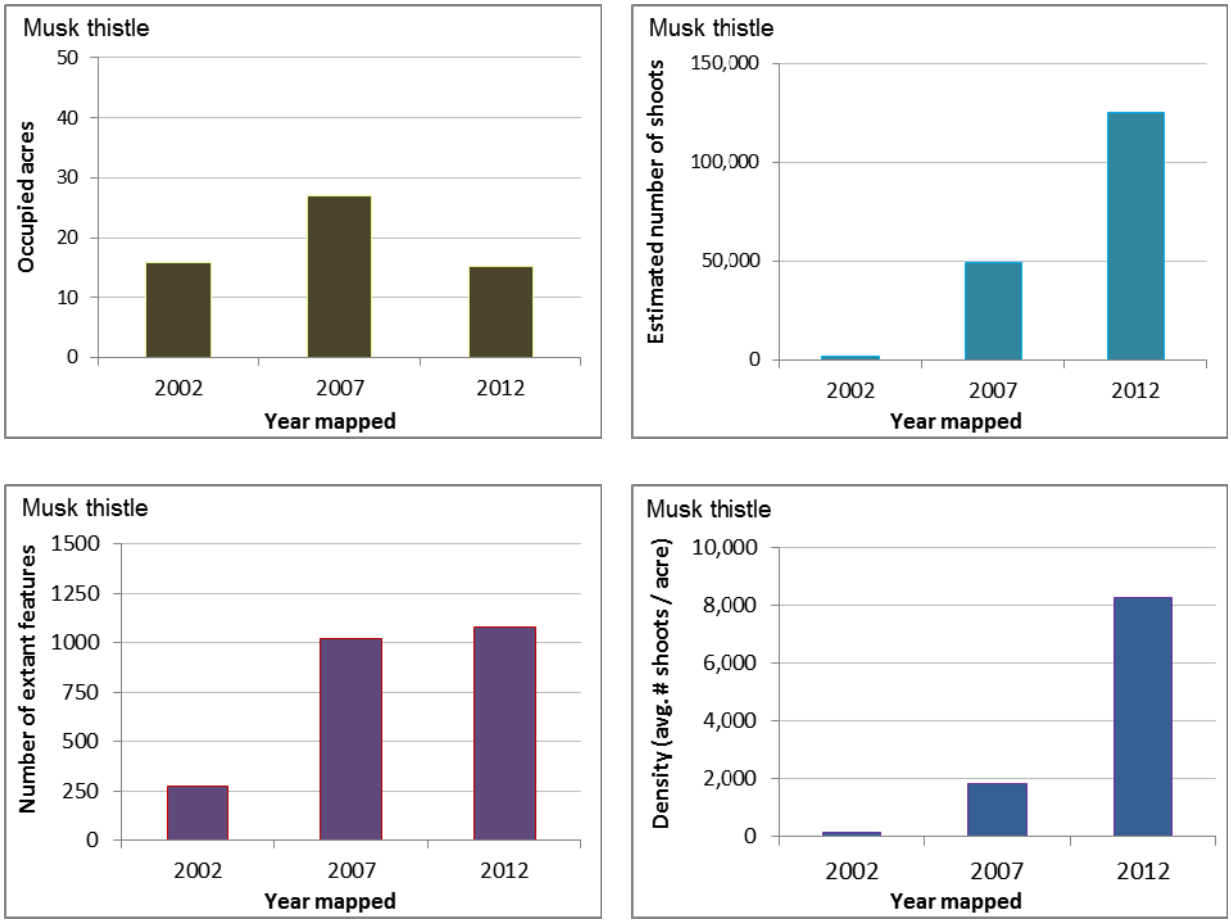


Figure 9. Musk thistle trend at U.S. Air Force Academy, 2002-2012.

Some infestations at the Academy were documented by Natural Resources Staff and previous weed surveys in areas that were not targeted in 2012. The full scope of known infestations is detailed below.

Table 13. All infestations of musk thistle at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**16.15**	**28.95**	**17.43**
Estimated Number of Shoots	**2,244**	**76,213**	**166,992**
Number of Extant Features	**280**	**1,072**	**1,136**
Number of Eradicated Features	NA	4	639

At Farish, musk thistle occupied one acre, a 54% decrease from 2007, but the number of shoots increased 3.5-fold, and the number of extant mapped areas increased 100%, with 84 sites mapped in 2012 (Tables 8 and 14, Figure 10, Map 12).

Table 14. Infestations of musk thistle within comparable designated mapping areas at Farish Outdoor Recreation Area.

	2002	2007	2012
Occupied Acres	**0.82**	**2.46**	**1.12**
Estimated Number of Shoots	**56**	**643**	**2,829**
Number of Extant Features	**13**	**42**	**84**
Number of Eradicated Features	NA	0	20

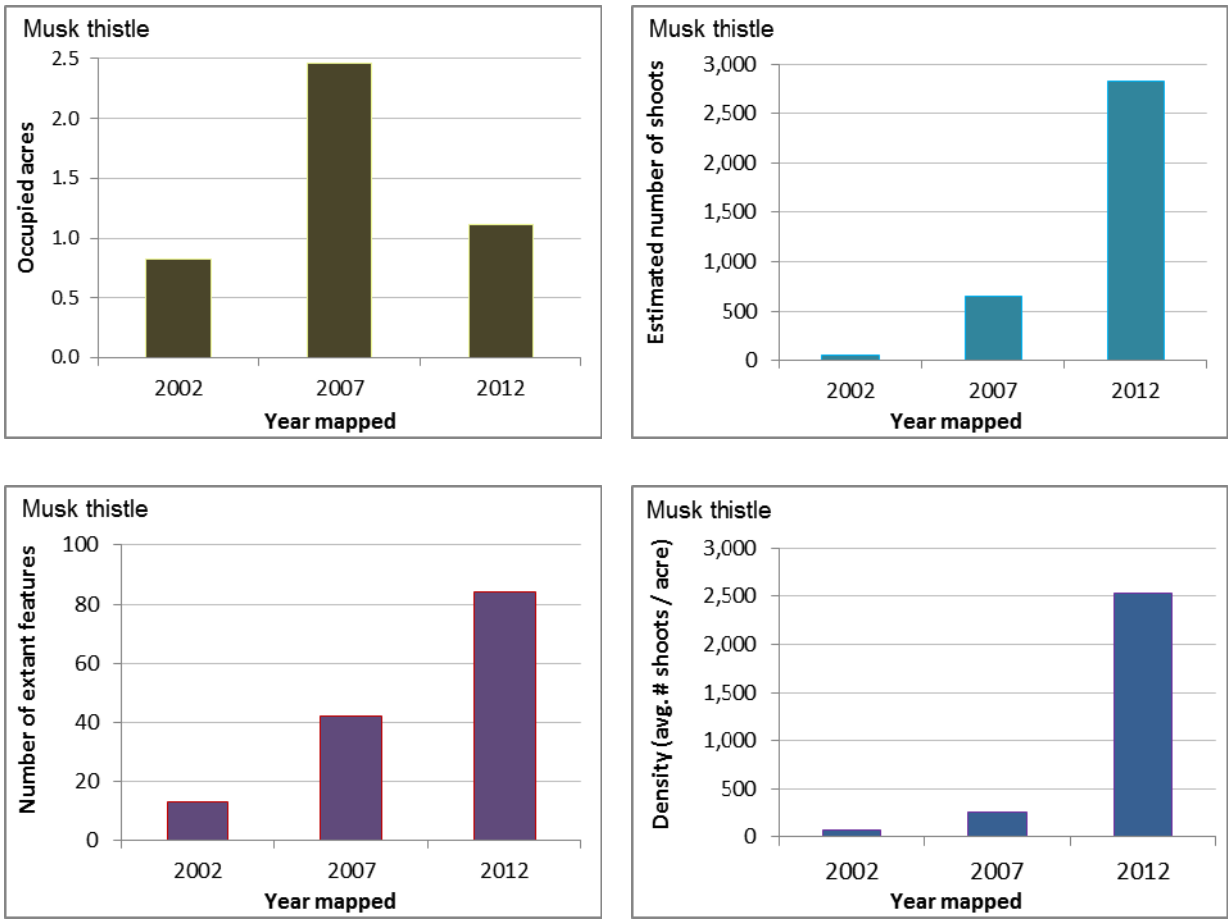
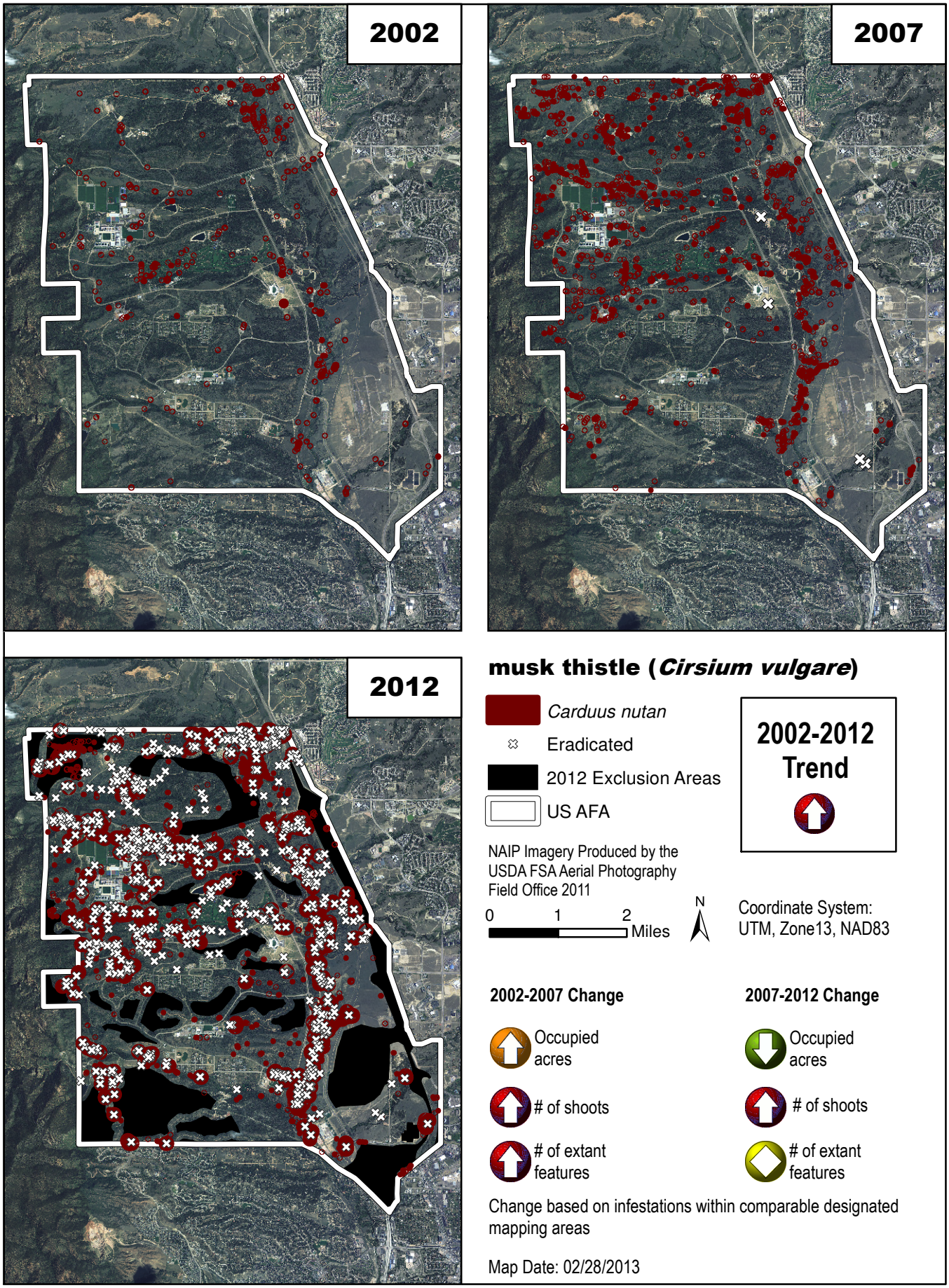


Figure 10. Musk thistle trend at Farish Outdoor Recreation Area, 2002-2012.

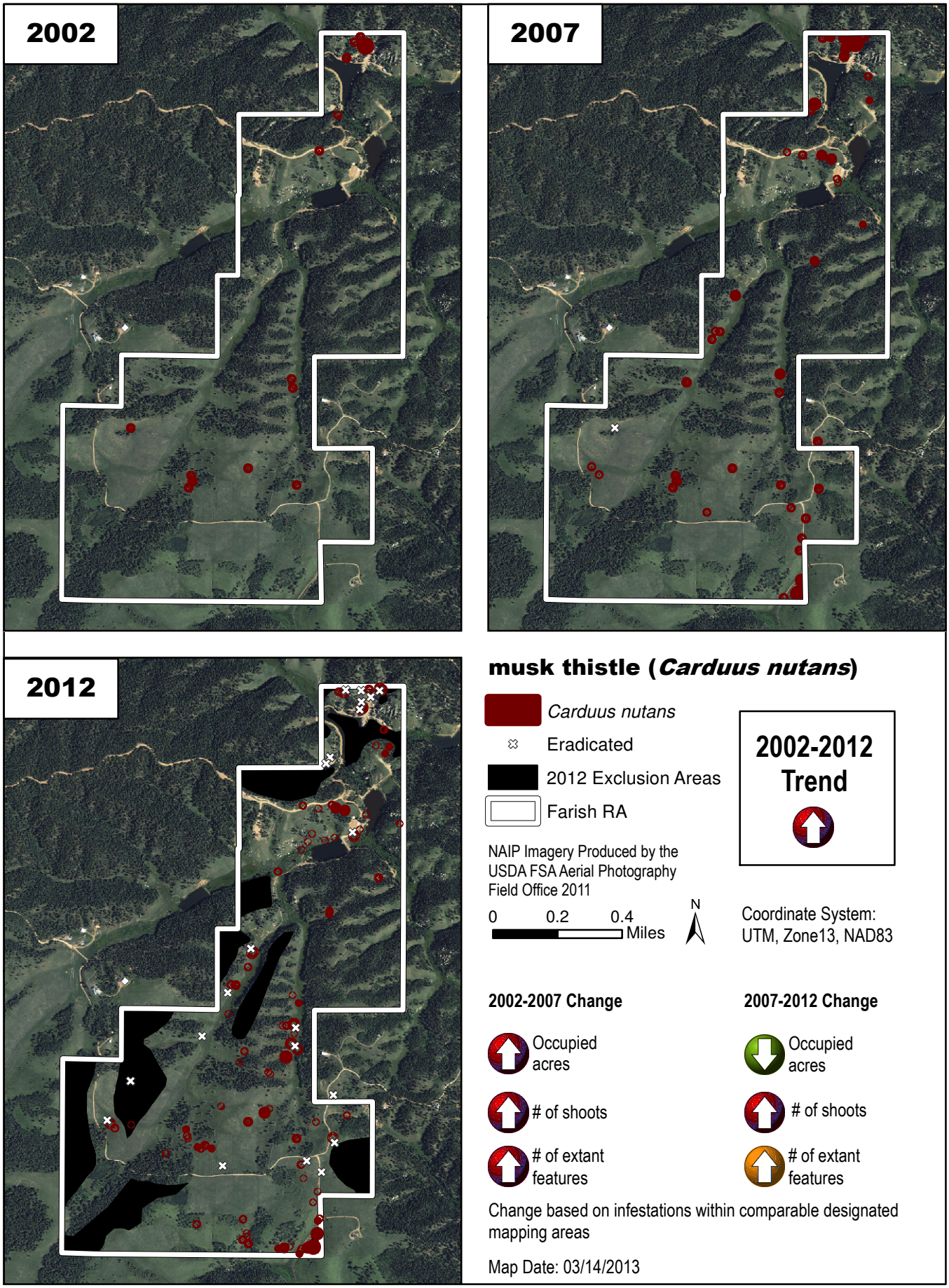
Some infestations at Farish were documented by Natural Resources Staff and previous weed surveys in areas that were not targeted in 2012. The full scope of known infestations is detailed below.

Table 15. All infestations of musk thistle at Farish Outdoor Recreation Area.

	2002	2007	2012
Occupied Acres	**0.85**	**2.77**	**1.43**
Estimated Number of Shoots	**57**	**1,269**	**3,456**
Number of Extant Features	**14**	**44**	**87**
Number of Eradicated Features	NA	1	21



Map 11. Distribution of musk thistle at the Academy in 2002, 2007, and 2012.



Map 12. Distribution of musk thistle at Farish Outdoor Recreation Area in 2002, 2007, and 2012.

Diffuse Knapweed (*Centaurea diffusa*)

Increasing and widespread. Select control may be most feasible option.

Photo by Michelle Washebek

Diffuse knapweed occupied 101 acres in 2012, 19 acres fewer than 2007, and 56 acres more than in 2002 (Table 16, Figure 11). All other indicators significantly increased in each sampling year. There was a 238% increase in number of shoots from 2007 to 2012. The number of extant mapped features also increased (37%) in the same time period (Table 7 and Map 13).

Diffuse knapweed is a short-lived, non-creeping plant that spreads solely from seed. It forms a new shoot each year from a taproot. Mature plants with seed heads break off at the soil surface and become tumbleweeds over winter, dispersing their seeds in the process. It does not tolerate flooding or shade and thrives in a 9-16 inch precipitation zone. Diffuse and spotted knapweeds occupy the same areas in Colorado and are hybridizing at the Academy; it is common to find hybrid swarms. Herbicide treatment can be very effective, especially at the rosette stage. Biological control is also available and is currently applied to one site at the Academy (Michels et al. 2013). The biocontrol seedhead flies cause plants to produce fewer viable seeds and abort terminal or lateral flowers. Due to the large number of sites and continued increase in density, we believe this species will most likely be part of AFA flora and selecting areas to control will probably be more effective than trying to control the entire AFA population.

Table 16. Infestations of diffuse knapweed within comparable designated mapping areas at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**45.42**	**119.86**	**100.58**
Estimated Number of Shoots	**130,589**	**394,197**	**1,334,253**
Number of Extant Features	**251**	**913**	**1,255**
Number of Eradicated Features	NA	0	406

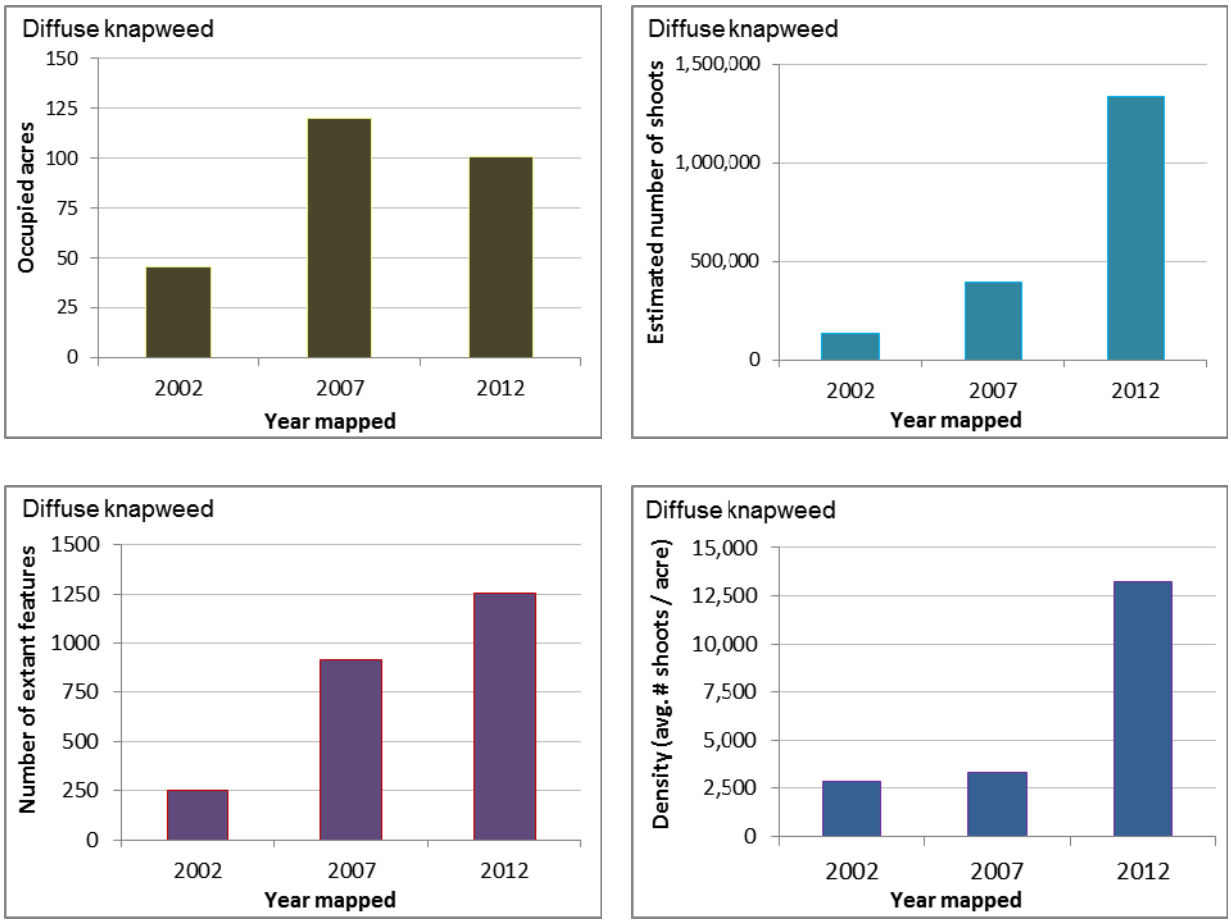
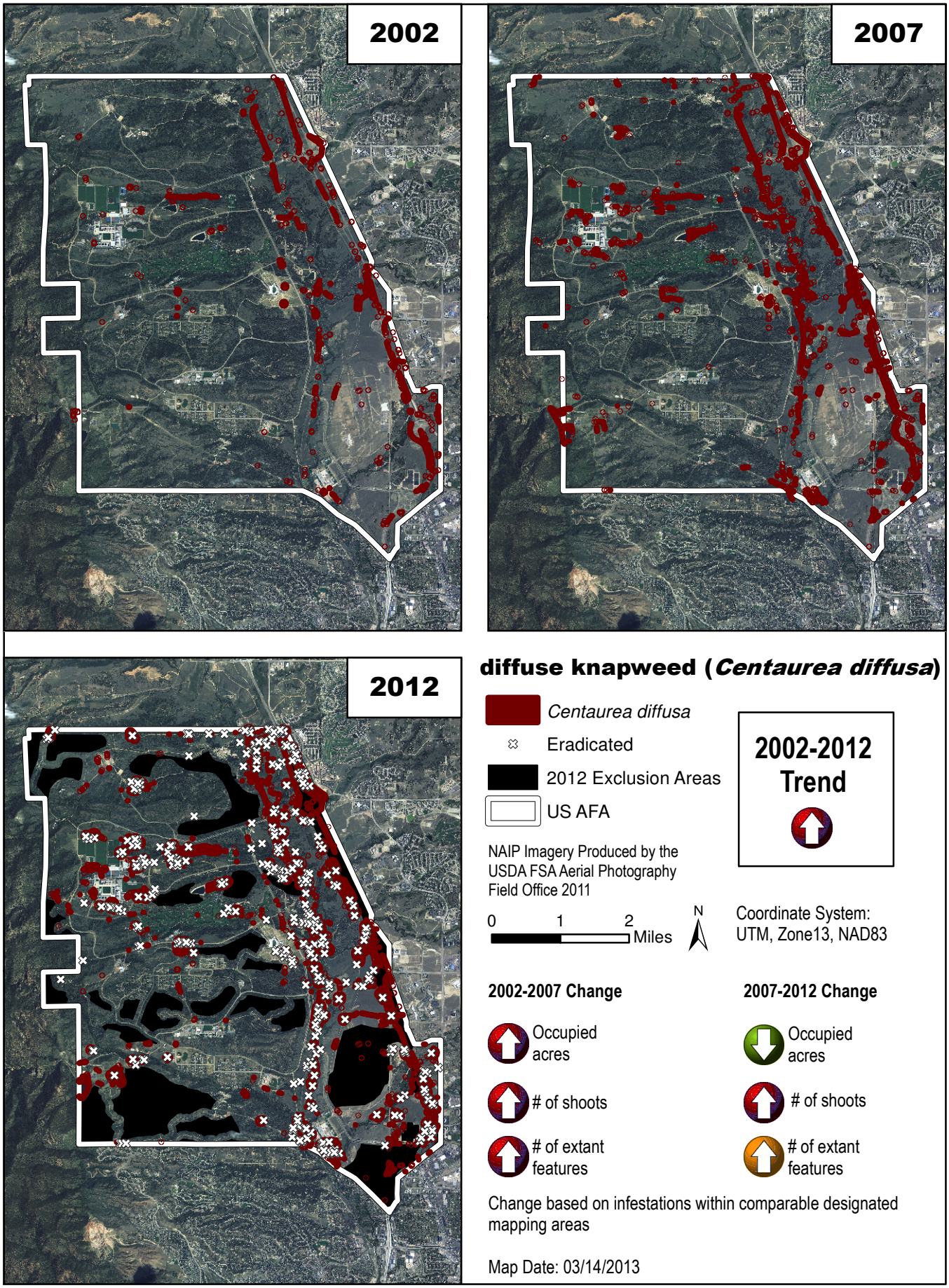


Figure 11. Diffuse knapweed trend, 2002-2012.

Some infestations at the Academy were documented by Natural Resources Staff and previous weed surveys in areas that were not targeted in 2012. The full scope of known infestations is detailed below.

Table 17. All infestations of diffuse knapweed at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**56.37**	**136.68**	**117.41**
Estimated Number of Shoots	**141,805**	**411,921**	**1,352,457**
Number of Extant Features	**328**	**985**	**1,329**
Number of Eradicated Features	NA	0	406



Map 13. Distribution of diffuse knapweed at the Academy in 2002, 2007, and 2012.

Diffuse/ Spotted Knapweed Hybrid (*Centaurea diffusa x maculosa*)

Photo by Michelle Washebek

Hybridization is increasing at a rapid rate.

The diffuse x spotted knapweed hybrid occupied 6 acres in 2012, a 239% increase over 2007. The number of shoots had a 14 fold increase and the number of extant mapped areas shot upward to 240, a 103% increase over 2007 (Tables 7 and 18, Figure 12).

Given that this hybrid was not mapped in 2002 and by 2007 there were nearly 2 acres and then a tripling by 2012, we believe we will continue to see an increase in hybrid swarms throughout the Academy (Map 14).

Table 18. Infestations of diffuse x spotted knapweed hybrid within comparable designated mapping areas at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**NA**	**1.75**	**5.93**
Estimated Number of Shoots	**NA**	**2,810**	**42,991**
Number of Extant Features	**NA**	**118**	**240**
Number of Eradicated Features	NA	NA	54

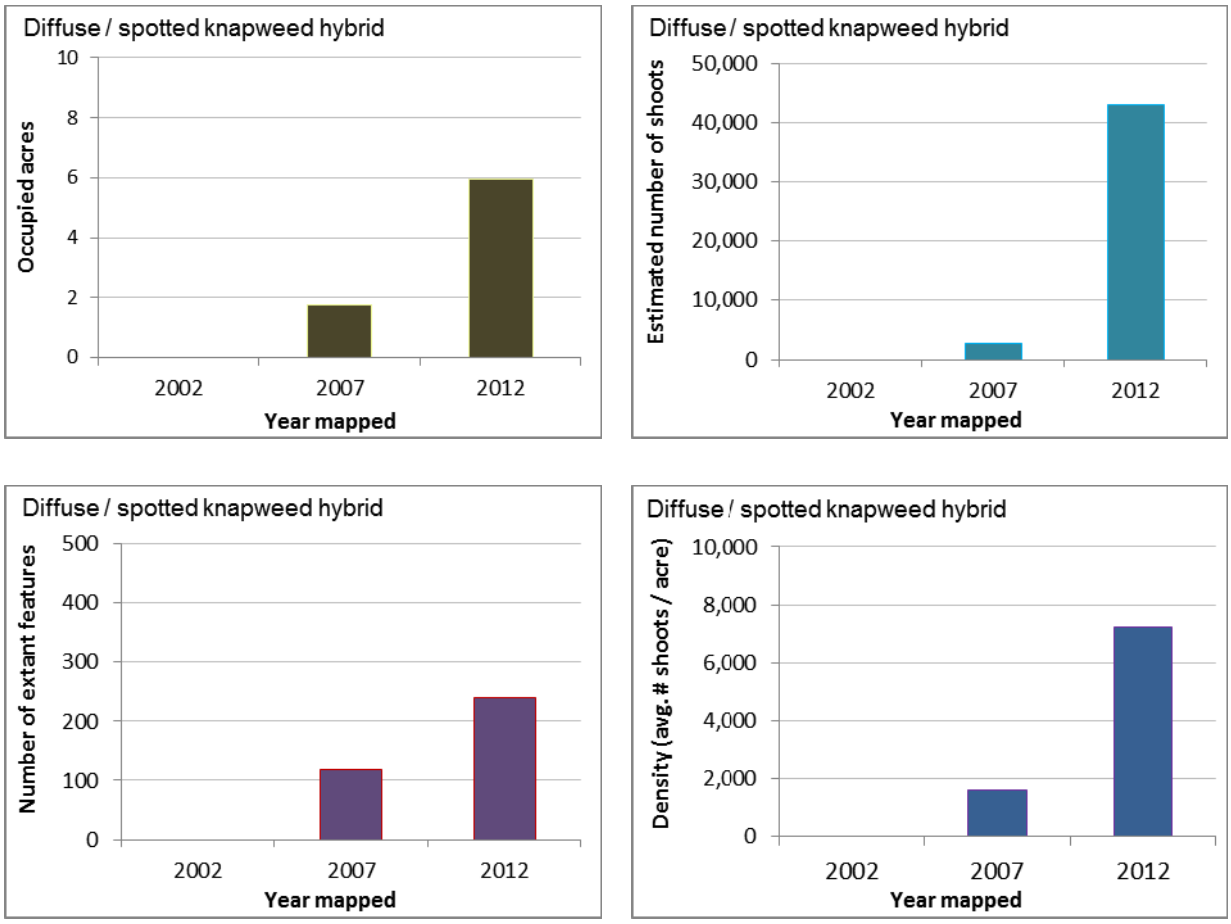
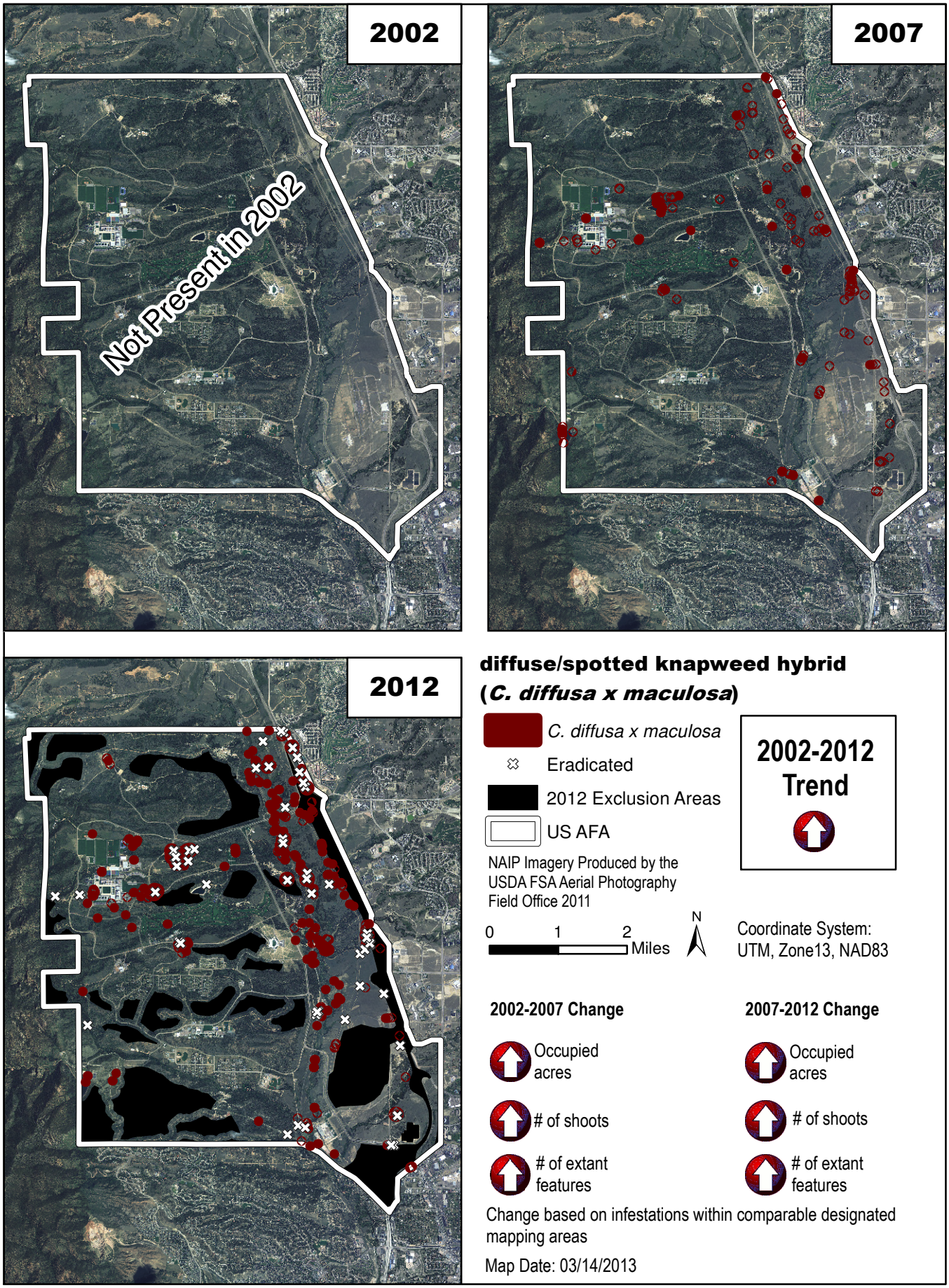


Figure 12. Diffuse x spotted knapweed hybrid trend, 2002-2012.

Some infestations at the Academy were documented by Natural Resources Staff and previous weed surveys in areas that were not targeted in 2012. The full scope of known infestations is detailed below.

Table 19. All infestations of diffuse x spotted knapweed hybrid at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**NA**	**1.8**	**5.98**
Estimated Number of Shoots	**NA**	**2,922**	**43,104**
Number of Extant Features	**NA**	**125**	**248**
Number of Eradicated Features	NA	NA	54



Map 14. Distribution of diffuse/spotted knapweed hybrid at the Academy in 2002, 2007, and 2012.

Spotted Knapweed (*Centaurea maculosa*)

Rapidly spreading and too common now for eradication.

Photo by Michelle Washebek

Spotted knapweed occupied 53 acres in 2012, just slightly less than 2007 (Table 20 and Figure 13). The number of shoots had a three-fold increase and the number of extant mapped areas increased 77%, from 319 to 565 (Tables 7 and 20, Figure 13).

It continues to spread at a rapid rate, an average of 5 acres/year and is now prevalent in Monument Creek (Map 15). It was relatively uncommon at the Academy in 2002, occupying only 4.7 acres. Unfortunately, this species has now become too common for eradication to be feasible without considerable effort.

This species is an excellent example of how fast a weed can increase and supports the management decision for rapid response for weeds occupying a low number of sites. Spotted knapweed 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 was 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, railroad right-of-way, and Monument Creek have also become infested.

Diffuse and spotted knapweeds occupy the same areas in Colorado and are hybridizing at AFA; it is common to find hybrid swarms. Herbicide treatment can be very effective especially at the rosette stage. Biological control is also available and is successfully being applied to three sites at AFA (Michels et al. 2013). The biocontrol

seedhead flies cause plants to produce fewer viable seeds and abort terminal or lateral flowers. Due to the large number of sites that we mapped in 2012 and the continued increase in density, we believe this species will most likely be part of AFA flora and selecting areas to control will probably be more effective than trying to control the entire AFA population.

We developed a model of suitable habitat and rate of spread for spotted knapweed at the Academy (Rondeau et al. 2010). Although it did not capture the Monument Creek expansion, the existing occurrences are primarily found in the highly suitable habitat (Map 16). We propose to learn from the current distribution and remodel this species. However, the current model suggests that knapweed will continue to expand.

Diffuse/spotted/hybrid combined

There is reason to consider diffuse, spotted, and the hybrid as one weed target since they are occupying the same habitats and hybridization is becoming a common event. When we do this, we see that there was a total of 151 acres on the Academy in 2012 and the number of extant mapped features is up to 2059, nearly a six-fold increase since 2002 and a 53% increase since 2007. The density also increased significantly between 2007 and 2012. The biocontrol agents and herbicide treatments have an impact on individual sites, but overall there is no complete control for this weed. We suggest that all rare plant occurrences be monitored regularly for weeds, especially knapweed. If knapweeds are observed then an aggressive management action will be needed to eliminate the weed from the rare plant occurrence. Potential Conservation Areas are also a high priority for controlling weeds, especially knapweeds.

Table 20. Infestations of spotted knapweed within comparable designated mapping areas at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**4.67**	**57.52**	**53.02**
Estimated Number of Shoots	**3,485**	**127,627**	**543,144**
Number of Extant Features	**54**	**319**	**565**
Number of Eradicated Features	NA	16	156

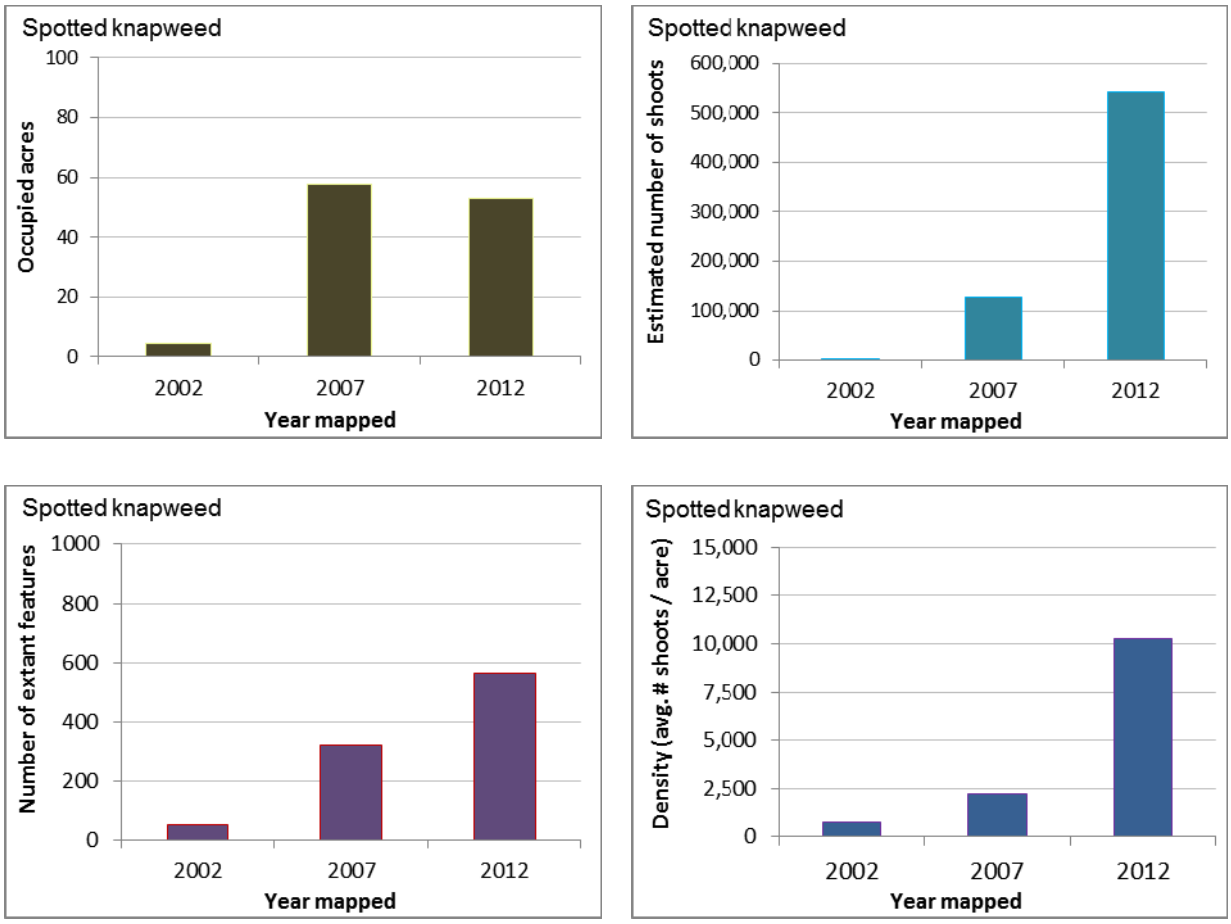
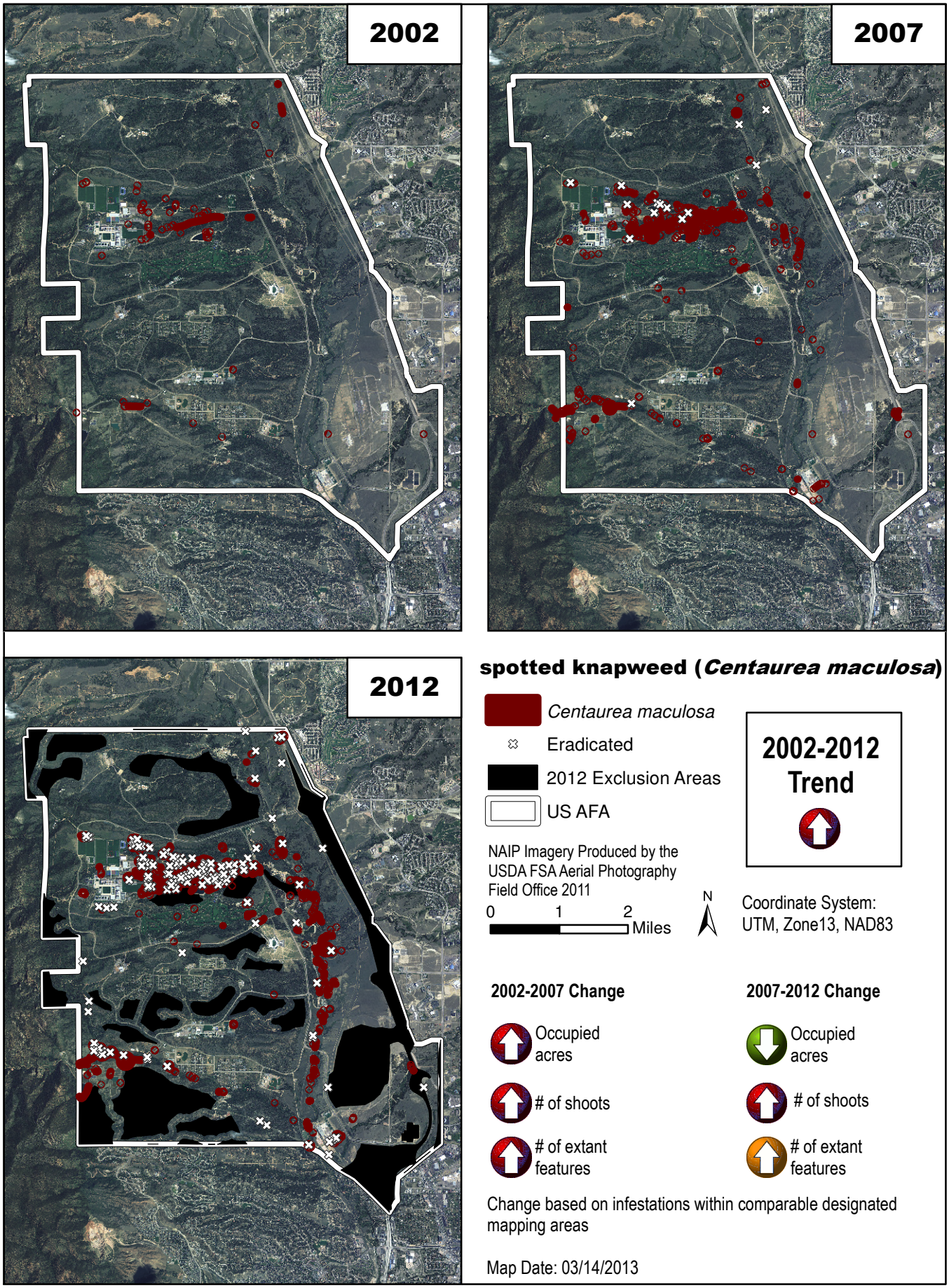


Figure 13. Spotted knapweed trend, 2002-2012.

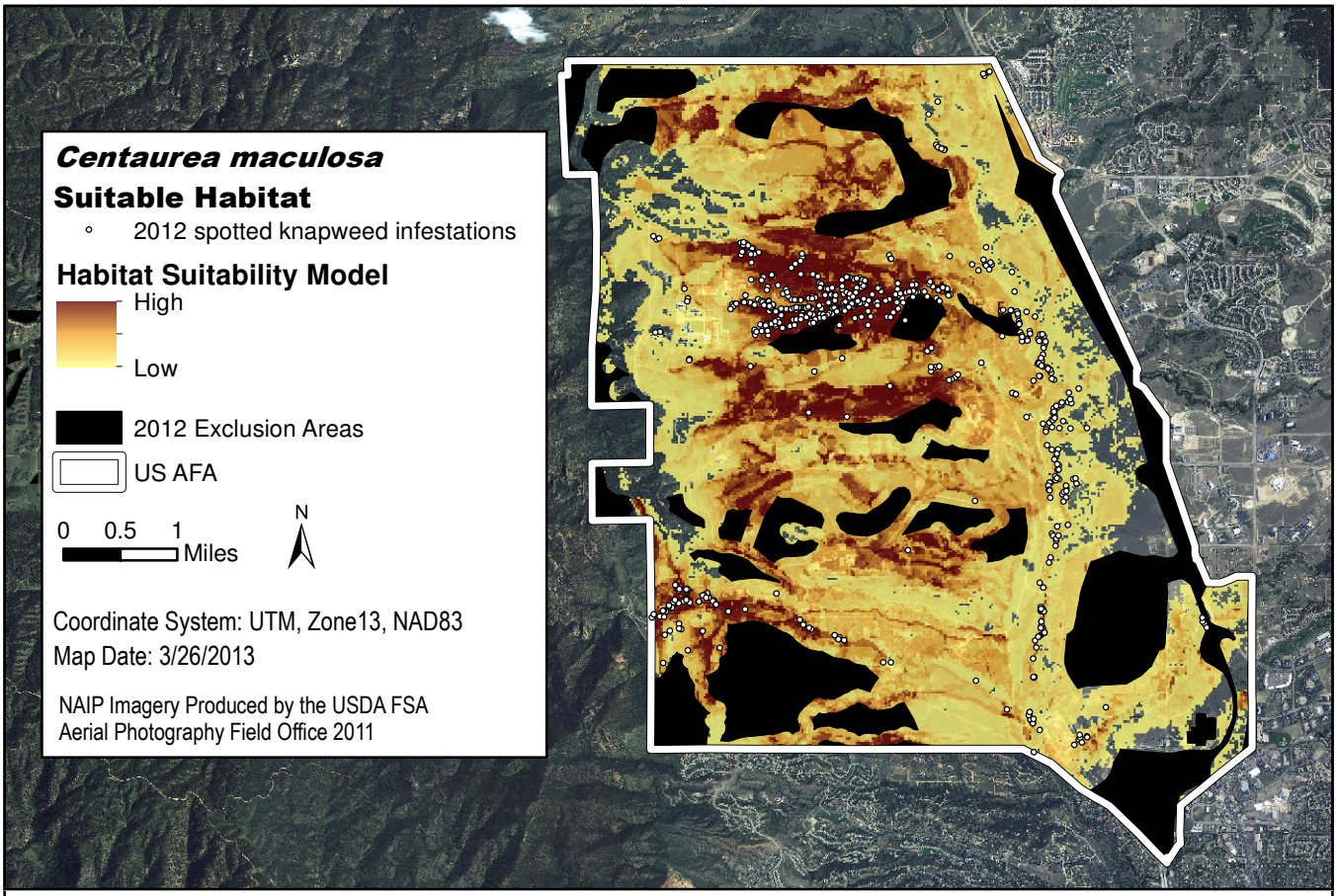
Some infestations at the Academy were documented by Natural Resources Staff and previous weed surveys in areas that were not targeted in 2012. The full scope of known infestations is detailed below.

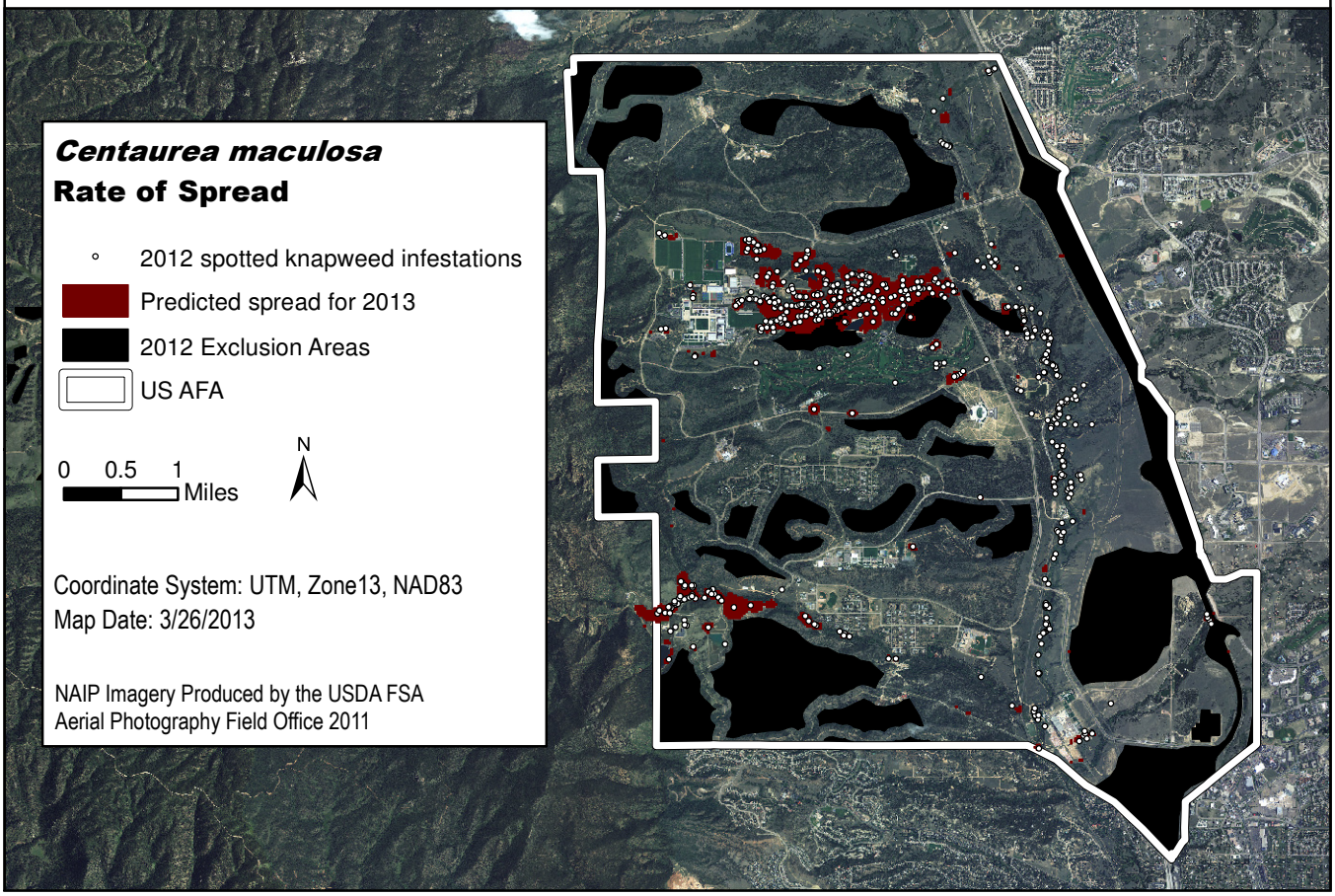
Table 21. All infestations of spotted knapweed at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**4.67**	**57.58**	**53.08**
Estimated Number of Shoots	**3,485**	**127,836**	**543,353**
Number of Extant Features	**54**	**323**	**569**
Number of Eradicated Features	NA	16	156



Map 15. Distribution of spotted knapweed at the Academy in 2002, 2007, and 2012.





Map 16. Habitat suitability model (Maxent) and 2013 predicted spread for spotted knapweed at the Academy.

Canada Thistle (*Cirsium arvense*)

On the rise and invading wet areas.

Photo by Michelle Washebek

Canada thistle occupied 90 acres in 2012, the same as 2007, and 11 acres more than in 2002 (Table 22). While the acres occupied remained fairly stable, the number of shoots increased 184% since 2007 (Table 7). The number of extant mapped features increased 43-52% each sample year, by approximately 200 new sites (Figure 14). Nearly all of the occurrences were associated with Monument Creek or its tributaries (Map17).

In 2007 it was the second most abundant weed at the Academy (Anderson and Lavender 2008), however in 2012, knapweed surpassed Canada thistle. The Academy continues to target this weed only in high priority areas.

This trend suggests that this species will continue to invade wet areas. Active management of this species now may offset more expensive control efforts in the future.

Three biocontrol agents are successfully being used at four sites at AFA (Michels et al. 2013).

Table 22. Infestations of Canada thistle within comparable designated mapping areas at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	*79.27	*90.68	*90.17
Estimated Number of Shoots	*408,121	*379,992	*1,079,070
Number of Extant Features	*358	*543	*776
Number of Eradicated Features	NA	0	*232

* Canada thistle numbers derived from 2007 designated mapping areas

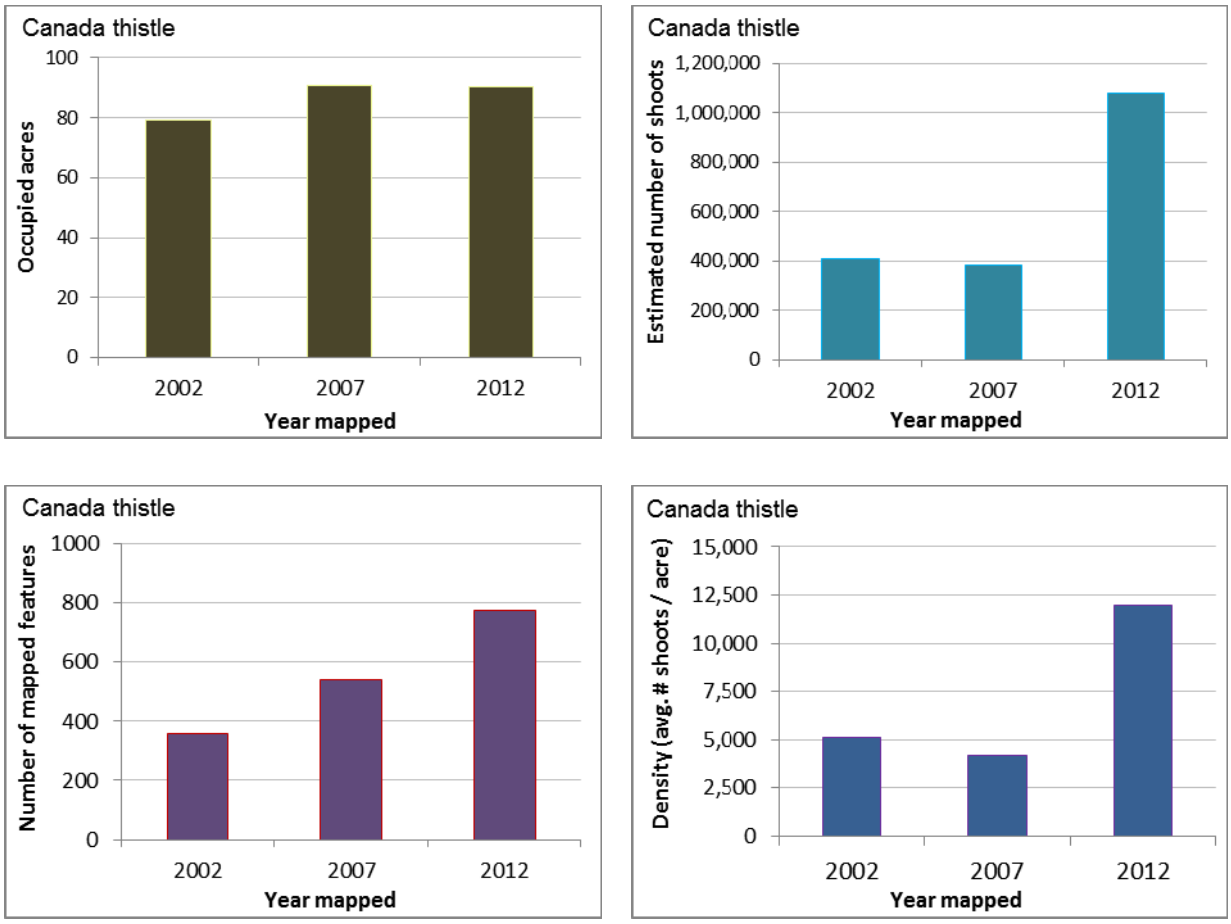


Figure 14. Canada thistle trend at the U.S. Air Force Academy, 2002-2012.

Some infestations at the Academy were documented by Natural Resources Staff and previous weed surveys in areas that were not targeted in 2012. The full scope of known infestations is detailed below.

Table 23. All infestations of Canada thistle at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**101.36**	**93.62**	**95.95**
Estimated Number of Shoots	**529,103**	**400,021**	**1,169,173**
Number of Extant Features	**543**	**563**	**963**
Number of Eradicated Features	NA	0	232

At Farish, there were 1.3 occupied acres in 2012, a decrease of ¼ of an acre since 2007 (Table 24). While the acres occupied apparently decreased, the number of shoots and extant mapped areas increased 63% and 52% respectively in the same time frame (Tables 8 and 24, Figure 15, Map 18).

Table 24. Infestations of Canada thistle within comparable designated mapping areas at Farish Outdoor Recreation Area.

	2002	2007	2012
Occupied Acres	**0.23**	**1.55**	**1.27**
Estimated Number of Shoots	**3,488**	**14,734**	**24,082**
Number of Extant Features	**8**	**23**	**35**
Number of Eradicated Features	NA	1	8

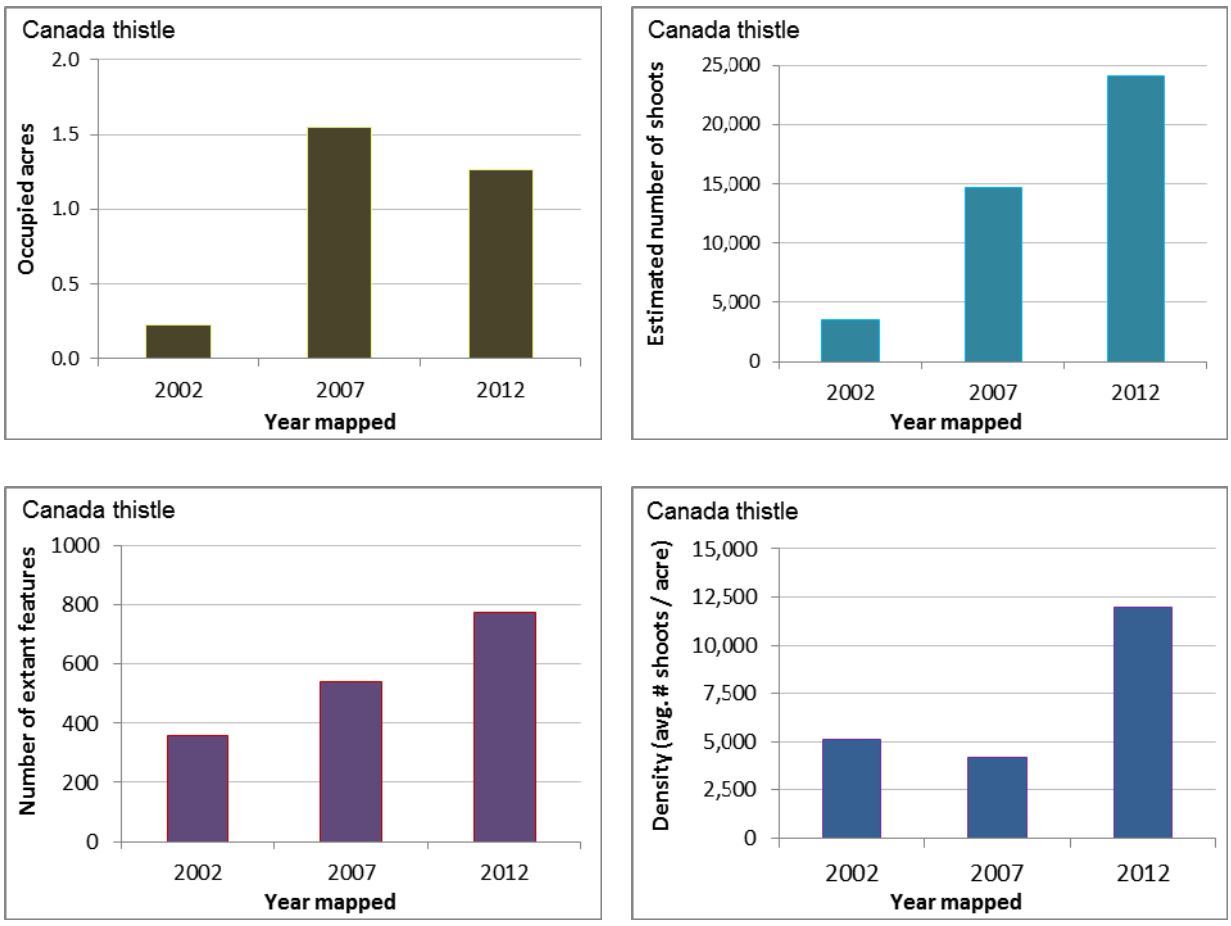
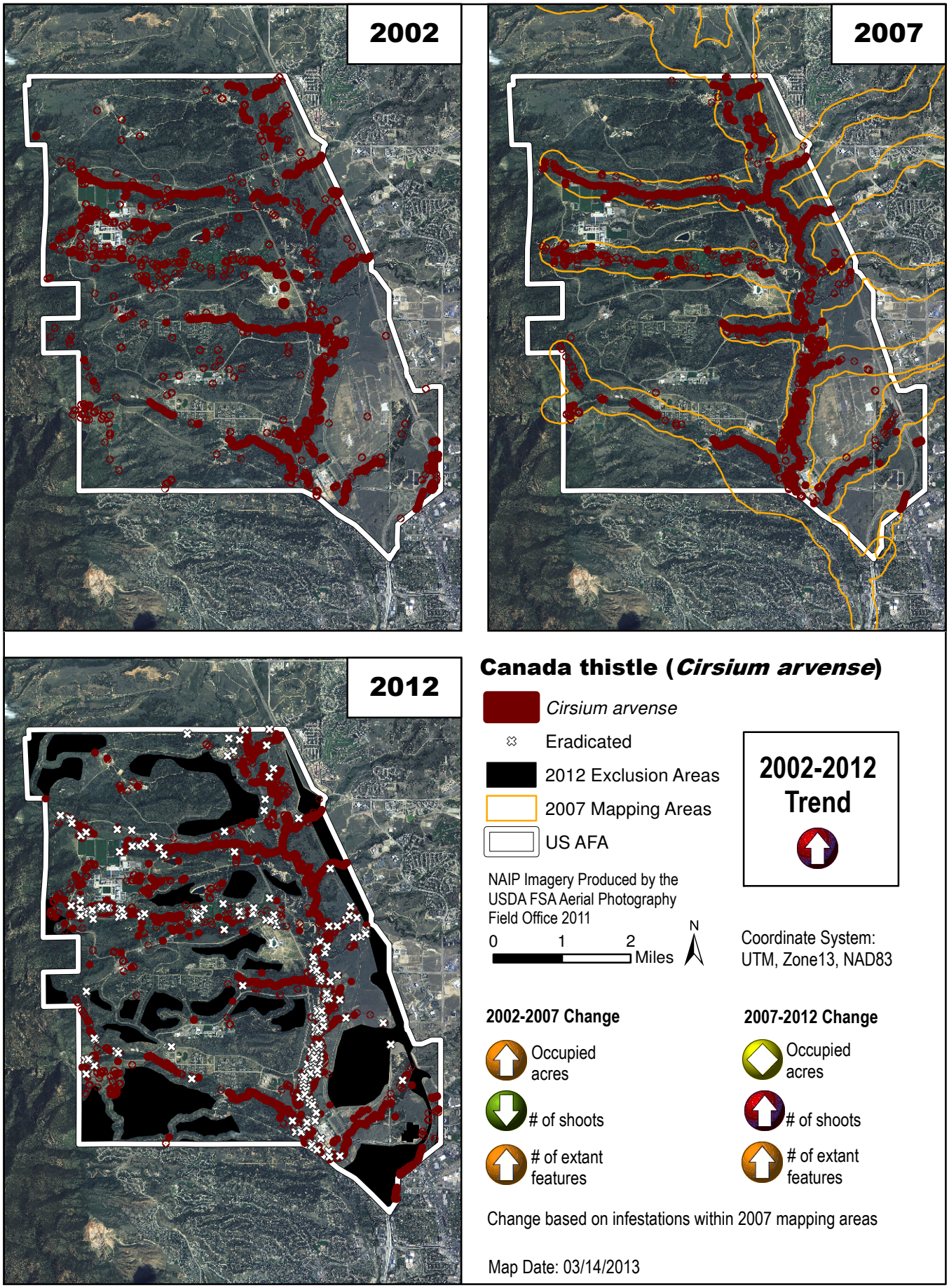


Figure 15. Canada thistle trend at Farish Outdoor Recreation Area, 2002-2012.

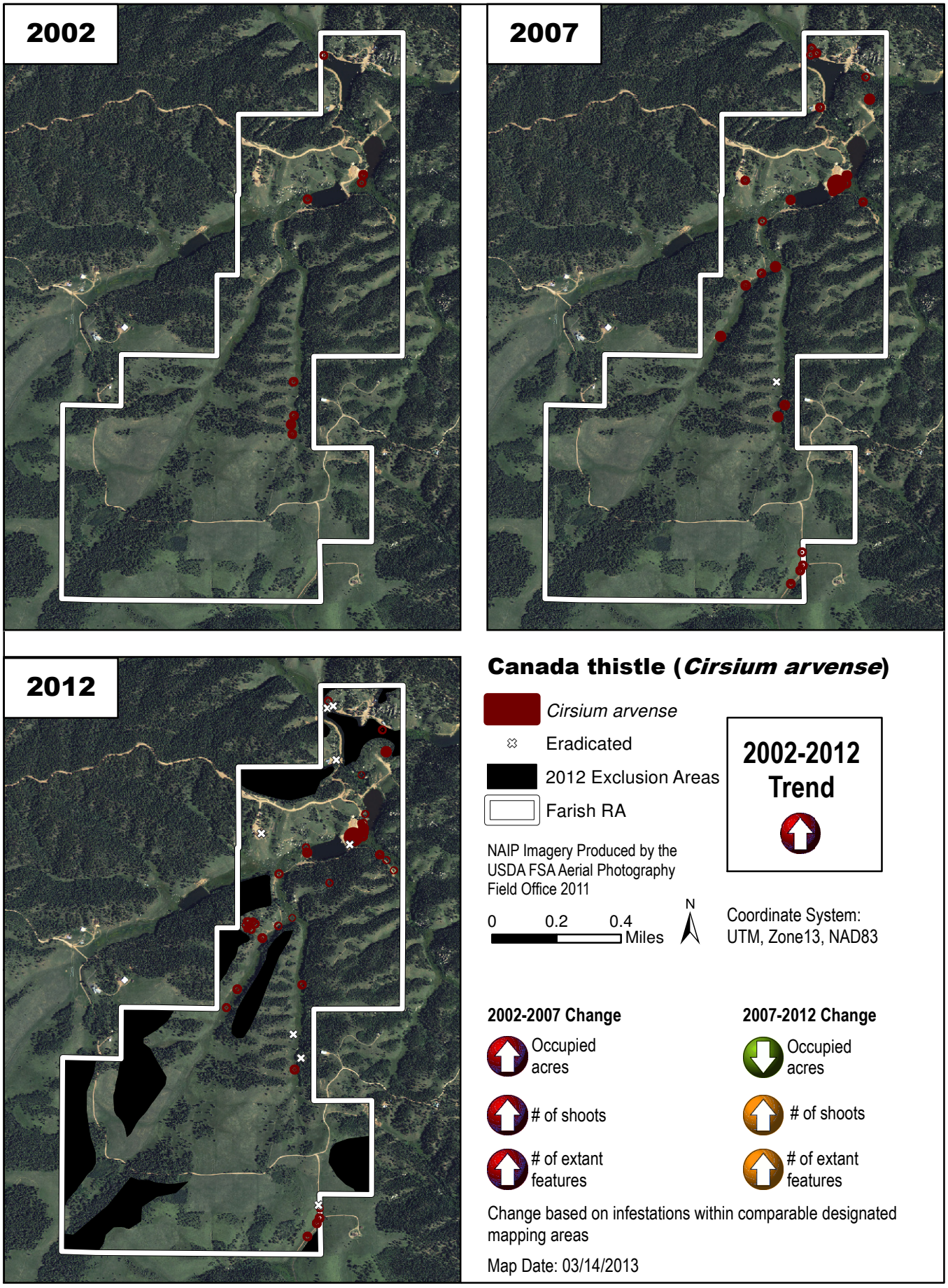
Some infestations at Farish were documented by Natural Resources Staff and previous weed surveys in areas that were not targeted in 2012. The full scope of known infestations is detailed below.

Table 25. All infestations of Canada thistle at Farish Outdoor Recreation Area.

	2002	2007	2012
Occupied Acres	**0.23**	**1.56**	**1.28**
Estimated Number of Shoots	**3,488**	**14,785**	**24,132**
Number of Extant Features	**8**	**24**	**36**
Number of Eradicated Features	NA	1	8



Map 17. Distribution of Canada thistle at the Academy in 2002, 2007, and 2012.



Map 18. Distribution of Canada thistle at Farish Outdoor Recreation Area in 2002, 2007, and 2012.

Bull Thistle (*Cirsium vulgare*)

Is spreading into new territory in the north and south.

Photo by Michelle Washebek

Bull thistle occupied 1.2 acres in 2012, a significant decrease from the 6.5 acres mapped in 2007 (Table 26). The number of shoots slightly declined by 6% in the same time frame, but the number of extant mapped features was 62% higher, from 128 to 207 (Tables 7 and 26, Figure 16). This species spread into new areas in both the north and south part of the Academy (Map 19). Therefore, the overall trend is considered to be a moderate increase as the species is poised to significantly increase given more time.

Bull thistle was not adequately mapped in 2002 and therefore it was challenging to compare 2002 data with 2012 data. The 2002 mapper took copious notes that allowed us to estimate occupied acres and density, but since the locations were not documented, it makes comparing 2002 with other years challenging. We have a high confidence in comparing 2007 with 2012.

Bull thistle is distributed widely throughout the Academy property (Map 19). 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.

Since it does not occupy many acres, it is still considered a high priority for weed control measures, especially in potential conservation areas.

Table 26. Infestations of bull thistle within comparable designated mapping areas at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**5.54	6.42	1.19
Estimated Number of Shoots	**596	4,347	4,089
Number of Extant Features	**73	128	207
Number of Eradicated Features	NA	0	79

**values from field notes; not mapped in GIS

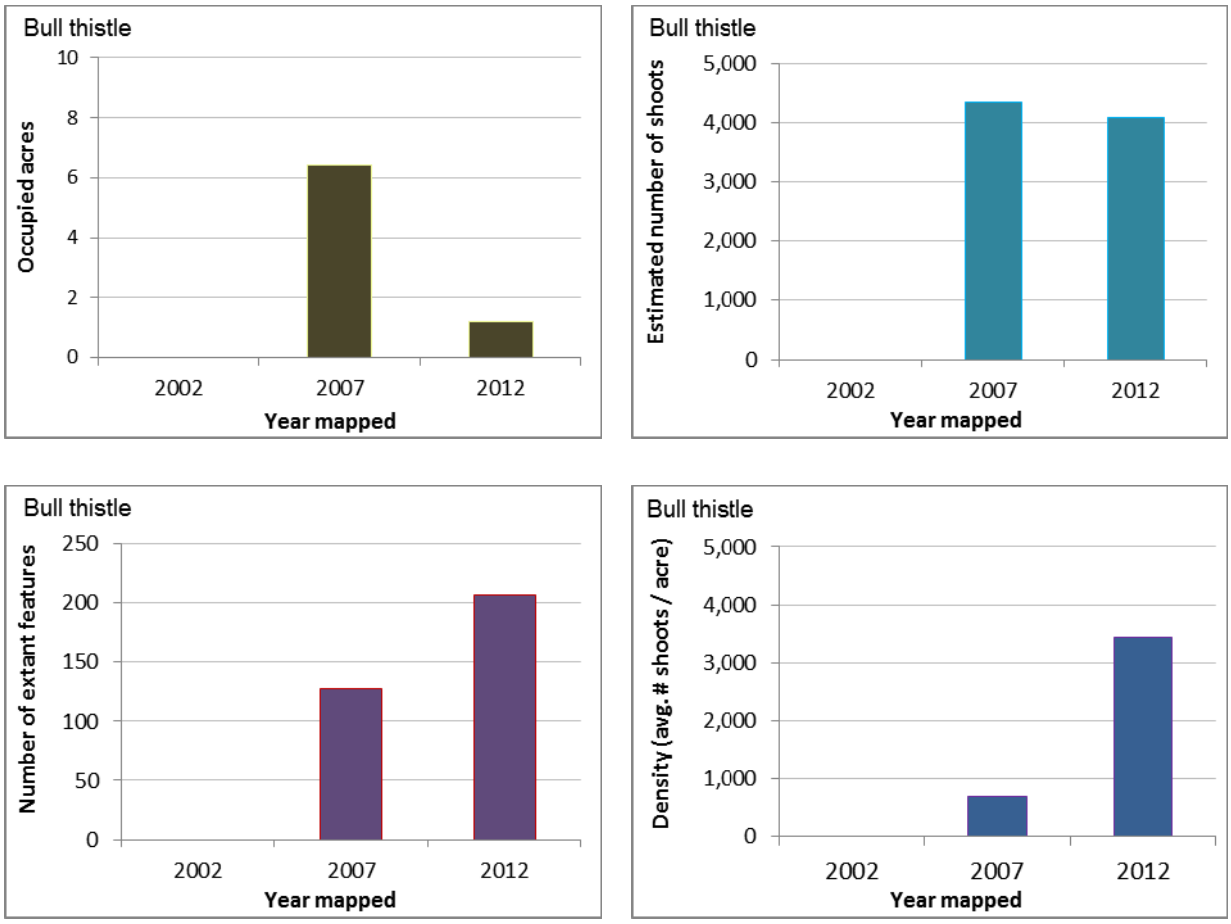


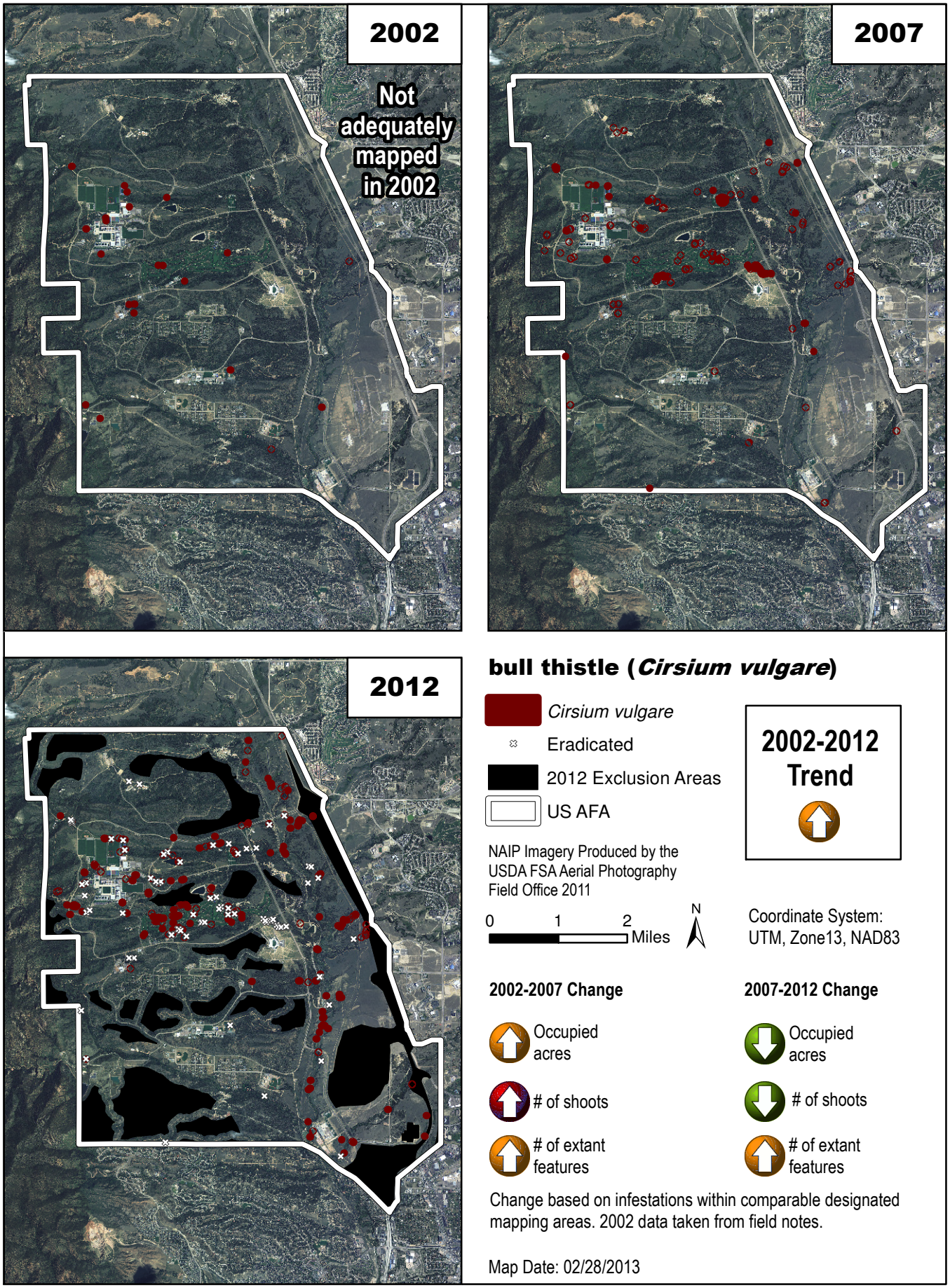
Figure 16. Bull thistle trend, 2002-2012.

Some infestations at the Academy were documented by Natural Resources Staff and previous weed surveys in areas that were not targeted in 2012. The full scope of known infestations is detailed below.

Table 27. All infestations of bull thistle at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**5.54	6.46	1.23
Estimated Number of Shoots	**596	4,412	4,154
Number of Extant Features	**73	131	210
Number of Eradicated Features	NA	0	79

**values from field notes; not mapped in GIS



Map 19. Distribution of bull thistle at the Academy in 2002, 2007, and 2012.

Houndstongue (*Cynoglossum officinale*)

Increasing but aggressive management is controlling this species.

Photo by M. DiTomaso, University of California - Davis

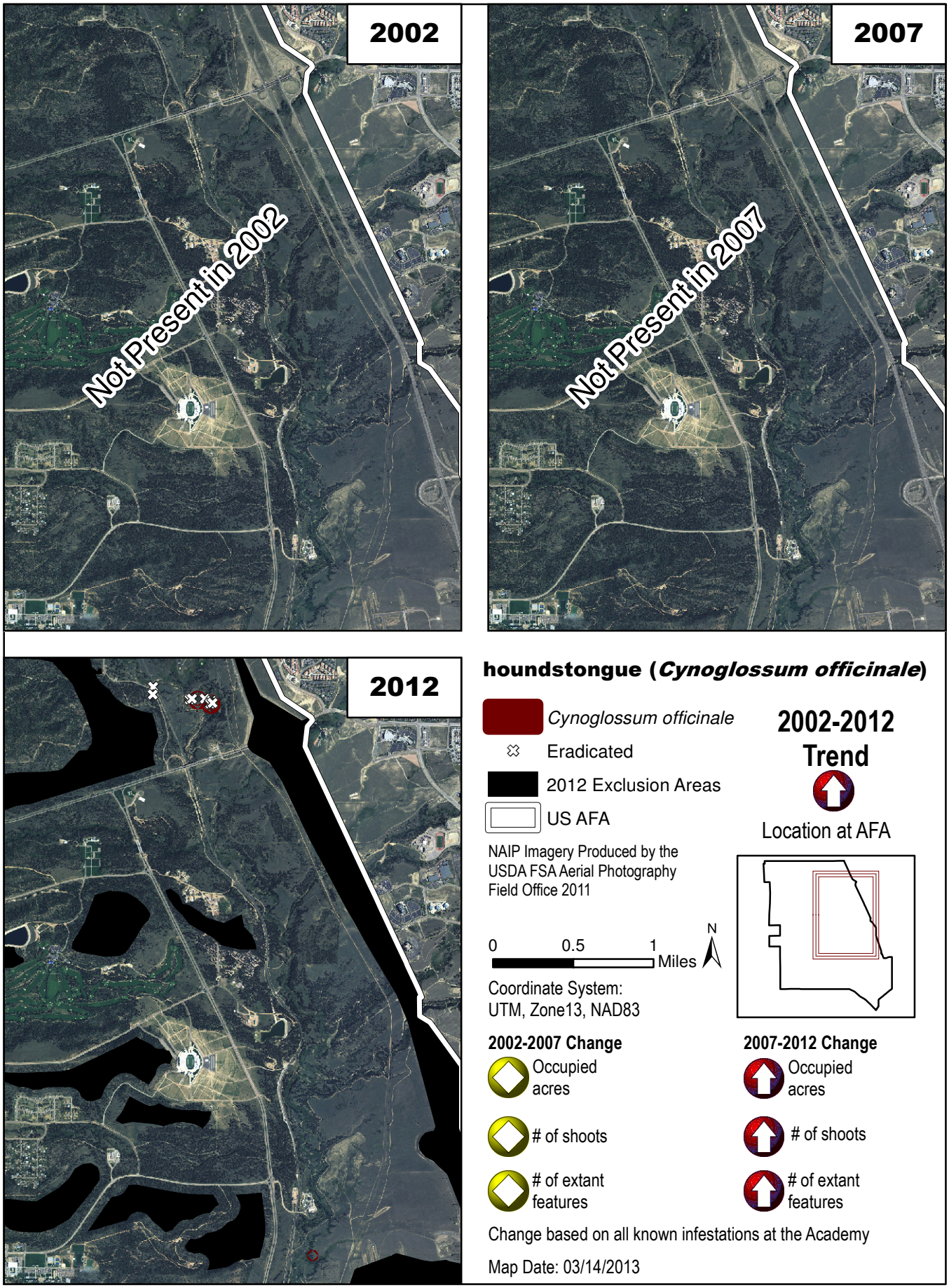
Houndstongue occupied less than 0.01 acres with an estimated 70 shoots at three distinct mapped areas (Table 28, Map 20).

Houndstongue was not discovered until 2009 (Rondeau et al. 2010) when eight areas were mapped. The northern occurrences were aggressively treated with herbicide and hand pulling in 2010 and 2011, with a noticeable decrease in the number of individuals and sites (Rondeau and Lavender 2012). The seed bank is most likely surviving at these sites and continued monitoring along with vigilant management is required.

This is an excellent example of the effectiveness of a rapid response, and although it may be challenging to completely eliminate this species from the Academy, little effort is needed to keep it under control.

Table 28. All infestations of houndstongue at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**NA**	**NA**	**0.01**
Estimated Number of Shoots	**NA**	**NA**	**70**
Number of Extant Features	**NA**	**NA**	**3**
Number of Eradicated Features	NA	NA	9



Map 20. Distribution of houndstongue at the Academy in 2002, 2007, and 2012.

Fuller's Teasel (*Dipsacus fullonum*)

Photo by Michelle Washebek

Spreading and has expanded into North Monument Creek. Aggressive treatment of outliers is recommended.

Fuller's teasel occupied 9.3 acres in 2012, just slightly less than 2007 and around 50% less than in 2002 (Table 29). While the trend in occupied acres was slightly downwards between 2007 and 2012, the number of shoots and extant mapped areas steadily increased with a 118% and 76% increase respectively (Table 7, Figure 17).

In 2002 and 2007, the distribution of Fuller's teasel at the Academy was concentrated in the southern portion of Monument Creek and along Kettle Creek. By 2012 there was a major northward migration up Monument Creek in addition to a few new outliers west of Monument Creek (Map 21). Its invasion has been limited to wetlands, riparian areas, and areas kept wet by runoff or lawn watering at the Academy.

This species has the ability to invade nearly all of the wet areas within the Academy. We recommend that the outlier populations (west of Monument Creek) be treated aggressively to reduce the rate of spread into uncontaminated wetlands.

Table 29. All infestations of Fuller's teasel at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**18.33**	**10.51**	**9.26**
Estimated Number of Shoots	**1,693**	**53,454**	**116,595**
Number of Extant Features	**35**	**181**	**319**
Number of Eradicated Features	NA	0	65

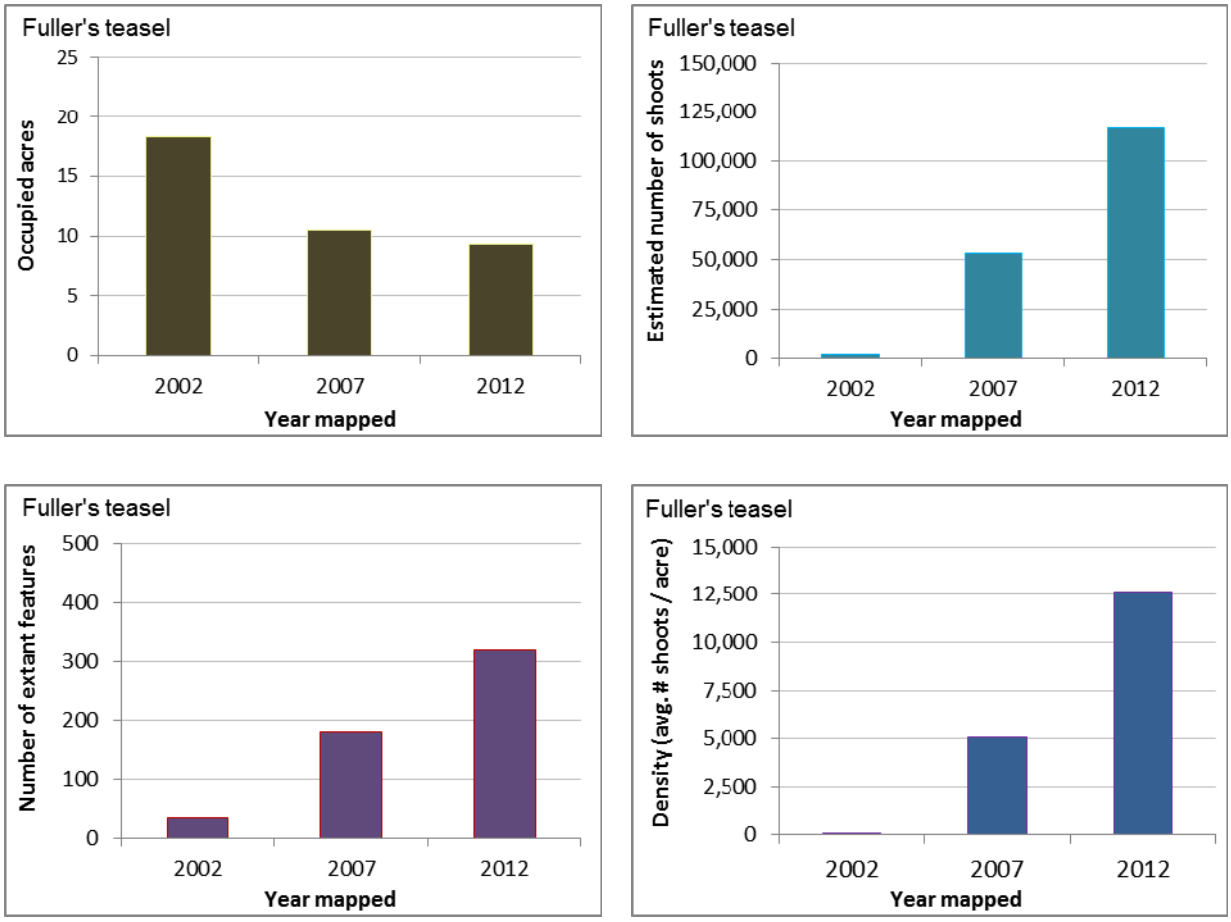
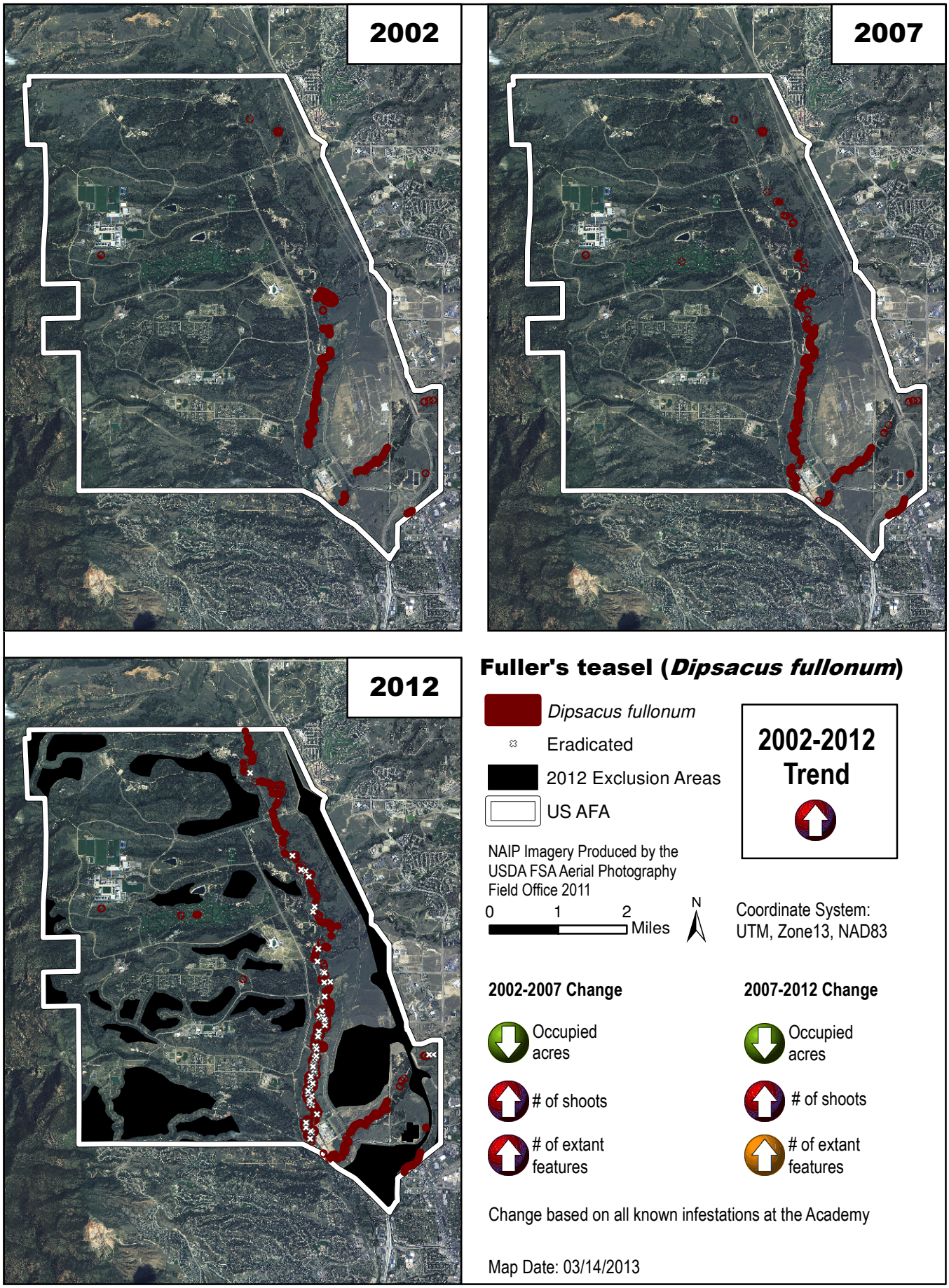


Figure 17. Fuller's teasel trend, 2002-2012.



Map 21. Distribution of Fuller's teasel at the Academy in 2002, 2007, and 2012.

Russian Olive (*Elaeagnus angustifolia*)

Decreasing due to aggressive management but vigilance is necessary.

Photo by Michelle Washebek

Russian olive occupied 11 acres in 2012, a 19% decrease from 2007 (Tables 7 and 30). However, there was an increase in number of shoots (5%) and extant features (75%) over the same time period (Tables 7 and 30, Figure 18). In 2012, nearly a dozen new sites were mapped in the area just south of the classrooms (Map 22).

The control of Russian olive is one of the greatest weed management success stories at the Academy. Treatment of this species in 2003 and 2004 was highly successful (Map 22). This species has been nearly eradicated in much of the Academy, compared to 2002, but continued eradication efforts are needed to eliminate this species.

Table 30. Infestations of Russian olive within comparable designated mapping areas at the U.S. Air Force Academy.

	2002†	2007	2012
Occupied Acres	**38.70**	**13.30**	**10.80**
Estimated Number of Shoots	**1,079**	**531**	**557**
Number of Extant Features	**216**	**89**	**154**
Number of Eradicated Features	NA	129	173

†2002 values are sums of 2002 and 2003 mapping

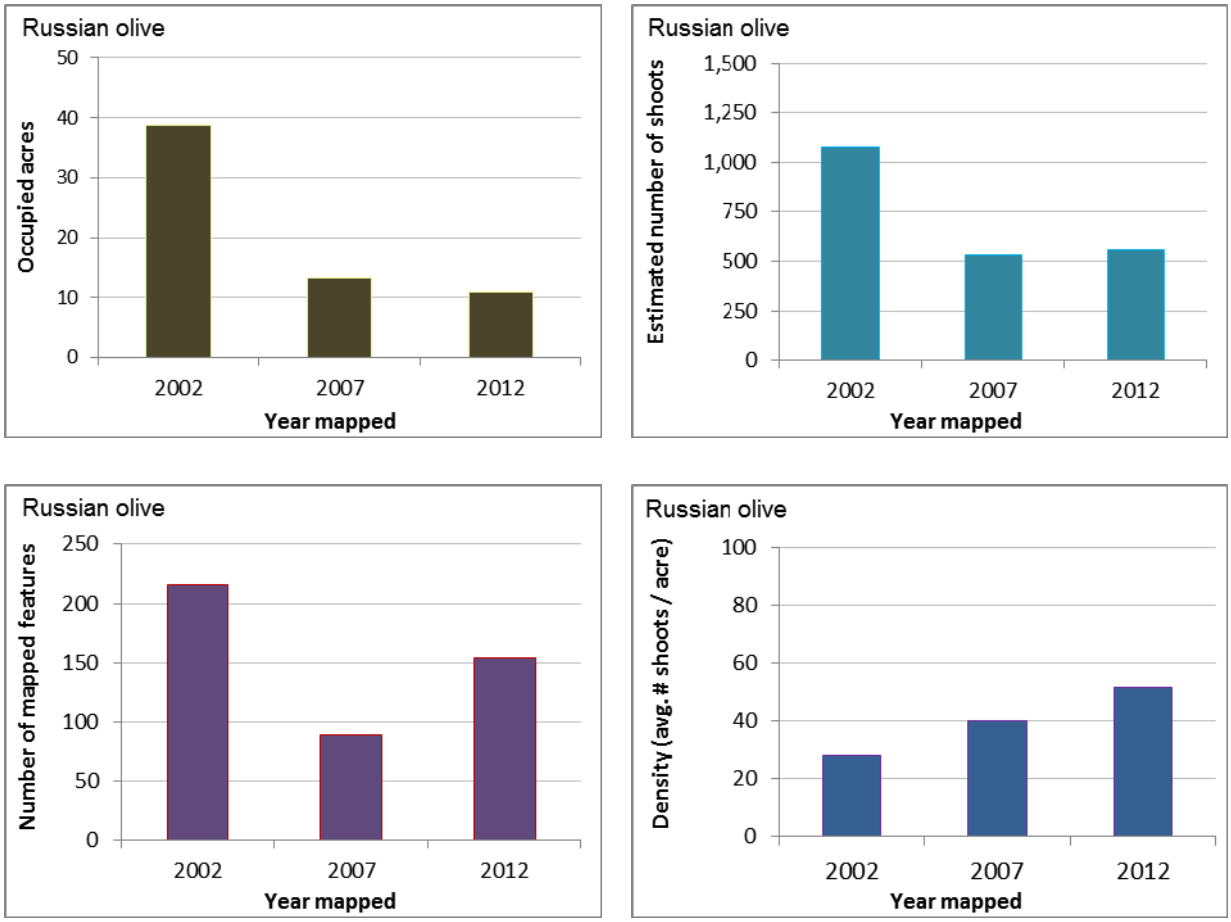
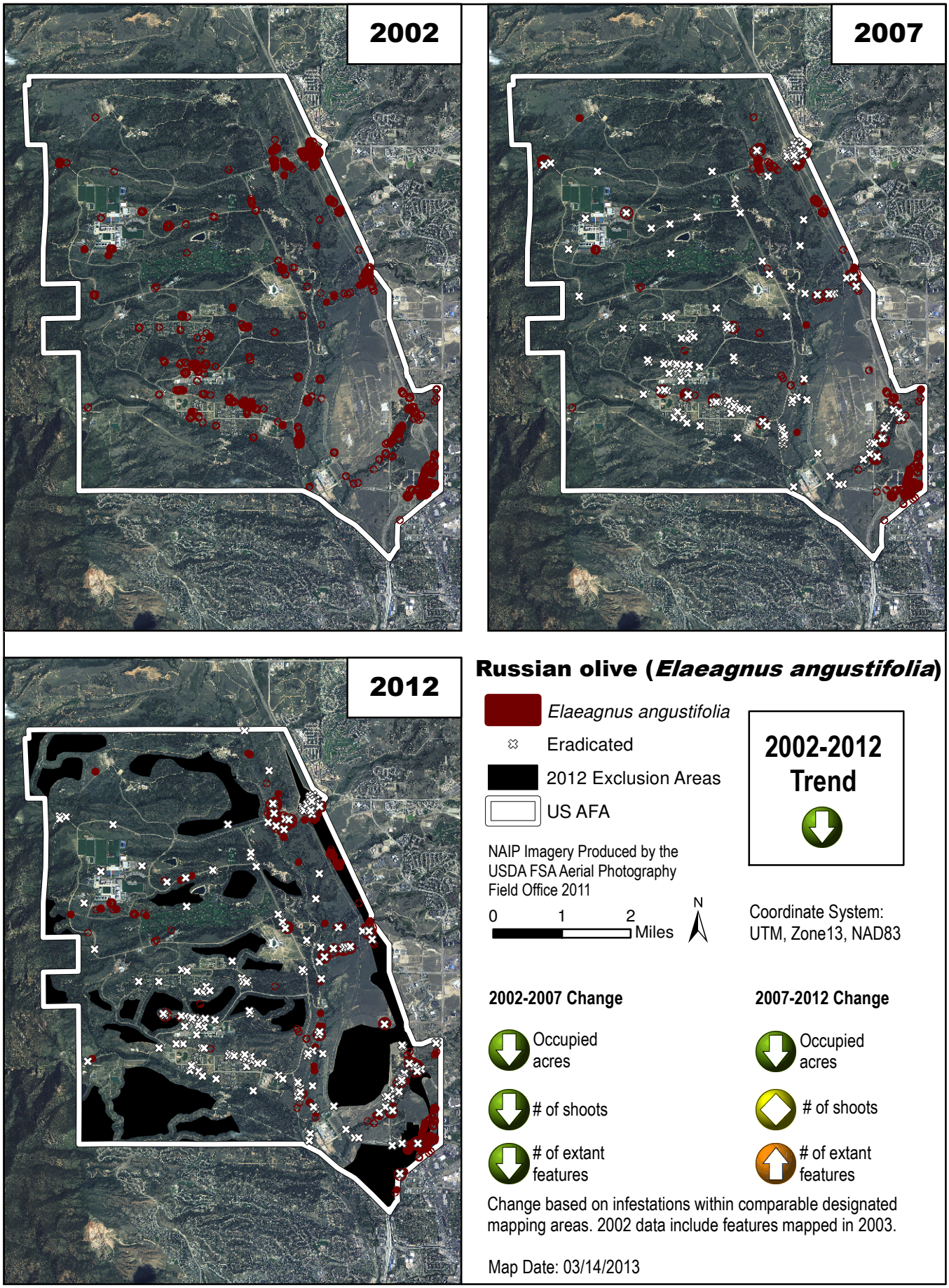


Figure 18. Russian olive trend, 2002-2012.

Some infestations at the Academy were documented by Natural Resources Staff and previous weed surveys in areas that were not targeted in 2012. The full scope of known infestations is detailed below.

Table 31. All infestations of Russian olive at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**49.77**	**18.96**	**16.27**
Estimated Number of Shoots	**1,344**	**641**	**689**
Number of Extant Features	**275**	**117**	**193**
Number of Eradicated Features	NA	156	200



Map 22. Distribution of Russian olive at the Academy in 2002, 2007, and 2012.

Leafy Spurge (*Euphorbia esula*)

Increasing and spreading south. Focus on outlier populations as eradication is not likely feasible.

Photo by Michelle Washebek

Leafy spurge occupied 11 acres in 2012, an increase of 3 acres since 2007 (Table 32). The number of shoots decreased by18%, but the number of extant mapped areas increased by 34% in the same time period (Tables 7 and 32, Figure 19). Over a dozen new populations were mapped in 2012 in the southeastern portion of the Academy (Map 23).

Despite aggressive management with herbicide and biocontrol, the footprint of leafy spurge at the Academy continues to increase. 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's 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).

Until 2007, leafy spurge was concentrated in the northwest portion of the Academy property in the vicinity of Jacks Valley and around the cadet area. By 2012, this species was migrating south (Map 23). Eradication of this species is probably not a realistic goal, but high priority areas to treat are the outliers and rare plant occurrences.

Table 32. Infestations of leafy spurge within comparable designated mapping areas at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**0.91**	**7.58**	**10.64**
Estimated Number of Shoots	**28,338**	**336,337**	**275,713**
Number of Extant Features	**32**	**152**	**204**
Number of Eradicated Features	NA	2	30

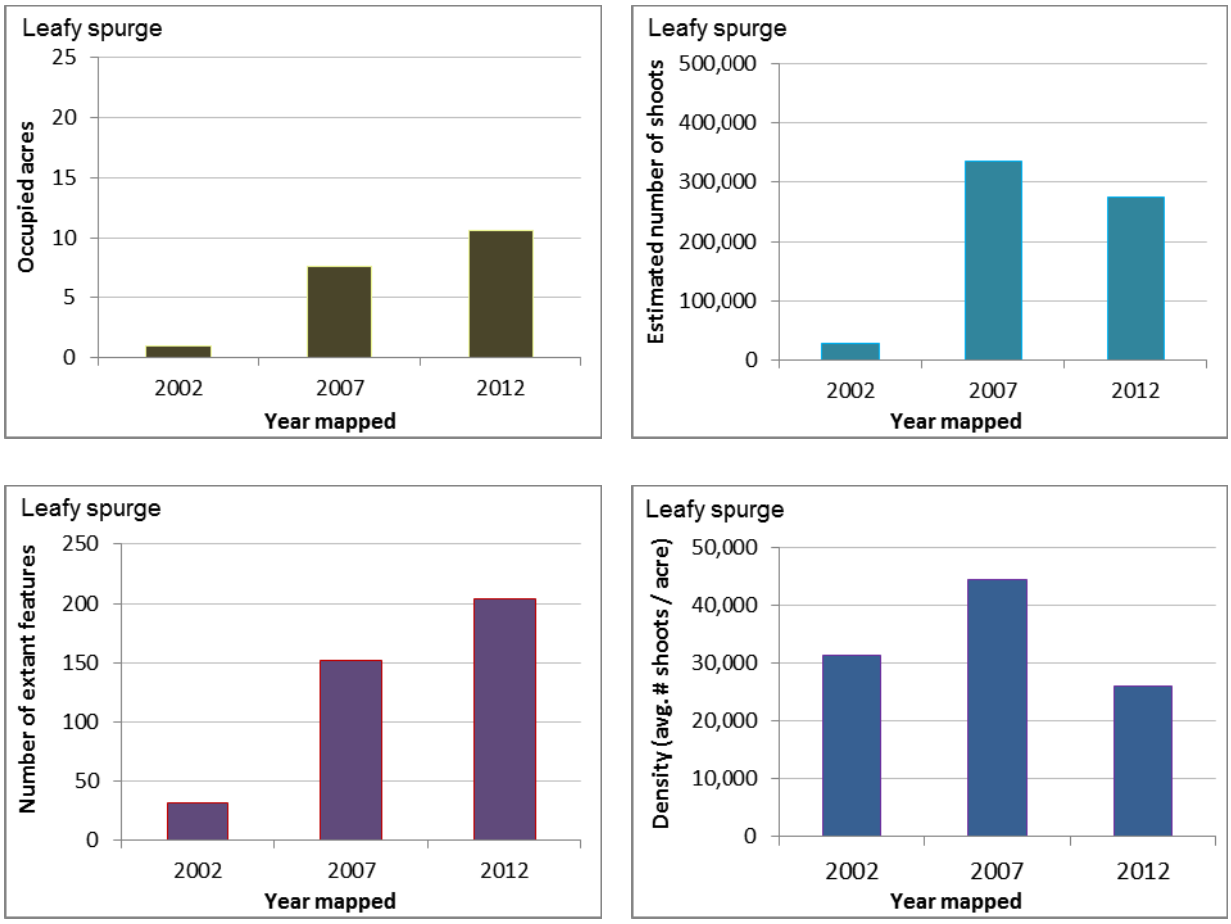


Figure 19. Leafy spurge trend at the U.S. Air Force Academy, 2002-2012.

Some infestations at the Academy were documented by Natural Resources Staff and previous weed surveys in areas that were not targeted in 2012. The full scope of known infestations is detailed below.

Table 33. All infestations of leafy spurge at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**1.09**	**8.21**	**11.97**
Estimated Number of Shoots	**35,387**	**372,666**	**327,018**
Number of Extant Features	**38**	**162**	**215**
Number of Eradicated Features	NA	2	30

At Farish, a small infestation of leafy spurge remained outside the boundary in 2012 (Map 24) and had not spread into the facility. This infestation is also a very high priority for eradication; however, it is located on adjacent lands and control may not be possible without the cooperation of the land owners.

Table 34. All infestations of leafy spurge near Farish Outdoor Recreation Area.

	2002	2007	2012
Occupied Acres	**NA**	**0.03**	**0.03**
Estimated Number of Shoots	**NA**	**113**	**113**
Number of Extant Features	**NA**	**1**	**1**
Number of Eradicated Features	NA	0	0

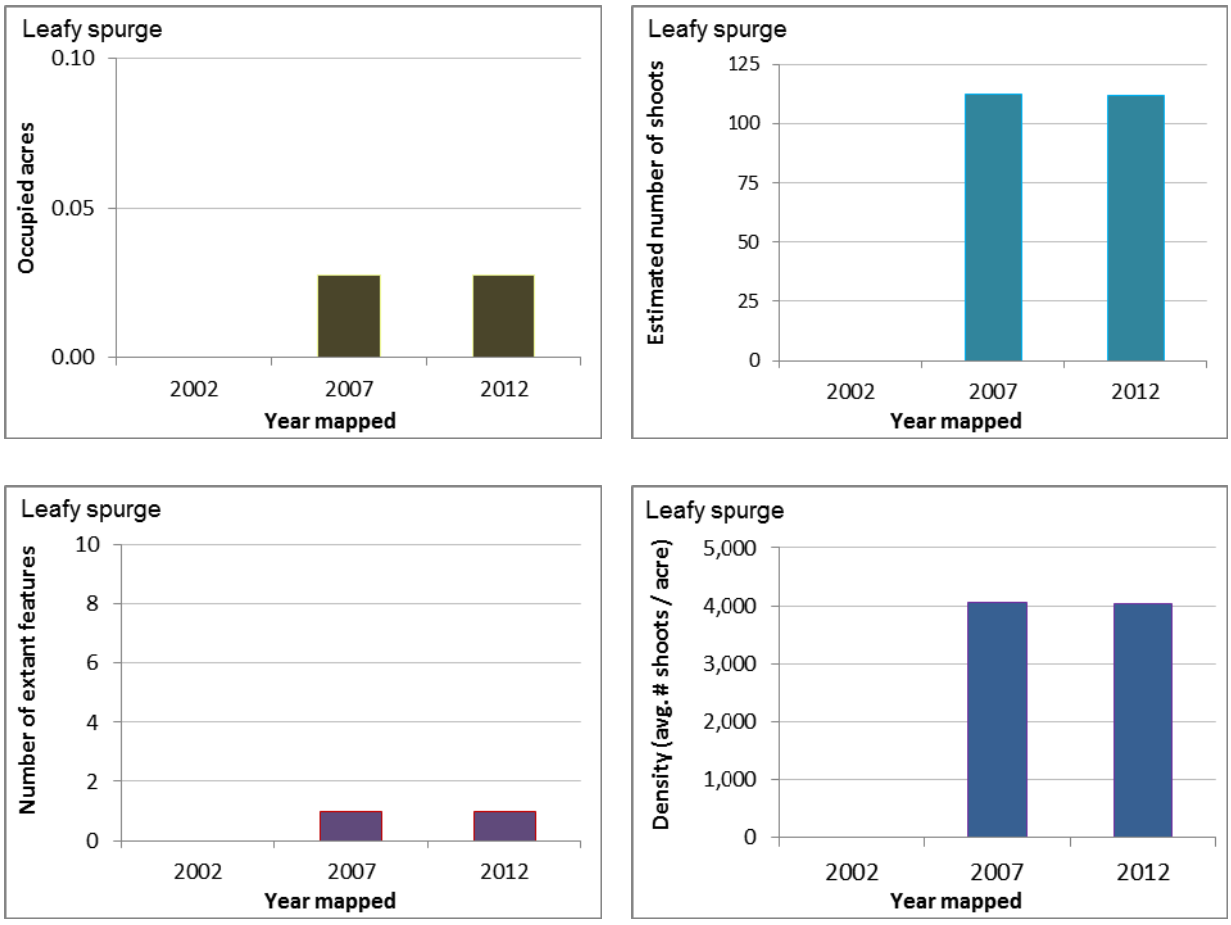
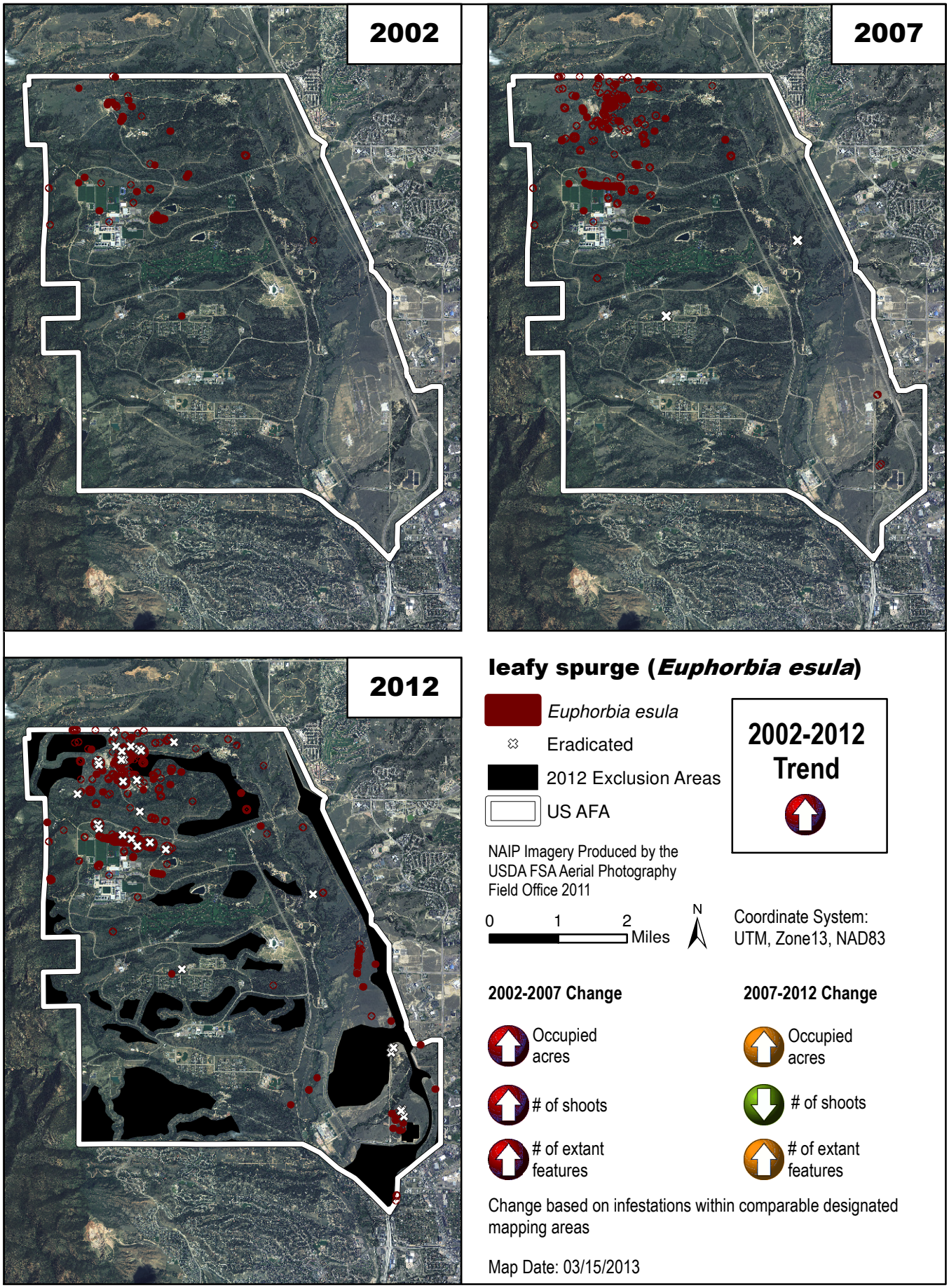
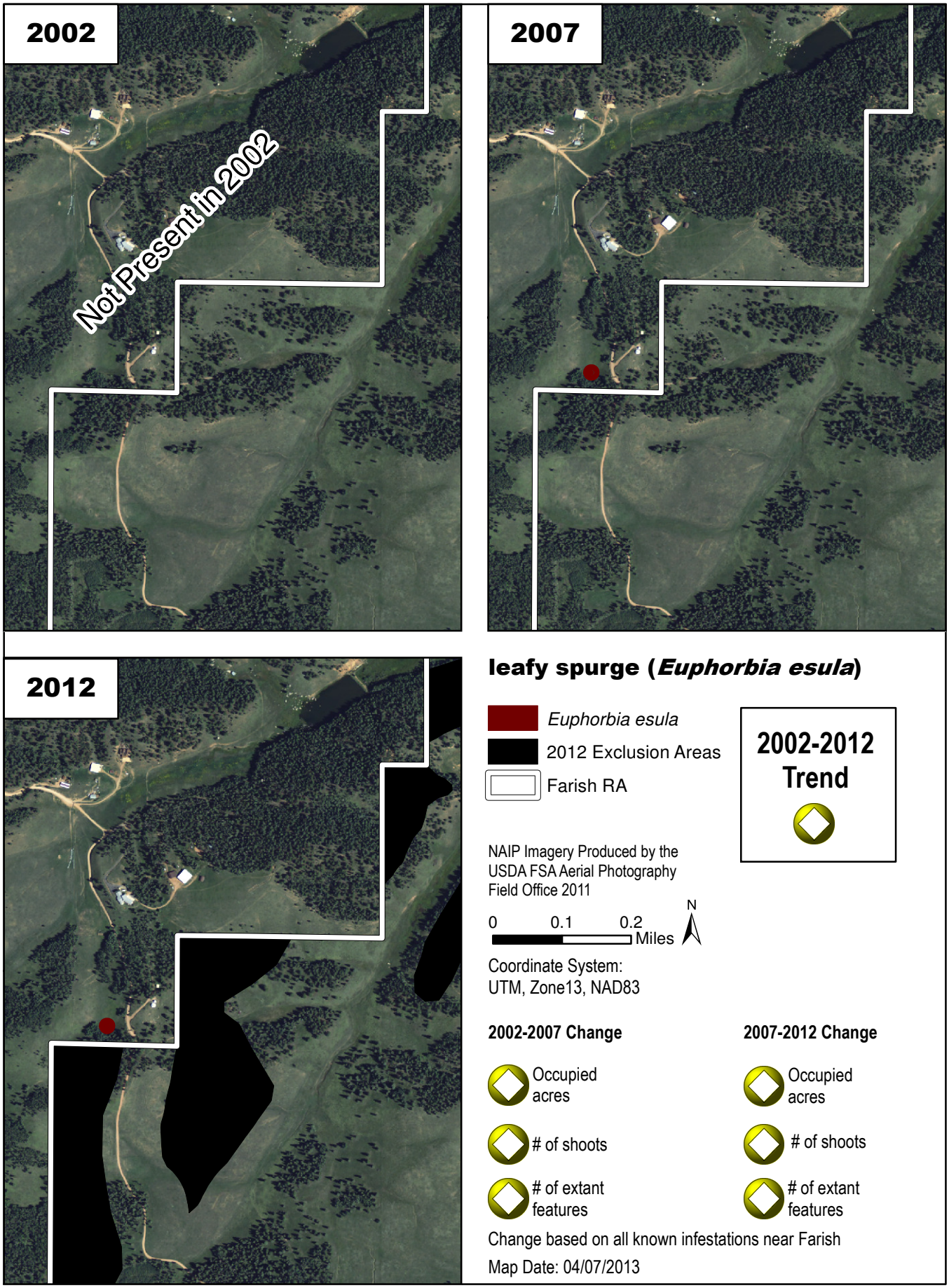


Figure 20. Leafy spurge trend at Farish Outdoor Recreation Area, 2002-2012.



Map 23. Distribution of leafy spurge at the Academy in 2002, 2007, and 2012.



Map 24. Distribution of leafy spurge near Farish Outdoor Recreation Area in 2002, 2007, and 2012.

Myrtle Spurge (Euphorbia myrsinites)

Low cover but continues to spread into new territory. Eradication is still possible.

Photo by David Anderson

Myrtle spurge occupied nearly ¼ of an acre in 2012, a 30% increase from 2007 (Tables 7 and 35). The number of shoots decreased by 90% and extant mapped features increased 43% over the same time period (Tables 7 and 35, Figure 21). Although it occupies very little area on the Academy, it is widely spread (Map 25).

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 2005). Fortunately, Natural Resources Staff at the Academy identified the presence of myrtle spurge at an early stage of its invasion, and progress is being made towards its eradication. The soils seed reserve is estimated to be eight years and must be monitored for at least nine years after the last flowering adult plants have been eliminated (Colorado Department of Agriculture 2013). The key to effective control is to remove plants prior to seed set. Mechanical treatment is known to be effective. All known extant infestations of this species have been and will continue to be monitored (Rondeau and Lavender Greenwell 2013).

Table 35. All infestations of myrtle spurge at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**NA**	**0.18**	**0.23**
Estimated Number of Shoots	**NA**	**1,021**	**113**
Number of Extant Features	**NA**	**7**	**10**
Number of Eradicated Features	NA	0	25

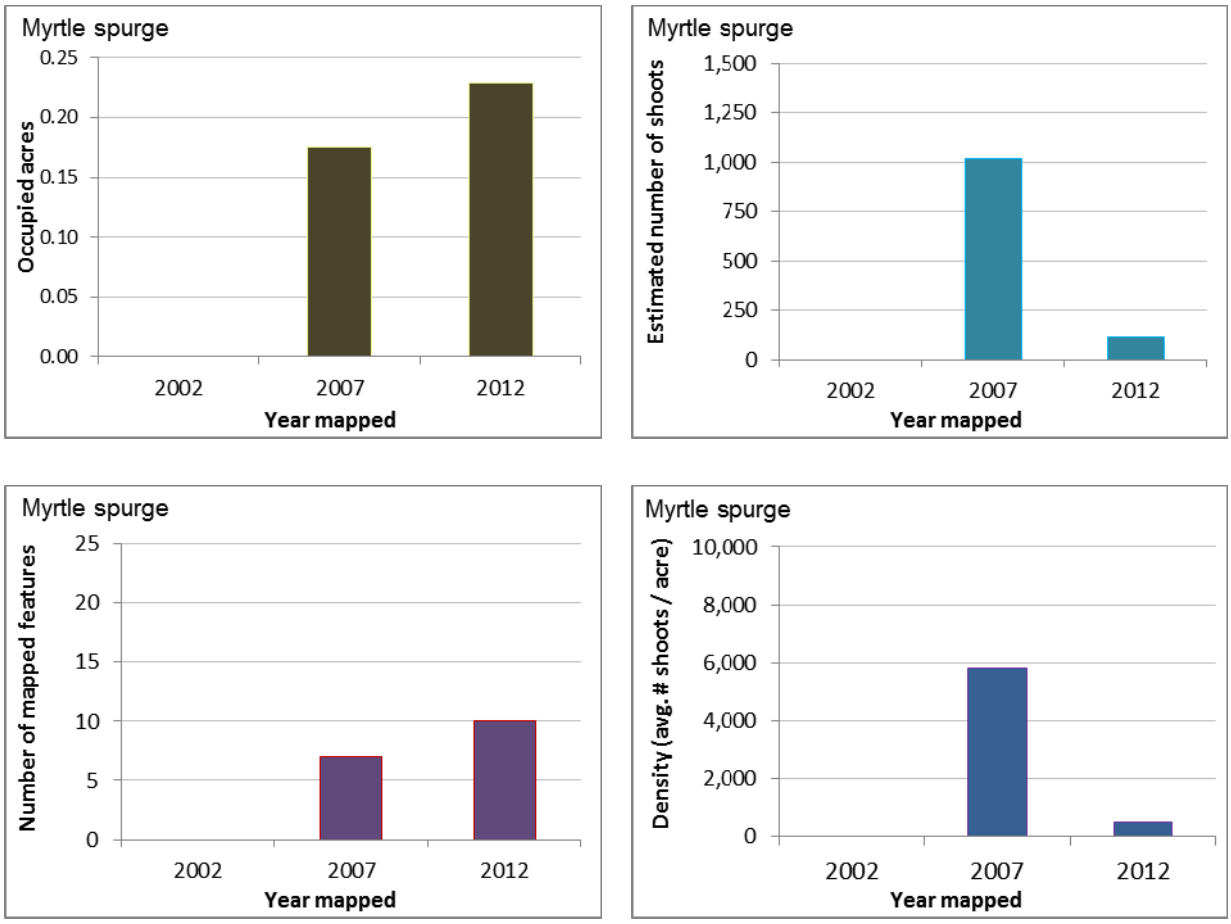
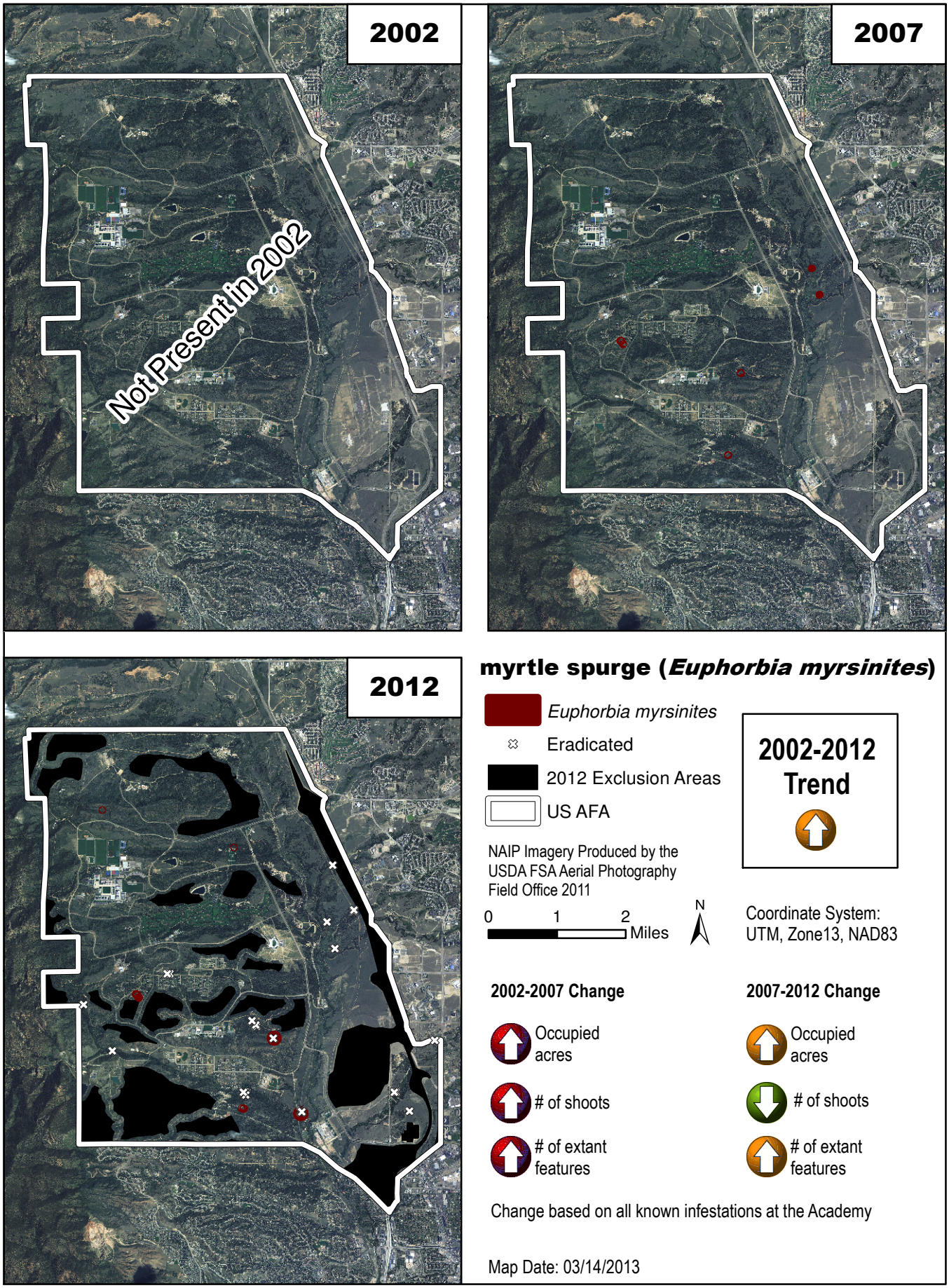


Figure 21. Myrtle spurge trend, 2002-2012.



Map 25. Distribution of myrtle spurge at the Academy in 2002, 2007, and 2012.

Yellow Spring Bedstraw (*Galium verum*)

Wikipedia photo

Low cover from two known sites. Eradication is possible with aggressive treatment.

Yellow spring bedstraw occupied 0.01 acres in 2012, with 566 estimated shoots over the two separate and extant sites (Table 36, Map 26).

This species was first discovered in 2010 and immediately eradicated from the one known site (Rondeau et al. 2011). The 2012 mapping project discovered two new and extant sites while the original site was still free of this weed. A high priority should be placed on eradicating this species as it is still in a responsive stage.

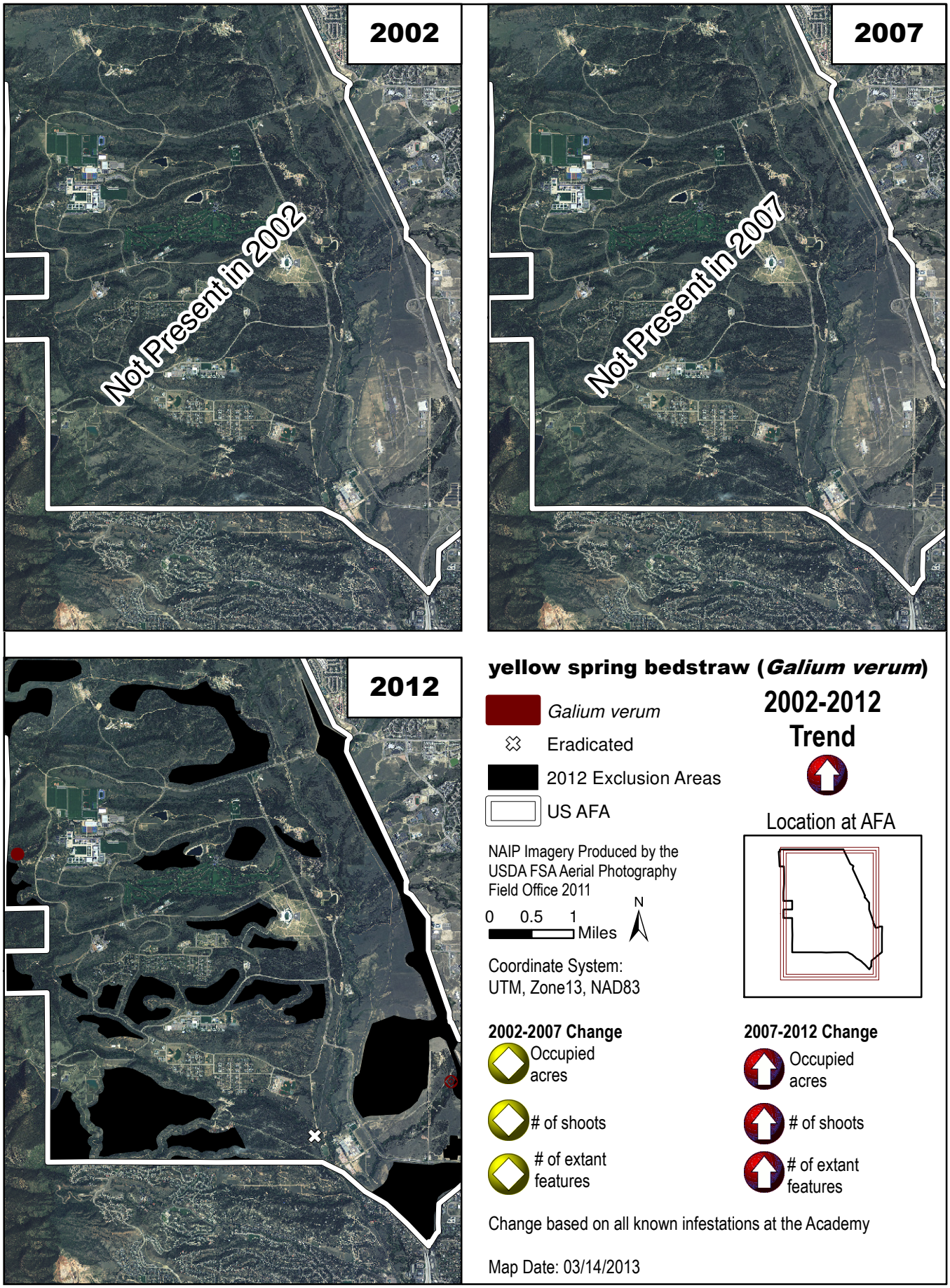
Table 36. All infestations of yellow spring bedstraw at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**NA**	**NA**	**0.01**
Estimated Number of Shoots	**NA**	**NA**	**566**
Number of Extant Features	**NA**	**NA**	**2**
Number of Eradicated Features	NA	NA	1

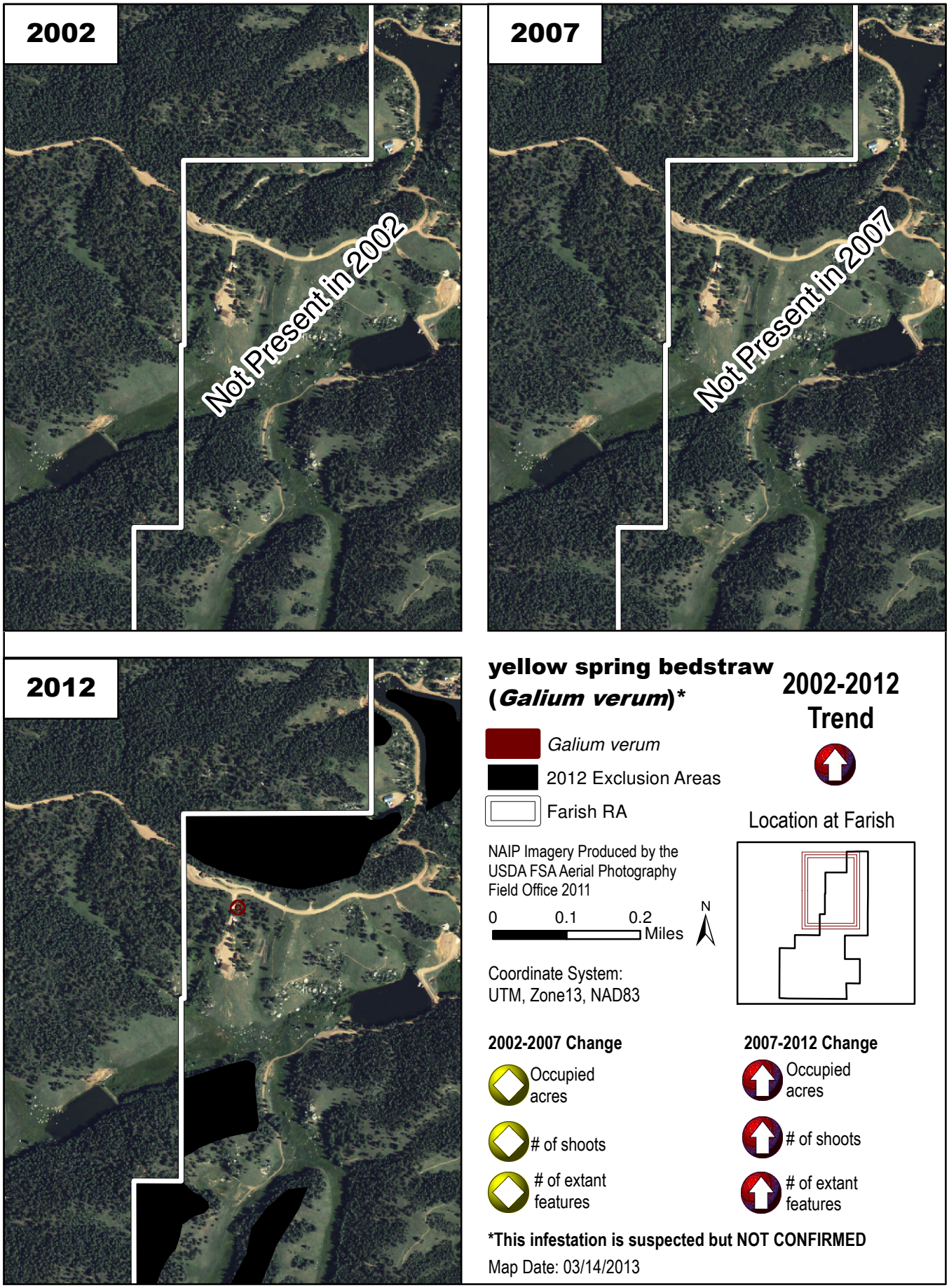
At Farish, one point was potentially documented (Table 37, Map 27). This should be checked in 2013 and if it is present, then eradication is critical.

Table 37. All infestations of yellow spring bedstraw at Farish Outdoor Recreation Area.

	2002	2007	2012
Occupied Acres	**NA**	**NA**	**<0.01**
Estimated Number of Shoots	**NA**	**NA**	**3**
Number of Extant Features	**NA**	**NA**	**1**
Number of Eradicated Features	NA	NA	0



Map 26. Distribution of yellow spring bedstraw at the Academy in 2002, 2007, and 2012.



Map 27. Distribution of yellow spring bedstraw at Farish Outdoor Recreation Area in 2002, 2007, and 2012.

Dames Rocket (*Hesperis matronalis*)

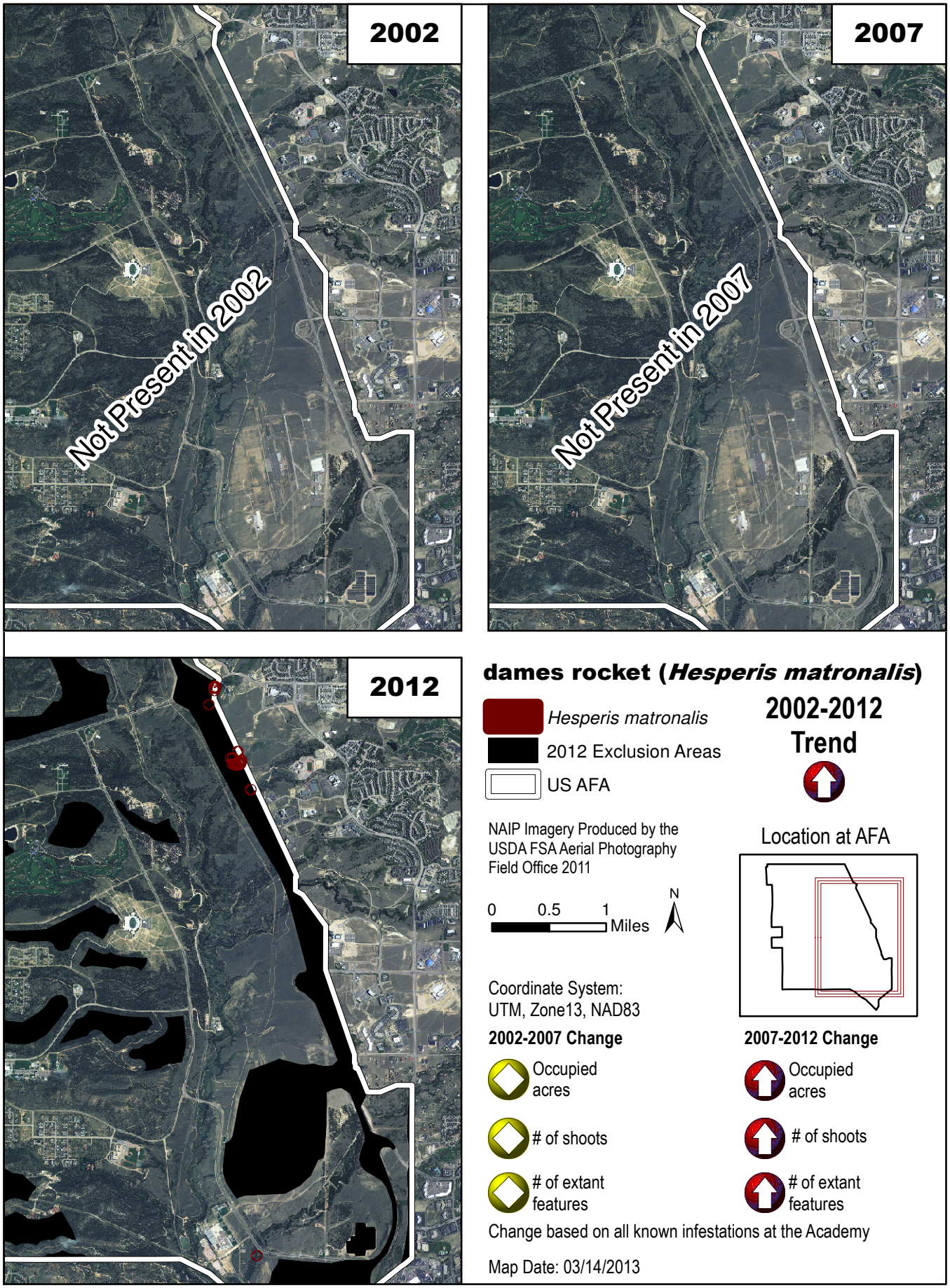
Newly discovered in 2012 and eradication is possible. Note outlier population in the south.

Photo by Brian Mihlbachler

Dames rocket was first mapped at the Academy during this project; it occupies 0.83 acres with 16,871 shoots in 14 distinct locations (Table 38, Map 28). Most of these occurrences are very close to I-25. Eradication should be possible and therefore this species is a high priority for control. We will also add it to the yearly monitoring list.

Table 38. All infestations of dames rocket at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**NA**	**NA**	**0.83**
Estimated Number of Shoots	**NA**	**NA**	**16,871**
Number of Extant Features	**NA**	**NA**	**14**
Number of Eradicated Features	NA	NA	NA



Map 28. Distribution of dames rocket at the Academy in 2002, 2007, and 2012.

Common St. Johnswort (*Hypericum perforatum*)

On the rise but control is possible with aggressive treatment.

Photo by Renée Rondeau

Common St. Johnswort occupied 1.2 acres in 2012, a 34% increase from 2007 (Tables 7 and 39). Number of shoots increased by 86% and the extant mapped areas was nearly 2 times greater in the same time period (Tables 7 and 39, Figure 22, Map 29). This species is monitored annually and a full description of annual variation and response to treatments are described (Rondeau and Lavender Greenwell 2013).

The distribution of common St. Johnswort at the Academy is primarily 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) 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; however, the occurrence is still present.

Despite these successes, additional infestations of common St. Johnswort were discovered along Kettle Creek in 2007, illustrating that this species was continuing to spread at the Academy (Map 29). The infested area increased considerably between 2002 and 2007 (Table 39) but all of the management efforts are managing to keep this species from becoming a widespread weed. This species has been monitored annually by CNHP and in 2008 and 2009 common St. Johnswort had a significant upward trend in number of individuals and occupied area, in spite of the control efforts (Rondeau and Lavender 2012). In 2010, the Natural Resources staff decided to increase the herbicide treated area to ensure that the spread was curtailed (Rondeau and Lavender 2012). These efforts appear to be working to stabilize the weed infestation. Since it is still occupies around 1 acre, we believe this should remain a top priority for control and that yearly visits and treatments are necessary.

Table 39. All infestations of common St. Johnswort at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**<0.10	0.86	1.16
Estimated Number of Shoots	**363	44,745	83,115
Number of Extant Features	**5	10	29
Number of Eradicated Features	NA	0	10

**values from field notes; not mapped in GIS

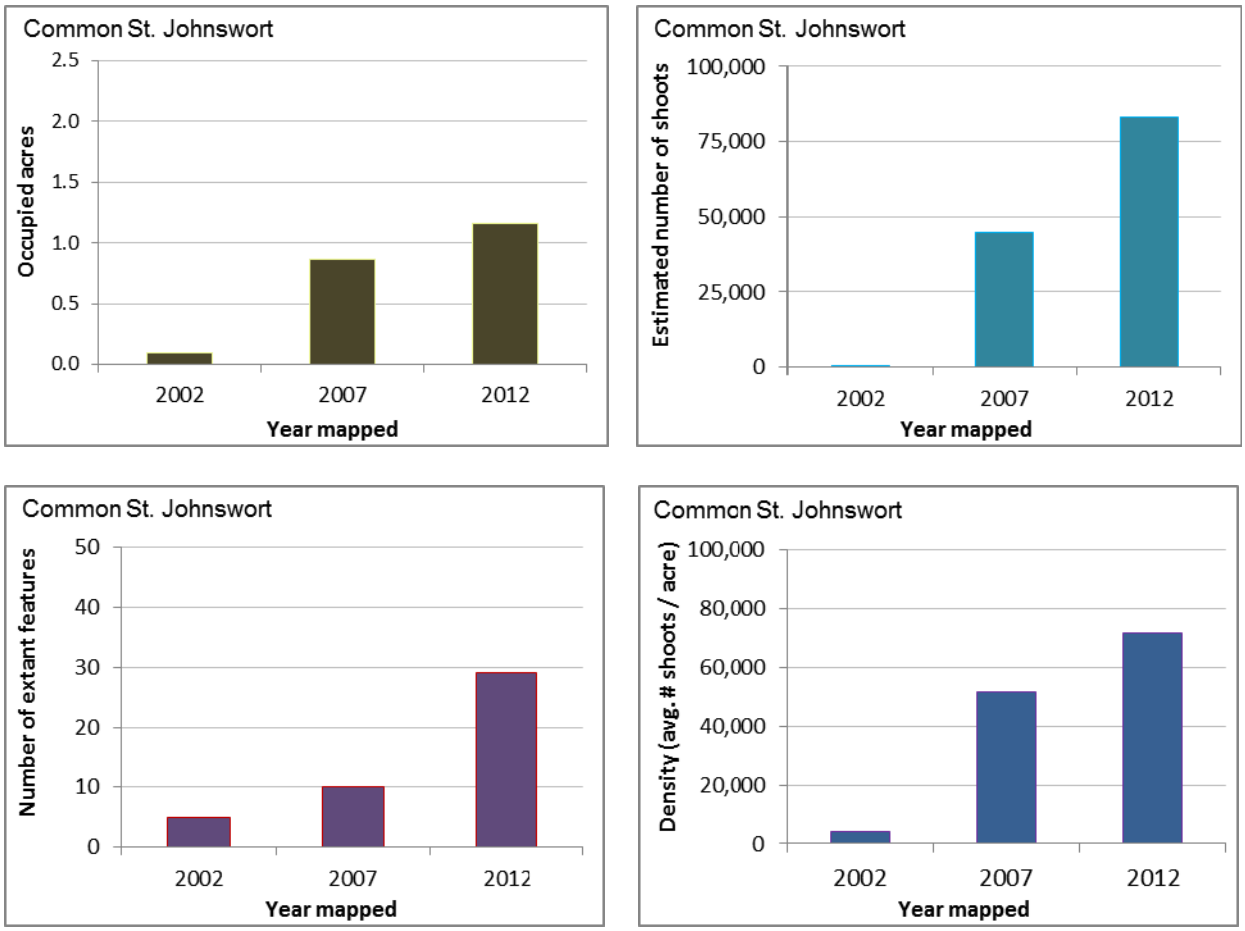
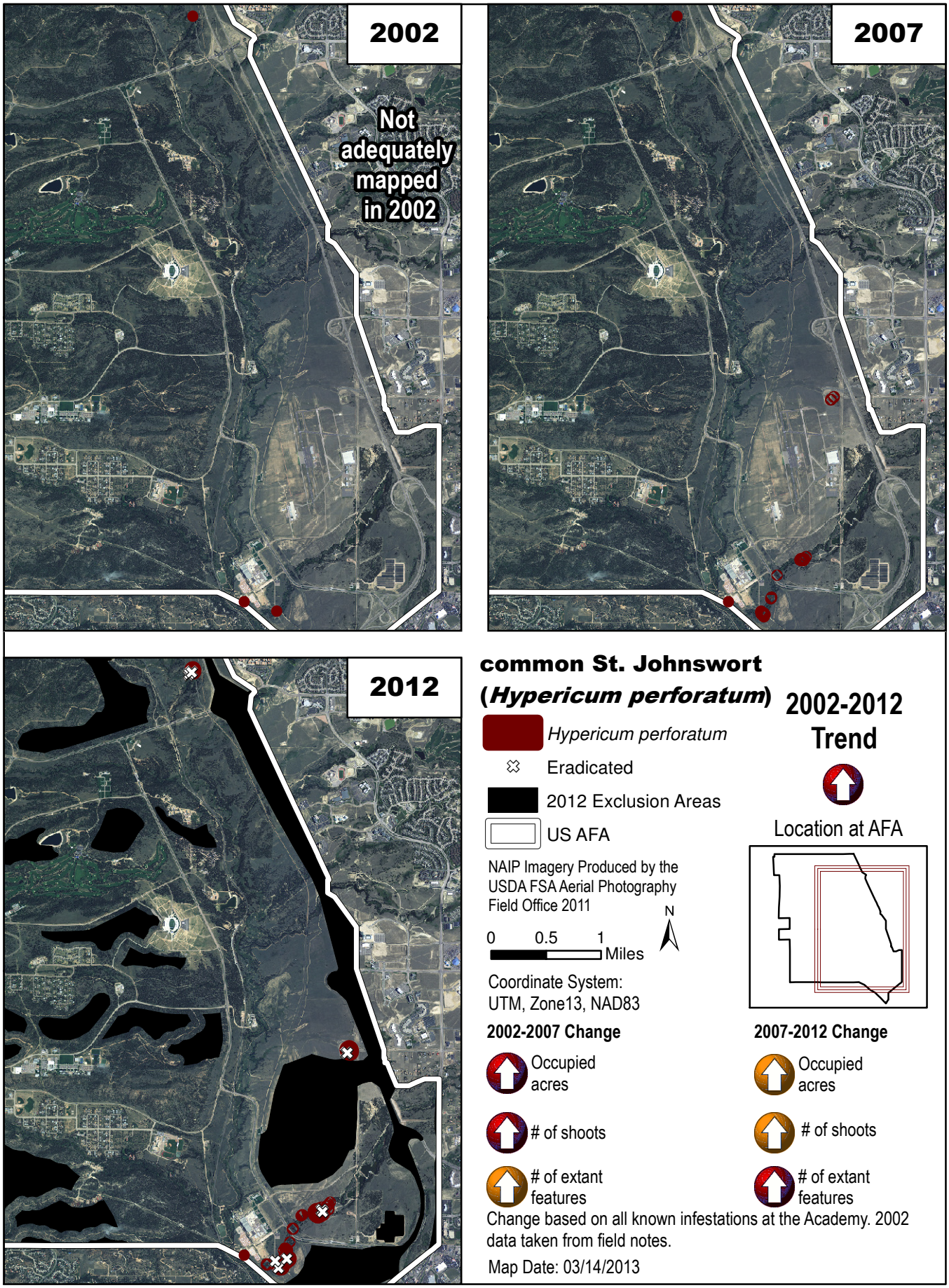


Figure 22. Common St. Johnswort trend, 2002-2012.



Map 29. Distribution of common St. Johnswort at the Academy in 2002, 2007, and 2012.

Dalmatian Toadflax (Linaria genistifolia spp. dalmatica)

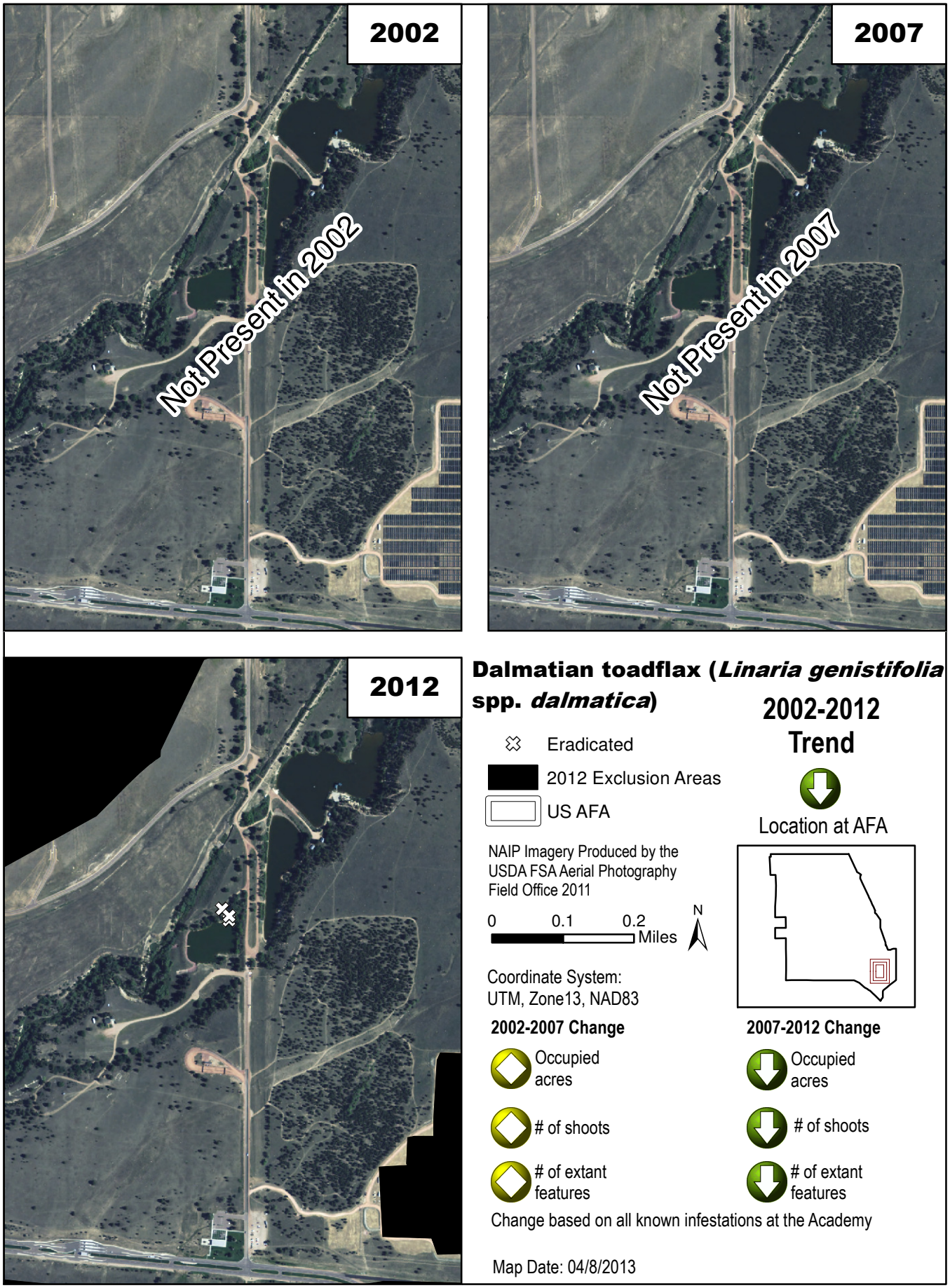
Wikipedia photo

Appears to be eradicated but vigilant monitoring is required.

Dalmatian toadflax did not occupy any acres in 2012 (Table 40). This species was discovered at the Academy in 2009 with one occurrence found near Kettle Lake #1 near the boat ramp. In 2010 there were two patches (Map 30). The AFA Natural Resources staff sprayed the plants in 2010 and no plants have been observed since. This is an excellent example of how early detection and rapid response leads to success (Rondeau and Lavender 2012). CNHP will continue to visit these sites during their annual weed monitoring.

Table 40. All infestations of Dalmatian toadflax at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**NA**	**NA**	**0**
Estimated Number of Shoots	**NA**	**NA**	**0**
Number of Extant Features	**NA**	**NA**	**0**
Number of Eradicated Features	NA	NA	3



Map 30. Distribution of Dalmatian toadflax at the Academy in 2002, 2007, and 2012.

Yellow Toadflax (*Linaria vulgaris*)

Increasing at Farish and so widespread that comprehensive mapping is no longer cost effective. (This arrow is stable for AFA)

Photo by Michelle Washebek

Yellow toadflax was the most abundant noxious weed at the Academy and Farish in occupied acreage, number of shoots, and number of mapped features in 2007 (Anderson and Lavender 2008). It is present in low densities throughout most of the Academy in a wide range of habitats and it has become entrenched at the Academy and is now impossible to eradicate. In 2012 we conducted a presence/absence subsample at AFA and Farish to see if we could detect any trend (Table 41). A Fischer's exact test between two years, 2002-2007, 2002-2012, and 2007-2012 found that the only significant change ($P<0.05$) was at Farish between 2007-2012 ($P=0.03$) with an increase between 2007 and 2012 (Table 41).

Table 41. Yellow toadflax results.

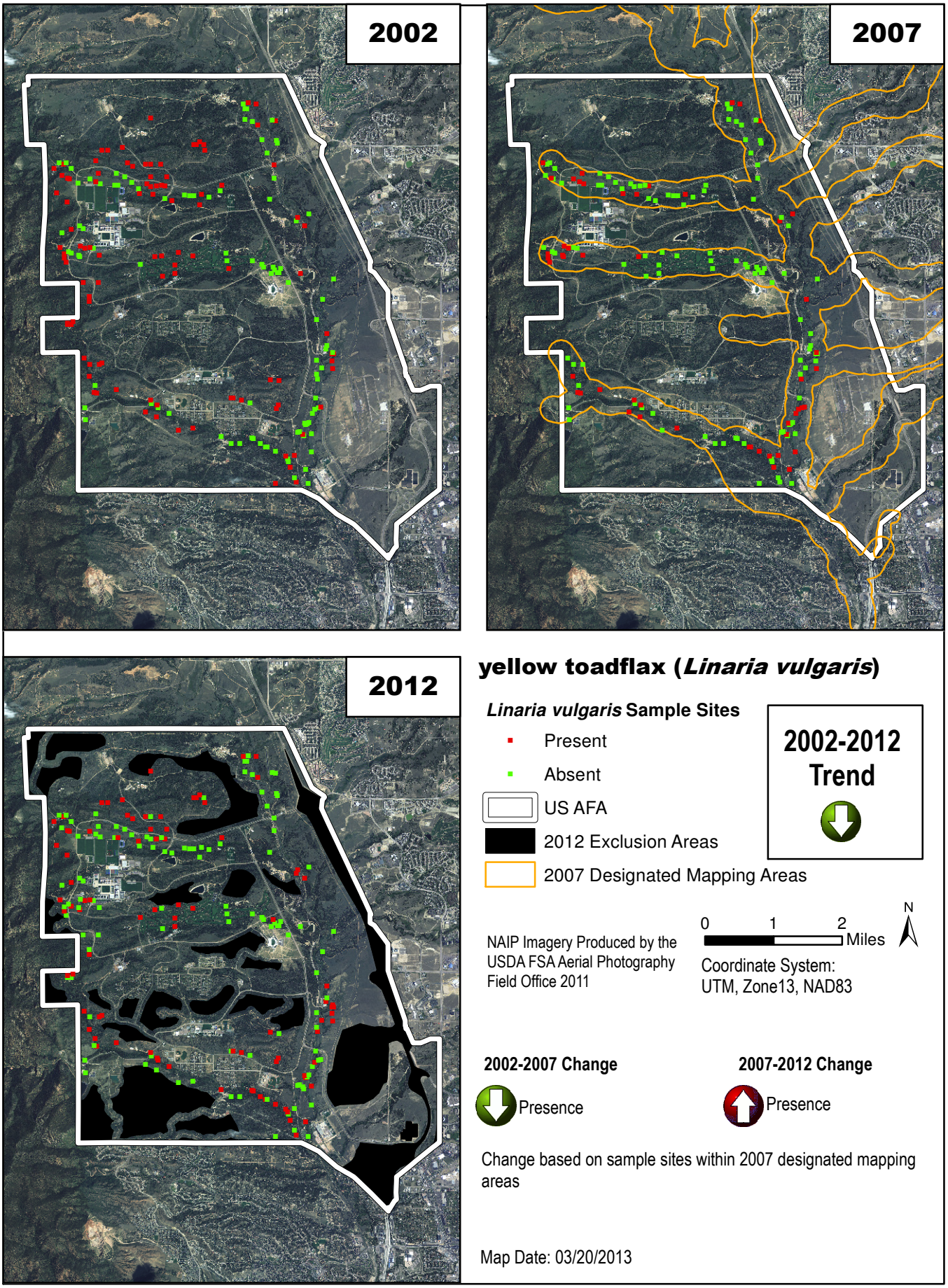
Area/Year	Present	Absent	# Sample Sites
AFA 2012	89	111	200
AFA 2002	103	97	200
Fischer's Exact Test 2002-2012 P-value =0.19			
Farish 2012	18	2	20
Farish 2007	11	9	20
Farish 2002	16	4	20
Fischer's Exact Test 2002-2007 = 0.18			

Area/Year	Present	Absent	# Sample Sites
2002-2012 = 0.66 2007-2012 = **0.03**			
Within Monument Creek and I-25 Shamrock PCAs (159 sample sites overlap these areas)			
AFA 2012	62	97	159
AFA 2007	51	108	159
AFA 2002	66	93	159
Fischer's Exact Test 2002-2007 = 0.1 2002-2012 = 0.7 2007-2012 = 0.2			

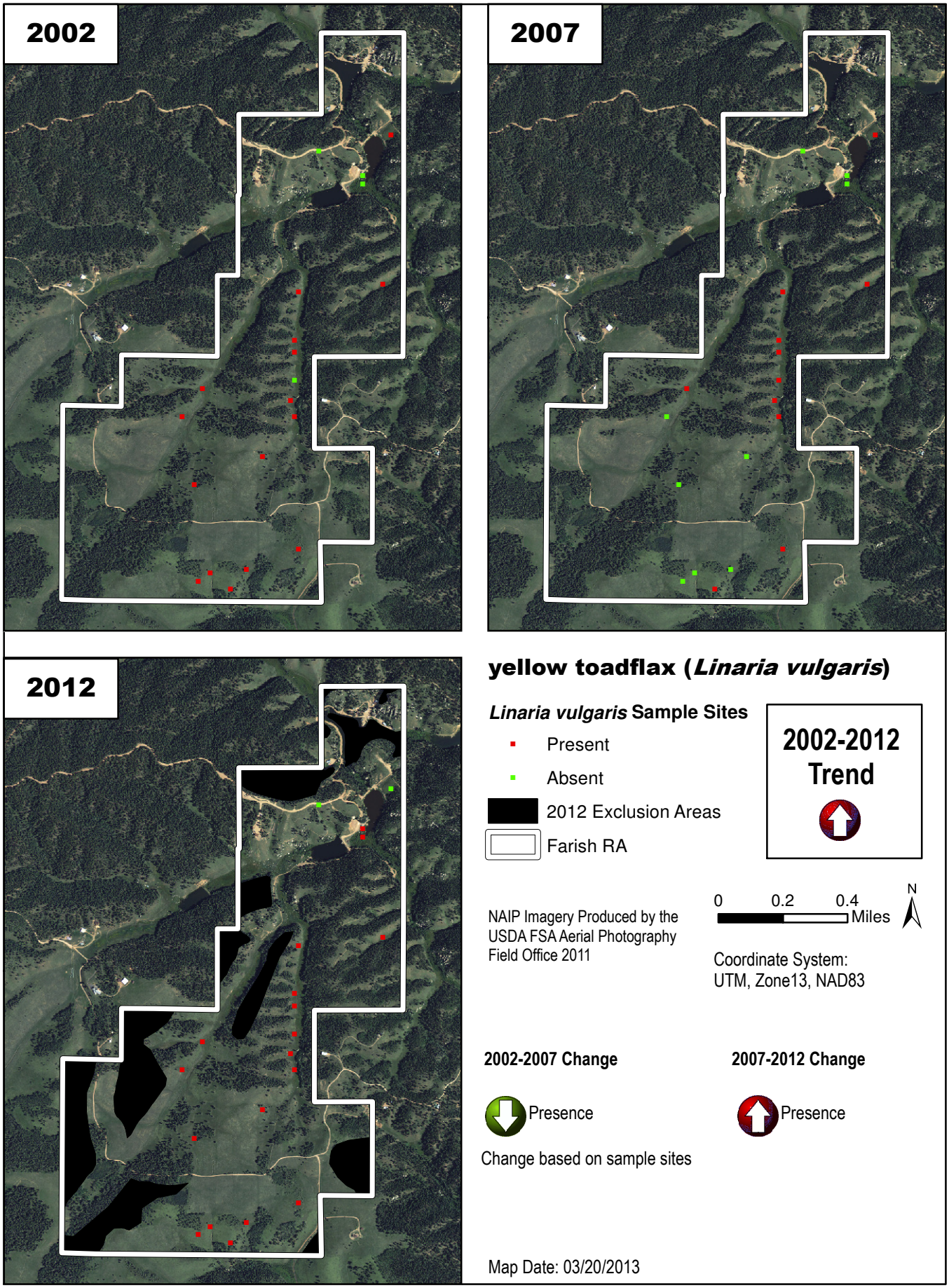
At Farish, yellow toadflax is also very common but it appears that it has not yet spread to all available habitats. We saw the same trend, that is, there was significantly higher number of points that had Linaria present in 2012 than in 2007 and since 2007 had more moisture available, we believe there is an upward trend at Farish. In 2011, we established permanent monitoring points at Farish in order to detect change and we had mixed results (Rondeau and Lavender 2012). We recommend resampling the Farish plots within the next few years.

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.

Biocontrol agents are being applied to select locations with unknown results at this point (Michels et al. 2013).



Map 31. Presence of yellow toadflax within sample sites at the Academy in 2002, 2007, and 2012.



Map 32. Presence of yellow toadflax within sample sites at Farish Outdoor Recreation Area in 2002, 2007, and 2012.

Tatarian Honeysuckle (*Lonicera tatarica*)

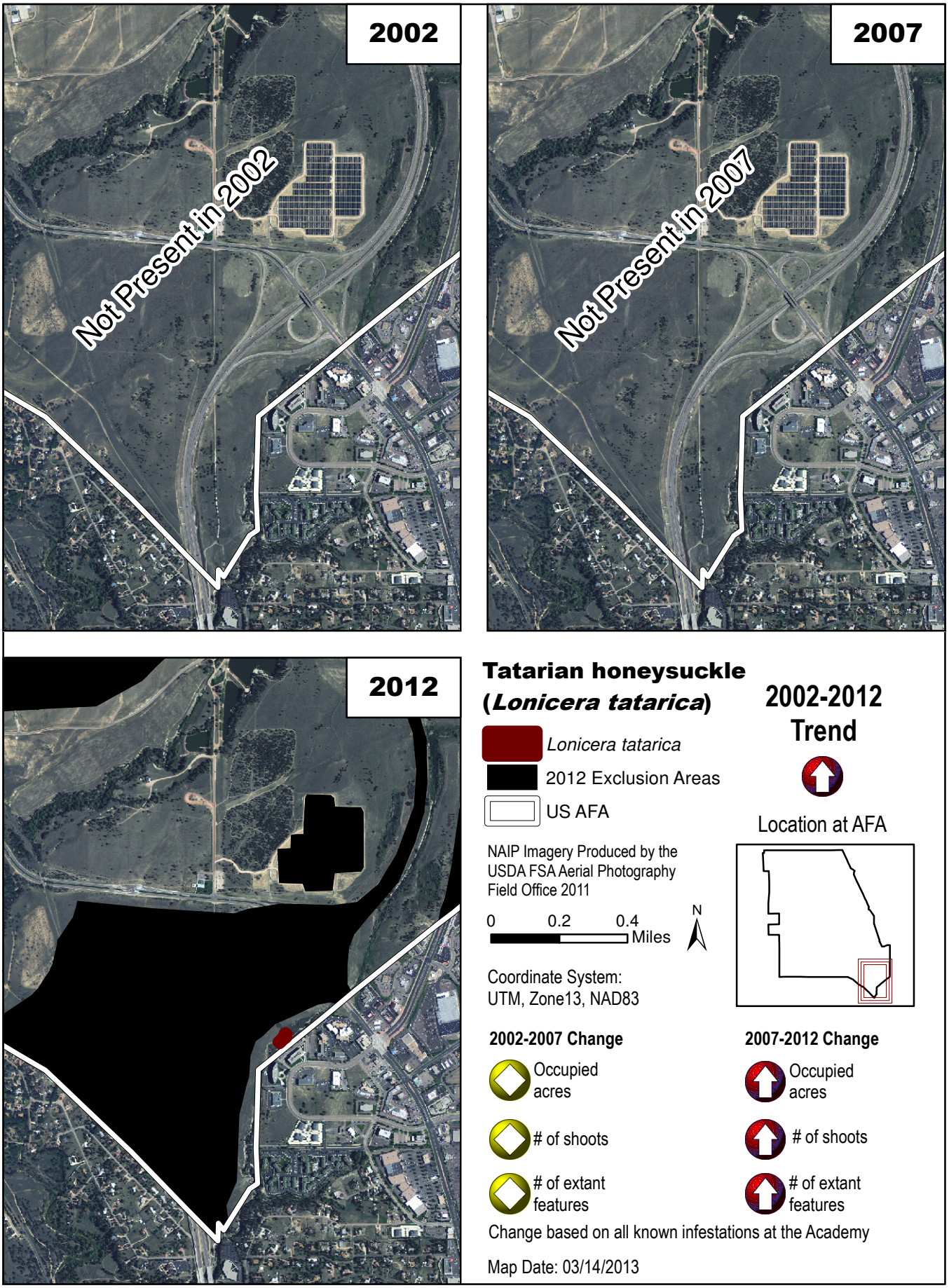
Only present at one location so eradication is possible. Pulling is recommended due to nearby rare plant.

Wikipedia photo

Tatarian honeysuckle occupied 0.15 acres with approximately 30 individuals at one site in 2012 (Table 42). This species was first discovered at the Academy near the eastern boundary (Map 33) in 2008, embedded with the state rare plant *Ribes americanum*. The invasion of Tatarian honeysuckle is a concern due to its potential to dominate the site at the exclusion of the rare currant. Since this site is sensitive to herbicide spraying, pulling plants is likely the best way to control this infestation. Weed technicians should be informed of the presence of the rare plant prior to pulling weeds. Plants may need to be pulled for three to five years to fully eradicate the honeysuckle, but success is high if the weed is targeted early on in its establishment and the site is monitored annually for resprouting (Batcher and Stiles 2000).

Table 42. All infestations of Tatarian honeysuckle at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**NA**	**NA**	**0.15**
Estimated Number of Shoots	**NA**	**NA**	**30**
Number of Extant Features	**NA**	**NA**	**1**
Number of Eradicated Features	NA	NA	0



Map 33. Distribution of Tatarian honeysuckle at the Academy in 2002, 2007, and 2012.

Scotch Thistle (*Onopordum acanthium*)

Increasing and expanding in its distribution. Treatment has been successful at slowing the spread of this weed.

Photo by David Anderson

Scotch thistle occupied 0.3 acres in 2012, a significant reduction from the 1.3 acres mapped in 2007 and a 77% increase from 2002 (Tables 7 and 43). The number of shoots decreased 32% between 2007 and 2012 (Tables 7 and 43, Figure 23). The number of extant mapped features is the only indicator that increased between 2007 and 2012 (83%). Several new areas were mapped in 2012 (Map 34).

Scotch thistle is monitored annually by CNHP (Rondeau and Lavender 2012), and the 2012 mapping effort added new sites that will be part of the annual monitoring. The Natural Resources staff at the Academy has been treating this weed aggressively via herbicide treatment and pulling. These efforts are slowing the invasion and although it may be hard to eradicate this species it does appear possible to keep the infested acres to a manageable size. We highly recommend that all infestations be visited and controlled every year. Where treatment has been thorough, we see a significant reduction in number of individuals. Early detection and rapid response is an excellent management plan for this species. This plant has a tap root and can be pulled easily, especially when it is young. This is an effective measure for small infestations, ideally prior to flowering.

Table 43. All infestations of Scotch thistle at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**0.17	1.31	0.3
Estimated Number of Shoots	**52	1,307	889
Number of Extant Features	**7	36	66
Number of Eradicated Features	NA	0	73

**values from field notes; not mapped in GIS

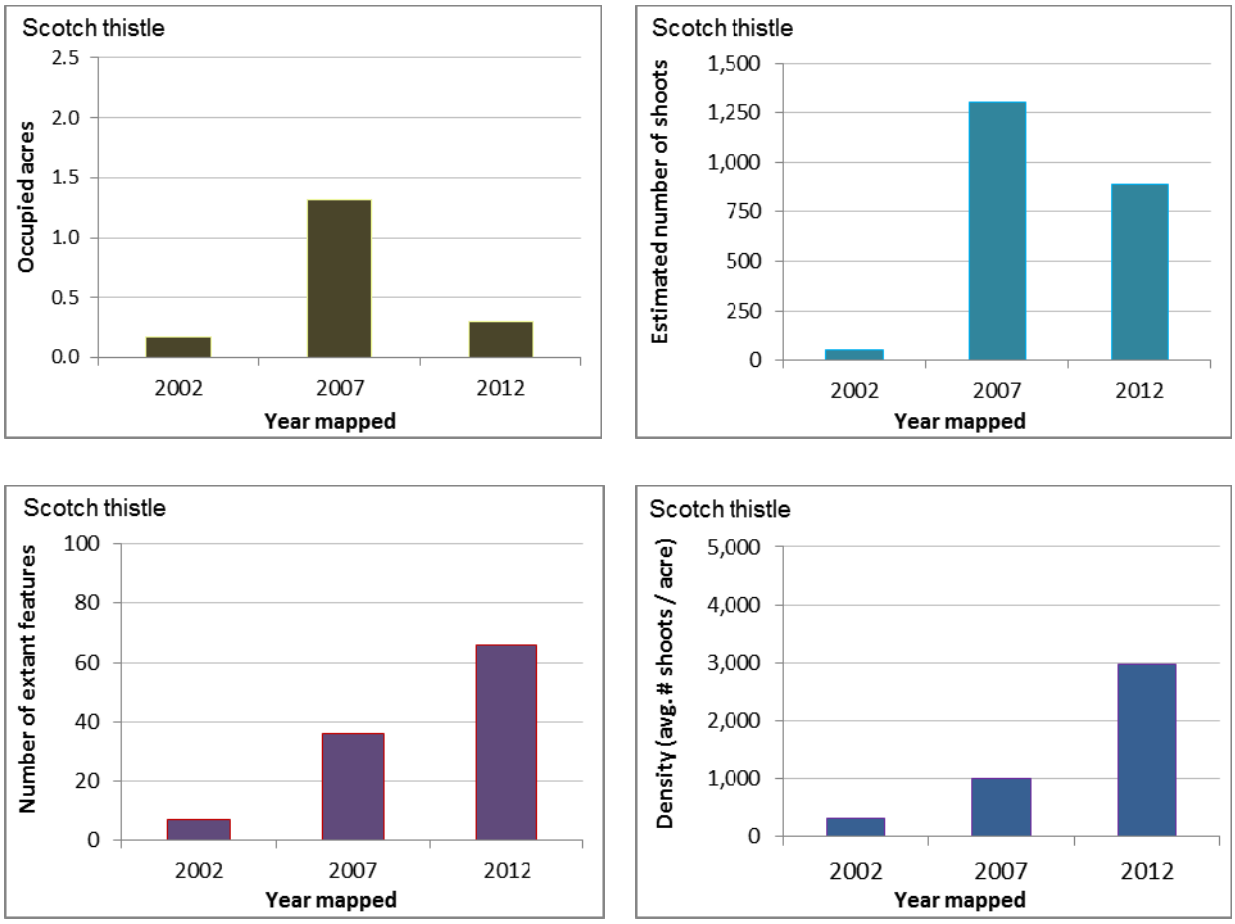
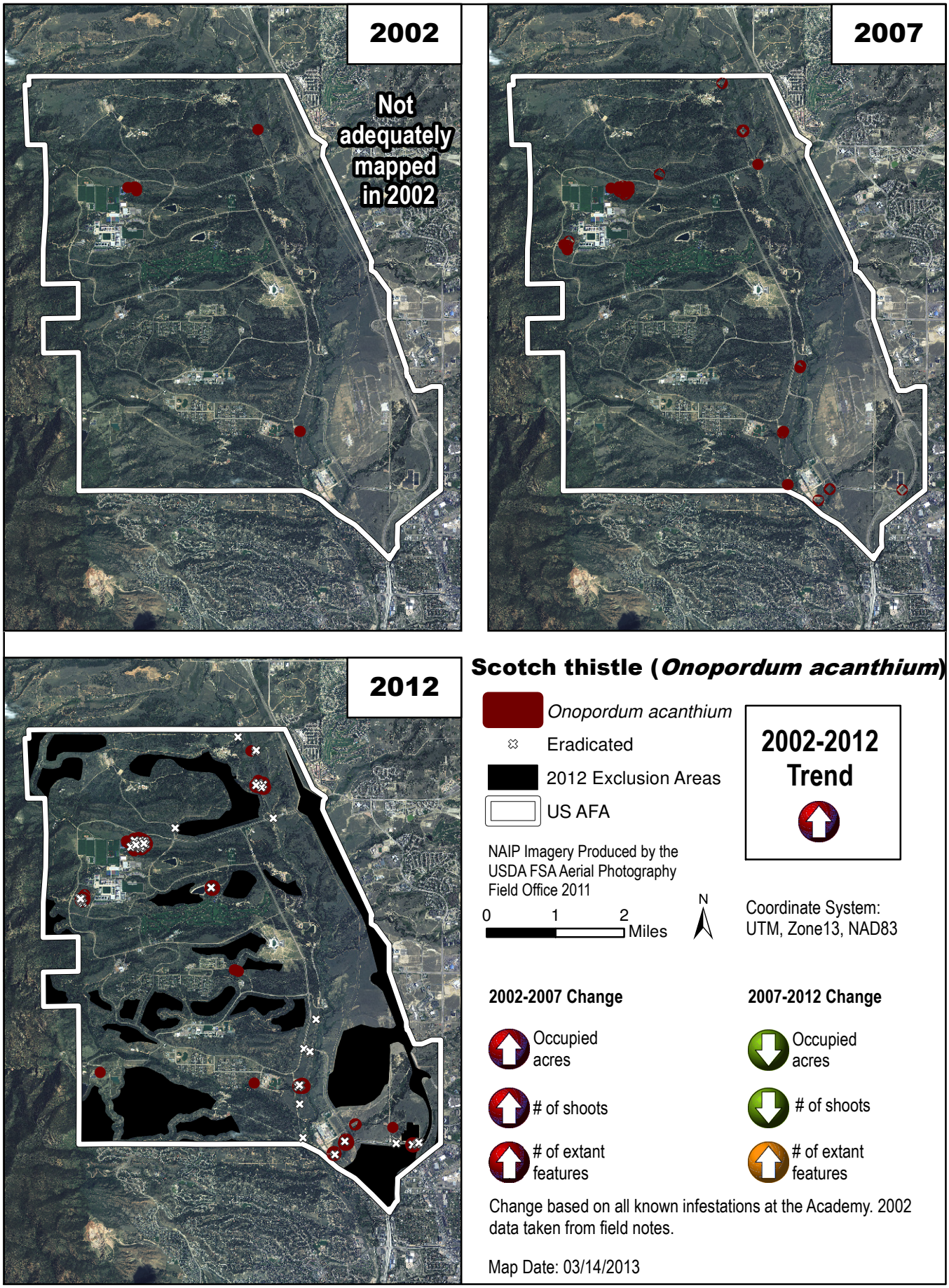


Figure 23. Scotch thistle trend, 2002-2012.



Map 34. Distribution of Scotch thistle at the Academy in 2002, 2007, and 2012.

Bouncingbet (*Saponaria officinalis*)

?

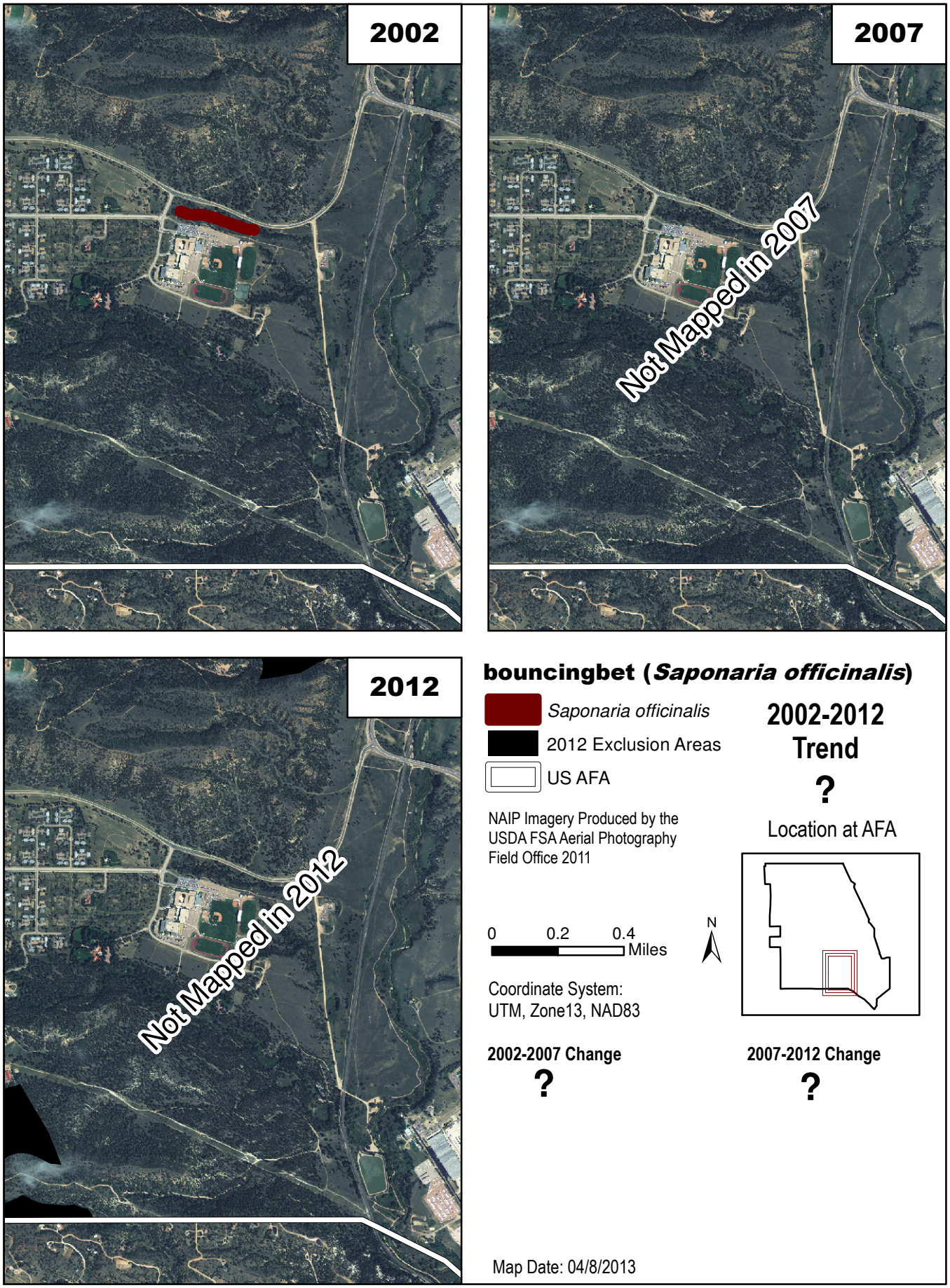
First documented in 2002, this weed has not been searched for since. Site will be visited in 2013 during the monitoring project.

Wikipedia photo

Bouncingbet occupied 0.2 acres in 2002 from one site (Table 44, Map 35) and has not been seen in any other year. It is cultivated for its showy flowers, and is a widely naturalized, sometimes troublesome weed. It can be poisonous upon ingestion and can spread rapidly. The key to effective control is early detection and prevention of new infestations, since it is not yet widespread on the Academy or in Colorado. It reproduces clonally from its root system, so mechanical control is not recommended (Colorado Department of Agriculture 2013). CNHP will add this site to their annual monitoring.

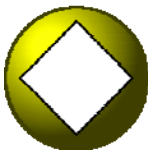
Table 44. All infestations of bouncingbet at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**0.19**	**?**	**?**
Estimated Number of Shoots	**?**	**?**	**?**
Number of Extant Features	**1**	**?**	**?**
Number of Eradicated Features	NA	?	?



Map 35. Distribution of bouncingbet at the Academy in 2002, 2007, and 2012.

Tamarisk (*Tamarix ramosissima*)



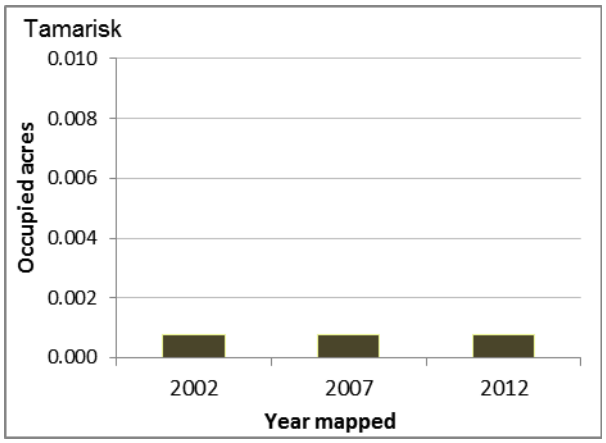
Number of individuals is stabilized but weed is spreading into new locations. Monitoring is essential.

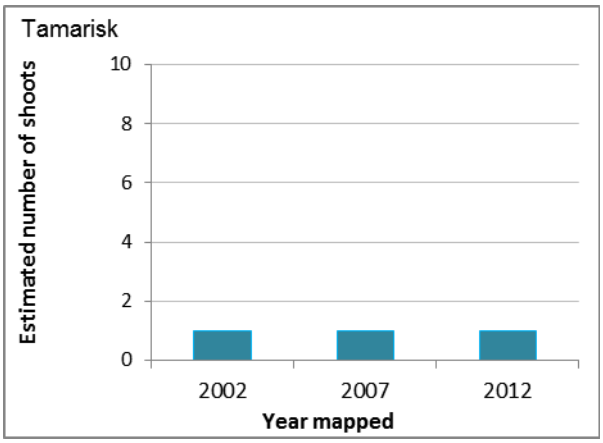
Photo by Renée Rondeau

There is currently one mapped occurrence with one plant on the Academy (Table 45, Figure 24, Map 36). The Natural Resources team at the Academy has been diligent and successful with the removal of any tamarisk. We will continue to monitor this species on an annual basis as it can become extremely invasive.

Table 45. All infestations of tamarisk at the U.S. Air Force Academy.

	2002	2007	2012
Occupied Acres	**<0.01**	**<0.01**	**<0.01**
Estimated Number of Shoots	**1**	**1**	**1**
Number of Extant Features	**1**	**1**	**1**
Number of Eradicated Features	NA	1	4





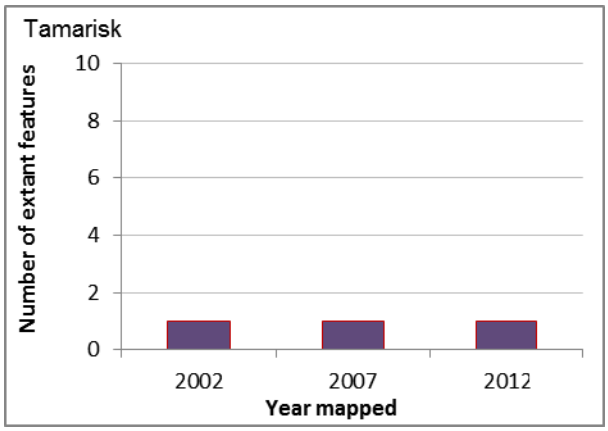
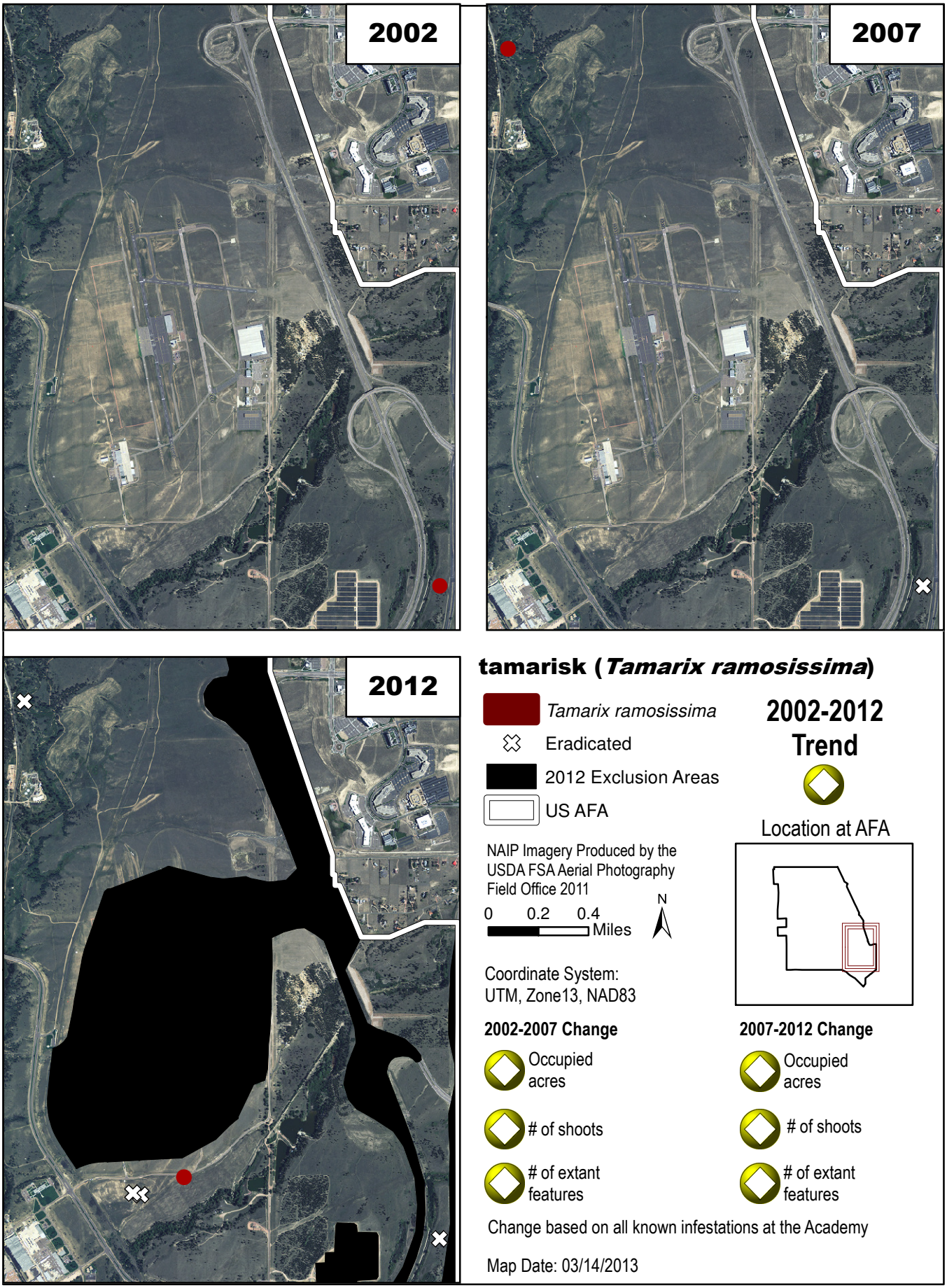


Figure 24. Tamarisk trend, 2002-2012.



Map 36. Distribution of tamarisk at the Academy in 2002, 2007, and 2012.

DISCUSSION

We utilized three indicators to detect changes between sampling years: occupied acres, estimated number of shoots, and number of extant mapped features. All of these indicators have their challenges yet when they are combined they offer a robust conclusion of trend or change. In general, the overall trend was a decrease in occupied acres between 2007 and 2012, while the other two indicators increased. Two reasons might explain the slight decline in acres while other indicators increased: 1) mapping was conducted by different folks in each year and most occurrence sizes were estimated, therefore it is possible that there was an observer bias; 2) 2007 was wetter than 2012 and therefore acres occupied may be a reflection of precipitation. Potentially, both reasons may have merit. Since we have three indicators for each species, it is best to look at the preponderance of the evidence.

In general, the increase in shoots and mapped features from 2002 to 2007 was greater than from 2007 to 2012. The 2002 to 2007 increase was not surprising as 2002 was exceptionally dry and 2007 was much closer to an average year. More surprising, was the continued increase in shoots and mapped features from 2007 to 2012 as 2012 was much drier than 2007. There appears to be a preponderance of evidence that weeds continue to expand at AFA and Farish with each passing year.

With that said, most of the expansion is coming from just a few species (the knapweed complex, Canada thistle, and musk thistle). The weeds infesting one acre or less are being diligently managed by AFA Natural Resources staff and most of these species are staying within a manageable level. Early detection and rapid response is working for ten species. Tables 46 and 47 list species by management priority for the Academy and Farish, respectively. Species that are ranked 1-11 are high priority for control measures. The species 12-23 are still of interest but at a site specific level, primarily at sites where other natural resources, e.g., rare plants, are threatened by invasive species.

Table 46. Priority table for the Academy.

Rank	*Scientific Name*	Common Name	Occupied Acres in 2012
1	*Linaria genistifolia* spp. *dalmatica*	Dalmatian toadflax	0.00
2	*Tamarix ramosissima*	Tamarisk	<0.01
3	*Galium verum*	Yellow spring bedstraw	0.01
4	*Cynoglossum officinale*	Houndstongue	0.01
5	*Acroptilon repens*	Russian knapweed	0.05
6	*Lonicera tatarica*	Tatarian honeysuckle	0.15
7	*Euphorbia myrsinites*	Myrtle spurge	0.23
8	*Onopordum acanthium*	Scotch thistle	0.30
9	*Hesperis matronalis*	Dames rocket	0.83
10	*Hypericum perforatum*	Common St. Johnswort	1.16
11	*Cirsium vulgare*	Bull thistle	1.19
12	*Centaurea diffusa* x *maculosa*	Diffuse / spotted knapweed hybrid	5.93
13	*Dipsacus fullonum*	Fuller's teasel	9.26
14	*Caragana arborescens*	Siberian peashrub	9.71
15	*Euphorbia esula*	Leafy spurge	10.64
16	*Elaeagnus angustifolia*	Russian olive	10.80
17	*Cardaria draba*	Whitetop	13.08
18	*Carduus nutans*	Musk thistle	15.20
19	*Centaurea maculosa*	Spotted knapweed	53.02
20	*Cirsium arvense*	Canada thistle	90.17
21	*Centaurea diffusa*	Diffuse knapweed	100.58
22	*Saponaria officinalis*	Bouncingbet	?
23	*Linaria vulgaris*	Yellow toadflax	Widespread

Table 47. Priority table for Farish.

Rank	*Scientific Name*	Common Name	Occupied Acres in 2012
1	*Galium verum*	Yellow spring bedstraw	<0.01
2	*Euphorbia esula*	Leafy spurge	*0.03
3	*Carduus nutans*	Musk thistle	1.12
4	*Cirsium arvense*	Canada thistle	1.27

*Infestation is on adjacent property; control may not be possible

Weed map data are extremely useful for developing a weed management program (Barnett et al. 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 and 2012 a temporal dimension was added that greatly increases the value of the spatial and tabular data. Comparing the data from 2007 and 2012 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 all three sample years of weed map data and utilizing results from the Academy's monitoring program, it is possible to measure progress towards the weed management objectives developed by Carpenter et al. 2004. These objectives 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. 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).

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. 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 2017.

Future of Weed Mapping Efforts

We recommend repeating weed mapping in 2017, 5 years from the date of this project. Due to the increase of infestations and new species likely to occur on the Academy and Farish between now and 2017, careful thought should be given to the current mapping methodology so goals can be attained within the constraints of available resources. The use of designated mapping areas, a strategy employed to save resources by focusing efforts on biologically important areas and areas most likely to harbor weeds, complicated our ability to compare data between years. New species and infestations of weeds on the monitoring list were identified outside of the 2012 designated mapping areas during the course of this project. We understand that weeds will continue to move into the exclusion areas, and therefore we do not have a complete picture of where all the weeds are located; however, we suggest using the same mapping exclusion areas in 2017 in order to have comparable data/census. Exceptions should be made for rare weeds or any new weeds. Exclusion areas should be surveyed for these species.

Spotted knapweed, diffuse knapweed and the spotted/diffuse knapweed hybrid are so widespread that comprehensive mapping may be too expensive in the future. Unlike yellow toadflax, which was sampled in 2012, these are management targets for Natural

Resources staff. Comprehensive mapping of knapweeds has been beneficial to managers thus far. We recommend that the Academy update their Weed Management Plan, and revise goals based on information derived from recent weed mapping and monitoring projects at the Academy (CNHP related mapping and monitoring activities are detailed by species in Appendix A). Additionally, an ongoing dialogue with Natural Resources staff is encouraged in order to identify the best approach to mapping these challenging, widespread species.

ACKNOWLEDGEMENTS

The help and generosity of many experts is gratefully acknowledged. This project would not have been possible without the support of our partners at the Academy. Brian Mihlbachler, our primary contact at the Academy, played a critical role in the success of 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. Greg Speights was especially helpful in guiding field staff to the yellow toadflax sampling sites.

Jared Pappert-Stockton spent four months tirelessly traversing the Academy and Farish during the summer of 2012 in order to complete the mapping portion of this project. His enthusiasm and dedication to the project were admirable. His high quality work serves as the foundation for this report and distinguishes him as an excellent fieldworker. The work of Ron Abbott in 2002, Joe Stevens in 2003, and Michelle Washebek in 2007 were critical in guiding the 2012 mapping efforts, and their experience was valuable for refining the mapping methodology employed in this project. David G. Anderson provided guidance and insight from his past weed mapping and monitoring projects at the Academy.

Thanks to Tass Kelso, professor at Colorado College for continued support via housing, dinners, and students, especially Sophie.

Karin Decker performed statistical analyses and provided technical assistance. Lee Grunau provided editorial and technical assistance with report production. Mary Olivas, Carmen Morales, and others at CSU assisted with contract administration.

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APPENDIX A – Summary of mapping and monitoring activities by species at the Academy since 2002. Monitoring activities (not necessarily mapping) are indicated by brown shading.

Common Name	Scientific Name	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Russian knapweed	*Acroptilon repens*			M*	M	M	M	M	M	M	M	M
Siberian peashrub	*Caragana arborescens*											M
whitetop	*Cardaria draba*	M	M				M					M
musk thistle	*Carduus nutans*	M					M					M
diffuse knapweed	*Centaurea diffusa*	M					M					M
diffuse / spotted knapweed hybrid	*C. diffusa x maculosa*				M*		M					M
spotted knapweed	*Centaurea maculosa*	M			M	M	M					M
Canada thistle	*Cirsium arvense*	M					PM					M
bull thistle	*Cirsium vulgare*	M					M					M
field bindweed	*Convolvulus arvensis*	M					M					
houndstongue	*Cynoglossum officinale*								M*	M	M	M
Fuller's teasel	*Dipsacus fullonum*	M					M					M
Russian olive	*Elaeagnus angustifolia*	M	PM		PM		M					M
leafy spurge	*Euphorbia esula*	M					M					M
myrtle spurge	*Euphorbia myrsinites*				M*	M	M		M	M	M	M
yellow spring bedstraw	*Gallium verum*									M*	M	M
dames rocket	*Hesperis matronalis*											M*
common St. Johnswort	*Hypericum perforatum*	M			M	M	M	M	M	M	M	M

Common Name	Scientific Name	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Dalmatian toadflax	*Linaria genistifolia ssp. dalmatica*								M*	M	M	M
yellow toadflax	*Linaria vulgaris*	M					PM					PM
Tatarian honeysuckle	*Lonicera tatarica*							M*			M	M
Scotch thistle	*Onopordum acanthium*	M			M	M	M	M	M	M	M	M
tamarisk	*Tamarix ramosissima*	M					M	M	M	M	M	M

M = mapped; PM = partially mapped; * indicates year discovered

APPENDIX B – Weed Mapping Instructions

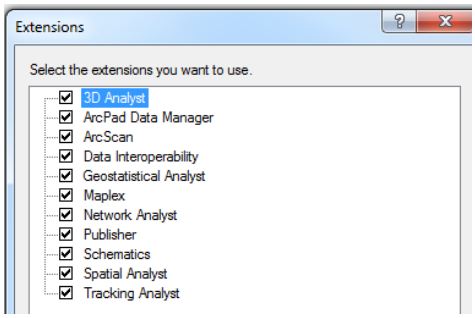
Set-up (this only needs to be done once)

Windows Explorer:

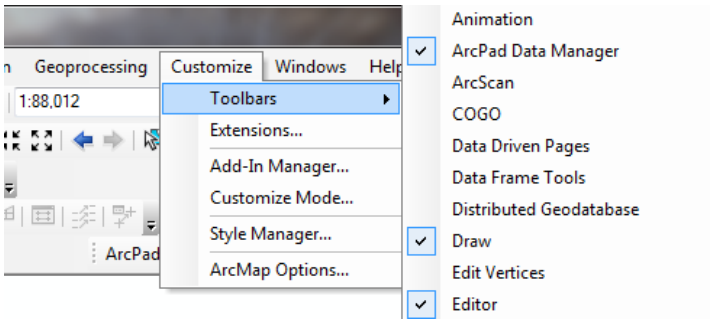
1) Create a subfolder under the AFAWeeds2012 folder called Daily_Files. We will store all pre/post data for each day in this folder and we will back it up on the external hard drive daily.

ArcGIS:

1) Make sure the ArcPad Data Manager extension is turned on under Customize => Extensions.



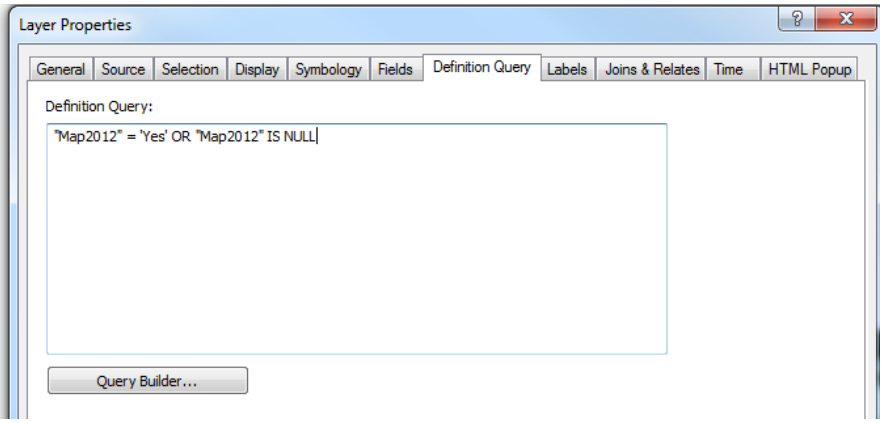
2) Make sure the ArcPad Data Manager toolbar and the Editor toolbar are turned on under Customize => Toolbars



3) On the first field day at AFA, overwrite the Master_Field_Forms and Master_Weed_Data folders on the desktop computer with the files on the external hard drive. Be sure to do this prior to collecting data in the field.

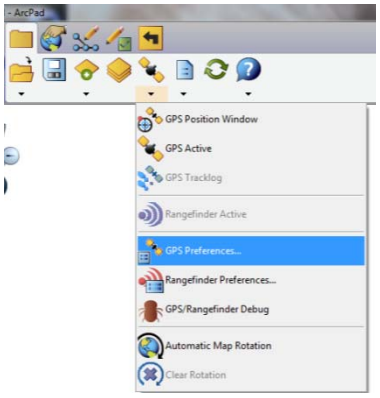
4) Open AFAWeeds2012.mxd and apply theme filters to the point and line files (we are mapping all polygons so no filter is needed). This is necessary because we are not mapping features within exclusion areas. Double-click on the weed point file in the table

of contents and select the Definition Query tab. Enter the following query to select all features not equal to No and hit Ok: "Map2012" = 'Yes' OR "Map2012" IS NULL
Follow the same procedures for the weed lines file and save the ArcMap project (.mxd). This will ensure that only features outside of exclusion areas are checked out for editing.

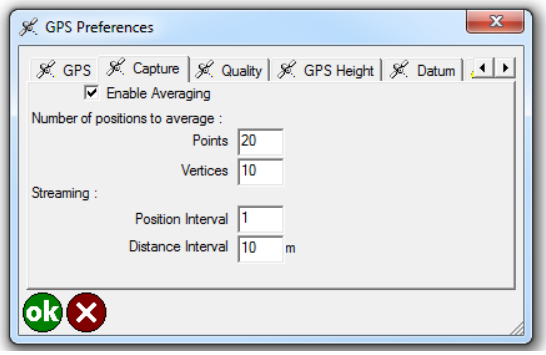


ArcPad on the Yuma Tablet:

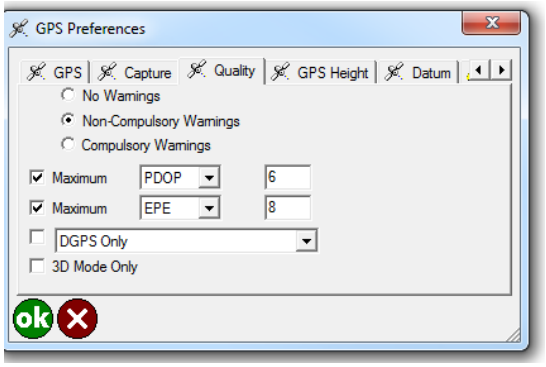
1) In the AFA_WeedMap2012 folder on the Yuma tablet, open AFAWeeds2012.apm and open GPS Preferences



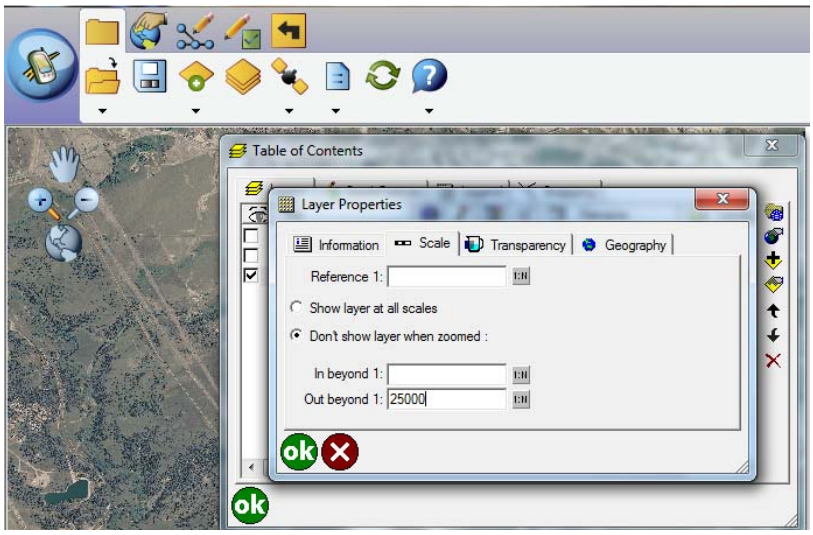
2) Under the Capture Tab, check Enable Averaging and under number of positions to average select 20 for points and 10 for vertices (if this seems too slow in the field, cut these numbers in half). Ignore the streaming since we are not using this feature.



3) Under the Quality tab, check Non-Compulsory Warnings. Check Maximum next to PDOP (Maximum Position Dilution of Precision) and EPE (Estimated Precision Error). Set PDOP to 6 and EPE to 8.



4) Set a maximum viewable scale for the AFA background image. Double-click on the stack of layers to open the Table of Contents and double-click on AFA_DOQ_2009.tif. On the scale tab, check "Don't show layer when zoomed:", in the "Out beyond 1:" box enter 25,000. Hit Ok twice to save your changes.

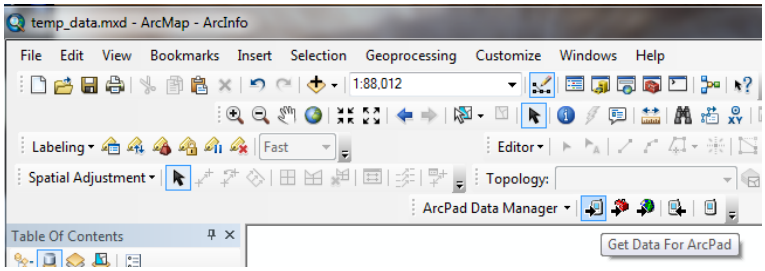


5) Save the map and exit ArcPad.

Check-out/Check-in Data (done daily)

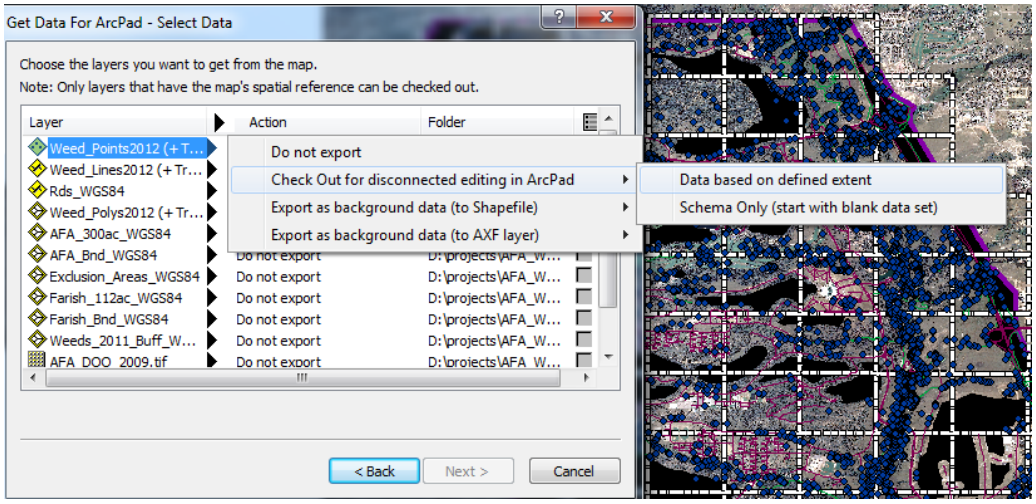
1) Open AFAWeeds2012.mxd on the desktop computer in ArcMap

2) Click on the "Get Data for ArcPad" icon on the ArcPad Data Manager Toolbar

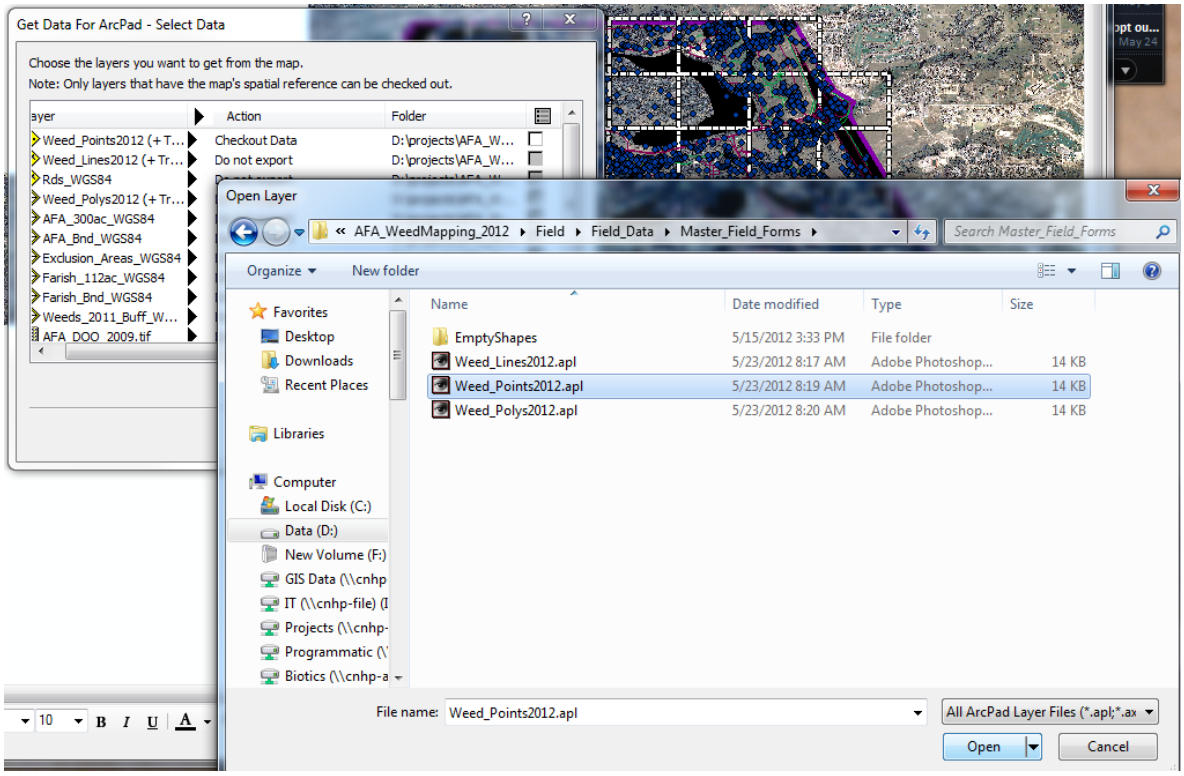


3) At the Welcome menu, click Next

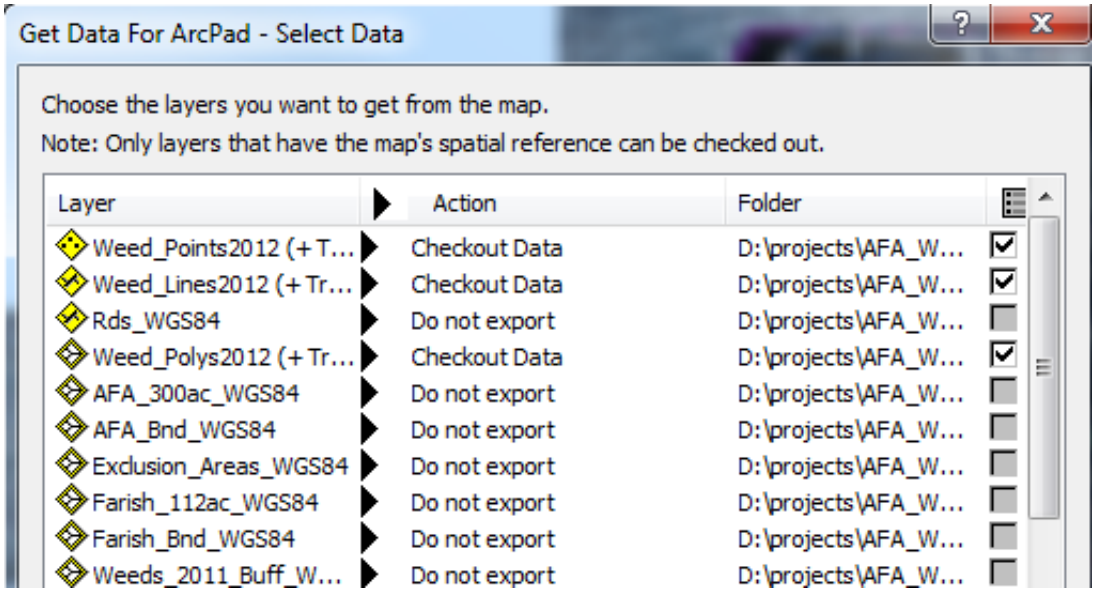
4) At the Select Data menu, click on the Action arrow to the right of Weed_Points2012. Select Check Out for disconnected editing in ArcPad => Data based on defined extent.



5) On the far right, click on the check box under the Select existing forms column. This will open Windows Explorer so you can browse to the Master_Field_Forms folder. Select Weed_Points2012.apl and hit Open. This will associate the spatial weed point data with the weed point custom field forms. If the master field forms change, you will need to link these files again.

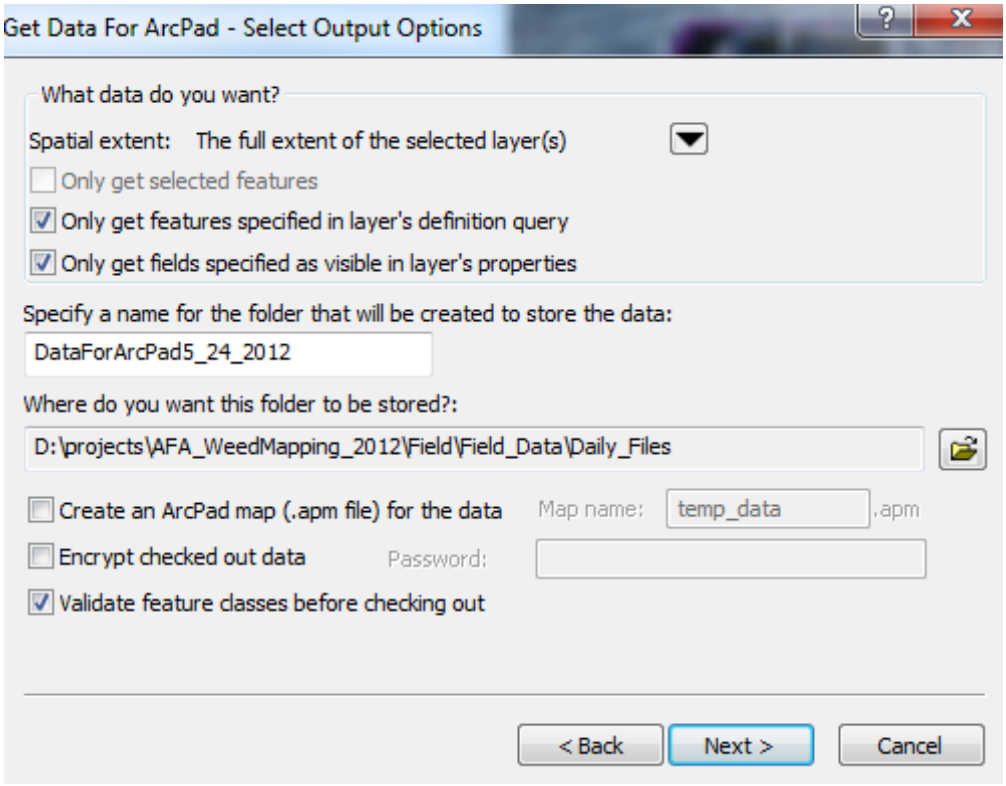


6) Follow the same procedures for weed lines and weed polygons. Each weed feature type should have "Checkout Data" listed under the Action column and have check marks under the "Select existing forms" column. No other data layers should be checked out. Click on Next.

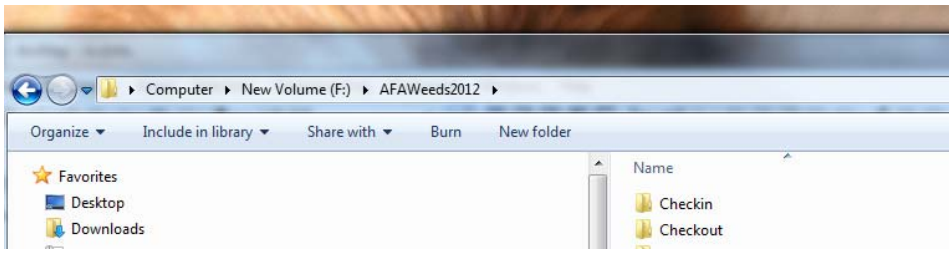


7) Ignore Picture Options and click on Next to bypass the window which will take you to the Select Output Options window. Next to Spatial extent, select "The full extent of the

selected layer(s)". Check "Only get features specified in layer's definition query". "Only get fields specified as visible in layer's properties" can be checked or unchecked (this is irrelevant to us since all of our fields in the attribute table are visible). Change the default folder name to DataForArcPad<current date> (I'll use 5/24/2012 as the current date in my examples). Store DataForArcPad5_24_2012 folder in your Daily_Files folder. Uncheck "Create an ArcPad map (.apm) for the data" since you will be using an existing .apm set up specifically for AFA. Check "Validate feature classes before checking out". Click on Next and click on Finish to create ArcPad data on the computer now.



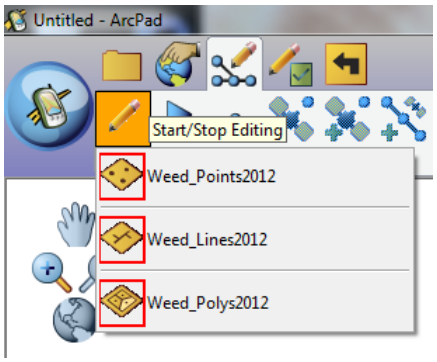
8) Copy the DataForArcPad05_24_2012 folder to the Yuma tablet using the external hard drive. Copy it into the Checkout folder and be sure to remove the drive from the Yuma tablet before going out into the field.



9) Open the AFAWeeds2012.apm on the Yuma tablet in ArcPad. Be sure the weed point, line and polygon data are the files you just exported from ArcMap and not the previous day's data. *Go through this with Jared. ******

10) Go out in the field and wait until you have a fix from the GPS unit. This can take a minute or two.

11) Navigate to the Editing toolbar in ArcPad and put the weed point, line and polygon files in edit mode. All three datasets can be in edit mode at the same time since they are different feature types.



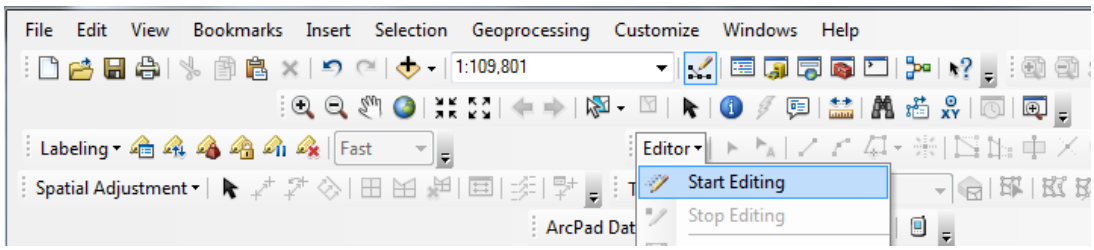
12) Collect data using the GPS wherever possible. If necessary, use simple offsets for lines and polygons. Hand map hard to access point features using the stylus and orthophoto quad for reference and make note of this in the comments field. Take the ArcPad Quick Reference Guide out with you in the field.

13) When you are done with field work for the day, Stop Editing before you close the ArcPad project. Simply click on the weed files again, so the red boxes disappear. Do NOT save the ArcPad map.

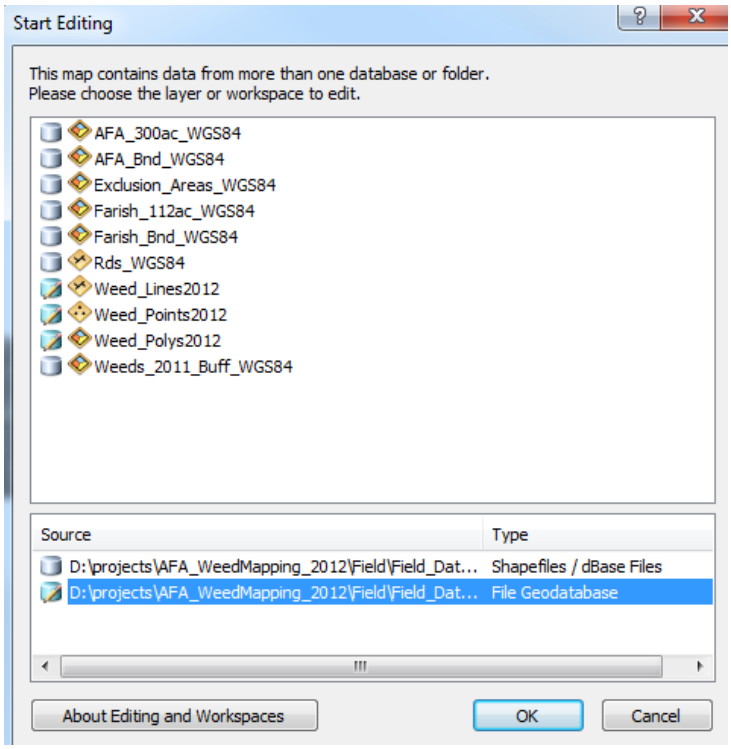
14) Once you are finished editing in ArcPad, copy the DataForArcpad5_24_2012 folder on the Yuma tablet into the Checkin folder on the external hard drive.

15) Rename the DataForArcPad5_24_2012 folder on the desktop computer to PreField5_24_2012. Copy DataForArcPad5_24_2012 in the Checkin folder on the external hard drive to the Daily_Files folder on the desktop computer.

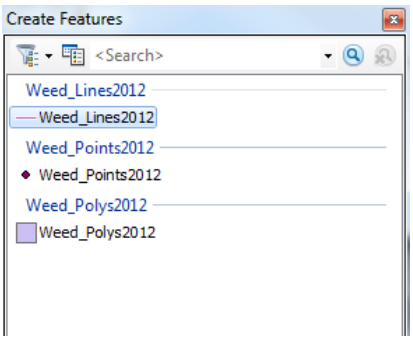
16) Open the AFAWeeds2012.mxd ArcMap project and use the Editor toolbar to put the weed point, line and polygon geodatabase files in edit mode. If the features are in edit mode, you do not have to save your changes from the check-in process if something goes awry. If features are not in edit mode, check-in results cannot be undone.



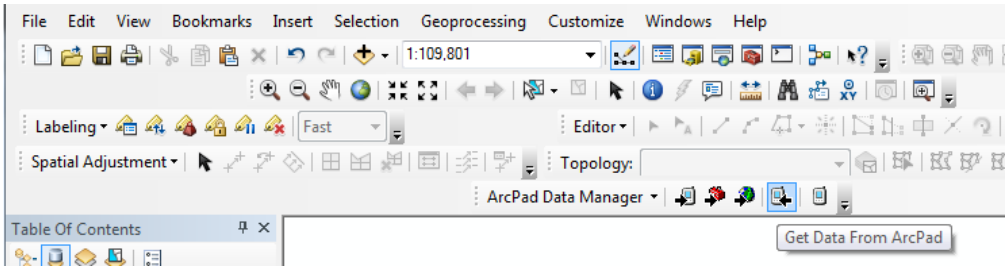
17) At the bottom of the Editing window, under Source, select the File Geodatabase to put the weed points, lines and polygons in edit mode. Double-click on the File Geodatabase or hit Ok.



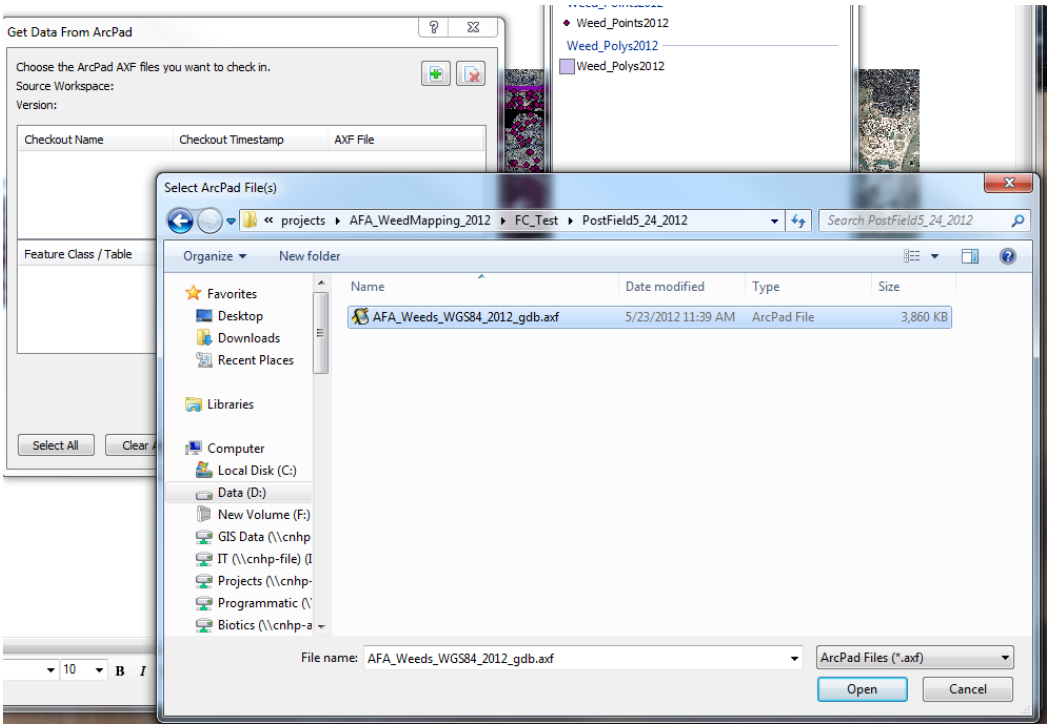
18) This will bring up the Create Features window. You should see that weed lines, points and polygons are editable.



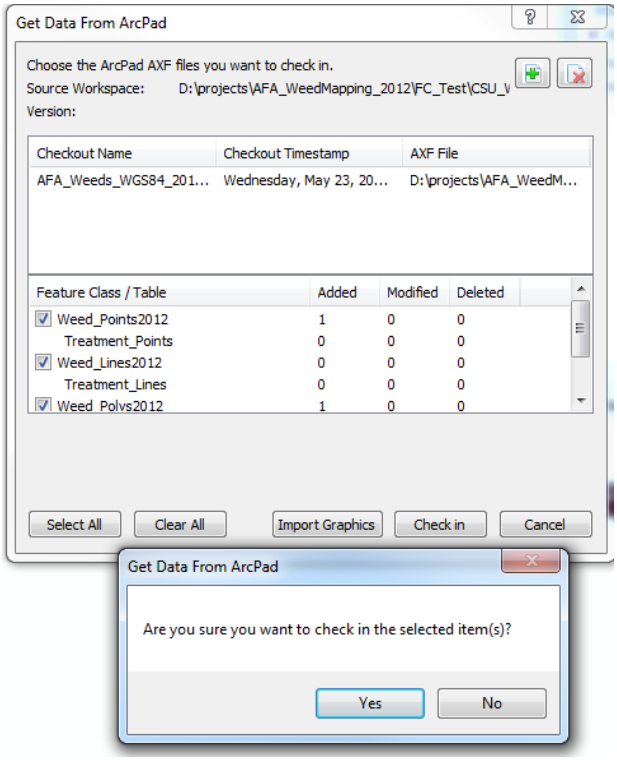
19) Next, click on the “Get Data from ArcPad” icon on the ArcPad Data Manager Toolbar



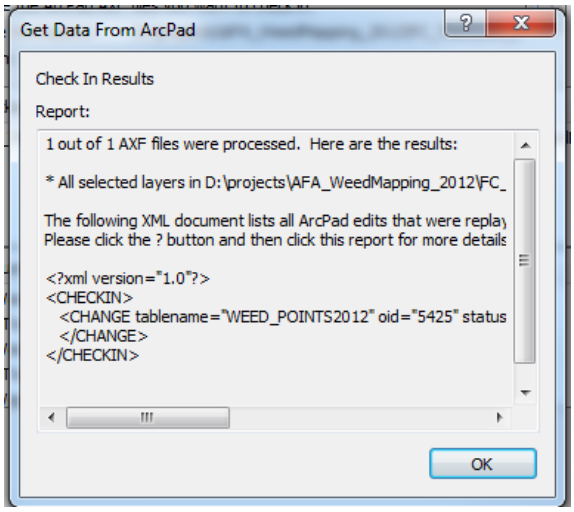
20) In the “Get Data from ArcPad” window, click on the green + at the upper right side of the menu and scroll to Dailey_Files\DataForArcPad5_24_2012. Highlight the .axf and double-click or hit Open.



21) Weed points, lines and polygons should appear noting the number of added, modified and deleted features. Checkmark each dataset that has new or modified data, click Check-in and select Yes.

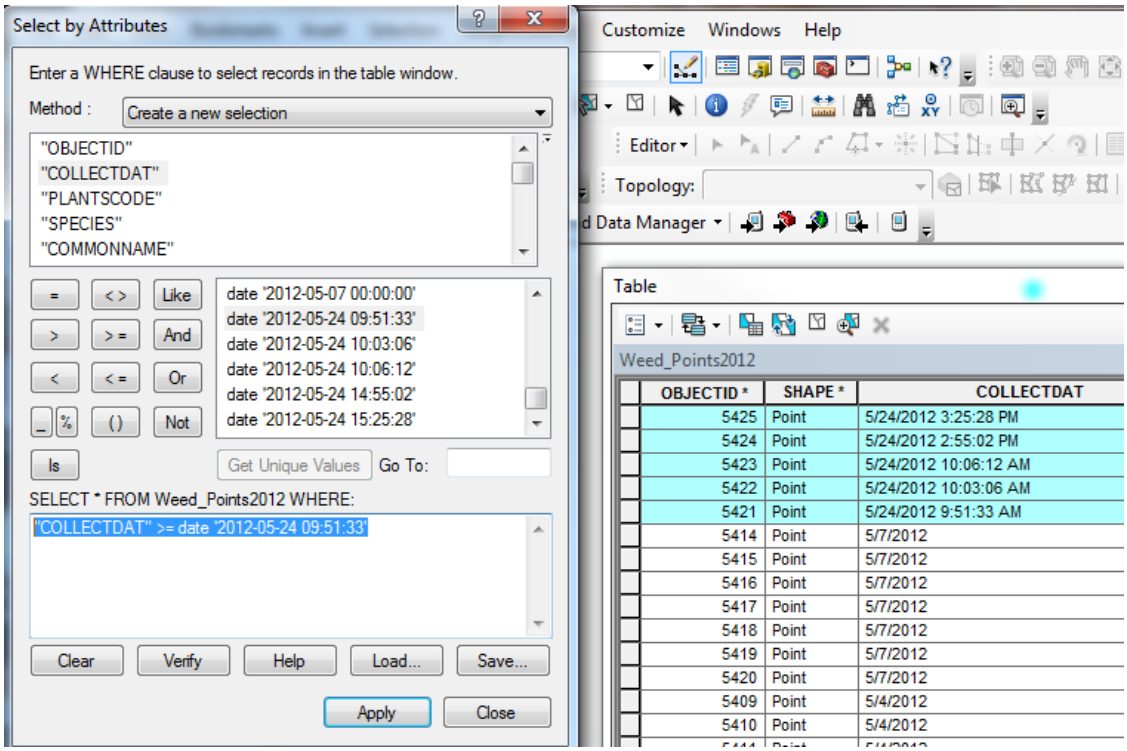


22) This will generate a check-in report with details on the edited features. Copy this text and paste it into a MS Word document. Save the file as CheckIn5_24_2012.docx in the DataForArcpad5_24_2012 folder. Hit Ok to close the results window and X to close the "Get Data From ArcPad" menu.

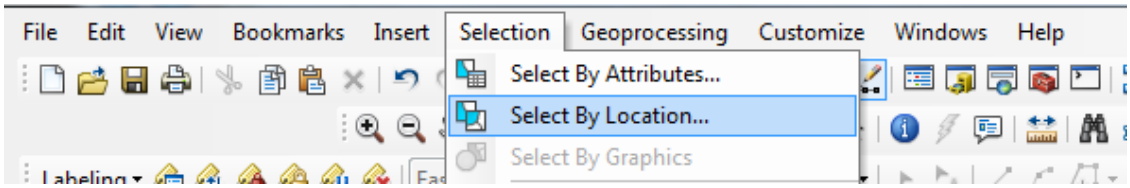


23) While the geodatabase is still in edit mode, review the spatial data and attributes. If polygon or line geometry needs to be modified, use the tools on the Editor toolbar to modify features. For quality control, it is best to check records by the current date AND by the geographic location you covered using the 300 acre grids.

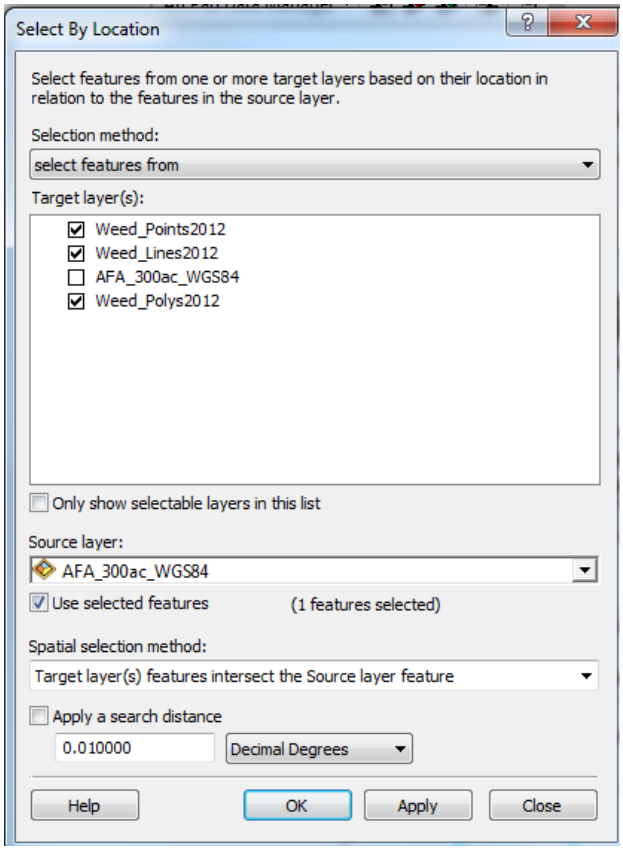
To select features from the current date you will need to select a range of dates since the GPS is collecting date and time. For example, if your first point was collected at 9:51:33 am, your query would look like this: "COLLECTDAT" >= date '2012-05-24 09:51:33'. If you hit “Get Unique Values” in the Select by Attributes window, you can double-click on the first date-time stamp of the day as opposed to typing it in. Make sure the attribute table is open and show only selected records. Sort on the number of individuals and density to make sure one or the other is filled out. Both of these fields cannot be blank. Also, sort on radius and make sure there are no zeros. If data are missing, make a note to revisit the weed infestation.



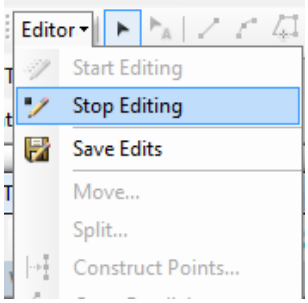
You can also use the “Select by Location” feature on the Selection menu to select all of the weeds overlapping the 300 acres grids you surveyed that day. This will help identify any infestations you may have missed.



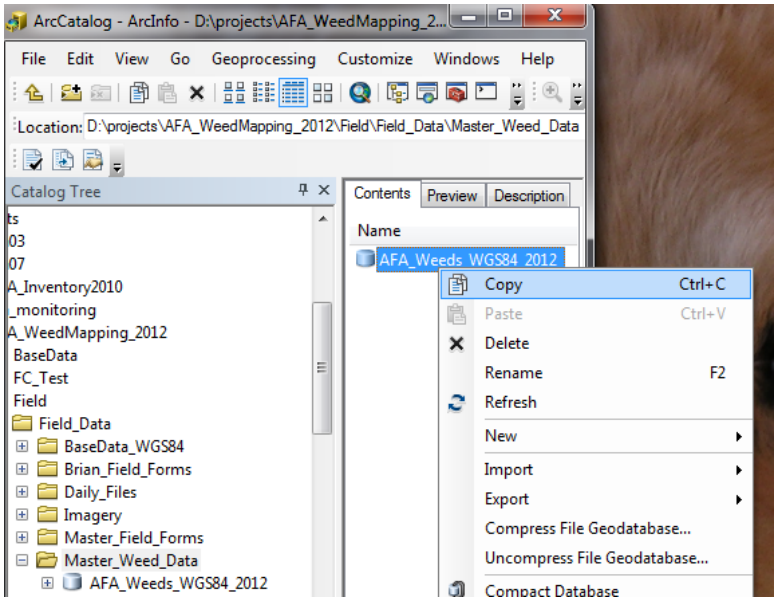
Select the 300 acre grids you surveyed in the AFA_300ac_WGS84 shapefile (either select feature directly or select attributes). Open “Select by Location” and check weed points, lines and polygons. Select AFA_300ac_WGS84 as the Source Layer and check the box for “Use selected features”. Hit ok. Then, you can open the attribute table for the weeds, show only selected records and sort the dates to make sure all records have been updated in 2012.



24) Once you’ve made any necessary geometry and attribute changes, and performed quality control by selecting on date and by location, Stop Editing and save your edits. Exit ArcMap.



25) In Windows Explorer, rename the DataForArcPad5_24_2012 folder to PostField5_24_2012. Make a copy of the master file geodatabase using ArcCatalog. Open ArcCatalog and browse to the Master_Weed_Data folder. Right-click on the AFA_Weeds_WGS84_2012 geodatabase and select copy.

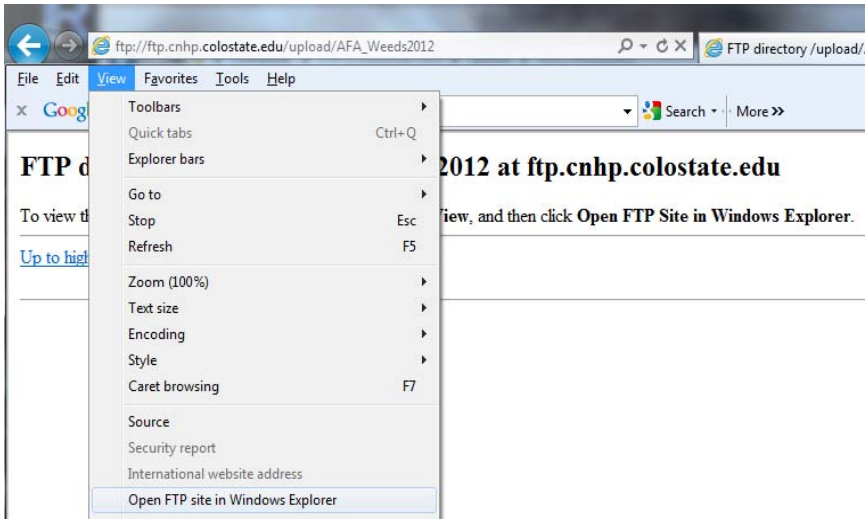


Browse to the PostField5_24_2012 folder, right-click and paste the geodatabase. Right-click on the geodatabase again to rename it to AFA_Weeds_WGS84_5_24_2012. Copy both PreField5_24_2012 and PostField5_24_2012 folders to the external hard drive in the Backup folder (keep them on the desktop computer too). This way we will have a complete set of data for each day.

26) Follow the check-out procedures again to prepare your files for the next field day. I recommend doing this at the end of the work day, after you have checked-in data, so you do not have to access the desktop computer in the morning. In this example, you would check your field data into a folder under Daily_Files called DataForArcpad5_25_2012.

27) Every week, post your daily files in the backup folder on the external hard drive to CNHP's FTP site so I can keep a copy onsite at CSU. When you come to Fort Collins on the weekend, bring the external hard drive with you. From a computer with the internet, go to ftp://ftp.cnhp.colostate.edu/upload

Enter "cnhpftp" for the user name and "cnhp" for the password (without quotes). Open the AFA_Weeds2012 folder. Hit Alt on the keyboard and select "Open FTP Site in Windows Explorer".



Copy daily files for the week onto the FTP site and close browser.

Mapping Protocol

Do not map weeds of the same species that are within 5 meters of each other. Since weeds are mobile from year to year, we will consider these the same infestation. If you cannot locate an existing feature in the exact same location, but there is a weed of the same species within 5 meters, move the existing point (or line, polygon, etc.) to the new location and update the radius, # of ind, etc. If there is no weed within 5 meters of a mapped location, mark it as eradicated but do not delete it. Set number of individuals to 0 and set radius to 1 for eradicated features (we will filter these out of the buffered dataset before calculating area). If several points now represent a polygon, delete the points and draw a new polygon. Conversely, if a polygon is now a point, delete the polygon and replace it with a point.

There will be situations where you will not need to update the shape, but rather only the attributes. At minimum, you will need to set the current date and click on the Standard Info tab of the field form to make sure your name is entered as the Examiner. Even if nothing has changed, we still need to know that this information is current as of 2012 and verified by you. This will probably be infrequent, as I'm sure number of individuals, radius, or cover class would be different. Also, be sure to check the comments on the Standard Info tab and make sure they are still applicable. The date has to be physically clicked on every existing record to populate the

current date. New features will automatically have the current date. The Standard Info tab has to be activated in order to populate your name as the examiner. You must hit Ok to save changes. Hitting the X will cancel your changes.

The weed map ultimately will tell AFA how well their management treatments are working on noxious weeds. Two things we need to know are size and total individuals. Every point and line will have a radius (or buffer distance which will be applied to both sides of the line) filled out so we can calculate area (polygons already have area so we do not need to assign a buffer distance). Every point, line and polygon will have EITHER number of individuals or density filled out. Density represents number of individuals per square meter. Ultimately, I will calculate number of individuals but you can pick which field to use for any given occurrence. We also need cover class filled out to help with estimating size. This is especially important because of situations like *Linaria vulgaris*. If we map a bunch of polygons for *Linaria*, the area might look high, but we'll be able to state that the bulk of the infestations have a low cover class (so, for example, we could report 5 acres, but 4 of these acres have low cover class). Note, that Brian's data has incomplete attributes so even though he has mapped a feature in 2012, you'll need to revisit it and gather all of the required information. Also, you will need to revisit and map the new population of dame's rocket, even if it is in an exclusion area because this species is new to the Academy.

Map irregularly shaped features over approximately 600 square meters (30m x 30m) as polygons as opposed to points. If large features are relatively circular, just map them as points. Linear features will be mapped as lines, regardless of size.