Fire Behavior and Ecological Effects in Blackbrush (*Coleogyne ramosissima*) Shrublands and Invasive Annual Grasslands of the Mojave Desert

STUDY PLAN

20 August, 2001

Project leader: Matt Brooks, Research Botanist
United States Geological Survey, Biological Resources Division
Western Ecological Research Center, Las Vegas Field Station
6770 South Paradise Rd. Las Vegas NV 89119-3721
matt_brooks@usgs.gov 702-914-2206 x225

Assistant project leader: Todd Esque, Research Ecologist
United States Geological Survey, Biological Resources Division
Western Ecological Research Center, Las Vegas Field Station
6770 South Paradise Rd. Las Vegas NV 89119-3721
todd_esque@usgs.gov 702-914-2206 x226

SUPPORTING AGENCIES

Funding for Research and Monitoring

- DOI, Joint Fire Science Program (JFS)
- NPS, Pacific West Region, Fire Program (NPS-PWR)
- USGS-NPS Park Oriented Biological Support program (USGS/NPS)

In-kind Operational Support

- BLM, Arizona Strip Field Office
- BLM, California Desert District
- BLM, Las Vegas Field Office
- NPS, Joshua Tree National Park
- NPS, Mojave National Preserve
- USFS, Toiyabe National Forest

COOPERATORS

Richard Bahr, Fuels Management Specialist, National Interagency Fire Center
Tony DeFalco, District Fire Control Office, BLM Las Vegas Field Office
Curt Deuser, Natural Resource Specialist, Lake Mead National Recreation Area
Tim Duck, Wildlife Biologist, BLM Arizona Strip Field Office
Deb Couche, Ecologist, Toiyabe National Forest
Richard Franklin, Regional Fire and Aviation Management Officer for the California Desert, Bureau of Land Management and National Park Service
Tom Kuekes, District Ranger, Toiyabe National Forest
Kristy MacMillan, Interagency Fire Management Officer, Mojave National Preserve and BLM Needles Field Office
Hank McCutcheon, Chief of Resource Management, Joshua Tree National Park
Tom Patterson, Fire Management Officer, Joshua Tree National Park
Jane Rogers, Botanist, Joshua Tree National Park
Tom Suwyen, Interagency Fire Management Officer, BLM Las Vegas Field Office and Toiyabe National Forest
Jessica Wade, Fuels Specialist, BLM Arizona Strip Field Office

Robin Wills, Fire Ecologist, NPS Pacific West Region

JUSTIFICATION

The Federal Wildland Fire Management Policy defines fire as a critical natural process that should be reintroduced for the benefit of ecosystem integrity (Glickman and Babbitt 1995). It also recognizes fire hazards that can result as fuels accumulate where fire has been previously suppressed and recommends that fire be used to reduce these high fuel loads. However, in some ecosystems fire may not be a natural ecosystem component or an appropriate tool to reduce fuel loads. One such ecosystem may be the Mojave Desert, where fire appears to be historically rare (R. Minnich unpublished data, NPS and BLM records), plant communities are generally slow to recover from fire (O'Leary and Minnich 1981, Brown and Minnich 1986, M. Brooks unpublished data), and recent increases in fire frequency appear to have increased landscape flammability by promoting the postfire dominance of invasive annual grasses (Brooks 1999). These observations are based on limited data, but they indicate that fire may have mostly negative effects in the Mojave Desert. Additional studies are needed to determine if fire is an appropriate and useful tool for land managers. This information is a critical component that is lacking in existing fire and resource management plans in this region.

The frequency of fire and the size of human populations increased recently in the Mojave Desert, and fire is now a threat to both homes and wildlands in some areas. Land managers need tools to reduce the chance of fire spreading from wildlands into urban areas, and from urban areas, campgrounds, and roadsides into wildlands. Although most desert plant communities do not burn easily, those dominated by blackbrush (*Coleogyne ramosissima*), invasive annual grasses, or especially those dominated by both, can fuel very large fires. Prescribed fire has been used to reduce woody fuels from blackbrush (*Coleogyne ramosissima*), but the profusion of fine fuels from invasive annual grasses that typically follow create a new fire hazard and other threats to ecosystem integrity. Management tools need to be tested that can reduce fire hazards, but not create new hazards or threaten natural resources. This study will document the behavior and ecological effects of fire, and evaluate the use of fire and herbicides to reduce woody and fine fuel loads in vegetation dominated by blackbrush and invasive annual grasses.

BACKGROUND

Blackbrush can produce the most continuous cover of any perennial shrub in the Mojave Desert, and it is one of the few vegetation types that can carry fire and create complete burns without substantial fine fuel loads (Bowns 1973). It has a compact growth form with many senescent terminal buds that increase its ability to burn. It is generally considered to be the most flammable native vegetation type in this region, and as such is a potential fire hazard, especially where invasive annual grasses are also present and where ignition sources are frequent at the interface between urban and wildland areas and in areas of high lightning occurrence. One example is at Joshua Tree National Park, where blackbrush scrub intermixed with invasive annual grassland has recently fueled large fires that threaten the neighboring community of Yucca Valley. The postfire dominance of invasive annual grasses creates additional fire hazards. Other areas in the eastern and northeastern Mojave Desert are experiencing similar problems with fire in blackbrush vegetation and the invasive annual grasslands that dominate postfire landscapes.

Although blackbrush can carry fire, historic fire return intervals were probably very long because stands are typically found on old undisturbed sites (Webb et al. 1987) and they are slow to reinvade burned areas, especially on shallow soils with low soil moisture (Bowns 1973, Bates 1984). Blackbrush is considered a relictual endemic of arid and semi-arid western North America

(Stebbins and Major 1965), and very old stands that established hundreds to thousands of years ago may not be able to reestablish in the recent climate of increasing fire frequency. Disjunct populations in the southwestern part of its range may be especially endangered due to their relatively small size (e.g. at Joshua Tree National Park).

Methods to Reduce Blackbrush Cover

Prescribed fire has been used to reduce the cover of blackbrush, because it is easily killed by doesn't recover even after 40 years (Callison et al 1985). Reestablishment of blackbrush stands after fire have not been documented, largely because recovery times are so long, possibly on the order of centuries. Burned blackbrush can be replaced by annual plants during the first few postfire years, then by perennial grasses that can dominate for decades (Bates 1984). However, this pattern is highly variable (Bowns 1973, Wright and Bailey 1982, Callison et al. 1985), and invasive annual grasses dominate areas of burned blackbrush at Joshua Tree National Park (DOI unpublished data) and at sites in the northeastern (Jensen et al. 1960, Rickard and Beatley 1966) and northwestern Mojave Desert (Bates 1984), creating a new type of fire hazard from flashy fuels that promote recurrent burning (Whisenant 1990, Brooks 1999). Recurrent fire promotes the dominance of invasive annual grasses, and their competition with native plants for soil nutrients and water threaten native plant communities and the wildlife species that depend on them.

Other methods have been use to reduce the cover of blackbrush to promote the production of more palatable livestock forage, and there is some indication that these methods may also reduce fire hazards. Chaining, cabling, and brush beating of blackbrush can shred flammable dead woody material and promote the regrowth of new less flammable live shoots without appreciably promoting the dominance of early successional species (Bowns 1973). Grazing by goats has also been used to reduce dry stem biomass and promote the regrowth of more succulent live shoots (Provenza et al. 1983). However, these mechanical methods for fuel reduction cause high levels of soil disturbance which may produce other undesirable ecological effects that have not yet been adequately evaluated. In addition, it is likely that these tools or others such as the complete manual removal of vegetation would only be considered a last resort to reduce fire hazard in wildlands. Thus, other options that cause less soil disturbance must be considered. In this project we will evaluate the use of fire and herbicides to reduce blackbrush cover.

Fire Behavior

There is a debate over which vegetation type constitutes the greater fire threat: blackbrush because it appears to burn more intensely, or invasive annual grassland because it appears to ignite easily and promote a higher rate of fire spread. The behavior of fire in these plant communities has not yet been evaluated, and one objective of our study is to compare fire intensities and spread rates in these two fuel types. We will evaluate fire behavior during spring and summer, two seasons with contrasting environmental and fuel conditions. These analyses are necessary to accurately evaluate fire hazards and weigh the benefits of fuel management treatments to reduce these hazards against the potential negative ecological effects caused by the treatments. These data will be integrated along with detailed descriptions of fuel characteristics and environmental conditions before and during fires to develop custom fuel models that can be use to predict fire behavior in blackbrush and invasive annual grasslands during spring and summer.

Conditions during fires strongly affect the ecological effects of fires. The environmental, fuel, and fire behavior variables that we will monitor during the experimental fires will be correlated with fire effect variables monitored after the fires to develop comprehensive models.

Ecological Effects of Fire

The ecological effects of fire can vary based on seasonal differences in plant phenology and fire behavior. Fire can also affect the availability of soil nutrients, which in turn affects plant communities. The effects of fire on soil nutrients varies with soil heating so hot blackbrush fires during summer should have very different affects than cooler invasive annual grassland fires during spring.

Management of Invasive Annual Grasses

Desert fires can have variable short term effects on the dominance of invasive annual grasses. For example, during the first few postfire years density and biomass of either *Bromus rubens* or *Bromus tectorum* decreased in burned compared to unburned sites in the Mojave (Baldwin 1979, Brooks in review *a*), Sonoran (Cave 1982, Cave and Patten 1984), and Great Basin deserts (Hassan and West 1986, Rasmussen 1994), but these species or *Schismus* spp. also increased at burned sites in the Mojave (Brooks submitted), Sonoran (Loftin 1987), and Great Basin deserts (West and Hassan 1985). Fires that occur before *Bromus tectorum* seeds disperse to the ground can reduce densities 400 to 1,000% during the following spring (Pechanec and Hull 1945) because seeds suspended above-ground within inflorescences are more susceptible to lethal temperatures than seeds located on or beneath the soil surface (Rasmussen 1994). Regardless of what happens during the first few postfire years, *Bromus rubens* and *Bromus tectorum* often return to or exceed prefire dominance during subsequent years in the Mojave (Beatley 1966, Hunter 1991, Brooks in review *b*), Sonoran (Tratz 1978, Brown 1984), and Great Basin deserts (Callison et al. 1985, Rasmussen 1994). These results indicate that fire can be used to temporarily reduce the dominance of invasive grasses, but in the longterm fire may actually increase their dominance. Environmental conditions, fuel characteristics, fire behavior, and plant phenology during fires must be documented and the effects of fires must be monitored to accurately evaluate their effects and develop effective burn prescriptions for the control of invasive annual grasses, or to determine if such prescriptions even exist.

Postfire dominance of invasive annual grasses appears to be strongly affected by changes in nutrient availability caused by fire (Giovannini et al. 1990). These mechanisms must be understood to predict potential invasion patterns and develop techniques to restore invaded ecosystems (Crawley 1987). In addition, there exist theoretical temperature thresholds below and above which fire-induced soil fertility changes should not promote postfire dominance of invasive annual grasses. Fire prescriptions targeted for these zones may minimize the postfire dominance of these grasses.

Herbicides have been used to control invasive grasses and to reduce fine fuel loads, but collateral effects on non-target plants can be significant. Atrazine (Aatrex) can reduce biomass of *Bromus* (Evans and Young 1977, Currie et al. 1987), but its negative effects on native plants can persist for at least 8 years (Hunter et al. 1978). Sulfomethuron methyl (Oust) can reduce biomass of *Bromus tectorum*, but collateral damage can occur to native perennials at doses as low as 1oz/acre (Pellant et al. 1999). Fluazifop-p-butyl (Fusilade) can be used to control annual and perennial grasses, and at low doses can be used to selectively kill annual species. However, the use of all these herbicides are restricted in some states (especially California) and they can be expensive.

Glyphosate (Roundup) is widely used to control invasive weeds and is one of the least expensive most widely tested herbicides available. It can control *Bromus tectorum* at application rates of 2.6-2.9 oz/acre (Blackshaw 1991) and 5.9-8.0 oz/acre (Beck et al. 1995), and *Bromus rubens* at rates of 12 oz/acre (Larry Jensen, Helena Chemical Company, personal communication) with minimal collateral affects on native perennials. Rates above 16 oz/acre often damage and may kill non-target perennial plants, according to the manufacturer (Monsanto). We plan to use glyphosate at an application rate of 10oz/acre in this study. This concentration should be high enough to kill invasive annual grasses and reduce fine fuel loads, but low enough to only partially defoliate blackbrush and other native perennial plants thus reducing the fuel loads of woody plants without killing them.

OBJECTIVES

(primary funding sources listed in parentheses)

- Compare fire behavior and develop custom fuel models for blackbrush and invasive annual grassland vegetation. (NPS-PWR, USGS/NPS)
  Prediction: Fire will ignite easier and have a higher rate of spread in invasive annual grassland, but have a higher intensity in blackbrush vegetation.

- Document the effects of spring and summer fires on native annual and perennial plants. (NPS-PWR, USGS/NPS)
  Prediction: Cover and diversity of native plants will decrease during 3 post-treatment years after spring and summer fires compared to unburned controls.

- Document the ecological effects of a short fire-return interval. (NPS-PWR, USGS/NPS)
  Prediction: Native annual and perennial plant cover and diversity will be lower, and cover of invasive annual grasses will be higher in plots that burned within 10 years before experimental fires than in plots with no evidence of burning before experimental fires.

- Document the ecological effects of herbicide treatments on native annual and perennial plants. (JFS)
  Prediction: Cover and diversity of native plants will not change during 3 post-treatment years after herbicide application compared to unburned controls.

- Determine the relationship between fire-induced changes in soil nutrients and postfire dominance of invasive annual grasses. (NPS-PWR)
  Prediction: Cover of invasive annual grasses will correlate positively with postfire increases in available soil nutrients such as N and P.

- Evaluate the effects of spring fire and herbicide treatments on postfire dominance of invasive annual grasses. (JFS)
  Prediction: Cover of invasive annual grasses will be lower during 3 post-treatment years after spring fires and after herbicide treatments than untreated controls.

- Evaluate the effects of spring fire and herbicide treatments on postfire fine fuel loads. (JFS)
  Prediction: Fine fuel loads will be lower during 3 post-treatment years after spring fires and after herbicide treatments than untreated controls.

- Compare the cost-effectiveness of spring burning versus herbicide applications for reducing fine fuel loads and controlling invasive annual grasses. (JFS)

- Develop educational materials and establish the three field sites as demonstration sites of the effects of alternative management treatments for the reduction of fuel loads and the control of invasive annual grasses. (JFS)

- Develop a long-term monitoring protocol to evaluate the effects of treatments over multiple years. (NPS-PWR)

STUDY SITES

Three study sites will be established across the Mojave Desert from the southwest to the northeast to represent possible regional variation and to provide information for localized areas where fires are a recognized problem for land managers. All sites will be located in areas containing blackbrush scrub and invasive annual grassland. Blackbrush scrub will include emergent Joshua tree (*Yucca brevifolia*) and California or Utah juniper (*Juniperus californica* or *Juniperus osteosperma*) with invasive annual grasses in the interspaces between shrubs. We chose this species composition because it is common throughout the region, it is typical of the urban-wildland interface at places like Joshua Tree National Park, and the arborescent species add to the overall fire hazard. California junipers increase the intensity and Joshua trees increase the spotting potential of fires. The invasive annual grassland in this study will be dominated by the invasive annual grasses *Bromus rubens* and/or *Bromus tectorum*, and early successional woody shrubs, bunchgrasses, and herbaceous perennials.

The nolina cove area of Joshua Tree National Park will represent the southwest Mojave Desert in California. During the past few decades fires have been very frequent, and some have been very large (>13,000 acres) in this area. The invasive annual grassland at this site was created after a prescribed burn administered by NPS in 1993 (Nolina III prescribed burn).

The spring mountain area of the Bureau of Land Management, Las Vegas Field Office and the Toiyabe National Forest, will be used to represent the eastern Mojave Desert of Nevada. This area has experienced frequent fires during the past few decades, mostly in plant communities dominated by blackbrush and creosote bush. The invasive annual grassland at this site was created by a wildfire in 1987.

The beaver dam slope southwest Arizona of the Bureau of Land Management, Arizona Strip Field Office, will represent the northeastern Mojave Desert. Fires have recently been very frequent in this region and have destroyed vast expanses of vegetation dominated by blackbrush, creosotebush, and Joshua trees.

METHODS

The proposed experiment is within the range of a federally threatened species, the desert tortoise (*Gopherus agassizii*), although tortoise densities are usually low in blackbrush vegetation. Wildlife biologists will conduct 100% surface surveys at the sites before burning to ensure that no tortoises or other sensitive species are present. If tortoises are present on the study sites, then personnel certified by the United States Fish and Wildlife Service will relocate them to adjacent sites away from the burn plots and fire equipment. Resource management personnel from NPS, BLM, and USFS will conduct the environmental assessment and help obtain clearances. We previously conducted similar experimental fires in the Mojave Desert which requires a proposed study from the United States Fish and Wildlife Service through a Section 7 consultation. Additional guidelines may be required by the Fish and Wildlife Service through their Biological Opinion for this project.

Spring fire, summer fire, herbicide, and unburned control treatment plots (200 x 200m, 4 ha or 10 acres) will be established in blackbrush scrub and adjacent invasive annual grasslands at the three study sites. Spring and summer fires will each be applied to 4 ha of blackbrush and 4 ha of invasive annual grassland at each site (16 ha burned at each site). Herbicide will also be applied to 4 ha of each vegetation type (8 ha per site). These plots will be large enough to document fire behavior and allow us to evaluate fire and herbicide effects at multiple spatial scales within each treatment plot. Remnants of old fire breaks, dirt roads, and a 10m blackline around each treatment plot will prevent the experimental fires from escaping and becoming wildfires. Fire personnel from the NPS, BLM, and USFS will write the burn plans and conduct the fires.

Fire treatments will be applied in spring and summer 2002. Seasonal fire treatment plots will be burned during the same or consecutive days in the blackbrush and invasive annual grassland portions of each site. The fires will be started by igniting all vegetation in a strip along the upwind border of each plot with a drip-torch, and letting it spread as a headfire through the fire treatment plot. Each fire will be allowed to extinguish naturally on its own within each treatment plot, but the spread of fire outside of the plots will be prevented by fire crews using hand tools, water, or foam at the discretion of the burn boss.

Herbicide treatments will be applied during spring 2002 on the same or consecutive days in the blackbrush and invasive annual grassland portions of each site. Glyphosate (RoundUp) will be applied at 10oz/acre.

Experimental Design

Treatments will be applied in a fixed effect, blocked, randomized, split-plot design (Steele and Torrie 1980). The three study sites will be treated as replicate blocks. Each block will be split by vegetation type (blackbrush, invasive annual grassland), to which treatments will be applied (spring fire, summer fire, herbicide, unmanipulated control) (2 x 4 = 8 treatment plots/site). Vegetation will be the main plot factor and treatment will be the sub-plot factor.

Sampling Design

Physical variables. Prior to the fires, weather conditions will be recorded for 48 hours, fuel moisture will be estimated for herbaceous and woody fuels, and fuel loads will be measured in random clip-plots. During the fires, air temperature, relative humidity, and wind speed will be recorded. To document fire behavior within each treatment combination, fireline intensity will be estimated by documenting flame length and rate of spread at replicate locations, and by recording with a digital video camera. Digital images will be processed later using software to precisely quantify fire behavior. Peak temperatures will be measured above and below the soil surface using thermocouples connected to data loggers within 10 shrub-intershrub sampling pairs (20 sampling points per fire treatment plot).

Biological variables. The modified-Whittaker, nested sampling method will be used for plants in this study (Stohlgren et al. 1995). This method allows us to evaluate treatment effects at multiple spatial scales. Two 20 x 50m (100 m^2) sampling plots will be established within each of the 24 treatment plots. The two sampling plots within each treatment will be oriented 50m from each other with their long axes parallel, and 55m from the treatment plot edge. The basic sampling units within each 100m^2 sampling plot will be ten 1m^2 (0.5 x 2m) subplots where annual and perennial plant cover will be estimated using the Braun-Blanquet index (Greig-Smith 1964). Adjacent to five of the ten $1m^2$ subplots we will establish a single shrub-intershrub sampling pair to document treatment effects along this gradient of soil nutrients and fuel loads. We will use coppice mounds and remnants of basal shrub crowns to locate where shrubs previously existed in the invasive annual grassland. The sampling unit for the shrub-intershrub samples will be $0.1m^2$ (0.2 x 0.5m) plots where annual plant cover will be estimated using the Braun-Blanquet index. Cover estimates will include live annual plants identified to species, and dead annual plants as invasive annual grasses, invasive forbs, and native forbs.

Species richness will be recorded as the total number of plant species present in the live standing crop at 0.1, 1, 10, and $100m^2$ scales. We will also measure species richness by growing out soil seedbank samples collected adjacent to each of the $0.1m^2$ shrub-interspace samples. This will allow us to compare the reliability of these two sampling methods for future studies. Sampling the seedbank will also ensure a valid estimation of species diversity in case low rainfall leads to limited germination.

Soil cores (3cm deep) will be collected adjacent to the $0.1m^2$ samples, and grown out in the greenhouse at Joshua Tree National Park or Lake Mead National Recreation Area to identify the species present (5 shrub-intershrub pairs/treatment plots x 2 cores/pair x 24 plots = 240 cores). We will also collect soil cores (5cm deep) adjacent to each of the $0.1m^2$ samples to evaluate soil nutrient composition. Samples collected before the fires will be used to estimate baseline nutrient availability by measuring levels of NO_3, NH_4, total Kjeldahl N, Olsen-P, pH, $CaCO_3$, and soil texture. Samples collected after the fires will be analyzed for NO_3, NH_4, total Kjeldahl N, Olsen-P, and pH to evaluate changes in nutrients that are caused by fire.

Data Analyses

Analysis of variance will be used to evaluate the differences between the main and interaction effects of the fire and herbicide treatments, nested within the two vegetation type. The three study sites will serve as replicate blocks, without replication of treatment-by-vegetation combinations within blocks. Appropriate error terms will be used for tests of statistical significance (P0.05).

RESEARCH SCHEDULE

FY01

- Establish experimental plots at three study sites
- Write burn plan and obtain biological and cultural clearances
- Collect pre-treatment annual and perennial plant data during spring

FY02

- Apply herbicide treatments in March
- Apply fire treatments and document fire behavior and intensity in spring and summer
- Analyze pre and post-fire soil nutrients and seedbanks to establish immediate fire effects on nutrient availability and seed viability
- Grow out seedbank samples and identify species
- Collect post-treatment (yr 1) soil samples in the early fall
- Analyze soil nutrients (yr 1)
- Grow out seedbank samples and identify species in the winter (yr 1)

FY03

- Collect post-treatment (yr 1) plant measurements in the early spring
- Collect post-treatment (yr 2) soil samples in the early fall

- Grow out seedbank samples and identify species in the winter

FY04

- Collect post-treatment (yr 2) plant measurements in the early spring
- Collect post-treatment (yr 3) soil samples in the early fall
- Grow out seedbank samples and identify species in the winter

FY05

- Collect post-treatment (yr 3) plant measurements in the early spring
- Establish long-term monitoring protocol

PRODUCTS

Baseline comparisons of plant cover and diversity in blackbrush and invasive annual grasslands will be reported at the end of FY01. Information on fire behavior and the first year effects of fuel management treatments will be reported at the end of FY02. Custom fuel models will be developed by the end of FY03. A final report will be completed by the end of FY2005. Data will be reported annually to federal land managers in the Mojave Desert and the board of directors of the Joint Fire Science Program. We will also provide stakeholder tours of the sites, and coordinate a regional workshop on the ecology and management of fire and invasive plants in the Mojave Desert (tentatively planned for FY02). We expect to publish approximately 6 journal articles using these data, in addition to fact sheets and press releases that focus on specific management issues. The principal investigators will continue to provide technical assistance on fire management issues for federal land management units in the Mojave Desert.

LITERATURE CITED

Baldwin, R. F. The effects of fire upon vegetation in Joshua Tree National Monument. Bachelors (senior) thesis. University of California, Santa Barbara.

Bates, P.A. 1984. The role of fire in blackbrush (*Coleogyne ramosissima* Torr.) communities in California. Master's thesis, University of California Davis. 56 pp.

Beatley J. C. 1966. Ecological status of introduced brome grasses (*Bromus* spp.) in desert vegetation of southern Nevada. Ecology 47:548-554.

Beck, G.K., J.R. Sebastian and P.L. Chapman. 1995. Jointed goatgrass (*Aegilops cylindrica*) and downy brome (*Bromus tectorum*) control in perennial grasses. Weed Technology 9:255-259.

Blackshaw, R.E. 1991. Control of downy brome (*Bromus tectorum*) in conservation fallow systems. Weed Technology 5:557-562.

Bowns, J.E. 1973. An autecological study of blackbrush (*Coleogyne ramosissima* Torr.) in southwestern Utah. PhD Dissertation, Utah State University, 115pp.

Brooks, M.L. In review a. Fire temperatures and effects on annual plants in the Mojave Desert. Ecological Applications.

Brooks, M.L. In review b. Alien plants and fire in desert tortoise (*Gopherus agassizii*) habitat of the Mojave and Colorado deserts. Chelonian Conservation Biology.

Brooks, ML. 1999. Alien annual grasses and fire in the Mojave Desert. Madroño 46:13-19.

Brown, D. E. 1984. Fire and changes in creosote bush scrub of the western Colorado Desert, California. Masters thesis. University of California, Riverside.

Brown, D.E. and R.A. Minnich. 1986. Fire and creosote bush scrub of the western Sonoran Desert, California. American Midland Naturalist 116:411-422.

Callison, J., J. D. Brotherson, and J. E. Bowns. 1985. The effects of fire on the blackbrush (*Coleogyne ramosissima*) community of southwestern Utah. Journal of Range

Management 38:535-538.
Cave, G. H. 1982. Ecological Effects of Fire in the Upper Sonoran Desert. Masters thesis. Arizona State University.
Cave, G. H. and D. T. Patten. 1984. Short-term vegetation responses to fire in the upper Sonoran Desert. Journal of Range Management 37:491-495.
Crawley, M. J. 1987. What makes a community invasible? Pages 429-453 in A. J. Gray, M. J. Crawley, and P. J. Edwards, eds. Colonization, succession, and stability. Blackwell Scientific Publications, Oxford.
Currie, P.O., J.D. Volsky, T.O. Hilken, R.S. White. 1987. Selective control of annual bromes in perennial grass stands. Journal of Range Management 40:547-550.
DAntonio, C.M. and P.M. Vitousek. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annual Review of Ecology and Systematics 3:63-87.
Evans, R. and J. Young. 1977. Weed control-revegetation systems for big sagebrush-downy brome rangelands. Journal of Range Management 30:331-336.
Giovannini, G. S. Lucchesi, and M. Giachetti. 1999. Effects of heating on some chemical parameters related to soil fertility and plant growth. Soil Science 149: 344-350.
Glickman, D. and B. Babbitt. 1995. Federal Wildland Fire Management Policy. Available online: http://www.fs.fed.us/land/wdfire.htm.
Greig-Smith, P. 1964. Quantitative Plant Ecology, second edition. Butterworth, London.
Hassan, M. A. and N. E. West. 1986. Dynamics of soil seed pools in burned and unburned sagebrush semi-deserts. Ecology 67:269-272.
Hunter, R., A. Wallace, and E. Romney. 1978. Persistent atrazine toxicity in Mojave desert shrub communities. Journal of Range Management 31:1989-203.
Hunter, R. B. 1991. *Bromus* invasions on the Nevada Test Site: present status of *B. rubens* and *B. tectorum* with notes on their relationship to disturbance and altitude. Great Basin Naturalist 51:176-182.
Jensen, D.E., M.W. Buzan, and D.E. Dimock. 1960. Bureau of Land Management report on field examinations. Blackbrush burns on Las Vegas grazing district (Nev. 5). 18pp.
Loftin, S. R. 1987. Postfire dynamics of a Sonoran Desert ecosystem. Masters thesis. Arizona State University.
O'Leary, J.F. and R.A. Minnich. 1981. Postfire recovery of creosote bush scrub vegetation in the Western Colorado Desert. Madroño 28:61-66.
Pechanec, J. C. and A. C. Jr. Hull. 1945. Spring forage lost through cheatgrass fires. National Wool Grower. 35:13.
Pellant, M. 1999. Use of OUST herbicide to control cheatgrass in the northern Great Basin. Proceedings: Ecology and Management of Pinyon-Juniper Communities within the Interior West. United States Department of Agriculture, Forest Service, Rocky Mountain Research Station, RMRS-P-9.
Provenza, F.D., J.E. Bowns, P.J. Urness, J.C. Malechek, and J.E. Butcher. 1983. Bioloigical manipulation of blackbrush by goat browsing. Journal of Range Management 36:518-529.
Rasmussen, G. A. 1994. Prescribed burning considerations in sagebrush annual grassland communities. Pp 69-70 in S.B. Monsen and S.G. Kitchen (eds.). Proceedings – Ecology an Management of Annual Rangelands. U.S. Forest Service General Technical Report INT-GTR-313.
Rickard, W.H. and J.C. Beatley. 1966. Canopy-coverage of the desert shrub vegetation mosaic of

the Nevada Test Site. Ecology 46:524-529.

Stebbins, G.L. and J. Major. 1965. Endemism and speciation in the California flora. Ecological Monographs 35:1-35.

Steele, RGD and Torrie JH. 1980. Principles and Procedures of Statistics: A Biometrical Approach. McGraw-Hill Book Company, New York, New York, USA.

Stohlgren, T.J., M.B. Falkner, and L.D. Schell. 1995. A Modified-Whittaker nested vegetation sampling method. Vegetatio 117:113-121.

Tratz, W. M. 1978. Postfire vegetational recover, productivity, and herbivore utilization of a chaparral-desert ecotone. Masters thesis. California State University, Los Angeles.

Webb, R.H., J.W. Steiger, and R.M. Turner. 1987. Dynamics of Mojave Desert shrub assemblages in the Panamint Mountains, California. Ecology 68:478-490.

West, N. E. and M. A. Hassan. 1985. Recovery of sagebrush-grass vegetation following wildfire. Journal of Range Management 38:131-134.

Whisenant, S.G. 1990. Changing fire frequencies on Idaho's snake river plains: ecological and management implications. Pp. 4 -7 *In* E.D. McArthur, E.D. Romney, E.M. Smith, and S.D. Tueller (eds.). Proceedings — symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management.; 1989 April 5-7; Las Vegas, NV. Gen. Tech. Rep. INT-276, Department of Agriculture, Forest Service, Intermountain Research Station.

Wright, H. E. and A. W. Bailey. 1982. Fire Ecology, United States and Canada. Wiley, New York.