Integrated Weed Management Plan for the Northern District of Bighorn Canyon National Recreation Area

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Recommendations

- Maps of noxious weed occurrence in the northern section of BCNRA show that the populations are distributed in many areas of the formally disturbed areas of the park. While many populations have been observed close to roads, trails and the waterways there are some at greater distances which are also of concern.

- A small area should be surveyed to fill in the gaps from previous surveys. A map of these areas is provided.

- These areas, and the less disturbed areas to the north and south west should be walked on a 2-3 year interval to search for any new infestations. Controlling newer infestations has a higher probability of eradication.

- Coordinates of transects which could be completed to provide a total inventory of the area are provided should time and resources become available.

- Monitoring for invasiveness of NIS, impact and effectiveness of management on NIS and the surrounding vegetation is the next step which should be taken.

- Monitoring should be performed on patches chosen from the survey and which represent the range of environment where the specific target species is found.

- Reasons for monitoring are provided along with details of how to apply these methods.

- Control practices including herbicides, mechanical, cultural and biological are provided for each noxious species targeted in the BCNRA

- Using the survey and monitoring methods and evaluating the different control practices in small plots as outlined in this report, will lead to the most effective management of noxious and NIS species in BCNRA.

Introduction

Purpose

This report presents an adaptive, integrated weed management plan for the northern district of the Bighorn Canyon National Recreation Area (BCNRA). The purpose of this plan is to help the BCNRA identify and locate noxious plant species, discuss future areas to survey areas, highlight the relevant monitoring methods and how they could be applied, and provide a review of management practices which could be used. This plan recognizes that non-indigenous species (NIS) management must be tailored to the unique management and ecological needs of BCNRA. Plus, that control of all NIS within the BCNRA cannot be met by the current budget or personnel available.

Maps of known locations of noxious weeds are provided and these data are combined with previous surveys to determine further areas requiring a survey. Techniques to monitor for changes in NIS populations, surrounding vegetation and the impact of management strategies on NIS and surrounding vegetation is provided, along with suggestions of adaptive management alternatives which should be evaluated in small plots to establish the most effective approaches to use over the wider area. Using the approaches suggested will help the park stratify resources to those populations which are the greatest threat to the area, or to populations which have a greater chance of effective control.

The primary weeds to be targeted are spotted knapweed (*Centaurea maculosa*) diffuse knapweed (*Centaurea diffusa*), russian knapweed (*Acroptilon repens*), Canada thistle (*Cirsium arvense*), houndstongue (*Cynoglossum officinalis*) and other species listed as noxious by the State of Montana and or by Bighorn County, within which the northern district lies.

Site description

The Bighorn Canyon National Recreation Area is administered by the National Park Service, U.S. Department of the Interior. It was established as a National Recreation Area by the U.S. Congress in 1966 with a mission to provide enjoyment for visitors today and to protect the park for future generations. While the BCNRA extends from southern Montana into Northern Wyoming, this project will take place only in the northern district of BCNRA in southern Montana.

The northern district consists of 540 acres around the Fort Smith Headquarters (see Figure 1). Capitol improvements include the park headquarters, an airstrip, two camping areas, a picnic area and three river access points. The National Park Service is also responsible for weed control in areas managed by the Bureau of Reclamation including the Yellowtail Dam Visitor Center, a landfill, three miles of highway east of Ft. Smith, the Ft. Smith government camp, the Three Mile fishing access, and the 11 mile road to the Ok-A-Beh river access. The Crow Tribe owns most of the surrounding lands and manages these lands for grazing. Valley bottoms to the north of the BCNRA are farmed.

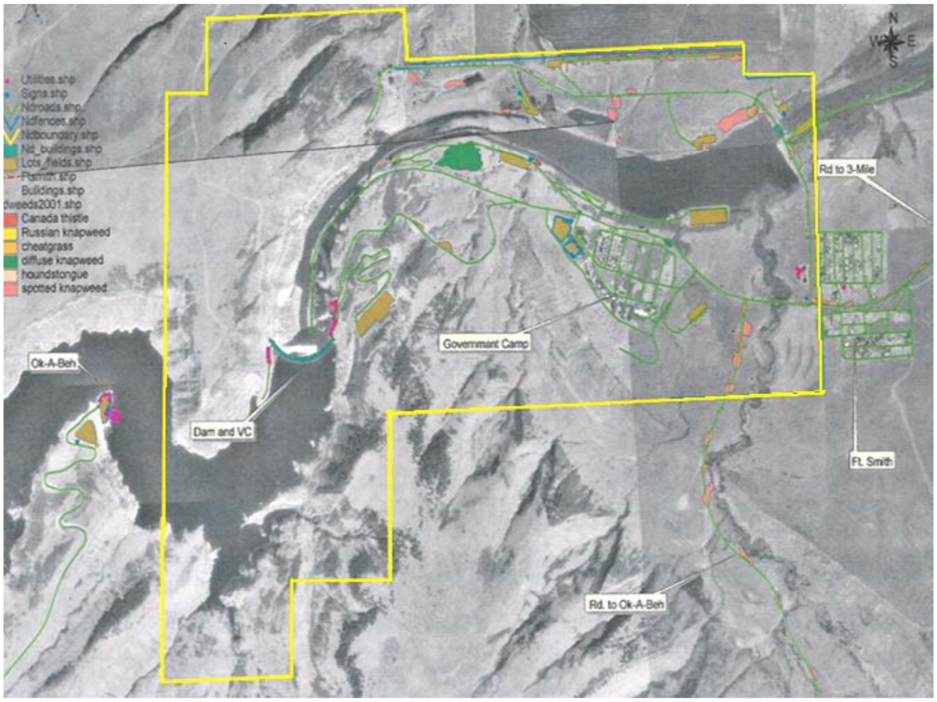


Figure 1: Aerial photo showing northern district of Bighorn Canyon National Recreation Area. The integrated weed management plan addressed land within the yellow boundary. Colored polygons show non-indigenous species mapped in 2001. remove those

Site disturbance history

The area has been heavily disturbed by a number of anthropogenic influences, particularly in the early to mid 1900's. There has been disturbance by ranching and farming with the creation of an irrigation system, heavy machinery disturbance due to the construction of the Yellowtail Dam, which was completed in 1965. The area was dedicated as a National Recreation Area in 1968. Since that time anthropogenic disturbance has been due to recreation, in the form of camping and fishing.

The annual precipitation at Fort Smith averages 483 mm (19.03 ").

Justification for action

According to the National Park Service, the invasion of NIS (exotics, non-native species, weeds) is one of the most serious threats that Park Service administered lands face today, and "If exotics are not actively and aggressively managed, the National Park System is at risk of losing a significant portion of its biological resources" (National Park Service, 1997). Invasive exotic plants on National Park Service lands infest 7 million acres, or the equivalent of 31% of Park land outside of Alaska (Cacek, 2000). Non-indigenous species are considered the second greatest threat to biodiversity after habitat destruction (Randall, 1996). When such species have characteristics that permit them to rapidly invade new areas and out-compete native plants for light, water, and nutrients they are often termed "invasive weeds" (Westerbrooks, 1998).

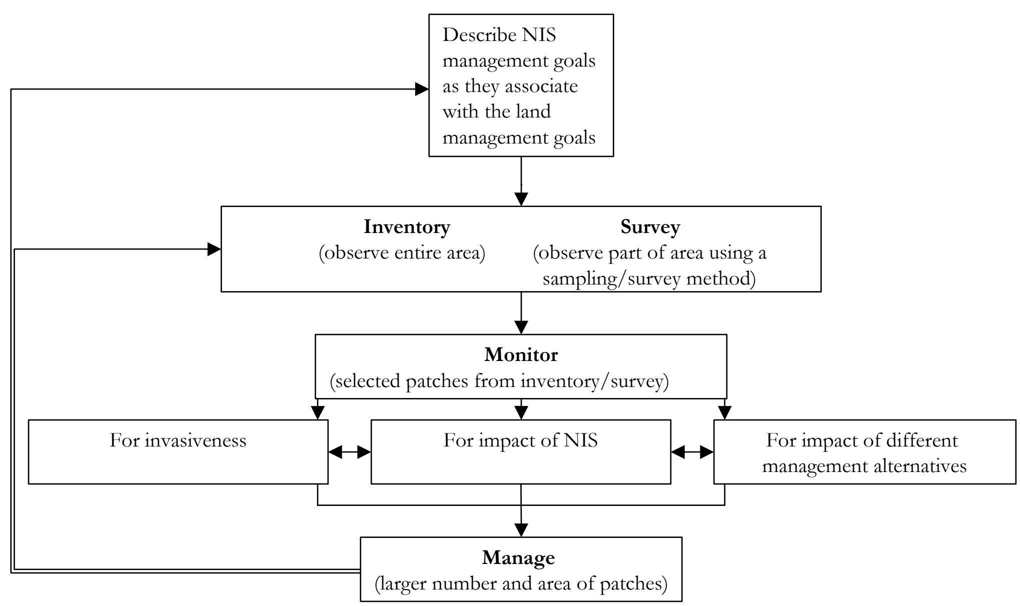
A "noxious weed" is any plant species which has been designated by a Federal, State or county government as injurious to public health, agriculture, recreation, wildlife or property (Sheley, Petroff &

Borman, 1999). Montana has defined noxious weeds to include "...any exotic plant species established or that may be introduced in the state which may render land unfit for agriculture, forestry, livestock, wildlife, or other beneficial uses or that may harm native plant communities" (County Noxious Weed Control Act (CNWCA). The control of "noxious weeds" is justified by the CNWCA (7-22-2101 MCA), which requires the control of designated noxious weeds within county districts. Weed management plans are required by the CNWCA to incorporate all appropriate methods, including: education, prevention, mechanical methods, biological controls, cultural methods, and general land management practices.

The three phases of non-indigenous species management

Management of non-indigenous species should be regarded as a three phase process: inventory/survey, monitoring and management (Fig. 2). Although all three phases can be performed simultaneously, considering them as different phases is important for conceptual, theoretical, methodological, logistic and practical reasons. The first phase, inventory/survey, determines which species are present and their distribution within the environment. The second phase, monitoring, provides information on how patches are changing with time, their impact on the ecosystem and the impact of management on the patch. The final phase, management, is important for control of non-indigenous patches and populations, by reducing their distribution and impact.

Fig 2 Three phases of non-indigenous species management



Non-indigenous plant survey

Three studies have addressed the presence of NIS in this area. In 1983 the University of Wyoming surveyed the area for all vascular plant species. This was published as the "Vascular Plant Species Checklist of Bighorn Canyon National Recreation Area" in 2002 (Heidel & Fertig, 2002). This study was a checklist of NIS and did not address species location or frequency.

A survey of noxious weeds and their locations was performed by Suzanne Morstad and other BCNRA staff in 2001. They targeted five noxious weeds including, Canada thistle (*Cirsium arvense*), diffuse knapweed (*Centauria diffusa*), houndstongue (*Cynoglossum officinale*), Russian knapweed (*Acroptilon repens*), and spotted knapweed (*Centauria maculosa*). These species were mapped in developed areas and along roads. Polygons were created around infestations (Fig. 1). Further polygon sampling was performed in 2002 (Fig. 1).

In the summer of 2002, another survey was performed which covered a greater area of northern district, this was performed by Montana State University. The species of interest was extended to cover all noxious weeds listed in MT (Appendix 1) and the following species were observed and maps created:

Table 1 Non-indigenous species targeted by MSU survey (*These species are not of major interest to BCNRA staff at the current time).

bull thistle (Cirsium vulgare)	Russian knapweed (*Acroptilon repens*)
Canada thistle (*Cirsium arvense*)	spotted knapweed (*Centauria maculosa*).
diffuse knapweed (*Centauria diffusa*)	houndstongue (Cynoglossum officinale)
field bindweed (Convolvulus arvensis)	downey brome (*Bromus tectorum*) *
Skeleton weed (Chondrilla juncea)	smooth brome (*Bromus inermis*) *

A targeted transect method was used, which has been used in other National Parks in the region. Transects where positioned perpendicular to the boundary fence and airstrip / roads; the exact location of transects was random.

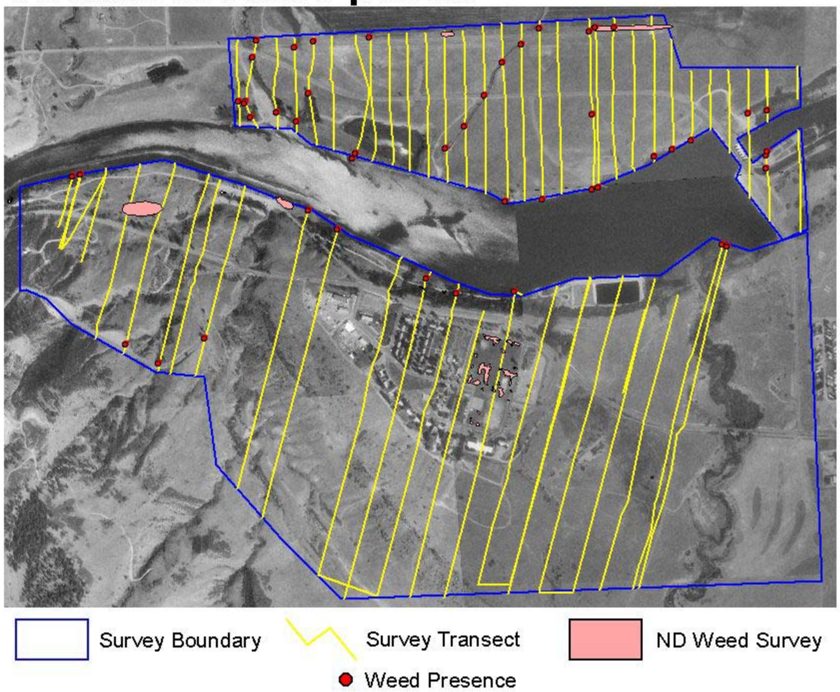
Transects were walked and locations recorded with a GPS (Global Positioning System), by two person teams. Transects were 20 m wide. Trimble GeoExplorer® 3 units were used and the data post-processed to improve accuracy. The coordinate system and projection used was Universal Transverse Mercator (UTM) Zone 13N, WGS 1984 Datum. Transects were walked and information gathered when a target species was located, the habitat type changed or a disturbance feature was reached. The habitat classifications were based on the classifications devised by Knight *et al.*, 1987. (For more detail of the sampling approach see Rew *et al.*, 2002).

Fifty-two transects were walked in the area surrounding the government buildings, camping and main fishing areas. The preliminary results of these data are provided in the following graphics with location of target NIS shown in red and the transects walked shown in yellow (Fig 2).

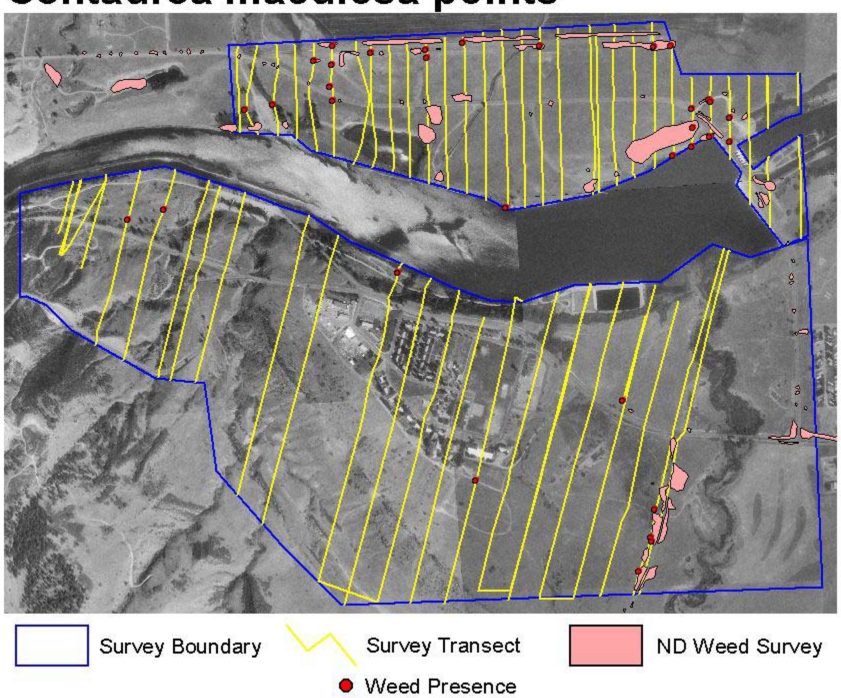
A list of the species found by their study, the Montana State 2002 survey, and designated noxious weeds of Montana can be found in Appendix I. A list of the categories allocated to different noxious weeds is provided in Appendix II.

Fig 3 Locations of NIS patches when surveyed using transects and point locations (weed presence) and using polygons (BCNRA weed survey).

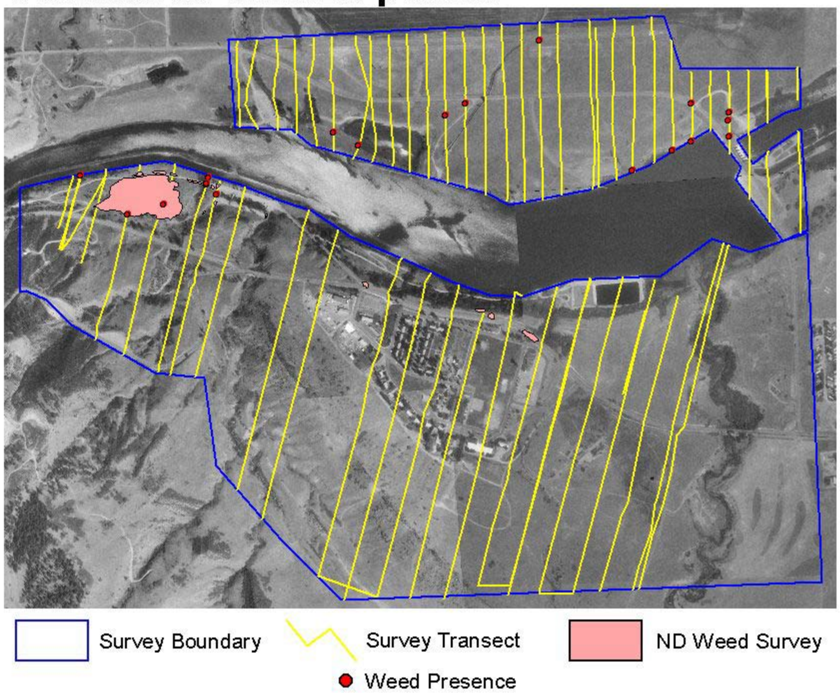
Cirsium arvense points



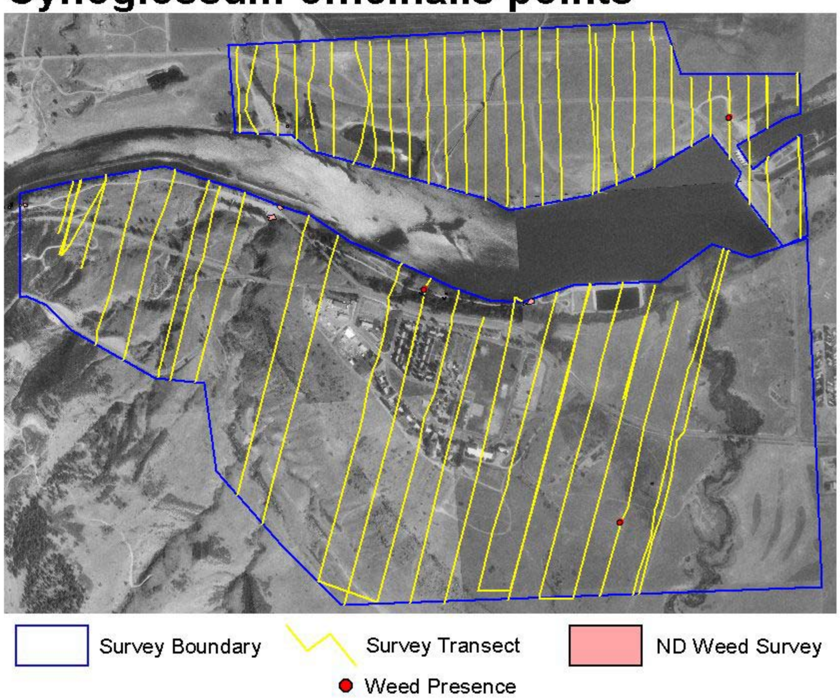
Centaurea maculosa points



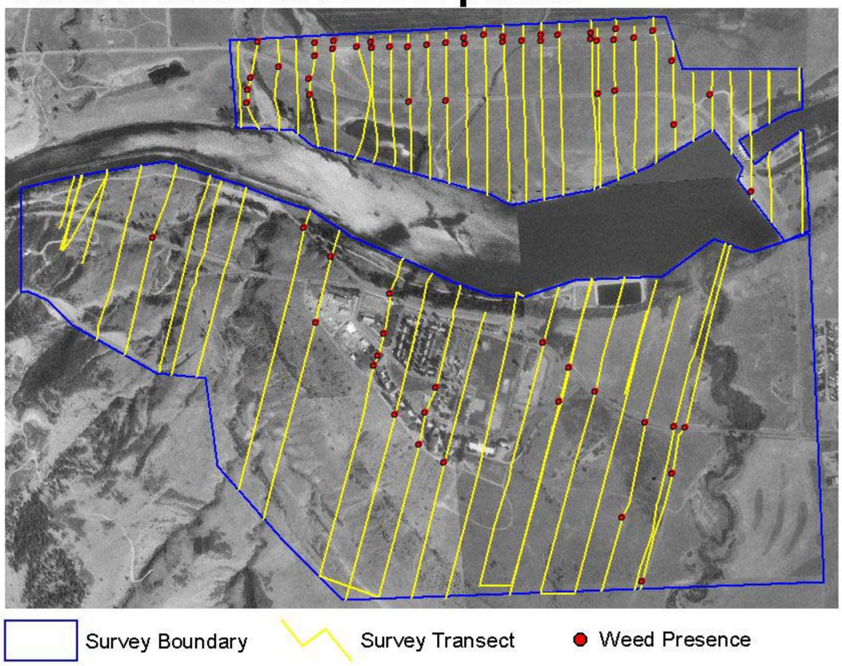
Centaurea diffusa points



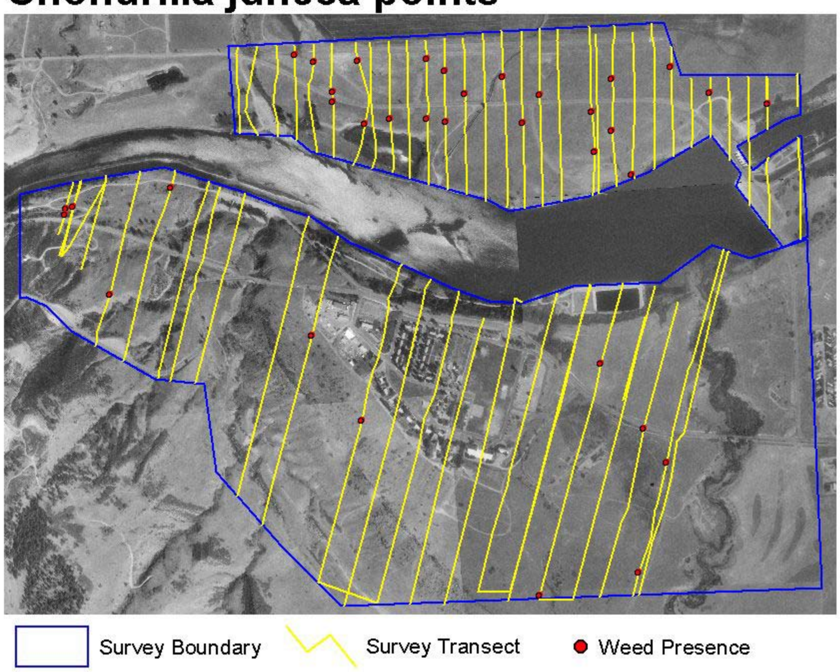
Cynoglossum officinalis points

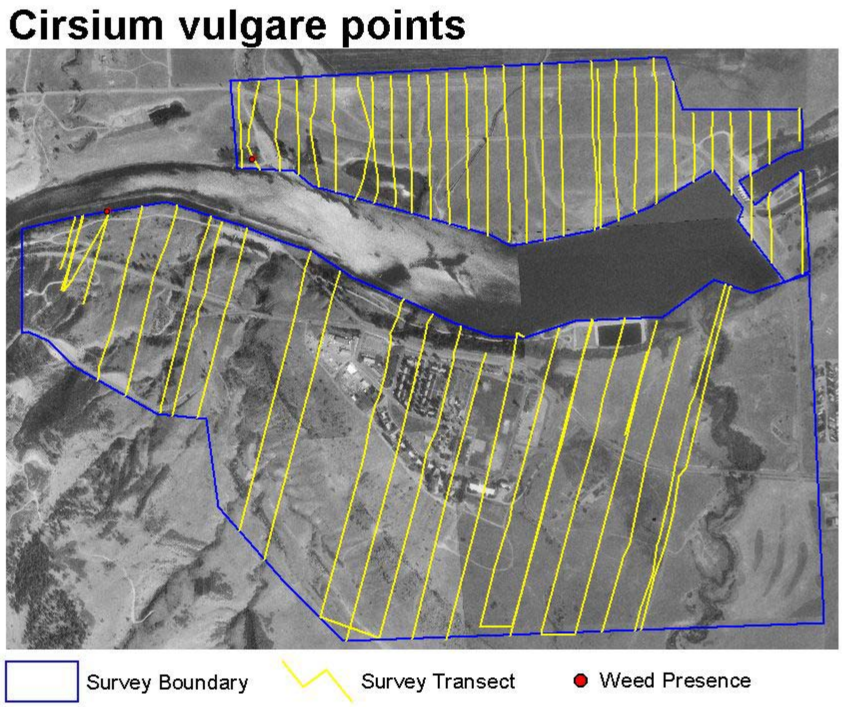


Convolvulus arvensis points



Chondrilla juncea points





The less disturbed land to the north-west was assessed during 2002 and no noxious weeds were located.

Areas which should receive further survey attention

The number of target patches observed in 2001 and 2002 was relatively low and the area of interest is relatively small (540 acres). Therefore, we suggest that predictive models would be of only moderate value and instead over a period of years, the whole area could be sampled. This would mean the whole area was inventoried rather than surveyed. Co-ordinates of transects to fill in between the areas covered by MSU are given in Appendix 2.

The amount of time which can be allocated to weed management may be limited. Therefore, we have specified certain areas which should be surveyed (on foot) to ensure the completeness of the survey data. Data should be recorded continuously even if no weeds are located.

How to perform the survey. Transects 20 m wide should be walked by a crew of 1 or 2 adjacent to areas of high disturbance including roads, trails, disused roads and trails, old irrigation channels, shoreline of reservoir or river. These areas are depicted in Fig 3.

Insert 3

If one person is completing the transects they should walk down the center of the transect and look 10 m either side. If there are 2 people (which is preferable) they should walk 10 m apart and each look over 5 m either side (Fig 4a).

The location of all patches should be recorded with a GPS and details of the species found, a rough estimate of the patch width and length, and density should be made. We would suggest that a patch rule be imposed. If there are plants more than 5 m from a patch these be recorded as a new location (Fig 4b). This will help with relocation of the patches for monitoring and management. A smaller distance would only be useful if a differential GPS is used in the field.

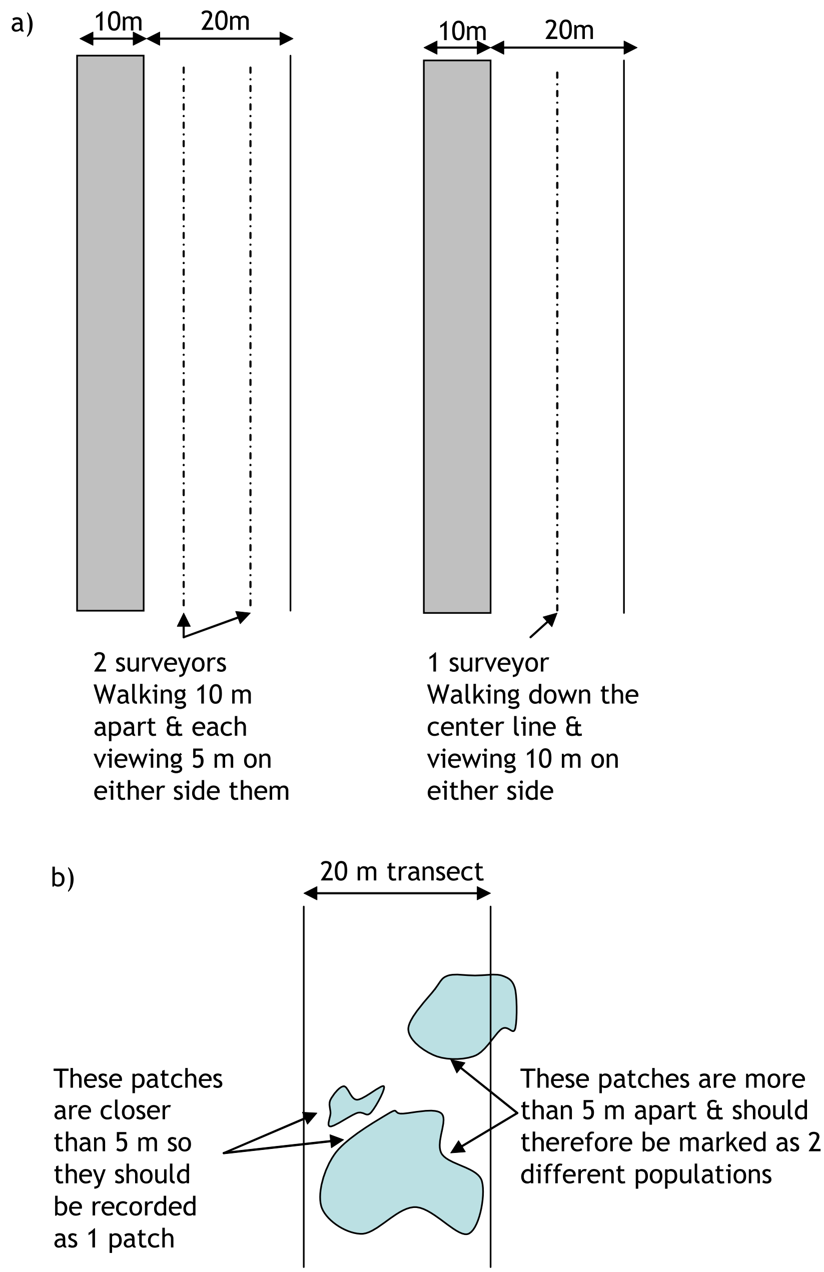


Fig 4a) Diagram of mapping additional survey areas with 1 or 2 persons, and b) how to distinguish between patches for recording purposes.

Monitoring of NIS populations

There is rarely enough money to control all NIS and therefore we need to know which species under which environmental conditions are changing most rapidly. Species and areas can then be ranked according to rate of spread. The problem list can then be systematically worked down as time and money allows. To achieve the ranking we need to select a number of patches and set up permanent markers to determine how much the patches are changing over time in situations where no management practices are being used and areas where they are. We would also want to know if the management practices are reducing the density or size of the patch as we intend. We may also want to compare different management practices and see how they compare.

The different reasons for monitoring will be discussed in more detail, followed by an outline of how these can be applied to BCNRA.

Monitoring NIS can be broken into three general categories of objectives (see Fig 5 below):

- Monitoring to determine if NIS populations are growing at a rate fast enough and consistent enough to be considered invasive (increasing in spatial extent).
- Monitoring to determine if NIS populations are having a significant impact on an ecosystem under the management objectives for the ecosystem.
- Monitoring to determine if invasive species management is having a significant impact on the NIS without an equally significant impact on the ecosystem under the management (i.e. cost benefit analysis) objectives for the ecosystem.

Each of these objectives may require different methods to accomplish the objective. There are no set of well tested conventional methods for monitoring. We have been experimenting with some methods in the field and with simulation models. Thus, the concepts for monitoring methods presented here are general, preliminary, and are suggested based on theory and experience, but are not well tested.

Monitoring for invasiveness

Monitoring for invasiveness is determining if representative populations of a NIS (from across the environments where the species was found with the survey or inventory) are consistently increasing in spatial extent. It is important to select populations from across a range of the habitats where the species was found in the survey, to ensure identifying which populations are truly invasive. Plants tend to increase in spatial extent (spread) in two different ways:

- as a moving front where patches enlarge with expanding radius, and
- by establishing new colonies away from a source population forming groups of patches (metapopulation) which can coalesce to form larger patches (Cousens and Mortimer, 1995).

In order to rapidly determine if a population is increasing in spatial extent, we need to use a technique which will allow us to accurately quantify the area occupied so that the change in area can be detected from one generation (year) to the next. It is extremely unlikely that a GPS will serve the purpose of mapping patches with sufficient accuracy to detect consistent changes in patch dynamics within a few years.

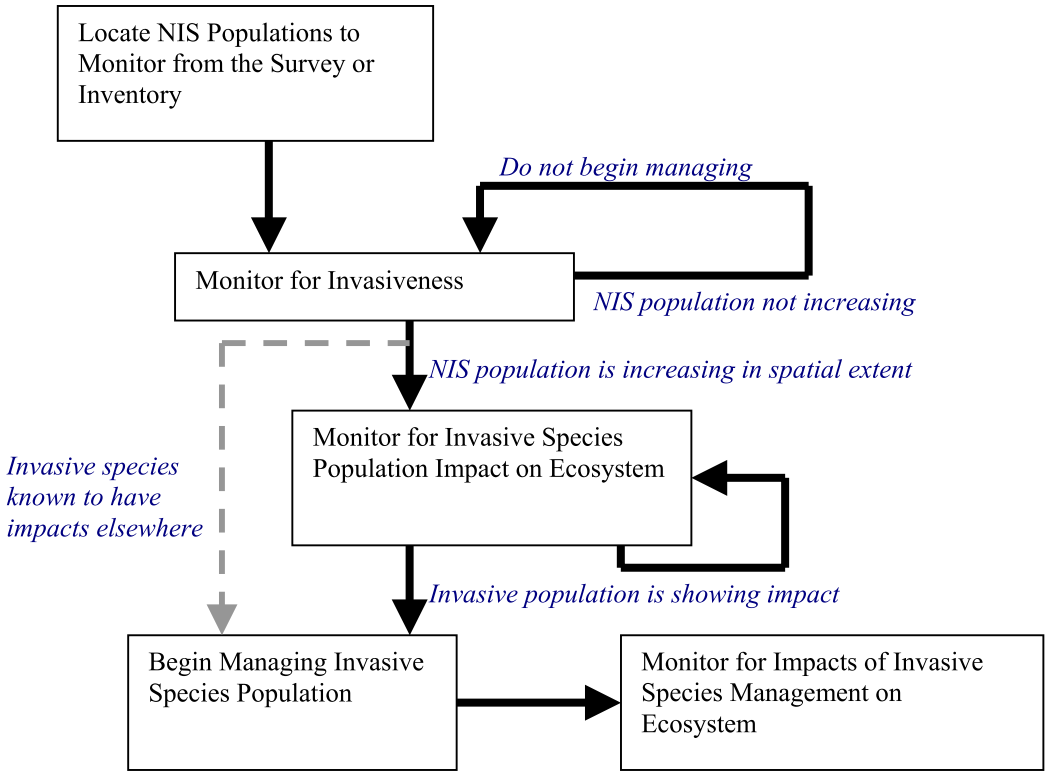


Fig 5 Flow diagram linking monitoring objectives

A more accurate and consistent approach would be to establish permanent points on the ground and measure the distance to patch borders with a tape measure. This is a "low tech" approach but will enable accurate detection of only small changes in patch borders which is necessary to assess invasiveness in only a few years. It also does not take long to do. It is quite possible that populations may show increases in area occupied in one year, but not other years. If patches are mapped each year the number of times the patch increases, decreases or stays the same can be calculated and used to determine the degree of invasiveness. The degree of invasiveness that will trigger management or monitoring for ecosystem impacts, is the decision of the manager.

If monitoring shows that the species is invasive (all replicate patches are expanding) then it should be monitored for impact and/or management could be initiated. If some patches are found to be consistently expanding and others not expanding then monitoring should continue and the patches that are expanding should be considered for management. Many may think that most NIS populations are expanding rapidly and that measuring that expansion is of academic interest, and it would only delay proactive management to mess with tedious measurements. In fact, where NIS patches/populations have been measured (data not published), there was high variability in area occupied from year-to-year and it was often difficult to make accurate measures and conclude that the population was consistently growing or declining. Inconsistent invasion has been well documented in agroecosystems (Colliver *et al.*, 1997; Gerhards *et al.*, 1997).

Monitoring for invasive plant impacts

Monitoring populations found to be invasive for impacts on ecosystem function, species assemblage, and/or productivity can be complicated. There is a well-developed theory for quantifying the economic impacts of a weed on a crop in agroecosystems. A good review of the theory and methods for quantifying weed impacts in crops is available in Cousens and Mortimer (1995). There is a rich body of theory applicable to assessing impacts of invasive species on ecosystem function and species assemblage

(Shea & Chesson, 2002; Davis *et al.* 2000; Rejmánek *et al.*, 2000; Mack *et al.*, 2000; Levine, 2000; Lonsdale, 1999), but there are far less empirical studies that allow comparison of methods (Levine, 2000). Quantifying impacts will typically require small spatial scale observations over longer periods of time to draw conclusions with confidence. In order to offer some methodology that will comply with typical land management goals, that is, protecting ecosystems, one might establish permanent monitoring plots on the edge or on a tangent to the invasion, and observe the invasion and any coincidental change in the desirable plant community. If desirable species are consistently displaced, one may consider the invasive species to have a significant impact. Upon measuring a significant impact, it would be logical to commence management.

Methodology to quantify species displacement by invasive species requires careful consideration to ensure random selection of invasive populations and placement of sample plots. Random selection of populations or patches of an invasive plant should follow the same logic as selection for determining species invasiveness. That is, the selection of populations from across the environmental conditions where the species is found, within the specific management area. The best approach for selecting sample plots may be to create maps of the edge of several randomly chosen invasive plant patches, then randomly select edge points on the map that can be relocated in the field for repeated sampling (using GPS and field markers). Sample plots (quadrats) should be between 0.25 m² and 5 m² depending on the size of the plants. Larger plants require larger plots, and nesting of quadrat sizes would provide more information (Stohlgren *et al.*, 2003)

Clearly, desirable species displacement does not necessarily result in disruption of ecosystem function, nor does the lack of species displacement mean that the ecosystem could not be significantly disrupted through influence on critical cycles or indirect effects. There is no conventional set of measures to detect these effects, so it will require a keen ability to observe changes, assess their significance and adapt the sampling methodology to quantify such changes. In turn, there must be careful weighing of significance of impacts of the invasive species against the potential disruption of the ecosystem from the management.

Monitoring for impact of weed management

The third phase of monitoring after the invasiveness and negative impact of the NIS has been quantified is monitoring for the impacts of weed management practices on ecosystem function, species assemblage, and/or productivity. Management would be initiated preferably only on part of a patch, or on one patch and not an adjacent patch of the same species. In this way the impact of the management could be measured by continuing the same measurements, in the same plots, as established to quantify impacts of the invasive species. In addition, the same metrics of community response to the invasion should be good measures of community impact by management.

Applying monitoring methods to BCNRA's NIS populations

Monitoring for invasiveness

Select several patches each of field bindweed, skeleton weed and Canada thistle from different areas across the environmental conditions where the species were found. Select 1 or 2 but preferably 3-4 patches from each of the environmental conditions for each species of interest e.g. by road or airstrip, by a water source, old irrigation channel, and further from roads/trails and water. These patches should be chosen from the survey data.

Patches should then be measured along the longest axis and perpendicularly to that axis with a tape measure using the directions below for different shaped patches. The measures do not take long to complete. An accurate tape measure, compass, rebar cut in 20 – 30 cm (8-12") lengths and roadhairs (plastic strips about 2 mm wide and 15 cm long bound together in a "tuft", made in bright colors) are required. We suggest placing rebar and roadhairs in the center of patches but also at the last plant measured on the edges. This reduces confusion and improves accuracy and relocation in future years. The coordinates of the patch centers should also be recorded for ease of relocation.

Record diameter length in meters and azimuth in degrees. The first diameter (Diam. 1) is the longest possible diameter that you can find for the patch using the base of the plants to mark the ends (Fig 6). Locate the center of the diameter and place a roadhair at the patch center (1/2 the length of Diam. 1). The second patch diameter is located perpendicular (use the azimuth of Diam. 1 + 90^o) to the first and through the patch center point (roadhair) to the edges of the patch (Fig 6). Extend the tape measure on Diam. 2 to the base of the farthest plants within 1 m of the end of the diameter staying on the azimuth.

Table 2 Record your data in a table similar to the one below, further columns will need to be added as more radii and azimuth are measured.

		Diam. 1		Azimuth	Diam. 2		Azimuth	Length
Species	**Patch**	**radii 1**	**radii 2**	**1**	**radii 3**	**radii 4**	**2**	**Diam. 2**

The area of the patch can then be calculated in m^2 using the measurement of the first 2 diameters (or 4 radii (TM2de)). The measured diameters can each be split into radii and thus used to calculate the area of an ellipse using the following equation:

$$A = \pi \cdot r_1 \cdot \left(\frac{r_3 + r_4}{2} \right)$$

where A is area of the ellipse and r_1 and r_2 are the 2 radii of the ellipse. Radius 1 and 2 should be the same as the middle of it was chosen as the point where Diam 2 perpendicularly intersected it.

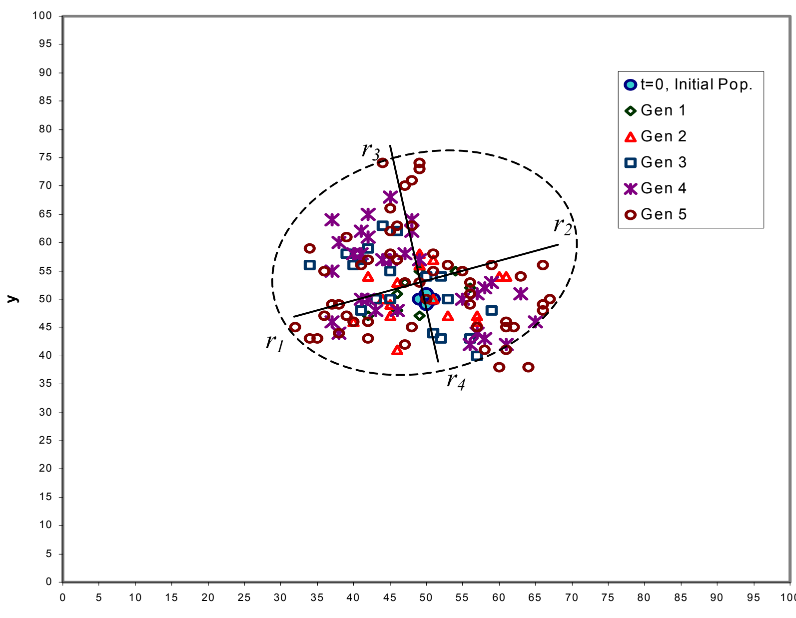


Fig 6 Diagram of how to sample a "simple" patch.

If the second diameter does not bisect the center of the first diameter (TMD2b), but remains perpendicular to the first diameter, the area can be calculated as the area of four right triangles using the equation:

$$A = \tfrac{1}{2} r_1 r_2 + \tfrac{1}{2} r_2 r_3 + \tfrac{1}{2} r_3 r_4 + \tfrac{1}{2} r_4 r_1$$

where r_i are the radii measured from the intersection of the two patch diameters to the ends.

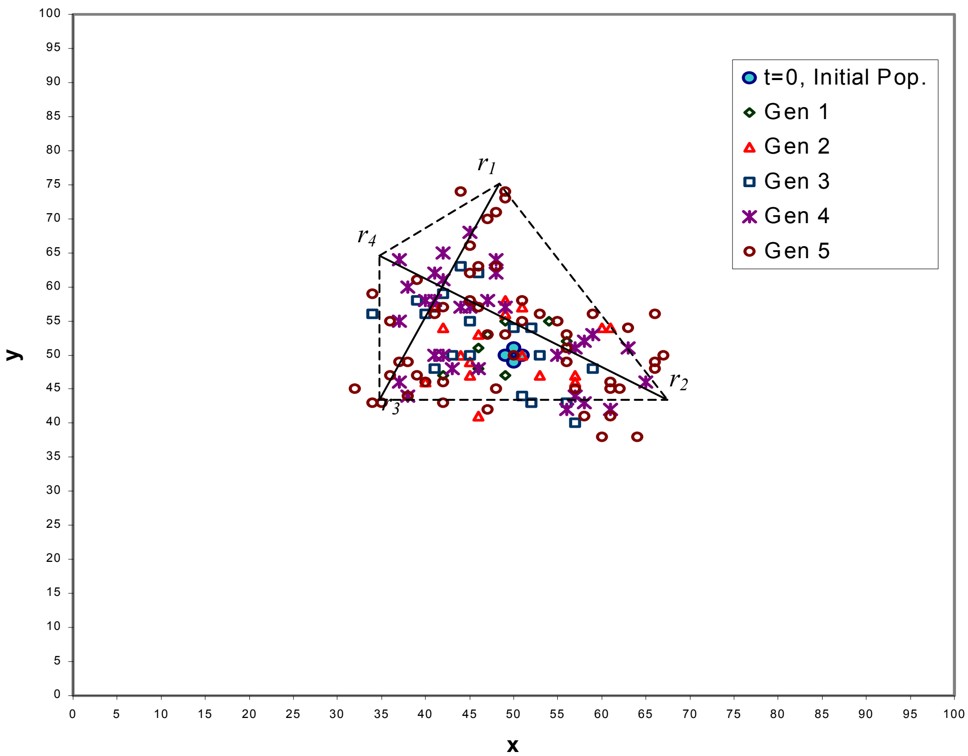


Fig 7 Diagram of how to sample a patch where the second diameter does not bisect the cnter of the first diameter (TMD2).

There may also be situations where there are two patches which have coalesced and are now one. In this situation we need to measure and calculate 4 diameters or 8 radii (TMD4) see Fig 6. The azimuth for Diam. 3 and 4 are calculated from the azimuth of Diam. 1 and are placed so that they pass through the patch center (use a roadhair). Make sure that radii 5 is between radii 1 and 3, radii 7 is between radii 3 and 2, radii 6 is between radii 2 and 4 and radii 8 is between radii 1 and 4. If we remain consistent with the sequence of measurement of the radii it will be easy to automate the calculations of area in Excel.

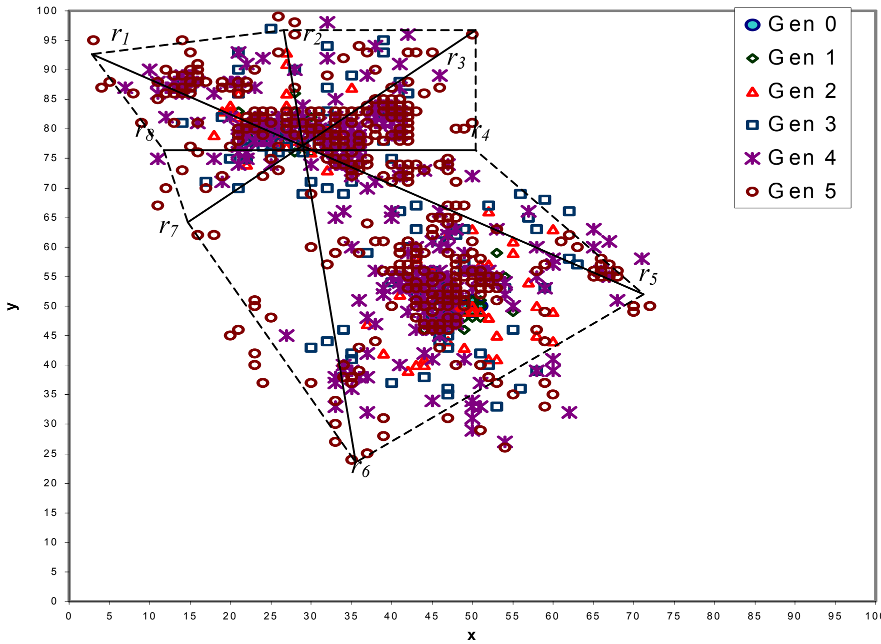


Fig 8 Diagram of how to measure a coalesced patch (TMD4)

In this case the patch is broken into a set of triangles that may or may not be right triangles which makes the calculation of area slightly more difficult. One must start by first calculating the height of each triangle so that the area can then be calculated.

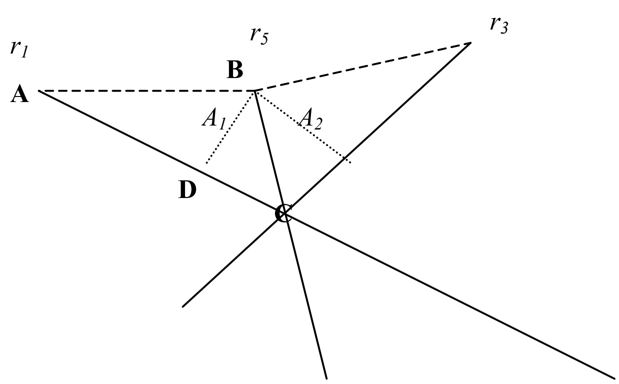


Fig 9 Diagram of how to calculate the patch area for a coalesced patch.

In order to calculate the area of triangle A_1 the geometric rule for the area of a triangle is used where

$$Area = 0.5 \cdot base \cdot height \quad \text{in our case} \quad r_1 = A_1 = 0.5 \cdot \text{AC} \cdot \text{BD}$$

where AC is the length of radii r_1 and BD is the distance from point B to D which we did not measure, but we can calculate using another geometric rule:

$$\frac{\text{AC}}{\text{BC}} = \frac{\text{BC}}{\text{DC}} \text{ and } \frac{\text{AD}}{\text{BD}} = \frac{\text{BD}}{\text{DC}}$$

so

$$DC = \frac{BC^2}{AC} \quad \text{and} \quad BD = \sqrt{(AC - DC) \cdot DC}$$

then the areas of the triangles can be added together to estimate the area of the patch.

Monitoring for invasive plant and management impacts

In other situations it may be more appropriate to make measurements of changes in density, cover and composition, this can be used to help determine changes in NIS density, changes in the surrounding vegetation which is relevant for estimating impact of NIS, and impact of management on NIS and the surrounding vegetation.

Estimates of change in population density over time is divided into two estimates, one for the portion of the population that is at the edge of the patch and the other that is interior to the edge. A 1.0 m² frame is placed at three randomly located points along the edge of a weed patch so that the frame is approximately half in the patch and half out.

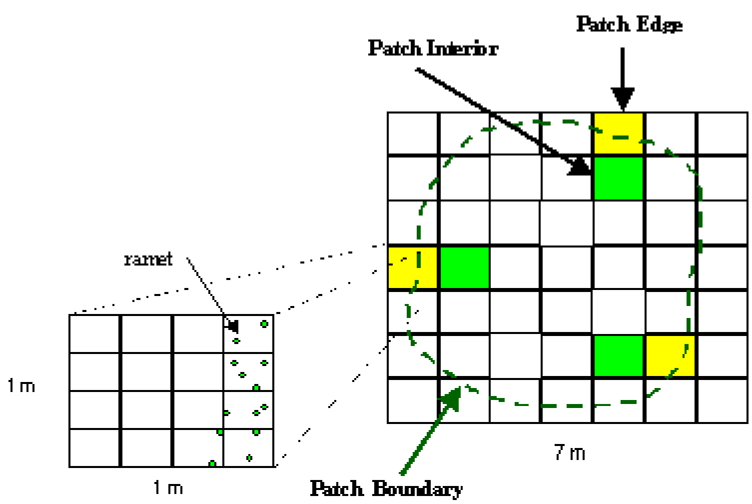


Fig 10 Monitoring changes in population density and species cover.

It is important to randomly locate each of the edge plots in order to reduce bias in the density estimates. All plots must be permanently marked on the corners so that the frames can be exactly relocated each year. Count the number of individuals (ramets) in each quadrant (1/16 m²) of the 1 m² plots. It will be easier to determine when individuals are moving into new areas by counting individuals in these small quadrats.

To obtain a better understanding of:

- changes in the surrounding vegetation as a result if the NIS,
- the effects of management on the NIS
- and, the surrounding vegetation

measurements of bare ground, composition and cover of other species should be made. The same plots should be used as above plus 3 further frames which should be placed randomly outside of the patch (> 5 m). The frames outside the patch should be randomly chosen but still be in the same habitat, have the same aspect etc.

The percentage cover of target species, bare ground and native species should be measure in each (1/16 m^2) quadrat, or at least 50% of them. This will provide data to compare changes in species diversity and cover over time and thus the impact of NIS and management approaches. Plots should be sampled at a similar time of year. Ideally if certain species or patches are found to be invasive it would be best to use the management practice of choice on half of the patch and not the other to evaluate impact of the management on NIS and surrounding vegetation before using the approach more widely.

Spotted and diffuse knapweed. After surveying for noxious weeds in 2001, knapweed patches were sprayed in 2001 and 2002. Nearly all patches of spotted and diffuse knapweed were sprayed with Redeem. Three spotted knapweed patches were left unsprayed on the road to Ok-a-Beh, and 1 patch by pretty eagle. The only patch of Russian knapweed observed was sprayed with Tordon.

Few spotted knapweed plants and even fewer diffuse knapweed plants were observed by the MSU crew in 2002, in areas where they had been sprayed the previous year suggesting that herbicide efficacy was high. Due to the invasive potential of knapweed species in other areas of MT and WY, S. Morstad would like to continue controlling these species with herbicide as soon as individuals are located. It would still be appropriate to monitor a number of the patches for the impact of weed management. Such monitoring would determine herbicide efficacy and cover and recovery of native species. The patches should be selected from a range of sites where spotted knapweed was located, thus, adjacent to the airstrip, tarred road to Yellowtail dam and the north side of the Afterbay dam.

Monitoring for new populations

We understand that little time can be allocated to surveying, monitoring and management of NIS in many situations and this is particularly true in the northern section of BCNRA. Noxious weed patches in the northern section of BCNRA are generally small and if would be good to keep it that way. The only exceptions are downey brome/downey brome (*Bromus tectorum*) and desert alyssum (*Alyssum desertorum*) neither of which are of concern to BCNRA (S Morstad, pers. comm.). However, we would suggest that when performing the monitoring for impact that changes in downey brome are recorded and practices which reduce its density should be given high priority.

Highest levels of management control are often achieved with new populations. We would therefore recommend that the survey area depicted in Fig 3 be walked every 2 or 3 years. This should be completed with a GPS and locations of the whole area walked should be recorded even if no NIS are found so that a database of areas surveyed at different intervals can be generated.

In addition the areas to the north and south of the Yellowtail dam which are currently essentially free of noxious weeds should be traversed to check for new infestations. The area to the north has many native grasses and the area to the south some relatively undisturbed riparian creek woodlands. Parts of these areas were walked by the MSU crew team in 2002 but no noxious weeds were located (Fig 11). A random search pattern or the targeted transects would be the best approach for traversing these areas.

Management options to be considered

"Successful weed management will ultimately rely on combinations of tools that are used to decrease weeds and directly increase desired species" (Rinella, Jacobs and Sheley, 1999).

Specific management options for each species are provided later in this report. We are purposely not suggesting particular management practices and different approaches will be more or less appropriate for certain areas. We believe that BCNRA should be adaptive in their management approach. Some of the methods mentioned in the management section should be used on small plots within the park and the results monitored with the methods suggested above. Using this type of adaptive management approach would mean that the best management approach be selected for the different areas of the park. For political as well as practical reasons it may be necessary to continue to control the knapweeds and other key noxious weeds with herbicides in the heavy visitor use area such as around Afterbay dam. However, using addition approaches and monitoring the effectives of the control practices should yield some useful information to apply in other heavy use areas of the park.

Preventing the introduction of non-indigenous species but particularly noxious weeds is the most practical and cost-effective method for their management. Prevention programs should include limiting seed dispersal, minimizing soil disturbance and properly managing desirable vegetation. The importance of preventing seed spread should be emphasized to everyone but particularly staff as they are more like to venture further from infested to non-infested areas and on a more regular basis. New weed introductions can be minimized by:

- refraining from driving vehicles and machinery through infestations and washing the undercarriage of vehicles and machinery after driving from a weed-infested area to an uninfested area. This is particularly important for the spraying and mowing machinery

- requesting that campers, hikers and sportsmen brush and clean themselves and equipment after participating in activities in weed-infested areas

- minimizing unnecessary soil disturbance by vehicles, machinery, water flow (and livestock). This may need to include building platforms and steps to access fishing areas and barriers to prevent people eroding additional areas as much as possible

- managing grasses to be vigorous and competitive with weeds

- ensuring that any construction practices such as building accesses, maintaining trails, roads etc minimize traffic and soil disturbance away from the main site and that any gravel brought in, or used from the dump, be free of weed seeds

- allowing livestock to graze weed-infested areas only when weeds are not flowering or producing seeds, or moving livestock to a holding area for about 14 days after grazing a weed-infested area and before moving them to weed-free areas

- using weed-seed-free hay, feed grain, straw and mulch.

Techniques which should be evaluated in addition to herbicide application are mowing, fire, revegetation and biological control.

Herbicide application

Herbicide application is obviously the most regularly used control tactic but there are areas where application is difficult and where the non-target impact may be unacceptable. We have not provided much information on herbicide options as these are easiest to come by and S Morstad has considerable experience of which herbicides and herbicides mixes are working best the in BCNRA area.

Mowing

The Montana State University Extension Service states that while mowing will not eliminate noxious weeds, it can stress weeds and provides desired plants a competitive edge (Sheley, Goodwin & Rinella, 2001). They state that timing is the key. The best time is when the desired plants are dormant. Mowing after bolting and the production of reproductive structures can eventually deplete root resources and can eliminate seed resources. They also state that mowing is best combined with herbicide application because many species will adapt to repeated mowing by seeding closer to the ground. Rinella *et al.* (2001) reported in more detail on the experiments. A 10 cm mower height was chosen to minimize native grass removal and maximize knapweed biomass removal. They recommended a single annual mowing at the flowering or seeding stage of knapweed for maximum impact on those species. However, if the aim was to reduce downey brome, desert alyssum or other earlier flowering NIS mowing earlier in the season before the native grasses start to grow would be more effective. Taller stands of downey brome should also be targeted to reduce the chance of cutting native grasses below the meristem if mowing is performed later in the season. These difficulties again stresses the need to develop some small trial plots which use different management practices and monitor the effect of the control practice on the target and non-target species.

Revegetation

Management of NIS and noxious weeds is a continuous process. Herbicide application can control target species, and non-target species, but it is necessary to have desirable native vegetation surrounding areas where elimination control measures are used so that the available sites can be established by desirable species not more undesirable species. If there is insufficient amounts of desirable vegetation reseeding with desirables may be necessary. The most frequent causes of revegetation failure are insufficient soil moisture and intense weed competition in which case revegetation may require multiple seedings (Rinella, Jacobs & Sheley, 1999).

As stated above the area to the north-western could be used as a native seed supply for reseeding management trials in the main disturbance areas. Trails plots evaluating different control practices such as, mowing, burning as well as herbicide should be attempted. Burning should be performed early in the year as soon as snow cover allows to reduce the downey brome seed bank. Downey brome has a short seed life (around 3 years) and burning the grass before the native become active in the spring may be an effective means of reducing it even if it is not that target of management for that area. This could be attempted over a few years to reduce the seed bank. The most successful practices could then be used prior to reseeding the heavy disturbance areas such as those around the Afterbay dam and other fishing accesses maybe appropriate.

Biological Control

Biocontrol agents can be an effective means of reducing NIS populations down to manageable levels.

Advantages of biocontrol include longer term control relative to other technologies, lower overall costs, as well as plant-specific control that leads to enhanced environmental compatibility. Disadvantages include the fact that control takes time, years instead of weeks, agents are available for only a limited number of target plants, and their are relatively strict environmental conditions for success.

See the individual species sections for information of species.

Specific management approaches for target noxious weeds in BCNRA

Canada thistle (*Cirsium arvense*).

Biological, chemical, cultural, and mechanical methods have all been used to control Canada thistle with varying levels of success. An important consideration in controlling C. thistle is that the seeds have the potential to remain viable in the seed bank for at least 20 years. Thus, removal of living plants may not totally eliminate the problem.

Prior to applying any control method, it is important to determine if enough desirable plants are present to replace the C. thistle. If desired vegetation is scarce or absent control will be of little value. Most control methods harm other plants. The resulting disturbances favor reinvasion by C. thistle or other NIS. It is also important to note that native thistles are present in the area, and should not be subjected to control. Proper identification is important.

BCNRA currently uses a mix of summer mowing and fall spraying plus release of biocontrol agents (S. Morstad). Considering the low density but wide spatial distribution of C. thistle in BCNRA this seems to be the best approach. Below we provide more information about these and other control practices.

<u>Chemical Control</u>

A number of chemical control options exist for C. thistle. Many herbicides are not specific to C. thistle or may not be specifically licensed for this use. It is important to read and follow all label directions.

Numerous herbicides are now available for control of C. thistle. Tordon (picloram) is probably the most effective. Tordon may give a 95% control in the first year when applied in the spring prior to flowering or in the fall during active rosette growth. Banvel (dicamba) or 2,4-D amine will suppress or control C. thistle. However, more effective control may be achieved by combining the two herbicides in a 1:1 mixture with the label recommendation of water. This mixture should be applied in the spring prior to flowering or in the fall when the rosettes are actively growing. Roundup (glyphosate) applied at the bud stage or during the active growth period in the fall will also control C. thistle. Amitrol (amitrole) applied when the plants are in the bud stage has yielded 70% control in the first year. Most herbicides, except Tordon, should not be applied while the plants are in a moisture stressed condition. Other herbicides that have shown potential to control C. thistle are Buctril (bromoxynil), Curtail (clopyralid plus 2,4-D), and Stinger (clopyralid).

Studies[i,2] show that the control of Canada thistle requires a herbicide application, repeated for many years. Effective herbicides include Picloram and Clopyralid, each of which is applied annually in late fall during the rosette stage. Clopyralid may be used instead of picloram because it breaks up quicker and is therefore not hanging around in soil for an extended period of time. In addition to Picloram applications, mowing two or three times a year consistently enhances C. thistle control (see below).

Clopyralid. Clopyralid effects on C. thistle were studied in greenhouse experiments for one year. Plants were grown in fine vermiculite soils and watered with tap water or a nutrient solution. Once plants had 5-7 leaves, they were transplanted into pots containing a greenhouse potting soil mix. A slow release fertilizer was added. Plants were grown 2-2.5 months before clopyralid treatments were applied. Treatments were as follows: untreated controls, foliar applied clopyralid plus surfactant at 0.25% soil surface applied clopyralid, foliar plus soil-applied clopyralid, decapitated controls, and decapitated soil surface applied clopyralid. Plants were harvested 2 months after treatment.

Results showed that new shoot growth became epinastic (bend outward and often downward) within 7 days of foliar clopyralid treatment and all leaves became chloritic following foliar or foliar plus soil treatment. New leaves showed signs of chlorosis (yellowing) after soil treatment alone. Newly emerged shoots of decapitated plants growing through clopyralid treated soil became both epinastic and chloritic. Foliar or foliar plus soil treated plant shoots died within a month, but new emerging shoots were green but stunted and deformed. Shoots of soil treated plants were killed more slowly than either of the foliar treatments. Foliar treatment of intact plants or soil treatment of decapitated plants with clopyralid prevented roots from growing and increasing their fresh weight.[ii]

Glyphosate Hunter (1996) studied Canada thistle in southern the Canadian prairies to see if rosettes could be initiated early enough to be chemically controlled before fall frost damaged tissue. He also tried to determine the effectiveness of the herbicide glyphosate at the bud-stage compared to the rosette stage. Field research was conducted on a natural thistle infestation near Regina, Saskatchewan. The soil of the area was a heavy clay with 5% sand, 25% silt, 70% clay, and organic matter of 4%. Glyphosate with an activity of 356g 1-1 was applied to plots using a tractor mounted air sprayer.

Experiment 1. In year one, the area was summer-fallowed with cuts into soil 7cm deep. Tilling in July was done with a rodweeder. Standard summer-fallow plots were tilled 5 times. The bud-stage treatment was tilled June 8, allowed to grow to the bud-stage when it was sprayed on July 28 and tilled August 30 and October 5. The rosette treatment was tilled June 8, July 4, July 28, and October 5. Regrowth was allowed on all plots tilled on July 28 remained as rosettes without stem elongation and formed dense clusters of large, young leaves. The rosette treatment was sprayed on August 30 when rosettes averaged 5-8cm in diameter. Glyphosate was applied at rates of 2.25kg ha^{-1} and 1.5kg ha^{-1} (66% recommended rate). In years two and three the seedbed was disked 5cm deep and keep weed free by hand weeding. (Hunter 1996)

Results of Experiment 1 showed that herbicide treatments reduced the density of shoots and had a major impact on when they emerged. When glyphosate was applied to the bud-stage, the number of C. thistle shoots decreased each year compared to the intensely fallowed summer plot. Control with 2.25kg ha^{-1} was more effective than the lesser amount. One year after application to the rosette stage, there was no difference in the density by herbicide rate. In year three, a rate of 2.25kg ha^{-1} was more effective. Glyphosate applied at both rates at the rosette stage was much more effective at reducing shoot density.

Experiment 2. The effect of application of glyphosate was compared to a control by intense summer-fallow-tillage. The rate of glyphosate applied was less than half of the recommended amount. In year one, the area was tilled 8cm deep on June 17 and July 24. Followed immediately with tilling with a rodweeder at 7cm depth. Standard fallow plots were tilled on August 27 and glyphosate applied in the fall rosette stage. In year two and three, the whole area was over sprayed in early May with paraquat in order to control winter annual weeds that may come up before C. thistle. June 5th, the area was tilled 5cm deep and thistle density and dry weight were assessed at the end of August.

Results of Experiment 2 showed a greater reduction in shoots when 0.9kg ha^{-1} was applied at the rosette stage than when applied to areas of summer-fallow with intense tillage. Control after year 1 was 93%. Control remained constant through all years of the study.

Conclusions: It was shown that under the natural photoperiod in the Canadian Prairies, rosettes of C. thistle can be initiated by cultivation to remove shoot growth at the end of July. Application of glyphosate in August in the rosette stage resulted in consistent control of C. thistle when half as much herbicide was used as is recommended for a bud-stage application.[iii]

Biological Control

Biological control of Canada thistle has received some attention. Over 80 native species of insects and over 50 species of animals and fungi utilize C. thistle to some extent. A few have the potential for providing some measure of control. The four with the greatest threat are two beetles [Cassia rubiginosa Muell. (Coleoptera:Chrysomelidae) and *Cleonus piger* (Coleoptera:Curculionidae)], one fly [*Orellia ruficauda* Fab. (Diptera:Tephritidae)], and the painted lady butterfly [*Vanessa cardui* L. (Lepidoptera:Nymphaidae)]. Only *Orellia ruficauda* appears to do significant damage to C. thistle, and this level of damage is not sufficient for control. Five European insect species [*Ceutorhynchus litura* F. (Coleoptera:Curculionidae), *Rhinocyllus conicus* Froelich (Coleoptera:Curculionidae), *Altica carduorum* Guerin-Meneville

(Coleoptera:Chrysomelidea), *Lema cyanella* L. (Coleoptera:Chrysomelidae), and *Urophora cardui* L. (Diptera:Tephritidae)] have all been released in North America for C. thistle control. To date, only *Ceutorhynchus litura* has become established, spread, and begun to suppress this plant.

Fungus species of the genus *Puccinia* hold some promise as control agents. *Puccinia punctiformis* (Strauss) Roehling (Fungus:Uredinales) has been tested in Europe and New Zealand and has been found to only reduce plant vigor. The best biological control of C. thistle has come when this fungus has been used in conjunction with either 2,4-D or *Ceutorhynchus litura*. Plants treated with the fungus followed by introduction of the weevil had over a 50% increase in damage over nontreated plants.

Currently, the Park is using three biocontrol insects-*Ceutorhynchus litura*, *Larinus planus*, and *Urohora cardui* to try to control Canada thistle. While these insects do cause stress to the thistle, studies have shown that the insects alone are not a successful control, even when used together.

L. planus – unable to find studies on *L. planus* and its effect on C. thistle. One study details the effects on a native thistle, *Cirsium undulatum var. tracyi*, but mentions no more than that *L. planus* is an exotic weevil used to control Canada thistle by limiting its seed production or density. *L. planus* is a risky insect to use because of its high frequency and high level of feeding on the native Tracy's thistleiv.

Sclerotinia scleritonium – release at surface causes high thistle mortality. Studies in New Zealand but none found in the USA

Ceotorhyncus litura was evaluated in Western and Eastern Canada at 24 locations between 1974 and 1977. 4934 adults were released and 290 galls, measured galls and counted galls at 6 sites, plants cut and weighed.

Results show that C. litura caused minor stress to thistle. There was no significant impact of galls on C. thistle vigor. In a lab study, galls caused a reduction in thistle vigor.v

Ceutorhyncus litura & *Urophora cardui* were studied in Regina, Saskatchewan to investigate the combined effects of the two insects on the vigor of C. thistle. 16 metal pails were placed into the ground and planted with 3 C. thistle rosettes in each. Soil used was coarse sand, loam, peat moss, vermiculite at 3:2:1 ratio. Between 1984 and 1986, insects were released into cages surrounding the thistle plants. Applied at rosette stage, adults were released at the following times:

- 1984- 1 female *C. litura* on May 22, 13 male and 14 female U. cardui between June 11-July 11.
- 1985- 2 male and 3 female *C. litura* between May 17 and May 23, 17 male and 16 female *U. cardui* between June 60-July 11.
- 1986-2 male and 3 female *C. litura* on May 14, 20 male and 17 female *U. cardui* between June 18 and July 10.

The experiment showed that in the first year, the number of live buds and dry weight of roots of attacked plants were significantly reduced compared with unattacked plants. No significant difference in the number of aborted buds, mature seed heads, new shoots, dry weight of all vegetative parts and galls in all 3 years was reported.

A second part of the experiment was to determine the effect of the mining of thistle stems by *C. litura* larvae on the available carbohydrate content of the plant. C. thistle shoots were collected in an area naturally infested with C. thistle where *C. litura* had been established since 1972. Mined and unmined shoots were collected and length of mines, shoot height, and length of underground stems were noted. The first collection when mining had just started showed there was no difference in carbohydrate content between attacked and unattacked plants. Nearer to the end of the mining period, at collection two, mined roots had fewer carbohydrates than unmined roots. At the collection 6-8 weeks after mining had ended, there was no difference found between roots. It is suggested that *C. litura* causes little damage and that the damage is temporary.[3]

Mechanical Control

Mulching Effective at suppressing flowering rates of C. thistle in Idaho. Hay mulch was applied several feet deep to prevent light from getting to seeds.vi

Mowing Frequent mowing after flowering stage and before seeding occurs is effective if continued over a number of yearsvii,. Most studies indicate the need to mow patches of C. thistle at least twice a year to prevent seed dispersal and reduce root reserves. Systematic monthly mowings may be necessary to prevent lateral flower bud development and to keep root reserves depleted. Again care should be taken with the height of the mower where native grasses are present. Most effective when combined with mowing.

Plow, disk, lime, fertilizer combination - increases biomass, decreases thistle productivity.[viii]

Irrigation - water stresses C. thistle but doesn't control it alone. Water increases perennial plant growth.[ix]

Cultural Control

Burning To control C. thistle should be done annually for the first three years in late spring (May-June) for bet results. Studies by Hutchinson and othersx determined that fewer thistles were seen in years following a burn than in the year of burn. Late spring burns are more detrimental, although thistles may increase the first year following, they will decline within two growing seasons. Immediate reductions in thistles has been shown to occur following a June burn, possibly because earlier burns can increase sprouting and reproduction.

Spotted Knapweed (*Centaurea maculosa*)

Chemical Control

Study 1 Sheley *et al.* (2000) studied spotted knapweed and grass responses to Picloram, Clopyralid and 2,4-D, and Dicamba and 2,4-D in various amounts at two sites. Site one was near Avon, MT where land was native rangeland with a grazing history of light to moderate (0-50%) grazing. Dominant grasses are Festuca scabrella, Festuca idahoensis, Pseudoroegneria spicatum, and Koeleria cristana. At the time of study, it had not been grazed for eight years. The elevation at the site was 1455m with a Typic Haploboroll, gravelly loam soil type. Site two was near Missoula, MT where land had been grazed until the 1930s, then seeded with Agropyron cristatum in the 1940s with no grazing since. The dominant grass is Agropyron cristatum. Elevation at the site is 975m with a Typic Argiboroll, gravelly loam textured soil. Over a four year period, three herbicide treatments were applied to spotted knapweed: Picloram, Clopyralid plus 2,4-D, and Dicamba plus 2,4-D.

Picloram was applied at 0.07, 0.11, 0.14, 0.22, 0.25, and 0.28kg a.i. ha^{-1} during the bud growth stage. Results showed 100% control for 3-5 years. Disadvantages to this method are that Picloram persists in soil for 12-30 months and spotted knapweed seeds persist in the seed bank for up to eight years so when new plants germinate, spot spraying is needed. Since Picloram is so effective, it releases residual perennial grasses from competition, therefore increasing biomass.

Clopyralid and 2,4-D was applied at various rates to the bud/bolt (before flowering) stage. 0.21kg a.i. ha^{-1} and 1.12kg a.i. ha^{-1} respectively, gave nearly 100% control one year after application at both sites. 50% control was recorded after 3 years at the Missoula site. Benefits of using this method is that because of shorter soil residue periods, the herbicides may allow a greater species diversity than Picloram and doesn't limit future land management options.

Dicamba and 2,4-D were applied at various rates at the bud/bolt stage. Rates of 0.56kg a.i. ha-1 and 1.12kg a.i. ha-1, respectively, were the most effective with control for 2-3 years. It is currently recommended for controlling spotted knapweed on small ranchettes because it is not persistent enough to limit options of landowner's in the future.

Of the three treatments, Dicamba and 2,4-D yielded the lowest amount of grass biomass.[xi]

Study 2 Between 1996 and 1998 a study was done at two Montana locations to determine effects of *Picloram* on plant communities.[xii] Study sites were the Story Hills northeast of Bozeman and Beartrap Canyon, near Norris. The Bozeman site has an elevation of 1478m, 432mm of precipitation, and a clayey skeletal mixed, Typic Argiboroll soil type. The Norris site has an elevation of 788m, 305mm precipitation and a loamy skeletal, mixed Aridic Argiborolls soil type. Both sites are the *Festuca idahoensis/ Pseudoroegneria spicatum* habitat type. At each site, 5 transect 20m long, each beginning in dense knapweed stands and ending in areas of low to zero densities of knapweed. Picloram was applied along transects in 2m swaths at 0.25kg a.i. ha^{-1} in the month of October. 30 temporary plots were established along the knapweed gradient to sample soil and biomass at each site. Biomass was determined by clipping plants to ground level.

At the Story Hills site, 9 indigenous grasses, 2 non-indigenous grasses, 9 indigenous forbs, and 3 non-indigenous forbs were identified. After treatment, *Pseudoroegneria spicatum* was found in 3 or more transects, *Agropyron smithi* in at least 1 transect, *Festuca* i*dahoensis* in all transects except at 85% and 90% of pretreated knapweed. All other indigenous grasses were limited after 50% pretreated spotted knapweed. *Bromus japonicus* was present along entire transect and *Poa pratensis* was limited in presence below 30% pre-treated spotted knapweed. The most abundant indigenous forbs include *Chrysopsis villosa, Liatris punctata*, and *Artemesia ludoviciana*. Post treatment *Comandra umbellata* was the most non-indigenous forb present.

At the Beartrap site, 7 indigenous grasses, 3 non-indigenous grasses, 5 indigenous forbs, and 2 non-indigenous forbs were identified. *Bouteloua gracilis* was found along the entire gradient, *Festuca Idahoensis* at all except at pretreated 70-100%, *Calamovilfa longifolia* and *Stipa comata* present except where 60% cover was spotted knapweed. Berteroa species were the most abundant of the nonindigenous forbs.

Results showed a decrease in 14 of 30 post-management indigenous forbs and grass species. Five out of thirty species were no longer present after picloram treatment, four of which were indigenous forbs. It is suggested that the decrease may be due to an increase in post management grass presence (*Western wheatgrass, Idaho fescue, Stipa comata*). Spotted knapweed may have influenced grass production because its removal may have favored grasses.

Study 3 Picloram, clopyralid, dicamba, and 2,4-D all effectively control spotted and diffuse knapweed. Picloram has been shown to provide control of spotted knapweed for 3-5 years and increase residual grasses by 200-700% (Davis 1990). Many studies show the effectiveness of herbicides on knapweeds.

Study 4 Sites at Rock Creek, MT and Hamilton, MT were used to determine a herbicide mix that would maximize grass establishment in Spotted knapweed/Cheatgrass and Spotted knapweed/Bluegrass infested rangeland in one application. The Rock Creek site has an elevation of 1160m with a *Festuca scabrella/Pseudoroegleria spicata* habitat type. Dominant vegetation is *Poa pratensis, Bromus inermus*, and *Phleum pratense*. The Hamilton site has an elevation of 1341m and the dominant vegetation is *Centaurea maculosa* and *Bromus tectorum*. Eight treatments were applied and seeding of 3 grass species ('Luna' pubescent wheatgrass, bluebunch wheatgrass, and 'Bozoyski' Russian Wildrye) was done in four replications.

The eight treatments applied were:

- None
- Glyphosate at 0.5kg a.i. ha-1
- Picloram at 0.14kg a.i. ha-1
- Picloram at 0.28kg a.i. ha-1
- Clopyralid at 0.21kg a.i. ha-1 plus 2,4-D at 1.12kg a.i.ha-1
- Picloram at 0.14kg a.i. ha-1 plus glyphosate at 0.5kg a.i. ha-1
- Picloram at 0.28kg a.i. ha-1 plus gypohosate at 0.5kg a.i. ha-1
- Clopyralid at 0.21kg a.i. ha-1 plus 2,4-D at 1.12kg a.i. ha-1 plus glyphosate at 0.5kg a.i. ha-1

Results showed Picloram at 0.14kg a.i. ha^{-1} or 0.28kg a.i. ha^{-1} applied in late fall yielded the lowest spotted knapweed density and biomass. Glyphosate alone, initially, had lowered spotted knapweed density and increased biomass. However, by the end of the study there was more knapweed and less seeded grass establishment. In treatments where grasses established successfully, 'Luna' pubescent wheatgrass consistently yielded the highest density and biomass. 'Bozoisky' Russian wildrye was the poorest establishing grass. A native species, 'Goldar' bluebunch wheatgrass didn't establish as well as 'Luna' pubescent wheatgrass but developed a successful stand in plots where Picloram was applied.[xiii]

Biological Control

The first biological control agents developed for use against diffuse and spotted knapweed (*C. maculosa*) were seedhead flies. The banded seedhead fly [*Urophora affinis* Frauenfeld (Diptera:Tephritidae)] was released in British Columbia during 1970 and in Montana and Oregon in 1973. In addition, from 1974 to 1980 it was released in Washington, Idaho, and California. It readily established in all of these states. The knapweed seedhead fly [*U. quadrifasciata* Meigen (Diptera:Tephritidae)] was also released in British Columbia in 1972. By 1981, it had dispersed as far as Montana. It is now found throughout the Pacific Northwest. These flies oviposit into knapweed flower heads and the larvae develop within the galls that form from receptacle tissue. As well as directly reducing seed production, the seedhead flies' galls may devitalize the rest of the plant by acting as metabolic sinks for nutrients from other plant parts. The activities of these flies can cause up to 95% reduction in knapweed seed production.

The leaf galling mite, *Aceria centaureae*, can cause severe damage to the rosettes and shoots of diffuse knapweed. A budgalling mite, *Aceria* sp., causes witches broom growth of the plants. This species appears to reduce the growth and seed production of diffuse knapweed. In addition, it can be fatal to plants in the rosette stage.

Other insects being released against diffuse and spotted knapweed are the root boring beetles and moths. These insects, because of their direct damage and gall formation plus the pathogens that may enter through their tunnels, are probably the most effective bioagents to use against these biennial and perennial weeds. The diffuse knapweed root beetle, [*Sphenoptera jugoslavica* Obenberger (Coleoptera:Buprestidae)] was released in British Columbia in 1976 and by 1981 was infesting 25-50% of the plants at White Lake. In the United States, release began in 1980, and it is now established in Idaho, Oregon, and Washington. A European root-mining moth [*Agapeta zoegana* (L.) (Lepidoptera:Cochylidae)] attacks the rosette stage of diffuse knapweed. This moth was released in Idaho, Montana, Oregon, and Washington, in 1984 and is now established in Montana.

In addition, a rust, *Puccinia jaceae* Otth., may provide some control. The rust infection discovered in British Columbia, has since spread into diffuse knapweed infested areas of the interior. The rust infection stresses the plant, and it is expected that in combination with other control agents, diffuse knapweed will be controlled biologically.

BCNRA currently uses *Agapeta zoegana*, *Cyphocleonus achates*, *Urophora affinis*, *Urophora quadrifasciata*, *Metzneria paupipunctella*

Insects U. affinis, U. quadrifasciata, A. zoegana, M. paucipundctella

Many natural enemies of knapweeds have been released for spotted and diffuse knapweed, proving to effectively decrease knapweed vegetative growth. *Urophora affinis* and *Urophora quadrifasciata*, seed-head feeding flies induce galls on flower heads and feed on phloem, reducing seed production up to 50%. The moth *Metzneria paucipundctella* feeds on the flowers and seeds of knapweeds and may reduce seed production by 20%.[xiv]

Root-mining insects have also been released: the root moth *Agapeta zoegana* and root weevil *Cyphocleonus achates* damage roots of spotted knapweed.[xv] Clark *et al*(2001) focused on assessing factors influencing the rate of establishment on *A. zoegana* and *C. achates*, two root feeding insects. Re;ease sites of both insects were visited where history, knapweed infestation and physical features of the site were recorded. Overall, 20 site characteristics and three weed stand features were measured. Site features measured were: habitat type, elevation, percentage slope, aspect, topographic type, forest structure at or by site, disturbance factors, land use category, percentage forest canopy at or near site, percentage bare soil, annual precipitation, and soil type. Release histories were obtained through total numbers of insects released, the number of years releases were made at the site, and the number of years between first release at a site and the year of sampling in the current study. Knapeweed stands were classified at sites by size of infestation, infestation type, and knapweed plant density. All variables were measures for *A. zoegana* at 44 sites in 1997 and 42 sites in 1998. All variables were measured for *C. achates* at 23 sites in 1997 and 22 sites in 1998. 86 total sites were measured, 76 in Montana, 7 in Idaho, and 3 in Washington.

At 86 *A. zoegana* release sites, the numbers of insects released varied from 49-1945 and establishment rates varied from 40-69%. However, establishment rates didn't vary significantly among releases of different sizes. Most site received one release, 20 sites received releases in 2 years, 3 years, 4 years, or 5 years and establishment was not significantly different among site receiving releases in different numbers of years. No significantly different relationships could be determined for the number of years since the first release. There was no significant difference in the establishment of *A. zoegana* for sites with knapweed patches differing in size or between establishment rates of the insect and knapweed plant densities at release sites. Establishment was highest at sites having continuous, linear infestations of knapweed(versus linear roadside strips of the plant or sites where areas of knapweed were intermixed with areas of other plants). Only soil types and forest structure were significantly related to the insect establishment rate. The highest probability of establishment occurred at sites with clay loam or sandy clay loam(100% establishment) and even aged forests(85% establishment). Slope, precipitation and disturbance were not statistically significant but P values were high enough to merit further consideration. A multifactoral model was created to predict the highest probability of establishment of *A. zoegana* which showed sites with continuous knapweed, regardless of forest structure to be the highest. Releases at linear roadside strips of knapweed were least likely to result in

At 45 release sites, *C. achates* was released in densities ranging from 25-750 insects but establishment rates were not significantly different among releases of differing amounts. Sites receiving releases in each of 3 years, had the highest establishment rates(67%). The number of years since first release was 1-6 but had no effect on the probability of establishment. The size of knapweed patch has a significantly impact on the probability of establishment. The largest patches had the highest establishment rate(100%) and establishment was most frequent in continuous knapweed patches, least in patchy infestations. Knapweed plant density had no effect on the probability of the establishment of *C. achates*. No multifactor model was found to be a better predictor of *C. achates* establishment.

In conclusions, release areas should be continuous stands of spotted knapweed with loamy soils and even-aged forests for the successful establishment of *A. zoegana* . Also, one release of 100-200 insects is most effective. Site physical characteristics other than soil type and habitat type don't seem to matter in establishment. For *C. achates*, establishment is more likely at larger sites with continuous knapweed stands at elevations between 910 and 1515m. Releases made along roadsides in strips of knapweed were less effective and there was no evidence that knapweed density affected establishment rate of the weevil.[xvi]

See Diffuse Knapweed Biological Control section for more about *C. achates*.

Grazing - low amounts of grazing of spotted knapweed by cattle, sheep and goats have been effective in Montana. Cattle seem to prefer grass to knapweed but the following study shows that sheep grazing may help control knapweed production.

Sheep grazing has been studied to determine effects on spotted knapweed infested *Festuca idahoensis* (Idaho fescue) communities. Olson, Wallander and Lacey (2001) looked at these effects near Bozeman, MT. They were interested in knowing whether repeated grazing could be used as a control for spotted knapweed.

The site is located 14km south of Bozeman, MT at an elevation of 1570m with 487mm precipitation. The soil is shallow-moderate silty clay loam over sand and gravel, Typic Argiboroll class, Beaverton Series on an alluvial fan. The plant community is dominated by *Centaurea maculosa* but includes *Festuca idahoensis, Balsamirhiza sagittata, Poa pratensis, Lupinus senceus, Psuedoroegnena spicata* and *Geranium viscosissimum*. For three years the site plots were grazed in the summer: 5-7 days in mid-June, 2-6 days in mid-July when fescue is dormant, and 1-2 days in early September before fescue resumes its growth. Density and frequency measurements were done before grazing in June 1992 and 1993, and June 1994, nine months after the September 1993 grazing. Samples of the soil seed bank were taken from 1991-1994 and age class distribution of spotted knapweed in previously grazed and ungrazed areas was determined in 1994.

Results showed that from 1991 to 1992, Idaho fescue in grazed areas increased and then remained constant. In ungrazed areas, fescue density was unchanged from 1991-1994. Grazing effects on *Poa pratensis* density in 1994 was greater than in 1991 and in ungrazed areas there was no change in *Poa* presence. Arrowleaf balsamroot density was not affected in grazed or ungrazed areas. In ungrazed areas, spotted knapweed density was greater in year 4 than in year 2 and year 3. Bare soil was measured and shown to have increased with grazing and decreased without grazing. Spotted knapweed seedling density in grazed areas were much lower in 1992 than in 1991, and remained low throughout the next two years. In ungrazed areas, density was greatest in 1994.

Seed bank cores showed that more viable knapweed seeds were found in ungrazed areas than grazed areas. The mean age of s. knapweed plants was greater in grazed than ungrazed areas. It was concluded that grazing altered the age class of s. knapweed plants, as sheep preferred to eat the younger age plants. Idaho fescue plants had shorter leaves and a lower biomass as a result of grazing. The findings suggest that repeated grazing initially reduces current flower stem production and in order to continue this trend, grazing should be continued. Repeated grazing may also slow the rate of increase in native plant communities since sheep eat a variety of plant species.xvii

Mechanical Control

Mowing. Rinella *et al* (2001), looked at the response of grasses and s. knapweed to season and the frequency of mowing. A three year study using 16 mowing treatments at two sites was conducted to show that s. knapweed would decrease as mowing frequency increased. It was also hypothesized that late season mowing would decrease knapweed more than early season mowing, and that mid-season mowing would decrease knapweed cover more than grass cover.

Site 1, near Belgrade, MT has an elevation of 1349m and a Beaverell gravelly loam soil type. Dominant vegetation is *Festuca idahoensis, Centaurea maculosa, Bromus inermis*, and *Bromus tectorum*. Site 2, southwest of Bozeman, MT has an elevation of 1340m and a 70% Beaverton cobbly loam and 30% Hyalite loam soil type. Dominant vegetation is spotted knapweed, Idaho fescue, bluebunch wheatgrass and Kentucky bluegrasss. Both sites have *Festuca idahoensis-Agropyron spicatum* habitat types.

Fifteen mowing regimes were implemented and one control:

- Spring mowing
- Summer mowing
- Fall mowing
- 2 spring mowings
- 2 summer mowings
- 2 fall mowings
- 1 spring and 1 summer mowing
- 1 spring and 1 fall mowing
- 1 summer and 1 fall mowing
- 1 spring, 1 summer, 1 fall mowing
- 2 spring and 2 summer mowings
- 2 spring and 2 fall mowings
- 2 summer and 2 fall mowings
- 2 spring, 2 summer, 2 fall mowings
- Mowing at 2 week intervals throughout growing season
- Control with no mowing

Mower height was 10 cm. The growth stage of s. knapweed was recorded at each mowing.

Results showed the growth stage of spotted knapweed to be similar for each mowing treatment among years at both sites. Treatment or year did not affect the amount of bare ground at Site 1 but treatment and year did increase bare ground with mowing frequency at Site 2. Most mowing treatments decreased knapweed seedling densities below the control at Site 2 with seedling reduction increasing as mowing frequency increased. At Site 1, none of the mowing treatments reduced knapweed density below the control. Every mowing treatment reduced spotted knapweed adult density, except 1 spring mowing at Site 1 in 1998. No treatment decreased adult density below the control at Site 1. Most treatments decreased adult density at Site 2 in both years. Fall mowing was more effective than spring or summer mowing and late season mowing removes more knapweed biomass and may enhance knapweed mortality. One fall mowing while plant is in flowering or seed-producing stage decreased knapweed cover and adult density as much as any treatment that had repeated mowing at both sites. Only three treatments decreased grass cover at Site 1 in 1998: 1 summer mowing, 1 fall mowing and 2 spring-2 fall mowings. In 1997 at site 1, two treatments increased grass cover above the control: 1 spring and 1 summer mowing, and 2 summer and 2 fall mowings.

This study suggests that a single fall mowing when plants are in flowering or seeding stage reduces s. knapweed cover as much as any repeated mowing treatment.[xviii]

*Hand Pulling*_ entire plants must be removed in order for hand-pulling to be successful. Regrowth can occur from crowns and viable seeds in the soil so hand-pulling must be done before seeding each year.3

Cultural Control

*Seeding*_ establishing competitive plants is essential to the management of knapweeds and the restoration of a desired community.[3] Sheley *et al*(1998) suggest late fall cultivation, followed by seeding of a dormant grass. Knapweeds emerge first in the spring so an application of glyphosate may be necessary to control them. Grasses should survive until mid-summer and mowing or 2,4-D can be applied to weaken knapweed plants. Seeding at higher rates should help grasses compete and increase their numbers in the seed bank.

In 1997, a study by Velagala, Sheley and Jacobs (1997) found that increasing intermediate wheatgrass density removed the competitive influence of s. knapweed under conditions where interspecific interference was significant. This suggests that the competitive balance can be shifted from s. knapweed by establishing high densities of greater than 1000 plants m^{-2} of wheatgrass.

Study sites at the Arthur Post Farm, west of Bozeman, MT and the Redbluff Research Ranch, east of Norris, MT were seeded with various densities of intermediate wheatgrass and spotted knapweed. Seeds were sown in pots of soil which were placed underground, watered, covered and allowed to grow for 60 days. Both sites have a *Festuca idahoensis/Agropyron spicatum* habitat type. The Arthur Post Farm has an elevation of 1463m and 457mm of precipitation. The Redbluff Research Ranch has an elevation of 1500m and 305mm of precipitation.[xix]

Burning a single low intensity fire does not effectively control spotted and diffuse knapweed. However, herbicide efficacy on both knapweeds may increase when applied after burning. Sheley and Roche(1982) showed that Picloram applied at 0.28kg/ha provided 100% control of both weeds 2 years after post burning application. Residual understory grass cover and density on burned plots increased over unburned plots where picloram had been appied.[13]

Watson and Renney (1974) found that repeated prescribed burns will reduce knapweed but it is difficult to get a burn to carry through dense patches. Burning is only effective where re-growth of a native species is vigorous.[xx]

Diffuse Knapweed (Centaurea diffusa)

Mechanical, cultural, chemical, and biological control methods have all been used on diffuse knapweed with varying levels of success. An important consideration prior to applying control is to determine if enough desired plants are present to replace the controlled species. If desired vegetation is scarce or absent control will be of little value. Control methods may harm other plants and result in a disturbance that will favor reinvasion by diffuse knapweed or other NIS.

Chemical Control

Generally the same as for spotted knapweed above because many herbicides are not specific to diffuse knapweed or may not be specifically licensed for this use. It is important to read and follow all label directions.

Biological Control

P. junceae (a rust) – stresses knapweeds, should be used with other method(s)[15]

Four species of biocontrol insects were released primarily on a 30-ha site in Boulder County, Colorado. The site was a degraded pasture with 30% *Centaurea diffusa* cover. Native grasses represented a modest cover component and non-natives such as annual peppergrass, Japanese brome, and field bindweed were common. Two other sites were used, Site 2 as a reference and Site 3 which was mowed from 1997-2000. The goal was to measure knapweed densities and seed production for five growing seasons for a site infested with knapweed, determine how mowing might affect use of plants by insects and monitoring the abundance the *Urophora* spp. and determine the fate of the newly released biocontrol insects *Sphenoptera jugoslavica, Cyphocleonus achates, Metzneria paucipunctella,* and *Larinus minutus.* Release of the banded gall fly and knapweed seed head fly had previously occurred in 1989 and were assumed to be in the area.

The main site (Site 1) had been grazed but wasn't during the study period. It was broken up into three areas: the Mowed area, Release site, and Reference area. Treatment at the Mowed site was a single mowing event per year in the 3rd or 4th week of June, just before flowering of diffuse knapweed. Plants were cut to a height of 20cm and mowing ceased after three years. An area adjacent to the mowed site, Site 1 was the central release point for the insects and included a vegetation transect, Transect A. 550 *Larinus*, 1500 *Sphenoptera*, 200 *Cyphocleonus*, and 2000 *Metzneria* were released between 1997 and 2000 at the release site. Site 2, another unmowed site was located 300m from Site 1 and included vegetation transect B. Transect C was 200m from and adjacent to the release point. Transect D was 600m from the release point. Transect E was 1km from the release point and had vegetation similar to the main study area and cover estimates were done at this site as a reference. The reference area had been slightly grazed in the past.

Plants responded to the insect release although results showed that the spotted knapweed seed head moth didn't establish at the site. Drought affected the results, as in 2000 there was a decline in total vegetation cover of over 50% relative to 1997 values. Diffuse knapweed cover declined in 41% and cover by other nonnative species dropped 84%. From 1997-2000 average native perennial grass cover declined slightly and to a lesser degree than total vegetation cover declined. Relative cover of diffuse knapweed and native perennial grass actually increased in relative cover.

In 2001, precipitation was increased and total vegetation cover and native perennial grass cover increased to levels close to 1997. Cover by nonnative species other than diffuse knapweed jumped to 40% greater than in 1997. Between 2000-2001, diffuse knapweed cover decreased on all transects and those nearest the release site showed the largest decline.

Data from Site 2(Transect E) showed that knapweed continually declined from 1997 to 2001, probably resulting from continuous dry conditions.

Mowing initiated in 1997 increased knapweed flowering stem densities in 1998-2000. When mowing was ended in 2000, flowering stem densities declined in 2001. At Site one where insects were release there was a constant number of flowering stem densities through 1999. In 200 densities increased but in2001 had declined.

Plant size was smaller at Site one in treated areas than untreated plants. Seed production per seed head declined for 1997 to 2001 at both sites. Mowing significantly reduced the number of seed heads. Also, by 2001, seeds per square meter were reduced to less than 100 seeds m^{-2}. Rosette densities also declined at all sites.

Uphora spp. numbers on the sites mowed through 2000 was significantly larger than densities found on other sites. Knapweed seed head flies seemed to be attracted to the late season mowing, however the banded gall fly didn't seem to favor this. Large densities of the lesser knapweed flower weevil moved from Site 1 to Site 2 by 2000. Seed heads from the mowed area in 2000 showed the lesser knapweed flower weevil densities to be the lowest and it was assumes that the plants had flowered after the weevil had finished laying its eggs. Seed head data from the reference site 1 km away showed continued high numbers of seeds per seed head in the absence of weevils.[xxi]

Sphenoptera jugoslavica, a root beetle has been released on diffuse knapweed, as have the root moths *Pelochrista medullana* and *Pteroloche inspersa*.[4]

Mechanical Control

Mowing at flower stage and before seeding is somewhat effective, use other method(s)8

Refer to study done by Rinella *et al*., in Spotted knapweed section.

Cultural Control

Seeding Determining the effects of the level of a single grass defoliation and two seeding rates of *Centaurea diffusa* on its establishment. For two years, two sites Northwest of Plymouth, WA were studied: Site 1, a bluebunch dominated community and Site 2, a crested wheatgrass pasture. Both sites were the *Pseudoroegeneria spicata* (bluebunch wheatgrass)/*Stipa* comata(needle and thread) habitat type, susceptible to invasion by diffuse knapweed. Site 1 has an elevation of 450m and dominant vegetation is *Poa sandbergii* with a few forbs. The site hadn't been grazed in 20 years. Site 2 has an elevation of 720m and was a seeded monoculture of *Agropyron cristatum* established in 1982 with no grazing or human disturbance since. Soil types of the sites are the same, a well drained Warden, very fine sandy loam without slope. Precipitation is 225mm per year. At the beginning of the study, there was no knapweed present at either site.

12 treatments were applied-2 diffuse knapweed seeding rates and 6 defoliation levels- to 1m^2 plots. Plots were clipped to an 8cm stubble height in mid-August 1992. Diffuse knapweed seeds were broadcast biweekly in densities of 500 or 1000 from September 1–November 15, 1992. Grasses were hand-clipped at defoliation levels of 0, 20, 40, 80, 100% in April 1993 when in boot stage. The above biomass of knapweed and grasses were clipped and plants harvested in 1994. Densities of adult, juvenile, and seedling knapweed plants were also determined. Knapweed plants were harvested on July 1, 1994, dried and weighed.

Results indicated that by 1994, Diffuse knapweed plants weighed more where grasses were defoliated at the 100% level than when defoliation of 0-60% occurred on Site 1. The number of *Pseudoroegeneria spicata* flowering culms and plant dry weight were reduced by the increase in level of defoliation. Plants were defoliated at boot stage when they are least tolerant. Grasses were able to fully recover from moderate to low levels of defoliation and minimized knapweed establishment and growth.

On Site 2, diffuse knapweed weighed more where grasses defoliated by 100% than where defoliated 0-80%. *Agropyron cristatum* recovered regardless of the level of defoliation, as it is grazing tolerant. With or without defoliation, diffuse knapweed successfully established on both sites. It has been proposed that small scale disturbances can cause this to occur in ungrazed areas. Foliar cover of diffuse knapweed was not affected by grass defoliation at either of the two sites studied.

A higher seeding rate may increase the seed bank, as the data shows that knapweed increased in the *Agropyron cristatum* site in year 2. Viable knapweed seeds are known to remain in the seed bank for up to 10 years. It is suggested that on dry sites *Agropyron cristatum* will be more affected by defoliation. It should also be noted that Agropyron can reduce soil moisture early in the growing season, thus hindering establishment of other species.[xxii]

Sheep grazing Moderate grazing in fall, use with other method(s) for full effectiveness. See study done by Olson for Spotted knapweed above.

Plowing Effective only when used in conjunction with seeding afterward[8]

Russian Knapweed (*Acroptilon repens*)

BCNRA is currently using no control methods.

Chemical Control

A study was conducted on the Wind River Indian Reservation near Arapaho and Fort Washakie, WY to determine the potential of perennial grass competition as an alternative to the repetitive herbicide treatments and cultural control of Russian knapweed. Sites were located on Lander Complex sandy loam soils using split-plot design with three replications. Herbicide treatments were applied after frost on October 10 and 11, 1991.Plots were tilled in May 1991. Treatments of Metasulfuron(8.5g ai/ha), clopyralid (0.32kg ai/ha) plus 2,4-D (1.65kg ai/ha) and picloram (0.28kkg ai/ha) were applied in August 1992. All herbicides except picloram were reapplied in August 1994. Plots were seeded with streambank wheatgrass, thickspike wheatgrass, crested wheatgrass, and western wheatgrass at 11.2 kg/ha on Aril 11 and 12, 1992. The same days, Russian wildrye was seeded at 40cm and 6.6kg/ha. Plots were then mowed in fall 1996 to simulate grazing and allow regrowth.

Results indicated that a single application of picloram reduced Russian knapweed cover from an average of 86.9% in tilled and 79.4% in untilled plots. Clopyralid plus 2,4-D also reduced knapweed cover 79.6% in tilled and 83.6% in untilled plots.. Burning, mowing and metsulfuron didn't provide effective control. The two grasses with the highest overall establishment in tilled plots were thickspike wheatgrass and streambank wheatgrass. The two grasses with the highest overall establishment in untilled plots were Russian wildrye and western wheatgrass. The lowest amount of Russian knapweed and highest amount of grass cover were plots treated with picloram and seeded with Russian wildrye.[xxiii]

Biological Control

No studies found

Mechanical Control

No studies found.

Cultural Control

At the Nature Conservancy's Red Canyon Ranch in Lander, WY an experiment takes place where 800 head of cattle are used to trample *Acroptilon repens* (Russian knapweed) infestations. Salt licks are placed in areas where infestation is high, helping to keep animals in certain areas. Cattle are kept in these areas for one half to a full day, moved and then the area is reseeded with a native grass. Applications of 2,4-D have been sprayed before trampling occurs as an aide. No official study has been done to show the effects of these methods to date.[5]

Walker suggests that sheep and goats are specialized animals that are able to neutralize the phytochemicals present in knapweeds that are toxic to other animals.[5] Sheley *et al* also suggest this in their studies detailing sheep grazing spotted and diffuse knapweeds.

Field Bindweed (*Convolvulus arvensis*)

BCNRA is currently using no control methods.

Chemical Control

Lab studies were conducted to determine the effects of 2,4-D acid, MSO, and the 28% UAN on quinclorac absorption in field bindweed. Quinclorac was applied alone and mixed with 2,4-D at rates of 0.3 and 1.1kg ha^{-1}, respectively. Ring-labeled ^{14}C-quinclorac was added to each treatment solution. Greenhouse studies were conducted to assess quinclorac soil activity in field bindweed. Quinclorac was applied at either preemergence or subsurface application, at rates of 0, 35, or 280g ha^{-1}. Plants grew for 45 days and were harvested.

Results show Quinclorac to not be absorbed alone but absorption was greatest when MSO and 28%UAN were applied together with quinclorac plus 2,4-D. Quinclorac absorption was found to be lower than previous studies using Picloram and 2,4-D, and glyphosate or dicamba.

Soil activity results showed quinclorac to cause leaf malformation, crinkling, chlorosis, stem epinasty, and reduced shoot biomass at all applied rates in the preemergence application. In the subsurface application, rates of 35 and 280g ha^{-1} significantly reduced bindweed shoot fresh weight. It was observed that quinclorac causes stunting and chlorosis, affecting root growth and development at both herbicide rates. At a rate of 280g ha^{-1}, plants showed some regrowth occurring after treatment.

It is suggested that root absorption coupled to a lack of metabolism may prolong quinclorac effects in field bindweed, therefore leading to the overall reduction in plant vigor. This is an important step for managing perennial weeds. Growth reductions following root removal may indicate a potential beneficial tillage following a quinclorac application. Quinclorac should not be used alone but as part of a control for field bindweed.[xxiv]

From 1976-1982, 22 experiments to determine relative effectiveness of the herbicides dicamba, glyphosate, fosamine, and picloram on field bindweed were conducted. There were three experimental sites with the Pullman clay loam soil type, containing on third sand, silt and clay. Average rainfall was45cm annually. Herbicides were applied by tractor to plots 3 or 4 cm wide and 8.2m long. Treatments were replicated three times in a randomized complete block design. Visual observations were made on bindweed growth stage, length of runners, and plant vigor. Plots were evaluated one and two years after treatment.

Results showed all herbicides to be effective at controlling field bindweed to some degree. Overall, after 1 year, 3.3 kg/ha glyphosate averaged a control of 71%, 1.1kg/ha dicamba a control of 57%, and 13.4kg/ha fosamine a control of 73% Glyphosate control ranged from 0-100%, the later being most common as many dates showed 91% or better control. Control with 2,4-D ranged from 75-97%. Dicamba control was 88% or better. The best control using glyphosate and 2,4-D was any time of year when bindweed was growing vigorously. Dicamba control was best when applied in the fall, regardless of growing conditions.

Control in the second year after treatment resulted in an average control with glyphosate of 53%, with 2,4-D of 31%, dicamba control of 34% and fosamine control of 66%. Fosamine gave the best long-lasting control any time it was used in year two, although this was not the case in year one, because it effects persisted into year two.

Timing of application is important. Spring applications of glyphosate worked best for control with that herbicide. The effectiveness of dicamba in spring and fall were very close, suggesting either season will work. 2,4-D also provided better control when applied in spring.

Studies where picloram was mixed with dicamba, glyphosate or 2,4-D showed similar average controls. Picloram plus dicamba (0.28kg/ha each) gave 74% control. Picloram plus 2,4-D at rates of 0.28kg/ha and 0.56kg/ha averaged control of 65%. Picloram plus glyphosate at rates of 0.84 and 0.22kg/ha averaged control of 70%.[xxv]

Twenty herbicide treatments were applied to various sites in Colorado, Wyoming, Montana and Kansas to evaluate long-term bindweed control. Herbicides were applied alone, in combinations, or as commercial herbicide premixes. Growth stage at application, environmental conditions, and application dates were recorded. Treatments were applied to green bindweed with 10cm or longer runners. Herbicides were applied in water with compressed-air pressurized sprayers. In Ft. Collins(CO), Denver(CO), Hays(KS), Wheatland(CO), and Park City(MT), winter wheat was seeded in the fall of 1989. Field bindweed control was visually estimated 6-8 weeks and 10-13 months after treatment at all sites. Colorado and Wyoming sites were estimated 2 years after treatment as well.

Three treatments were effective for controlling field bindweed at all locations except Hays, KS: dicamba at 0.56kg ha^{-1}, 2,4-D at 0.56kg ha^{-1}, and 1.12kg ha^{-1} mixed with picloram at 0.28kg ha^{-1} all controlled greater than 83% one year after treatment. Picloram alone at 0.28kg ha^{-1} provided the best single herbicide control at all site, except Hays where both rates showed equal results. The Hays site may have reacted differently because it was abnormally warm and dry in 1988. Picloram in a mix with other herbicides provided 4-11 times the control the other components did. Herbicide combinations containing picloram, such as adding dicamba or 2,4-D, improved bindweed control two years after treatment compared to only picloram treatment.[xxvi]

Biological Control

Galled tissue from field bindweed plants were collected in Greece and a location in Texas, imported to greenhouse facilities in Regina, Saskatchewan and Bozeman, Montana. Here, colonies were established and maintained on potted bindweed plants in Alberta and Bozeman. In Alberta, the insect was released at 7 sites near Medicine Hat on 12 occasions between 1993 and 1998. Release sites included pastures, edges of cultivated fields, roadsides and wastelands. Sites were inspected once or twice annually. In Montana, the mite was released at 8 sights on 20 occasions in areas that were vacant land, former cropland, nonirrigated pastures, and along edges of croplands or hayfields. Sites were visited periodically in the summer and early fall after the initial release and then again in the spring to determine overwintering success.

Alberta plants showed gall formation on bindweed within one year of release at 10 of 12 releases (6/7 sites). 4/6 sites showed overwintering success where releases were made in 1998. At most sites damage to bindweed was slight the following summer with only a few roots or leaves galled and mites did not survive the second winter. At the Redcliff site, strong and persistent populations of mites lasted from 1998 from a 1995 release. The release at the site contained 200 pieces of galled tissue attached to plants over an area of 750m^2. Damage on plants ranged from slight with a few galled leaves to heavily and severely damaged plants where the entire plant was galled and stunted.

Montana releases were successful at establishing mites, mostly from transplanted plants. Galls were observed within the same growing season as the release at 11 of 16 sites. Only 45% of total releases showed mite survival the following year. Almost half of the sites where mites didn't overwinter were areas disturbed in the year of release, either by cultivations, herbicide application or heavy grazing. Mites at over 20% of releases survived overwintering in undisturbed sites. No plant mortality was observed at any of the release sites and infestation was variable ranging from plants with few leaves infested to severely stunted plants 1-2cm in length. Heavily infested plants at the Roy site were found in clumped distribution within the infestation, indicating possible preference of microhabitats for overwintering. Roy and Wolf Point population development was slow for the first 3 seasons, increasing by 1997. Infestation at Roy was 12% in 1997 and mites infested up to 1400m^2. In 1998 the infested area expanded significantly and 65% of plants at the immediate release point were infested. Total are infested was 14.3

ha with an infestation rate of 22%. At Wolf Point, less than 1% of plants have been infested and dispersal if just several meters.[xxvii]

Mechanical Control

No studies found

Cultural Control

No studies found

Houndstongue (*Cynoglossum officinalis*)

An important consideration in controlling hound's tongue is that seeds are readily dispersed and have the potential to remain viable for 2-3 years, if they remain on the parent plant. Also, prior to using any control it is important to determine if enough desirable plants are present to replace the controlled species. If desired vegetation is scare or absent control will be of little value.

Chemical Control

Many herbicides are not specific to hound's tongue or may not be specifically licensed for this use. It is important to read and follow all label directions. In Montana, research indicates that 2,4-D amine applied at a rate of 1.12 kg/ha applied in May controlled up to 97% of the first-year hound's tongue plants. Application at flowering controlled up to 77% of the second-year plants. It has also been found that seed production of second-year hound's tongue plants in Montana was most sensitive to 2,4-D applied when the bolted plants were 28 cm tall. Glean (chlorsulfuron) gave complete control when applied any time beginning with the rosette stage until the bolted plant had attained 28 cm in height. In British Columbia, Tordon (picloram), Glean (chlorsulfuron), and Banvel (dicamba) applied at rates of 0.56-1.68 kg/ha, 0.04 kg/ha, and 1.12 kg/ha, respectively, applied either in spring or fall provided excellent control of this weed.

BCRNA have been having good response with spot treatment of Escort (metsulfuron methyl) applied before shrubs have leafed out and by clipping surviving heads.

Biological Control

No studies found.

Mechanical Control

Research indicates that mowing second-year plants during flowering dramatically reduces seed production. Sixty percent of plants cut 0-7 cm above ground failed to regrow. Seed production of the plants which resumed growth (16.5 cm average height compared to 75 cm for unclipped plants) declined to approximately 25 seeds per plant compared to 364 seeds per plant in the unclipped controls. However, most of the houndstongue plants in the BCNRA are in areas which would be difficult to mow.

Cultural Control

No studies found

Rush Skeletonweed (*Chrondrilla juncea*)

BCNRA is currently using no control methods.

Chemical Control

No studies found.

Biological Control

No studies found.

Mechanical Control

No studies found.

Cultural Control

No studies found

Downey brome (*Bromus tectorum*)

Downey brome, also called cheatgrass, is a winter annual that is reknowned for displacing native species, changing fire frequency, and offers poor grazing after seed set and can injure grazing animal mouths and eyes. Seeds stay viable for 2-5 years and densities of stems are often high.

Many sources of new propagules surround BCNRA. Desirable vegetation is scarce or absent in the main area and control of downey brome will be of little value without revegetation. Most control methods harm other plants and may result in a disturbance that will favor reinvasion by downey brome or other NIS. This shows the need for a number of trials to be performed before an area wide recommendation is created.

Chemical Control

University of Nebraska extension did not have success with spraying paraquat or Roundup to kill the existing weeds and downey brome and stated that grass densities must be reduced prior to seeding desirable grasses (Klein, Wicks and Lyon, 1996).

The majority of the work on the chemical control of downey brome has focused on infestations in agricultural crops. Chemical control research in prairies has been primarily limited to AAtrex (atrazine). Herbicides active on downey brome in various crops include Hoelon (diclofop), Kerb (pronamide), Nortron (ethofumesate), AAtrex (atrazine), Princep (simazine), Amizol (amitrole), Arsenal (imazapyr), Hyvar (bromacil), Oust (sulfometuron methyl), Cyclone (paraquat), and Roundup (glyphosate). Many herbicides are not specific to downey brome or may not be specifically licensed for this use. It is important to read and follow all herbicide label directions.

Biological Control

Research into the biological control of downey brome is limited. It is known that rabbits and mice will feed extensively on this species as do migratory grasshoppers (*Melanoplus sanquinipes*). Downey brome is often infected with a head smut (*Ustilago bulleta* Berk.) that, when severe, may reduce seed yield. Some research has been conducted on pink snow mold (*Fusarium nivale*) as a biological control agent, but information has yet to be released. In addition to these molds and smuts, over 20 diseases of downey brome have been reported.

Mechanical and Cultural Control

Fire, mowing, grazing, tillage, and interseeding of competitive native plants have all been shown to reduce populations of downey brome. The results of wildfires on this species have been considered to be a catastrophic stand renewal process. This is because wildfires often occur at the worst time for perennial plants. One result is that open ground is created for readily colonizing species such as downey brome. Based on the fact that this is a cool-season annual, it could be assumed that prescribed fire in as early in the spring as possible - just after snow melt - could be a valuable tool in controlling this species, especially on an area where the preferred vegetation is primarily warm-season grasses. A prescribed fire should kill seedlings and further reduce the surface seed bank. A study conducted on spring burning of the closely related Japanese brome (*Bromus japonicus* Thunb. ex Murr.), showed that consecutive annual burns reduced brome density and standing crop.

Mowing has been shown to reduce seed production when the stand is mowed within 1 week following flowering. This reduces seed production, but does not eliminate it because later developing plants will escape mowing and will produce seed, however, it could provide some reduction in seed production. As stated elsewhere care must be taken to mow at a height above the growing meristems of native grasses.

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Appendix I.
Table 1: Non-indigenous plants found within the north district of the BCNRA

Family	Species Name	Common Name	Vascular Plant Checklist	MSU Weed Survey	Noxious weed Category
Apiaceae	*Conium maculatum*	Poison hemlock	X		Bighorn Co. List
Asteraceae	*Acroptilon repens*	Russian knapweed	X		✓
	Arctium minus	Lesser burdock	X		Bighorn Co.List
	Centauria diffusa	Diffuse knapweed	X	✓	✓
	Centauria maculosa	Spotted knapweed	X	✓	✓
	Chondrilla juncea	Rush skeletonweed	X	✓	✓
	Chrysanthemum leucanthemum	Ox-eye daisy	X		✓
	Cichorium intybus	Chichory	X	✓	
	Cirsium arvense	Canada thistle	X	✓	✓
	Cirsium vulgare	Bull thistle	X		
	Crupina vulgaris	Common crupina			✓
	Cynoglossum officinale	Hound's tongue	X	✓	✓
	Lactuca serriola	Prickly lettuce	X		
	Logfia arvensis	Field cotton rose	X		
	Senecio jacobaea	Tansy ragwort			✓
	Sonchus arvensis	Sow thistle			
	Sonchus asper	Prickly sow thistle	X		
	Tanacetum vulgare	Common tansy	X		✓
	Taraxacum leavigatum	Red-seed dandelion			
Brassicaceae	*Alyssium alyssoides*	Pale madwort	X		
	Alyssum desertorum	Desert alyssum	X	✓	
	Arabidopsis thaliana	Thalecress	X		
	Capsella bursa-pastoris	Shepherd's purse	X		
	Cardaria draba	Hoary cress			✓
	Cardaria spp.	Cardaria complex			✓
	Descurainia Sophia	Flixweed	X		
	Hesperis matronalis	Mother-of-the-evening	X		
	Lepidum perforiatum	Clasping pepperwort	X		
	Rorippa nasturtium-aquaticum	Watercress	X		
	Sisymbrium altissimum	Tumblemusturd	X		
	Sisymbrium loeselii	Loesel's tumble musturd	X		
	Thlaspi arvense	Field pennycress	X		
Caprifoliaceae	*Lonicera tatarica*	Tatarian honeysuckle	X		
Caryophyllaceae	*Arenaria serpylifolia*	Thyme-leaf sandwort	X		
	Bassia scoparia	Summer cypress	X		
	Halogeton glomeratus	Saltlover			
	Salsola tragus	Russian thistle	X		
	Stellaria media	Common chickweed	X		

Clusaceae	*Hypericum perforatum*	Common St. Johnswort			✓
Convovulaceae	*Convolvulus arvensis*	Field bindweed	X	✓	✓
Cucurbitaceae	*Bryonia alba*	White bryony	X		
Eleagnaceae	*Astragalus cicer*	Chickpea milkvetch			
	Eleagnus angustifolia	Russian olive	X		
Euphorbaceae	*Euphorbia esula*	Leafy spurge			✓
	Medicago lupulina	Black medic	X		
	Medicago sativa	Alfalfa	X		
	Melilotus officinalis	Yellow sweet-clover	X		
	Meliltus albus	White sweet-clover	X		
	Shaerophysa salsula	Red bladder-vetch	X		
	Trifolium fragiferum	Strawberry-head clover	X		
	Trifolium hybridum	Alsike clover	X		
Geraniaceae	*Erodium circutarium*	Red-stem stork's-bill	X		
Lamiaceae	*Nepeta cataria*	Catnip	X		
Plantaginaceae	*Plantago major*	Great plantain	X		
Poaceae	*Aegilops cylindrical*	Jointed goatgrass	X		
	Agropyron cristatum	Crested wheatgrass	X		
	Agrostis stolonifera	Redtop	X		
	Bromus commutatus	Meadow brome	X		
	Bromus inemis	Smooth brome	X	✓	
	Bromus japonicus	Japanese brome	X		
	Bromus tectorum	Downey brome	X	✓	
	Dactylis glomerata	Orchard grass	X		
	Eragrostis cilianensis	Stinkgrass	X		
	Festuca ovina	Sheep fescue	X		
	Festuca srundinaceae	Tall fescue	X		
	Phleum pratense	Common timothy	X		
	Poa bulbosa	Bulbous blue grass	X		
	Poa compressa	Flat-stem blue grass	X		
	Poa pratensis	Kentucky bluegrass	X		
	Setaria viridis	Green bristle grass	X		
	Thinopyrum ponticum	Eurasian quackgrass	X		
Polygonaceae	*Polygonum lapathifolium*	Dock-leaf smartweed	X		
	Rumex crispus	Curley dock	X		
	Ranunculus testiculatus	Hornseed buttercup	X		
Scrophulariaceae	*Linaria dalmatica*	Dalmatian toadflax			✓
	Verbascum thapsis	Common mullein	X		
Solanaceae	*Solanum dulcamara*	Climbing nightshade	X		
Tamaricaceae	*Tamarix ramosissima*	Salt-cedar	**X**		✓
Ulmaceae	*Ulmus pumila*	Siberian elm	X		
Zygophyllaceae	*Tribulus terrestris*	Puncturevine	**X**		

Adapted from Heidel & Fertig, 2002, and incorporating the Montana Noxious Weed List and Bighorn County list.

Appendix II: Montana County Noxious Weed List

Category 1.

Category 1 noxious weeds are weeds that are currently established and generally widespread in many counties of the state. Management criteria includes awareness and education, containment, and suppression of existing infestations and prevention of new infestations. These weeds are capable of rapid spread and render land unfit or greatly limit beneficial uses.

1. Canada Thistle (*Cirsium arvense*)
2. Field Bindweed (*Convolvulus arvensis*)
3. Whitetop or Hoary Cress (*Cardaria draba*)
4. Leafy Spurge (*Euphorbia esula*)
5. Russian Knapweed (*Centaurea repens*)
6. Spotted Knapweed (*Centaurea maculosa*)
7. Diffuse Knapweed (*Centaurea diffusa*)
8. Dalmation Toadflax (*Linaria dalmatica*)
9. St. Johnswort (*Hypericum perforatum*)
10. Sulfur (Erect) Cinquefoil (*Potentilla recta*)
11. Common Tansy (*Tanacetum vulgare*)
12. Ox-eye Daisy (*Chrysanthemum leucanthemum*)
13. Houndstongue (*Cynoglossum officinale*)

Category 2.

Category 2 noxious weeds have recently been introduced into the state or are rapidly spreading from their current infestation sites. These weeds are capable of rapid spread and invasion of lands, rendering lands unfit for beneficial uses. Management criteria includes awareness and educaiton, monitoring and containment of known infestations and eradication where possible.

1. Dyers Woad (*Isatis tinctoria*)
2. Purple Loosestrife (*Lythrum salicaria*)
3. Tansy Ragwort (*Senecio jacobea*)
4. Meadow Hawkweed Complex (*Hieracium pratense, H. floribundum, H. piloselloides*)
5. Orange Hawkweed (*Hieracium aurantiacum*)
6. Tall Buttercup (*Ranunculus acris*)
7. Tamarisk [Saltcedar] (*Tamarix* spp.)

Category 3.

Category 3 noxious weeds have not been detected in the state or may be found only in small, scattered, localized infestations. Management criteria includes awareness and education, early detection and immediate action to eradicate infestations. These weeds are known pests in nearby states and are capable of rapid spread and render land unfit for beneficial uses.

1. Yellow Starthistle (*Centaurea solstitialis*)
2. Common Crupina (*Crupina vulgaris*)
3. Rush Skeletonweed (*Chondrilla juncea*)

Bighorn County Noxious Weeds

1. Common Burdock (*Arctium minus*)
2. Black Henbane (*Hyoscyamus niger*)
3. Poison Hemlock (*Conium maculatum*)

Appendix III Contacts, costs & schedule

Contacts

NPS Contact: Suzanne Morstad, Telephone: (307) 548-5416,
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Montana State University Contact: Lisa J. Rew (PI), Telephone: (406) 994-7966
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Project Costs and Schedule

Cost of Project: $12,860 for Fiscal Year 2002, $7260 for MSU and $5,600 in kind from BICA.

Project Initiation – April, 2002
Invoice Payable up to 90% - May, 2002
Database, maps, aerial photographs provided to MSU by BICA – July 1st, 2002

Progress Report (Mid-Year) – March, 2003
Final Report – December 31st, 2003
Invoice Payable up to 100% Final Report 2003

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[ii] **Clopyralid effects on shoot emergence, root biomass, and secondary shoot regrowth potential of Canada thistle (*Cirsium arvense*)**
Donald,-William-W.
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[iv] **Unexpected Ecological Effects of Distibuting the Exotic Weevil, Larinus planus(F.), for the Biological Control of Canada Thistle.** Louda, S.. and O'Brien, C.W. Conservation Biology: 16(3). June 2002. p. 717-727

[v] **Biocontrol of the weed Canada thistle(*Cirsium arvense*): releases and development of the gall fly *Urophora cardui* (Diptera: Tephritidae) in Canada**. Peschken, D.P., Finnamore, D.b., and Watson, A.K. The Canadian Entomologist, April 1982. pp.349-356.

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[xi] **Spotted knapweed and grass response to herbicide treatments**
Sheley,-Roger-L; Duncan,-Celestine-A; Halstvedt,-Mary-B
Journal of Range Management v 53 no2 Mar 2000. p. 176-82

[xii] **Predicting plant community response to picloram**
Kedzie-Webb,-Susan-A; Sheley,-Roger-L; Borkowski,-John-J
Journal of Range Management v 55 no6 Nov 2002. p. 576-83

[xiii] **Revegetating spotted knapweed infested rangeland in a single entry**
Sheley,-Roger-L; Jacobs,-James-S; Lucas,-Daniel-E
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[xiv] **The seed moth, Metzneria paucipuntella: its impact on spotted knapweed seed production and two seed head flies, Urophora spp.** Story, J.M., K.W. Boggs, W.R. Good, and R.M. Nowierski. In P.K. Fay and J.R. Lacey, eds. Proceedings of the Knapweed Symposium. Bozeman, MT. 172-174. 1989.

[xv] **Distribution, biology, and management of diffuse knapweed (Centaurea diffusa) and spotted knapweed (Centaurea maculosa).**
Sheley-Roger-L {a}; Jacobs-James-S; Carpinelli-Michael-F
Weed-Technology. April-June, 1998; 12 (2) 353-362.

[xvi] **Effects of Site characteristics and release history on Establishment of *Agapeta zoegana*(Lepidoptera:Cochylidae) and *Cyphocleonus achates*(Coleoptera:Curculionidae), Root-feeding herbivores of Spotted Knapweed, *Centaurea maculosa.*** S.E. Clark, R.G. Van Driesche, N. Sturdevant, J. Elkinton, and J.P. Buonaccorsi. Biological Control: 22(2). October 2001.

[xvii] **Sheep grazing spotted knapweed and Idaho fescue**
Olson,-Bret-E; Wallander,-Roseann-T
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[xviii] **Spotted knapweed response to season and frequency of mowing**
Rinella,-Matthew-J; Jacobs,-James-S; Sheley,-Roger-L
Journal of Range Management v 54 no1 Jan 2001. p. 52-6

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