Fire and Invasive Annual Grasses in Western Ecosystems

JFSP Project Number 00-1-2-04
Final Report
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Project Overview

Invasive non-native plants (hereafter called invasive plants) pose significant threats to natural and cultural resources, and in many cases these threats involve the alteration of natural fire regimes (D'Antonio 2000, D'Antonio and Vitousek 2002, Brooks et al. 2004). Fires can also promote plant invasions by removing native plant cover and increasing the availability of soil nutrients (Hobbs and Huenekke 1992, Vitousek et al. 1996, Klinger et al. in press). The individual effects of plant invasions and altered fire regimes on native species, communities, and ecosystems are particularly threatening to natural resources, including species with statutory protection under state and federal laws (e.g. the desert tortoise, Brooks and Esque 2002). Mitigation of these effects is difficult enough when focusing solely on either invasives or fire, but when these factors interact to create management problems, the solutions become orders of magnitude more complex (Brooks et al. 2004). Unfortunately, the interactions between fire and invasive plants are poorly understood by both scientists and land managers, which make finding solutions to mitigate their effects very difficult. Although land managers can find valuable information on individual invasive species in places like the Fire Effects Information System (www.feis.gov), this information has not been condensed into comprehensive management recommendations that most directly facilitate the development of effective plans for the integrated management of invasives and fire. The focus of this research project was to help fill this information gap.

The two main objectives of this project were to: (1) review and summarize the various interactions that can occur between invasive plants and fire, and developed management recommendations based on what is currently known; and (2) conduct new research to evaluate the specific interactions between fire, soil nutrients, and dominance by invasive annual grasses in arid and semi-arid regions of western North America. This final report for JFSP project 00-1-2-04 explains how we accomplished these two objectives.

To accomplish Objective 1, we developed and hosted 5 major symposia and workshops, all of which resulted in the publication of abstracts, individual papers, or full proceedings. Seven comprehensive state-of-knowledge review documents were also produced as part of Objective 1, each of which focused on a geographic or topical area of significant concern for land managers. Geographic foci included the arid and semi-arid western United States and the state of California. Topical foci included the effects of invasive plants and fire on the Federally Threatened desert tortoise (*Gopherus agassizii*), the relationships between plant invasions and fire regimes, the use of fire to control invasive plants, the integration of invasive plant and fire management into planning documents, and the effects of fire on soil nutrients. Major findings and recommendations from these reviews are summarized in this report.

For Objective 2, we conducted new research to evaluate the effects of fire on dominance by invasive annual grasses in western North America. This topic is perhaps the most widespread invasive plant/fire management challenge in the region. In this report we describe how we implemented this research, summarize our major accomplishments and products, and list products that are currently in preparation. Objective 2 involved many individual research projects which are largely completed and at various stages of publication. The final product for Objective 2 will be a comprehensive overview document (Brooks et al. in prep) which integrates the findings of this new research, with additional information integrated from the review documents produced for Objective 1. Major conclusions and recommendations from this project will be presented in the final overview document which we expect to complete by 30 September, 2006.

Objective 1: Review of Current Knowledge for Managing Invasives and Fire

Although our original proposal was focused primarily on Objective 2, specifically the implementation of a new research project focused on fire and invasive annual grasses in western ecosystems, our proposal also acknowledged the additional need for more comprehensive syntheses. We also stated that "the proposed project will investigate and document (1) the process by which invasive plant species are inhibited, stimulated, and/or proliferated by fire; (2) which ecosystems or vegetation types are most susceptible to invasion following fire; and (3) the effect of treatments by which invasive plants can be controlled." Although we originally did not plan to conduct comprehensive syntheses beyond the topic of fire and invasive annuals grasses in western ecosystems, soon after the project began we realized the need for broader syntheses of existing information.

We therefore added Objective 1 as a major focus of our activities during the course of this project. To achieve this objective we organized a number of symposia/workshops and published a number of review papers. These collaborative efforts involved a wide range of scientists and land managers from North America and elsewhere, each with specific experience in various topical areas related to fire and invasives. Most of the major experts from North America were involved in this process. We communicated our results and recommendations to land managers and scientists to facilitate and guide the development of future land management plans and research proposals.

Symposia and Workshops Summarizing Current Knowledge

We helped organize five major symposia and workshops designed to synthesize current state-of-knowledge regarding the interrelationships between invasive plants and fire. The first occurred soon after the project began in 2000, and the most recent was in 2004. Some were supported with supplementary funding from the JFSP and other sources to cover logistical expenses not originally budgeted. Specific information about each of these workshops/symposia is provided in the text boxes below.

Symposium/Workshop #1
Fire and Invasive Species Ecology
Special session of the California Exotic Pest Plant Council annual symposium to review the primary management issues related to fire and invasives, with special emphasis on western North America.
Concord, CA, October 6, 2000

Agenda
Fire Regimes Changed by Exotic Plants
Jon Keeley (US Geological Survey)
The Role of Fire in Promoting Plant Invasions
Matt Brooks (US Geological Survey) and Carla D'Antonio (UC Berkeley)
Ecological Effects of Exotic-altered Fire Regimes
Steve Knick (US Geological Survey)
Use of Fire to Control Exotic Plants
David Pyke (US Geological Survey)
Postfire Restoration Strategies to Minimize Dominance by Aliens
Jan Beyers (US Forest Service)

Audience
Mostly state, federal, and NGO land managers, plus University scientists and students

Other funding support
None

Publications
Abstracts published in the CalEPPC symposium proceedings, available online at: www.cal-ipc.org/file_library/18602.pdf

Symposium/Workshop #2

Invasive Species Workshop: The Role of Fire in the Control and Spread of Invasive Species
This was a special session of Fire Conference 2000: The First National Congress on Fire Ecology, Prevention and Management. The purpose of this symposium was to provide a synthesis of the inter-relationships between invasive species and fire in six major ecoregions of the United States. San Diego, CA, November 27 – December 1, 2000.

Agenda
Deserts/Semi-Desert Regions
Interactions Between Fire and Invasive Plants in the Deserts of North America
Matthew Brooks (US Geological Survey) and David Pyke (US Geological Survey)
Cheat Grass Management in the Great Basin Desert
Mike Pellant (Bureau of Land Management)
Role of Fire in Juniper and Pinyon Woodlands: Past and Present
Rick Miller (Oregon State University) Robin Tausch (US Forest Service)
Fire, Grazing and Shrub Invasion in the Chihuahuan Desert
Paul Drewa (USDA Agricultural Research Service), Debra P.C. Peters (USDA Agricultural Research Service), and Kris M. Havstad (USDA Agricultural Research Service)
Temperate Grassland Regions
Interactions Between Fire and Invasive Plants in Temperate Grasslands of North America.
James Grace (US Geological Survey), Melinda Smith (Kansas State University), Susan Grace (US Geological Survey), Scott Collins (Kansas State University), and Thomas Stohlgren (US Geological Survey)
Mediterranean Regions
The Interaction of Fire Effects and Site Characteristics on Diversity and Composition of a Grassland Community on Santa Cruz Island, California
Robert Klinger (The Nature Conservancy) and Ishmael Messer (National Park Service)
Fire and Invasives in Mediterranean-Climate Ecosystems of North America
Jon Keeley (US Geological Survey)
The Relative Effectiveness of Prescribed Burning and Herbicide Application for Controlling Fennel on Santa Cruz Island, California
Robert Klinger (The Nature Conservancy)
Temperate and Boreal Coniferous Forest Regions
Fire and Invasive Species within the Temperate and Boreal Coniferous Forest of North America
Richey Harrod (US Forest Service) and Sarah Reichard (University of Washington)
Interaction between Fire Intensity and Invasive Plants in Sierran Forests
Jon E. Keeley (US Geological Survey) and Daniel Lubin (US Geological Survey)

Reducing Invasive Exotic Plant Spread Following Fire in Western Forests, Deserts and Grasslands. *Jerry Asher (Bureau of Land Management), Steve Dewey (Utah State University), Curt Johnson (US Forest Service), and Jim Olivarez (US Forest Service)*

Temperate Deciduous Forest Regions

Fire and Invasive Plants in the Northeast and mid-Atlantic States: An overview and new study. *Alison Dibble (US Forest Service), Julie Richburg (University of Massachusetts), and William A. Patterson III (University of Massachusetts)*

Tropical and Subtropical Regions

Biological Invasion and Fire in Tropical Ecosystems
Dieter Mueller-Dombois (University of Hawaii)

Fire and Invasive Plants in Hawaii Volcanoes National Park
Tim Tunison (National Park Service) and Rhonda Loh (National Park Service)

Prescribed Fire in the Management of Melaleuca in Subtropical Florida
Ron Meyers (The Nature Conservancy), Holly Belles (US Geological Survey), and James Snyder (US Geological Survey)

Session Summary

Invasive Plants and Fire in Resources Management: the Need for Integration
Guy McPherson (University of Arizona)

Audience

Mostly state, federal, and NGO land managers and scientists, plus University scientists, students, and people from other countries

Other funding support

JFSP symposium project 01-S-05

Publications

Full papers published as a proceedings by the Tall Timbers Research Station (Galley and Wilson, 2001)

Symposium/Workshop #3

Fire and Invasive Plant Ecology and Management: The Need for Integration to Effectively Restore Ecosystems

This was a special session at the joint meeting of the Ecological Society of America and the Society for Ecological Restoration. This session brought together international experts to discuss the ecology and management of fire and invasive plants throughout the world.
Tucson, AZ, August 6, 2002.

Agenda

Introduction and Brief History of Fire and Invasive Plant Ecology and Management
Matt Brook (US Geological Survey)

Fire and Other Forms of Disturbance: Are They Similar and Do They Have the Same Effects on Invasive Species?
Matt Brooks (US Geological Survey) and Carla D'Antonio (USDA Agricultural Research Service)
The Role of Fire in Promoting Plant Invasions
Richard Hobbs (Murdoch University, Australia)
Impacts of Invasive Alien Plants on Fire Regimes
David Richardson (University of Cape Town, South Africa), Philip Rundel (University of California, Los Angeles), and Brian van Wilgen (CSIR Division of Water, Environment & Forestry Technology, South Africa)
A General Conceptual Model of the Interactions Between Invasives and Fire: Current Status and Future Directions
James Grace (US Geological Survey)
When Restoring Fire to Ecosystems, Can Dominance of Invasive Plants be Minimized?
Jon Keeley (US Geological Survey)
Can Post-fire Plant Restoration Minimize the Dominance of Invasive Plants?
Mike Pellant (Bureau of Land Management) and David Pyke (US Geological Survey)
Fire as a Component of Integrated Pest Management
Joe DiTomaso (University of California, Davis)
Session Summary
Mike Pellant (Bureau of Land Management)

Audience
Mostly University scientists and students, plus state, federal, and NGO land managers and scientists, and people from other countries

Other funding support
JFSP symposium project 02-S-03 to support speaker travel

Publications
Abstracts published in the Ecological Society of America Bulletin
Journal article published in BioScience (Brooks et al. 2004)

Symposium/Workshop #4
Use of Fire to Control Invasive Plants
A workshop at the 7th International Conference on the Ecology and Management of Alien Plant Invasions designed to provide an overview and examples of how fire can be used to manage invasive plants.
Ft. Lauderdale, FL, Nov. 3-7, 2003.

Agenda
Use of Fire to Control Invasive Plants: Workshop Introduction
Matt Brooks (US Geological Survey), Carla D'Antonio (USDA Agricultural Research Service), and David Pyke (US Geological Survey)
Managing Invasions of Fire-frequented Ecosystems: Hardwoods and Graminoids in Southeastern Savannas, Prairies, and Marshes
Bill Platt (Louisiana State University) and Lee Stanton (Louisiana State University)

Prescribed Fire for Controlling Exotics in the California Grassland: Factors Influencing Success
Susan Bainbridge (University of California Jepson Herbarium) and Carla D'Antonio (USDA Agricultural Research Service)
Fire as Part of an Integrated Management Approach for Saltcedar
Brent Racher (Corona, New Mexico) and Carlton Britton (Texas Tech University)
Managing Native Invasive Juniper Species Using Fire
Jim Ansley (Agricultural Experiment Station, Vernon, TX) and Allen Rasmussen (Texas A&M University)
Post-fire Treatments to Reduce Future Wildfires
Mike Pellant (Bureau of Land Management)
Using Post-fire Revegetation to Control Invasive Plants in Sagebrush Steppe and Pinyon-juniper Woodlands
Jeanne Chambers (USDA Forest Service), Robert Nowak (University of Nevada, Reno), Paul Doescher (Oregon State University), David Pyke (US Geological Survey), and Gene Schupp (Utah State University)
Rehabilitation and Restoration Monitoring: Evaluations of Treatment Effectiveness
Jan L Beyers (US Forest Service) and David Pyke (US Geological Survey)
What We Know and Where We Need to Go With the Use of Fire to Control Invasive Plants
David Pyke (US Geological Survey), Matt Brooks (US Geological Survey) and Carla D'Antonio (USDA Agricultural Research Service)

Audience
Mostly University scientists and students, plus state, federal, and NGO land managers and scientist, and people from other countries

Other funding support
None

Publications
Abstracts published in the symposium proceedings

Symposium/Workshop #5
The Use of Prescribed Burning for the Management of Invasive Plants
A workshop to evaluate the current state of knowledge on prescribed burning as an invasive plant management tool and to develop a general reference for practitioners to use. Through this process we also identified knowledge gaps inhibiting the effective use of fire to manage invasives and proposed potential solutions to these limitations.
Las Vegas, NV, 29-30 March, 2004.

Agenda
Workshop Introduction
The Goals of the Workshop
Joe DiTomaso (University of California, Davis)
Knowledge Synthesis of the Role of Fire as a Management Tool to Contain Invasive Plants
Peter Rice (University of Montana)
Database Summarizing the Benefits and Risks of Using Prescribed Burns to Contain Invasive Plant Species
Diana Kimberling (Oregon State University)

Fire and Invasive Plants, a General Overview *Matt Brooks (US Geological Survey)* Topical Sessions (each session was comprised of an introduction followed by breakout groups, group reporting, and open discussion) Risks and Challenges of Prescribed Burning *Ralph Minnich (California Dept. Forestry & Fire Protection)* Control of Invasive Plants Using Prescribed Burning *Joe DiTomaso (University of California, Davis)* Using Prescribed Burning in IPM Strategies *Dave Boyd (California State Parks)* Impact of Prescribed Burning on Plant Communities *Matt Brooks (US Geological Survey)* Impacts on Soil Characteristics and Other Organisms *Edith Allen (University of California, Riverside)* Effects of Fire on Invasive Plant Potential *Lisa Rew (Montana State University)* Workshop Summary Information Gaps—Where Do We Need to Go From Here? *Matt Brooks (US Geological Survey) and Joe DiTomaso (University of California, Davis)*
Audience Primarily University scientists, but also state and federal land managers.
Other funding support Center for Invasive Plant Management, California Invasive Plant Council
Publications Report for the Center for Invasive Plant Management (DiTomaso et al., in prep) Journal article for Weed Technology (DiTomaso et al. in review)

Review Papers

Brooks, M.L. and D. Pyke. 2001. Invasive plants and fire in the deserts of North America. Pp. 1-14 *In* K. Galley and T. Wilson (eds.), Proceedings of the Invasive Species Workshop: The Role of Fire In the Control and Spread of Invasive Species. Fire Conference 2000: The First National Congress on Fire Ecology, Prevention and Management. Miscellaneous Publications No. 11, Tall Timbers Research Station, Tallahassee, Florida, USA

Invasive plants and fire create substantial challenges for land managers in the deserts of North America. Invasive plants can compete with native plants, alter wildlife habitat, and promote the spread of fire where it was historically infrequent. Increased fire frequency in the Mojave and Sonoran deserts has converted native shrublands to alien annual grasslands. Fire suppression and overgrazing of livestock has allowed native woody shrubs such as mesquite and creosotebush to invade perennial grasslands in the Chihuahuan Desert, and native trees such as juniper and pinyon to invade sagebrush steppe in the Great Basin. The reintroduction of fire can be complicated by fire's positive effect on alien invasive plants and the subsequent effects of invasives on postfire establishment by native species.

Invasive alien grasses especially benefit from fire, and promote recurrent fire, in many cases to the point where native species cannot persist and native plant assemblages are converted

to alien invasive annual grasslands. This vegetation type conversion can affect wildlife ranging from herbivores to carnivores, and reduce overall biodiversity. The effective management of many wildlife species can depend on the control of invasive plants and the maintenance of appropriate fire regimes.

Fire can be used to either control invasive species or restore historical fire regimes. However, the decision to use fire as a management tool must consider the potential interrelationships between fire and invasive species. Historical fire regimes did not occur in the presence of invasive plants, and the use of fire may not be a feasible or appropriate management action if fire tolerant invasive plants are present. The management of fire and invasive plants must be closely integrated for each to be managed effectively.

Brooks, M.L., and T.C. Esque. 2002. Alien annual plants and wildfire in desert tortoise habitat: status, ecological effects, and management. Chelonian Conservation and Biology 4:330-340.
Alien plants and fire have recently been recognized as significant land management problems in the Mojave and Colorado deserts. Annual species dominate the alien flora, although only *Bromus rubens*, *Schismus* spp., and *Erodium cicutarium* are currently widespread and abundant. These species can compete with native plants, and *B. rubens* in particular has contributed to significant increases in fire frequency since the 1970s. Native desert plants are often poorly adapted to fire, and recurrent fire has converted native shrubland to alien annual grassland in some areas. Changes in plant communities caused by alien plants and recurrent fire may negatively affected native animals such as the desert tortoise (*Gopherus agassizii*) by altering habitat structure and the species composition of their food plants.

The dominance of alien annual plants and the frequency of fire may increase in the future due to increased levels of urbanization and atmospheric nitrogen and carbon dioxide. Increases or decreases in rainfall could also cause changes in alien plant dominance and fire frequency. Land managers should focus on early detection and eradication of new alien species, especially those that pose significant fire threats, and law enforcement to minimize the frequency of ignitions by humans. Additional information on the ecology and effects of invasive plants and fire in the Mojave and Colorado deserts are needed to develop effective management plans.

Brooks, M.L. C.M. D'Antonio, D.M. Richardson, J. Grace, J. J. Keeley, J.M. DiTomaso, R. Hobbs, M. Pellant, and D. Pyke. 2004. Effects of invasive alien plants on fire regimes. BioScience 54:677-688.
Plant invasions are widely recognized as significant threats to biodiversity conservation worldwide. One way invasions can affect native ecosystems is by changing fuel properties, which can in turn affect fire behavior and, ultimately, alter fire regime characteristics such as frequency, intensity, extent, type, and seasonality of fire. If the regime changes subsequently promote the dominance of the invaders, then an invasive plant/fire regime cycle can be established. As more ecosystem components and interactions are altered, restoration of preinvasion conditions becomes more difficult. Restoration may require managing fuel conditions, fire regimes, native plant communities, and other ecosystem properties in addition to the invaders that caused the changes in the first place. We present a multiphase model describing the interrelationships between plant invaders and fire regimes. This model is called the "invasive plant / fire regime cycle." We also provide a system for evaluating the relative effects of invaders and prioritizing them for control, and recommend ways to restore preinvasion fire regimes.

Klinger, R. C., M .L. Brooks, and J. M. Randall. In press. Fire and Invasive Plant Species. Chapter 22 in: Sugihara, N. G., J. W. van Wagtendonk, J. Fites-Kaufman, K. E. Shaffer, and A. E. Thode (eds.). Fire in California ecosystems. University of California Press, Berkeley.
Invasive plants pose significant challenges to fire management in California. In this book chapter we described specific management challenges in California, and discuss their implications for regions outside of this state.

DiTomaso, J.M., ML Brooks, EB Allen, R Minnich, PM Rice, and GB. Kyser. In review. Control of invasive weeds with prescribed burning. Weed Technology.
Prescribed burning has primarily been used as a tool for the control of invasive late season annual broadleaf and grass species, particularly yellow starthistle, medusahead, barb goatgrass, and several bromes. However, timely burning of a few invasive biennial broadleaves (e.g., sweetclover and garlic mustard), perennial grasses (e.g., bluegrasses and smooth brome), and woody species (e.g., brooms and Chinese tallow tree) has also been successful. In many cases, the effectiveness of prescribed burning can be enhanced when incorporated into an integrated vegetation management program. Though there are some excellent examples of successful use of prescribed burning for the control of invasive species, only a limited number of species have been evaluated. In addition, few studies have measured the impact of prescribed burning on long-term changes in plant communities, impacts to endangered plant species, effects on wildlife and insect populations, and alterations in soil biology, including nutrition, mycorrhizae, and hydrology. In this review, we evaluated the current state of knowledge on prescribed burning as a tool for invasive weed management.

Brooks et al. In prep. Integrated management of fire and invasive plants. Handbook for the US Fish and Wildlife Service, Refuge system
Fire management activities can often mitigate or exacerbate invasive plant management problems. Similarly, invasive plant management activities can positively or negatively affect fire management problems. This handbook will provide guidance to land managers on how to most efficiently and effectively manage both fire and invasive plants. Although it will be specifically developed for the US Fish and Wildlife Service, Refuge System, its recommendations will be based on concepts that are relevant to other land management agencies as well.

Wojcik, N.J. and R. Sanford. In prep. The effects of fire on soil nutrients; a review. Journal publication.
This manuscript will synthesize the state-of-knowledge of how fires affect the availability of soil nutrients.

New Review Project Supported by the JFSP
Smith, J.K. et al. In prep. Effects of Fire on Nonnative Invasive Plants. 6th volume in the US Forest Service, Rocky Mountain Research Station, General Technical Report, Wildland Fire in Ecosystems "Rainbow" series.
The Team Lead Scientist in JFSP project 00-1-2-04 is taking what he has learned in developing the summaries described above, and applying this knowledge as a co-editor of a new document coordinated by Jane Kapler-Smith of the US Forest Service. This document will provide the most comprehensive overview of integrated fire and invasive plant management in the United States. This new effort is supported by JFSP project 04-4-1-08.

Objective 2: New Research on Fire and Invasive Annual Grasses

We adopted three primary research approaches to accomplish Objective 2 (Table 1). First, we conducted extensive surveys across public lands within the arid to semi-arid regions of western North America to determine the soil characteristics associated with invaded and non-invaded sites. Second, we implemented intensive field experiments to evaluate the immediate postfire effects of fire on soil nutrient availability, seed bank composition, above ground community composition, and invasive grass productivity at three field sites within ponderosa pine forest (NPS), sagebrush steppe (BLM), and the ecotone transition between ponderosa forest and sagebrush steppe (NPS/BLM). Third, we coupled these field studies with laboratory experiments to further pinpoint the relationship between soil heating, nutrient availability, and responses by invasive annual grasses. Lab experiments were conducted at both University and Federal research labs. We will use this information to produce specific recommendations on managing fire and invasive annual grasses in western North America.

Table 1. Study locations for each of the three research approaches to Objective 2 in this study.

Extensive Field Surveys	**Intensive Field Experiments**	**Lab Experiments**
Numerous public land management units in arid and semi-arid regions of AZ, CA, CO, NV, NM, and UT	Ponderosa site: Sequoia-Kings Canyon National Park Sagebrush site: BLM Bishop Field Office Ecotone site: Lake Mead National Recreation Area / Grand Canyon – Parashant National Monument	Denver University; USGS, Southwest Biological Science Center, Moab Field Station; USGS, Western Ecological Research Center, Sequoia Kings Canyon Field Station

Extensive Field Surveys

We investigated how climate and soil factors control the distribution of exotic annual grasses by sampling 432 sites in the Chihuahuan, Mojave, Colorado Plateau, and Great Basin deserts. At each site we measured plant cover by species, ground cover, slope, aspect, elevation, soil chemistry, soil texture, soil pH, and soil cation exchange capacity. Our results show that, within a given climate region, soil characteristics are different between uninvaded and invaded patches. Invaded patches in regions with lower winter precipitation (Mojave Desert) had higher available phosphorus than uninvaded patches. As winter precipitation increased (Colorado Plateau and Great Basin), potassium, manganese, and total phosphorus became important as well. Soil depth was important in areas where soils were relatively shallow, and texture played a role in some regions as well. Because the soil nutrient limiting invasive annual grass growth was dependent on climate, it is expected that the distribution of annual grasses will change with potential future changes in climate. We developed a conceptual model of nutrients limiting invasive annual grass cover and distribution to visually describe these patterns (Fig. 1). Publications that are currently in review or in preparation will include this model and other interpretations of the patterns we observed, in addition to specific management recommendations.

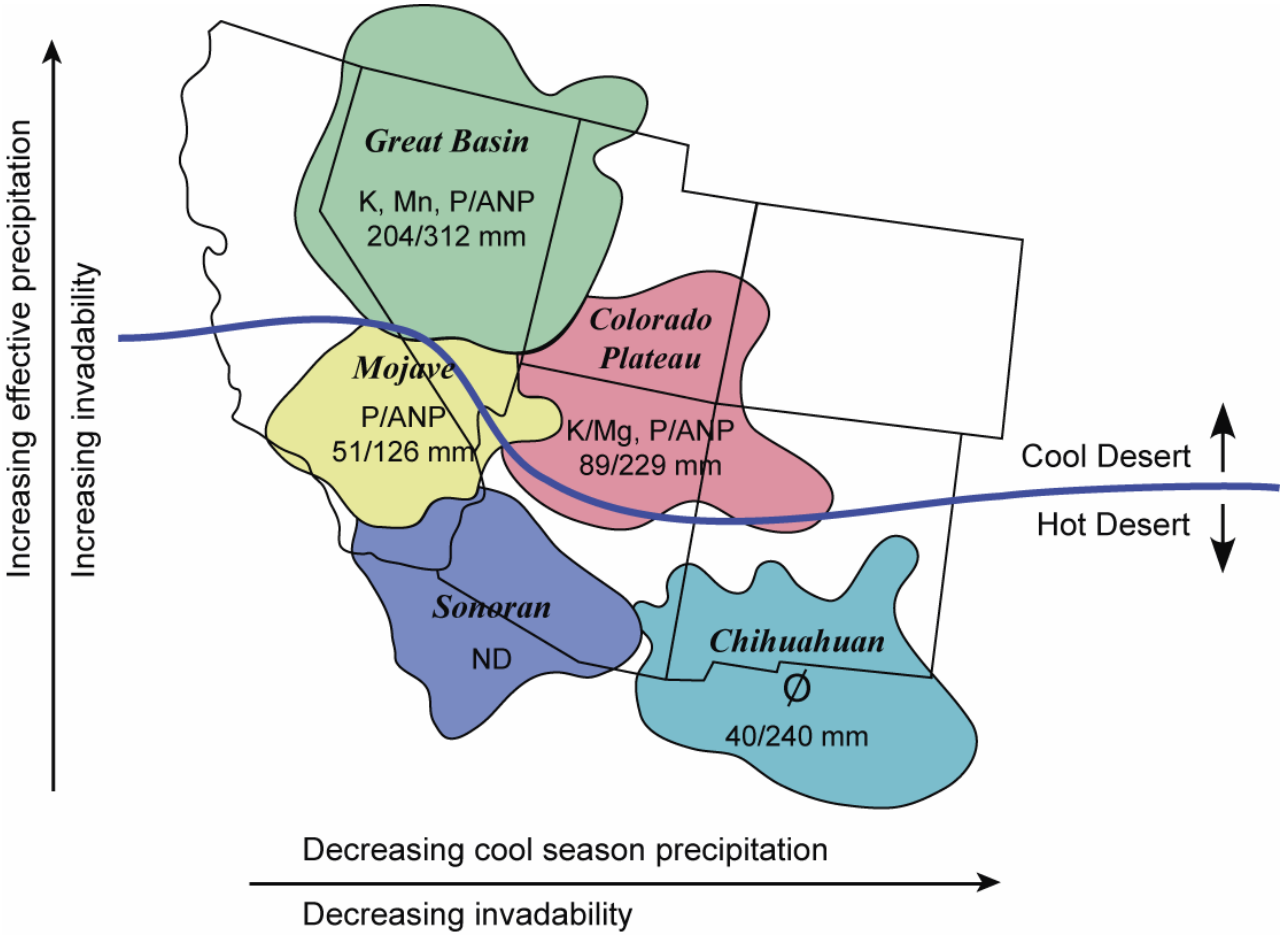

Figure 1. Conceptual model illustrating the primary soil nutrients positively correlated with dominance by invasive annual grasses in five major ecoregions with differing rainfall regimes in western North America.
** P = phosphorus, ANP = acid neutralizing potential (capacity of the soil to buffer acids; high ANP reduces P availability), K = potassium, Mg = magnesium, Mn = manganese.*
*** Rainfall ratios represent the winter rainfall (amount occurring below 10˚C) versus the total annual rainfall (mm) (Belnap et al. in review).*

Intensive Field Experiments

The original proposal indicated that we would establish a field experimental site in each of three ecoregions: the Sierra Nevada, Great Basin, and Mojave Desert. The plan for the Sierra Nevada (ponderosa pine) site was implemented as planned. Implementation at the other two desert sites was delayed due in part to shifting priorities of our original land management partners, but mostly due to multiple years of drought beginning in 2000. Low rainfall continued in the Mojave Desert throughout the course of this study, but enough rainfall occurred at higher latitudes to implement burns at a Great Basin (sagebrush steppe) site in 2004. In addition, we replaced the Mojave Desert site with an ecotonal site on the Colorado Plateau (ponderosa-sagebrush ecotone) and conducted burns at that site in 2004 as well. During FY03 we were granted by the JFSP Governing Board a no-cost extension to make these changes and to extend the project through the end of FY05. Thus, we conducted field experiments at three locations as

originally planned, but the nature of these sites shifted to: (1) ponderosa pine forest; (2) sagebrush steppe; and (3) ponderosa-sagebrush ecotone.

Ponderosa Pine Forest

The ponderosa pine study area was in the valley of the South Fork of the Kings River, in the Cedar Grove area of Sequoia-Kings Canyon National Park. This site was selected because of its unprecedented abundance of cheatgrass that had spread throughout the valley floor soon after a century of fire suppression was followed by high-intensity prescribed burning.

The field experiment was designed to evaluate the effects of fire season and plot treatments selected to simulate fire and fire-free conditions (pine needle addition, seed additions, shade addition and soil nutrient amendments) on the success of cheatgrass and other understory species in the ponderosa pine forest of Cedar Grove, Kings Canyon National Park. Beginning in 2001, six valley floor study sites were selected in Kings Canyon, from Cedar Grove to Zumwaldt Meadow, that were large enough (~3 ha each) to accommodate 70 5x5 m cheatgrass-infested (>5% cheatgrass cover) plots separated by 1 m (minimum) buffers, for a total of 420 plots.

This study began with the collection of baseline data in the plots (i.e., plant cover, litter cover and depth, tracking shade patterns, fuel, and soil). These baseline data characterized the state of the plots before they were manipulated. Among other things, these data indicated that cheatgrass cover was highly variable from year to year, and therefore, treatment effects would need to be analyzed against controls within the same growing season, rather than by comparing pre and post treatment observations.

The study design included four burn treatments (no-burn, fall 2001 burn, summer 2002 burn and fall 2002 burn) and nine other treatments (Table 2). Each of the burn treatments was crossed with one of the plot treatments (with the exception of the needle addition plot treatment, which was added after the fall 2001 burn had occurred). Fire temperatures were monitored 2 cm belowground, at the soil surface and 15 cm aboveground.

Table 2. Ponderosa pine forest experimental treatments (predictor variables)

Burn Treatments	
Fall 2001	
Summer 2002	
Summer 2002 and Fall 20002	
No burn	
Other Treatments	**Surrogate for:**
Pine needle addition	long fire return interval
Shade addition	long fire return interval
Nitrogen addition	Fire
Nitrogen reduction (sawdust)	long fire return interval
Phosphorous addition	Fire
Phosphorous reduction ($CaCO_3$)	long fire return interval
Cheatgrass seed addition	test for propagule limitation
Native seed addition	test for propagule limitation
Untreated control	

It was hypothesized that burning during the early summer, at the time of seed maturation, would reduce cheatgrass cover, but this was not supported. Burning in the summer as well as during the normal fall season did not significantly impact cheatgrass cover or biomass. Part of the explanation for the lack of cheatgrass inhibition from early season burning was the sparse fuels that resulted in generally low temperatures. The addition of 5 cm of pine needles prior to summer fires, to mimic a longer fire cycle, produced substantially higher burn temperatures and resulted in lower cover and biomass of cheatgrass and other understory species. Cover was not significantly reduced in fall burned needle plots, compared to plots burned in the fall with natural fuel loads.

A subset of the predictor variables was significantly associated with cheatgrass biomass. The amounts of fall sun, soil nitrogen, and precipitation were positively correlated with cheatgrass biomass (Fig. 2, Keeley and McGinnis in review). In contrast, the amounts of summer sun and fire intensity were negatively correlated with cheatgrass biomass.

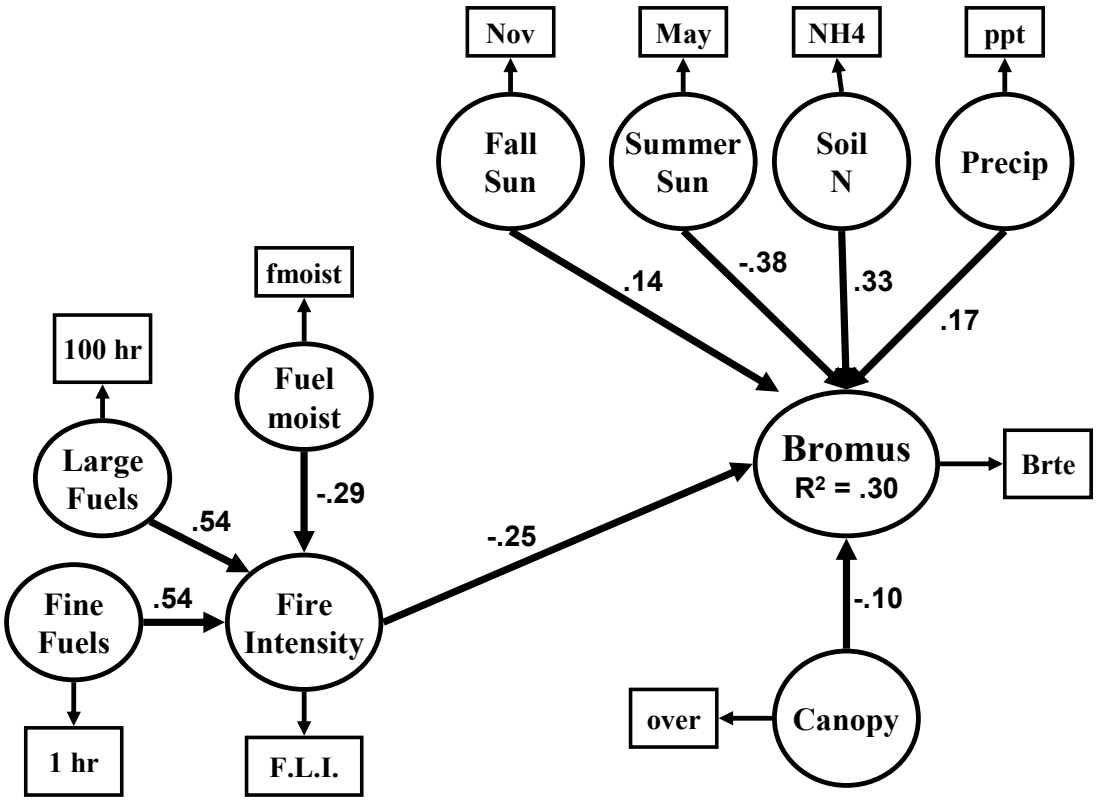

Figure 2. Correlational path diagram illustrating the relationships of the various predictor variables with cheatgrass (Bromus tectorum) biomass. From Keeley and McGinnis (in prep).

The results of this study suggest that a century of fire suppression in Kings Canyon contributed to litter buildup that inhibited cheatgrass. Removal of these fuels through fire restoration has removed this litter and contributed to cheatgrass success. Where cheatgrass is established, management with short return-interval fires is likely to maintain cheatgrass

indefinitely in the ponderosa pine forest. Conversely, implementing a long fire return interval should temporarily suppress cheatgrass through litter buildup.

In addition, two cheatgrass seed bank depletion methods were tested outside of the plots in Kings Canyon. One method "inappropriate timing of germination," was to stimulate germination by watering in the summer, but then to withhold water so that the seedlings would die. The other method, "solarization", was to kill seeds before they germinated by saturating dry grass with water, and then covering it with black plastic to intensify solar heating. We also evaluated the physical parameters through which cheatgrass seeds could remain viable. Among these were experiments in which the seeds were heated to different temperatures for varying lengths of time, experiments that tested viability of buried seeds, experiments that tested the effects of seed refrigeration in combination with pre and post refrigeration heating, and experiments that tested the effect of moisture on heated seeds. The results of these studies will be reported in manuscripts currently in preparation.

Sagebrush Steppe

The sagebrush steppe study site was in the Mono Basin, just north of Lee Vining, CA, within an area managed by the Bureau of Land Management, Bishop Field Office. Predominant vegetation at the site included mature mountain big sagebrush (up to 2m tall) (*Artemisia tridentata* ssp. *vaseyana*), perennial grasses (*Elymus cinereus*, *Achnatherum hymenoides*, *Hesperostipa comata*) and various forbs. Cheatgrass (*Bromus tectorum*) was present at the site and was especially dense near Hwy 395.

Fire treatments were applied randomly to 5 x 5 m plots for a total of 40 burned and 40 unburned controls during April 2004. Each plot was burned individually and allowed to extinguish naturally. Temperatures below, above, and at the soil surface were recorded before, during and after each fire using Chromel alumel thermocouples. Soils were collected immediately pre- and postfire and microhabitat noted, to investigate immediate soil nutrient and seed bank changes beneath the shrub canopy, at the dripline and in the interspace. Seedbank composition was subsequently evaluated by growing out samples in a greenhouse using standardized methods (T. Esque et al. unpublished manuscript).

Fuel load was visually estimated on all plots and related to quantitative models developed via double sampling of herbaceous and shrub vegetation. Fuel continuity and moisture were also measured quantitatively. Flame length and rate of spread were recorded during each fire. Fire severity was described using NPS Fire Monitoring Handbook (FMH) standards and evaluated using the same metric as vegetation cover, which allowed us to evaluate relationships among cover, biomass, temperature, and burn severity. These data will allow us to relate fire effects of fuel and fire behavior parameters.

Post-treatment year 1 seedbanks were collected in Fall 2004, and vegetation was collected in Spring 2005. Post-treatment year 2 seedbanks and vegetation will be collected again during Fall 2005 and Spring 2006. Analyses of these data are in progress and manuscripts will be completed and submitted for publication by the end of FY06.

Ponderosa-Sagebrush Ecotone

The ponderosa-sagebrush ecotone study site was located on the Shivwits Plateau, near the north rim of the Grand Canyon, AZ, in an area jointly managed by Lake Mead National Recreation Area and the Grand Canyon-Parashant National Monument. Predominant vegetation at the site included basin big sagebrush (*Artemisia tridentata ssp. tridentata*), Ponderosa pine

(*Pinus ponderosa*), rubber rabbitbrush (*Chrysothamnus nauseosus*), perennial grasses (*Elymus elymoides, Bouteloua gracilis*) and various forbs. Cheatgrass was extremely dense the year of the burn.

Fire was applied as a large scale burn during late summer 2004; all plots were burned together, not in individual 5 x 5 m plots as at the sagebrush site. Designing the prescription in this manner created fire behavior more similar to wildfire, and provided excellent data that directly related to immediate post fire effects of fire temperature and duration, fuel load, weather, vegetation community structure and soil nutrient availability at this site. All pre-fire and post-fire data, and data during fire, were collected in the same manner as described above for the sagebrush steppe site.

Post-treatment year 1 seedbanks were collected in Fall 2004, and vegetation was collected in Spring 2005. Post-treatment year 2 seedbanks and vegetation will be collected again during Fall 2005 and Spring 2006. Analyses of these data are in progress and manuscripts will be completed and submitted for publication by the end of FY06.

Variation Among Sites in Fire Effects on Soil Nutrients

Wojcik, N.J. In preparation. Effects of fire on soil nutrients following cheatgrass invasion in ponderosa pine and sagebrush communities, Doctoral Dissertation

Abstract - Cheatgrass (*Bromus tectorum* L.) is one of the most dominant invasive annual grasses in North America, affecting over 40 million hectares. Wildfire and prescribed fire have increased invasion of cheatgrass in old growth, ponderosa pine forest and sagebrush steppe throughout the intermountain west. Soil exposure to heat flux during fire may change soil nutrient availability and subsequently alter nutrient cycling. The objectives of this research are: 1) to measure the effect of fire on soil C, N, and P in lower-montane ponderosa pine forest, sagebrush steppe, and ponderosa-sagebrush ecotone and 2) to determine how cheatgrass invasibility is affected following fire induced changes in soil C, N, and P. Soil nutrients were monitored before and after burning in three ecosystems. Under ponderosa pine, soil nutrients were measured during summer and autumn seasons for two years following burning. Total soil C is unchanged in surface soils (0-3 cm) from ponderosa pine and ecotone areas but increases significantly (by 49.3 %) in sage dominated systems regardless of whether soil $CaCO_3$ is abundant or scarce. Total soil N does not change following fire in ponderosa pine. However, in the ecotone it increases from 1480 mg kg^{-1} to 1560 mg kg^{-1} under sagebrush (*Artemisia tridentata ssp. tridentata*) but decreases from 1970 mg kg^{-1} to 1700 mg kg^{-1} under rabbitbrush (*Chrysothamnus nauseosus*). Finally total soil N increases by 67.4 % from 880 mg kg^{-1} to 1465 mg kg^{-1} under sagebrush. Fire intensity and sometimes the timing of the burn alters seasonal patterns of labile soil P, NO_3 and NH_4. In ponderosa forest, summer fires increase labile soil P significantly from 119.5 mg kg^{-1} to 152.4 mg kg^{-1}. Subsequently, labile soil P decreases to below pre-burn levels (102.5 mg kg^{-1}) twelve months after fire. Autumn fires initially increased labile soil P from 122.1 mg kg^{-1} to 146.0 mg kg^{-1}, which decreased to 94.4 mg kg^{-1} six months later. Soil NO_3 decreases significantly from 3.15 mg kg^{-1} to 1.10 mg kg^{-1} regardless of fire intensity during summer fire but does not change after autumn fires, and increases significantly by 468 % (1.10 mg kg^{-1} to 6.25 mg kg^{-1}) twelve months after fire. Soil NH_4 increases by 59.7 % under the most intense fires regardless of season and continues to increase six and twelve months following fire (87.1 % and 272 %, respectively). Soil C, N, and P in these ecosystems have surprisingly different responses

to fire. In ponderosa pine forests, labile soil P and NH_4 increase immediately after fire regardless of season. In contrast, soil NO_3 is reduced immediately following fire and decreases significantly following summer fires. The immediate changes in labile soil P, NO_3, and NH_4 are ephemeral under ponderosa pine, where labile soil P is reduced to below pre-burn levels and soil NO_3 and NH_4 increase significantly one year after fire.

Lab Experiments

We tested multiple types of soils (that represented a range of soil nutrients) collected from the Mojave, Colorado Plateau, and Great Basin deserts. Each soil type was exposed to treatments that increased its temperature 0, 50, 100, and 200^{o} C. We then planted *Bromus* (*B. tectorum* and *B. rubens*) in burned and unburned soils, and measured its growth response. *Bromus* performed better in almost all of the soils that were heated, compared to unheated soils, regardless of burn temperature. Soil chemistry changed in all burned soils as well. However, the response of most nutrients was variable. Cations (potassium, magnesium, calcium, sodium) had a limited response. A few soils showed a significant increase in phosphorus, and a few soils showed a significant increase in nitrogen with burning. However, neither response was consistently related to *Bromus* performance. In contrast, manganese always increased with burning (by up to 400%) and patterns of increased *Bromus* growth followed that of increased manganese. Therefore, our results corroborate those found in the extensive field surveys: it appears that manganese plays a large role in determining *Bromus* performance. These findings need further exploration, both in the lab and the field. Manuscripts describing these results and their management implications are either in review or in preparation.

Application and Technology Transfer

The four principal investigators in this project and their staffs have used a variety of technology transfer methods to disseminate the information we have generated to land managers, research scientists, University students, and the general public. We have relied heavily on direct interaction with our target audiences through scientific meetings, management workshops, University lectures, informal consultations with small groups (e.g. Burned Area Emergency Response teams), and reporter interviews. Our strategy for information transfer over the long-term is to publish our results in the peer-reviewed literature. These publications include seven major review and synthesis documents that are currently either published, in review, or in preparation as part of Objective 1 of this project (three journal articles, one symposium proceedings, one book chapter, one management handbook for the US Fish and Wildlife Service Refuge System, and one dissertation). This strategy of publishing in the open literature both creates a permanent record for people to reference in future, and provides land managers with reliable sources of information that can be cited in land management plans.

The Team Lead Scientist has also used the information generated from this project as the foundation for the invasive plant module of the Fire in Ecosystems Management course which he teaches each year at the BLM National Advanced Fire and Resource Institute in Tucson, Arizona. This course is specifically designed to give land managers current and practical science-based information to help guide planning and implementation of land management plans.

Linkages and Other Funding Sources

The Bureau of Land Management and National Park Service partners in this project contributed significant amounts of time and other resources to make this project successful.

Specifically, they wrote burn plans, conducted necessary evaluations to approve experimental treatments, provided on-site management of study areas, and completed various other logistical tasks.

The results of this project have subsequently led to numerous other scientific studies integrating the management of fire and invasive plants. These other projects range from fuels management to post-fire emergency stabilization, rehabilitation, and ecological restoration treatments. Many have been funded by the Joint Fire Sciences program, while others have been supported by the Bureau of Land Management, National Park Service, and US Fish and Wildlife Service.

Summary of Deliverables Listed in the Original Proposal

The information below lists the six categories of deliverables identified in our original proposal, each followed by a summary of the actual deliverables we produced. More comprehensive and detailed information is included in the next major section which lists the complete list of our products.

- Data from this study will be coupled with an NRCS soil survey to create a landscape-level map of post-fire soil susceptibility to invasion for one of the studied regions.
  - This is the only deliverable that will not be produced as originally planned. This is because the element that was found to most strongly correlate with *Bromus* dominance was Manganese, and this element is not typically mapped in NRCS soil surveys.
  - Alternatively, we produced a map showing the major soil nutrients associated with dominance by *Bromus* in 5 major bioregions with differing rainfall regimes in western North America: the Chihuahuan Desert, Colorado Plateau, Great Basin, Mojave Desert, and Sonoran Desert (see Fig. 1 in this report).

- Technical report for land managers within 1 year of project completion
  - The Objective 1 products provide various types of summaries for land managers focused on different topics and geographic scales.
  - The comprehensive summary of Objective 2 is in preparation, and will be completed by the end of FY06 (Brooks, M.L. et al. In prep. Effects of fire on invasive annual grasses in western North America).

- Six scientific publications will be submitted to peer-reviewed journals within 2 years of project completion.
  - 7 peer-reviewed publications published
  - 5 peer-reviewed publications accepted or in press
  - 3 peer-reviewed publications in review
  - 14 peer-reviewed publications in preparation
  - 6 Publication briefs for peer-reviewed publications
  - 13 non-peer-reviewed publications

- An annual report will be submitted to the Joint Fire Science Board
  - Completed each year of the project as per instructions from the JFSP Program Manager.

- Website
  - Completed, but currently in the process of being updated
  - http://www.werc.usgs.gov/fire/lv/fireandinvasives/

- Results will be presented at a minimum of two national and two local scientific meetings, and Joint Fire Science Program workshops.
  - 51 presentations between 2000 and 2005.

Complete List of Products
(items either completely or partially supported by JFSP project 00-1-2-04)

Peer-reviewed Publications

Brooks, M.L.2002. Peak fire temperatures and effects on annual plants in the Mojave Desert. Ecological Applications 12:1088-1102.

Brooks, M.L. 2003. Effects of increased soil nitrogen on the dominance of alien annual plants in the Mojave Desert. Journal of Applied Ecology 40:344-353.

Brooks, M.L. C.M. D'Antonio, D.M. Richardson, J. Grace, J. J. Keeley, J.M. DiTomaso, R. Hobbs, M. Pellant, and D. Pyke. 2004. Effects of invasive alien plants on fire regimes. BioScience 54:677-688.

Brooks, M.L. and D. Pyke. 2001. Invasive plants and fire in the deserts of North America. Pp. 1-14 *In* K. Galley and T. Wilson (eds.), Proceedings of the Invasive Species Workshop: The Role of Fire In the Control and Spread of Invasive Species. Fire Conference 2000: The First National Congress on Fire, Ecology, Prevention and Management. Miscellaneous Publications No. 11, Tall Timbers Research Station, Tallahassee, Florida, USA.

Brooks, M.L., and T.C. Esque. 2002. Alien annual plants and wildfire in desert tortoise habitat: status, ecological effects, and management. Chelonian Conservation and Biology 4:330-340.

Galley, K.E. and T.P. Wilson. 2001. Proceedings of the Invasive Species Workshop: The Role of Fire In the Control and Spread of Invasive Species. Fire Conference 2000: The First National Congress on Fire Ecology, Prevention and Management. Miscellaneous Publications No. 11, Tall Timbers Research Station, Tallahassee, Florida, USA.

Keeley, J.E. 2004. Invasive plants and fire management in California Mediterranean-climate ecosystems. *In* M. Arianoutsou (ed) 10th MEDECOS – International Conference on Ecology, Conservation and Management, Rhodes Island, Greece.

Peer-reviewed Publications Accepted or In Press

Brooks, M.L. and K.H. Berry. Accepted. Dominance and environmental correlates of alien annual plants in the Mojave Desert. Journal of Arid Environments.

Brooks, M.L. and R.A. Minnich. In press. Ecological effects of non-native annual grasses. Sidebar in: Sugihara, N. G., J.W. van Wagtendonk, J. Fites-Kaufman, K.E. Shaffer, and A.E. Thode (eds.). Fire in California ecosystems. University of California Press, Berkeley.

Brooks, M. L. and R. A. Minnich. In press. Fire in the Southeastern Desert Bioregion. In press. Chapter 16 in: Sugihara, N. G., J. W. van Wagtendonk, J. Fites-Kaufman, K. E. Shaffer, and A. E. Thode (eds.). Fire in California ecosystems. University of California Press, Berkeley.

Dudley, T. and M.L. Brooks. In press. Saltcedar invasions can change riparian fire regimes. Sidebar in: Sugihara, N. G., J. W. van Wagtendonk, J. Fites-Kaufman, K. E. Shaffer, and A. E. Thode (eds.). Fire in California ecosystems. University of California Press, Berkeley.

Klinger, R. C., M .L. Brooks, and J. M. Randall. In press. Fire and Invasive Plant Species. Chapter 22 in: Sugihara, N. G., J. W. van Wagtendonk, J. Fites-Kaufman, K. E. Shaffer, and A. E. Thode (eds.). Fire in California ecosystems. University of California Press, Berkeley.

Peer-reviewed Publications In Review

Belnap, J., H. Humphreys, S.L. Phillips, and D. M. Miller. In review. Soil and climate controls on the distribution of exotic annual grasses in the Western US. Journal of Rangeland Ecology.

DiTomaso, J.M., ML Brooks, EB Allen, R Minnich, PM Rice, and GB. Kyser. In review. Control of invasive weeds with prescribed burning. Weed Technology.

Merriam, K.E., J.E. Keeley and T.W. McGinnis. In review. The role of fire and fire management in the invasion of nonnative plants. Park Science.

Peer-reviewed Publications in Preparation

Belnap, J, R.L. Sanford, S. L. Phillips, and M.L. Brooks. In prep. Burning changes the chemistry of high pH, low organic matter soils and affects *Bromus tectorum* germination and biomass. Plant and Soil.

Brooks, M.L. et al. In prep. Effects of fire on invasive annual grasses in western North America.

Brooks M.L. et al. In prep. Effects of soil nutrient enrichment on dominance by red brome (*Bromus rubens*) in previously burned and unburned desert vegetation.

Brooks, M.L. et al. In prep. Fuel conditions, fire behavior, and fire temperature patterns in sagebrush steppe.

Brooks et al. In prep. Integrated management of fire and invasive plants. Handbook for the US Fish and Wildlife Service, Refuge system.

Brooks M.L. et al. In prep. Mortality rates of cheatgrass (*Bromus tectorum*) seeds in the soil seedbank during fires in sagebrush steppe.

DiTomaso, J.M., M.L. Brooks, E.B. Allen, and R. Minnich. In prep. The Use of Fire as Tool for Controlling Invasive Weeds. Report to the Center For Invasive Plant Management, Bozeman, Montana.

Keeley, J.E. and T.W. McGinnis. In prep. Fire intensity during prescription burns in a ponderosa pine forest and its effect on cheatgrass.

McGinnis, T.W. and J.E. Keeley. In prep. Experimental analysis of fire impacts on cheatgrass success in a Sierra Nevada yellow pine forest.

McGinnis, T.W., and J.E. Keeley. In prep. Fire related heating affects on cheatgrass in the ponderosa pine forest.

Wojcik, N.J. In preparation. Effects of fire on soil nutrients following cheatgrass invasion in ponderosa pine and sagebrush communities, Doctoral Dissertation

Wojcik, N.J. and R. Sanford. In prep. The effects of fire on soil nutrients; a review.

Wojcik, N.J. and R. Sanford. In prep. Fire effects and soil heating on available nitrogen (NH4 and NO3) and phosphorus in yellow pine forests.

Wojcik, N.J. and R. Sanford. In prep. Impacts of prescribed fire on soil nutrients in sagebrush steppe communities.

Publication Briefs for Peer-reviewed Publications

Brooks, M.L. 2002. Fire temperature patterns and effects on annual plants in the Mojave Desert. U.S. Geological Survey, Western Ecological Research Center, Publication Brief for Resource Managers. Available online at www.werc.usgs.gov/pubbriefs/brookspbaug2002.html.

Brooks, M.L. 2002. Potential effects of atmospheric nitrogen deposition on annual plants in the Mojave Desert. U.S. Geological Survey, Western Ecological Research Center, Publication Brief for Resource Managers. Available online at www.werc.usgs.gov/pubbriefs/brookspbapr2003.html.

Brooks, M.L. and T.C. Esque. 2003. Alien plants and fire in desert tortoise habitat. U.S. Geological Survey, Western Ecological Research Center, Publication Brief for Resource Managers. Available online at www.werc.usgs.gov/pubbriefs/ brookspbmar2003.html

Brooks, M.L., J.B. Grace. J.E. Keeley, D.A. Pyke. 2004. Effects of invasive alien plants on fire regimes. U.S. Geological Survey, Western Ecological Research Center, Publication Brief for Resource Managers.

Brooks, M.L. and J.R. Matchett. 2003. Plant diversity and fire effects in blackbrush shrublands. U.S. Geological Survey, Western Ecological Research Center, Publication Brief for Resource Managers. Available online at www.werc.usgs.gov/pubbriefs/brookspbaug2003.html.

Brooks, M.L. and D. Pyke. 2002. Invasive plants and fire in the deserts of North America.. U.S. Geological Survey, Western Ecological Research Center, Publication Brief for Resource Managers. Available online www.werc.usgs.gov/pubbriefs/brookspbmar2002.html.

Non-peer-reviewed Publications

Brooks, M. L. 2001. Fire and invasive plants in the wildlands of California. Noxious Times 3(4):4-5. California Interagency Noxious Weed Coordinating Committee. On-line at http://pi.cdfa.ca.gov/noxioustimes/spring2001.pdf.

Brooks, M.L. 2003. Introduction and overview of invasive species in the southwest. *In* M. Kelly (ed.). Proceedings of the California Exotic Pest Plant Council Symposium. Vol. 6:49. Brooks, M.L. 2003. Multidisciplinary research needs for invasive plants in southwestern North America. In M. Kelly (ed.). Proceedings of the California Exotic Pest Plant Council Symposium. Vol. 6:52.

Brooks, M.L. 2003. Research highlight: fire and invasive annual grasses in western ecosystems. Pg. 14 *In* Joint Fire Science Program, 2002 Business Summary. Available online at http://jfsp.nifc.gov/2003business_summary.pdf.

Brooks, M.L. 2004. *Schismus barbatus*. Species profile for the Invasive Species Specialist Group of the World Conservation Union (http://www.issg.org/database/welcome)

Brooks, M.L. 2005. Immediate postfire effects on soil nutrient availability and seedbank composition in sagebrush steppe invaded by annual grasses. US Geological Survey, Western Ecological Research Center, Fact Sheet.

Brooks, M.L. and C.M. D'Antonio. 2003. The role of fire in promoting plant invasions. *In* M. Kelly (ed.). Proceedings of the California Exotic Pest Plant Council Symposium. Vol. 6: 29-30.

Brooks, M.L. C.M. D'Antonio, D.M. Richardson, J. Grace, J. Keeley, J. DiTomaso, R. Hobbs, M. Pellant, and D. Pyke. 2004. Fire regimes and potential for ecosystem recovery after plant invasions. Proceedings of the California Exotic Pest Plant Council Symposium. Vol. 7:21.

Brooks, M.L., S.H. Cannon, and N.B. Kotliar. 2003. White paper on post-fire effects, including physical and biological. Pp. 53-56 *In* R.K. Livingston (ed.). Third U.S. Geological Survey Wildland Fire-Science Workshop, Denver, Colorado, November 12-15, 2002. U.S. Geological Survey Scientific Investigations Report 2004-5005, 67pp.

Brooks, M. L. and T. C. Esque. 2000. Fire and exotic grasses changing Mojave's face. U.S. Department of the Interior. People, Land & Water (July/August):25.

Keeley, J.E., T.W. McGinnis, M.L. Brooks, J. Belnap, and R. Sanford. 2004 National Park Service Final Report.

Keeley, J.E., T.W. McGinnis, M.L. Brooks, J. Belnap, and R. Sanford. 2001 National Park Service Investigator's Annual Report.

Keeley, J.E., T.W. McGinnis, M.L. Brooks, J. Belnap, and R. Sanford. 2002 National Park Service Investigator's Annual Report.

Keeley, J.E., T.W. McGinnis, M.L. Brooks, J. Belnap, and R. Sanford. 2003 National Park Service Investigator's Annual Report.

Website

http://www.werc.usgs.gov/fire/lv/fireandinvasives/

Presentations for Land Managers and Scientists in 2005

Belnap, J. 2005. Exotic annual grasses: where they occur, what they do when they get there, and what to do about it. USGS Science for Land Managers, March 2005, Salt Lake City, UT.

Belnap, J. 2005. The effects of disturbance on exotic plant distribution, soil stability, and soil fertility in the western United States. Missoula Fire Laboratory Seminar Series, April 2005, Missoula, MT

Brooks, M.L. 2005. Fire and Invasive Plants. Module for the Fire in Ecosystem Management (FIEM) course at the BLM National Advanced Resource Technology Center. 29 February, Tucson, AZ.

Presentations for Land Managers and Scientists in 2004

Brooks, M.L. 2004. Desert fire ecology and the integrated management of fire and invasive plants. Humboldt State University, Fire Ecology Seminar Series, 11 October, Arcata, CA.

Brooks, M.L. 2004. Integrated management of invasive plants and fire. Department of the Interior Science Seminar, 16 April, Boise, ID.

Brooks, M.L. 2004. Fire and invasive plants: general management issues. Workshop: The use of fire to manage invasive plants, 28-29 March, Henderson, NV.

Brooks, M.L. 2004. Effects of fire on plant communities. Fire and invasive plants: general management issues. Workshop: The use of fire to manage invasive plants, 28-29 March, Henderson, NV.

Brooks, M.L. 2004. Fire and Invasive Plants. Module for the Fire in Ecosystem Management (FIEM) course at the BLM National Advanced Resource Technology Center. 1 March, Tucson, AZ.

Brooks, M.L., J. Belnap, J. Keeley, and R Sanford. 2004. Fire and invasive annual grasses in western ecosystems. Joint Fire Science Program Principal Investigator Workshop. 7 March, Phoenix, Arizona.

Keeley, J.E. 2002. Fire management Impacts on Invasive Plants, at the Fire and Invasive Plant Ecology Symposium, ESA annual meeting, Tucson, AZ, Aug. 2002

Wojcik, N.J. and R.L. Sanford, Jr. 2004. Temporal changes following fire in soil nutrients in a Sierra Nevada yellow pine forest. 79th Annual Meeting of the Southwestern and Rocky Mountain Division of American Association for the Advancement of Science. Denver, CO.

Wojcik, N.J., R.L. Sanford, Jr., and T. McGinnis. 2004. Fire-caused changes of soil nutrients in a Sierra Nevada ecosystem invaded by cheatgrass. Ecological Society of America 89th Annual Meeting. Portland, OR.

Presentations for Land Managers and Scientists in 2003

Belnap, J. 2003. Predicting the occurrence of exotic annual grasses in the western United States. Northern Arizona University, Forestry Department Seminar Series. January 2003, Flagstaff AZ.

Belnap, J. 2003. Predicting how exotic annual grass distribution will change as with climate. USGS Global Change Conference, March 2003, Phoenix, AZ.

Belnap, J. 2003. The effect of soil chemistry on exotic annual plant distribution in the western United States. Colorado Plateau Biennial Science Conference, November 2003, Flagstaff, AZ.

Belnap, J. 2003. Soil food web legacies of Bromus tectorum: do they influence native plant establishment? Invasive plants in natural and managed ecosystems, Ft. Lauderdale, FL, November 2003.

Belnap, J. and S. Sherrod. 2003. Soil chemistry controls exotic annual grasses: using this concept to depress exotic annual grass and enhance native grass establishment.
DOD-SERDP Annual Conference, Washington DC, December 2003.

Brooks, M.L. 2003. Effects of plant invasions on fire regimes. 2nd International Fire Ecology and Fire Management Congress, 16-20 November, 2003. Orlando, FL.

Brooks, M.L. 2003. Management of Invasive Plant and Fire in the Deserts of North America. USFWS Brown Bag Seminar Series, Region 1 Headquarters, 4 August, Sacramento, CA.

Brooks, M.L., J. Belnap, J. Keeley, and R Sanford. 2003. Fire and invasive annual grasses in western ecosystems. Joint Fire Science Program Principal Investigator Workshop. 12 March, Phoenix, Arizona.

Brooks, M.L., C.M. D'Antonio, and D. Pyke. 2003. The use of fire to control invasive plants. 2nd International Fire Ecology and Fire Management Congress, 16-20 November, 2003. Orlando, FL.

Brooks, M.L., C.M. D'Antonio, and D. Pyke. 2003. The use of fire to control invasive plants. Invasive Plants in Natural and Managed Systems: Linking Science and Management, 3-7 November, Ft. Lauderdale, FL

Brooks, M.L. and T.C. Esque. 2003. Invasive Plant and Fire Research in the Southwestern Deserts. USGS-BLM Science Briefing, BLM Headquarters Office, 7-8 May, Washington D.C.

Brooks, M.L. 2003. Fire and Invasive Plants. Module for the Fire in Ecosystem Management (FIEM) course at the BLM National Advanced Resource Technology Center. 3 March, Marana, AZ.

Brooks, M.L. T.C. Esque, and J.R. Matchett. 2003 Current status and management of alien plants and fire in desert tortoise habitat. Desert Tortoise Council Symposium. 22 February, Las Vegas, Nevada.

Brooks, M.L., T.C. Esque, and J.R. Matchett. 2003. Management of alien plants and fire in the Mojave and Colorado deserts. Aridlands Restoration Workshop. 3 March, Palm Springs, California.

Brooks, M.L. and R. Shaw. 2003. Effects of global change on plant invasions. Invasive Plants in Natural and Managed Systems: Linking Science and Management, 3-7 November, Ft. Lauderdale, FL

McGinnis, T., J.E. Keeley, M.L. Brooks, R. L. Sanford Jr. and J. Belnap. 2003. Effects of fire temperatures on cheatgrass in a Sierra Nevada yellow pine forest. Invasive Plants in Natural and Managed Systems: Linking Science and Management and 7th International Conference on the Ecology and Management of Alien Plant Invasions, 3-7 2003, Ft. Lauderdale, Florida.

McGinnis, T.W. J.E. Keeley, M.L. Brooks, R. Sanford, and J. Belnap. 2003. Above and below ground fire-related temperatures in a cheatgrass (*Bromus tectorum* L.) infested Sierra Nevada yellow pine forest: effects on cheatgrass seeds and native plants. North America Forest Ecology Workshop. 16-20 June, Corvallis, Oregon.

McGinnis, T.W. J.E. Keeley, M.L. Brooks, R. Sanford, and J. Belnap. 2003. The response of cheatgrass (*Bromus tectorum* L.) and native flora to ecological manipulations in the yellow pine-mixed conifer forest. Joint Fire Science Program Principal Investigator Workshop. 12 March, Phoenix, Arizona.

Pyke, D., Brooks, M.L., and C.M. D'Antonio. 2003. What we know and where we need to go with the use of fire to control invasive plants. Invasive Plants in Natural and Managed Systems: Linking Science and Management, 3-7 November, Ft. Lauderdale, FL

Wojcik, N.J. and R.L. Sanford, Jr. 2003. Effects of fire on soil nutrients following cheatgrass invasion of Sierra Nevada yellow pine forest. Ecological Society of America 88th Annual Meeting. Savannah, GA.

Wojcik, N.J, R. Sanford, J.E. Keeley, M.L. Brooks, and J. Belnap. 2003. Fire in a cheatgrass (*Bromus tectorum* L.) infested Sierra Nevada yellow pine forest: effects of nitrogen and phosphorous soil fractions. The 4th North American Forest Ecology Workshop: Ecosystems in transition.16-20 June, Corvallis, Oregon.

Wojcik, N.J. and R.L. Sanford, Jr. 2003. Effects of fire on soil nutrients following cheatgrass (Bromus tectorum L.) invasion of Sierra Nevada yellow pine forest. 10th Annual Front Range Student Ecology Symposium. Fort Collins, CO.

Presentations for Land Managers and Scientists in 2002

Brooks, M.L. 2002. Fire, invasive plants, and the recovery of the Desert Tortoise (Gopherus agassizii). Desert Tortoise Management Oversight Group, Annual Meeting. 5 June, Las Vegas, Nevada.

Brooks, M.L. 2002. Introduction and brief history of fire and invasive plant ecology and management. Joint symposium of Ecological Society of America and the Society of Ecological Restoration. 6 August, Tucson, Arizona.

Brooks, M.L. 2002. Research to support the management of arid and semi-arid ecosystems. Biology Department seminar series, University of Nevada, Las Vegas, 1 May, 2004. Las Vegas, NV

Brooks, M.L. 2002. Relationships between fire and invasive plants. Southwest Landscape Change Workshop. 22 February, Las Cruces, New Mexico.

Brooks, M.L. 2002. The importance of integrating fire and invasive plant management. Seminar series of the U.S. Forest Service, Fire Sciences Laboratory. 21 February, Missoula, Montana.

Brooks, M.L. 2002. Plenary Session Introduction – The challenge of implementing fuels management treatments in the western United States. Fire Conference 2002: Managing Fire and Fuels in the Remaining Wildlands and Open Spaces of the Southwestern United States. Co-hosted by the Association for Fire Ecology and the Western Section of the Wildlife Society. 2-5 December, San Diego, California.

Brooks, M.L. J. Belnap, J. Keeley, and R Sanford. 2002. Fire and invasive annual grasses in western ecosystems. Joint Fire Science Program 2001 Principal Investigator Workshop.

Brooks, M.L. and C. D'Antonio. 2002. Fire and other forms of disturbance: are they similar and do they have the same effects on invasive species? Joint symposium of Ecological Society of America and the Society of Ecological Restoration. 6 August, Tucson, Arizona.

Brooks, M.L. and T.C. Esque. 2002. Desert fire ecology and management. California Desert Fire Managers Planning Workshop. Joshua Tree National Park, California.

Brooks, M.L., T.C. Esque, and J. D'Elia 2002. Fire Behavior in the Mojave Desert: Potential Effects of the El Nino/La Nina Cycle. Fire Conference 2002: Managing Fire and Fuels in the Remaining Wildlands and Open Spaces of the Southwestern United States. Co-hosted by the Association for Fire Ecology and the Western Section of the Wildlife Society. 2-5 December, San Diego, California.

McGinnis, T.W. J.E. Keeley, M.L. Brooks, R. Sanford, and J. Belnap. 2002. The response of cheatgrass (*Bromus tectorum* L.) and native flora to ecological manipulations in the yellow pine-mixed conifer forest. Sierra Nevada Science Symposium. 8-10 October, Kings Beach, California.

Presentations for Land Managers and Scientists in 2001

Brooks, M.L. 2001. Peak fire temperatures and short-term ecological effects in the Mojave Desert. Symposium of the Ecological Society of America.

Brooks, M.L. 2001 The burning desert. Western Ecological Research Center, Annual Meeting. Sacramento, CA.

Brooks, M.L. and J.R. Matchett. 2001. Fire promotes exotic annual vegetation and reduces plant species richness in Mojave Desert blackbrush communities. 6th Biennial Conference of Research on the Colorado Plateau. Flagstaff, AZ

Presentations for Land Managers and Scientists in 2000

Brooks, M.L. 2000. Effects of a changing fire regime in the Mojave Desert. California Association of Fire Ecology Symposium, San Diego, CA.

Brooks, M.L. and C. D'Antonio. 2000. The role of fire in promoting plant invasions. California Exotic Pest Plant Council Symposium. Concord, CA.

Brooks, M.L. and D. Pyke. 2000. Invasive plants and fire in the deserts of North America Invasive Species Workshop: The Role of Fire in the Control and Spread of Invasive Species. Special Session of the Fire Conference 2000: The First National Congress on Fire, Ecology, Prevention and Management. San Diego, CA.

Literature Cited

Brooks, M.L. et al. In prep. Effects of fire on invasive annual grasses in western North America.

Brooks, M.L. C.M. D'Antonio, D.M. Richardson, J. Grace, J. J. Keeley, DiTomaso, R. Hobbs, M. Pellant, and D. Pyke. 2004. Effects of invasive alien plants on fire regimes. BioScience 54:677-688.

Brooks, M.L., and T.C. Esque. 2002. Alien annual plants and wildfire in desert tortoise habitat: status, ecological effects, and management. Chelonian Conservation and Biology 4:330-340.

D'Antonio, C. M. 2000. Fire, plant invasions, and global changes. Pages 65-93 *in* H. A. Mooney and R. J. Hobbs, editors. Invasive Species in a Changing World. Island Press, Washington, D.C. USA.

D'Antonio, 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 23:63-87.

DiTomaso, J.M., M.L. Brooks, E.B. Allen, and R. Minnich. In prep. The Use of Fire as Tool for Controlling Invasive Weeds. Report to the Center For Invasive Plant Management, Bozeman, Montana.

DiTomaso, J.M., ML Brooks, EB Allen, R Minnich, PM Rice, and GB. Kyser. In review. Control of invasive weeds with prescribed burning. Weed Technology.

Galley, K.E. and T.P. Wilson. 2001. Proceedings of the Invasive Species Workshop: The Role of Fire In the Control and Spread of Invasive Species. Fire Conference 2000: The First National Congress on Fire Ecology, Prevention and Management. Miscellaneous Publications No. 11, Tall Timbers Research Station, Tallahassee, Florida, USA.

Hobbs, R. J., and L. F. Huenneke. 1992. Disturbance, diversity, and invasion: implications for conservation. Conservation Biology 6:324-337.

Klinger, R. C., M .L. Brooks, and J. M. Randall. In press. Fire and Invasive Plant Species. Chapter 22 in: Sugihara, N. G., J. W. van Wagtendonk, J. Fites-Kaufman, K. E. Shaffer, and A. E. Thode (eds.). Fire in California ecosystems. University of California Press, Berkeley.

Vitousek, P. M., C. M. D'Antonio, L. L. Loope, and R. Westbrooks. 1996. Biological invasions as global environmental change. American Scientist 84:468-478.