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A Reinventory of Invasive Weed Species in Dinosaur National Monument to Determine Management Effectiveness

Corey V. Ransom, Stephanie D. Christensen, Kimberly A. Edvarchuk, and Tamara Naumann*

Invasive weed management in wildland areas is often challenging due to the need to protect and preserve the integrity of natural ecosystems. Russian knapweed is an aggressive, deep-rooted, creeping perennial forb that was first identified as a problematic species in Dinosaur National Monument in 1977. From 2002 to 2005, extensive nonnative plant inventories were conducted in portions of the monument. Results were used to develop and implement an aggressive weed management program beginning in 2005. Emphasis was placed on reducing Russian knapweed infestations around Josie's Ranch in the Cub Creek Watershed. Several other species were targeted as well. In 2010, a reinventory was conducted in selected areas to evaluate how implemented management strategies affected the overall distribution and abundance of targeted species on the landscape. Comparisons between inventories indicate that management strategies were successful in reducing the total infested area of Russian knapweed by 79%. Treatments used for other targeted species also appear to have been effective in reducing their overall distribution and abundance on the landscape. In addition, the reinventory identified several new species with the potential to become problematic in the area. Although this case study documents the substantial progress that has been made at Dinosaur National Monument toward obtaining specific weed management objectives, it more importantly illustrates the process and benefits of an adaptive approach in sustaining long-term invasive plant species management efforts.

Nomenclature: Russian knapweed, *Acroptilon repens* (L.) DC. CENRI.

Key words: Invasive weeds, wildland weed mapping, invasive weed management, adaptive management.

Invasive weeds have been widely recognized as a serious economic and environmental threat (Mack et al. 2000; Masters and Sheley 2001). Managing invasive weeds is difficult due to the extensive number of plant species, dynamic nature of weed populations, and their variable ecosystem effects over time (Hobbs and Humphries 1995; Strayer et al. 2006). Invasive weed management is even more complicated in wildland areas where the goal is to maintain the integrity of natural ecosystems (Brooks 2007). Gaining more information on the impacts that control efforts have on target weeds, and the surrounding environment, can help further our understanding of invasive plant management in wildland areas (Pearson and Ortega 2009; Randall 2000).

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* First, second, and third authors: Assistant Professor, Research Assistant, Research Assistant, Department of Plants, Soils, and Climate, Utah State University, 4820 Old Main Hill, Logan, UT 84322-4820; fourth author: Botanist, Dinosaur National Monument, U.S. Department of the Interior National Park Service, 4545 E. Hwy 40, Dinosaur, CO 81610-9724. Corresponding author's E-mail: corey.ransom@usu.edu

Russian knapweed [*Acroptilon repens* (L.) DC.] is a deep-rooted, creeping perennial that reproduces primarily through vegetative root buds. Due to its extensive root system, aggressive nature, and allelopathic properties, Russian knapweed can establish dense monocultures and is extremely persistent (Jacobs and Denny 2006; Sheley 1994). Introduced from Eurasia in the early 1900s, Russian knapweed is now considered a serious noxious weed in 25 states (Mangold et al. 2007).

Long-term success of Russian knapweed control depends upon depleting root reserves, and encouraging the establishment of competitive, desirable plants (Beck 2008; Skelly 2005). The most common method is chemical control. The most successful herbicides include: clopyralid, clopyralid + 2,4-D, aminopyralid, and picloram (Benz et al. 1999; Bottoms and Whitson 1998; Duncan et al. 2001; Jacobs and Denny 2006). Although effective, retreatments are often necessary, and nontarget species can be damaged, resulting in bare ground (Benz et al. 1999). This often leads to secondary invasion by other weed species, further degrading the system (Pearson and Ortega 2009).

An integrated management program combining chemical, cultural, and mechanical methods has been suggested as a more effective approach for obtaining long-term success (Beck 2008; Duncan et al. 2001; Kettle and Wilson 1998). In this approach, herbicides provide important short-term control, and improve the effectiveness of other control measures (Bottoms and Whitson 1998; Duncan et al. 2001). Targeted grazing with goats or sheep has been shown to help suppress seed production and stress plant roots (Graham and Johnson 2004; Kettle and Wilson 1998). Mowing multiple times a year can also suppress spread, but might not be practical or economical in wildland areas (Duncan et al. 2001; Jacobs and Denny 2006). Cultivation can temporarily help alleviate the allelopathic effects of Russian knapweed, allowing desirable species to grow. Unfortunately, it also can assist in the spread of Russian knapweed by transporting root segments to new areas (Bottoms and Whitson 1998; Mangold et al. 2007). Fire has proved to be ineffective in providing knapweed control (Duncan et al. 2001; Jacobs and Denny 2006). Ultimately, active revegetation of the infested area often is necessary in order to regenerate the soil seedbank (Benz et al. 1999; Kettle and Wilson 1998; Mangold et al. 2007). Implementing site-specific prevention and early detection strategies also is important to protect noninfested land from invasion (Graham and Johnson 2004; Sheley et al. 1996).

A successful weed management program also requires the utilization of weed inventories and long-term monitoring (Dewey and Andersen 2004). Weed inventories provide valuable point-in-time information on the location, abundance, and distribution of invasive species on the landscape. These data can be used to plan and prioritize management and monitoring efforts (NAWMA 2002; Wilson et al. 1999). Long-term monitoring is the repeated collection of precise, site-specific data to detect small changes in vegetation and other ecosystem conditions. It allows a detailed evaluation of progress towards management goals. Although inventories provide less detail than long-term monitoring, time-repeated inventories allow managers to measure changes in the overall distribution of weeds and total acres infested on a landscape scale (Dewey and Andersen 2004; Rew and Pokorny 2006). Utilizing these different types of information managers can accurately assess the overall effectiveness of management strategies, and evaluate the impact of control on target species and the surrounding ecosystem (Barnett et al. 2007; Masters and Sheley 2001).

Background. Russian knapweed was first identified as a problematic species in Dinosaur National Monument in 1977 (Morris and Call 2005). Dinosaur National Monument is located in northwestern Colorado and northeastern Utah and includes portions of the Yampa and Green Rivers. The landscape is extremely diverse and contains cultural and natural resources of national importance, including a variety of rare plant communities. Due to the threat posed to these valuable monument resources, weed management activities were initiated in 1996 with an organized weed inventory. In 1997, a Weed Warrior program began, which engaged volunteers in the mechanical removal of perennial pepperweed and saltcedar from campgrounds and along river corridors. Some limited chemical spot-treatments were also applied by Moffat County, CO and Uintah County, UT along Cub Creek Road and around housing areas (USDI–NPS 2005). Weed management often is difficult in Dinosaur National Monument, because efforts must be limited to measures that will not alter the integrity of the cultural or natural resources they strive to protect (Morris and Call 2005).

During the summers of 2002 through 2005, extensive inventories for nonnative plants were conducted by Utah State University in portions of Dinosaur National Monument. Twenty problematic weed species were identified. Russian knapweed was one of the most prevalent, particularly in the Cub Creek drainage. Resulting weed distribution maps were used to develop and implement an aggressive weed management program in select areas of the monument. As part of this program, plans were made to reinventory portions of the monument in 2010 which were initially inventoried in 2002 and 2003 to evaluate the effectiveness of management strategies. The main goal of the weed management program was to prevent the spread of weeds onto adjacent lands. Objectives to obtain this goal were to: (1) eradicate small satellite populations, especially along travel corridors; (2) suppress large infestations of Russian knapweed by 95–100% in target areas over the course of 5 yr; and (3) establish healthy, diverse plant communities (Morris and Call 2005).

This article presents the results of reinventory efforts in Dinosaur National Monument. Particular emphasis was placed on evaluating the effects that integrated weed management efforts had on the overall distribution and abundance of Russian knapweed in selected areas and in documenting changes in other invasive weed populations over time. The specific approach used in this setting illustrates the utility and necessity of combining inventory, planning, treatment, and evaluation in weed management efforts.

Materials and Methods

Two areas approximately 11 km (7 mi) apart within Dinosaur National Monument were inventoried for invasive plant species in 2002 and 2003 and were reinventoried in July of 2010. Approximately 648 ha (1,600 acres) were inventoried in the Cub Creek Watershed (40°25′25.29″N, 109°10′29.50″W, 1,618 m [5,310 ft] elevation) where an aggressive weed management program, focusing primarily on Russian knapweed, was implemented for 5 yr. An additional 648 ha in the Island Park area (40°31′05.97″N, 109°09′11.12″W, 1,515 m elevation) also were reinventoried for comparison purposes. Weeds in this area were not managed as intensively as in the Cub Creek Watershed. Both areas have a mesic soil temperature regime, and an aridic soil moisture regime. Soils consist of well-drained alluvial and colluvial material described as fine-loamy, fine sandy-loamy, fine sand, and coarse-loamy.

Weed Management Techniques. Russian knapweed control within the Cub Creek Watershed allowed for the use of herbicides, selective grazing, mowing, and prevention. The use of biological control agents was rejected based on potential risks to special-status, nontarget plant species. Cultivation also was rejected due to the potential for damaging cultural and natural resources (Morris and Call 2005).

Initially, focus was placed on containing and shrinking the perimeter of a heavily infested area around Josie's Ranch, a historic ranch site within the Cub Creek drainage. In 2006 aminopyralid (Milestone®, Dow AgroSciences, Indianapolis, IN) was applied in mid-June to 1 ha at a rate of 70 g ae ha^{-1} (4.0 ounces ae $acre^{-1}$), which is lower than recommended labeled rates for Russian knapweed (88 to 123 g ae ha^{-1}). Monitoring reported that this application provided little, if any, control. In 2007 and 2008, several small areas were selectively grazed with goats in June and July. Grazing was followed by an application of aminopyralid in mid-October at a rate of 105 g ae ha^{-1} to 9 ha and 12 ha. An additional 13 ha were treated in mid-October 2009 using aminopyralid at 105 g ae ha^{-1}. By 2010 the majority of the infested area had been treated, and focus was placed on locating and treating missed patches and regrowth with backpack sprayers. Implemented prevention measures required that equipment used in infested areas was thoroughly washed before use at other sites. No reseeding was undertaken because a strong positive response from desirable vegetation was observed after herbicide application.

In addition to Russian knapweed, weed management efforts targeted several other problematic invasive weed species. Canada thistle [*Cirsium arvense* (L.) Scop.] also was selectively treated using aminopyralid in mid-October at 105 g ae ha^{-1}. Russian-olive (*Elaeagnus angustifolia* L.) and saltcedar (*Tamarix ramosissima* Ledeb.) were treated on an ad hoc basis using cut-stump applications of triclopyr (Garlon4®, Dow AgroSciences) in basal oil (JLB Oil Plus®, Brewer International, Vero Beach, FL) (1 : 3) in both the spring and fall. Tamarisk beetles also were discovered within the watershed in 2010. A small patch of hoary cress [*Cardaria draba* (L.) Desv.] was treated with chlorsulfuron (Telar®, DuPont, Wilmington, DE.) at 53 g ai ha^{-1}. An aggressive early detection strategy for the control of leafy spurge also was initiated, and any patches discovered within monument boundaries were immediately hand-pulled.

Table 1. List of invasive plant species targeted in Dinosaur National Monument in the nonnative plant inventories.

Invasive species	Common name
Acroptilon repens	Russian knapweed
Arctium minus	Common burdock
Cardaria draba	Hoary cress
Carduus nutans	Musk thistle
Centaurea diffusa	Diffuse knapweed
Centaurea maculosa	Spotted knapweed
Cirsium arvense	Canada thistle
Conium maculatum	Poison-hemlock
Cynoglossum officinale	Houndstongue
Elaeagnus angustifolia	Russian-olive
Euphorbia esula	Leafy spurge
Hyoscyamus niger	Black henbane
Isatis tinctoria	Dyer's woad
Lepidium latifolium	Perennial pepperweed
Linaria dalmatica	Dalmatian toadflax
Lythrum salicaria	Purple loosestrife
Onopordum acanthium	Scotch thistle
Taeniatherum caput-medusae	Medusahead
Tamarix ramosissima	Saltcedar
Tribulus terrestris	Puncturevine
Ulmus pumila	Siberian elm

Reinventory. Within the two designated areas, field inventories (Dewey and Andersen 2006) were conducted by a two-person crew at as fine a scale necessary to be confident that 90 to 100% of all target invasive weed infestations 0.004 ha or larger were detected. Although the original search routes were followed as closely as possible, search swath widths were individually adjusted based on variations in terrain, vegetative cover, size, and visibility of targeted weed species to ensure detection confidence. On open plateaus search swaths were generally 50 to 100 m wide (25 to 50 m to the right and left).

The same 21 species identified as high priorities in the original inventory (Table 1) were included in the reinventory. Any other nonnative species recognized as relatively new to Dinosaur National Monument, and potentially invasive, also were documented if found. Infestation size was initially recorded in acres and later converted to hectares for analysis. Weed infestations 1 acre or less in size were mapped as point features. The size of each infestation was estimated, using a laser rangefinder to measure the patch width, and placed in a size category most closely matched to its actual area: (1) 1 to few plants, (2) 0.001 acre, (3) 0.01 acre, (4) 0.1 acre, (5) 0.25 acre, (6) 0.5 acre, (7) 1.0 acre, (8) 2.5 acres, or (9) 5.0 acres. Crew members had the choice to map infestations greater than 1 acre in size as point, polygon, or line features. Previous research has shown that point and polygon features are

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Table 2. Monthly and annual precipitation during the years between invasive plant inventories from 2002 to 2010 compared to the 70-yr average at Jensen, UT, just east of Dinosaur National Park.

	Precipitation[a]												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
	mm												
2001	9.65	10.92	1.52	28.19	11.43	1.02	21.59	20.89	5.08	17.53	20.32	8.89	156.97
2002	1.52	0	13.97[b]	5.08	0	0.76	9.14[b]	16.00	44.96	35.56	10.92	9.65[b]	147.57[b]
2003	5.84	16.00	17.53	9.14	26.67	12.70[b]	0.51	8.13	5.33[b]	6.35	15.24	20.07	143.51[b]
2004	2.03	14.99	1.27	21.08	2.79	8.38	6.35	2.79	37.34	69.09	29.97	7.11	203.20
2005	37.34	22.86[b]	19.05	14.99	24.13	12.70	0.25	21.08	35.81	25.65	12.45	0.76	227.08[b]
2006	19.05	0.51	25.91	10.41	5.59	16.26	3.81	9.91	26.67	72.14	10.92	8.13	209.30
2007	28.45	—[b]	3.30	15.49	31.75	0.76	2.03	16.00	39.12	26.67	0	66.55	230.12[b]
2008	18.54	12.45	12.95	7.11	11.43[b]	29.97	1.02	3.81	33.27	16.76	12.95	25.65	185.93[b]
2009	41.66	3.30	8.38	32.26	7.37	39.88	4.83	8.89	17.27	16.26	14.22	32.00[b]	226.31[b]
2010	9.91[b]	5.84	14.48	36.83	19.05	33.78	14.99	15.24	2.79	27.69	26.92	71.88	279.40[b]
70 yr Ave.	13.46	12.954	14.73	19.30	19.05	17.78	13.72	17.27	23.11	26.16	13.46	16.51	207.52

[a] Precipitation data at Jensen, UT (weather station ID: 424342) accessed through the Utah State University, Utah Climate Center.

[b] Precipitation data within these months and corresponding annual totals might be incomplete because some of the daily measurements for the weather station were not recorded.

similar in accuracy for estimating infestation location and size (Christensen et al. 2011). As a rule, scattered plants 50 m or more apart were considered separate infestations. Patches or plants less than 50 m apart from each other were regarded as a single infestation. Canopy cover of each infestation, or the total space within the boundary of the infestation occupied by the species being mapped, was visually estimated and placed in a corresponding category: (1) trace = less than 1%, (2) low = 1 to 5%, (3) moderate = 6 to 25%, (4) high = 26 to 50%, or (5) majority = 51 to 100%. Other information recorded by the surveyor for each patch included: species, phenology, physiognomic class, hydrology, and record number. Date, time, horizontal precision, maximum Position Dilution of Precision (PDOP), feature type, and Universal Transverse Mercator (UTM) coordinates were automatically recorded by the Global Positioning System (GPS) unit (Trimble XM GPS Units, Trimble, Sunnyvale, CA and Archer Field PC, Juniper Systems, Logan, UT). Minimum accuracy of the GPS units was 2 to 5 m.

Data Management and Analysis. Each evening GPS data files were downloaded onto a laptop and reviewed for accuracy by crew members. Between-feature positions, automatically recorded by the GPS unit, indicated the search route followed by the surveyor and provided verification that areas were thoroughly covered. Log entries also were made reporting where they had searched, what species were encountered, thoroughness of coverage, difficulties encountered, and any other information of interest.

Data records were edited, differentially corrected, and converted to ArcGIS shapefiles using Trimble Pathfinder (Pathfinder, version 2.90, Trimble) software. ArcGIS (ArcGIS, version 9.3.1, ESRI, Broomfield, CO) was then used to calculate the acres infested by each weed species in both 2002 and 2010. Changes, or differences, in the infested area were found by subtracting the acres infested for each weed species in 2002 from the total infested acres in 2010. The infested acres for each weed species were also categorized according to their approximate canopy cover. Canopied area was calculated for each species by multiplying the acres in each category by the midpoint percentage in each canopy class: (1) trace = 0.05%, (2) low = 2.5%, (3) moderate = 15.5%, (4) high = 35.5%, or (5) majority = 75%. All measures were then converted from acres to hectares.

Points and lines were altered in size (buffered) according to radius or width to reflect true patch size, as well as to increase visibility on maps. Maps were created using aerial images obtained from Geospatial Data Gateway (High Resolution Orthophotography [HRO] 2009. [NRCS] Natural Resource Conservation Service, Geospatial Data Gateway. http://datagateway.nrcs.usda.gov/). All records were projected in the coordinate system NAD 1983, UTM Zone 12. Weed maps for 2002 and 2010 were then compared to determine if any additional patterns, trends, or changes in weed distribution were evident.

Statistical comparisons of infested area and canopied area in response to management were made by ANOVA using proc GLM (SAS, version 9.2, SAS Institute Inc., Cary, NC). Data for Russian knapweed, Russian olive, and

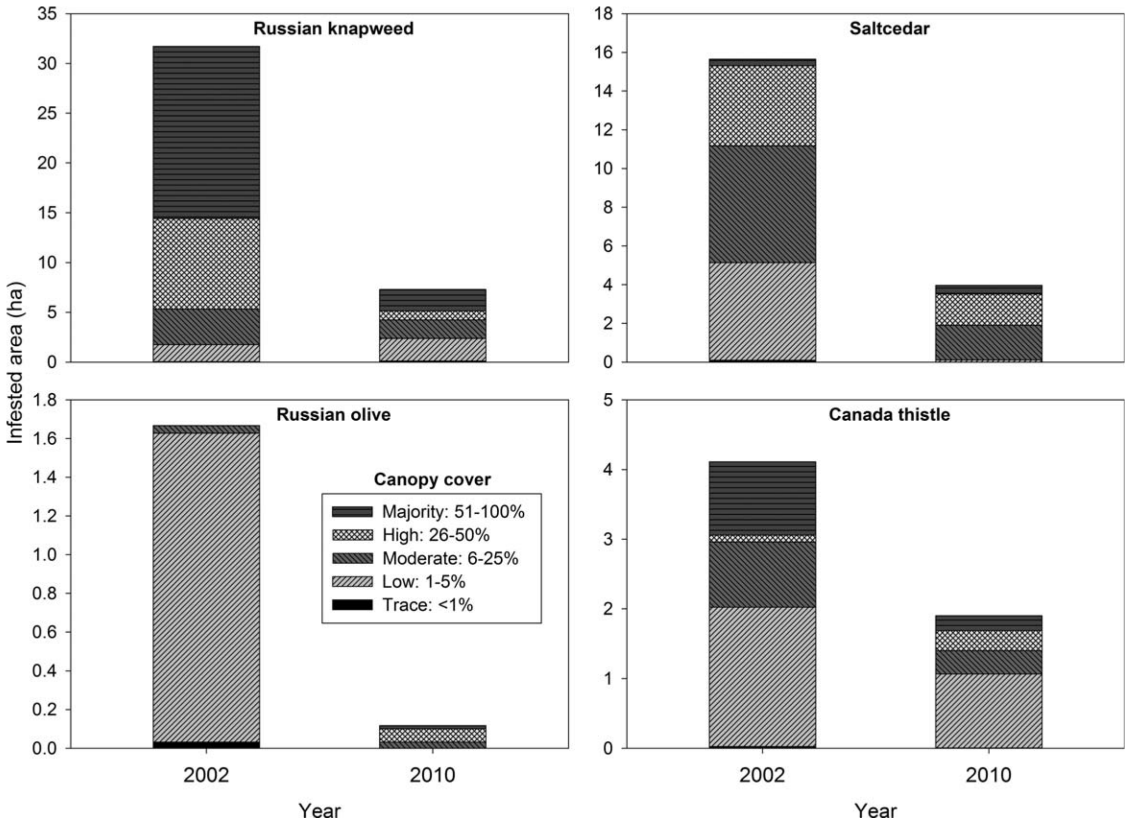

Figure 1. Total hectares infested and canopy cover (percentage of space of the infested area occupied by the invasive species being mapped) distributions for major weeds identified in the Cub Creek Watershed.

saltcedar, which were targeted for management, served as replicates. Prior to analysis, absolute percentage change data were log-transformed and assigned positive or negative values depending on whether the change was an increase or decrease. More detailed analyses were not possible due to lack of replication and relatedness of inventory polygons.

Results and Discussion

Overall, within each inventory, field crews searched 740 ha in Cub Creek and 874 ha in Island Park. In 2002–2003, invasive plants infested a total of 59 ha in Cub Creek and 90 ha in Island Park, equaling approximately 8 and 10% of the land inventoried. In 2010, invasive plants were found to infest 14 ha in Cub Creek and 79 ha in Island Park, equaling 2 and 9% of the land inventoried, respectively. Annual precipitation in the years prior to and during the initial inventory (2001–2003) were below the long-term average, whereas precipitation was above average in some of the subsequent years, including the year (2009) prior to the reinventory (Table 2).

Russian Knapweed. Russian knapweed was the most abundant invasive species discovered in the Cub Creek Watershed, infesting approximately 35 ha in 2002. The majority of these infestations were estimated to have a canopy cover greater than 26%. Following 5 yr of control, Russian knapweed populations were reduced 79% to 7 ha with a canopy cover of less than 26% (Figure 1). In terms of total canopied area, Russian knapweed initially covered 18 ha of land, but decreased 87% to 2 ha (Table 3). Distribution map comparisons also showed a major reduction in the area infested, especially near the road, parking lot, and hiking trails. The majority of the remaining patches were scattered and less than a 0.5 ha in size (Figure 2).

In addition, the first year following aminopyralid application, Tamara Naumann, Dinosaur National Monument botanist, reported a positive response in the growth of desirable vegetation (perennial grasses), even in densely infested areas. Unfortunately, observations in the second year found downy brome (*Bromus tectorum* L.) invading several areas where desirable grasses were present, but not yet well-established. Although not well-understood, the occurrence of secondary invasion in wildland areas has been identified as a common management challenge. Downy brome also has been reported as one of the primary offenders (DiTomaso et al. 2006; Pearson and Ortega 2009).

In contrast, in the Island Park area Russian knapweed initially infested 1.76 ha of land with a canopy cover

Table 3. Comparison of the total hectares and canopied hectares infested in the Cub Creek Watershed.

	Total hectares infested				Total canopied hectares			
Species	2002	2010	Change	%	2002	2010	Change	%
Bouncing bet	0	0.05261	0.0526	—	0	0.33851	0.33851	—
Bull thistle	1.04732	0.04225	−1.0051	−96%	0.03881	0.00386	−0.03495	−90%
Common burdock	0.09712	0.01068	−0.0864	−89%	0.00227	0.00119	−0.00108	−48%
Canada thistle	4.24515	1.90097	−2.3442	−55%	1.02909	0.33986	−0.68924	−67%
Field bindweed	0	0.05706	0.0571	—	0	0.0084	0.0084	—
Hoary cress	0.04047	0.01416	−0.0263	−65%	0.01437	0.00665	−0.00771	−54%
Houndstongue	0.3885	0.08474	−0.3038	−78%	0.02804	0.00878	−0.01926	−69%
Musk thistle	0.01214	0.00004	−0.0121	−100%	0.00022	0.00003	−0.00019	−85%
Perennial pepperweed	0.11736	0.0518	−0.0656	−56%	0.06372	0.01296	−0.05076	−80%
Russian knapweed	35.108	7.29409	−27.8139	−79%	17.6037	2.28215	−15.32155	−87%
Russian-olive	1.728	0.11710	−1.61	−93%	0.04765	0.04150	−0.00615	−13%
Saltcedar	15.7746	3.96219	−11.8124	−75%	2.24511	1.1884	−1.05671	−47%
Scotch thistle	0.00405	0	−0.004	−100%	0.00002	0	−0.00002	−100%
Total hectares inventoried: 740								

generally greater than 26%. By 2010, this infested area had increased 14% to 2 ha. Most of the associated canopy cover remained greater than 26% (Figure 3). Surprisingly, the total canopied area did not change significantly, remaining at roughly 1.07 hectares (Table 4). Distribution map comparisons revealed that although existing infestations did not alter significantly, 13 new infestations were discovered along the river.

Other Targeted Species. Other species targeted for management in the Cub Creek Watershed included: saltcedar, Russian olive, Canada thistle, and hoary cress. Saltcedar infested 16 ha in 2002 with a canopy cover mainly between 1 and 25%. This infested area was reduced 74% to 4 ha with a canopy cover primarily between 6 and 50% (Figure 1). Total canopied area declined 47% from 2.2 to 1.2 ha (Table 3). Approximately 1.7 ha of Russian olive was discovered in 2002 with an associated canopy cover of 1 to 5%. By 2010 the infested area had declined 89% to 0.2 ha, with cover ranging from 6 to100% (Figure 1). Factoring in cover estimates, the total canopied area of Russian olive actually increased from 0.05 to 0.08 ha (Table 3). Canada thistle infested roughly 4.2 ha with cover mostly between 1 and 25%. Populations declined 55% to 1.9 ha, but cover remained the same (Figure 1). Overall, canopied area decreased 68% from 1.03 to 0.34 ha. Roughly 0.04 ha of hoary cress was recorded in 2002, and decreased 65% to 0.01 ha. The total canopied area showed a decline of 54% (Table 3). In the Island Park area, roughly 0.004 ha of leafy spurge with cover between 26 and 50% was discovered in 2002. No infestations were detected in the 2010 inventory (Table 4).

In comparison, with the exception of leafy spurge, no treatments were applied to invasive species in the Island Park area. Initially, 48 ha of saltcedar were discovered with a canopy cover ranging from 1 to 100%. This area increased 4% to 50 ha with cover between 26 and 100% (Figure 3). Coverage estimates indicated that total canopied area expanded 75% (Table 4). Canada thistle infested 4 ha with cover generally between 1 and 25%. In 2010 this area showed a decline of 68% to 1.3 ha with cover greater than 26% (Figure 3). The total canopied area actually increased 55% due to increases in canopy cover density (Table 4).

Weed Species Not Directly Targeted. Other species identified in small patches, but not targeted for management in the Cub Creek Watershed included: Scotch thistle (*Onopordum acanthium* L.), perennial pepperweed (*Lepidium latifolium* L.), common burdock (*Arctium minus* Bernh.), houndstongue (*Cynoglossum officinale* L.), bull thistle [*Cirsium vulgare* (Savi) Ten.], and musk thistle (*Carduus nutans* L.). Although Scotch thistle infested 0.004 ha in 2002, no patches were identified within the watershed in 2010. All other species showed minor reductions in the total area and canopied area infested (Table 3). Distribution maps show that these species generally occurred in the same area where control was applied for Russian knapweed. Although they were not targeted, it is possible that some population changes are a result of treatment in the process of treating the target species.

Additional species inventoried in the Island Park area included perennial pepperweed, musk thistle, bull thistle, and common burdock. Perennial pepperweed was the second most abundant species within the Island Park area, infesting about 36 ha with an associated canopy cover ranging from 1 to 50%. By 2010, this area had declined 29% to 26 ha with a cover between 6 and 100% (Figure 3). Overall, total canopied area expanded 40% to 10 ha. Musk thistle only infested 0.004 ha in 2002, but increased to 0.3 ha by 2010. Distribution maps show the

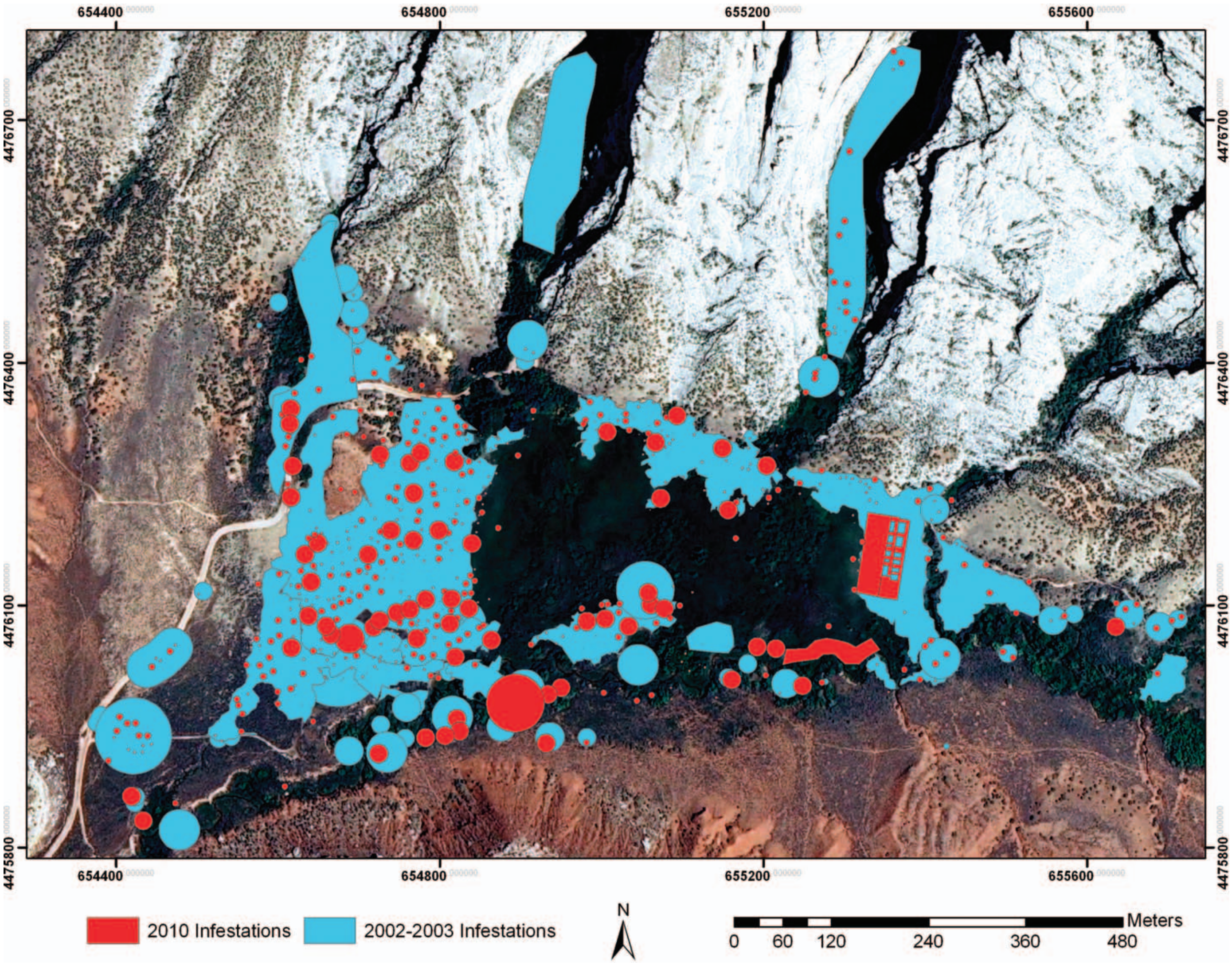

Figure 2. Example distribution map comparing Russian knapweed infestations in 2002–2003 to infestations in 2010 within the Cub Creek Watershed.

discovery of 13 new, small infestations. Bull thistle remained stable at roughly 0.06 ha of infested area. Burdock populations declined from 0.43 to 0.05 ha in total infested area (Table 4).

New Species. Bouncing bet (*Saponaria officinalis* L.) and field bindweed (*Convolvulus arvensis* L.) were new nonnative species documented in the Cub Creek Watershed in 2010. These species, although not on the inventory list, were recorded due to their high potential to be invasive. It is possible that field bindweed was present but not mapped in 2002, because it was not included on the initial inventory list. Bouncing bet infested an area of 0.05 ha. The majority of this area had a canopy cover greater than 50%. Field bindweed infested 0.06 ha with an associated canopy cover between 1 and 50% (Table 3).

Russian olive and field bindweed were new weed species recorded in the Island Park area. A 0.6 ha patch of Russian olive was discovered with a canopy cover greater than 50%. Field bindweed infested an area roughly 0.09 ha in size with an associated canopy cover between 26 and 50% (Table 4).

Management Implications

Although inventory results provide limited information on changes in individual infestations, overall trends indicate that applied management strategies are significantly reducing infestations of target species. In regard to Russian knapweed control, the application of aminopyralid in the fall at 105 g ae ha^{-1} appeared to be fairly effective. After 5 yr, treatments provided a 79% reduction in the

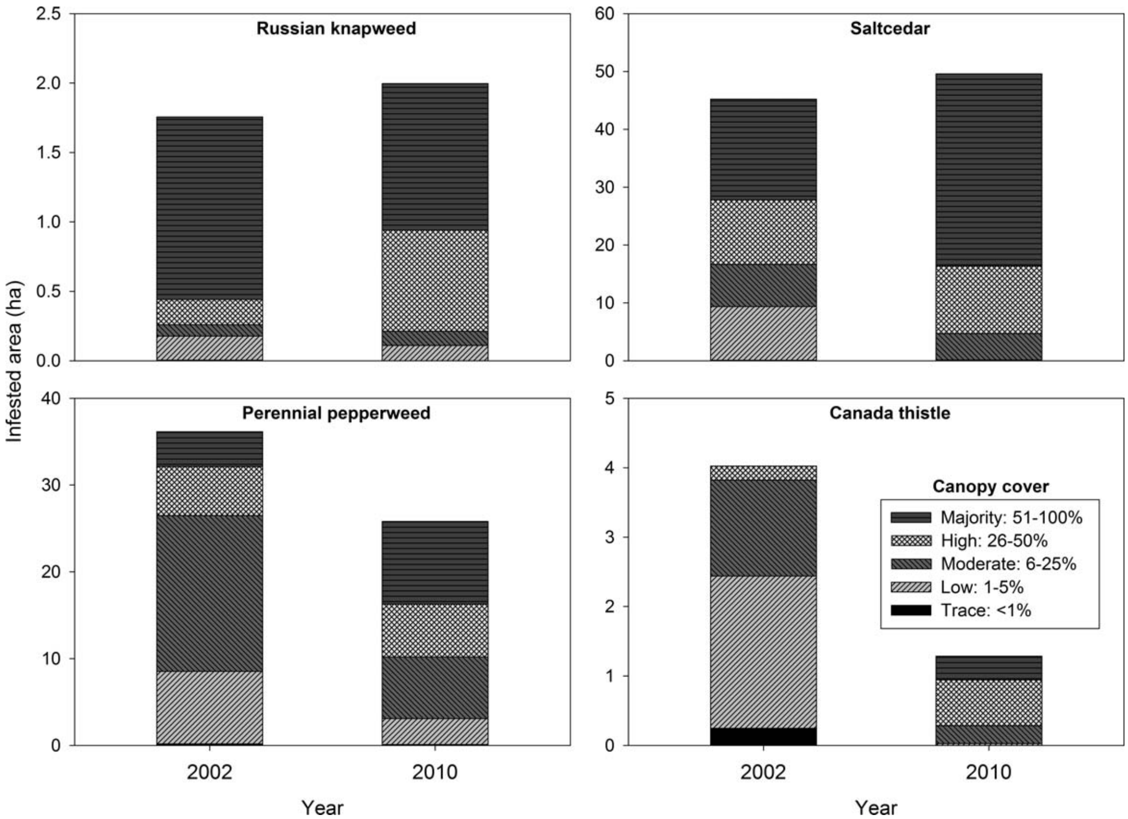

Figure 3. Total hectares infested and canopy cover (percentage of space of the infested area occupied by the invasive species being mapped) distributions for major weeds identified in the Island Park area.

total area infested, and an 87% decline in the canopied area. Conversely, untreated Russian knapweed infestations in the Island Park area showed an increase of 14% in the total area infested. The specific management objective of reducing large infestations of Russian knapweed by 95 to 100% was not fully achieved within the specified time, requiring additional treatment since the reinventory was completed. Reinventory data has been used to target remaining plants and infestations, increasing treatment efficiency.

It also appears that aminopyralid is selective enough that the growth of desirable grasses was not significantly inhibited. Research has found that growth regulators, such as aminopyralid, also might affect the growth of invasive annual grasses (Rinella et al. 2010). This could explain the delayed invasion of downy brome following aminopyralid applications. The potential for secondary invasion is a definite barrier to management success in areas of Dinosaur National Monument. Further research has already been initiated to identify possible management strategies that could be implemented to address the problem.

The treatments used to control other target species also appear to have been effective in reducing their abundance and distribution on the landscape. During the reinventory, no leafy spurge populations were detected within the Island Park area. This supports the idea that if managers respond rapidly to new weed infestations, they can be controlled cost-effectively with methods such as hand pulling (Aslan et al. 2009). Further, following treatments in the Cub Creek Watershed, saltcedar, Russian olive, Canada thistle, and hoary cress each showed reductions of 55% or more in the total area infested. Saltcedar, Canada thistle, and hoary cress also declined 47% or more in the total canopied area. Canopied area for Russian olive decreased by only 13% and likely was influenced by changes in plant distribution and maturity. Initially, plants were often too close together to be considered separate infestations, but they were still scattered and low in density. This caused the total area infested to be much larger in size than the canopied area. Although the total area infested by Russian olive was reduced over time, it is likely that rapid growth in remaining plants caused canopy cover reductions to be less dramatic.

Comparisons of treated and nontreated areas for Russian knapweed, saltcedar, and Russian olive revealed that management was significant for reductions in infested area ($P = 0.019$) and in canopied area ($P = 0.011$).

Inventory results revealed a wide range of population responses for species which were not targeted for management. In the Island Park area, saltcedar, Canada thistle, and perennial pepperweed each increased in

Table 4. Comparison of the total hectares and canopied hectares infested in the Island Park area.

	Total hectares infested				Total canopied hectares			
Species	2002	2010	Change	%	2002	2010	Change	%
Bull thistle	0.0607	0.062	0.0013	2%	0.00119	0.00912	0.00792	664%
Common burdock	0.41278	0.04225	−0.37053	−90%	0.01497	0.00176	−0.01321	−88%
Canada thistle	4.02378	1.28568	−2.7381	−68%	0.34199	0.53062	0.18863	55%
Field bindweed	0	0.08948	0.08948	—	0	0.03273	0.03273	—
Leafy spurge	0.00405	0	−0.00405	−100%	0.00144	0	−0.00144	−100%
Musk thistle	0.00405	0.32359	0.31954	7898%	0.00022	0.17348	0.17326	78044%
Perennial pepperweed	36.3716	25.8172	−10.5544	−29%	7.4848	10.4925	3.00772	40%
Russian knapweed	1.75633	1.99603	0.2397	14%	1.06798	1.0692	0.00122	0%
Russian-olive	0	0.05969	0.05969	—	0	0.04477	0.04477	—
Saltcedar	47.7956	49.5953	1.7997	4%	17.0385	29.7759	12.73740	75%
Total hectares inventoried: 874								

canopied area 75%, 55%, and 40%, respectively. Saltcedar also showed a slight increase in the total area infested, whereas Canada thistle and perennial pepperweed populations declined. Increases in the canopied area again can be attributed to changes in distribution and plant maturity over time. Tamara Naumann, Dinosaur National Monument botanist, has also observed that for several years a fungus has been attacking perennial pepperweed plants growing on poorer soils. This fungus could be a contributing factor in the decline of perennial pepperweed infestations. Changes in the flow of the Green River also might have contributed to the decline of Canada thistle and perennial pepperweed populations in the Island Park area. River flow data indicates that the average monthly discharge in the months of June and July were approximately four times greater in 2010 than in 2002 (USGS 2010). The majority of the infestations discovered in 2002 were located along the banks of the Green River. Due to significantly higher river levels, many of these infestations might not have been found because they were underwater at the time of reinventory.

Overall, changes in weed infestations not targeted for treatment appear to be due to natural fluctuations in weed populations that can occur over time in response to a variety of environmental factors. Such changes are most evident in small populations of weed species (Mack et al. 2000; Theoharides and Dukes 2007). Even in areas where Russian knapweed was not controlled, the rate of spread appears to be fairly slow, and existing patches have remained relatively stable. This might be related to the areas where the initial infestations invaded and not an indication of the potential for Russian knapweed to expand in this area. Further, many invasive plant populations experience lag phases in which growth is slow, or stable, until favorable conditions appear allowing for rapid expansion (Hobbs and Humphries 1995; Theoharides and Dukes 2007). When these conditions arise, invaders stemming from many small, scattered patches can spread more quickly across a landscape than a single infestation of the same approximate acreage (Moody and Mack 1988; Pysek and Hulme 2005).

Weed population dynamics observed in Dinosaur National Monument would then suggest that many species could potentially become problematic if they are completely ignored while resources are directed at bigger, more pressing problems. Further, several new species were discovered, and though still few in number, appear to be growing. This emphasizes the value of weed inventories or surveys in a wildland weed management program. Utilizing these tools, managers can track the shifting dynamics of existing weed populations, and discover new infestations soon after introduction (Dewey and Andersen 2004; Randall 2000). Managers then can better prioritize efforts to eliminate problem species before they become well established, reducing total control costs, damages, and propagule pressure (Aslan et al. 2009; Dewey et al. 1995; Hobbs and Humphries 1995).

The integrated invasive plant management strategies employed at Dinosaur National Monument have been effective in significantly reducing Russian knapweed and other targeted weed populations, while not completely eliminating those species. Further, reinventory results identified several new species with the potential to become problematic. This illustrates the importance of utilizing inventory data, identifying treatment priorities, evaluating treatment performance, and reevaluating management objectives in designing and conducting effective invasive plant management programs. Success of invasive plant management efforts relies on using current data to make management decisions and adjustments in order achieve long-term management goals.

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