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Weed Management Plan

for

Hebgen Lake Ranger District – South Half

Gallatin National Forest

2005-2010

1.0 Introduction

A. Description of the Site, Conservation Targets, and Management Goals

This Weed Management Plan, specific for the management of yellow toadflax (*Linaria vulgaris*), has been prepared for the south half of the Hebgen Lake Ranger District in the Gallatin National Forest of southwest Montana. The south portion of the District covers an area of approximately 74,000 hectares. It is bordered to the north by Highway 287 (which parallels the north shore of Hebgen Lake and the Madison River), to the east by Yellowstone National Park, and to the south and west by the state of Idaho.

The area is mostly flat with an average elevation of about 2000 m. Annual precipitation is approximately 55 inches, mostly in the form of snow, and mean temperatures range from approximately -11^{o}C in January to 15^{o}C in July (Western Regional Climate Center 2004). Soils in much of the area are formed on glaciofluvial outwash formed from rhyolite (Rodman et al. 1996). These soils are typically low in nutrients, coarse textured and very well drained, and susceptible to drought.

Biological communities in the area are dominated by lodgepole pine (*Pinus contortus*) forests and semiarid big sagebrush (*Artemisia tridentata*) shrublands. These communities are susceptible to large, catastrophic fires that occur at least every 300 to 600 years (Despain 1990). Riparian communities of willow and sedge occupy lower lying areas along river corridors.

Since the late 1800's, the area has been heavily disturbed by activities such as grazing, logging, and transportation, which have facilitated the introduction of many weeds including *L. vulgaris* (Olliff et al. 2001). Intensive logging from the 1970's to early 1990's has disturbed much of the forested area.

Management goals for the District are multiple and varied. An overarching goal is to protect native plants and animals and provide habitat for fish and wildlife, including several salmonid species, black and grizzly bears, mule deer, elk and numerous songbirds and raptors. Rare species, including Indian Paintbrush (*Castilleja spp.*), are also being protected within the District. In addition to managing for wildlife habitat and rare plants, the District is managed for commercial or extractive uses. Timber sales can occur in any of the forested areas, and there are grazing allotments for cattle in much of the District. Finally the area is managed for recreation, including fishing, hunting, snowmobiling and cross country skiing.

B. How *L. vulgaris* Threatens Targets and Interfere with Management Goals

L. vulgaris is a persistent, aggressive invader of disturbed lands. It has an extensive root system, and once established, forms dense colonies through clonal, vegetative growth. These colonies are known to be problematic in agricultural settings (Saner et al. 1995), but their effects on wildland communities are not well documented. It is believed that native species diversity is reduced in *L. vulgaris* patches. Also, *L. vulgaris* is in the same family (Schrophulariaceae) as the rare *Castilleja* species that are present in the management area and may compete with them (Susan Lamont, USDA Forest Service, West Yellowstone, personal communication).

Additionally, *L. vulgaris* patches may present a problem in burned or clearcut areas by limiting *P. contortus* recruitment through competition with seedlings for resources. Such competition would greatly slow the regrowth of forests in infested areas, thereby limiting the value of future timber sales.

The presence of *L. vulgaris* in grazing allotments may interfere with cattle grazing. Saner et al. (1995) report that cattle avoid eating the plants because they contain glycosides (in stems and leaves), flavonoids (in flowers), and saporing (in seeds). Lajeunesse (1999) reported that *L. vulgaris* evolved in communities that were moderately to intensely grazed, and the cattle may occasionally browse flowering shoots of the plant. In either case, cattle do not use the plant as a major food source, and heavily infested areas may not be suitable for cattle grazing, especially if native vegetation or preferred forage species are limited because of displacement by *L. vulgaris*.

It is unknown whether or not herbivorous wildlife such as deer and elk consume the plant, but it is reasonable to assume that it is not a major part of their diet because of the chemicals mentioned above, and it could possibly limit grazing or browsing opportunities through competitive exclusion of preferred species.

The presence of *L. vulgaris* should not interfere with recreational uses such as skiing, snowmobiling or fishing. Dense infestations of the plant could potentially interfere with hunting, however, if deer and elk do not use the area because of decreased food supply.

C. Philosophy of Invasive Species Assessment and Subsequent Adaptive Management

Management of invasive species generally proves to be very difficult because biological systems are unpredictable. Species, both those desired and the ones being managed, often do not behave as they are expected under a particular management regime. Because of this unpredictability, management plans must be flexible and managers must be willing to redefine goals and alter management techniques as conditions change. An adaptive management philosophy is required where an emphasis is placed on gathering information about the invasive species and adjusting management practices in response to this new information. This Weed Management Plan will use adaptive management by relying heavily on information gathered during monitoring phases, both before and after implementation of any management controls. Initial monitoring will include an inventory of *L. vulgaris* locations, assessment of the invasiveness of the plant, and assessment of its impacts. Not until this information is obtained, and management alternatives are evaluated, will management begin. After implementation of management, this information will be updated regularly (at least annually), and the success of the management strategy will be assessed. At this point it will also be important to assess how the management practices are affecting the stated goals (e.g., Has a management practice such as herbicide treatment exacerbated the problem of limited *P. contorta* recruitment?). Information gathered during this assessment phase will be used to change management practices if deemed necessary.

2.0 Inventory / Survey of Non-Indigenous Species

A study was conducted by Pauchard et al. (2003) in the summer of 2001 to locate existing *L. vulgaris* patches. Additionally, patches have been identified by Hebgen Lake Ranger District weed crews. Positions and sizes of these known patches have been recorded with a Trimble GeoExplorer GPS and are shown on Figure 1.

In the Pauchard et al. (2003) study, regions of patch clusters were reportedly "searched systematically" to identify patch locations, but the exact procedure used to locate patches is unknown. Patches located by weed crews are found along major road corridors where extensive weed inventory and control operations have occurred. As shown in Figure 1, there are vast areas away from the road corridors that do not have known patches. The lack of known patch locations in these areas may be the result of an inadequate survey rather than the absence of the species.

Because of uncertainty in the existence of *L. vulgaris* patches throughout much of the management area, additional survey work needs to be conducted. The survey will focus on areas where *L. vulgaris* is most likely to occur, including old clearcuts, old burn areas, roadsides, river corridors and sagebrush flats (Pauchard et al. 2003). Transects will be stratified along these types of areas and randomly located within each. [Note: While transects will be randomly located, the locations of transects that extend across roads will be biased away from areas of heavy forest cover since these areas have been shown to not support *L. vulgaris.* Rather, road transects will be located such that they extend into more open areas.] The transects will be walked along and *L. vulgaris* patch locations within 10 meters of either side of the transect will be marked via GPS. Each time a *L. vulgaris* patch is marked, additional information including slope, aspect, type of disturbance (if any) and habitat type will be recorded in the GPS unit. Also, changes in habitat type along the transect will be noted by recording a GPS location at the point of change. Finally, the survey transects will also be used to record the locations of any

Castilleja species that are identified to aid managers in understanding the distribution of these plants throughout the management area.

A total of 50 transects will be placed throughout the management area. The length of each transect will vary depending upon its location. Transects that are located in burn areas or clearcuts will begin 100 meters before the targeted area, extend through the area, and finish 100 meters on the other side. Transects that intersect roads or waterways will extend 250 meters on either side of the road or waterway. Within sagebrush flats areas, transects will be 500 m in length or, for smaller areas, the length of the sagebrush flat. Finally, 500 m long transects will be randomly located within remote areas that are not expected to have *L. vulgaris* populations. The following table provides a summary of the number and lengths of transects in each type of area.

Table 1. Location, length and number of transects.

Location	**Length**	**Number**
Clearcut	length of clearcut + 100 m on each end	10
Burn	length of clearcut + 100 m on each end	10
Road	250 m before and after road	15
Waterway	250 m before and after waterway	5
Sagebrush Flats	500 m or length of flat (whichever is smaller)	5
Remote	500 m	5

These transects are not intended to locate all of the *L. vulgaris* patches within the management area. Rather, the intentions are to locate additional patches for monitoring, provide a better understanding of the plant's distribution, and to collect data that will be used in the creation of distribution probability maps for *L. vulgaris*. To generate these maps, data including disturbance type, distance from road, habitat type, slope, aspect, elevation, and presence or absence of *L. vulgaris* will be analyzed through regression equations to determine the probability of the weeds occurrence throughout the management area.

Each transect will be walked yearly to look for new *L. vulgaris* patches, and any new patches identified will be marked via GPS. New patches will include not only patches where none were present before, but also any colonies that may have started from seed dispersed from adjacent known patches. Measurements of density will be conducted in the fall of each year and compared to previous results to determine if the density is increasing, decreasing, or remaining constant in the different patch positions (interior, edge and outside). Likewise, patch area will be calculated each fall using the TMR8 method to evaluate changes in overall patch area.

3.0 NIS Assessment for Invasiveness (Monitoring)

Many non-indigenous species (NIS) are routinely called invasive, even though there may be little or no evidence that they are consistently increasing in density or spatial extent. A research study may show that a given species is invasive under a certain set of geographical and climatic conditions, but this same species may not be invasive in a different geographic setting or under the influence of different weather patterns. With limited resources, in terms of manpower, time, and funds, it is crucial to assess which species and individual populations are actually invasive in the management area, and then prioritize populations for management.

A. Prioritization of Species to be Monitored

While this Weed Management Plan is specifically for *L. vulgaris*, managers in the District are concerned with many other weed species. Therefore, *L. vulgaris* must be considered a part of the overall plan for managing weeds in the District. To determine the importance of managing this species relative to others, all weed species present in the District must be prioritized to determine which merit the most immediate attention and which are of lesser concern. This prioritization should be based on the invasiveness of each species with respect to certain aspects of its biology, ecology and management potential. Specifically, the prioritization should include (1) impacts on native species, habitats, and ecosystems, (2) biological characteristics and dispersal potential, (3) distribution and abundance in the management area, and (4) difficulty of control (Heffernan et al. 2001). Species prioritization is beyond the scope of this *L. vulgaris* Management Plan, and will not be covered herein.

B. Where, When, and Under What Circumstances is *L. vulgaris* Likely to be Invasive

For a NIS to be invasive, it has to be consistently increasing in density or spatial extent. The invasiveness of *L. vulgaris* in the management area has not been thoroughly assessed, but within at least some of the area, patches of the species have been shown to not meet this definition of invasiveness. They are reported to be in equilibrium or declining in density over the past several years (Repath 2004, unpublished data). Data from other regions show that *L. vulgaris* can establish and spread rapidly in disturbed areas such as roadsides, fencelines, clearcuts and pastures (Lajeunesse 1999), and in undisturbed but sparsely vegetated areas including bunchgrass communities, sagebrush communities, open coniferous forests and riparian areas (Allen and Hansen 1999 and Pyke 2000). Invasion by *L. dalmatica*, a close relative of *L. vulgaris*, has been shown to be facilitated by repeated grazing and herbicide applications (Rice and Randall 2003). In Europe, large populations of *L. vulgaris* have been observed in fields where competing vegetation had been suppressed by grazing or fire (Saner et al. 1995).

While patches of *L. vulgaris* have the ability to expand rapidly through vegetative growth (Saner et al. 1995), dispersal distance of seeds is limited. Nadeau and King (1991) report that 92 % of seeds fall within 50 cm of plant indicating that the winged seeds of *L. vulgaris* are not as efficient for long-distance dispersal as are seeds with pappi. Thus, populations of this species are often completely absent from natural communities and rarely occur away from its point of introduction (Saner et al. 1995).

From this information, the most likely places for *L. vulgaris* to occur in the management area are sagebrush communities, riparian areas, burn areas, clearcuts and along roadways. These types of areas that have also been grazed by livestock may be especially vulnerable.

C. Methods for Monitoring Invasiveness

To assess whether populations of *L. vulgaris* are invasive, a sample of existing patches will be selected for monitoring. Five patches from each type of area (clearcut, burn, road, waterway, riparian, and remote), as described in Section 2, will be monitored to determine whether or not the species is increasing in density or spreading in spatial extent.

Density will be evaluated using six permanent monitoring plots for each patch. The plots will include two sets of paired (edge of patch and outside of patch) plots and 2 plots within the interior of the patch. All sampling plots will be 1 m^2. *L. vulgaris* density for each plot will be recorded twice yearly (spring and fall) as the total number of stems within the plot. The growth rate (λ) of *L. vulgaris* can then be calculated as the number of stems at time t+1 divided by the number of stems at time t. That is: $\lambda = N_{t+1}/N_t$. A $\lambda > 1.0$ indicates a population that is increasing in density, whereas a λ of more than 0 and less than 1 indicates a population that is declining, and $\lambda = 1.0$ indicated the populations is in equilibrium.

Increase in spatial extent will be determined by calculating patch area in the spring and fall of each year. The area of each patch will be calculated using the TMR8 method as described in Appendix 4. Area measurements for individual patches over time can be compared, and if patches are consistently increasing in spatial extent, then the population can be considered invasive.

4. NIS Assessment for Impact (Monitoring)

As previously discussed, not all NIS are invasive. Similarly, not all NIS have an impact on the ecosystem, and those that do may have different degrees of impact under different environmental conditions. For example, a species could fill unoccupied gaps in a grassland and have no effect on the ecosystem structure or function other than to increase species richness. This same species may greatly reduce plant diversity in a sagebrush community, but have little impact in terms of biodiversity in a riparian area. Therefore, before management of any *L. vulgaris* populations, it will be important to assess their impact and then prioritize management to those populations having the greatest impact. Knowledge of the invasiveness (Section 3) and the impact of *L. vulgaris* populations, combined with the management goals for the area, can be used to tailor management practices to meets specific goals. For example, if *L. vulgaris* is present in mature *P. contorta* forests that are managed for timber sales, and the weed has no negative impact on timber production, then management in this setting is not necessary. Conversely, if *L. vulgaris* is present in grazing areas, and its presence limits usage by cattle, then it should be controlled to help meet the management goal.

A. Where, When, and Under What Circumstances is *L. vulgaris* Likely to Have Impact

Information regarding *L. vulgaris* impact in natural settings is limited. It has been shown, however, that its seedlings are poor competitors with established perennials and winter annuals (Morishita 1991). Once established though, toadflax can provide intense competition for limited soil water, and mature plants are very competitive with winter annuals and shallow-rooted perennials (Robocker 1974).

More information on the impact of *L. vulgaris* is available for agricultural or rangeland settings. Robocker (1974) reported that toadflax free plots in a rangeland habitat produced 2.5 time more grass seed than plots with *L. vulgaris* present. A study in Alberta, Canada showed that *L. vulgaris* densities greater than 180 stems/m^2 reduced seed yields of some forage crops by 33%

(Saner et al. 1995). It is also reported that *L. vulgaris* may inhibit cattle grazing because it is unpalatable and possibly mildly poisonous (Mitich 1993 and Lajeunesse 1999). These findings, however, are somewhat disputed by reports that cattle will occasionally browse the flowering shoots of toadflax (Lajeunesse 1999).

None of these studies provide firm evidence to indicate that *L. vulgaris* will have impacts on all communities that it may inhabit. Rather, the data indicates that impacts are widely varied and therefore not consistent between different types of areas or land.

B. Methods for Monitoring Impact

Impact of *L. vulgaris* on the ecosystem will be monitored using the 1 m^2 sampling plots described in part 3B above. Because effects of *L. vulgaris* on particulars such as health of grazing animals or native plant seed production would be difficult and expensive to quantify, the simple parameters of native plant richness and diversity will be used to quantify impact. Richness is the total number of species recorded in the plot. Diversity, or evenness, will be calculated as the relative species abundance determined by percent cover of each species within the plots. Measurements of total species present and each species' percent cover in each plot will be recorded in the spring and fall of every year. The Inverse Simpson's Diversity index will be used to calculate diversity. Procedures for this calculation are included in Appendix 5. *L. vulgaris* may be considered to be having an impact in populations that show declines in species richness or diversity over time, provided *L. vulgaris* is present and increasing in percent cover in the plots measured.

5. Overview of Weed Management

Weed management in the Hebgen Lake Ranger District will rely on adaptive management, where information on *L. vulgaris* invasiveness and impact will be continually updated, and this information used to make management decisions, including changing the current management practices if necessary. Because of the inherent unpredictability and high variability of plant response to management techniques such as herbicide spraying, the information gathered during monitoring will be crucial in determining the effectiveness of management activities in reaching the goals for the District. Additionally, before full scale treatments are initiated in areas where deemed necessary, it will be very important to conduct test treatments to examine the effectiveness of the treatment methods employed. These test treatments can be conducted on 1 m^2 plots established expressly for this purpose. Control plots (no treatment) for comparison purposes will also be needed in this assessment. Managers must be willing to change their proposed strategies based on the results of the test treatments before any management begins, as well as adapting management in response to results from monitoring after treatments begin.

6. Specific Weed Control Methods

After completion of assessments for *L. vulgaris* invasiveness and impact, it may be determined that the species should be controlled in certain locations in order to meet the management goals. Management of *L. vulgaris* can be achieved in several ways including hand pulling, grazing with sheep, biological control with any of several species of insects, and chemical control via herbicide.

Hand pulling can be effective for small infestations in sandy soils or when soils are moist. Care must be taken to remove as much of the lateral root system as possible, and pulling for five to six years is needed to deplete the reserves of the remaining root system. The area must be revisited periodically for 10 to 15 years to remove seedlings produced from dormant seeds (Lajeunesse 1999).

Grazing by sheep may be a viable option for *L. vulgaris* control in areas that are not cattle grazing allotments. Field trials in Montana have shown that sheep can help suppress stands of *L. dalmatica* and limit seed production (Lajeunesse 1999) although information is not available for *L. vulgaris*.

Biological control agents that have been released to control *L. dalmatica* include a defoliating moth (*Calophasia lunula*), an ovary-feeding beetle (*Brachypterolus pulicarius*), a stem-boring weevil (*Mecinus janthinus*), a root-boring moth (*Eteobalea intermediella*), and two seed capsule-feeding weevils (*Gymnaetron antirrhini* and *Gymnaetron netum*) (Lajeunesse 1999). All of these species also attack *L. vulgaris* (Saner 1991). At least one species of seed capsule-feeding weevil is present in *L. vulgaris* patches in the management area, and these weevils may be able to control or slow the spread of the weed by limiting seed production.

The effectiveness of herbicides in controlling L. vulgaris is quite variable, at least partly because of high genetic variability within the species (Lajeunesse 1999). Moderately successful control has been reported in the management area using Picloram (Tordon-K) at a rate of 1 lb ai/ac (Lamont 2004, personal communication). Re-application of herbicide is needed every three or four years for up to 12 years for complete eradication (Lajeunesse).

The specific control measures to be used will depend on the patch characteristics and the management goals for the infested area. Hand pulling may be effective in small areas, but is not a reasonable approach to managing large, well established patches. Herbicide application should not be used in areas where the management goal is to reestablish *P. contorta* stands after wildfire or timber harvest because this herbicide will hinder tree growth. Herbicide should also not be used in areas that contain species of *Castilleja* for risk of damaging these rare plants. Application of herbicide would, however, be appropriate in areas that are managed for cattle grazing, provided the treatment is scheduled to avoid times when cattle are using the areas. For maximum effectiveness, herbicide use should be concentrated at the time of plant flowering when carbohydrate reserves are at their lowest. The use of sheep to control *L. vulgaris* should generally not be conducted in cattle grazing allotments because they may consume forage that is valuable for the cattle. Sheep could, however, be used in the grazing allotments after cattle have been removed. Sheep could also be used to control *L. vulgaris* in areas that are managed for timber harvest because the sheep would not affect growth of the trees. Biological control agents are appropriate for use in all of the management area. Patches of *L. vulgaris* that do not currently have populations of biological control insects can have such insects introduced from nearby patches.

Table 2: Weed Management Plan Implementation Schedule

Item	Schedule
Transect Survey	Annually (fall)
Plot Monitoring	Semi-annually (spring and fall)
Weed Treatment	To Be Determined
Re-evaluate Management Methods	Annually After Initiating Treatment

Table 3: Projected Resource Costs

Item	Cost
Transect Survey	
Weed Probability Distribution Map Development	
Semi-annual Plot Monitoring	
Hand Pulling of *L. vulgaris* (labor)	
Biological Control (insects + labor)	
Sheep Grazing (sheep + labor)	
Herbicide (chemical + labor)	

Table 4: Itemized Actual Annual Cost and Labor Worksheets

To be determined after completion of Table 3.

Table 5: Projected and Actual Resource Uses

To be determined after completion of Table 3.

Literature Cited

Allen, Karen; Hansen, Katherine. 1999. Geography of exotic plants adjacent to campgrounds, Yellowstone National Park, USA. The Great Basin Naturalist. 59(4): 315-322.

Despain, D.G. 1990. Yellowstone vegetation. Roberts Rinehart Publishers, Boulder, CO.

Heffernan, K.E., P.P. Coulling, J.F. Townsend, and C.J. Hutto. 2001. Ranking Invasive Exotic Plant Species in Virginia. Natural Heritage Technical Report 01-13. Virginia Department of Conservation and Recreation, Division of Natural Heritage, Richmond, Virginia. 27 pp. plus appendices.

Lajeunesse, S. 1999. Dalmation and Yellow Toadflax. Pages 202-216 in R.L. Sheley and H.K. Petroff, editors, Biology and Management of Noxious Rangeland Weeds. Oregon State University Press, Corvallis.

Mitich, Larry W. 1993. Yellow toadflax. Weed Technology. 7(3): 791-793.

Morishita, D.W. 1991. Dalmatian toadflax, yellow toadflax, black henbane, and tansymustard: importance, distribution, and control. Pages 399-408 In: L.F. James, J.O. Evans, M.H. Ralphs, and R.D. Child (editors) Noxious range weeds. Westview Press, Boulder, San Francisco and Oxford.

Nadeau, Leonie B.; King, Jane R. 1991. Seed dispersal and seedling establishment of Linaria vulgaris Mill. Canadian Journal of Plant Science. 71(3): 771-782.

Olliff, T.T., C. McClure, P. Miller, D. Price, D. Reinhart, and J. Whipple. 2001. Managing a complex exotic vegetation program in Yellowstone National Park. Western North American Naturalist. 61:347-358.

Pauchard, Anibal, Alaback, Paul B., Edlund, Eric G. 2003. Plant Invasions in Protected Areas at Multiple Scales: Linaria Vulgaris (Scrophulariaceae) in the West Yellowstone Area. Western North American Naturalist. 63(4): 416-428.

Pyke, David A. 2000. Invasive exotic plants in sagebrush ecosystems of the Intermountain West. In: Entwistle, P. G.; DeBolt, A. M.; Kaltenecker, J. H.; Steenhof, K., compilers. Sagebrush steppe ecosystems symposium: Proceedings; 1999 June 21-23; Boise, ID. Publ. No. BLM/ID/PT-001001+1150. Boise, ID: U.S. Department of the Interior, Bureau of Land Management, Boise State Office: 43-44.

Rice, Barry Meyers; John, Randall, compilers. 2003. Weed report: Linaria vulgaris--common toadflax. In: Wildland weeds management and research: 1998-99 weed survey.

Davis, CA: The Nature Conservancy, Wildland Invasive Species Program. 2 p. On file with: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT.

Robocker, W.C. 1974. Life history, ecology, and control of dalmatian toadflax. Technical Bulletin No. 79. Washington Agricultural Experiment Station.

Rodman, A., H.F. Shovic, and D. Thomas. 1996. Soils of Yellowstone National Park. Yellowstone Center for Resources, Yellowstone National Park, Wyoming.

Saner, M.A., D.R. Clements, M.R. Hall, D.J. Doohan, and C.W. Crompton. 1995. The Biology of Canadian Weeds. 105: Linaria vulgaris Mill. Canadian Journal of Plant Science. 75:525-537.

Western Regional Climate Center. 2004. West Yellowstone climate summary. Retrieved on 9/29/04 from http://www.wrcc.dri.edu/.

Appendix 1.
Emergency Information/Map to Hospitals

Appendix 2.
Blank Maps/Sample Maps

Appendix 3.
Examples of Forms Used in Collecting Monitoring Data

Appendix 4.

TMR8 Method for Calculating Patch Area

Rules for making Field Measurements for the TMR4 and TMR8 Methods:

1. Upon inspecting a patch and finding its borders, run a tape measure line across the longest possible axis of the patch and mark the midpoint with a road hair.
The edge of a patch is the base of the outermost plant in the direction of the radii.
A plant is considered to be in a patch only if it is < 2.0 m from the nearest plant of the same species that is considered to be in the patch.

2. Using a compass while standing over the center point (roadhair), record the azimuth (Az1)and the length of the first radii (r1) looking out toward the edge of the patch. Turn and record the azimuth (Az2) and length of radii two (r2) along the longest axis (Az2 = Az1 + 180). All radii will be measured in m to the 0.01 m.

3. At approximately 90^o to the first two radii place a third radii from the center point to the patch edge. Measure the length of the r3 and record its azimuth (Az3). Radii 3 should always be clock wise from r1 so that Az3 > Az1 unless Az1 is between 270^o and 360^o then Az1 > Az3.

4. The fourth radii should then be placed approximately 180^o from r3 and the azimuth (Az4) and length (r4) recorded.

5. The fifth radii (r5) is established to split the patch to the edge between r1 and r3 and r6 is oriented 180^o from r5 to split r2 and r4. In each case the radii length is measured and the azimuth from center to edge is recorded.

6. The r7 and r8 radii are oriented to split r3 and r2, and r4 and r1, respectively.

Calculate Area as follows:

A = pi * r1(r3+r4+r5+r6+r7+r8)/6   where pi = 3.14159 and r1...r8 are the radii.

Appendix 5.

Inverse Simpson's Diversity Index

Diversity = D = 1 / 3 p_i^2

where p_i = the % cover of individuals of the *i*th species

Percent cover values must be entered as decimals (i.e., 63% = 0.63) Higher values indicate a greater diversity.

Examples: 1. 5 species identified in plot.

Spp. 1 = 68 % cover
Spp. 2 = 9 % cover
Spp. 3 = 13 % cover
Spp. 4 = 1 % cover
Spp. 5 = 3 % cover

$D = 1 / [.68^2 + .9^2 + .13^2 + .01^2 + .03^2] = 2.0475$ This indicates low diversity.

2. 5 species identified in plot.

Spp. 1 = 21 % cover
Spp. 2 = 15 % cover
Spp. 3 = 20 % cover
Spp. 4 = 16 % cover
Spp. 5 = 19% cover

$D = 1 / [.21^2 + .15^2 + .20^2 + .16^2 + .19^2] = 5.9418$ This indicates high diversity.

Appendix 6.

Herbicide Use Protocol

Appendix 7.

Herbicide Use Record Forms

Appendix 8.

Herbicide Label