FUEL CONSUMPTION AND FLAMMABILITY THRESHOLDS IN SHRUB-DOMINATED ECOSYSTEMS

Final Report to the Joint Fire Science Program

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PROJECT SUMMARY:

Fuel loading, fuel consumption, fuel moisture, site conditions, and fire weather were measured on a series of operational prescribed fires in big sagebrush (n=16), pine flatwoods (n=40), chamise chaparral (n=12), and pitch pine scrub (n=7) ecosystem types with a particular focus on consumption of the standing shrub biomass. Multiple linear regression models to predict fuel consumption from fuel and environmental variables are being developed and programmed into the software package CONSUME, an application for predicting fuel consumption and emissions for fire, fuel and smoke management planning. Relations between plant dimensions and biomass, and plant cover, height and biomass are also being developed to allow non-destructive biomass estimation from common and easy-to-make measurements.

PROJECT LOCATIONS:

In-situ measurements of fuel characteristics and fuel consumption were made before and after operational prescribed fires in four shrub-dominated vegetation types in the United States (Figure 1, Appendix A): big sagebrush, pine flatwoods, chamise chaparral, and pitch pine scrub. Vegetation types were selected to maximize the application of this research for fire management. Selection criteria for these four types included: large acreage, wide geographic range, fire and emissions are likely to impact populated areas, and extensive annual prescribed burning in the type.

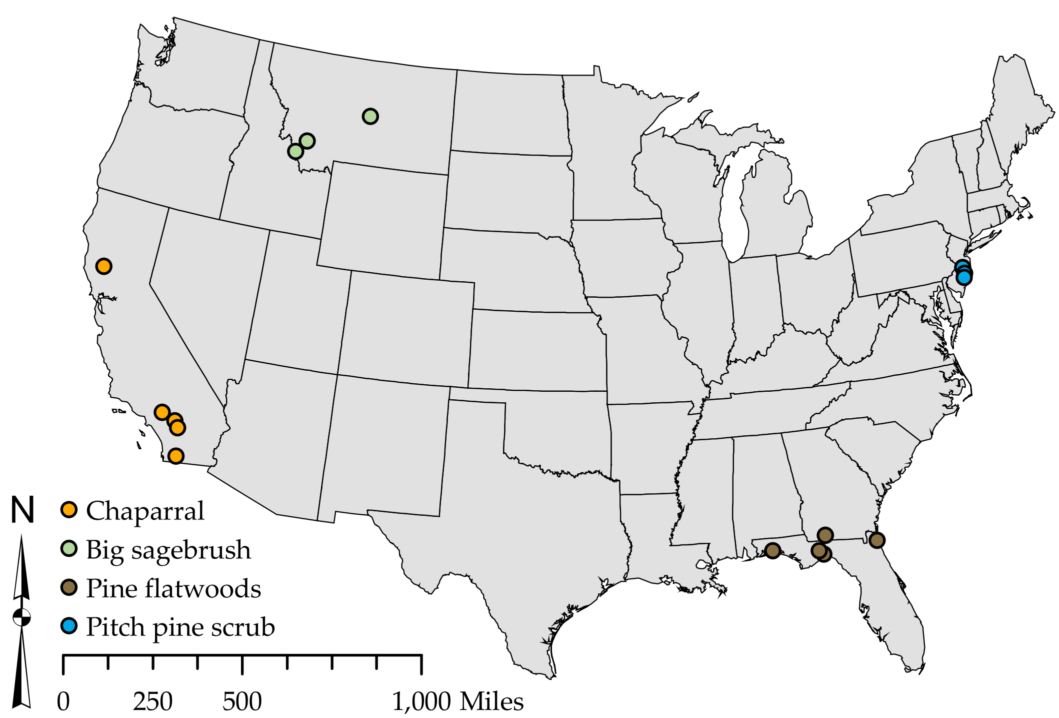

Figure 1. Sampling locations for shrub consumption project.

INTRODUCTION:

Research to quantify and model fuel consumption during wildland fires has been conducted in "natural" and managed forest types (e.g., Ottmar 1983, Sandberg and Ottmar 1983, Little et al. 1986, Hall 1991, Brown et al. 1991, Albini and Reinhardt 1997, Reinhardt et al. 1997, Myanishi and Johnson 2002), but is generally lacking or of limited scope in shrub-dominated ecosystems (Sapsis and Kauffman 1991, Wright and Ottmar 2002). Most research in shrub types has focused on fire behavior prediction in a limited number of ecological types (e.g., Lindenmuth and Davis 1973, Green 1981, Brown 1982). Fire-adapted ecosystems wholly or partially composed of shrub species, including a wide variety of forms of chaparral, various species of sagebrush, southern pine flatwoods, and pitch pine scrub, among others occur across several hundred million acres of private, state and federal lands nationwide. These types may be remotely located or they may occur at the wildland/urban interface throughout their range. In addition, many shrub-dominated ecosystems are home to sensitive, rare, threatened and endangered species, including numerous species of birds, mammals, mollusks, insects, plants, fish, reptiles and amphibians.

An increasing awareness of environmental issues by the public mandates that land managers fully evaluate regulatory requirements and potential impacts of land management decisions (i.e., no action, prescribed fire use, wildland fire use, grazing, mechanical treatment, chemical treatment, etc.) using the best available information. Where fire is concerned, quantification of fuel consumption is critical for effective modeling of fire effects, including smoke emissions, regional haze, nutrient cycling, plant succession, species composition changes, plant/tree mortality, wildlife habitat restoration and maintenance, erosion, soil heating, and carbon cycling. An understanding of the variables that can be used to predict fuel consumption is basic to effectively managing and evaluating the consequences of prescribed and wildland fire as related to land management objectives.

Land managers have and will continue to use prescribed fire as a landscape-level treatment in a wide variety of shrub-dominated ecosystems for a number of specific purposes, including, for example, fuel and fire hazard reduction, wildlife habitat improvement, and ecosystem restoration. In contrast to forested systems where a large proportion of the fuelbed is composed of dead and down organic matter, a much larger proportion of the fuelbed is composed of living (and standing dead) vegetation in shrub-dominated ecosystems. As with forests, it is desirable to predict fuel consumption, and therefore immediate treatment effects (i.e., emissions) and the likelihood of treatment success prior to the application of fire. Change in the vegetation structure (i.e., fuel composition, amount and arrangement) is often the most critical first order fire effect and measure of treatment success. Regulatory restrictions on smoke production because of negative impacts on community health, air quality, visibility and other factors, however, can severely limit the use of prescribed fire for management purposes. If managers are to develop effective fire plans designed to meet desired objectives in terms of terrestrial and atmospheric resource management, research to quantify both fuel characteristics and fuel consumption during prescribed and wildland fires in these vegetation types is required.

OBJECTIVES:

The primary objective of this research project was to improve a preliminary fuel consumption model for big sagebrush (interior West) and to develop new fuel consumption models for pine flatwoods (Southeast), chamise chaparral (Pacific Southwest), and pitch pine scrub (Northeast) ecosystem types. Vegetation types were selected to cover a broad geographic area promoting a national scope to the maximum extent possible as requested in the original Joint Fire Science Program Announcement for Proposals in 2003. These improved and new fuel consumption models are being incorporated into an updated version of the software package CONSUME (version 3.1). Achievement of this objective promotes more effective and informed management and use of fire in shrub-dominated vegetation types.

METHODS:

Differences in vegetation structure and composition among types necessitated that we modify and adapt our sampling methods to best characterize the fuels in each ecosystem type. Our general approach was to consult with fire managers to identify operational prescribed fires and, within each planned fire boundary, locate an area with relatively homogeneous vegetation composition and structure, and install a grid of plots in which to destructively sample the pre-burn and post-burn biomass of different fuel categories and components (Figure 2). Post-burn biomass was subtracted from pre-burn biomass to derive fuel consumption. Prescribed fires at multiple times and locations were sampled for all four types (Appendix A). Along with fuel loading, site topography, day-of-burn weather, and fuel moisture (both of live and dead fuels) were also measured for inclusion in predictive models (Table 1).

Owing to difficulty in executing prescribed burns in chamise chaparral we also elected to quantify consumption using a retrospective approach in areas that had been previously burned to improve our sample size. In many cases, individual plants are not totally consumed in chaparral fires. Only the foliage and smaller diameter twigs, branches and an elevated portion of the stems are consumed; the basal portion of the plant is blackened, but otherwise unaffected. We took advantage of this phenomenon by measuring the basal area of residual plants in fixed-area plots within burned areas,

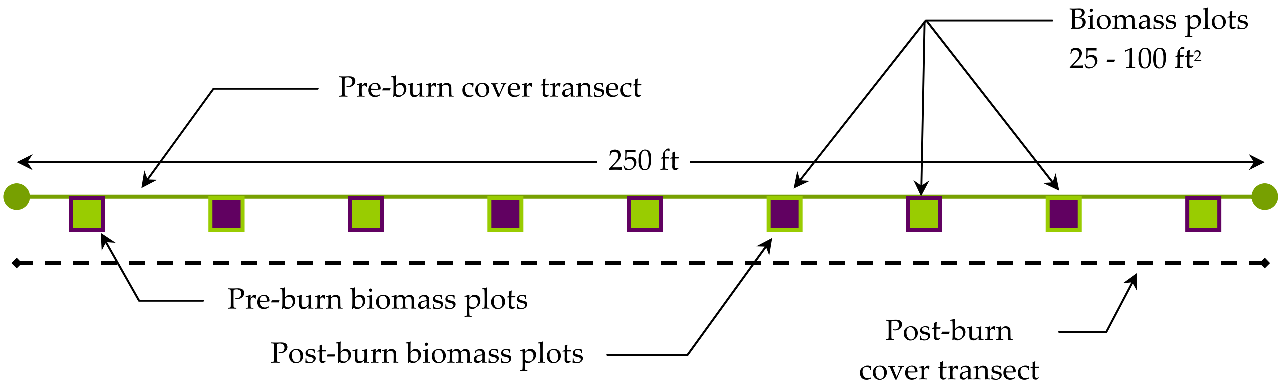

Figure 2. Sampling layout and specifications for each set of plots. Multiple sets of plots were co-located within the boundaries of large prescribed burn units in several instances. Species composition, mineral soil exposure, and "understory" vegetation cover were quantified on 2-4 parallel pre-burn transects spaced 33-66 ft apart, and proportion of sample area burned and shrub coverage remaining were quantified on 2-4 post-burn transects. Plots and transects were located 66 ft or more from the edge of each unit. Shrubs, grasses, forbs, litter and woody debris were collected and weighed on 9-18 biomass plots pre-burn and the remaining biomass was collected on 9-18 biomass plots post-burn. Shrubs were separated into live and dead fractions and size classes during pre-burn sampling. All samples were oven dried or corrected to reflect oven-dry conditions based on moisture content sub-samples collected for each biomass plot.

calculating their pre-burn biomass using allometric methods, and destructively sampling the residual stems to determine post-burn biomass and overall consumption. We determined species-specific allometric relationships between plant basal area and different biomass fractions (i.e., foliage, 0-1/8" diameter twigs, 1/8-1/4" diameter twigs, 1/4-1/2" diameter twigs, 1/2-1" diameter stems and branches, 1-3" diameter stems) by sampling individual plants across a range of sizes in unburned areas that were both within the perimeter of the fire and adjacent to the post-fire sample area where we measured the basal area and biomass of residual plants. Standing dead and dead and down woody fuels typically consume completely during chaparral fires; these components of the fuelbed were also sampled in fixed-area plots in these adjacent unburned areas to estimate pre-burn biomass and consumption. Fire weather and fuel moisture conditions were estimated from local weather station and fuel moisture archives at the time the area burned, which was derived from time-stamped aerial images of the fire.

Fuel consumption models were developed from the suite of fuel characteristics and environmental variables measured before and during the fires. We identified the variables that were the best single predictors of fuel consumption using a simple correlation matrix and included the most promising variables in forward and backward stepwise multiple linear regressions (Neter et al. 1990) to identify preliminary models; expert opinion was used to construct the final models. Final models were ultimately chosen to include variables commonly measured or estimated by fire and fuel managers, and to be both physically logical and parsimonious.

Table 1. Shrub consumption trial methodology summary. Independent variables measured before the fire were selected because of their likelihood for being good predictors of fuel consumption based on previous fuel consumption research and their documented influence on fire behavior.

Independent Variables	Method
Pre-burn biomass	Harvested, separated (live/dead, species/lifeform, size class), and weighed multiple (9-18) 25-100 ft^2 sample plots
Post-burn biomass	Harvested, separated, and weighed multiple (9-18) 25-100 ft^2 sample plots
Pre-burn vegetation coverage	Line intersect transects; noted coverage by species for shrubs, forbs, and grasses.
Vegetation height	Systematic point measurements every 10 ft along line intersect transects by species/lifeform
Live and dead fuel moisture	5-10 day-of-burn grab samples each of; 10-hr downed wood, shrub foliage, shrub twigs, shrub branches, grass, litter, and soil
Fire weather	Site measurements; temperature, relative humidity, wind speed, days since rain
Ignition pattern	Field observations (e.g., strip heading fire, flanking fire, backing fire, etc.)
Topography	Site measurements; slope, aspect, elevation
Proportion of sample area burned	Line intersect transects; also noted unburned coverage of shrubs by species

RESULTS AND DISCUSSION:

Data analysis, model construction and software re-programming is ongoing with completion anticipated by December 2007. Preliminary models for big sagebrush have already been incorporated into CONSUME 3.0; new models for big sagebrush, pine flatwoods, chamise chaparral, and pitch pine scrub will be programmed once final model development is completed in conjunction with other programming-related tasks required to update CONSUME. An updated version of the CONSUME software will be delivered to users and made available online upon completion of final programming.

Big Sagebrush – The pre-burn loading of big sagebrush (*Artemisia tridentata*) and other shrubs and fuels was measured on 16 sets of experimental plots at three locations in Montana (Figure 3). Ten of the 16 sets of plots were burned as part of operational prescribed fires in the spring of 2004; high fuel moisture conditions prevented four sets

Figure 3. Prescribed fire in big sagebrush.

of plots from burning during firing operations. Unsuitable weather conditions prevented three sets of plots from being burned in either 2005 or 2006. These data points characterized prescribed burning conditions under moderate to marginal burning conditions and successfully supplemented data collected as part of a previous JFSP project (JFSP 98-1-9-06) that, in part, examined fuel consumption in big sagebrush ecosystems.

The big sagebrush model uses proportion of the area expected to burn and loading of shrubs and herbaceous vegetation as inputs for calculating fuel consumption. If necessary, users can estimate shrub loading from measurements of coverage and height, and can predict proportion of area expected to burn by using a model that includes coverage of herbaceous vegetation, 10-hr fuel moisture, wind speed and slope.

New big sagebrush consumption data added as part of this study will allow us to expand the range of environmental and fuel conditions under which our predictive model is applicable. Input variables selected for the preliminary model (Wright and Prichard 2006) will remain the same, with small changes to regression constants. Outputs compared favorably to independently-derived datasets (Sapsis and Kauffman 1991, Kauffman and Cummings 1989).

Pine Flatwoods – Longleaf (*Pinus palustris*) and slash pine (*P. elliottii*) forests with a typical "southern rough" understory of predominantly saw palmetto (*Serenoa repens*) and gallberry (*Ilex glabra*) were sampled in Florida and Georgia (Figure 4). Fuel consumption data were successfully collected at 28 of 40 locations between 2004 and 2006. Sample sites represented a range of fuel loadings and were burned at various times during the year; burns occurred in January-April and July.

Figure 4. Prescribed fire in pine flatwoods.

Pine flatwoods occur primarily in the southeastern Coastal Plain in terrain with very little (if any) topographic relief. They are subtropical ecosystems that typically have continuous fuel coverage, and often a very shallow or surface-level water table throughout much of the prescribed burning season. Because of topographic and fuel conditions, which are distinctly different than those found in big sagebrush types, different variables will be incorporated into predictive fuel consumption equations for pine flatwoods. Data processing and model development are ongoing; loading of understory shrubs, litter, and woody fuels; relative humidity and wind speed; and live and dead fuel moisture are expected to be strong predictors of fuel consumption.

<u>Chamise Chaparral</u> – Pre-burn biomass of all vegetation and surface fuels in eight stands of predominantly chamise (*Adenostoma fasciculatum*) with some manzanita (*Arctostaphylos* spp.) and other chaparral-associated shrub species was sampled within the boundaries of planned prescribed burns in central and southern California (Figure 5). Four of these experimental areas were burned during prescribed fire operations. Two additional locations that were prescribed burned before pre-burn sampling was conducted were also sampled; fuel consumption was calculated by subtracting post-burn biomass from pre-burn biomass of an immediately adjacent unburned area.

Figure 5. Partially consumed shrub skeletons typical of post-fire conditions in chamise chaparral.

Three locations that had been predominantly chamise with adjacent unburned patches within the boundaries of the Esperanza fire (October 2006) in the North Mountain Experimental Area were sampled using retrospective methods. Post-burn biomass of sampled sites ranged from 0.8 to 2.3 tons/acre. Sampling within the boundaries of a wildfire for which detailed fire progression and fire behavior data were available allowed us to expand the applicable range of environmental conditions for our model while minimizing the danger and possibility of escape that would have been presented by prescribed burning at and beyond the dry end of the burn prescription. We avoided areas within the wildfire boundary with total consumption of the aboveground plants so our data do not represent the highest intensity wildfire conditions.

An unplanned benefit of our retrospective sampling approach was a more finely divided size-class categorization and better characterization of plant allometry for chamise, whitethorn (*Ceanothus leucodermis*), hoaryleaf ceanothus (*Ceanothus crassifolius*), mountain mahogany (*Cercocarpus betuloides*), and manzanita. Over 90 plants ranging from 0.002 to 12.1 lbs (oven dry weight) were dissected as part of this effort.

Consumption data from prescribed fires in chaparral fuels are very difficult to collect for a number of reasons, including the size of the vegetation, the time and labor required to perform pre-burn sampling, the steepness of the slope, the limited number of planned prescribed fires in the type, the proximity to the wildland/urban interface, limited access points, and the narrow weather window available to accomplish the burning. Work to produce a preliminary model for predicting fuel consumption is ongoing; further development of retrospective methods could lead to a more robust data set for model development and validation in the future.

Figure 6. Pitch pine scrub stand with 1.9 tons/acre of understory blueberry and oak loading.

<u>Pitch Pine Scrub</u> – Pre-burn biomass representing a range of understory shrub fuel loading conditions was collected from seven pitch pine (*Pinus rigida*) -dominated stands in the New Jersey Pinelands (Figure 6). Shrub loading was composed of a mixture of primarily deciduous species that ranged from 0.8 to 5.2 tons/acre. Only two of the sets of plots were burned during the spring of 2007; 18 additional plots, burned in prior years for other research purposes (Kenneth Clark, unpublished data, USFS, Northern Research Station), were used to develop total fuel consumption models for this fuel type.
While shrub loading can be significant in this type (sampled sites ranged from 0.80 to 5.18 tons/acre), most burning occurs before leaf-out, so the bulk of the fuel consumed is in the surface fuel layer which is composed of pine needles, leaf litter, and small dead and downed woody fuels. Litter and woody fuel loading ranged from 1.7 to 3.7 and 0.9 to 2.1 tons/acre, respectively. With the contribution of data from the USFS Northern Research Station, we feel the model data set represents typical fuel consumption for the surface fuels, although additional shrub fuel consumption data in this type are necessary to refine and validate the consumption model developed for this project.

DELIVERABLES:

The Shrub Consumption study was originally proposed as a 3-year project, however, field data collection delays forced a one-year extension. This extension allowed us to sample fuel consumption in an additional fuel type (pitch pine scrub). The primary deliverable will be an updated version of the software program CONSUME (Table 2). The user's manual and online tutorial (JFSP 04-4-1-19) will also be updated to reflect changes in the software. One manuscript in a Forest Service conference proceedings has been published, one peer-reviewed journal article is in preparation, and one is proposed. This project will also generate one chapter in PI Wright's Ph.D. dissertation.

Annual written progress reports were submitted in 2004, 2005, and 2006, and a presentation of project progress and preliminary results was given at the JFSP PI's workshop in San Diego, CA in November 2005. Hands-on training sessions for the software have been given at nine locations nationally (JFSP 05-4-1-14), and PI Ottmar has incorporated the software into the curriculum of RX-300, RX-310, RX-410 and Technical Fire Management.

Table 2. Proposed and delivered products for Shrub Consumption study.

Proposed	Delivered	Status
CONSUME software update	Available for download from: http://www.fs.fed.us/pnw/fera/research/smoke/consume/consume_download.shtml. CONSUME is programmed in Microsoft Visual Basic with a Java-based calculator for increased flexibility. The software provides shrub biomass, fuel consumption, heat release, and emissions estimates from wildland fires.	In progress; Dec. 2007
Shrub biomass prediction tool	Users may enter shrub biomass directly, or they may use simple calculators for estimating shrub biomass from other easily measured variables such as vegetation coverage and height.	Partially in CONSUME 3.0; Dec. 2007
CONSUME user's manual	Available from within the CONSUME software or for download from: http://www.fs.fed.us/pnw/fera/research/smoke/consume/consume31_users_guide.pdf	In progress; Dec. 2007
Internet download site	http://www.fs.fed.us/pnw/fera/research/smoke/consume/consume_download.shtml.	Done
JFSP progress reports	JFSP progress reports were submitted annually starting in 2004. Also, WRIGHT, C.S., R.D. OTTMAR AND R.E. VIHNANEK. 2005. Fuel consumption and flammability thresholds in shrub-dominated ecosystems. Presentation. Joint Fire Science Program Principal Investigator's Workshop. November 1-4, 2005, San Diego, CA.	Done
JFSP final report	WRIGHT, C.S., R.D. OTTMAR, S.A. FERGUSON AND R.E. VIHNANEK. 2007. Fuel consumption and flammability thresholds in shrub-dominated ecosystems. JFSP final report.	Done

Table 2. Continued.

Proposed	Delivered	Status
Training materials/tutorial	Web-based and downloadable self-taught tutorial is available at http://www.fs.fed.us/pnw/fera/research/tutorials/consume.shtml (JFSP #04-4-1-19).	In progress; Dec. 2007*
Training sessions	CONSUME has been presented to Federal, state and private land managers and scientists as part of the 2.5-day *Suite of Fuel Management Tools* workshop curriculum at: Ichauway, GA (Nov. 7-9, 2005 and Sept. 11-13, 2007); Hilo, HI (Feb. 28-Mar. 2, 2006); Sunriver, OR (May 16-18, 2006); Fairbanks, AK (Aug. 15-17, 2006); Portsmouth, OH (Nov. 28-30, 2006); San Luis Obispo, CA (Mar. 13-15, 2007); Moscow, ID (Apr. 3-5, 2007); and Albuquerque, NM (May 1-3, 2007).	Done*
	CONSUME has been presented as part of ½-day *Suite of Fuel Management Tools* workshops preceding the Fire Behavior and Fuels Management conferences in San Diego, CA (Mar. 27, 2006) and San Destin, FL (Mar. 26, 2007), the Forest Service Region 8 Prescribed Fire workshop and Staff Ride in Johnson City, TN (Oct. 17-19, 2006), and the Third International Fire Ecology and Management Congress in San Diego, CA (Nov. 13, 2006).	Done*
Research paper(s)	WRIGHT, C.S. AND S.J. PRICHARD. 2006. Biomass consumption during prescribed fires in big sagebrush ecosystems. Proceedings RMRS-P-41. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. pp. 480-500.	Done
	WRIGHT, C.S. *In prep.* Predicting shrub consumption during wildland fires. Target journal: Ecological Applications.	In progress; Dec. 2007
	WRIGHT, C.S. *In prep.* Equations for predicting fuel biomass of chamise (*Adenostoma fasciculatum*). Target journal: International Journal of Wildland Fire.	Prospective; May 2008*
New items (not originally proposed)	WRIGHT, C.S. AND S.J. PRICHARD. 2006. Biomass consumption during prescribed fires in big sagebrush ecosystems. Poster. Fuels management - how to measure success. March 28-30, 2006, Portland, OR.	Done*
	Pitch pine scrub fuel consumption algorithm	In progress; Dec. 2007*
	Chapter in PI Wright's Ph.D. dissertation	In progress; Dec. 2008*
	FIREHouse entry and fact sheet	Done; Posted Sept. 2005*

* Deliverables in excess of proposed

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APPENDIX A
FUEL TYPES/STUDY LOCATIONS:
Locations for i*n-situ* measurements of fuel consumption in four shrub-dominated vegetation types in the United States.

Big Sagebrush
Sixteen sets of experimental plots were established in big sagebrush (*Artemisia tridentata*) vegetation types in western and central Montana. These sites complement sagebrush consumption data collected as part of an earlier JFSP project (JFSP 98-1-9-06). The Armells Creek sites were not burned owing to unsuitable weather condition in the years following initial pre-burn sampling.
- Armells Creek, Bureau of Land Management, Lewistown Field Office, Lewistown, MT
- Dyce Creek, Bureau of Land Management, Dillon Field Office, Dillon, MT
- North Black Canyon, Bureau of Land Management, Dillon Field Office, Dillon, MT

Pine Flatwoods
Forty sets of experimental plots were established in longleaf pine (*Pinus palustris*) and slash pine (*Pinus elliottii*) forests with saw palmetto (*Serenoa repens*) and gallberry (*Ilex glabra*) understory vegetation in northern Florida and southern Georgia. Several sites on the Apalachicola National Forest and at Pumpkin Hill Creek Preserve State Park were not burned for safety reasons due to severe drought conditions in northern Florida in 2006 and 2007.
- Apalachicola National Forest, Crawfordville, FL
- Big Woods Preserve, (formerly) The Nature Conservancy, Thomasville, GA
- Eglin Air Force Base, Niceville, FL
- Pumpkin Hill Creek Preserve State Park, Jacksonville, FL
- St. Marks National Wildlife Refuge, U.S. Fish and Wildlife Service, St. Marks, FL

Chamise Chaparral
Thirteen sets of experimental plots were established in primarily chamise (*Adenostoma fasciculatum*) chaparral. Pre-burn and post-burn sampling was conducted at the Kitchen Creek, Lone Pine Canyon and West Ridge locations. Some sites at the Lone Pine Canyon and West Ridge locations were not burned for safety reasons due to severe drought conditions in southern California in 2006 and 2007. Sampling in the North Mountain Experimental Area employed a retrospective methodology to calculate fuel consumption during the Esperanza Fire that occurred in October 2006.
- Grindstone Creek, Mendocino National Forest, Glenn County, CA
- Kitchen Creek, Cleveland National Forest, Mt. Laguna, CA
- Lone Pine Canyon, San Bernardino National Forest, Lytle Creek, CA

- North Mountain Experimental Area, Bureau of Land Management, Banning, CA (administered by the USDA Forest Service, Pacific Southwest Research Station in Riverside, CA)
- West Ridge, San Bernardino National Forest, Idyllwild, CA

Pitch Pine Scrub

Seven sets of experimental plots were established in pitch pine/black oak (*Pinus rigida/Quercus velutina*) forest types with shrub understories in the Pinelands in central New Jersey specifically for this study. Five sets of plots remain unburned at this time owing to unsuitable weather conditions during the prescribed burning season following sampling. Data collected for other purposes in prior years by scientists at the USDA Forest Service, Northern Research Station (Dr. Kenneth Clark and Nick Skowronski) will be used to supplement the small data set collected as part of this study (n=18). Conditions permitting in 2008, unburned experimental plots will be burned and used as a test data set for predictive models developed as part of this study.

- Bass River State Forest, New Jersey Division of Parks and Forestry, Ocean County, NJ
- Greenwood Forest Wildlife Management Area, New Jersey Division of Fish and Wildlife, Ocean County, NJ
- Pinelands National Preserve, NJ