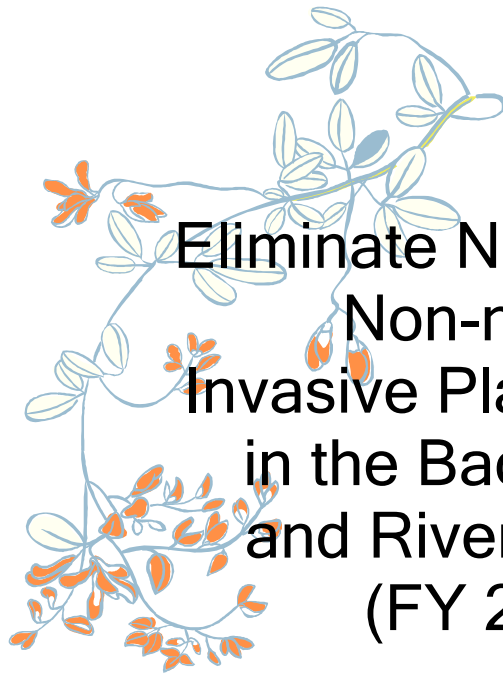




**Eliminate New Starts of
Non-native,
Invasive Plant Species
in the Backcountry
and River Corridor
(FY 2003)**

research funded by

Grand Canyon National Park Foundation

and

Cooperative Conservation Initiative

Report prepared by Julie Crawford, Biologist
Grand Canyon National Park

October 2003

Executive Summary:

Non-native invasive plant species, hereto in referred to as exotic plant species are plants that have been introduced, either accidentally or intentionally, into a region from somewhere else. They have the potential to outcompete native plants for nutrients, light, and water and can alter ecosystem processes. Exotic plants dominate disturbed lands, but many are capable of surviving and thriving in wildlands as well. Not all exotic plant species pose a threat to wildlands and not all wildlands are threatened by invasion. In wildlands such as the backcountry of Grand Canyon National Park (GRCA), it was unknown if exotic plants were a threat. Our study on Rainbow Plateau during the summer of 2003 began a quest into answering the question “do exotic plant species threaten remote areas of the Park?”.

Our research consisted of the placement of 155 vegetation relevé plots on the remote Rainbow Plateau, north Rim, GRCA. This study was designed to investigate the presence and distribution of exotic plants in remote areas of the Park. We took advantage of this opportunity to expand our study to include both native and exotic plant species. In this way we can see what species are present, in what quantities, and how they are distributed across the Plateau. Rainbow Plateau was chosen as our study area because of its remote location, lack of trails or easy access, and due to its relatively natural fire regime. Our intended study site of Powell Plateau experienced a fire in June/July which hastened our decision to relocate our study to the nearby Rainbow Plateau.

Results from our study revealed that this backcountry area of GRCA is indeed threatened by exotic plants. It is our goal to continue investigating other remote areas of the Park to see if this threat is consistently found. Our results revealed that in this area of frequent burn, areas of low severity fire were dominated by “weedy” native species. That is, native species with the capability to produce large quantities of easily transported seed and those that reproduce vegetatively. In areas of higher severity fire (small patches across the Plateau) there tended to be a stronger presence of exotic plant species. In all, there were 10 exotic plant species found on the Plateau with cover ranging from less than 1% to 63% in a single plot.

Plant distribution was not uniform across the Plateau; the Lower section of the Plateau contained much greater quantities of both exotic and weedy native species. In addition to vegetation data, we also gathered abiotic factor data including slope; aspect; cover of ground, rock and litter; and overstory canopy cover. These data, in conjunction with anecdotal evidence of fire char height and stump / snag presence, provide a clearer picture of the reason behind the plant distribution that we encountered. The Lower section of the Plateau has more soil exposure (less litter accumulation), less overstory canopy closure, and appears to have burned hotter than any other part of the Plateau.

Among the exotic plants present on Rainbow Plateau are the undesirable cheat grass (*Bromus tectorum*), red brome (*Bromus rubens*), and Kentucky bluegrass (*Poa pratensis*). It is a well known fact that cheat grass follows fire and, in return, fuels future fires. So it is not surprising that in areas of high severity fire cheat grass is present. What is surprising is that this and the other 9 exotic species were present in such a remote and rarely visited area of the Park. How did the plants get there? Where did the propagules come from? We can only surmise a combination of wind, animal, and human visitor/researcher dispersal initiated the infestations. With the use of proper equipment such as leather shoelaces, we may ensure that at least the human vector is lessened or eliminated.

Introduction:

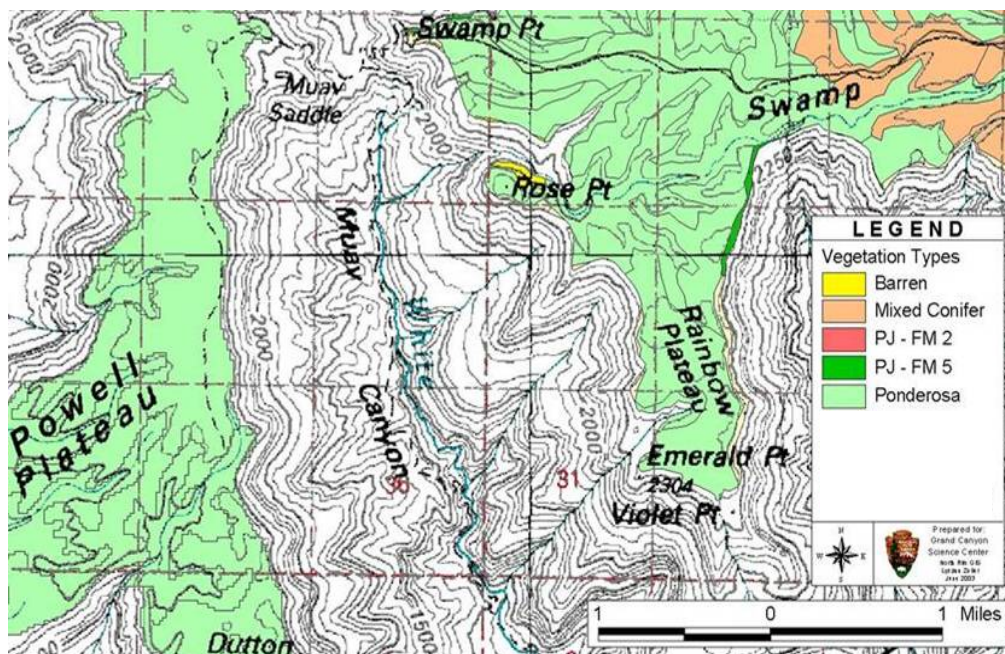
Location:

Rainbow Plateau is located on the north rim of GRCA, 27 linear kilometers to the west of Bright Angel Lodge. It is a peninsular land-mass 2.4 kilometers across at its widest point, 0.7 kilometers at its narrowest, and 3.6 kilometers in length. For ease of discussion, we have divided the Plateau into four main sections: the Upper, Upper Middle, Lower Middle, and Lower (Figure 2). To the north, the Swamp Ridge Road is a cultural divider of the Plateau from the mainland.

The Northern section of the Plateau contains the Saffron Valley and a complex network of its tributaries. An additional unnamed and much smaller tributary, running in a northeast to southwest direction, separates the Middle (including Upper and Lower Middle sub-sections) and the Lower sections of the Plateau (Figure 2). We focused the study on the understory vegetation in the upland areas of the Upper Middle, Lower Middle, and Lower sections only.

Why Rainbow Plateau?:

The intended location of this study was Powell Plateau, a relict island mesa just west of Rainbow Plateau (Figure 1). Within a few days of beginning the Powell Plateau vegetation survey, June 15th, a lightning caused fire began in Muav Saddle, an area between Powell and Rainbow Plateaus. The fire spread westward onto Powell Plateau and burned for a total of 24 days over 1460 hectares (3606 acres).



It has been established in recent work by the Ecological Restoration Institute of Northern Arizona University (Fulé and others, in press; Fulé and others, 2002; Gildar and others, in press; Gildar, 2002) that Rainbow Plateau is similar to Powell Plateau in having a relatively natural fire history. In addition, since there are no trails to Rainbow Plateau, this area is rarely visited (a mere 46 backcountry permits issued in 2002 for Rainbow Plateau plus the surrounding area to the north boundary and east to the North Entrance Station). Based on these two factors, It was then determined that Rainbow Plateau was an excellent substitution for our study of backcountry exotic vegetation in GRCA.

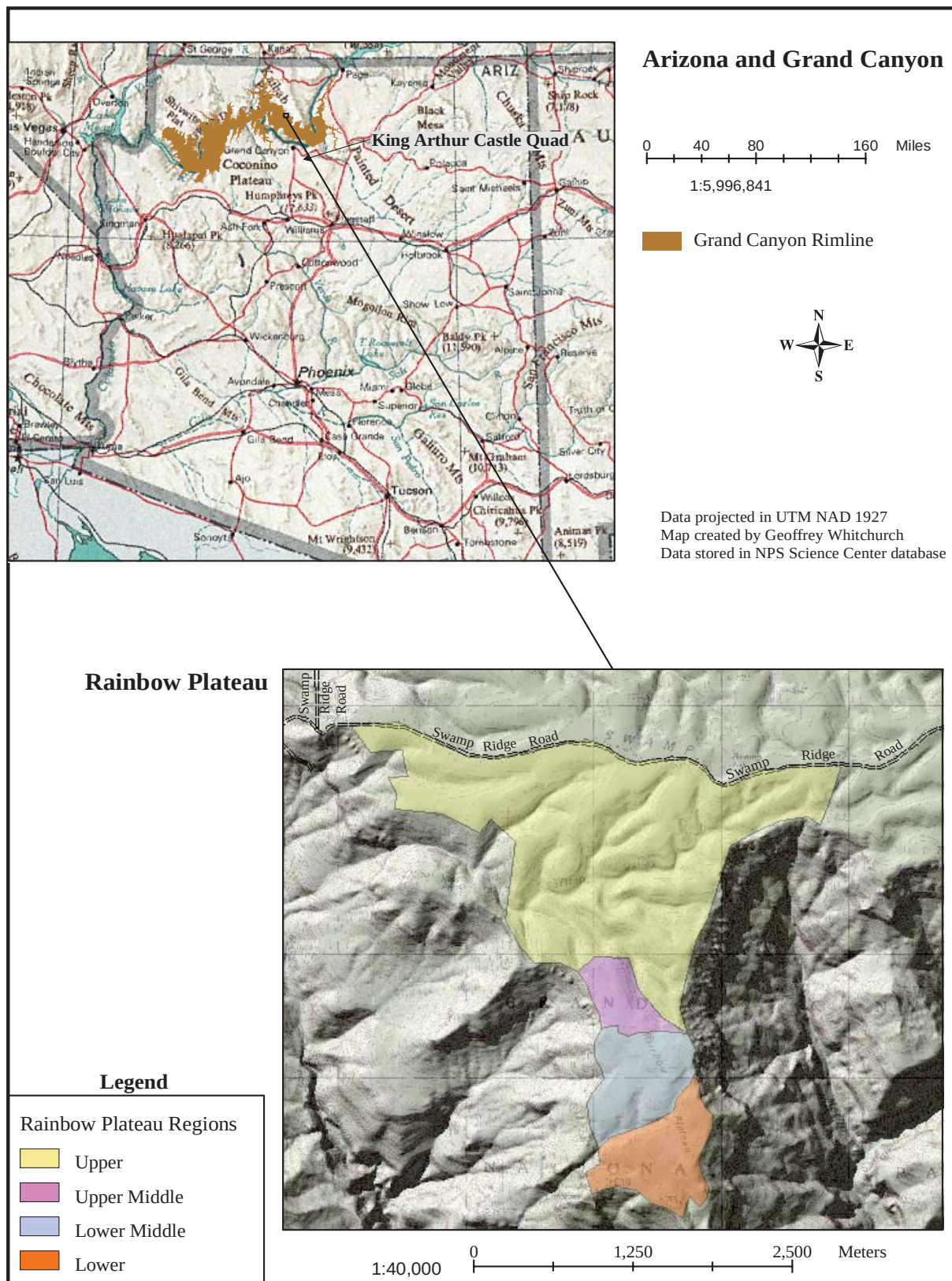


Figure 2. Rainbow Plateau in relation to Arizona; four regions of the Rainbow Plateau study area, north rim, GRCA.

History of Research on Rainbow Plateau:

Historical surveys of Rainbow Plateau include three understory vegetation plots put in by the foresters A.C. Hawbecker and H. Marion in August of 1935. This research was part of a larger study administered by J.D. Coffman, Chief Forester with the National Park Service Field Division of Forestry in Berkeley, California. Their plots, numbers 155, 157, and 161, were located in the Northern section of the Plateau in Saffron Valley. They reported roughly equal proportion of graminoids and litter with *Quercus gambelii* and *Robinia neomexicana* as a minor component in one plot (number 155). Unfortunately, species of graminoids were not differentiated and no other species were reported in this survey. Two photographs from this survey are known (Figure 3; Appendix 1).



Figure 3. Plot 161, Field Division of Forestry study, Rainbow Plateau, Saffron Valley, north rim, GRCA, August 2, 1935.

Since this time, no other studies of vegetation have occurred on Rainbow Plateau until the 1990's. Pete Fulé and co-workers from the Ecological Restoration Institute at Northern Arizona University extensively researched the fire history of the Plateau (Fulé and others, 2002; Fulé and others, in press). In addition, one member of the ERI group, Cara Gildar, studied the understory vegetation of Rainbow Plateau, Powell Plateau, and Galahad Point (Gildar and others, in press; Gildar, 2002). Their results are discussed in later sections of this report.

The only other known vegetation research on Rainbow Plateau consists of rudimentary species lists created during the 1980 and 1997 archaeology surveys of the Plateau's rim. These lists all contain the species New Mexico locust (*Robinia neomexicana*), Gambel's oak (*Quercus gambelii*), and "grasses"; while some plots list pinyon (*Pinus edulis*), cliffrose (*Purshia mexicana*), and century plant (*Agave* sp.) (clearly not in the ponderosa pine forest). There are often comments regarding fire blackened trees, re-sprouting shrubs, and the presence of weedy species like thistle (*Cirsium* sp.): all evidence of previous fire activity on the Plateau.

Vegetation:

The tributary vegetation of the Upper section of the Plateau consists of a combination of upland species such as ponderosa pine (*Pinus ponderosa*), and New Mexico locust, as well as more cold-tolerant and water-loving species such as aspen (*Populus tremuloides*), mountain lover (*Paxistima myrsinites*), lovage (*Ligusticum porteri*), snowberry (*Symphoricarpos sp.*), and Rocky Mountain maple (*Acer glabrum*). As the vegetation of the ponderosa pine community is our primary focus in this study, we chose not to sample this tributary community; however it may be surveyed in the future.

The vegetation of the Upper Middle and Lower Middle Plateau sections are typical of an upland ponderosa pine forest with a largely open understory layer (Figure 4). This forest is dominated by native bunchgrasses and forbs such as mutton grass (*Poa fendleriana*), goldenrod (*Solidago spp.*), and purple aster (*Machaeranthera canescens*). It also contains the fire sprouting shrubs New Mexico locust and Gambel's oak in both the understory and mid-canopy vegetation layers.



Figure 4. Typical upland ponderosa pine forest of Rainbow Plateau, north rim, GCNP.



Figure 5. Cheat grass dominates plot in Lower section, Rainbow Plateau, north rim, GRCA, September, 2003.

The Lower section is dryer, containing higher proportions of exposed Kaibab Limestone soils and less overstory canopy. This section is characterized by more weedy species such as carruth sagewort (*Artemisia carruthii*), fleabane (*Erigeron divergens*), hairy goldenaster (*Heterotheca villosa*) and the exotic cheat grass (Figure 5).

The perimeter of the Plateau is even more xeric, with the vegetation blending into the chaparral and pinyon-juniper woodlands of lower elevations and containing such species as cliffrose, silktassle (*Garrya flavescens*), manzanita (*Arctostaphylos sp.*), and mock orange (*Philadelphus microphyllus*). Again, as this rim community was not the primary focus of the study, we avoided sampling the Plateau's edge.

Exotic Plants:

Exotic plants are those that have been introduced either accidentally (*e.g.* cheat grass) or intentionally (*e.g.* horehound - *Marrubium vulgare*) into an area outside of its natural range (NPS, 1997, 2001; USGS, 2000). Frequently, exotics arrive to their new location without their natural predators and pathogens that would otherwise limit their population growth (Torchin and others, 2003). Exotic plants have the ability to reproduce quickly and prolifically and are able to withstand poor conditions giving them great advantages over native species. This makes them especially prominent in areas of disturbance.

While all exotic plants are able to thrive in disturbed areas, not all are able to colonize and reproduce in undisturbed areas. Those that do have the ability to out compete native plants for sunlight, nutrients, and water and may even alter ecosystem processes such as fire regimes. They have the ability to turn diverse wildlands and productive agricultural lands into *monocultures* (dominated by one plant species) unfit for wildlife, farming, or recreation. These species are considered invasive and are often deemed “noxious” by local, regional, and even federal governments.

Exotic plant (and animal) species are a problem worldwide, with the number of exotic species and their abundance increasing dramatically over the last century. Exotic plants pose serious threats to National Parks (Bratton, 1982; Randall, 1996; Wuerthner, 1996; NPS, 1997, 2001), infesting more than 30% of National Park Service lands in the contiguous 48 states (USGS, 2000) and comprising up to 25% of the flora of some Park areas (Vitousek and others, 1996). In GRCA, the number of exotic species has increased from 9 exotic plant species reported in 1930 to over 160 exotic plant species known from the Park today.

Exotic plant species on Rainbow Plateau include the following: cheat grass, red brome, prickly lettuce (*Lactuca serriola*), goatsbeard (*Tragopogon dubius*), lambsquarters (*Chenopodium album* and *C. desiccatum*), dandelion (*Taraxacum officinale*), horsetweed (*Conyza canadensis*), Kentucky bluegrass, and woolly mullein (*Verbascum thapsus*). Stickseed (*Lappula occidentalis*), an invasive native, is also present. Exotic plant distribution across the Plateau is not uniform, with highest concentrations in the Lower section.



Figure 6. Researchers boot filled with cheat grass seed, Rainbow Plateau, north rim, GRCA, September, 2003.

The seed source for this exotic invasion is unknown, but wind, bison, hikers and biologists, and native mammals are likely candidates for transport of seed from nearby infested areas (Figure 6). It is the intention of the Vegetation Program during the summer of 2004 to treat concentrated infestations of both woolly mullein and Kentucky bluegrass on the Plateau. This will be followed by re-examination in later years. It is also our hope to determine the feasibility of controlling exotic *Bromus* spp. on the Plateau.

Fire:

Fulé and others established the fire history of the Plateau showing that prior to 1879 the maximal fire-free intervals ranged from 11 to 18 years. Since then, there have been fires in 1900, 1908, 1938, 1944, 1948, 1970, 1985, Emerald Fire Use Fire of 1993, and an aerially ignited fire of 1998 (Fulé and others 2003, Tim Bowden personal communication, Ken Kerr personal communication). The southern tip of the Plateau has been the recipient of the majority of these fires (1908, 1938, 1944, 1948, and 1970), including the start of the Emerald Fire which began in the southwest corner of the Plateau, moving northeast, and covering 138.4 hectares (342 acres). Evidence of past fire was found in most of our plots and, based on tree charring, appears to have been moderate to low severity in most locations across the Plateau, with occasional pockets of high severity fire, especially on the Lower section (personal observation).



Figure 7. Exotic and weedy native vegetation following a hot burn flare-up, Rainbow Plateau, north rim, GRCA.

Recent understory vegetation studies of southwestern ponderosa pine forests show that fire severity plays a large role in post-fire vegetation recovery (Allen, 2002; Crawford and Moir, in preparation; Crawford and others, 2001; Griffis and others, 2001). High severity fires support populations of exotic plant species by creating openings and allowing these highly competitive plants to establish and spread along with weedy natives, but before later successional natives have an opportunity (Figure 7).

Post-fire species composition often differs greatly from pre-fire conditions. While species diversity often increases following both high and moderate severity fires, this may be attributed to the increased presence of exotic plant species (Crawford and others, 2001). Typically both above and below ground (seedbank) floras differ greatly, with seedbanks of frequently disturbed areas containing more weedy and exotic species and being more depleted (Warr and others, 1993; Manders 1990).

These findings are corroborated by Gildar's study of the understory vegetation composition and cover on the frequently burned Rainbow and Powell Plateaus in comparison to the nearby unburned Galahad Point (Gildar and others, in press; Gildar, 2002). Her study revealed several interesting things:

- 1) a depleted seedbank existed in areas of frequent fire and a large seedbank was found in an unburned area
- 2) no exotic species were present in an unburned area, but exotic species were present in recently burned areas
- 3) great variation in understory composition occurred between the two years of her study - one year dry (260 mm in 2000), the other wet (505 mm in 2001)
- 4) herbaceous cover and species composition at the unburned site differed significantly from the two burned sites in both years.

Although it is evident that fire severity plays a great role in the vegetation composition and distribution on Rainbow Plateau, the author is unaware of the existence of fire severity maps for any of the Rainbow Plateau fires. During our vegetation survey, no direct measures of fire severity were taken; however, fire severity may be surmised from our qualitative site descriptions. In addition, our ocular estimates of soil and litter cover as well as canopy closure shed light on the distribution of fire severity levels across the Plateau.

Bison:

We found evidence of bison in 154 out of our 155 vegetation plots. This evidence was in the form of entrenched hoof prints, dung, and bedding sites (Figure 8). The bison have been reported from the Park for the last 10 years only and have been documented in recent years to be in large herds of up to 90 animals (personal communication Elaine Leslie). Bison cause damage to soils and are effective vectors for exotic plant dispersal.



Figure 8. Bison dung and hoof prints on Rainbow Plateau, north rim, GRCA, September, 2003.

Currently, studies by Park personnel are underway to determine both if the bison are historically native to the Grand Canyon region and if these bison are genetically pure or a hybrid with domestic cattle. Even if bison were present in the area and the herd proves to be genetically pure, NEPA analysis would be required before bison could be allowed to expand in the Park (Jurgensen, in preparation).

Methods:

The purpose of our research was three-fold: to determine the extent and location of exotic plant species infestations in this remote backcountry area; to conduct a survey in which plant species composition was determined for Rainbow Plateau; and to determine an appropriate methodology for similar surveys in other remote areas of the Park. We used the relevé method in a stratified sampling scheme as a rapid, yet accurate, survey technique which met all of our research needs.

Used traditionally in vegetation classification and mapping, the relevé method served as an excellent tool for detecting native and exotic plant species distribution and abundance in the homogeneous upland ponderosa pine plant community of Rainbow Plateau. Our relevé method consists of one or two qualified personnel listing every plant species within the plot area (see plot description below). After the lists are created, the percent cover of each species as well as total exotic and total native vegetation cover was determined based on ocular estimation and the use of a modified Braun Blanquet scale (less than 1% cover, 1-5% cover, 6-25% cover, 26-50% cover, 51-75% cover, 76-95% cover, and 96-100% cover).

Within each section (Upper Middle, Lower Middle, and Lower), 50 or more plot centers were located and 40 meter diameter relevé vegetation plots established around each point, for a total of 155 plots (Figure 9). We chose a random location for our first point in each section,

with all additional plots placed 50 meters apart in a north-south-east-west grid pattern (Figure 9). All points were determined with a compass and 50 meter measuring tape or laser DataScope. Because points were 50 meters apart and relevé plots 40 meters across, only 10 meters between plots are unaccounted for, providing an intense sample of the Plateau's vegetation.

In addition to understory vegetation measures, percent cover of soil, rock, and litter were determined as well as total native and total exotic cover, slope, percent canopy closure, and aspect. The Garmin V Global Positioning System (GPS) was used to collect elevation and UTM coordinates for each plot center. This data was downloaded in the office for use in ArcGIS mapping software. Attribute data for vegetation in the individual plots were entered into ArcGIS from datasheets filled out by investigators in the field.

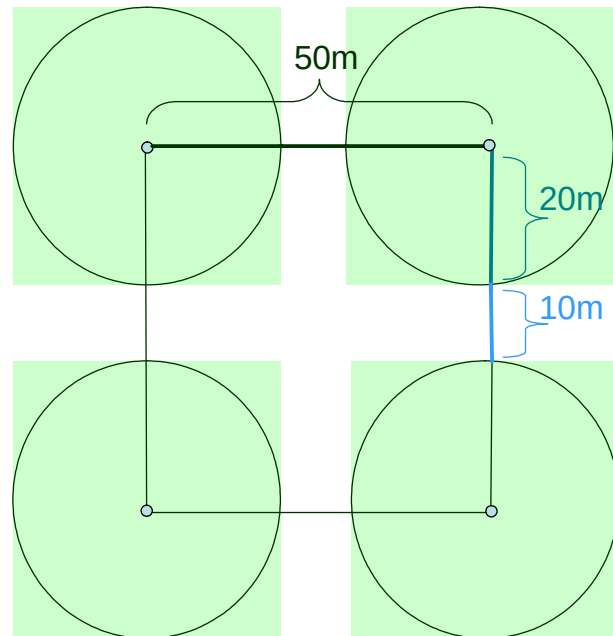


Figure 9. Configuration of the measured relevé plots, Rainbow Plateau, north rim, GRCA.

All unknown plants were collected and identification determined in the Deaver Herbarium on the campus of Northern Arizona University. Not all specimens collected were in fruit or flower making identification of some species impossible. Voucher specimens were deposited in the north rim Herbarium, GCNP.

Data Analysis:

Midpoints of each cover class category were used for all analyses (0.05; 3; 15.5; 38; 63; 85.5; 97.5). Species diversity of each plot was calculated using species richness - total number of species per sample (Moore and Chapman, 1986), the Shannon-Wiener function (Kent and Coker, 1992), and Pielou's evenness index (Pielou, 1975). Plants were separated into lifeform group (graminoid, forb, shrub, tree) for basic statistical comparisons.

Floristic composition among plots was explored using global non-metric multidimensional scaling, herein referred to as NMDS (Minchin, 1989). This method created a spatial representation of ranked species composition and cover data from our 155 vegetation plots. Relationships between environmental variables and NMDS configurations were examined by fitting vectors of maximum correlation within the NMDS configuration (Downes and others, 1995; Wahren and others, 1999). The non-parametric ANOSIM procedure of Clarke (1993) was used to compare floristic differences among and between the three Plateau sections. The SIMPER routine (Clark 1993) was used to calculate the relative contribution of each species and identify the most important species that characterized the three Plateau locations. This analysis also revealed amount of dissimilarity between Plateau sections.

The GIS team created two maps illustrating the geographic locations of Rainbow and Powell Plateaus. In addition, a map showing total exotic plant cover relative to total vegetation

cover (native and exotic) in plots across the Plateau was created. As not all points fell in straight lines, we slightly modified the UTM coordinates for 23 of the 155 plot centers. Plot centers deviated from straight lines for two main reasons: point locations were not always averaged on the GPS units in the field, and vegetation was often thick, making navigation difficult.

Results:

There were 10 exotic species among the 123 vascular plants recorded from our plots on Rainbow Plateau (Appendix 2). The mean cover of exotic plant species (graminoids and forbs) in the Upper Middle, Lower Middle, and Lower sections of Rainbow Plateau were 2.6, 1.0, and 9.3 respectively (Figure 10). The mean of exotic cover by Plateau section is deceptively conservative, as individual plots often had much higher cover of exotic species. In general, the Southern portion of the Plateau has much higher concentrations of exotic plants than the other sections. This is with two exceptions, plot 11-6 of the Upper Middle section contained 63% Kentucky bluegrass and plot MAA2 of the Lower Middle section contained over 15% cheat grass. In the Lower section cheat grass reached 38% cover in 8 plots and over 15% cover in 12 plots.

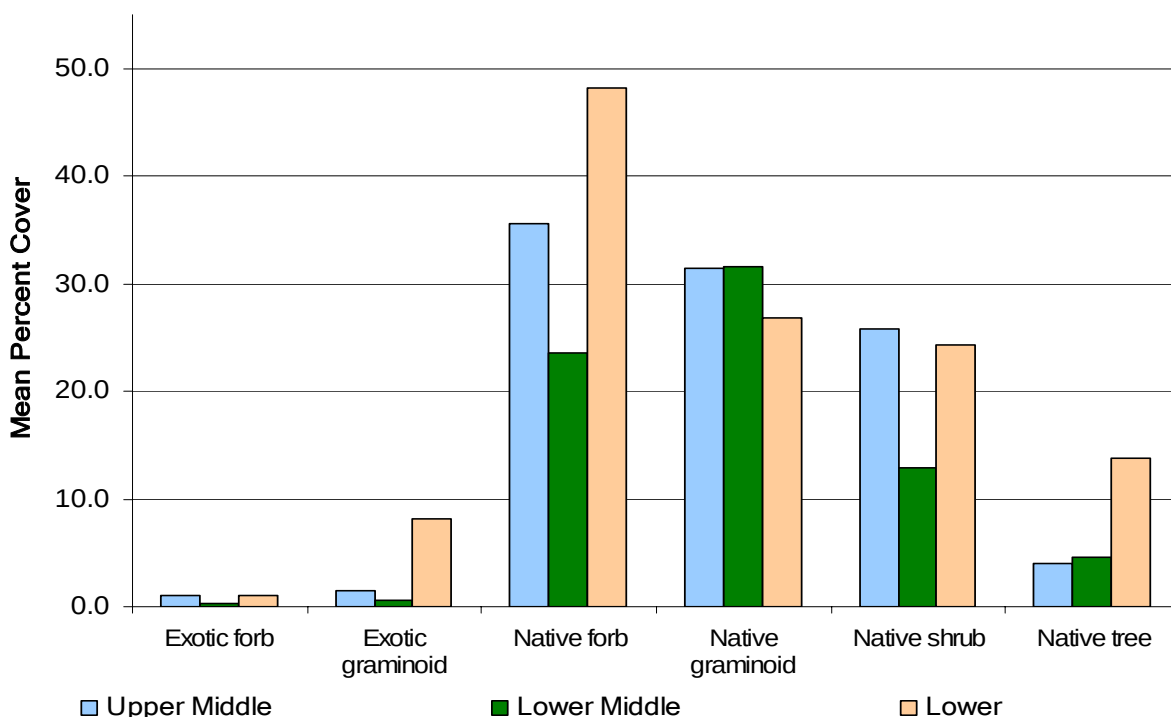


Figure 10. Mean vegetation cover by lifeform across Rainbow Plateau, north rim, GRCA.

Mean species diversity in each of the three Plateau sections are similar although the Lower section is highest in Richness, Evenness, and Shannon Diversity Index (Table 1). This is likely due to the higher proportion of exotic species found there.

	Richness	Evenness	Shannon	Table 1. Mean Richness, Evenness, and Shannon Diversity Index for the three Rainbow Plateau sections, north rim, GRCA.
Upper Middle	24.96	0.68	0.95	
Lower Middle	25.68	0.66	0.92	
Lower	28.90	0.69	1.01	

The ordination of floristic data revealed a clear separation of the Lower Plateau section cluster from the Upper Middle and Lower Middle section clusters (Figure 11). Less clear is the separation of Upper Middle and Lower Middle clusters. These separations are supported by results from ANOSIM, which showed significant differences in floristic composition among the three Plateau sections (global $R = 0.34$, $p < 0.001$). Results from SIMPER revealed a high average dissimilarity between the Lower section and either the Upper Middle or the Lower Middle ($>70\%$). Nearly as high (60%), was the average dissimilarity between the Upper Middle and Lower Middle sections. Similarity among plots within each location was low, which we interpret as the patchy nature of the vegetation.

Vector fitting showed that bare soil, litter, canopy closure, and slope were each significantly correlated with configuration scores (Figure 11). The vectors for litter, slope, and canopy closure were very similar, with that of soil oriented in roughly the opposite direction through the Lower Plateau section cluster. This shows both higher canopy closure and less soil exposure in the Upper Middle and Lower Middle sections of the Plateau.

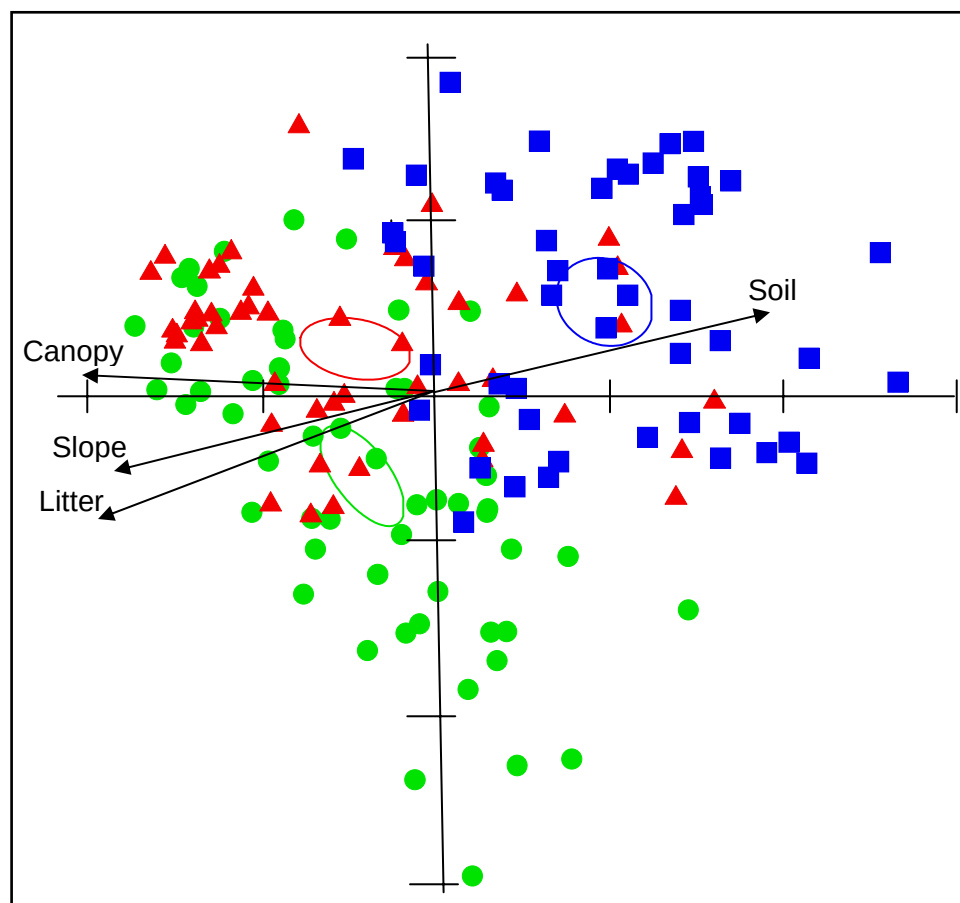


Figure 11. Non-metric Multi Dimensional Scaling (NMDS) ordination of floristic data from three sections of Rainbow Plateau, north rim, GRCA. Curved lines represent 95% confidence ellipses (analogous to 95% error bars around a mean) and surround the floristic plots in the three Plateau sections. Arrows represent vectors of maximum correlation for litter, bare soil, slope, and canopy closure.

● Upper Middle ▲ Lower Middle ■ Lower

Results from SIMPER analysis also showed that species that contribute most to percent similarity among both the Upper Middle and Lower Middle sections of Rainbow Plateau were the woody re-sprouting shrub New Mexico locust and the graminoids mutton grass, elk sedge (*Carex geyeri*), and squirrel tail (*Elymus elymoides*) (Table 2). Characterizing the Lower section of the Plateau were the forbs hairy golden aster, redroot buckwheat (*Eriogonum racemosum*), the shrub Fendler ceanothus (*Ceanothus fendleri*), and the graminoid squirrel tail. In addition, while ponderosa pine seedlings played a roll in the similarity of all three Plateau sections, both seedlings and saplings were very important in the Lower Plateau section (Table 2).

The map of relative exotic plant cover shows both the distribution and quantity of exotic plants across the Plateau (Figure 12). Notice that in both the Upper Middle and Lower Middle sections only one plot exceeds 30% cover of exotics, while 8 plots of the Lower section do.

Discussion:

Not all exotic species are equally invasive (Baker 1965; Meffe and Carroll 1994; Williamson 1996); similarly, not all lands are equally invasible (di Castri 1989; Elton 1958; Orians 1986). Exotic plants tend to follow what is known as “the tens rule”, whereby 10% of exotics introduced into an area become established and 10% of these become problem species. Therefore it is not uncommon to find of a flora to contain roughly 10% exotic plant species. However, it was *not* expected that a remote area, such as Rainbow Plateau, with no trail or road access would contain exotic plant species; especially not 10 species with cover up to 63% in a single plot!

The distribution of exotic plants on Rainbow Plateau makes little sense in terms of natural movement of species from the mainland outward - onto the Plateau's Lower section. However, as Fulé and others (2002) have pointed out, there is a Natural biogeographic gradient across this and other north rim islands and peninsulas. The Lower section is different from the other two in several ways which likely attributes to the difference in exotic plant distribution. The Lower section has a less dense canopy and greater soil exposure, both which were statistically significant in our analyses of abiotic variables. The opposite vector directions for litter / canopy closure and bare

soil are typical for most plants as species respond differently to litter and bare soil. For example, exotic plants tend to favor areas of disturbed or eroded exposed soil, while native plants favor areas of less disturbance and greater accumulations of litter (Crawford and others, 2001).

Elton (1958) noticed that invasion most often occurred on lands disturbed or modified by humans. Similarly, Rejmanek (1989) stated that the probability of successful invasion seems to be crucially dependent on the extent and type of disturbance, on the number of exotic propagules deposited each year, and how long the community is exposed to import of these propagules. Vitousek and others (1996) state that humans have increased the frequency and intensity of disturbances which promotes the invasion of species. Stohlgren and others (1999) are concerned that even relatively undisturbed areas may be highly invasible and recommend maintaining natural disturbance to maximize the persistence of native species.

This Plateau has maintained a relatively natural fire history which, according to Stohlgren and others (1999) should help to maintain native species. How then did the exotics get to Rainbow Plateau and

Genus	Species	Average	Cumulative %	
<i>Robinia</i>	<i>neomexicana</i>	7.3	19.65	Upper Middle
<i>Poa</i>	<i>fendleriana</i>	7.2	39.11	
<i>Carex</i>	<i>geyeri</i>	6.1	55.65	
<i>Elymus</i>	<i>elymoides</i>	3.9	66.3	
<i>Solidago</i>	<i>canadensis</i>	3.2	74.93	
<i>Eriogonum</i>	<i>racemosum</i>	1.3	78.31	
<i>Heterotheca</i>	<i>villosa</i>	1	81	
<i>Achillea</i>	<i>millefolium</i>	0.7	82.82	
<i>Pinus</i>	<i>ponderosa</i>	0.7	84.58	
<i>Mahonia</i>	<i>repens</i>	0.6	86.32	
<i>Quercus</i>	<i>gambellii</i>	0.6	88.03	
<i>Cirsium</i>	<i>wheeleri</i>	0.5	89.46	

Genus	Species	Average	Cumulative %	
<i>Carex</i>	<i>geyeri</i>	15.9	31.16	Lower Middle
<i>Poa</i>	<i>fendleriana</i>	15.6	61.78	
<i>Robinia</i>	<i>neomexicana</i>	4.5	70.55	
<i>Elymus</i>	<i>elymoides</i>	2.3	75.16	
<i>Heterotheca</i>	<i>villosa</i>	2.3	79.68	
<i>Eriogonum</i>	<i>racemosum</i>	1.2	81.99	
<i>Pinus</i>	<i>ponderosa</i>	0.9	83.77	
<i>Ceanothus</i>	<i>fendleri</i>	0.8	85.43	
<i>Lotus</i>	<i>wrightii</i>	0.7	86.85	
<i>Delphinium</i>	<i>nelsonii</i>	0.6	88.01	
<i>Cirsium</i>	<i>wheeleri</i>	0.5	89.07	

Genus	Species	Average	Cumulative %	
<i>Heterotheca</i>	<i>villosa</i>	11.2	27.96	Lower
<i>Pinus</i>	<i>ponderosa</i>	4.8	39.97	
<i>Elymus</i>	<i>elymoides</i>	3.4	48.51	
<i>Ceanothus</i>	<i>fendleri</i>	2.6	55.02	
<i>Eriogonum</i>	<i>racemosum</i>	2.5	61.33	
<i>Robinia</i>	<i>neomexicana</i>	2.2	66.75	
<i>Poa</i>	<i>fendleriana</i>	2.1	71.88	
<i>Bromus</i>	<i>tectorum</i>	1.4	75.43	
<i>Artemisia</i>	<i>caruthii</i>	1.3	78.75	
<i>Pinus</i>	<i>ponderosa</i>	1.2	81.74	
<i>Carex</i>	<i>geyeri</i>	1	84.29	
<i>Quercus</i>	<i>gambellii</i>	1	86.71	
<i>Cirsium</i>	<i>wheeleri</i>	0.6	88.2	
<i>Erigeron</i>	<i>divergens</i>	0.4	89.16	

Table 2. Results from SIMPER analysis showing mean cover of important species of the three sections of Rainbow Plateau, North Rim, GRCA. Species are listed in order of their contribution up to a cumulative percent contribution of 90%. Similarity of Upper Middle = 37; Lower Middle = 50.93; Lower = 40.05.

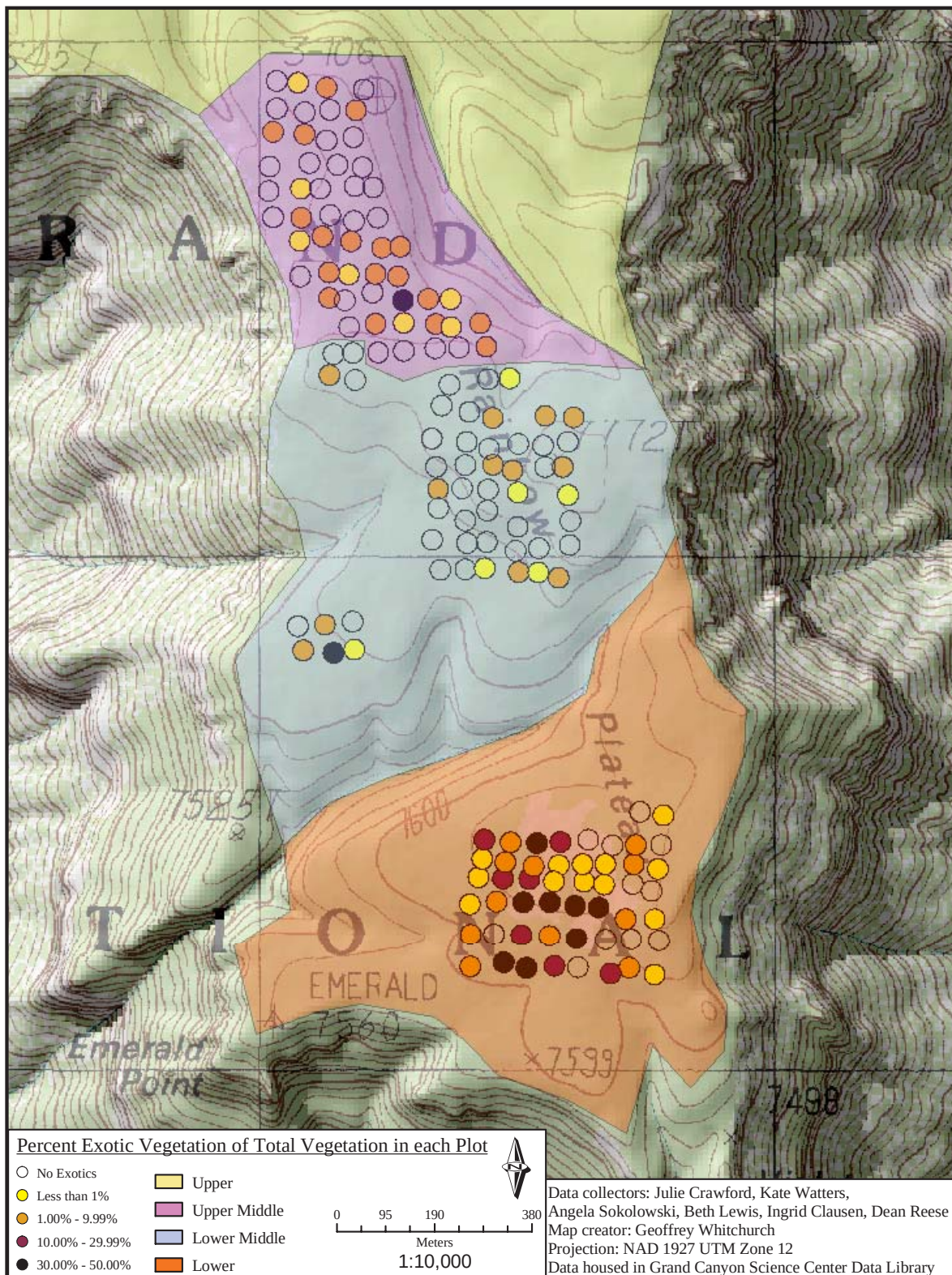


Figure 12. Relative exotic plant distribution and abundance on the Rainbow Plateau, north rim, GRCA.

what disturbance factor, if any, is maintaining these populations and perhaps spreading them? It can be surmised from height of tree charring and presence of charred woody debris that high severity fire *did* occur on the Plateau in small patches. One such patch, a large opening on the Lower section, is the area most heavily impacted by exotic plants. In particular, cheat grass is prominent in this area and it has been well established in the literature that this species responds positively to high severity fire (Hassan and West, 1986; Hulbert, Lloyd 1955; Humphrey and Schupp, 2001).

The question remains, where did the seed source come from? Species such as lambsquarters and Kentucky bluegrass likely got their start on the Plateau from early livestock grazing in the late 1800's up until (and shortly after) the creation of the Park in 1919. No specific records of grazing are known from Rainbow Plateau itself, but grazing of sheep and cattle were known to have occurred in nearby areas at that time (Haskett 1935, 1936). Prickly lettuce, horsetweed, dandelion, and goatsbeard are all composites with "aerially buoyant" or light, wind dispersed seeds. It is not unreasonable to assume these species arrived from the mainland, or even from the Canyon itself, through the unique adaptation of a parachuted seed. The remaining species may have arrived as unknown hitchhikers on wildlife, bison, visitors, or researchers.

This study is just the beginning in our understanding of exotic plant species and their relation to native plant species, wildlife, and fire in the backcountry of GRCA. As vegetation is tied to many aspects of Park management, the ability to understand the function of wildlife in the dispersal of exotic plant species and soil disturbance is important. This is especially significant as it relates to bison, which may

themselves be exotic to this area. As the natural fire regime is a fundamental component of this and other remote areas of the Park, we need to understand the response of all vegetation, both native and exotic, to fire. To aid in this understanding, the use of GIS allows a great visual interpretation of the distribution and abundance of vegetation across the Plateau. This technology allows us to track changes in vegetation over time and following exotic treatment.

This study allowed an investigation of both native and exotic plants and revealed the most important species in each section of the Plateau to be largely native species with "weedy" characteristics. That is, the production of light wind dispersed seeds (purple aster, hairy goldenaster, Wheeler's thistle (*Cirsium wheeleri*), fleabane); animal dispersed seed (squirrel tail); or prolific vegetative reproduction (New Mexico locust, Gambel's oak, goldenrod). The only exotic species that was statistically significant was cheat grass in the Lower section of the Plateau. Statistical significance is not necessary when speaking of exotic plant infestations however, as all infestations in wildlands are biologically significant and unwanted.

The presence of exotic plants on this Plateau reveals a possibility of their presence in other remote areas of the GCNP. This exemplifies the need to treat these infestations to preserve natural areas and the need for surveys of additional backcountry sites. While prevention is an optimal solution to the exotic plant problem in the Park, survey and treatment while populations are small is the next best solution. We plan to remove mullein and Kentucky bluegrass populations from the Plateau during the summer of 2004. These two species are located in two distinct and rather small populations and can be removed with herbicide and hand pulling.

We also plan to determine the feasibility of treatment of large infestations of cheat grass in the Lower section of the Plateau.

From this research we anticipate the following future needs:

- Determine if bison are a vector of exotic plants by working collaboratively with the wildlife staff of the Park to remove seeds from the coats and hooves of drugged bison during genetics studies. Also, bison dung should be collected for seed analysis.
- Determine the fire severity of past fires through a thorough investigation into files kept in a storage locker in Flagstaff and through interviews with fire staff past and present with knowledge of fires on the Plateau.
- Develop a more specific way to determine human presence on the Plateau. The current backcountry permit issued for this area encompasses an area much greater than Rainbow Plateau and therefore the statistics on visitor use for Rainbow Plateau alone are not precise.
- An investigation into the climate across the Plateau would allow for a better understanding of vegetation patterns. We propose the use of data loggers to record humidity, temperature, etc. along the rim, on the upland areas of the Plateau, as well as in the tributaries.
- Additional remote areas of the Park must be surveyed for exotic plant species and appropriate control measures taken if needed. We would like to survey multiple areas in each vegetation community (e.g. mixed conifer, ponderosa pine, pinyon juniper, tributaries etc.) within the Park.
- Develop permanent plots in locations deemed important for monitoring based on surveys from remote sites in the various vegetation communities.
- Develop protocols for researchers and visitors for traveling without spreading exotic plant propagules in the backcountry (*e.g.* stiff brush, leather shoelaces).

This research has added greatly to the body of knowledge regarding exotic plant species in the backcountry of GRCA and ties together multiple disciplines over a large geographic area. In addition to this report, we plan to continue analysis of this data with the program Spatial Analyst and anticipate the publication of this research in a peer reviewed journal so that others may be made aware of exotic plant issues in remote areas of GRCA. We thank the Grand Canyon National Park Foundation and the Cooperative Conservation Initiative for their invaluable contribution to this research. Without their financial assistance, this project and future projects of this sort would not be possible.

Acknowledgements:

We gratefully acknowledge Grand Canyon National Park Foundation for their contribution of funding; the Cooperative Conservation Initiative for their match of funds; the Fire Effects Monitoring Program for providing funding for Beth Lewis; Henrik Wahren for his voluntary assistance with statistical analyses; Geoff Whitchurch for his GIS and editing skills; Ingrid Clausen, Angela Sokolowsky, and Kate Watters for their botanical skills and diligence with data entry; and finally Beth Lewis and Dean Reese for their botanical skills.

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Appendix 1: Plot 157, Field Division of Forestry study, Rainbow Plateau, Saffron Valley, north rim, GRCA, August 2, 1935.



Appendix 2: List of all plant species found on Rainbow Plateau vegetation relevé plots. Exotic species are labeled with *. In addition, three separate unknown species were recorded.

<i>Aster falcatus</i>	<i>Eriogonum racemosum</i>
<i>Abies concolor</i>	<i>Eriogonum umbellatum</i>
<i>Acer glabrum</i>	<i>Eupharbia lurida</i>
<i>Achillea millefolium</i>	<i>Galium aperene</i>
<i>Achnatherum nelsonii</i> ssp. <i>dorei</i>	<i>Garrya flavescens</i>
<i>Agoseris glauca</i>	<i>Gayophytum diffusum</i>
<i>Allium</i> sp.	<i>Geranium caespitosum</i>
<i>Amelanchier utahensis</i>	<i>Gilia gracilis</i>
<i>Antennaria parvifolia</i>	<i>Gutierrezia sarothrae</i>
<i>Antennaria rosulata</i>	<i>Helimeris multiflora</i>
<i>Arabis</i> sp.	<i>Hesperostipa comata</i>
<i>Arctostaphylos</i> sp.	<i>Heterotheca villosa</i>
<i>Arenaria lanuginosa</i>	<i>Hieracium fendleri</i>
<i>Artemisia caruthii</i>	<i>Hymenopappus filifolius</i>
<i>Artemisia ludoviciana</i>	<i>Hymenoxys richardsonii</i>
<i>Artemisia tridentata</i>	<i>Juniperus monosperma</i>
<i>Asclepias tuberosa</i>	<i>Koeleria macrantha</i>
<i>Aster commutatus</i>	* <i>Lactuca serriola</i>
<i>Astragalus</i> sp.	<i>Lappula occidentalis</i>
<i>Bahia dissecta</i>	<i>Lomatium</i> sp.
<i>Blepharoneuron tricolepis</i>	<i>Lotus wrightii</i>
<i>Bouteloua gracilis</i>	<i>Lupinus argenteus</i>
<i>Brickellia californica</i>	<i>Lupinus kingii</i>
<i>Bromus ciliatus</i>	<i>Machaeranthera canescens</i>
* <i>Bromus rubens</i>	<i>Mahonia repens</i>
* <i>Bromus tectorum</i>	<i>Mirabilis linearis</i>
<i>Calochortus nuttallii</i>	<i>Muhlenbergia montana</i>
<i>Carex geyeri</i>	<i>Nicotiana attenuata</i>
<i>Carex occidentalis</i>	<i>Oenothera</i> sp.
<i>Castilleja linariifolia</i>	<i>Opuntia</i> sp.
<i>Ceanothus fendleri</i>	<i>Orthocarpus purpureo-albus</i>
<i>Cercocarpus montanus</i>	<i>Packera multilobata</i>
<i>Chamaebatiaria millefolium</i>	<i>Pascopyrum smithii</i>
* <i>Chenopodium album</i>	<i>Pedicularis centranthera</i>
* <i>Chenopodium dessicatum</i>	<i>Penstemon barbatus</i>
<i>Chrysothamnus nauseosus</i>	<i>Penstemon linarioides</i>
<i>Cirsium wheeleri</i>	<i>Penstemon virgatus</i>
* <i>Conyza canadensis</i>	<i>Pericome caudata</i>
<i>Conyza schediana</i>	<i>Phacelia magellanica</i>
<i>Delphinium nelsonii</i>	<i>Philadelphus microphyllus</i>
<i>Descurainia californica</i>	<i>Phlox gracilis</i>
<i>Dracocephalum parviflorum</i>	<i>Physalis hederifolia</i>
<i>Elymus elymoides</i>	<i>Pinus edulis</i>
<i>Epilobium brachycarpum</i>	<i>Pinus ponderosa</i> saplings
<i>Erigeron divergens</i>	<i>Pinus ponderosa</i> seedlings
<i>Erigeron flagellaris</i>	<i>Poa fendleri</i>
<i>Erigeron formosissimus</i>	* <i>Poa pratensis</i>

Polygonum douglasii
Populus tremuloides sapling
Populus tremuloides seedling
Potentilla hippiana
Pseudocymopterus montanus
Pseudognaphalium macounii
Purshia mexicana
Quercus gambellii
Ribes cereum
Ribes sp.
Robinia neomexicana
Rosa arizonica
Senecio eremophilus
Senecio spartioides
Silene scouleri
Solidago canadensis
Solidago velutina
Sporobolus cryptandrus
Symphoricarpos longiflorus
* *Taraxacum officinale*
Thalictrum fendleri
Townsendia excapa
* *Tragopogon dubius*
* *Verbascum thapsus*
Vicia americana
Vulpia octoflora