Problem Evaluation and Recommendations: Invasive Cheatgrass (*Bromus tectorum*) in Cedar Grove, Kings Canyon National Park

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The Problem

During the late summer of 1998 extensive areas (**Fig. 1 and 2**) of dense cheatgrass or downy chess (***Bromus tectorum*** L.) were reported in the Cedar Grove area of Kings Canyon (**Fig. 3**). Employees and repeat visitors had commented on the substantial increase in extent and density of cheatgrass during the El Niño winter of 1997/1998. Because of the highly invasive nature of this species and its documented expansion in relation to fire (Young and Evens 1973; Pellant 1990;Whisenant 1990; Billings 1994; Monsen 1994; Young and Allen 1997), there was immediate alarm about its presence and abundance. Park managers were concerned that burning these dense patches or nearby areas would provide more disturbance which would promote its success and spread as documented elsewhere. Autumn burning on the valley floor of Cedar Grove was suspended until an evaluation of the situation was conducted. A field survey to document distribution and density of the species was conducted in the fall of 1998 along with several other types of preliminary or background sampling.

Background

Cedar Grove is a spectacular glacially carved valley occurring between about 1,450 m and 1,600 m in elevation. Climate of the area is strongly Mediterranean with considerable year-to-year variability in precipitation. Predominant vegetation on the valley floor is open ponderosa pine stands mixed with wet meadows and drier bunchgrass-dominated openings or manzanita shrubfields. Pine stands of this nature are very unusual in Sequoia and Kings Canyon National Parks and thus of significance. Fire suppression has resulted in changes in species composition and fuel load that are most apparent in the

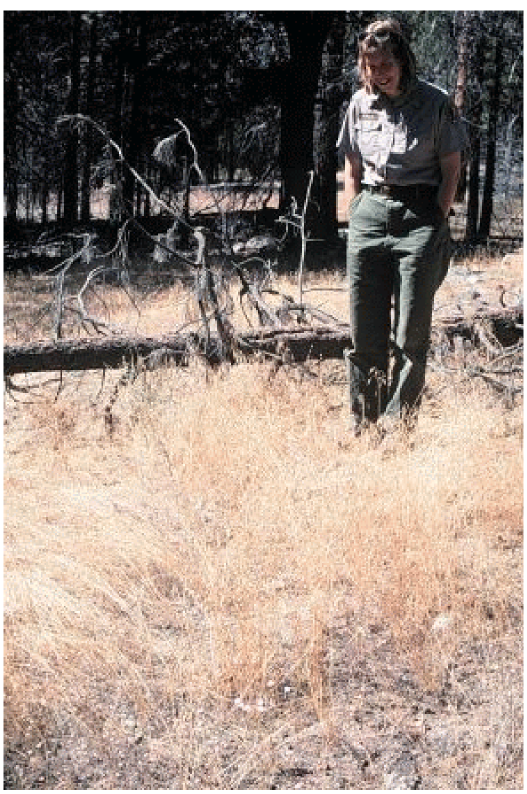

Figure 1. Moderately dense stand of cheatgrass near concession corrals (Oct. 1998 - photo by Tony Caprio).

Figure 2. Dense patch of cheatgrass in opening under dead pine in Roaring River area (Oct. 1998 - photo by Tony Caprio).

more productive forest stands on mesic benches along the Kings River. An active fire restoration program has been carried out in the valley during the last 10 - 15 years with the majority of the valley floor having been burned at least once during this time and some areas several times (**Fig. 4**).

Bromus tectorum

Cheatgrass has invaded and caused significant disruption of native plant communities in the Intermountain and Columbia River Basin Regions (Hulbert 1955; Billings 1994) where considerable research and management efforts have been undertaken over the last two-to-three decades (Young and Allen 1997). The species is highly invasive and can become dominant in nearly pure stands (**Fig. 5**) devoid of most native species (Morrow and Stahlman 1984; Whisenant 1990). Plant diversity declines in these communities along with associated resource values (Young and Evans 1978). In many instances communities are largely type-converted into simplified systems dominated by cheatgrass. The species is an aggressive and highly successful competitor with an array of features that contribute to its ability to dominate native species. Several case studies have documented impacts on rare and sensitive native species through direct or indirect competition (Rosentreter 1994). Degradation of native plant communities often occurs over an extended time, with sites initially occupied by scattered individuals of cheatgrass converted to pure stands through actions such as repeated burning or grazing (Monsen 1994; Billings 1994).

Cheatgrass can also cause dramatic changes in fire regimes within a plant community. It is highly flammable and as its dominance increases the potential fire frequency in these communities increases, usually to the detriment of native species (Young and Evens 1973; Pellant 1990;Whisenant 1990; Billings 1994). Its dominance causes significant modification of ecosystem attributes by altering fuel load and fuel distribution, and changing extent and intensities of fire (Peters and Bunting 1994).

Cheatgrass is a winter annual with initial germination beginning at the start of fall rains and continuing into the winter or early spring (Mack and Pyke 1983). Germination usually occurs earlier than native species giving a competitive advantage (Frasier 1994) and growth can occur at lower temperatures than many native plants due to fructan metabolism (Chatterton 1994). Phenological growth characteristics, such as rapid root elongation and the ability to deplete soil moisture in dense

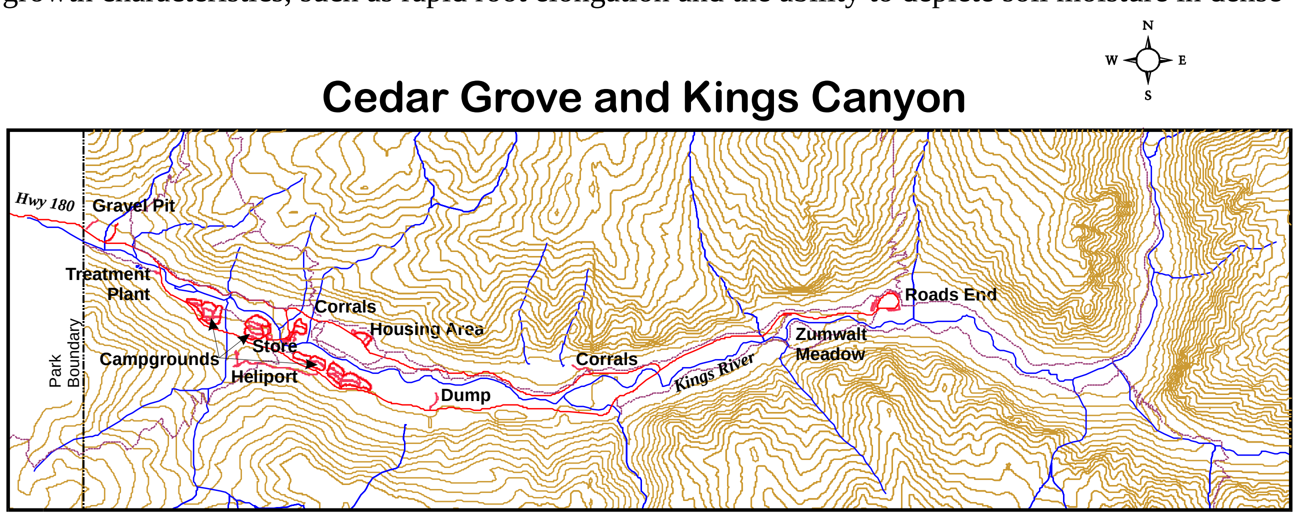

Figure 3. Overview of Cedar Grove area, Kings Canyon.

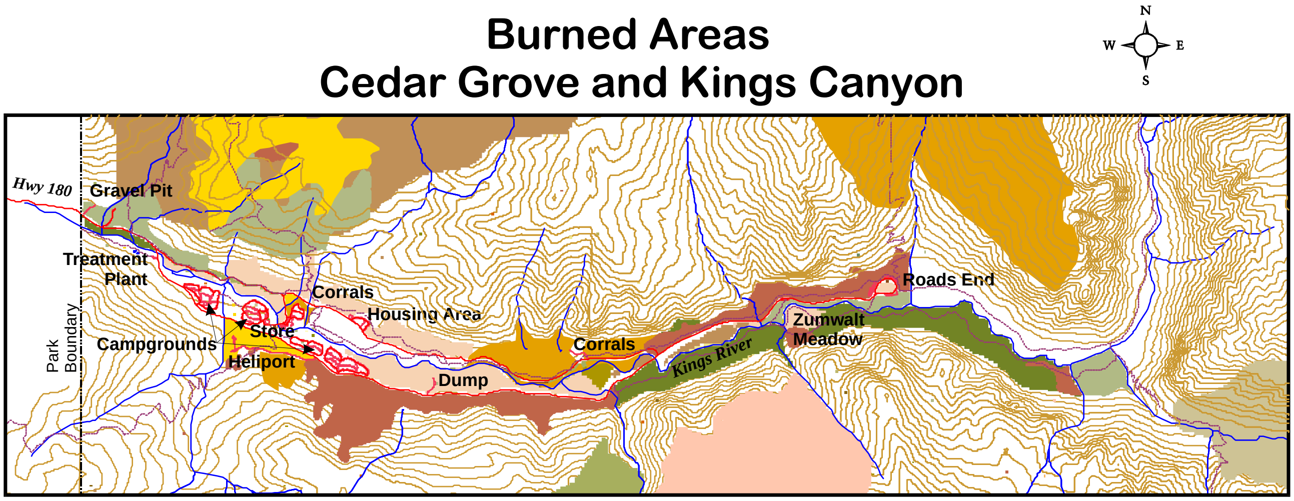

Figure 4. Burned areas (all fires back to 1970) in Cedar Grove area, Kings Canyon.

stands, also provide competitive advantages (Melgoza, et al. 1990; Melgoza and Nowak 1991). Additionally, the species has an extremely plastic growth form permitting a few plants without competition to produce as many seeds as numerous plants under dense competitive conditions (Pyke and Novak 1994). Plants usually produce enough seed each year to repopulate a site, although abundance depends on annual climate variation (Monsen 1994). Reproduction of cheatgrass relies on a few large seeds (11 seeds/plant in one study) in a large number of plants and a concentrated seed drop (Larson and Sheley 1994). Some debate exists over longevity of seed banks and their importance in succeeding years, although 95 to 100% germination is reported for 11.5 year old seeds in one study (Billings 1994). Genetic plasticity of the species is also high, permitting rapid adaptation to local environments which has lead to difficulties in developing restoration measures applicable to wide areas (Novak and Mack 1993; Pyke and Novak 1994; Novak 1994).

Control measures for cheatgrass have met with varying degrees of success, with most being quite limited. In a few cases native species have recovered and reestablished dominance at a site when additional disturbance did not occur. A variety of control measures have been attempted including herbicides (Tanel et al. 1993; Ogg 1994; Whitson et al. 1997, Whitson and Koch 1998), grazing (Tausch et al. 1994), mechanical tillage (Mattise and Scholten 1994), biological using rhizobacteria (Mazzola et al. 1995; Skipper et al. 1996; Kennedy 1991, 1997) or competitive perennials (Whitson and Koch 1998), fire (many papers within Monsen and Kitchen 1994), and various combinations of these treatments. Some experiments in sagebrush communities suggest that prescribed burning will only decrease cheatgrass in the short run (Rasmussen 1994). Success in burns depends on species composition, fuel load, fuel condition, and weather. Other work indicates less success using fire to reduce cheatgrass (Hosten and West 1994), as occurred at Lava Beds N.P. (Steve Underwood, personal communication). It has been suggested (Kevin Rice, UC Davis) that burning at the point in time when plants have cured but prior to seed drop

Figure 5. Dense nearly pure stand of cheatgrass at photo point in Picnic Estates area (May 1999 - photo by Dave Ashe).

may reduce population density. However, since native bunchgrasses and other species may also be more susceptible to fire impact at this time fire frequency and timing of the burns over time would be critical.

Problem Analysis and Preliminary Resource Investigations

Occurrence of Cheatgrass in Sequoia and Kings Canyon National Parks

In Sequoia and Kings Canyon National Parks cheatgrass is nearly always found at elevations above 900 m (Brent Johnson, BRD-USGS, personal communication) and not at lower elevations where diversity and density of other introduced winter annuals is high. Other species of ***Bromus***, such as ***B. hordeaceus*** L.**,**and ***B. diandrus*** Roth, form dense patches as part of the foothills annual grassland flora, along with ***B. madritensis*** L. ssp. ***rubens*** (L.) Husnot as a more scattered component (Sylvia Haultain, personal communication). Cheatgrass has been observed elsewhere in the Parks but not to the same extent and density as observed on the valley floor in Cedar Grove. In other areas of Kings Canyon small populations have been reported for tributaries to the Kings River, such as Roaring River (Dave Ashe, personal communication). In the East Fork of the Kaweah River it is common along the road at and above Lookout Point and uphill to about the Camp Conifer gate. Particular attention needs to be given to documenting any colonization of the Lookout Burn, ignited during October 1998, immediately above the Lookout Entrance Station (several fire effects plots are located in this area). In the 1996 NRI exotic plant survey cheatgrass was reported to be sparse and patchy along this road (Johnson et al. 1996) but was more continuous during 1998 (Caprio, personal observation). Additional small patches were also encountered on lower Paradise Ridge in the area of a 1970 burn (Caprio, personal observation 1998). The NRI survey also found populations at Camp Conifer and Redwood Creek in this drainage. In May 1999 it was observed growing off the Mineral King road shoulder forming patches in open areas of mixed black oak/chaparral in the 1995 Atwell burn (Caprio, personal observation). In the Middle Fork drainage the NRI exotics survey located substantial amounts of cheatgrass in the Bearpaw Meadow area. The report (Johnson and Whitmarsh 1996) states, "***B. tectorum*** *grew on many south-facing trail sides. We saw it ten meters and more off the trail in presumably undisturbed areas. Its densities were as high as twenty percent ground cover in some areas*." The species was also found in Rattlesnake Creek above the Kern Canyon at elevations up to 2360 m although populations were not abundant and generally isolated (Johnson and Whitmarsh 1996).

Vegetation Plots

Fire effects (Keifer, NPS) and Natural Resource Inventory (NRI) (Johnson and Whitmarsh, BRD USGS) plots in Cedar Grove (**Fig. 6**) were resampled or recent data reviewed to determine whether they recorded past occurrence of cheatgrass and if an increase through time could be noted from this limited data source.

Four fire effects plots (**Table 1**) were re-read during 1998 (several unburned fire effects plots that exist in the area could not be used because they were installed before current sampling methods developed and information about cheatgrass cannot be extracted). Aggregate data from the four plots showed cheatgrass increasing from 0.15% cover pre-burn to 18% cover post-burn (Keifer and Dempsey, personal communication). Individually, two of the four plots showed increases in cheatgrass density and were responsible for the increase in the aggregate data. One of these increased 60% by two years post-burn but then dropped back to 25% by five years post-burn. In contrast, another plot showed little to no change. Results were qualified since some of the pre-burn and year one data for the herbaceous component on all plots appeared incomplete (it was not known whether

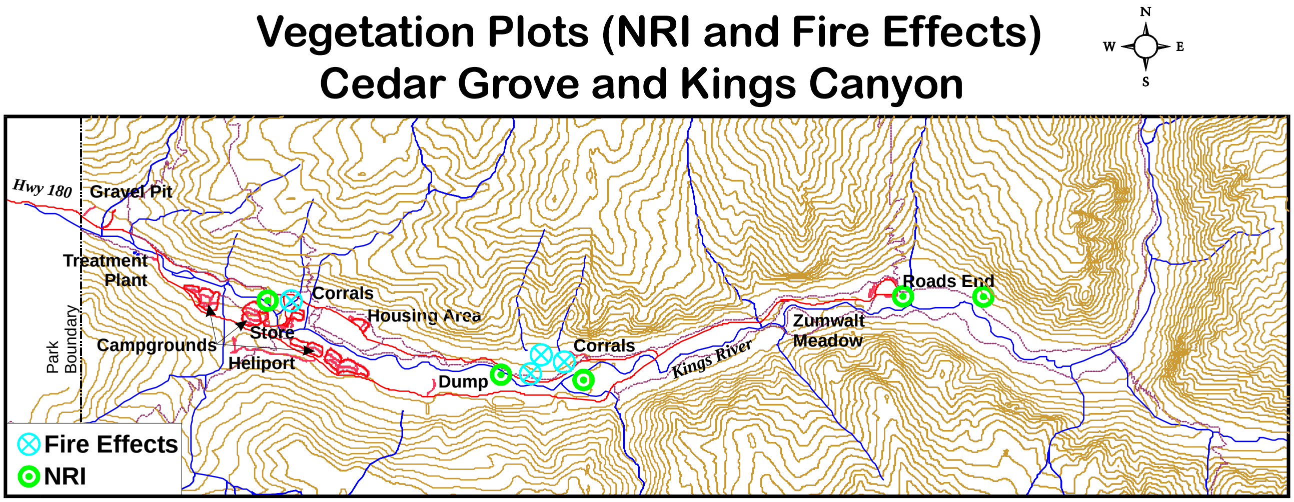

Figure 6. Vegetation plot (NRI and Fire Effects) locations in Cedar Grove area, Kings Canyon.

some of the unknown grasses recorded when plots were censussed were cheatgrass or another species).

The data from the these plots indicate the increase in cheatgrass had already begun prior to the wet 1997/98 winter. For example, data taken in 1995, two-years post-burn, showed an increase in cheatgrass from pre-burn to one-year post-burn levels.

Five Natural Resource Inventory (NRI) plots (**Table 1**) were reread by BRD-USGS and NPS staff . One plot showed a small increase in cheatgrass, three showed no change post-burn. A qualitative observation from Sylvia Haultain, after an informal survey of the valley floor, was that the cheatgrass seems to have taken hold in open clearings that appear to have burned hot.

Trends from the NRI plots differed considerably from the fire monitoring plots. The fire effects plots were specifically set up in areas that were burned and are designed and monitored specifically to detect trends following fire. The type of data collected in NRI (Natural Resource Inventory) plots is different and in this case, does not always record quantitative change for a particular species. Additionally, sample size was very limited with one of the plots located in an area that has not burned with two of the others located in fairly moist areas with heavy forest cover (Brent Johnson felt that even with canopy removal cheatgrass would not readily establish at these sites because of soil or moisture conditions or competition from native species such as ***Pteridium***).

<u>*Soil Sampling*</u>
Soil sampling (Williams 1998) was conducted in Cedar Grove to determine if there was a relationship between K/Mg ratios and site susceptibility to cheatgrass invasion as found on the Colorado Plateau

Table 1. Vegetation plot identification and location.

Plot Type	Plot ID	utmE / utmN	Plot Type	Plot ID	utmE / utmN
NRI	157	$^{3}60$ / $^{40}73$	***Fire Effects***	89	$^{3}51^{229}$ / $^{40}73^{012}$
	156	$^{3}59$ / $^{40}73$		90	$^{3}54^{831}$ / $^{40}72^{226}$
	153	$^{3}55$ / $^{40}72$		91	$^{3}54^{5--}$ / $^{40}72^{3--}$
	158	$^{3}51$ / $^{40}73$		92	$^{3}54^{351}$ / $^{40}72^{044}$
	152	$^{3}54$ / $^{40}72$			

and California Deserts. At these sites K/Mg ratios have generally been found to be high (Jayne Belnap, personal communication). In Cedar Grove, eight sites (**Fig. 7**) were sampled with a single composite soil sample (derived from 30-60 individual auger samples) collected from each site. Samples were stratified into four groups (2 samples each):

1) Recently burned, with BRTE
2) Recently burned, without BRTE
3) Not burned recently, with BRTE
4) Not burned recently, without BRTE

Samples were sent to Jayne Belnap (NPS) in Moab for analysis. The results of the soil chemistry analysis were interesting and quite different from that expected (Jayne Belnap, personal communication). Unlike desert soils, K/Mg ratios were lower in areas where cheatgrass was located and higher at non-cheatgrass sites. However, she did not feel this was the explanation. The analysis also indicated significantly higher N levels (3x) in cheatgrass versus non-cheatgrass sites which she felt was a more probable cause. Additionally, there were no significant soil chemistry differences found between burned and unburned soils. These results suggested to her that cheatgrass occurrence is related to disturbance and high soil N levels. In other research on sagebrush grassland, soils with elevated N levels, were found to increase the density of annuals and lengthen the time the site is dominated by annuals (McLendon and Redente 1994). The high N levels were required to support the high biomass production of the annuals and allow them to dominate. However, among the annuals investigated, the authors also stressed that "***Bromus tectorum*** *has the potential for extending the dominance of annuals on semiarid disturbed sites longer than would be otherwise possible because of its low N requirements and early growth characteristics*".

Mapping Survey

On October 6-9, 1998 a field survey mapped the extent and density of cheatgrass occurrence in many susceptible areas in the valley. The objective was to identify the location and relative density of cheatgrass stands in Cedar Grove. The survey information was intended to be used to assess the locations of existing cheatgrass in relation to past burns, disturbances, its possible relationship with soil or vegetation types, and to provide some comparative documentation for future surveys.

The survey consisted of directly mapping of cheatgrass occurrence onto color infrared digital orthophotos (DOQ) generated by the park GIS Lab. The lab (Pat Lineback and Karen Folger)

Soil Sampling
Cedar Grove and Kings Canyon

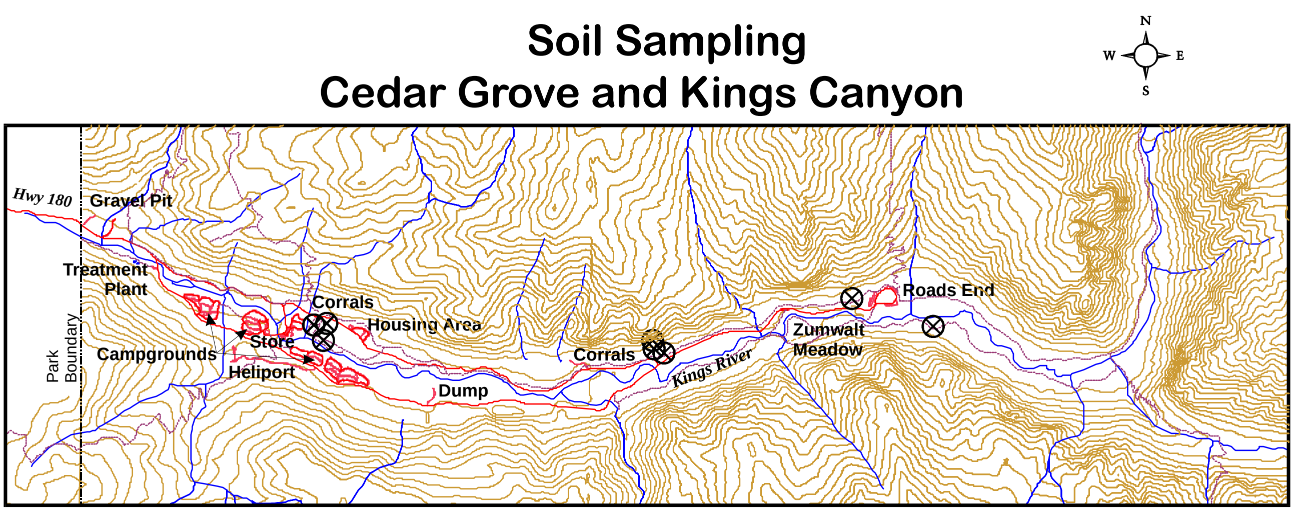

Figure 7. Soil sampling sites in Cedar Grove area, Kings Canyon.

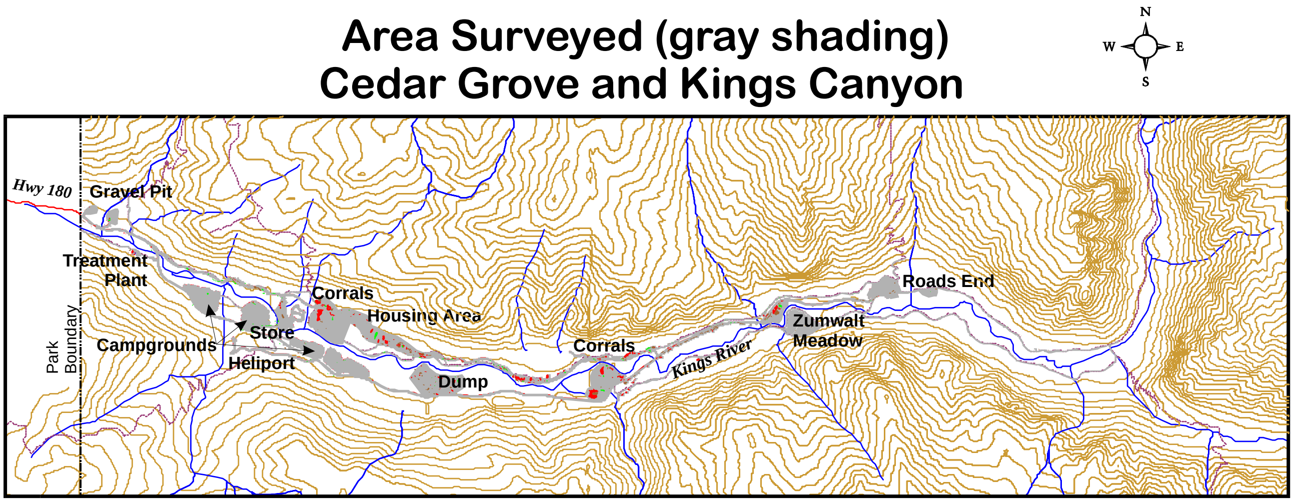

Figure 8. Area surveyed for cheatgrass occurrence (shaded gray) in Cedar Grove, Kings Canyon.

processed the photos to be consistent with the map projection (NAD27) of other park GIS data. The digital orthophotos of the survey area were produced at a 2,500:1 scale, and overlaid with road and trail information. Registration between the one meter orthophoto data and the USGS digital linear graph (DLG) road and trail data was imperfect, but useful. Ten to forty meter differences between the DLG overlay and occurrence of the same feature in the orthophoto data were evident.

An extensive survey of the much of the valley floor was conducted using the digital orthophoto maps, with individuals walking roads and trails and mapping cheatgrass occurrence (outline of patch) and density of patches (low, <10% cover; moderate, 10-50%; and high, >50%) visible from those corridors (**Fig. 8**). The only other attribute data collected for this extensive survey was relative density of patches. The survey concentrated on developed areas, stock trails, road corridors, and the Kanayers Loop out of Roads End to Bubbs Creek. Mapping along roads and trails allowed large areas to be mapped at a rapid pace. Several areas of high concentration, identified from roads and trails, were surveyed more intensively. All mapped cheatgrass patches were digitized and made available as an ArcView shapefile. Total area surveyed was also determined from field maps and by buffering areas visible from roads or trails (12.5 m and 10 m either side respectively).

Of the approximately 1,035 ha area of the Kings Canyon valley floor, ~261 ha (~25% of possible area, light gray shaded areas **Fig. 8**) were surveyed with 0.9% covered by low density patches (<10% cover), 1.6% moderate density (10 - 50%), and 3.1% high density patches (>50%). Patches were almost always associated with some kind of disturbance such as fire, pack animals, mechanical, or water courses. Of these, the predominant disturbance appeared to be fire (**Fig. 4 and 9** - diagonally-hatched areas); however, not all burned areas had been invaded indicating confounding influences. The main areas of high density patches not associated with fire appeared to be associated with stock use and manure piles near the corrals. Additionally, of note was that little cheatgrass was found in campground areas. Although these areas are probably highly disturbed, the type and magnitude of disturbance may not facilitate cheatgrass invasion. Campgrounds tend to be extensively trampled and with compacted soils.

<u>*Picnic Estates Burn*</u>

In consultation with Jeff Manley, Dave Ashe burned three acres in the Picnic Estates area where one fire effects plot is located. Pre- and post-burn photos were taken by Dave from a permanently established photo point at this site (**Fig. 10**). This burn was to provide mostly qualitative data on the

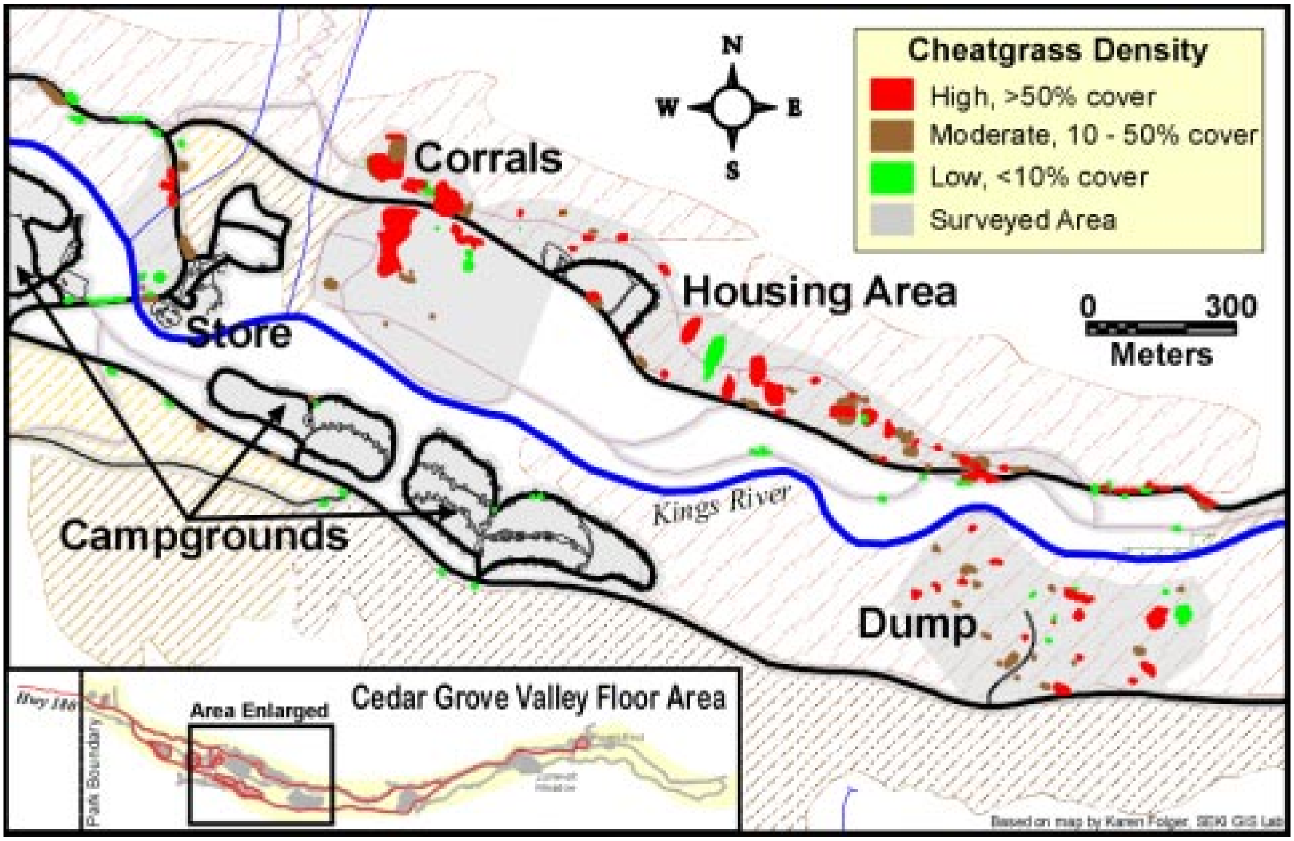

Figure 9. Surveyed areas (light gray shading) and cheatgrass density in Cedar Grove. Old manure dumping area is located south (across road) from corrals. Past burns are shown as diagonally hatched areas. Approximate valley floor area is shown in inset by light yellow shading. Trails are shown as dotted lines and roads as solid black lines.

response of cheatgrass to burning during the summer. Due to the sparse fuels in some areas, burn intensities were not high in many areas, and a layer of unburned litter remained in places beneath a surface scorch of the top layer. Germination of cheatgrass was observed in the burn during the cheatgrass mapping survey in early October, 1998 (Anthony Caprio, personal observation). In early May 1999 observations by Dave Ashe (personal communication) suggested that cheatgrass in this area was smaller and not as mature as in non-burned areas.

<u>*Seed Banks*</u>
During the 1998 field survey surface soil and litter samples were collected from a variety of sites (**Fig. 11** and **Table 2**) to examine seed banks and potential germination and whether seed banks could be used as a means of monitoring the occurrence and density of the species. This approach has been used successfully in several studies (Billings 1994). Understanding seed bank dynamics is critical in developing long-term control methods if viable seeds are maintained in the soil over multiple years. Additionally, monitoring seed banks may be important if plant establishment is variable between years and thus not a reliable estimator of potential problems during any given year.

Results of the soil seed bank germination trial indicate that monitoring cheatgrass population densities is possible (**Figure 12**). There was a fairly strong association between adult plant density and seed bank as measured by seed germination, although there was some variation in the high category. Average germination density for the four adult plant density classes used in the mapping survey (low, <10% cover; moderate, 10-50%; high, >50%; and none) were: none=0.64 plants per sample, low=2.54, moderate=0 (only one location was sampled with this density), and high=32.17.

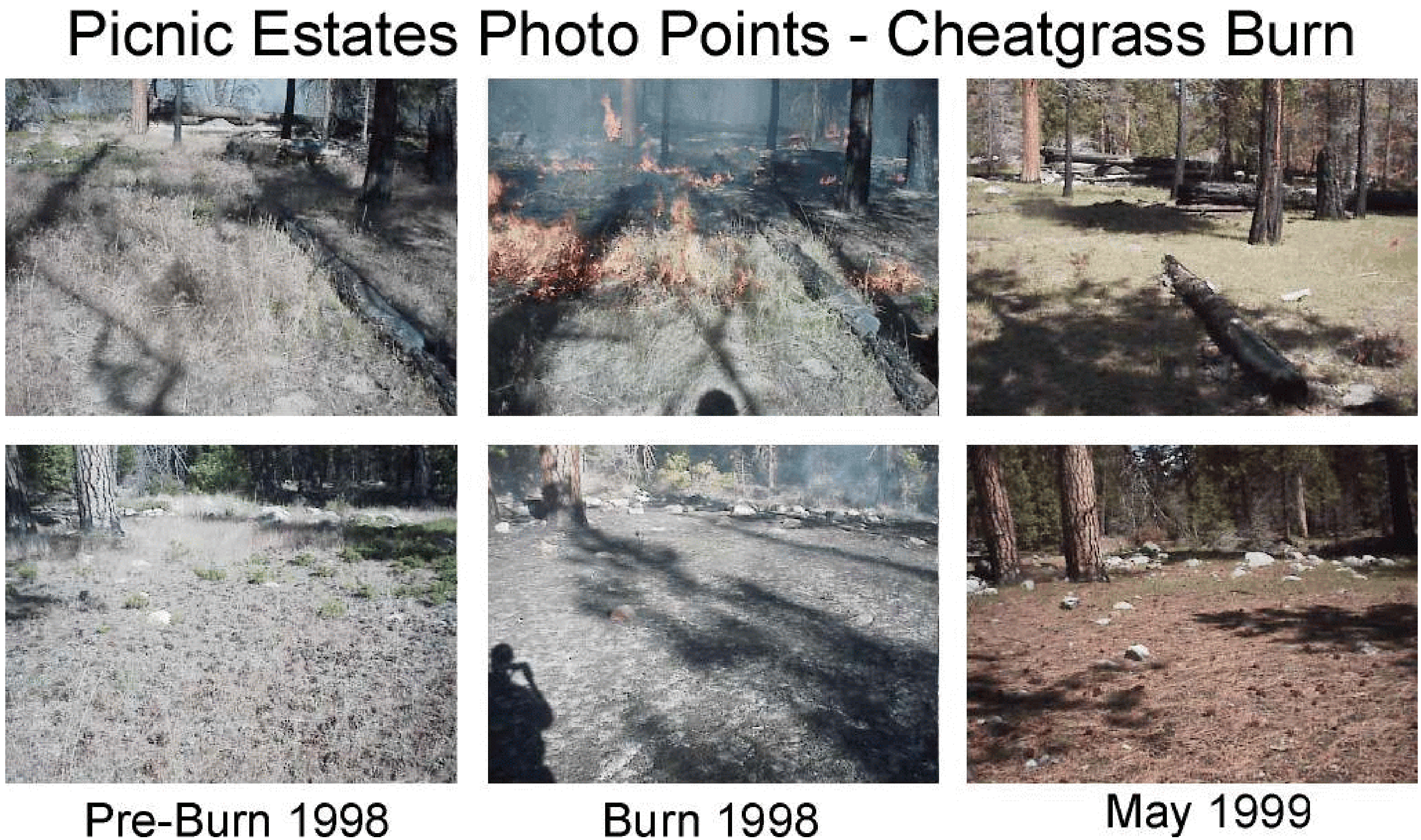

Figure 10. Repeat photography at two points showing occurrence and minimal change in cheatgrass density in burned area (photos by Dave Ashe).

The germination sample with the greatest seed density was obtained from the corral manure dump (141 seedlings in 237 cc of soil which is equivalent to about 594,000 seeds per cubic meter of soil).

Pack Station Manure Dump

In the fall of 1998 Jason DeNeau (1998) surveyed the extent of the manure dump at the Cedar Grove Pack Station where very high densities of cheatgrass is found. The historic dump site, 0.74 ha in size and used for at least the last 18 years, has been identified as a significant cheatgrass seed source. DeNeau also reviewed the scientific literature for potential cheatgrass control measures that might be used to restore the dump site. Potential methods for control or eradication include:

- Physical removal
- Solarization
- Prescribed burning

Table 2. Location and description of soil seed bank samples.

Site Area Name	Plot Number	Utm E*	Utm N*	BRTE Density	Canopy
Roads End	0	358895	4073053	low	open
Roads End	2	359268	4073126	low	open
Roads End	3	359464	4073110	none	open
Roads End	4	359331	4073088	none	open
Roads End	5	359352	4073099	low	closed
Roaring River	6	355250	4072068	low	closed
Roaring River	7	355209	4071996	high	open
Roaring River	8	355200	4072076	low	open
Roaring River	9	355238	4072058	none	open
Zumwalt	10	357445	4073014	high	open
Zumwalt	11	357408	4072881	low	open
Zumwalt	12	357386	4072836	none	open
Zumwalt	13	357748	4072746	none	closed
Roads End Circle	14	358696	4073178	none	open
Hole in Wall Corral	26	354464	4072019	low	closed
Hole in Wall Corral	15	354464	4071969	high	open
Hole in Wall Corral	16	354592	4071966	mod	open
Hole in Wall Corral	17	354571	4071963	low	open
Manzanita Field	18	353479	4072262	low	open
Corral Manure Pile	19	351715	4072809	high	open
Corral Manure Pile	20	351711	4072819	none	closed
Corral Manure Pile	21	351801	4072798	low	open
Fire Effects Plot - Picnic Estates	22	351261	4072996	high	open
Fire Effects Plot - Picnic Estates	23	351291	4072963	unknown	open
Fire Effects Plot - Picnic Estates	24	351240	4073038	high	open
Fire Effects Plot - Picnic Estates	25	351224	4073007	unknown	open

* UTM coordinates are ± ~20 m.

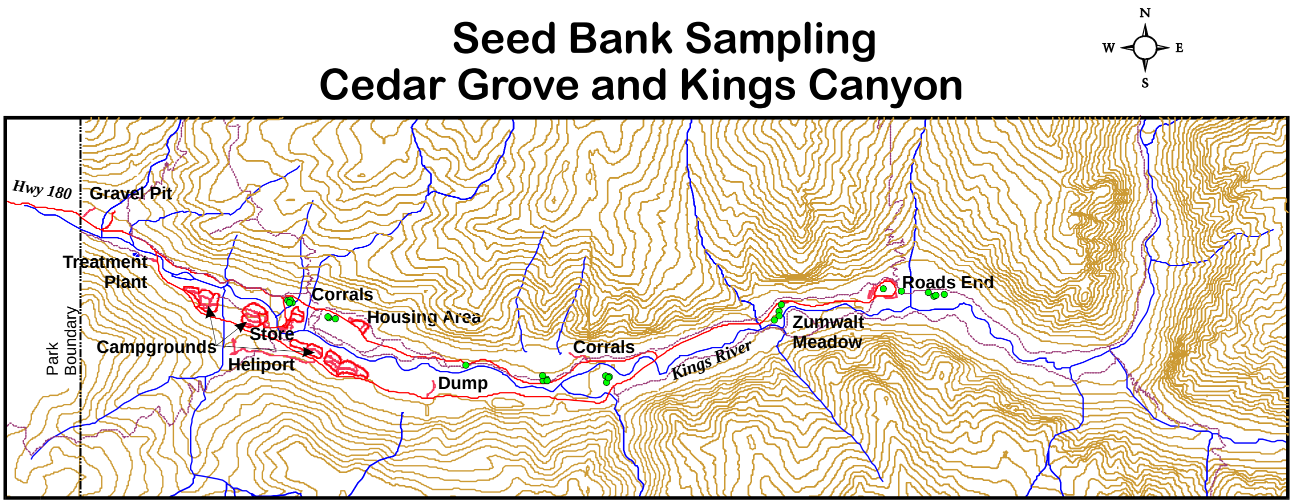

Figure 11. Soil seed bank sampling sites in Cedar Grove area, Kings Canyon.

- Chemical control
- Biological control
  - introduction of competitive perennial grasses
  - use of deleterious rhizobacteria

Cheatgrass Literature Search

A literature search of recent publications addressing cheatgrass management was contracted with Jason DeNeau. Concentration of the search was on articles referring to cheatgrass and fire and to cheatgrass and special management topics. This search was invaluable in providing up-to-date information on planning and for making recommendations.

Summary

The fall 1998 mapping survey documented the widespread occurrence of cheatgrass within Cedar Grove. Patches appeared to be associated with open areas and with disturbances, such as fire, pack animals, or mechanical. However, not all burned areas or sites with disturbance (campgrounds) have been invaded by cheatgrass. The current data collected from the various plots and the field survey mapping, combined with field observations suggests that cheatgrass on the valley floor of Kings Canyon tends to be limited to soils on drier well drained upland benches in contrast to moister areas along semi-perennial water courses (although it was observed in some ephemeral water courses). This was also noted by Brent Johnson during the NRI sampling. He felt that even opening the canopy of these lower wetter areas would not allow cheatgrass to invade (are relatively immune to cheatgrass invasion due to the moister availability). Soil chemistry analysis points to cheatgrass occurrence being related to disturbance and high soil N levels, although this needs further investigation, with a larger sample set and more extensive site descriptions and analysis.

Recommendations

Based on the limited data collected during 1998 and the available research literature, it appears likely that cheatgrass occurrence in Cedar Grove is at least partially associated with a combination of factors including: 1) high N concentration in soils, 2) soil disturbance, and 3) availability of a seed source. However, we want to stress that the current findings are still largely exploratory and were the result of sampling designed more to generate questions than to provide answers. Additional, more detailed field work is needed to provide thorough answers and verification of the current findings.

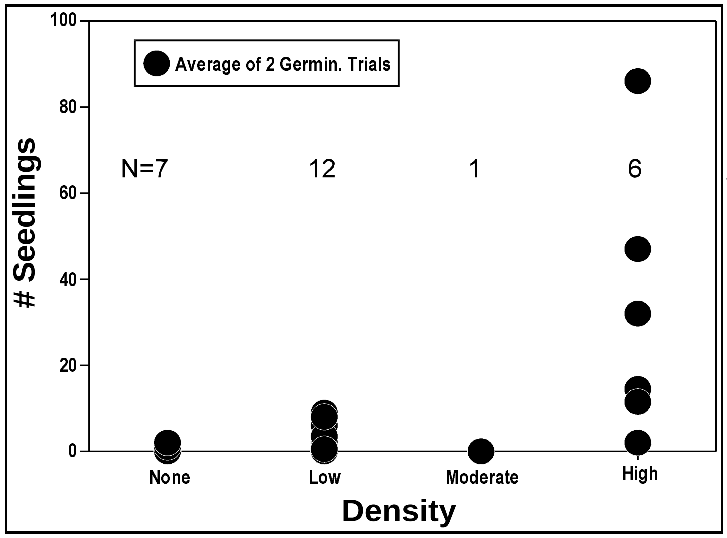

Figure 12. Soil seed bank germination results. Density categories correspond to values used in mapping survey (low, <10% cover; moderate, 10-50%; and high, >50%).

Of the three factors associated with cheatgrass occurrence, disturbance may be a result of any number of causes: fire, mechanical, stock, or water. High N in soils may be natural or artificial due to stock manure or other human sources. Seed source is probably due to vectors such as stock traffic and manure, human transport (vehicles or clothing), and possibly wildlife. At this time, we believe ***the most important consideration for reducing further spread of cheatgrass in the valley would be to minimize disturbances*** of any kind on the valley floor. However, it is not clear at this time what approach should be used to remove or reduce cheatgrass in areas where it has already become established.

A decision was reached to recommend limitations on burning on the valley floor in Cedar Grove (Maintenance and Hole-in-the-Wall Segments) during 1999 after examining these considerations. Our biggest obstacle to providing direction to burn operations is the lack of information about the basic biology of cheatgrass in this particular setting and how it might react or respond to various management actions. There is concern about two types of impacts. One is the direct resource impact caused by the occurrence of the species and the other is the more indirect but cascading impact of a curtailed or more limited burn program. However, because of the well documented association between cheatgrass expansion and fire we feel that caution needs to be exercised in the application of fire in the valley.

It is also important to address the issues surrounding manure disposal within the context of invasive weeds. The two-acre manure dump adjacent to the Cedar Grove Pack Station is likely a significant source of cheatgrass seed for the rest of the canyon. We recommend that action be taken to either treat or remove the accumulated manure from the corral site and the recently developed dumpsite (see Jason DeNeau's 1998 report re alternatives). In the long run, the issue of weed seed being brought into Cedar Grove through feed for both administrative and commercial pack stock must be evaluated. As weed free hay becomes available in California through the newly proposed certification program, requiring its use (or similar weed-free feed) in the park is strongly recommended. In the meantime, a proposal to have the manure from Cedar Grove trucked outside of the park is under preparation. Note that this is an imperfect solution, as it does not address the transport of weed seed by packstock as they travel into the backcountry after eating contaminated feed at frontcountry pack stations.

The literature on cheatgrass invasion and control also indicates that successful mitigation methods vary widely and are frequently site specific. For example, the strikingly different results from the soil chemistry analysis, when compared to desert areas, suggests that cause and responses of cheatgrass in the valley may be quite different from other more well studied locations. This highlights that care needs to be taken in extrapolating results to our area and that there is a need for more local studies to provide better information. It will be important to examine the relationship between cheatgrass and fire and other ecosystem components in Cedar Grove to provide information for long-term control or mitigation of the problem. Further, because this outbreak is occurring in a Mediterranean type climate regime, and most problems have been studied in the Intermountain and Columbia River Basin Regions, information from other regions may not apply or needs to be tested prior to broad application locally. Additionally, low background levels of cheatgrass have been observed in other areas of the park at low-to-mid elevations and any findings on mitigating the spread/impacts in Cedar Grove may have considerable value in managing this species in other locations. Lastly, because of the accessibility and layout of Cedar Grove, with good support facilities, it would be an ideal location for designing and carrying out experimental burning or other treatments. To follow are a number of suggested topics that may provide general guidance for further study.

1) <u>Document Changes in Spatial Distribution and Abundance</u>

Use field survey and GIS techniques to reassess extent and cover estimates of the species during 1999 to ascertain whether further increases in extent and cover occurred since the 1998 survey. Develop monitoring protocols and methods to assess future spread and occurrence of the species in the valley or in other areas of the parks. For example, sampling during 1999 should be carried out to provide an objective estimate of the distribution of cheatgrass on the valley. The objective of the survey would be a complete survey of the valley floor to document extent of cheatgrass occurrence with subsampling carried out to obtain quantitative data at large number of sites that could be revisited over time.

2) <u>Document and Analyze Relationship and Between Site Factors and Cheatgrass Abundance</u>

Carry out studies to examine whether a relationship exists between fire intensity, canopy scorch, soil N concentrations, or other factors and the present occurrence and density of cheatgrass. Examine the influence of other types of disturbance, especially stock corridors, and how these interact with fire. These efforts will provide quantitative information and insights on the relationship between fire and the occurrence of cheatgrass in the valley. These studies will require field surveys, GIS, and statistical analyses. Data could be partially provided by the subsampling carried out during the survey sampling.

3) <u>Mitigating Resource Impacts</u>

It is not known whether the current cheatgrass problem will expand in Cedar Grove or reoccur in other portions of the parks, but beginning to develop potential methods to deal with the immediate threat in Cedar Grove is critical. What is learned about mitigating the problem here may have direct application in other portions of the Parks and in other California parks. Control methods used could be those that have been applied elsewhere or developed specifically for this area. However, developing appropriate mitigation methods will require understanding the basic biological attributes of the species to help identify key points when these methods should be applied.

A) *Relationship to Fire* - The current occurrence and the potential spread of cheatgrass, not just in Cedar Grove but in other areas of the parks, could have significant impacts on the fire management program and the restoration of fire into key Sierran plant communities. Potential experimental burn treatments might include:

a) **season of burning**

b) **pattern of burning** - broadcast vs jackpotting
c) **combined treatments** - burning combined with native vegetation seeding or planting

B) *Relationship to Native Species* - What are the current and potential impacts on understory and overstory species? Are there ways to promote or restock natives so that they limit or out-compete cheatgrass? For example, would direct control of cheatgrass by physically removing individuals reduce its density and allow natural or artificial restocking of natives?

C) *Relationship to Soil Chemistry and Moisture* - The soil samples collected in 1998 have provided interesting preliminary data on differences in soil chemistry between areas with and without cheatgrass. They provide suggestions for further study and insight into the complexity of the problem. Additional soil sampling may be needed to further investigate the possible relationship between soil N concentrations and disturbance in order to better understand why some areas are more susceptible to high N levels and thus to cheatgrass invasion. For example, is the N/cheatgrass relationship actually cause and effect or simply correlative and what is the cause or source of the increased N in the soils? Is it due directly to mechanical disturbance and the loss of vegetation (St. John 1999) or to other factors such as release of N by burning, stock manure, atmospheric deposition of N from anthropomorphic sources, or a combination of these?

Several possible experiments have been suggested to test the N/cheatgrass relationship (Jayne Belnap, personal communication). One would be to add N to areas with low density or no cheatgrass and see if this results in a patch formation. Conversely, soil N could be reduced in current cheatgrass patch areas to determine if this reduces the cheatgrass density. This may be fairly easy to accomplish, as some experimental work suggests that adding organics to soils with high N content will reduce N concentrations temporarily through the immobilization of soluble nutrients in microbial biomass (St. Johns 1999). This temporary N reduction must be followed by the reintroduced and established of rapidly growing native species and an associated mycorrhizal host network in the soil to maintain the site.

Additionally, we should investigate the relationship between patterns of soil moisture across the valley which may also be important in understanding susceptibility of sites to colonization and success of cheatgrass. Considerable variation exists across the valley floor, from the moist lower benches located along the Kings River to much drier flats (such as the area locally known as the Gobi Desert) located away from the river.

D) *Life History Strategies and Population Dynamics* - Understanding basic population dynamics and life history strategies of this species in Cedar Grove could provide insight into strategic timing or points in the species life cycle when mitigation efforts are best applied. These attributes have been well described from the Intermountain and Columbia River Basin but are largely unknown from the Sierra Nevada where a distinctly different climate regime prevails.

a) **phenology** - Assessment of the relationship between synoptic weather patterns and cheatgrass phenology and response is needed to examine the potentially interacting effects of year-to-year moisture regimes on this invasive species. Dave Ashe has begun to implement basic monitoring of this type for 1999.
a) **life cycle** - What is the year-to-year variation in germination, establishment, and reproduction of the species? Are there certain "year types" related to climate variation

or other factors when the species would respond better to control measures?
b) **seed banks** - Description of seed bank dynamics is vital to understanding cheatgrass life history (Pyke 1994). Important components include: long-term viability, germination fraction within and between years, spatial variability, and potential predators. Understanding seed bank dynamics is critical in long-term control if viable seeds are maintained in the soil for any length of time. Pyke (1994) lists several specific questions that should be addressed in order to design effective control measures.

- Do seeds persist in the soil or litter, and if they persist for how long?
- How quickly does the seed bank decline over a growing season (and between growing seasons)?
- Does dispersal occur immediately after maturation of seeds or are seeds dispersed over an extended period?

For example, in Cedar Grove the noticeable flush of cheatgrass during 1998, an El Niño year, may have been due to a residual seed bank built up over several years (a previous flush may have occurred during the 1982/84 El Niño event [Scott Williams, personal communication]).

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