1 PROJECT SUMMARY

Integrated Restoration Strategies Towards Weed Control On Western Rangelands

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Although cheatgrass (*Bromus tectorum*) has been widely distributed across western rangelands for >70 years, the full ecologic and economic impacts of this non-native invasive plant have not yet occurred. Unfortunately, several independent lines of evidence indicate that the rate at which acreage becomes infested with cheatgrass is increasing rapidly. Furthermore, the invasion and spread of a number of emerging secondary weeds is coincident with cheatgrass infestation. Thus to control the spread of these secondary weeds, we must first control cheatgrass. Competitiveness and prolific seed production allow cheatgrass to invade both disturbed and intact native communities and to dominate after wildfire. Thus, efforts to control cheatgrass need to focus on these biological characteristics while simultaneously restoring native plants on Great Basin rangelands.

Our overall goal is to identify concepts and management strategies to control the spreading dominance of cheatgrass and other weeds on Great Basin rangelands and to restore native species and increase biodiversity. Our primary focus will be cheatgrass because it is the most widespread and damaging invasive weed, but we will also examine the extent that secondary weeds complicate cheatgrass control and native species restoration efforts. Supporting objectives are:

1. Conduct a series of common experiments across the Great Basin that test management techniques for controlling cheatgrass and other weeds, establishing native plant communities, and restoring ecosystem structure and function while reducing the cost of restoration.
2. Provide an ecological understanding of why restoration techniques succeed or fail.
3. Develop conceptual and economic bases for choosing appropriate management techniques.
4. Use partnerships among governmental agencies, universities, cooperative extension, and land managers to convey knowledge to ranchers and other professionals.
5. Use partnerships with educators to increase student and public awareness of invasive species issues and to develop educational tools that convey solutions to invasive species and native plant restoration problems.

By combining expertise and sharing resources, our multi-state, interdisciplinary consortium of research, education, extension, and agency personnel is poised to identify ecological principles and fundamental knowledge needed to manage invasive weeds and facilitate native plant restoration on Great Basin rangelands. We also plan an active program to disseminate that knowledge to managers and users of Great Basin rangelands.

The lead institution for this consortium, University of Nevada Reno, is eligible for small and mid-sized consideration.

2 RESPONSE TO PREVIOUS REVIEW

The IFAFS panel ranked last year's submitted proposal as "outstanding", *i.e.* in the top 9% of all proposals considered by the panel. Most of the panel's and reviewers' comments were laudatory, and we have retained (and in most cases strengthened) the positive aspects of the previous proposal. These **positive** comments included: thorough approach, excellent experimental design, well designed project management, applicability to a major problem covering a large area, and strong integration of research, extension, and education activities.

Negative comments from the panel and reviewer were:

1. "experiments difficult to carry out" — We recognize that our experiments are difficult and technically challenging, but most of us (key personnel and collaborators) <u>each</u> have >15 years of experience doing these types of studies. Given our publication records, we have clearly demonstrated the ability to carry out these experiments. Nonetheless, to help clarify our experiments, we have added some additional details in this year's proposal.
2. "project not on very productive lands" — Although rangelands are not as productive in a economic market context as crop lands, rangelands have a number of other uses such as recreation, wildlife habitat, aesthetics, and conservation. Furthermore, rangelands in general cover ~35% of the U.S. land surface, and the area targeted by our studies covers >100 million acres, *i.e.* most of 4 western states and portions of 5 other states. Wildfires on rangelands also have negative impacts on the social and economic frameworks of these states. Unless we control the invasive weeds and restore native vegetation, rangelands will lose almost all economic, recreation, aesthetic, and conservation value, and the negative impacts of wildlife will grow. Thus, our results truly have large economic and social impacts.
3. "rather pricey" — We have reduced our request funding by ~30%. We accomplished this reduction largely by reducing the number of study areas from 8 last year to 6 this year.

3 PROJECT DESCRIPTION
Integrated Restoration Strategies Towards Weed Control On Western Rangelands

3.1 Introduction

Cheatgrass (*Bromus tectorum* L.) is an invasive annual grass that dominates almost 2.9 million acres of BLM land in the Great Basin **(Fig.** 1 – red areas; Pellant & Hall 1994). Cheatgrass has greatly altered the community and fire dynamics of Great Basin rangelands by increasing the fine fuel needed to carry frequent fires (Billings 1990). If present in a community, cheatgrass usually remains a part of the herbaceous layer until a fire occurs, after which it expands its dominance by replacing fire-sensitive native shrubs and by competing successfully with grasses (Young *et al*. 1987). Thus, fire facilitates the conversion of rangelands from a perennial-dominated to an annual-dominated system (Billings 1990, Young & Evans 1973, Young *et al*. 1987). Once converted, these cheatgrass-dominated sites reduce suitable habitats for many wildlife species, accelerate erosion, provide an unpredictable forage supply for livestock, and lower the economic value for ranchers. Furthermore, secondary weeds are beginning to emerge as significant components in cheatgrass-dominated lands. For example, knapweeds (*Centaurea* spp.) now have a stronghold in central Utah and in west-central Oregon and are rapidly expanding in central Nevada; rush skeleton weed (*Chondrilla juncea* L.) is advancing in southern Idaho; and yellow starthistle (*Centaurea solstitialis* L.) is invading western Nevada, northern Idaho, and northeastern Oregon. **Thus, to decrease the ecologic and economic impacts of these invasive weeds, we need to break the cheatgrass-induced fire cycle by restoring Great Basin rangelands with a diverse, native plant community.**

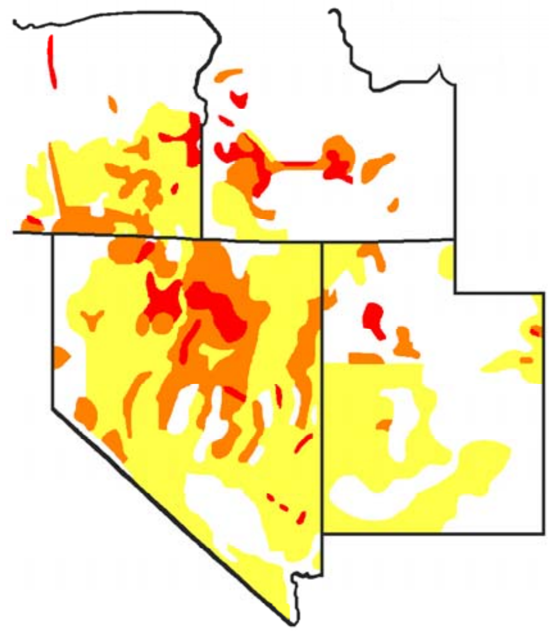


Figure 1. Extent that 2 annual weeds, cheatgrass and medusahead, dominate (red), are invading (orange), or potentially will dominate (yellow) Great Basin rangelands. Location of study areas for this proposal are: 1= Northern Great Basin Expt. Range, OR; 2=Boise, ID; 3= Winnemucca, NV; 4=Gund Ranch, NV; 5=Curlew Valley, UT; 6=Skull Valley, UT.

Although cheatgrass has been present in much of the Great Basin for ~70 years (Mack 1986), its full ecologic and economic impact has yet to be fully realized. First, almost 14 million acres of BLM lands in the Great Basin are currently undergoing a transition to cheatgrass dominance (**Fig. 1** – orange areas), with another 62 million acres susceptible to becoming dominated by this exotic weed (**Fig. 1** – yellow areas). Second, the impacts of cheatgrass are rapidly becoming more acute. For example, historical and paleoecological evidence indicate that acreage burned each year is increasing (Tausch *et al*. 1993, Gruell 1999), and dominance by this exotic annual grass fueled over 70% of the large fires (>5000 acres) in the Great Basin from 1980-1995 (Knapp 1998). Finally, the greater responses of exotic annual grasses to increased atmospheric CO_2 suggest that invasions will only worsen in the future if the system is left unmanaged (Smith *et al*. 2000).

Two biological features contribute to the remarkable success of cheatgrass (Smith *et al*. 1997): prolific seed production and high competitive ability. Seed production by cheatgrass can be 10-100 times greater on burned sites in the first year after fire, and although population density may be relatively small during this first year after a fire, field and modeling studies demonstrate that cheatgrass populations have an 80-90% risk of exploding to densities near 10,000 plants m^{-2} within 10 years (Young & Evans 1978; Pyke 1995). Cheatgrass competes with native species for soil water and negatively affects the water status and productivity of established perennial plants, and the reduced productivity and greater water stress experienced by the native perennials persist for at least 12 years after fire (Melgoza *et al.* 1990). Greater root elongation at low soil temperatures (Harris 1967) as well as competitive displacement of root systems (Melgoza & Nowak 1991) are mechanisms for cheatgrass to compete for limited soil resources. **Thus, strategies to enhance the restoration of Great Basin rangeland must destabilize the cheatgrass dominance by reducing the abundance of cheatgrass seed followed by establishing species that are competitive with cheatgrass.**

The **Overall Goal** of our consortium is to identify the necessary concepts and management strategies to control the spreading dominance of cheatgrass and other weeds on Great Basin rangelands and to restore native species and increase biodiversity. Our **Primary Focus** will be cheatgrass because it is the most widespread and damaging invasive weed. But given that cheatgrass appears to facilitate invasion of secondary weeds, we will also examine the extent that these secondary weeds complicate cheatgrass control and native species restoration efforts. **Supporting Objectives** are:

1. Conduct a series of common experiments across the Great Basin that are designed to test management techniques for controlling cheatgrass and other weeds, establishing native plant communities, and restoring ecosystem structure and function while reducing the high cost of current restoration efforts.
2. Provide a sound ecological understanding of why cheatgrass control and native species restoration techniques succeed or fail.
3. Develop conceptual and economic bases for choosing appropriate management techniques for the range of conditions that exist within the Great Basin.
4. Use active partnerships among governmental agencies, universities, cooperative extension, and land managers to convey knowledge of the processes, techniques, and results to ranchers and other rangeland professionals.
5. Use partnerships with educators to increase student and public awareness of invasive species issues and to develop educational tools that convey solutions to invasive species and native plant restoration problems.

Accomplishing these objectives provides solutions for the management of all lands in the Great Basin regardless of ownership.

Our integrated approach to restoration and weed control addresses 4 of the 5 key areas of the Non-native Invasive Species Program Area of the IFAFS 2001 RFP. Clearly we cannot prevent the introduction of cheatgrass and other invasive weeds (Area #1), but by obtaining the necessary information to restore native species and break the fire cycle, our studies will help prevent, and even reverse, the spreading dominance of cheatgrass and secondary weeds (Area #2). Second, results from our program will provide knowledge about successful management responses to weed invasions (Area #3). This knowledge includes not only what is feasible (*e.g.* what treatments, what plants, etc.), but also when it may be feasible (*i.e.* including areas in varying stages of weed invasion will allow us to identify the conditions that facilitate or limit reestablishment of native species). Third, our field experiments provide well-described systems to monitor long-term success (Area #4), and finally, the concurrent ecologic and economic studies will quantify the impacts of species control (Area #5).

3.2 Approach

3.2.1 Overall experimental design

To achieve our objectives, we will implement 2 core experiments that include a series of ecological process studies (*i.e.* population ecology, community ecology, etc.) and are complemented by economic assessments, educational development, and outreach initiatives. The 2 experiments will be replicated across a 4-state area that encompasses the range of environmental conditions typical for rangelands prone to cheatgrass invasion. Both experiments use a split-plot experimental design with the main plot factor as weed abundance, with weed abundance varying from: 1) diverse native vegetation with low cheatgrass abundance in the understory; to 2) cheatgrass as the dominant species but few secondary weeds; and 3) cheatgrass dominant and active invasion by secondary weeds.

Although typical species for restoration are exotic bunchgrasses such as the crested wheatgrasses *Agropyron cristatum* and *A. desertorum* (Keller 1979, Johnson 1986), exotic grasses are not a universal solution to rangeland restoration. Pressure is growing to restore native perennials because of aesthetic, recreational, and conservation values and because native rangelands provide benefits to livestock and wildlife that monospecific stands of exotics cannot (DePuit 1986, Richards et al. 1997, Roundy et al. 1997). Unfortunately, early trials with native species were largely unsuccessful, and thus little subsequent research focused on natives – despite a growing awareness that native species restoration can succeed (Roundy et al. 1997). For example, natives such as bottlebrush squirreltail (*Elymus elymoides*) have successfully invaded and suppressed annual weeds (e.g., Hironaka & Tisdale 1963, Hironaka & Sindelar 1973, Pyke & Borman 1993, Monsen 1994). Thus, we will concentrate our restoration efforts on native species.

Restoration is often described as directing the successional trajectory towards some pre-disturbance species assemblage and some prior level of ecosystem structure and function (Luken 1990; Aronson *et al*. 1993). But successional trajectories are seldom linear, and multiple alternative states exist for any given ecosystem type (Laycock 1991; Chambers 2000). From both the land management and restoration perspective, the state-threshold concept is an important underlying principle (Westoby *et al* 1989, Chambers 2000), *i.e.* alternative vegetative states exist on the landscape, with some of these states separated by abiotic or biotic thresholds. A critical aspect in defining thresholds that exist between target states is to quantify the abiotic and biotic ecosystem variables that separate them. For the sagebrush-steppe in the Great Basin, the influence of precipitation and available soil nitrogen on the competitiveness and abundance of cheatgrass appear to be defining thresholds.

The influence of annual species such as cheatgrass on perennial species appears to be smaller during wet years (Harris 1967; Stewart & Hall 1949). One factor that underlies this precipitation influence may be competition for spring moisture. For example, greater depletion of soil moisture in shallow soil layers was evident in early spring with cheatgrass competition (Melgoza *et al*. 1990), and the conversion of oak woodlands to annual grasslands in California results in less soil moisture available in the spring (Gerlach 2000). Although our experiments are not designed to test directly for the influence of varying water availability on competitive interactions (*i.e.* we do not impose irrigation or rain-out treatments), selection of replicate sites in areas with different mean annual precipitation coupled with repetition of experiments in a second year allow us to indirectly assess effects of variation in water availability.

Recent field studies have shown the importance of available inorganic nitrogen in controlling cheatgrass establishment (McLendon and Redente, 1991; Young *et al*., 1999), and cheatgrass invasion rapidly alters nitrogen cycling (Evans *et al*. 2001). Cheatgrass tends to thrive in a high nitrogen environment but is inhibited in a low one (McLendon & Redente 1991; Redente *et al*. 1992; Young & Allen 1997; Young *et al*. 1999). Application of sucrose, which causes microbial uptake of inorganic nitrogen, reduces cheatgrass density. Conversely, addition of inorganic nitrogen can encourage establishment in non-invaded areas and dramatically increase cheatgrass density and competitiveness. Thus, available inorganic nitrogen is a catalyst that influences the competitive stature of cheatgrass.

The **first experiment** investigates if the competitive interactions between cheatgrass and native species change with weed abundance or with soil N availability. Results from this experiment will indicate: 1) if weed abundance or soil N availability alters cheatgrass growth and thus its competitive advantage; 2) which native species are more competitive with cheatgrass under these different environmental conditions; and 3) the underlying ecological mechanisms for the observed results. The **second experiment** investigates if the effectiveness of 3 different restoration treatments changes with weed abundance. Two of the restoration techniques (a prescribed fire and a prescribed grazing treatment) are targeted at reducing the cheatgrass seed bank, whereas the third investigates if more competitive native species (identified in the first experiment) further enhance cheatgrass control. Results from this second experiment will indicate: 1) if prescribed management treatments are capable of reducing either the cheatgrass seed bank or soil N availability, and thus enhance the establishment of native species; 2) if restoration strategies that incorporate a transition community of competitive species have greater success; 3) the extent that weed abundance influences the control of cheatgrass and establishment of natives; and 4) the underlying ecological mechanisms for the observed results. Although our focus is primarily cheatgrass, we will also quantify effects on perennial species as well as secondary weeds.

Concomitant with the ecological investigations in these experiments, a least-cost **economic analysis** will determine the economic feasibility of different restoration strategies. Because all the monetary benefits of native plant restoration (*e.g.* monetary benefit of increased ecological health, aesthetics, etc.) cannot be quantified accurately, the least-cost method is the most appropriate analysis technique. These economic analyses will account for differences in weed abundance, precipitation, and soil N availability as well as consider the economic benefits of intensive spring grazing on cheatgrass for livestock ranches.

In addition, we will develop a **robust extension and educational program** that:

- produces practical, informational publications and handbooks for private and public land managers
- incorporates extension agent exposure at field days and training sessions
- includes internet access to publications, information, related websites, and chat rooms
- integrates invasive species and restoration issues into K-12 core curricula
- incorporates course materials plus research and management experiences for college undergraduates
- provides training workshops for teachers, resource specialists, and media representatives
- has proactive community outreach and public relations.

In both experiments, perennial plant cover, density, and biomass will be used as measures of plant "success". High values of these perennial plant metrics are desirable characteristics of almost all restoration efforts, and they are relatively simple to quantify. Clearly, cover, density, and biomass are not the only goals of restoration – we also need to understand <u>why</u> certain treatments resulted in higher cover and biomass. Thus, a series of ecological process studies that investigate seedling establishment, seed bank dynamics, resource competition, and soil processes (see Section 5.2.2) are integral parts of our experiments. This mechanistic understanding in turn provides the ability to extrapolate our results to scenarios that have different sites, different conditions, or different restoration techniques. Cover, density, and biomass of perennial plants will be determined at peak biomass on all plots using standardized protocols (NARSC 1996). (Tausch will supervise these measurements.) Production, reproduction, and seed banks of cheatgrass and secondary weeds will also be examined (see section 5.2.2).

Each experiment has 6 replications per main plot treatment (we refer to these replicates as "study areas"), with replicates distributed across the 4 western states that comprise the majority of the Great Basin. All replicates will share the following characteristics:

- Range site characterized by *Artemisia tridentata* subsp. *wyomingensis*. These sites constitute at least 25% of the entire sagebrush zone in the Great Basin (West 1999).
- Loamy to silt loam orthid soil with >1 m to any argillic or hardpan layers.

Three replicate study areas will be located in an area with relatively low precipitation (mean annual precipitation 200-230 mm) and 3 in areas with relatively high precipitation (mean annual precipitation 300-330 mm). Geographic locations of these study areas are shown in **Fig. 1**.

The 3 main plot treatments at each study area reflect an abundance of weeds in terms of both frequency and diversity. These treatments, from relatively low to relatively high weed abundance, are:

- Native community: >70% frequency of native perennials, <20% frequency of cheatgrass, and <<1% frequency of secondary weeds.
- Cheatgrass dominated: <20% native perennials, >60% cheatgrass, <<1% secondary weeds.
- Weed infested: <20% native perennials, >60% cheatgrass, 5-10% secondary weeds.

As in any field study, true statistical replicates are very difficult to obtain. For example, weather variation, soil structure, and other subtle site factors will not be identical among all sites. Thus, soil properties of each study area will be quantified (see section 5.2.2), and maximum and minimum daily air temperatures and precipitation will be measured for the duration of the studies at each site. Furthermore, 4 methods are available to account for the inherent variation that will occur:

1. First, we have purposely introduced the *potential* for variation in timing and amount of precipitation among the study areas. Obviously, nature may not cooperate, but the alternatives (irrigation treatments, rain-out shelters) are much too expensive to implement. Nonetheless, the extent that nature "cooperates" impacts the statistical analyses that we will need to employ, ranging from analysis of variance, to analysis of covariance, and to regression and meta-analysis methods as uniformity decreases.
2. Second, we will repeat the competition screening trials of Experiment 1 in 2 consecutive years to get a measure of year-to-year variation within a site.
3. Third, we will use a series of ancillary "garden" plots in the experiments to assess weather and site variation. These "gardens" are seeded in the same way as the perennials, but are carefully weeded to remove all cheatgrass plants, which allow the perennials to achieve their maximum growth potential under the prevailing weather and other site conditions. To account for site-to-site and year-to-year variation in prevailing growth conditions, vegetation measurements on experimental plots are referenced to the garden plots. This relative method facilitates statistical analyses across the replicates by using either the ratio of experimental to garden plot with standard split-plot analysis of variance or the results from the garden plots as a co-variate in analysis of co-variance.
4. A fourth technique is meta-analysis, which is a statistical technique to quantitatively synthesize and analyze a collection of experimental studies (Osenberg *et al*. 1999). Although meta-analysis in the ecological literature usually is used for retrospective analyses of published data (*e.g.* Curtis & Wang 1998; Gurevitch *et al*. 1992), the concepts and procedures that are inherent in meta-analysis will enhance our ability to synthesize the results from our studies. We plan to apply meta-analysis to achieve 2 distinct goals: 1) to aggregate the results from each site and from different years as a more powerful test of our null hypotheses; and 2) quantitatively estimate the magnitude of the restoration response as influenced by the environmental and biological variables that we measure in our experiments.

3.2.1.1 Experiment 1: Competitive interactions

The first experiment focuses on variation in the competitive relationships between cheatgrass and native species with weed abundance and soil N availability. Various scientists suggest that some native species, such as *Elymus elymoides* (Hironaka & Tisdale 1963; Hironaka & Sindelar 1973, 1975; Humphrey & Schupp 1999), are able to compete effectively with cheatgrass, and the species and lifeform of neighboring plants may reduce cheatgrass seed production by 75% (Reichenberger & Pyke 1990). Although these natives may not be the most desirable species to dominate a completely-restored site, they may provide an intermediate transition state to facilitate conversion from cheatgrass dominance to a diverse, perennial native plant community. Given that some native species compete effectively with cheatgrass but that the ability of cheatgrass to compete with any 1 native species varies with weed abundance or soil N availability, **specific objectives** of this experiment are: 1) identify promising plants that can be used to enhance the transition from cheatgrass dominance to a diverse, native plant community; 2) determine if competitive interactions between native species and cheatgrass change with weed abundance and available soil N; and 3) understand the mechanisms that explain variations in cheatgrass competitive ability. Because the potential number of species that could be used in this experiment is very large and hence the number of treatment combinations would quickly become unmanageable, we have split this experiment into: a) a screening trial focused on the first objective (identifying promising plants); and b) an experiment focused on the second objective (mechanisms of competition) that uses species with representative life histories.

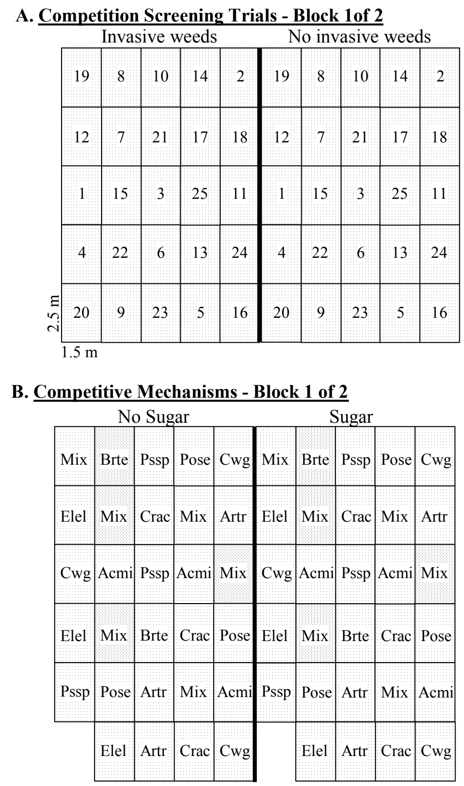


Fig. 2. Plot layout within 1 of 2 blocks at each of 6 study areas for competition experiments. Different shadings in B indicate different seed densities.

The competition screening trial will have a 3x2x25x2 split-split plot design (**Fig. 2A**) with weed abundance as the main plot factor, presence/absence of invasive weeds as the split plot factor, and plant variety as the split-split plot factor. All invasive weeds will be removed from half of each of 2 blocks (*i.e.* within site replicates) using an application of the pre-emergent herbicide OUST® (sulfometuron methyl) in the fall prior to seeding (*i.e.* during Year 1) coupled with hand weeding as needed. In the other half of each block, invasive weeds will be allowed to germinate and grow unimpeded. Within each split plot, a randomized block design will be used in which 25 plant varieties are completely randomized within each block. The plant accessions selected for screening are: 4 accessions of *Pseudoroegneria spicata* (‘Goldar’*, Anatone*, P-7*, Acc:238*); 3 of *Elymus wawawaiensis* (‘Secar’*, DPPX, E-35); 5 of *Elymus elymoides* (Sand Hollow*, Paradise Valley*, Mountain Home, Fish Creek*, Toe Jam Creek); 4 of *Achnatherum hymenoides* (‘Nezpar’*, ‘Rimrock’*, Rimrock HG*, Acc:89); 4 of *Leymus cinereus* (‘Trailhead’*, ‘Magnar’*, L8PX-1, Nevada MOPX); 3 of *Poa secunda* (‘Canbar’*, Yakima*, Mountain Home*); a forthcoming release of *Achillea lanulosa*; and commercially available *Agropyron cristatum*. Accessions with an asterisk could be available in quantity for Experiment 2. Seed of other accessions would not be available in the necessary time frame for Experiment 2, but they are included in Experiment 1 because their performance is of long-term interest. In a 26th plot, no perennials will be seeded, plants other than invasive weeds will be hand weeded, and invasive weeds will be allowed to grow to their maximum potential given the prevailing site and weather conditions. Individual 1.5 m x 2.5 m plots will be seeded with a single plant variety at 204 pure live seeds (PLS) m^{-2}. These screening trials will be seeded in the second year of the study and will be repeated in the third year.

Evaluation of the competition screening trials will involve measurement of plant traits that potentially indicate greater competitive ability with cheatgrass. These traits include: first leaf length, seedling establishment (frequency as measured with a calibrated rod), and plant height (year 1); frequency of plants heading and shoot biomass (year 2). Ogle (NRCS) and Jones (USDA ARS) will supervise and assist with the competition screening trials.

The experiment to examine mechanisms of competition will have a 3x2x29x2 split-split plot (**Fig. 2B**) experimental design with the original weed abundance of the site as the main plot factor, soil N availability as the split-plot factor, and seeding combinations as the split-split plots. Within each split plot, a randomized block design will be used in which the 29 seeding combinations are completely randomized within each of 2 blocks. Because the secondary weeds are listed as noxious weeds and thus by law we cannot seed them into plots, this experiment focuses on cheatgrass competition.

Competitive interactions with cheatgrass will be examined for the following individual species and species mixture: 1) monocultures of 6 native perennial species with different life history strategies and physiological characteristics; 2) a mixture of the 6 native species to maximize potential resource use; and 3) monocultures of crested wheatgrass because it is still the most frequently used introduced species, but its ability to compete with cheatgrass has not been rigorously assessed relative to that of native species. Many of the same native species exist across the broad geographic area of the Great Basin, but their relative importance and, thus, appropriateness for restoration varies. Nonetheless, the same species have been chosen for all 6 study sites in order to allow statistical comparisons across all replicates. The species are: *Artemisia tridentata* subsp. *wyomingensis* (shrub, uses soil moisture all year, roots throughout entire soil profile), *Poa secunda* (bunchgrass, earliest season moisture, shallowest rooting), *Elymus elymoides* (bunchgrass, primarily early season moisture, relatively shallow rooting), *Pseudoroegneria spicata* (bunchgrass, mid-season moisture, relatively extensive rooting), *Crepis acuminata* (tap-rooted forb, mid-season moisture, deep roots), and *Achillea millefolium* (rhizamotous forb, mid-season moisture, surface mat of roots). Although we recognize that the short study period (two years) may not allow sagebrush seedlings to become a competitively active component of the community, sagebrush is the dominant native shrub in the Great Basin and will eventually exert an important influence on competitive interactions.

The effect of cheatgrass competition on the establishment of the perennial species as well as the effect of the perennial plants on cheatgrass reproduction will be evaluated by seeding 3 different densities of cheatgrass into a fixed density of each of the perennial plant monocultures and into 2 densities of the native species mixture. The density of the monocultures and the lower density for the native species mixture will be 204 seeds m^{-2}. The density of the higher density native species mixture will be 408 seeds m^{-2}. The densities of cheatgrass will include a control (no cheatgrass), a low level of introduction (10% of the perennial monoculture densities and of the less dense species mixture; *i.e.*, 20 seeds m^{-2}) and a high level of introduction (50% of the perennial monoculture densities and of the less dense species mixture; *i.e.*, 100 seeds m^{-2}). The effect of the cheatgrass in the absence of the perennial species will be examined by seeding cheatgrass alone at the two densities (20 seeds m^{-2} and 100 seeds m^{-2}).

The study site will include an area large enough to accommodate the experimental plots plus a 10 m buffer zone. The plots will be prepared the fall prior to planting (*i.e.* during Year 1) by a one-time application of OUST® timed to minimize cheatgrass establishment and seed banks. The plots will be seeded the following fall (Year 2) as dormant plantings. Soil N availability will be altered on half of each block using sugar applications similar to those in our earlier studies (Young *et al*. 1999). Individual plots will be 1.5 m x 2.5 m with one half of the plot reserved for nondestructive sampling and the other half for destructive sampling. A planting grid with a uniform 7 cm spacing (204 seeds m^{-2}) or 3.5 cm spacing (408 seeds m^{-2}) will be used to obtain the proper density of the individual species and species mixture. For the treatments with cheatgrass, the additional 20 or 100 cheatgrass seeding locations will be superimposed over the uniform seeding grid and will be randomly located. Local seed sources will be used for cheatgrass and, when possible, for the native species. Seed viability of all species will be determined prior to seeding, and we will use only seed lots with >90% viability. Seed burial depths will be selected to maximize germination and emergence for each individual species. The plots will be weeded during the first growing season to maintain the proper plant densities. Perennials often require 2-3 years for establishment and seedling mortality can occur in the second year if cheatgrass densities increase. Thus, the planted cheatgrass will be allowed to seed in the first year, and all plots will be monitored one to two additional years.

3.2.1.2 Experiment 2: Restoration strategies

The second experiment focuses on restoration strategies and how weed abundance influences restoration success. The experimental design for this restoration experiment is a 3x4x2x2 split-split plot (**Fig. 3**), where the main plot factor is weed abundance, the split-plot factor is restoration strategy, and the split-split-plot factor is seeding mix. The restoration strategy (split-plot) factor consists of 4 potential methods to control cheatgrass: 1) no treatment (*i.e.* control); 2) a prescribed grazing treatment targeted to reduce current seed production by cheatgrass; 3) a prescribed burn-seed-burn-seed treatment targeted to reduce both the cheatgrass seed bank and cheatgrass' access to available soil N; and 4) a herbicide treatment to serve as an experimental reference point. The seed mix (split-split plot) factor has 2 seed mixes: 1) the same seed mix used in the competition mechanism experiment; and 2) the 6 varieties from the competition screening trials that were found to be most competitive with cheatgrass (and thus represents a transition community from cheatgrass to the desired community). (Note: Selection of these 6 varieties will also depend on sufficient seed availability from our seed increase efforts.) The overall goal of this restoration experiment is to determine the relative success of restoration strategies that incorporate prescribed methods to control cheatgrass competition and its prolific seed production. **Specific objectives** are: 1) determine if prescribed fire or grazing management reduces cheatgrass competition for available soil N and seed bank, and thus enhances the establishment of native species; 2) determine if the presence of secondary weeds influences the control of cheatgrass and establishment of natives; 3) determine if a transition community of competitive natives can be established more readily than a diverse community of different growth forms; and 4) understand the underlying ecological mechanisms for the observed results.

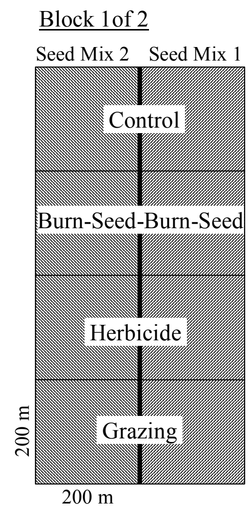


Fig. 3. Plot layout within 1 of 2 blocks at each of 6 study areas for restoration experiment.

The prescribed grazing treatment is a high intensity, short duration grazing in the spring during seed filling (before cheatgrass turns purple) to reduce current seed production by cheatgrass. The burn-seed-burn-seed treatment is a novel restoration strategy that is designed first to reduce weed seed production, then to deplete available soil N. The first burn is a slow moving, hot fire in early summer (prior to seed dispersal) to reduce the cheatgrass seed bank. A cover crop of annual rye is then seeded that fall. The cover crop has 2 purposes: first to uptake soil N leaving less available to the invasive weeds, and second to provide fine fuels to carry the second prescribed burn. (Note that if fuel loads are not sufficient to carry a prescribed fire, a crop-residue straw will be added.). The second burn is a low-intensity head fire to further reduce the cheatgrass seed bank as well as to volatilize nitrogen, and the second seeding is the final seed mix. Because herbicide restoration treatments have a high success rate in controlling cheatgrass before restoration, they serve as an experimental standard to judge the relative success of the other treatments. [Note: We are not specifically advocating the use of herbicides (selection of a specific herbicide and dosage is beyond the scope of our studies), but as in the case of sugar applications, we recognize its utility in an experimental framework.] OUST® will be used because of its relatively short half-life, low toxicity, and current use to control cheatgrass in the general study area (Pellant *et al*. 1999).

At each site, treatments will be applied in a randomized block design, with 2 blocks per site. Individual plots will be relatively large (4 ha) to provide better simulation of large-scale land treatments as well as more realistic cost estimates for each restoration strategy. The restoration experiment will be implemented in Year 3 of the study, and we will continue to monitor the treatments for a second year to assess if promising results persist for a second year.

3.2.2 Ecological processes

Process: **Seedling establishment** (Pyke, Schupp, & Chambers)

Null Hypothesis: Perennial plant seedling establishment will not differ with varying levels of cheatgrass competition.

Expected Result: Increasing densities of cheatgrass will result in increased seedling mortality and, thus, decreased establishment of the perennial species.

Null Hypothesis: Reproduction of cheatgrass will not differ among the perennial monocultures or mixtures.

Expected Result: Cheatgrass reproduction will be lower for species monocultures that use soil moisture earlier in the spring and lowest in the native perennial mixture.

Seedling Establishment Methods: Seedling emergence and survival will be monitored three times during the growing season (growing season dependent: April or May, June and late July) in the nondestructive portion of the plots using the planting grids seeding as a guide for mapping and censusing individuals. During the first year after seeding, both cheatgrass and the target perennials will be censused along with any secondary weeds that survive the plot treatments. In subsequent years, only the perennial species will be censused using the planting grids. Weed population sizes in subsequent years will be estimated by counting individuals in three randomly placed 0.1- m^2 quadrats in each non-destructive plot. At the end of each growing season, weed reproduction will be estimated by counting the seeds on 15 randomly selected plants per plot. The seeds will be returned to the plot and spread over the surface. At the end of the study, 10 randomly located individuals of the surviving target perennials (or all of the surviving individuals) will be harvested from each plot and dry mass will be determined.

Process: Weed reproduction and seed bank dynamics (Chambers, Pyke, & Schupp)

Null Hypothesis: Reproduction and seed banks of cheatgrass and secondary weeds will not be affected by restoration treatments that include prescribed burning or grazing followed by seeding perennial species.

Expected Results: Both prescribed burning and grazing should at least decrease cheatgrass seed banks and reproduction the year of the treatment. In subsequent years, seed production and seed bank densities of cheatgrass and secondary weeds will depend largely on the degree to which the seeded perennial species (1) establish on the treated sites and (2) effectively compete with cheatgrass and secondary weeds.

Seed Bank Methods: The seeds of cheatgrass typically mature in early summer, have a short after-ripening requirement, and then become highly germinable. Knapweeds and rush skeletonweed, the dominant secondary weeds on our sites, have seeds that mature from mid-summer to late fall and have more restrictive germination requirements. Cheatgrass seeds are larger than the secondary weed seeds, but significant vertical movement of seeds is unlikely given the soil types on the study sites (Chambers 2000). To assess densities of weed seeds in the seed bank, seed bank samples will be collected after most seeds have dispersed in the fall (to determine the current year's production) and the following spring after germination is complete (to determine seed bank carryover). Thirty, randomly-located samples will be collected for each treatment combination. Soil cores (10 x 10 cm and 2 cm deep) will be collected and separated into two depths: the litter layer and the 0-2 cm soil layer. Fall collected samples will receive a 60-day wet, cold stratification treatment. Spring samples will be allowed to dry for 30 days, and then will receive the wet, cold stratification treatment. After stratification, the soil samples will be thinly spread (< 1.0 cm) over moistened sterilized sand in a greenhouse with fluctuating day/night temperatures. Samples will be kept moist, and germinated seedlings of weeds will be counted and removed after 2 weeks and again at the end of a 6-week germination period. Samples will then be allowed to dry down and rewatered to check for additional seedlings.

Reproduction Methods: Seed production of cheatgrass and secondary weeds will be estimated on per individual and per unit area bases. Plot sizes for estimating reproduction will likely decrease for successive years after fire or grazing because weed populations will likely increase in successive years. For individual plant reproduction, 30 randomly-selected plants will have all seeds counted before dispersal. For reproduction per unit area, we will determine the appropriate number of plots, randomly place these plots, and then measure plant density and number of seeds on all plants in the plot.

Process: Resource Competition (Doescher & Svejcar)

Null Hypothesis: Perennial plant water status will not vary with weed competition, as measured by soil water extraction and water status of perennial plants.

Null Hypothesis: Perennial plant water status will not vary with restoration strategies.

Expected Results: If cheatgrass competition is the ultimate reason why restoration efforts fail, then we expect decreased perennial plant biomass with cheatgrass-induced faster depletions of soil water and consequently greater water stress. If the presence of secondary weeds has synergistic detrimental effects on the perennials, then we expect further decreases.

Null Hypothesis: Total aboveground plant nitrogen of perennials will not vary with weed competition or with restoration strategies.

Expected Results: If N availability is important for cheatgrass competitive success, then the proportion of total plant N in perennials should be positively related to their competitive ability, as measured by their relative increase in biomass. Furthermore, the relative increases for treatments that are targeted to reduce available soil N (*e.g.* sugar applications and the burn-seed-burn-seed restoration strategy) should be greater. The extent that secondary weeds alter these relationships indicates the extent that they also compete for N.

Resource Competition Methods: Measurement of soil water extraction will be made using 30- and 50-cm long TDR probes that are installed near the center of each plot. Although water can infiltrate below 50-cm soil depth, our previous studies did not show significant effects of cheatgrass competition on soil water extraction at 60-cm or deeper soil depths (Melgoza *et al*. 1990). Soil moisture will be measured twice per month. This technique allows direct, repeatable, and non-destructive measurements of soil moisture content. Concordant with the measurements of soil moisture, plant water status will be determined at predawn and midday using the pressure chamber technique (Boyer 1995). Soil water extraction and plant water status will be measured on all treatment and garden plots. Deviations of soil water extraction and plant water status on experimental plots from those on the garden plots provides a relative measure of weed competition, and these deviations will form the data base for statistical analyses. Total aboveground plant N will be measured similar to our earlier studies (*e.g.* Leavitt *et al*. 2000): sampling 3 individual plants per species per plot, compositing the individuals, finely grinding the biomass, and then analyzing with a CHN analyzer. We recognize that these measurements of aboveground N pool sizes underestimate total plant N uptake because they do not include belowground plant N, and thus they potentially confound comparisons across species. However, because the decomposition rates of shoot biomass generally is slower than that of root tissues, greater aboveground plant N in perennials potentially ties up that N for a longer period of time.

Process: Soil nutrient status and weed competition (Blank, Hilty, & Johnson)

Null Hypothesis: There is no threshold of soil nitrogen availability above which the establishment of cheatgrass or secondary weeds is favored.

Null Hypothesis: Invasive weeds do not alter soil nutrients.

Expected Results: We will enumerate boundaries of soil nitrogen availability and the availability of other soil nutrients that limit the establishment of cheatgrass and secondary weeds. For example, is there a threshold inorganic nitrogen level below which cheatgrass establishment is retarded relative to native perennial grasses? If such a threshold exists, what is its value and how do we manage the ecosystem to remain below that value? Do other soil nutrients influence the competitive stature of cheatgrass? Does cheatgrass alter the soil environment to favor its competitive stature as we have shown for *Lepidium latifolium* (Blank & Young 1999). In addition, we will determine if a prescribed series of burns can lower available soil nitrogen levels such that more nitrogen efficient native perennial grasses can re-establish in relative freedom from cheatgrass.

Soil Nutrient Methods: Soil nutrient studies will be overlain upon plant competition and restoration plots. Using a replicated factorial design, we will measure the following attributes over season (spring, summer, fall), by microsite (plant canopy, interspace) and among the various plot treatments: 1) *in situ* nutrient availability as captured by mixed anion and cation resin exchange capsules placed at 5 cm (NO_3^- , NH_4^+, Ca^{+2}, ortho-P, Mg^{+2}, K^+, Fe, Mn, Cu, Zn); and 2) from homogenized bulk soil samples 0-10 cm, KCl-extractable NO_3^- and NH_4^+, CEC, pH, SOM, soil enzyme activities of phosphatase, urease, asparaginase and amidase, 30-day aerobic mineralization potentials of NO_3^- and NH_4^+. Again using the same statistical design, cheatgrass and secondary weed aboveground mass will be harvested after maturation and analyzed for total N, P, K, Ca, Mg, and S. Plants will be chosen to represent a range of vigor from weak to robust. Correlation of a particular nutrient content in plant tissue with the corresponding soil nutrient content across the range of vigor types will expose the controlling nutrient and define a threshold. Regression techniques will be used to locate trends in our nutrient data set with other measure attributes on the plots such as cheatgrass density and biomass.

Process: Soil microbial community and biological crusts (Hilty & Blank)

Null Hypotheses: Functional diversity of soil microbial communities is not different: a) among communities with different levels of weed abundance; and b) between native plant communities and sites where restoration treatments have been applied.

Expected Results: If the soil microbial community is significantly changed following the invasion of weeds or due to restoration treatments, then subsequent restoration attempts with native species may fail because organisms (*e.g.* mycorhizzae) necessary for native plant establishment and survival, or for proper nutrient cycling, may not be present (Allen 1995).

Null Hypothesis: Reinvasion of sites by biological crust organisms (cyanobacteria, algae, moss, lichens) is not affected by type of restoration treatment.

Expected Results: Biological crusts (lichen, moss, algae, etc.) are sparse with regards to both cover and species diversity in cheatgrass-dominated communities. Restoration treatments (burning, herbicide, high-intensity livestock use, and seeding) also impact biological crusts. However, we have shown that biological crust reestablishment following restoration of native plant community structure is possible, and reestablishment of biological crusts in the restored plant communities may be important to future exclusion of cheatgrass (Kaltenecker 1997; Kaltenecker *et al*. 1999). We expect analogous results when secondary weeds are present.

Soil Microbiology Methods: 1) Random soil samples 2.5 cm diameter x 10 cm deep will be extracted from each native plant community (control) and restoration treatment replication each fall and spring (prior to and after treatment). Soil samples will be collected early during the period of active growth for cheatgrass and at peak rates of growth. Analyses will include determination of bacterial and fungal functional diversity using the Biolog and Fungilog methods of evaluating carbon substrate use (Zak *et al*. 1994; Dobranic and Zak 1999), assessment of mycorrhizal inoculum potential (MIP) (Schwab and Reeves 1981), and soil chemistry parameters (see soil nutrient process above). 2) Random soil samples 5 cm diameter x 1 cm deep will be collected from the soil surface in each native plant community (control) and restoration treatment replication each fall (prior to and after treatment). Photosynthetic biomass of surface soils (cyanobacteria, algae, moss protonema) will be estimated by spectrophotometric determination of chlorophyll *a* and *b* (Belnap 1993; Matthes-Sears *et al*. 1997). Visual cover of biological crust will be estimated in randomly placed plots within each treatment.

Data Analyses: Biolog data will be analyzed by creating similarity matrices and applying cluster analysis to look for similarity in composition between treatments. Canonical correspondence analysis will be used to investigate the relationship between the composition of the microbial community and soil variables. Soil chemistry, MIP and biological crust biomass and cover will be compared between treatments using analysis of variance.

Process: Soil physical properties (Norton, Johnson, Monaco)

Null Hypothesis: Invasive weeds do not alter soil characteristics in ways that inhibit restoration of native perennial plant communities.

Expected Results: Invasive weeds modify the soil environment through positive feedback mechanisms, and these soil impacts likely increase with increased age of invasion. These changes may culminate in altered soil physical and hydrological properties that affect the site's amenability to restoration or ability to recover naturally. Organic matter turnover is more rapid and shallower beneath fast-growing, fine-stemmed invasive annual grasses than under desirable grasses and shrubs. Dominance of annuals generates a carbon-limited soil environment with relatively abundant mineral N ("open" N-cycle). In contrast, soils beneath perennial plants store organic matter in relatively recalcitrant forms and are characterized by limited available N and rapid microbial immobilization ("closed" N-cycle). These shifts in composition and distribution of soil organic matter, along with altered plant canopy characteristics, may change how wind and water interact with the soil surface and subsurface. These combined effects could in turn lead to changes in: 1) soil texture and structure; 2) soil moisture content and available water holding capacity; and 3) hydraulic conductivity, runoff, and erosion. Improved understanding of how soil properties change with weed invasion and accumulate over time are important in order to avoid positive-feedback mechanisms that contribute to ecosystem degradation.

Soil Sampling Methods: Impacts of invasive weeds on soil physical properties will be examined by comparing soil organic matter, soil morphology, and soil hydrological attributes from the 4 restoration treatments as well as from analogous long-term native and weed-invaded sites. We will excavate, describe, and sample one soil pit to 1.5-m depth within each treatment by standard procedures. Auger samples from the bottom of the pits allow comparison of geomorphic setting among treatments and among sites. For each soil pit, we will establish transects consisting of four sample points to measure infiltration rate in the field and to collect soil samples to the depth of the A horizon or the deepest rooting zone. Samples will be analyzed laboratory for particle-size distribution, water-stable aggregate content, pH, bulk density, total organic C, total N, microbial biomass, and recalcitrant C.

3.2.3 **Economic assessment** (Tanaka & McCoy)

Most economic analyses of noxious weeds on rangelands has focused on those that are either poisonous to domestic livestock (Nielsen *et al*. 1988, Torell *et al*. 1988) or are in an active expansion mode with few benefits for domestic livestock (Bangsund *et al*. 1996, 1999). There is no information available on the economics of restoring cheatgrass dominated rangelands to native vegetation. Most of the economic analyses related to controlling one species to benefit another have focused on the benefit to livestock forage production (McDaniel *et al*. 1986, Workman and Tanaka 1991, and many others).

Estimating the economic benefits from restoring rangelands when the objective is community structure, ecological health, and native plant species restoration is difficult. Of the two methods available, the contingent valuation and hedonic pricing methods, neither is likely to provide useful information for making restoration decisions. In the first case, a willingness-to-pay value derived from a survey will be site and situation specific and has many inherent theoretical and practical difficulties. In the latter method, comparing land values from weed infested and noninfested rangelands adjusted for different sales characteristics may lead to a difference in value, but that value is likely most closely tied to livestock use (Godfrey *et al*. 1988). While this would be an interesting test, it will not help in making a decision regarding the restoration of rangelands. Hansen *et al*. (1991) have speculated, although not tested, that the costs of preserving or restoring biodiversity will be covered by the social, economic, and ecological benefits associated with such a strategy. One effort to calculate some of the recreational values lost due to leafy spurge infestations sought to determine the economic impact on regional economies using an input-output model (Bangsund *et al*. 1993). This model, however, looks at changes in gross expenditures (sales) and not on the value of the restoration work itself.

Null Hypothesis: There will be no difference in economic costs among treatments.

Expected Result: We expect that a higher success rate in establishing perennial vegetation will be associated with a higher treatment cost.

Methods: Because the goal of the project is to restore native perennial vegetation, there is no market value for that vegetation. It will have value for livestock forage, but also has values for biodiversity, ecological health, esthetics, and others. We will use a least cost approach to determine which treatment will lead to the most economical solution. The least cost approach is used in those cases where the costs are known, the objective is known, but the monetary benefits are unknown. Cost data for each treatment will be gathered for both the actual treatments and from other sources such as federal agencies to determine what the costs would be on an operational scale. A multi-period linear programming model will be developed to determine the least cost alternative over time given constraints of weed abundance, soil N availability, and meeting a specified restoration objective.

Null Hypothesis: There will be no economic effect from seeding into different abundances of weeds.
Expected Result: We expect that there will be a biological relationship between weed abundance and the success of the seeded native plant species and that an economically optimal time path can be determined from that information.
Methods: Data from experiment 1 will be analyzed to develop a functional relationship with native species success as a function of cheatgrass density, other weed abundance, and soil N availability. Once this relationship is known, an economic model will be built to determine what level of cheatgrass density is optimal. In order to determine this optimal level, we would need to know the costs of keeping cheatgrass at that density and the value of the native species success. Again this creates a problem – what is the value of the native plant species in and of themselves? There are two options at this point. The first is to conduct a contingent valuation study that would estimate how much people are willing to pay for different levels of native plant species restoration. The second is to use a threshold analysis and determine what the native plants would have to be worth to change the optimal solution. The resulting value estimate for the native plant species is only that amount that causes the economically optimal solution to be found. It is not what society would be willing to pay for that level of good. The actual amount society would be willing to pay may be either lower or higher. It would then be left up to the decision-maker as to whether that value was worth the expense.
Null Hypothesis: There will be no effect on Great Basin livestock ranches from intensively grazing cheatgrass in early spring.
Expected Result: We expect that ranches will increase profits from intensively grazing cheatgrass rangelands in the spring by reducing dependence on hay and other stored feeds and increasing the feed quality during this normally limiting seasonal grazing period.
Methods: Example ranch models will be developed for different regions of the Great Basin using existing work. These models are based on seasonal forage use by the livestock herds. The option of intensively grazing cheatgrass stands will be added to the models. Profit maximizing alternatives under different scenarios will be determined. The reason for doing this is if this is going to be a viable treatment alternative, livestock owners need to understand whether it will help or hurt their operations.

3.2.4 Extension initiatives (Glimp, Rasmussen, & Borman)

Results from this research will be provided to agency personnel, public land managers, policy makers, and other interested individuals through traditional Extension/outreach methods.

Periodic field tours will be conducted at selected research sites to keep collaborating scientists, agency personnel, local officials, county agents, and interested land managers appraised of current research findings. As research efforts advance, additional funding will be obtained to establish large-scale demonstration areas along key public highways, with descriptive signs at pullouts to showcase successful treatment options.

A publication entitled “Ecology and Management of Invasive Weeds on Western Rangelands” will be produced and distributed through campus and county Extension publications offices of the University of Nevada, Utah State University, and Oregon State University. An internet website by the same title will be developed, patterned after currently existing websites on yellow starthistle, jointed goatgrass, goatsrue, and other troublesome weed species. The Society for Range Management, the Western Society of Weed Science, Society for Ecological Restoration, and the Weed Science Society of America will be encouraged to link this site to their own websites.

Articles on weed ecology, negative impacts, and management will be prepared for publication in newspapers, newsletters, and appropriate trade magazines.

A summary of weed management recommendations will be included in both the Utah-Montana-Wyoming Weed Management Handbook and the Pacific Northwest Weed Control Handbook, which are updated and published cooperatively on an annual or biennial basis by Extension Weed Specialists in the corresponding states.

County Agricultural Extension Agents in affected areas will be given an overview of resulting cheatgrass management recommendations during regular district and/or state training workshops for Extension staff. In addition, compressed video technology (CD format) will be used to make data and video images available from all research and demonstration sites, allowing users to understand regional differences and impacts.

Research findings will be presented at area and regional weed management seminars, IPM workshops, and pesticide applicator training courses offered annually by the Bureau of Land Management, Forest Service, and other federal and state agencies. Results also will be presented at annual meetings and conferences of state weed associations, the Western Society of Weed Science, the Society for Range Management, and other appropriate conferences.

Opportunities for cost-share grants will be sought as a means to encourage private landowners to implement effective weed management techniques developed from this research.

3.2.5 Educational and community initiatives (Call, Markee, & Doescher)

Several approaches will be used to promote awareness of invasive weed issues in the Great Basin for K-12 students, undergraduate students, and the general public.

Many aspects of invasive weed ecology and management, from the individual plant level to the ecosystem level, can be tied to K-12 core curricula (science, social studies, math, language arts) for schools in the states represented in this consortium. As research advances, 2-day regional workshops will be held for teachers in weed-impacted areas. Teachers will be given an overview of the cheatgrass/secondary weed issue and work with scientists and land managers at research sites and demonstration areas to gain first-hand knowledge of the ecological, social, and economic aspects of the issue. Teachers will be provided with a support system to incorporate this knowledge and experience in the classroom and in local field settings (monitoring areas impacted and not impacted by cheatgrass and secondary weeds). Appropriate, existing materials and activities (Project Learning Tree, Project Wild, Ag in the Classroom, etc.) will be recommended; and new materials and activities (research highlights, case studies, compressed videos in CD format, web-based activities), specific to invasive species issues in the Great Basin, will be developed. An internet website, described in section 5.2.4, will contain a synopsis of the ecology and management of rangeland ecosystems in the Great Basin, with an emphasis on cheatgrass and other invasive weeds and with links to other relevant sites. The website will also serve as a database management and communication tool, where students can enter and compare monitoring data, photos, and historical and cultural information from their area with students in other areas of the Great Basin. Also via the internet, scientists and land managers will remain connected throughout the school year with teachers who have participated in the workshops.

Undergraduate students at colleges and universities in or adjacent to the Great Basin will have the opportunity to participate in research and management experiences associated with the program. Students interested in research aspects of invasive weeds will select a research project from an advertised list, identify a faculty advisor, and work with their advisor to develop a brief proposal. Students whose proposals are selected by a review panel will be awarded a $4000 mini-grant ($3000 stipend, $500 travel costs, $500 research expenses) to support the research. With guidance from faculty advisors, students will conduct the research, interpret the results, prepare a report, and present their findings to scientists, land managers and other interested individuals. Students interested in managerial aspects of invasive weeds and restoration can apply to a summer workshop/internship program that has been developed by Utah State University in conjunction with the Bureau of Land Management and the National Park Service (Oregon State University and University of Nevada, Reno have recently joined the program). During this internship, students attend a 2-week workshop that focuses on BLM land management issues in a particular area, and then spend the remainder of the summer with the BLM at several locations in the Great Basin (Ely, Elko, Battle Mountain, and Carson City, Nevada, and Richfield, Utah). In terms of undergraduate teaching, compressed video in CD format and web-based case studies will be made available for undergraduate courses (environmental science, ecology, natural resource policy and management, economics) at universities within and beyond the Great Basin.

Research findings from the program, and general information about the ecology and management of Great Basin rangelands, will be presented to various publics through different delivery systems. Regional and national media relationships will be developed through 1-day workshops/field tours during years 2 and 4. Media representatives will visit research sites, demonstration areas, and weed-impacted areas, discuss issues with scientists and land managers, and receive research summaries and background information. The purpose of these events is to generate interest in invasive species issues and provide a mechanism for accurate and continued reporting of these issues to the public, within and beyond the Great Basin. There is potential to reach the public through newspaper, magazine and internet articles, TV news reports, and public radio programs. An in-depth educational insert can be prepared for the Sunday edition of newspapers in the Great Basin region. Legislators (and/or staff members) will also be invited to participate in the media workshops/field tours to increase their awareness of invasive species issues. The volunteer monitoring and information sharing activities described above for school classes can also be performed by other groups in the community, including 4-H, FFA, Boy Scouts/Girl Scouts, Audubon, and others.

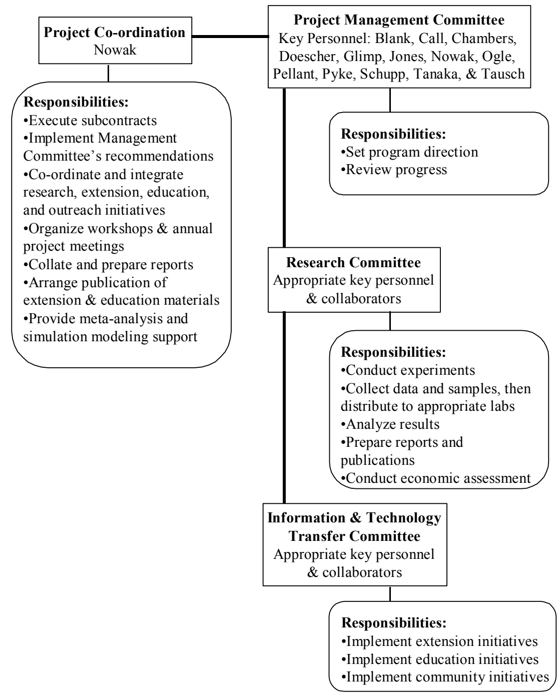
3.3 Project Management

3.3.1 Benefits from consortium

Our multi-state, multi-institution consortium to control invasive weeds and restore native species on Great Basin rangelands provides the following benefits:

- **More robust experiments –** Typically, smaller grants from a single institution would not have sufficient resources to conduct experiments at more than 1 or 2 sites. Hence, these single-institution experiments would have at best 1 degree of freedom in their statistical analyses. Our consortium experiments have greater statistical power because of the 6 sites per main plot factor. Thus, we have the potential to determine statistically both general patterns over a range of environmental conditions and fine-scale patterns that are relevant to specific sites. The net result is a more comprehensive understanding of the problems, potential solutions, and the constraints imposed by the environment.
- **Pooling of expertise –** The breadth of expertise, knowledge, and experience that is represented by our consortium simply does not exist at any 1 of our institutions. By pooling our expertise, we gain the critical mass of scientists, managers, and educators that are needed to tackle the pervasive problems of invasive weeds on Great Basin rangelands from the many different ecological, social, and management perspectives needed to resolve the problems.
- **Comprehensive, linked data sets –** The common protocols among sites coupled with our carefully-coordinated, interdisciplinary studies provide for both a comprehensive and a comparative examination of the results. These common, linked data sets provide a strong basis for statistical analyses and greatly enhance the capability for economic and ecological modeling.
- **Efficient use of resources –** Many of us as well as our collaborators have on-going research interests orientated around the control of cheatgrass on Great Basin rangelands or the restoration of these rangelands. The studies in this proposal provide a focal point for our interests and activities, and

thereby minimize duplication of experimental effort. Thus, the knowledge value added by each participant is relatively greater because each person can focus more of their resources on increasing knowledge rather than on performing the experiments. For a similar reason, our studies will likely attract many more additional collaborators once they are underway. Furthermore, because data will be collected using standardized protocols at all sites and usually analyzed by 1 lab, we gain additional efficiency. In an era of severely constrained funding, our consortium approach increases the efficiency of grant dollars.



- **Wide dissemination of knowledge –** Given the severity of cheatgrass invasion on Great Basin rangelands coupled with the associated problem of secondary weeds, the results and knowledge gained from our studies must be disseminated to other scientists, managers, educators, and the general public in a timely manner. Three features of our consortium facilitate the timely, wide distribution of knowledge: 1) our close ties with extension personnel, educators, and federal land management agencies; 2) our public outreach initiatives; and 3) our sponsorship of workshops and publications.

3.3.2 Management plan

The overall management structure of the consortium along with the responsibilities of each component is diagrammed at the right. The overall program goals, objectives, and directions will be determined by the Project Management Committee, which consists of the project's key personnel. Dr. Nowak will take responsibility for overall project co-ordination and administration and for integrating the research, extension, education, and outreach initiatives. Design, implementation, and publication of the experiments and their associated ecological and economic assessments measurements will be the responsibility of the Research Committee. Design, implementation, and publication of extension, education, and public outreach initiatives will be the responsibility of the Information & Technology Transfer Committee.

Overall financial management will be provided by the University of Nevada, Reno business management system with its existing framework and accounting systems. Transfer of funds and work responsibility will occur as a series of subcontracts with participating institution. Each participating institution has a designated Authorized Institutional Representative (identified on the Form CSREES-661) who is responsible for negotiation, execution, administration, and reporting of the subcontract fiscal concerns and a Principal Investigator who is responsible for negotiation, execution, administration, and reporting of specific programmatic responsibilities.

3.3.3 Evaluation and monitoring

3.3.3.1 Project objectives

Criteria to assess the success of meeting the project objectives include:

- Meet the proposed timetable with the proposed funding.

- Publish peer-reviewed scientific papers, extension bulletins, educational materials, and general brochures that are based on the proposed studies.
- Present the studies at scientific meetings, public forums, workshops, symposia, and classrooms.
- Develop human resources through training of technicians, undergraduate and graduate students, and postdoctorates.

3.3.3.2 Project administration

Criteria to assess the success of project administration include:

- Meet all project objectives within the proposed time frame with the proposed funding.
- Facilitate the exchange and use of data among project participants.
- Create and maintain web sites, link our web sites to related web sites, and develop web-based tools that are useful for scientists, managers, educators, and the public.
- Integrate the results using statistical and modeling tools.
- Sponsor the following workshops:
  1. **Measurements and Monitoring Workshop** (late winter, 2002). This workshop will examine the most appropriate techniques to measure and monitor the ecological processes in Section 5.2.2. Although a major objective is to train all our personnel so that we use common techniques and protocols, the workshop likely would interest other agency and university personnel. The major product would be a loose-leaf binder publication of Standard Operating Procedures (SOP's) that would also be accessible as PDF documents through our web sites.
  2. **Education and Public Outreach Workshop** (summer 2004). The primary purpose will be to examine techniques for us (agency personnel, students, and esp. university professors) to effectively educate and connect with the general public and other target audiences. Although we anticipate that this would be a stand-alone workshop, we will explore sponsoring a workshop in conjunction with a national society's annual meeting.
- Publish a restoration handbook in a loose-leaf, binder format targeted for use by land managers. The handbook and updates could also be downloaded from a web site maintained by the Nevada Agricultural Experiment Station.
- To ensure stability and support beyond the duration of the grant, the consortium will: 1) pursue the creation of a western regional project on cheatgrass; and 2) co-ordinate with and support existing or planned activities such as the BLM Great Basin Restoration Initiative, WCC-21 (Revegetation and Stabilization of Deteriorated and Altered Lands), the Joint Fire Science Program, and the Alliance for Natural Resource Research, Education, and Management in the Northern Rocky Mountains (aka "Northern Alliance").

3.3.4 Key personnel and collaborative arrangements

A summary of the key personnel and collaborators involved with this project are indicated in **Table 1**. Specific responsibilities for each person (or group) also have been identified in sections of the proposal.

3.4 Relevance and Significance

The sagebrush-steppe ecosystem in the Great Basin is changing at an alarming pace from a network of dynamic plant communities that support a diversity of plants and animals to a wildland fire – annual grass cycle system largely dominated by the invasive weed cheatgrass. We know that this loss of native habitat is not reversible without active restoration efforts, yet we lack definitive guidelines to direct the restoration efforts and to plan the appropriate restoration strategy. The ecological consequences of this change are striking: loss of wildlife species, unstable watersheds with degraded water quality, less forage for wild horses, reduced livestock grazing, and increased invasions of other noxious weeds. And social and economic impacts are apparent: more dangerous and costly wildfires, fewer recreation opportunities, lost income from tourism (hunting, fishing, camping), and reduction in the livestock-ranching industry that is the heart of many rural communities (USDI 1999). Finally, the problem is acute: approximately 50% of the 45 million hectares of Great Basin sagebrush-steppe communities has been converted to invasive weeds or is likely to convert to invasive weeds after the next wildfire (West 1999).

Our holistic systems approach that integrates research, education, and outreach is best suited to address the problems of controlling invasive weeds and restoring native plant diversity on Great Basin Rangelands. Our careful examination of ecological and environmental processes takes a scientific, problem-solving approach to determine strategies of controlling invasive weeds and restoring native plants. Our concomitant economic assessment provides an economic basis for choosing the appropriate management techniques and for evaluating the risks associated with non-native weed invasion. Our extension and educational initiatives will not only provide managers with timely information, but also increase public awareness of both the magnitude and complexity of the problem and its solutions. Ultimately, our project will provide solutions to critical land management issues that are shared by all who own or use Great Basin rangelands.

Table 1. Summary of responsibilities for personnel & collaborators.

Responsibility	Key personnel	Collaborators
Project management & coordination	Nowak	Project Management Committee
Seed & population ecology	Pyke	Chambers & Schupp
Community ecology	Tausch	Nowak
Competition & ecophysiology	Doescher	Svejcar
Soil ecology	Blank	Hilty, Johnson, Monaco, & Norton
Competition screening trials	Ogle	Jones
Resource economics	Tanaka	McCoy
Restoration ecology & technology	Pellant	Call & Perryman
Extension initiative	Glimp	Rasmussen & Borman
Education & community Initiatives	Call	Doescher & Markee

3.5 Time Table

	Year 1				Year 2				Year 3				Year 4			
	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S
1 Competition experiments																
A. Competition screening trials																
Characterize study sites	XXXX															
Prepare plots & apply OUST	XX				XX											
Seed					X				X							
Measurements						X	XXXX			X	XXXX					
B. Competition mechanisms experiment																
Prepare plots & apply OUST	XX															
Seed					X											
Measurements						X	XXXX			X	XXXX					
2 Restoration experiment																
Prepare plots					XX											
Apply cheatgrass control methods																
Herbicide					XX											
Grazing							XX									
Fire			XX					XX				XX				
Seed cover crop					XX											
Seed native plant mixes									XX							
Measurements										X	XXXX			X	XXXX	
3 Science workshops and symposia																
Measurements and Monitoring Workshop	X															
Education and Public Outreach Workshop													X			
4 Educational workshops																
Information specialist workshops/field tours												XX				XX
Media workshops/field tours																XX
Teacher workshops																XX

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