

# **Effects of Prescribed Grazing and Burning Treatments on Fire Regimes in Alien Grass-dominated Wildland-Urban Interface Areas, Leeward Hawaii.**

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## **Final Report to the Joint Fire Science Program**

Project No. 01-3-4-14

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This final report presents findings to date and identifies proposed and accomplished deliverables. The main body of this report is intended for use by land managers seeking practical tools for managing fountain grass fuels and similar alien-grass fuels along roadsides in Hawai‘i and in other areas facing similar situations. Details on the study methods, results, and evidence to support those findings are attached as appendices to this document. This document and subsequent related findings will be available through the following website as of September 1, 2006: [www.whwmo.org/jfsp](http://www.whwmo.org/jfsp).

## PROJECT OVERVIEW

The forests and shrublands of Hawai‘i’s leeward regions once formed continuous vegetative cover across the landscape, broken only by geologically young lava flows. However, today they occur only in small remnant patches imbedded within expansive non-native grasslands. This drastic reduction in forest cover has resulted from the direct and indirect effects of the following factors: wildfire, grazing (cattle, goats, and sheep), alien and invasive species, other land-uses, and related climatic and ecological changes. Many endemic Hawaiian plant and animal species have disappeared from this landscape as a result of these changes and today, 31 dry forest plants, 3 species of birds and one bat known from this region are federally recognized as being in danger of extinction. Lowland areas have suffered the greatest losses and highland areas still support the largest and most intact native plant communities.

Introduced as an ornamental to Hawai‘i island in 1917, fountain grass (*Pennisetum setaceum*) now covers approximately 208 square miles (132,965 acres). Native to northern Africa and Mediterranean coastal areas, the aggressive invasive continues its spread on all fronts where it overtakes native ecosystems and threatens residential areas. Land ownership within this leeward region locally referred to as “West Hawai‘i” is divided approximately evenly among State Management Areas, U.S. Army training lands, and private lands. Under dry and windy conditions typical in West Hawai‘i, fountain grass ignites easily from roadside sources and spreads across the landscape swiftly. Three fountain grass-carried fires in excess of 10,000 acres have occurred in the region over the past 20 years. If not caught immediately, these alien grass-carried fires often burn large areas as suppression efforts are hampered by rugged and inaccessible terrain and lack of firefighting resources.

This project was designed to evaluate at a practical scale the effectiveness and costs of a range of fine fuels management treatments. The study occurred along a major inland highway from which wildfires frequently originate. We applied four major treatments that included a control (no treatment), prescribed burning, cattle grazing, and a combined burning and grazing treatment. Aerially-applied herbicide was then applied to half of each of these primary treatments resulting in a total of eight unique treatment combinations.

Fire behavior was measured during the prescribed burns. The loading of fine fuels were measured and photographed in each treatment over a two year period. Effects of treatments on predicted fire behavior were modeled using the observed fire behavior and measured fuel load data. The relative cost and efficacy of each treatment were evaluated against the duration of their effect. Broad collaboration

between Hawai‘i-based agencies and organizations, local contributions of professional services, and collaboration with and between continental U.S.-based participants made the implementation of the treatments possible at the large-scale at which they were applied. Using GIS, an analysis of fire history records previously compiled was conducted to characterize the fire regime of the region. This project provided the first opportunity for herbicide to be applied aerially to manage wildfire fuels in Hawai‘i and an opportunity to hold the first prescribed burns on State lands.

## PROJECT OBJECTIVES

The purpose of this project was to ascertain the feasibility of various fuels management strategies and model effects of those treatments on landscape scale fire regimes in leeward northwest Hawai‘i island. Specific goals of the treatments were to:

- Reduce roadside 1-hour fuel biomass to 30-50% of pre-treatment levels.
- Evaluate the duration of the effect of the treatments in reducing one-hour fuels using periodic measurements of fuel loading and photographs.
- Model predicted fire behavior of various post-treatment fuel loads under an expected range of weather conditions.
- Demonstrate, using a GIS-based fire history map of the region and demonstration site, the effects of strategic use of various fuels management treatments on landscape wildfire regimes.

## PROJECT DELIVERABLES

Proposed	Delivered
Measure fire behavior in fountain grass fuel type under a range of weather scenarios during prescribed burns	Fire behavior was measured in each of 5 burns conducted in January and February of 2004
Assess the efficacy of specific fuels management strategies on the fountain grass fire regime in Hawai‘i	A range of new fuels management strategies are evaluated with this report
Directly involve the complex of regional resource managers in an actual demonstration study evaluating roadside fine fuels management techniques	All affected resource managers from adjoining lands participated in some aspect of the project, mostly in the implementation of treatments, but also in monitoring and development of demonstration project materials.
Utilize prescribed burning to control wildfire fuels or alien species invasions at the landscape scale	Prescribed burning was successfully applied cooperatively by local and federal agencies and local organizations. Burn plan prepared now serves as primary template for State burn Plan revisions.
Utilize the combination of grazing and aerial herbicide application to suppress fuel build up	The combination of cattle grazing and aerially-applied herbicide were used to suppress fuel build up in treatments 7 and 8.
Complete region-wide GIS-based fire history map and database and use data to characterize current fire regimes (fire frequency and size) within the North Kona District	Paper map delivered with report, and digital image of fire history map file available through website.
Based upon pre-treatment fuel loads, model the range of fire intensity, rate of spread and probability of	Fire behavior was modeled for each of the 8 treatments over the 2 year period following initial application of treatments.

<b>Proposed</b>	<b>Delivered</b>
ignition of fires within these regimes.	
Conduct range of fuels treatments cooperatively with multiple local agencies and organizations	All treatments were successfully implemented cooperatively by federal and state agencies, private businesses, and local organizations. Cattle grazing treatment was applied to lightly to yield significant reductions in fuel loading, however the site is now being utilized for further evaluation of repeated grazing treatments to determine the amount of grazing required to achieve desired reductions in grass fuel loading
Conduct post treatment monitoring to quantify fuel loads up to two years post-treatment	Monitoring was conducted over a 2-year period following application of initial treatments
Model expected fire behavior of resultant fuel loads of each treatment	Expected fire behavior was modeled for each treatment in Behave Plus using data obtained in each sample date over the two year period of the study.
Model predicted landscape trends in fire regimes based on expected fire behavior	Long-term effects of various treatment scenarios on landscape fire regimes were evaluated and discussed at workshops by investigators and workshop attendees.
Develop a Demonstration Site <ul style="list-style-type: none"> <li>• Brochure leading self-guided tour</li> <li>• Placards numbering/naming treatments</li> <li>• Interpreting results of study</li> </ul>	The study site used for the research has been developed into a demonstration site available for viewing using a self guided brochure provided at local Division of Forestry and Wildlife and Local non-profit West Hawai'i Wildfire Management Organization offices.
Conduct a workshop to identify and discuss fuels management issues affecting region	One workshop was held in September of 2005 and another is scheduled for June 10, 2006 for local participants, interested parties, adjoining landowners and others to learn about the research and join others in discussion of the merits and appropriateness of various fuels management techniques
Create a Website to disseminate results	A website link to the Fuels Management Study website: <a href="http://www.whwmo.org/puu_anahulu_fuels_study_2006.html">www.whwmo.org/puu_anahulu_fuels_study_2006.html</a> (coming soon)

## METHODS

The study site is a five kilometer by two-tenths of a kilometer area that spans the Mamalahoa Hwy (State 190) and a parallel upslope firefighting access road. The site was divided into three blocks (replicates) and the treatments were applied in each block, resulting in a randomized complete block experimental design.

### *Fire History Analysis*

Hawai'i DLNR wildfire response records used to create this map using a Geographic Information System database. Areas that burned were each mapped as a unique polygon and identified with the year and month. These records do not represent every fire that has burned in this landscape, but rather represent the majority of the fires that received a multi-agency response within this region over the past 55 years. Other records of numerous small fires that were effectively extinguished while small, thereby negating the need for a multi-agency response, and fires for which records are not available, were not included.

### *Fuel Treatments*

Eight unique fuels treatments were applied using four primary treatments, each split with an aerial herbicide spray to half (Table 1). The first set of treatments were applied in sequence between January and May 2004. The prescribed burns occurred between January 27 and February 4, 2004. Burning treatments were conducted at moderate intensity after clearing of fuel breaks. Treatment combinations required completion of the previous treatment before application of the next treatments. The cattle grazing treatments were applied as a light pulse at a rate of 0.23 to 0.32 AUMs. Glyphosate herbicide treatments were applied in April and May 2004 by helicopter at 5.3 lbs/acre after removal of the cattle. The Control units were left without treatment for comparison to the treatments. A second phase of the grazing treatment was applied between January 30 and March 23, 2006.

Table 1. Treatments

Primary Treatment	Split Polt Treatment
1. Control	2. Herbicide
3. Prescribed Burning	4. Burning x Herbicide
5. Cattle Grazing	6. Grazing x Herbicide
7. Burning x Grazing	8. Burning x Grazing x Herbicide

Of all the treatments, the prescribed burns were the most labor intensive treatment to apply. The burns were planned over a 15-month period by representatives from all participating agencies, including the Hawai'i Division of Forestry and Wildlife, the US Army, the US Fish and Wildlife Service, the US Forest Service, the Hawai'i Fire Department, and the Hawai'i Civil Defense Agency. The burn plan, which included a burn prescription, was prepared cooperatively by project leaders. The burn prescription set specific weather and fuels conditions under which the burn would be allowed to occur. Prescribed burn treatments were administered by qualified burn boss.

### ***Fire Behavior Measurements***

Weather, fuel moisture, rate of spread and flame length data were collected for each of the 5 plots that were burned. Weather data were recorded by near by automatic weather stations and manually. Fuel moisture was measured immediately prior to the burn. Rate of spread was estimated for various segments of uniform fuels by measuring time and distance. Flame length was recorded using a video camera and a FLIR Thermacam 500 thermal camera. A target of known size was placed in the plot to estimate flame length from the imagery.

### ***Fuel Load Sampling***

Sampling of the fuel loads and vegetation responses was conducted in each split plot prior to and over a two-year period following application of the treatments. Sampling was conducted for herbaceous fuel (plus non-woody litter), down dead woody fuel, and standing live and dead woody fuel. Using simple random sampling, herbaceous fuel loading was measured by cutting and weighing field samples and correcting those weights with oven dried sub samples. 10 samples per split plot unit were collected in each unit. Each unit was sampled 5 times: January 2004 prior to burning, between February and May 2004 after grazing and herbicide application, in August 2004, in March 2005, and again in March of 2006.

### ***Vegetation Sampling***

Vegetation sampling was conducted along three belt transects distributed randomly within each treatment plot. Species frequency was sampled at 10 locations along each of 3 50-meter transects in each treatment plot. A nested 1-square meter frame was used to sample at 5 meter intervals along each transect for a total of 10 1-square meter areas. All species that fell within each nested frame of each of the 10 sample frames were recorded. Woody species density was sampled by using 3 belt transects 2 meters wide and 50 meters long per sampling plot. Woody species were recorded according to size class (0-1m, 1-2 m, 2-3, and 3+ meters tall) and reproductive class (seedling, non-reproductive, and reproductive). Plant cover was estimated within a square 10m x 10m plot located at the end of each transect.

### ***Soil Seedbank Sampling***

The soil seedbank was sampled over a 18-month period extending from the summer of 2003 through winter of 2004-2005 in order develop baseline data pertaining to the extent and quality of the fountain grass seedbank and its tolerance to heat and wildfire. The methods used were to sample the soil seed bank in each of the 8 treatment plots within each of the three blocks using a piston-core sampler. Seed density of fountain grass and other species was determined by averaging samples taken from 15 stations along a transect oriented down the center of each treatment unit. Fountain grass seed germination trials were conducted by storing seed in dry dark conditions, then sowing them into moist sand in Petri dishes and monitoring for 10 days. The effects of fire on seed viability was determined by placing fountain grass seeds in aluminum packets and setting them at different depths in each of 3 burn units. Five

replicates in each treatment plot were placed at depths of 0 cm (soil surface), 2.5, and 5 cm depths and then collected following the fire (Appendix G).

### ***Fire Behavior Modeling***

Fire Behavior was modeled for each of the eight treatments using fuel load data from each of the 5 sample periods. Custom fuel models were developed for each of the treatment units using sampling data provided. The fire behavior software BehavePlus (3.0.1) was used because of the ability to use dynamic fuel models. The fountain grass is best modeled as a dynamic fuel model since the plant has a ratio of dead and live fuel that fluctuates with different relative humidities and moisture contents. Fuel load was transferred from live to dead as a function of the **live herbaceous moisture** entered on the worksheet. This moves a percent of the fuel into the 1 hour fuel load category which is critical for the model to calculate resultant fire behavior. Sampled values for **live herbaceous fuel load** and **fuel bed depth** were used as inputs to the model. Default values for Fuel model gr 9 (Very high load, humid climate grass) were used for all the input variables that were not sampled. Other inputs (fuel moisture, weather, and slope) were chosen which would represent a reasonable fire scenario.

Using this dynamic model allows the user to input the daily or seasonal profile that most represents the conditions and then run a fire behavior output for that day. The custom fuel models that were developed were specifically for the treatments that were done in association with this project. However, these outputs should be compared to real fire behavior observed on wildfires and calibrated to be more representative.

### ***Photography***

Photographic documentation of each of the fuels treatments was conducted at each time step as fuel load was sampled, including pre-treatment, immediate post-treatment, and 4-months, one-year, and two-years post-treatment. Digital, wide-angle, and stereoscopic film photographs were taken at designated photo stations within each treatment plot in the first block. Extra photographs were taken of treatments 1-4 of block 3 as a back-up set. Photographic plates of each treatment in block 1 are presented in Appendix C.

## **RESULTS**

### ***Fire History Analysis***

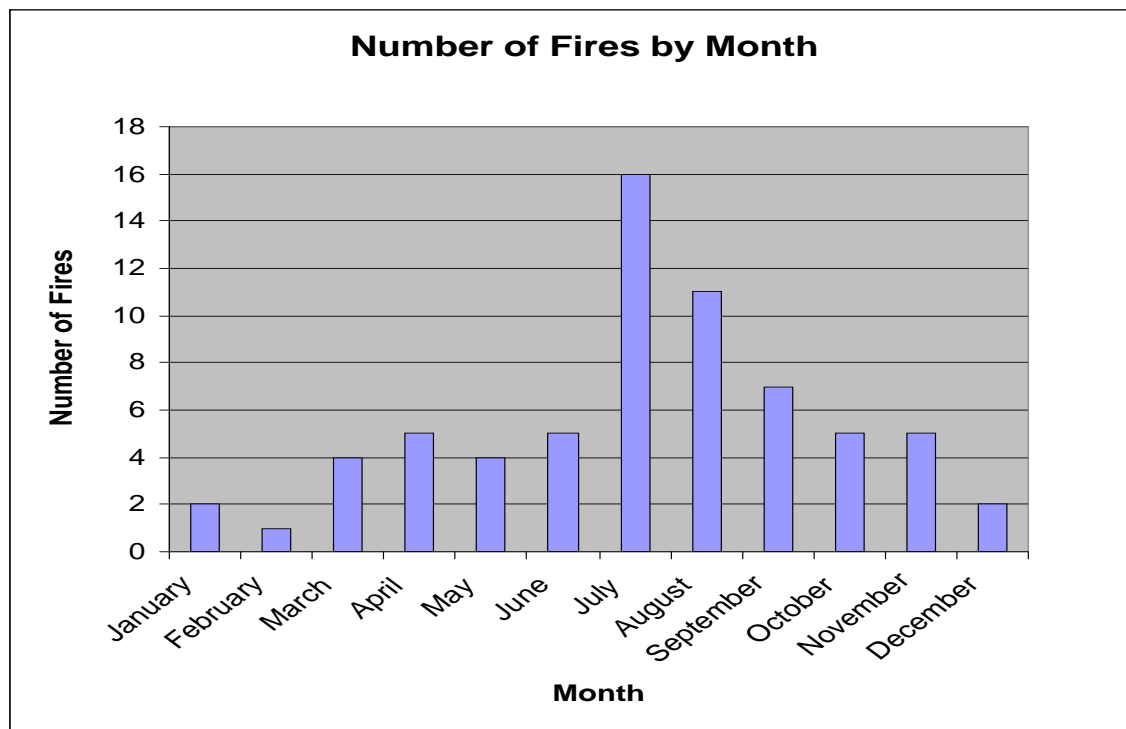
The map included as Appendix A depicts the history of large wildfires in the North Kona and South Kohala Districts over the past 55 years. During that time period, 68 records of fires that occurred within that region were mapped. These records represent major incidents that received a multi-agency response. Due to the unavailability of fire records for small fires, which have been more numerous than large fires, the fire history map and accompanying data underestimate total fire frequency and average fire size and can only be used to characterize general patterns of past large wildfires over that area.



The human population is rapidly expanding in West Hawai‘i and major developments are planned over the next 20 years. The Mamalahoa serves as the inland route between Kailua-Kona and Waimea and functions as a part of the major transportation artery around the island. The fire history map illustrates that this highway also serves as a major ignition corridor within this region. Continued expansion of alien grasses, such as fountain grass, and continued growth and development planned within this landscape underscore the need for the development of effective roadside fuels management and wildfire prevention strategies.

Information pertaining to specific source of ignition was not available for the majority of records analyzed, however it is apparent that certain major highways traversing leeward Hawai‘i serve as ignition corridors. Based upon careful scrutiny of the fire records and discussion with firefighting personnel, we estimate that over 95% of the fires mapped were started by human causes. Over the 55-year period, half of the fires (34) occurred during the summer months of July, August, and September (Figure 1).

Figure 1. Number of Wildfires in Leeward Hawaii by Month Over the Past 55 Years.



Average fire size for these records was 3,096 acres (1,254 ha) (+/- 2,833 acres), with the month of September averaging the largest fires (Figure 2). Over time, very large fires (< 10,000 acres) occur on the average of once every 9 years (Figure 3).

Figure 2. Average Size of Wildfires in Leeward Hawai‘i Over the Past 55 years (+/- 1 stdev).

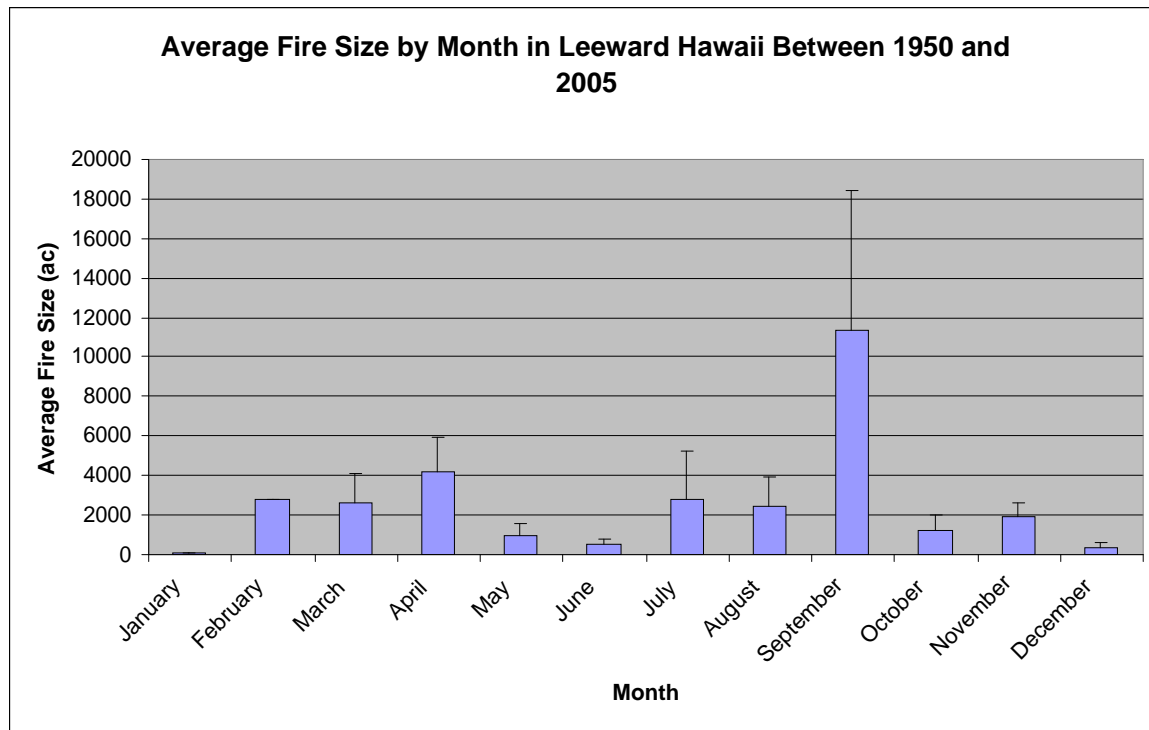
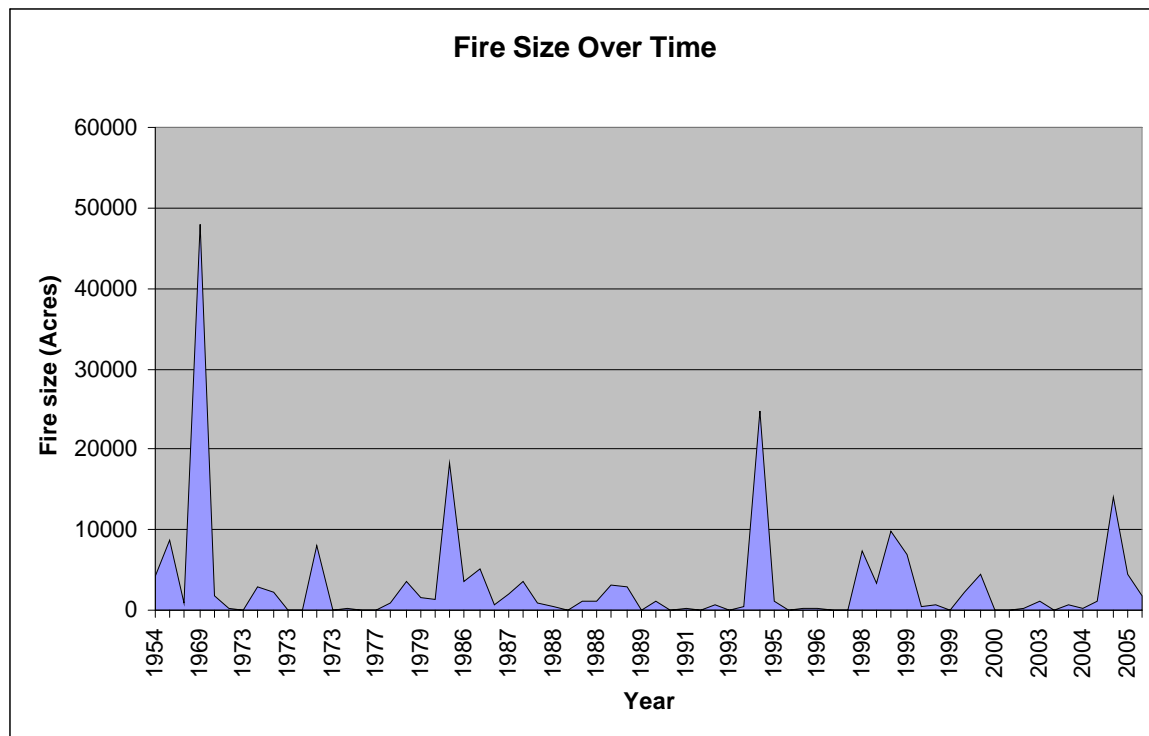


Figure 3. Size of Major Fires in Leeward Hawai‘i Over the Past 55 Years.



### ***Prescribed Fire Behavior***

Five plots were burned over an 8-day period between January 27 and February 4, 2004. For several months prior to the prescribed burning in January 2004, the leeward side of Hawai'i received significant rainfall. At the time of the burns, the fountain grass was vigorous, in flower, and very green in color. During the burns, fuel moistures of the predominantly live grass were high (over 270%) and dead fuel moisture contents fell in the 12 to 16 % range. Conditions in the 1st plot to be burned, while in prescription, were marginal resulting in approximately 50% consumption. Weather conditions for subsequent burns fell squarely within the prescription and approximately 90 % consumption was achieved.

### ***Fuel Loading***

A detailed report of the response of the fuel loading to the treatments can be found in Appendix B. Prior to the study, the fuel bed throughout the study area was almost entirely composed of fountain grass. Herbaceous fuel load at the beginning of the study averaged 9,225 lbs/acre. There was no significant difference between blocks. Downed dead woody fuel load and live woody fuel load were distributed unevenly, reflecting only the remnants of the former forest that has been removed through repeated wildfires. Live woody fuel increases in March 2006 were by two non-native pest plants, tree tobacco (*Nicotiana glauca*) and castor bean (*Ricinus communis*). The latter appeared in herbaceous form immediately after the application of treatments, but by March 2006, these plants had matured to tree size with woody stems.

Further analysis of the data is required to detect differences in herbaceous fuel loading within treatments over time, however the data shows that herbaceous fuel load remained relatively constant over the 2-year study period in the control treatment. In contrast, the glyphosate herbicide effectively killed nearly all of the fountain grass when applied alone or following grazing, which initiated a process of decomposition that noticeable changes in continuity and load at both one year and two years post-treatment (Photographic Plates - Appendix C).

As expected, prescribed burning removed the grass fuel load. The process of recovery of the herbaceous grass fuel bed from existing root stocks was set back when the green actively growing grass shoots were aerially sprayed 5 weeks following burning. This post-burn spray, however did not kill the plants and their recovery from the spray is shown in the data as being staggered behind the burn only treatment over the 2-year sample period.

The grazing treatment showed no substantial change in herbaceous fuel loading. Minor fluctuations over the two year period are likely a result of sampling error. When the grazing was followed by herbicide, the effects of the herbicide were similar to that of herbicide alone. The lack of effectiveness of this treatment was a result of the excessively low stocking rate applied. As a result, the 50% fuel load reduction goal was not achieved for the grazing treatment.

In contrast to the graze treatments, the burn followed by grazing treatment resulted in a substantial reduction in herbaceous fuel load. Application of herbicide to this combined treatment yielded an even greater reduction in herbaceous load that lasted throughout the duration of the study . This treatment

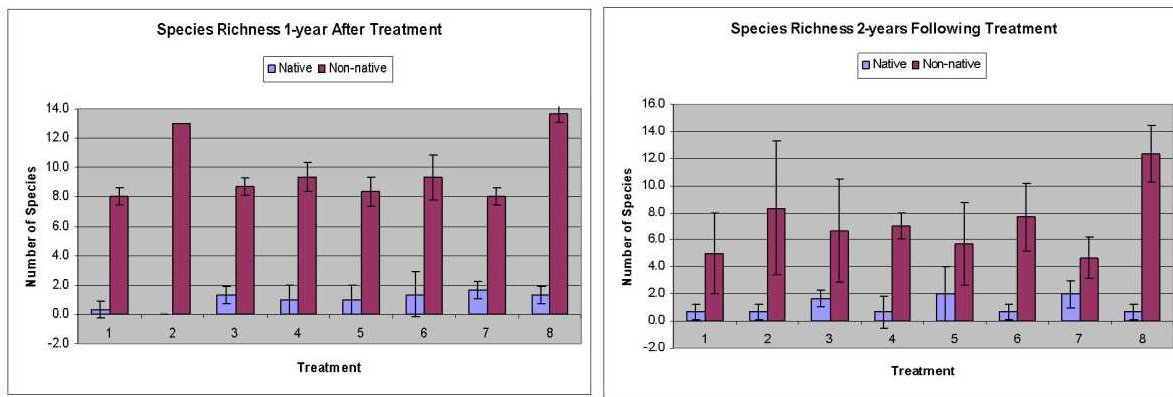
produced the most dramatic overall reduction in herbaceous fine fuel load, and the greatest reduction in grass load. This treatment also produced the greatest increase in woody plant cover and loading of any of the treatments. However this increase was minor and after 2 years totaled only about 1,200 lbs./acre, less than 13 % of the average total herbaceous load.

Considering the average fuel load one-year and two-years following initial treatment, the primary fuel load reduction goals of 50% reduction was achieved for the herbicide, prescribed burn, burn-herbicide, burn-graze, and burn-graze-herbicide treatments. However, further analysis of the fuel load data is required to determine the statistical significance of fuel load monitoring results.

### ***Vegetation***

The total number of species within the study area increased over the life of the project from a low of 8 species prior to 28 species two years after treatments were applied. The highest number of species was recorded one year following treatment (Appendix C). After one year the number of species was highest in the herbicide and combined burn-graze-herbicide treatments and remained highest in the combined burn-graze spray treatment (Figure 4). In these treatments, and to a lesser degree in other treatments receiving herbicide, a number of broadleaf herbaceous and woody plants established. There were no live woody species found before or immediately after treatment. Three live woody plant species appeared only after four months and one year; five live woody plants were present after two years. The recruitment of tall broadleaf plants into these treatments was conspicuous and easily noticed from the highway bordering the study (Photographic Plates - Appendix C), Tree tobacco, the tallest and most abundant woody species, was an established and spreading invasive the region prior the study. However, the herbicide treatments provided opportunity for this and other species to become well-established in the study area. Tree tobacco, Castor bean, which also grows over 3 m tall, and the low-growing Madagascar Fireweed (*Senecio madagascarensis*) are all considered noxious to livestock. The establishment of these species in the treatments receiving herbicide, particularly in the herbicide and combined burn-graze-herbicide treatment contributed to a shift in species composition and structure of the fuel bed that is expected to substantially reduce fire behavior characteristics. The effect of the herbicide and combined treatments in releasing the existing soil seed bank indicate that these treatments may have application in restoration of native dry forest ecosystems.

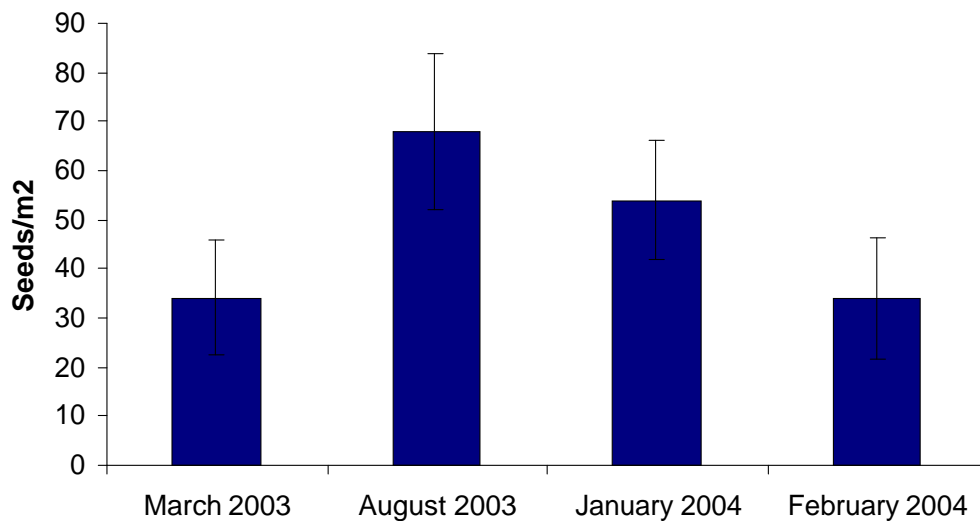
Figure 4. Species Richness one- and two-years following application of fuels treatments in Puu Anahulu, Hawai'i.

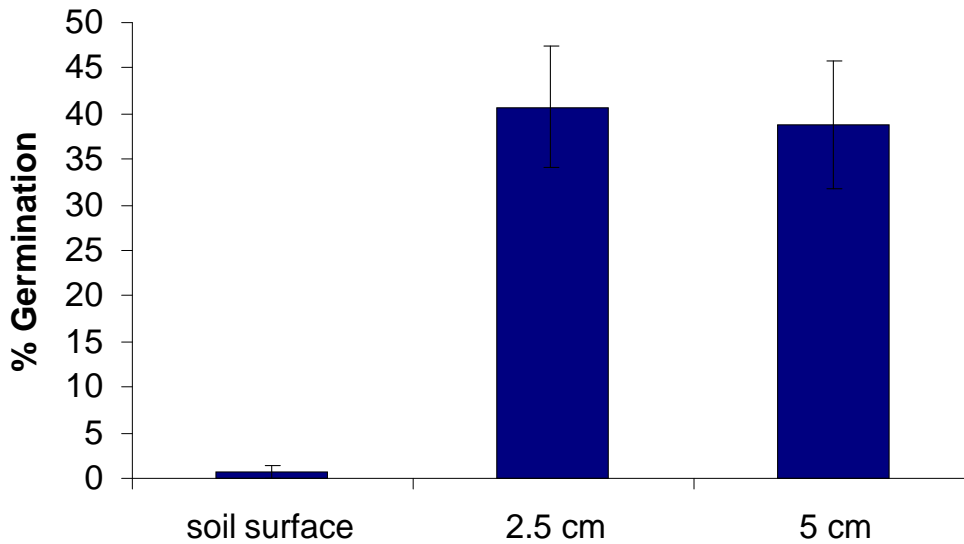


### Soil Seedbank

The Soil seedbank within the study site was comprised primarily of small seeds. Fountain grass seed dominated the seedbank. The seeds are non-dormant and their viability declined approximately 80% over the 18 month period that spanned from summer of 2003 through winter of 2004-2005 (figure 5). Seed viability was highest below the surface. Seeds on the soil surface were killed by the prescribed burns, but buried seeds remained viable (Figure 6). In laboratory tests, fountain grass seeds were found to be intolerant of temperatures greater than 75° C. Researchers found the fountain grass seedbank to be spatially variable (Nonner 2005) (See appendix G for reference to full soil seedbank study results).

Figure 5. Fountain grass Seedbank





### Photography

The photography component of this study proved extremely valuable a means of documenting the visual changes in the fuel loading over the two year time period. Photographs of treatments in Block 1 that correspond to each of the 5 sample dates for each of the 8 treatments graphically depict visual changes in fuel bed composition and structure over time. Photographic plates showing the evolution of the fuelbed within each of the 8 treatments over the two-year sampling period can be viewed in Appendix C.

### Fire Behavior Modeling

Fire Behavior outputs presented in Appendix D represent predicted fire behavior characteristics for each treatment relative to one another. These outputs can be used in their current form to predict rate of spread (ROS), flame length, and other variables for each treatment relative to other treatments in this study. In summary, two years following application of treatments, the combined prescribed burn-herbicide treatment had reduce fire ROS 63% over control and the combined Burn-cattle graze-herbicide treatment reduced the ROS by 95%. Likewise, flame length was reduced in the same two treatments by 93 and 66%, respectively (Appendix D). The relative effects of the treatments on flame length and rate of spread, the most tangible outputs used by firefighters, are summarized in Table 3.

Table 3. Fire Behavior Assessment for Each Treatment One- and Two-Years Following Application of Treatments.

		Behavior Increase = Red, Behavior Decrease = Green Moderate Behavior Decrease = Yellow	
	Treatment	Year 1	Year 2
1	Control	Moderate increase above pretreatment in ROS, minor increase in flame length	Increase over pre-treatment in ROS, increase in flame length
2	Spray	Moderate reduction in ROS and flame length	Moderate reduction in ROS and flame length

3	<b>Burn</b>	Substantial reduction in ROS	ROS predicted at higher than pretreatment conditions
4	<b>Burn-Spray</b>	Substantial reduction in ROS	Substantial reduction in ROS
5	<b>Graze</b>	No difference in ROS, Slight decrease in flame length	No difference in ROS or flame length
6	<b>Graze-Spray</b>	Moderate reduction in ROS and slight reduction in flame length	Reduction in ROS and flame length
7	<b>Burn-Graze</b>	Substantial reduction in ROS and flame length. Low probability of a fire ever starting in this roadside fuel type	Maintained same levels as year 1. Low probability of a fire ever starting in this roadside fuel type
8	<b>Burn-Graze-Spray</b>	Substantial reduction in ROS and flame length. Low probability of a fire ever starting in this roadside fuel type	Major reduction in ROS, Reduction in flame length, low probability of a fire ever starting in this roadside fuel type

### Costs

Economic analysis of the treatments used in this study is needed if these treatments are to be considered by private landowners as well as public agencies. The costs of the treatments and the time period that fire risk is reduced needs to be determined in order to perform such an analysis. Unfortunately, the economic data associated with this study are not representative of operational costs for several reasons. This was the first set of prescribed burns conducted by the State of Hawai'i and more resources were used to minimize the risk of fire escape. In order to control the cattle, the entire area was fenced. It is anticipated that actual treatment costs for both grazing and prescribed burning would be less than the costs in this study. These treatments (herbicide, grazing, and prescribed burning) each have a variety of risks and benefits associated with their use. However, we are able to infer the relative cost of treatments based upon this study. Approximate initial cost to apply treatments at a similar spatial scale, and annual maintenance costs are approximated in table 6 based upon real costs incurred in this study.

Table 6. Estimated Cost of Treatments for Start-up and Maintenance as Applied in this Study.

Treatment	Acres	Start up cost		Maintenance cost		Comments
		Total	per acre	Total	per acre	
Control		0				No cost
Spray	56	7,500	134	7,500	134	Cost remains relatively constant over time (*based on 2005 cost: \$9,000 for 150 Ac)
Burn	47	70,940	1,509	47,317	1,007	Over time, burn operation becomes more efficient and less expensive (approx. 33% more efficient)
Burn Spray	23	37,796	1,643	37,796	1,643	Assumes that changes in cost are proportional to changes in acreage
Graze	46	153,543	3,338	3,543	77	High initial start up cost, low maintenance cost (lasts 15 – 20 years)
Graze Spray	23	79,852	3,472	11,043	480	If grazing is objective, no sense in spraying
Burn Graze	23	111,487	4,847	25,430	1,106	Burning prior to grazing starts grazing cycle on nutritionally high quality forage – good pasture

Burn Graze Spray	23	114,567	4,981	36,473	1,586	Again, if grazing is objective, burning as a site preparation treatment enhances quality of forage, if affordable, but subsequent spraying would render pasture unusable.
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## MANAGEMENT IMPLICATIONS

### *Discussion of Treatments*

Preliminary results indicate that prescribed burning is an effective tool to reduce fuel loading in fountain grass. For this treatment to be effective as a stand alone treatment, repeated application every 1 to 2 years is needed to maintain reduced fuel loads. However, there is an element of risk associated with the use of prescribed burning. In this area of Hawai'i, there are few roads that interrupt the fuel continuity allowing an escaped prescribed burn to run miles under the influence of typical weather patterns. Because of risk and the limited experience with prescribed fire use in this area, the per unit cost of fire use is likely to be very high.

Cattle grazing has been shown to be an effective tool to reduce fuel loads in grass and herbaceous plants within this region. Palatability and nutritive content of the plants is an important consideration favoring winter grazing and resting areas during dry summer months.. We observed the cattle preferring the new green growth following the prescribed burns instead of the dried fountain grass. In our study, cattle grazing was applied in low intensity and of brief duration. As such, the cattle were able to chose their preferred forage and utilized the burned areas more than the unburned areas. Assisted by favorable growing conditions, lightly grazed areas recovered quickly. A grazing system utilizing a rotational grazing scheme as has been used at the adjacent Pu'u Wa'awa'a Ranch to effectively manage fountain grass fuel loads. However, the two light pulses applied in this study were insufficient to show a reduction in load and need to be applied at a higher intensity or at the same intensity but over a longer duration of at more frequent intervals in order to obtain at least a 50% reduction in loading. Very intensive grazing, and combined treatments such as burning-grazing-herbicide will likely result in the kill of the grass and its replacement by unpalatable species. While this outcome achieves the goal of reducing the fine fuel load and shifting the fuel type away from grass, it will render the area useless or of low value for future grazing use. We expect a light to moderate level of grazing applied during winter months to be tolerable to cattle, yet effective in reducing fuel load and breaking the continuity of the fuel bed. Further research is needed to determine the levels of grazing necessary to obtain adequate reduction in fuel loading, and how those levels effect livestock health, and range quality.

Glyphosate herbicide has been found to be an effective herbicide to kill fountain grass and facilitate restoration of dry forest in Hawai'i (Cordell et al 2002). In this study, glyphosate was also very effective in killing the fountain grass when applied aerially. However, much of the dead grass persisted as standing attached material throughout the first year. It appears that 1-2 years time is needed to allow the standing dead fine fuels to break down to the point that it does not significantly contribute to fire spread. After 2 years, fountain grass fuel continuity was discontinuous and bunches had been reduced to dead clumps of grass with large spaces between clumps. After 2 years, new grass clumps established



within these units and shared dominance of the vegetation and fuel bed with broadleaf woody and herbaceous species. The breakdown of the old grass fuel bed and the change in species composition initiated a shift in fuel type that may last beyond 2 years. Further treatment and maintenance of the new fuel type through repeated spraying, follow-up grazing, seeding, or combinations of these treatments may further shift the fuel type away from monotypic grasslands toward a mix of broadleaf forbs, shrubs, and trees in a fuel bed structure that does not carry fire well. Further experimentation through trial and error is warranted toward this end.

Continued monitoring is necessary in order to determine the full duration and ecological effects of these treatments and ascertain their utility for rehabilitation and restoration of native dry forests that once occupied this area. In addition, techniques such as seeding and planting should be evaluated in combination with these treatments to develop efficient techniques for fuel type conversion and ecosystem restoration.

## ***Products and Outcomes***

The following products were produced:

- 1) Presented a paper summarizing the first-year fine fuel load results at the annual Tall Timbers Fire Ecology and Management Conference, held in Bartlesville, Oklahoma, October 17 - 20, 2005. Paper to appear in peer-reviewed proceedings.
- 2) Two all-day fuels management workshops where the results of the study were used to catalyze discussion among land managers who face wildfire management/alien grass invasion issues. The first was held on September 30, 2005 at Tutu's House in Waimea and included an afternoon site visit and tour of treatment plots. The second workshop is scheduled for June 10 at the Waimea Civic Center and will also include an afternoon site visit (Appendix E).
- 3) A large-format revised Fire History of West Hawai'i map. The map, which shows the 55-year fire history of North Kona and South Kohala Districts of the island of Hawaii will be distributed to governmental agencies and other interested parties during the summer of 2006 (Appendix A).
- 4) A web site that summarizes the project and presents results using text, tables, graphs, photographs, and maps scheduled for completion on August 15 at the following URL: [www.whwmo.org/JFSP](http://www.whwmo.org/JFSP).
- 5) A printed brochure that describes the study and its key outcomes was produced by the WHWMO in consultation with local experts. The brochure interprets the study results in the context of mitigating wildfire hazards throughout the region through reduction and maintenance of fine fuels to protect communities and natural resources. The brochure also explains how to visit the study site and view the 8 treatment plots in block 1 (Appendix F). Brochures are now available at the Hawai'i Division of Forestry and Wildlife, the Natural Resource Conservation Service, and the West Hawai'i Wildfire Management Organization offices in Waimea.
- 6) A final report to the Joint Fire Science Program that summarizes the project and details performance on agreed deliverables.

Among the many outcomes of the project, is the working inter-agency relationships that were forged during the planning and execution of the prescribed burns. The experience of conducting a set of well-coordinated interagency burns further built confidence and strengthened friendships among the many federal, state, and county agencies that participated.

## **CONTRIBUTIONS**

The large scale of the project, both in acreage and in coordination, was made possible only through the generous funding from the Interagency Joint Fire Science Program and funding the combined contributions of the Portland and Honolulu offices of the U.S. Fish and Wildlife Service, the Hawai'i Division of Forestry and Wildlife, the U.S. Forest Service Riverside and Seattle Fire Labs, other local agencies, and several individuals and non-governmental organizations (Table 7). Many of the key local agencies involved in the planning and execution of the burns detailed staff from other duties to participate in this project. In addition, generous contributions of professional services from non-profit and private contractors helped make this project possible (Table 8).

Table 7. Summary of Contributions to Project

<b>Source</b>	<b>Proportion of total (%)</b>	<b>Amount</b>
Joint Fire Science Program	47	223,143
Other Federal (non-JFSP)	29	138,000
State and County Government	7	33,000
Non-Profit Organizations	7	31,000
Private Businesses	10	57,643
<b>TOTAL</b>		<b>482,786</b>

Table 8. Sources of Funding Used in Project Implementation

**Project Funding**

Joint Fire Science Program	\$223,143;
U.S. Fish and Wildlife Service, Honolulu: Project management (0.5 FTE, 1 yr.)	\$ 40,000;
U.S. Fish and Wildlife Service, Portland: WUI grant funding 2003	\$ 70,000;
U.S. Fish and Wildlife Service: Hakalau Forest Nat. Wildl. Ref.	\$ 6,000;
U.S.F.S., Riverside Fire Lab: staff 2 wks and other technical support	\$ 6,000;
U.S.F.S., PNW, Seattle: Photographic fuels monitoring services	\$ 10,000;
US Army /Naval Fac. Command, Hawai'i, Pohakuloa Training Area	\$ 6,000;
Hawaii DLNR Division of Forestry and Wildlife	\$ 18,000;
Hawai'i County Fire Department	\$ 10,000;
Hawai'i County Civil Defense Agency	\$ 5,000;
West Hawai'i Wildfire Management Organization, Kamuela: water,tank installation and filling, pipe, troughs, firefighter meals, workshop hosting, technology transfer, and project coordination services	\$ 31,000;
HNRS: Administrative support services, project coordination, and reporting	\$ 49,300;
Deluz Cattle Co.: Cattle transportation and cattle grazing services	\$ 3,543;
Scott Haw. Ent.: Fuel break estab./maint.,and digital photog. and video	\$ 4,800;
<b>TOTAL</b>	<b>\$ 482,786</b>

**ACKNOWLEDGEMENTS**

Initial funding from the USDA/USDI Joint Fire Science Program and subsequent funding from the US Fish and Wildlife Service Wildland-Urban Interface Program made this study possible. Without the enthusiasm, persistence, and support of local project participants, this project would not have been realized. This project was implemented cooperatively by the following agencies and organizations: the State of Hawai'i Division of Forestry and Wildlife; the U.S. Fish and Wildlife Service the U.S.F.S. Riverside and Seattle Fire Labs; the U.S. Army Hawai'i Naval Facilities Command Fire Management Branch and Pohakuloa Training Area Fire Department; the Hawai'i Fire Department; the West Hawaii Wildfire Management Organization; Hawai'i Natural Resource Services; Scott Hawaiian Enterprises;

the DeLuz Cattle Co.; the Pu‘u Wa‘awa‘a Cattle Co.; the Kaluau Cattle Co.; and the community of Puu Anahulu.



## USEFUL REFERENCES

- Andrews, P.L. 1986. BEHAVE: Fire behavior prediction and fuel modeling system. General Technical Report INT-194, U.S. Department of Agriculture, Forest Service, Ogden, UT.
- Blackmore M. and P.M. Vitousek. 2000. Cattle grazing, forest loss, and fuel loading in a dry forest ecosystem at Puu Waawaa Ranch, Hawaii. *Biotropica* 32: 625-632.
- Brooks, M.L. and D.A. Pyke. 2001. Invasive plants and fire in the deserts of North America. Pages 1-14 in K.E.M. Galley and T.P. Wilson (editors). Proceedings of the invasive species workshop: the role of fire in the control and spread of invasive species. Miscellaneous Publication No. 11, Tall Timbers Research Station, Tallahassee, FL.
- Castillo, J.M. 1997. Control of *Pennisetum setaceum* (Forssk.) Chiov. in native Hawaiian dry upland ecosystems. M.S. Thesis, Colorado State University, Ft Collins.
- Cordell, S., R.J. Cabin, S.G. Weller, and D.H. Lorence. 2002. Simple and cost-effective methods to control fountain grass in dry forests (Hawaii). *Ecological Restoration* 20(2): 139-140.
- Cuddihy, L.W., and C.P. Stone. 1990. Alteration of the native Hawaiian vegetation: effects of humans, their activities and introductions. University of Hawaii Press, Honolulu. 138 pp.
- D'Antonio, C.M. and P.M. Vitousek. 1992. Biological invasions, the grass fire cycle and global change. *Annual Review Ecological Systematics* 23:63-87.
- Ford, L.D. 2005. Puuanahulu fuels management study: site preparation and fuels and vegetation sampling 2006 annual status report: fuel load and vegetation response. Unpublished report submitted to U.S. Fish and Wildlife Service, Portland, OR (Purchase Order Number 1448-10181-04-M077(KY)). 34 p.
- Freifelder, R.R., Vitousek, P.M., and C.M. D'Antonio. 1998. Microclimate change and effect on fire following forest-grass conversion in seasonally dry tropical woodland. *Biotropica* 30(2): 286-297.
- Gagne, W.C. and L. W. Cuddihy 1990. Vegetation. Pages 45-114 in Wagner, W.L., Herbst D.R., and S.H. Sohmer. Manual of the Flowering Plants of Hawaii. Bishop Museum special publication, University of Hawaii Press.
- Hughes, R.F., P.M. Vitousek, and T. Tunison. 1991. Alien grass invasion and fire in the seasonal submontane zone of Hawai'i. *Ecology* 72: 743-46.
- Janzen, D.H. 1988. Tropical dry forests, the most endangered major tropical ecosystem. Pages 130-144 in E.O. Wilson (editor). Biodiversity. National Academy Press, Washington, D.C.
- McDonald, I.A., D. Graber, S. DeBenedetti, R. Groves, and W. Fuentes. 1988. Introduced species into nature reserves in Mediterranean-type climatic regions of the world. *Biological Conservation* 44: 37-66.
- Nonner, E.D. 2005. Seed Bank Dynamics and Germination Ecology of Fountain Grass (*Pennisetum setaceum*). Master's Thesis. Department of Botany, University of Hawaii at Manoa, Honolulu.

- Shaw, R.B., J.M. Castillo, and R.D. Laven. 1997. Impact of wildfire on vegetation and rare plants with the Kipuka Kalawamauna endangered plant habitat area, Pohakuloa Training Area, Hawaii. Pages 253–264 in J.M. Greenlee (editor). Proceedings of the first conference on fire effects on rare and endangered species and habitats conference. International Association of Wildland Fire, Coeur d'Alene, Idaho
- Smith, C.W. and T. Tunison. 1991. Fire and alien plants in Hawaii: Research and management implications for native ecosystems. Pages 394-408 in C.P. Stone, C.W. Smith, and T. Tunison (editors.) Alien Plant invasion in Hawaii: Management and research in native ecosystems. Univ. Hawaii Press, Honolulu, Hawaii.
- Tunison, J.T. 1992. Fountain grass control in Hawaii Volcanoes National Park: management considerations and strategies. Pages 376-393 in Stone, C.P., C.W., and J.T. Tunison. (Eds.) Alien Plant Invasions in Native Ecosystems of Hawaii: Management and Research. Cooperative National Park Resources Studies Unit, University of Hawaii, Manoa.
- United States Department of Agriculture. 2005. *Pennisetum setaceum*. In PLANTS database. Natural Resources Conservation Service.  
[http://plants.usda.gov/cgi\\_bin/plant\\_profile.cgi?symbol=PESE3&mode=Print&photoID=pese3\\_001\\_avd.tif](http://plants.usda.gov/cgi_bin/plant_profile.cgi?symbol=PESE3&mode=Print&photoID=pese3_001_avd.tif) (verified 10/15/2005).
- Wright, C.S. R.D. Ottmar, R.E. Vihnanek, and D.R. Weise 2002. Stereo photo series for quantifying natural fuels: grassland, shrubland, woodland, and forest types in Hawaii. General Technical Report PNW-GTR-545. U.S. Department of Agriculture, Forest Service, Portland, OR.

## Appendix A. Draft Fire History Map of West Hawaii.



# Draft 55-Year Fire History of West Hawaii



Kawaihae

Waimea

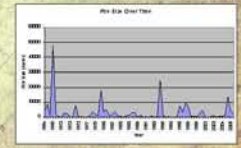
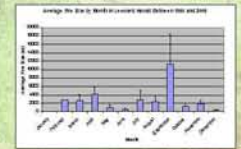
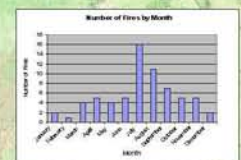
Puako

Waikoloa

Waikii

Puu Anahulu

Kalaoa



Draft Fire History of West Hawaii  
June 8, 2006  
Produced by: West Hawaii Wildfire Management Organization





## Appendix B. Fuel Load Sampling Report.

**Puuanahulu Fuels Management Study  
Site Preparation and Fuels and Vegetation Sampling:  
Fuel Load and Vegetation Response  
2006 Annual and Final Status Report**



*March 2, 2006 View East of Treatment Units 1-4 (L. Ford photo)*

***Draft:*** April 30, 2006

Prepared for the U.S. Fish And Wildlife Service

Prepared by Lawrence D. Ford, Ph.D.<sup>12</sup>  
USFWS Vendor #135411697 [Purchase Order Number 1448-10181-04-M077(KY)]  
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<sup>1</sup> Research Associate, Environmental Studies Department, University of California, Santa Cruz; Certified Range Management Consultant (#C05-02), Society for Range Management; Certified Senior Ecologist, Ecological Society of America.

<sup>2</sup> Cooperating sub-contractors on this study include Prof. Scott Stephens, University of California, Berkeley (study design and technical advice), Mr. Danny Fry, University of California, Berkeley (statistics, technical advice, field assistance), Mr. David Scott, Scott Hawaiian Enterprises, Honokaa, HI (site preparation), and Ned-Ace Mesa (field assistance); special thanks to Dr. Mark Thorne, Cooperative Extension, University of Hawaii, Kamuela (processing fuel samples, technical advice); Milton Yamasaki, Mealani Research Station, Kamuela, HI (drying oven); Danielle Frohlich, University of Hawaii, Manoa cooperator and botanist (plant id.); Miles Nakahara, Division of Forestry and Wildlife, State of HI (technical discussions and lodgings); and Mick Castillo (technical and logistical support).

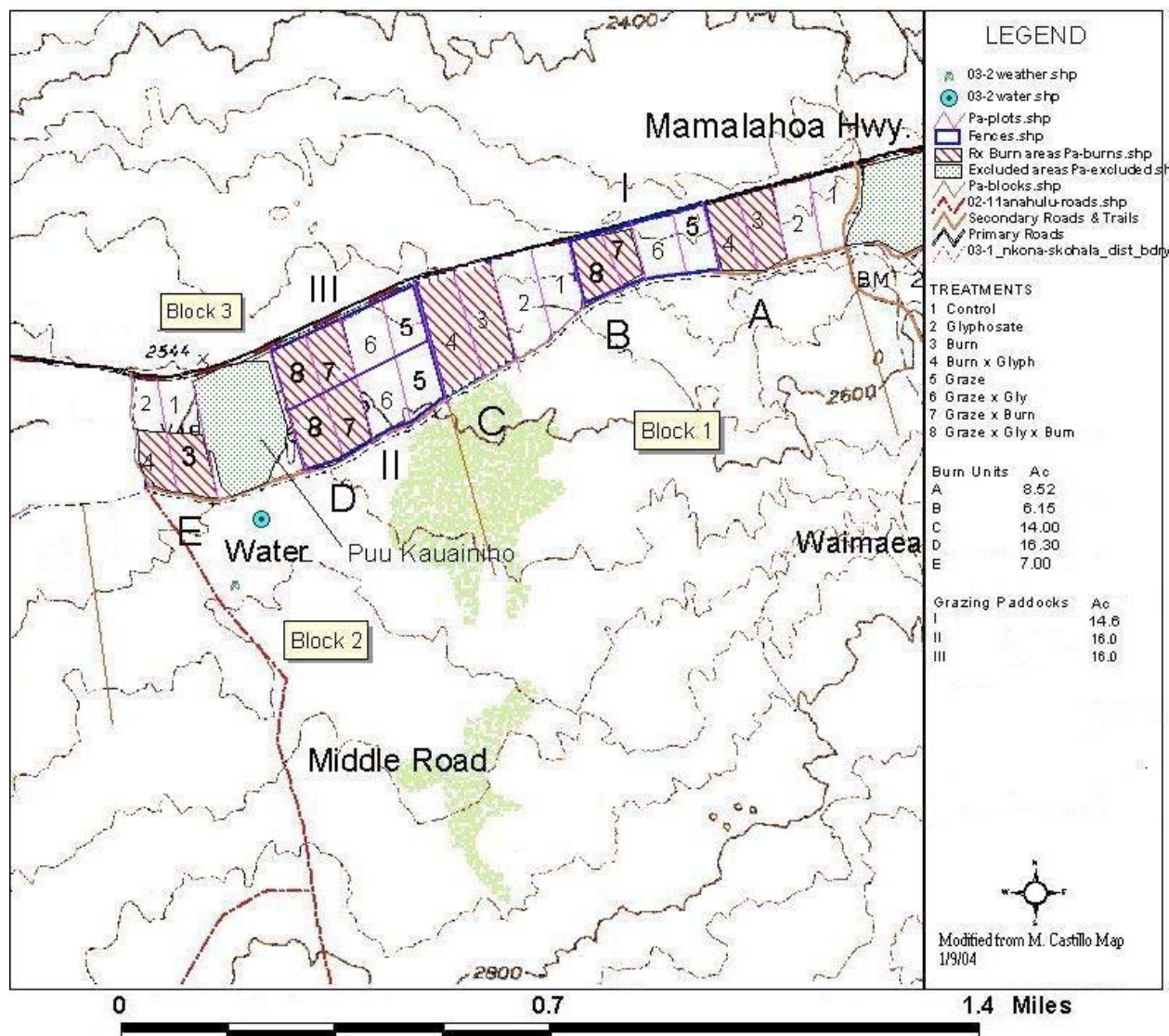
## 1. Introduction

*Study Overview.* The Puuanahulu Wildfire Management Study was designed to evaluate the effectiveness and costs of fuels management treatments in the reduction of environmental impacts caused by a high-frequency wildfire regime in West Hawaii. Recurrent wildfires are associated with the invasion of the non-native fountain grass (*Pennisetum setaceum*) that creates very high fuel loads. The study encompasses the experimental application of eight combinations of treatments to the grassland--control (no treatments), prescribed burning, cattle grazing, and aerial herbicide application--and the observation of changes in fuel loads and vegetation characteristics at five time periods between December 2003 to March 2006. The study has also developed fire behavior models of hypothetical wildfire regimes in the regional landscape associated with the observed effects of the fuel management treatments at the study site. The fuels and vegetation response component of the study includes the collection and analysis of fuel load and vegetation response data, and the reporting of results to the study principals.

*Study Area.* The study area is situated on the south uphill side of the Mamalahoa Highway (State Hwy 190) east of Puuanahulu surrounding the cinder cone, Puu Kuainiho in the North Kona District (Figure 1). The study site is state land managed for game hunting and conservation purposes by the Hawaii Department of Land and Natural Resources, Division of Forestry and Wildlife. The vegetation of the area is now dominated by fountain grass in a dense grassland with a few native and introduced trees and shrubs scattered across most of the Treatment Units at the study site. The area was dominated by tropical dry forest before the wildfire regime shifted to higher frequency, which reduced the woody cover and has favored the occupation and persistence of fountain grass (Castillo 2001). The busy roads of the region are a major source of wildfire ignitions, and the resulting wildfires have converted much of the region from forest to grassland. Minor remnants of the native forest occur in the region, but not at the study site. The study site occurs on rugged lava representing at least four flows from the Mauna Loa and Hualalai volcanoes in the last ten thousand years (Wolfe and Morris 1996).

*Study Component Goals and Objectives.* The goals of the Puuanahulu Wildfire Management Study are to develop fuels management techniques that reduce roadside ignitions, protect remaining dry tropical forest, improve habitat for game animals, and protect the human community (Castillo 2004). Results of the fuel load and vegetation response component of the study are used to evaluate the relative effectiveness of the treatments, individually and in combination, in reducing the fuel loads and in opening the dense cover of fountain grass for establishment of native plants. The fuel load and vegetation response component of the study includes the assessment of changes in:

- Herbaceous and woody fuel loads as a measure of fire hazard and for utilization in the fire behavior models;
- Herbaceous fuel height and cover to further characterize the fuels and the environment for establishment of native plants;
- Plant species composition of the fuels and their status as natives versus non-natives and pests.



**Figure 1. Map of the Puuanahulu Fuels Management Study Site with Approximate Arrangement of Treatment Units** (modified from basemap created by M. Castillo 1/9/04).

This component of the Puuanahulu Fuels Management Study examines the effects of the burning, grazing, and herbicide treatments on the herbaceous and woody fuels and related vegetation characteristics present at the study site for two years post-treatment. The results characterize the fire hazards associated with the treatments and are applied in two concurrent studies: models of fire behavior at scales representing the study area and the natural untreated regional landscape (conducted by Rod Moraga<sup>3</sup>); and the Forest Service Stereo Photo Series for Quantifying Natural Fuels of Hawaii (conducted by Robert Vihnanek<sup>4</sup>). The vegetation

<sup>3</sup> Mr. Moraga oversees operations of the Ecosystem Management division and related education and training for Anchor Point Group LLC of Boulder, CO.

<sup>4</sup> Mr. Vihnanek is Supervisory Forester, Fire and Environmental Research Applications Team, Pacific Wildlands Fire Laboratory, Pacific Northwest Research Station, Seattle, WA.



characterization results also help to describe the potential changes in community composition and structure associated with the treatments. The combined results provide fundamental information about fuel management options and effectiveness to regional lands managers, and serve in the development of hypotheses to test in future studies.

*Experimental Design and Treatments.* The overall study was designed by Mick Castillo, David Weise, Miles Nakahara, and Joel Godfrey (Castillo 2001)<sup>5</sup>. Mr. Castillo supervised or performed all management of the study operations in the study area, installation of supporting facilities, and applications of treatments in cooperation with the Hawaii Department of Land and Natural Resources, Division of Forestry and Wildlife.

The Treatment Units were arrayed and applied in a non-randomized complete block design (single treatments and all combinations). Randomization of the treatment assignments was not feasible; instead the areas of similar treatments were clustered to assure that access, fuel breaks, livestock watering facilities, and similar treatment could be provided in adjacent Treatment Units cost-effectively, and to avoid excessive herbicide drift to inappropriate Treatment Units. The resulting arrangements of Treatment Units at the study site are shown in Figure 1. Thus the design necessitates a split-plot analysis.

The control, burning, grazing, and herbicide treatments were applied in a factorial array with three replicates (Table 1.A). This resulted in eight treatment types and 24 Treatment Units. The first phase of treatments were applied in sequence between January and May 2004. The prescribed burns occurred between January 27 and February 4, 2004. Burning treatments were conducted at moderate intensity after clearing of fuel breaks. Treatment combinations (TUs #4, 6, 7, and 8) required completion of the previous treatment before application of the next treatments. The cattle grazing treatments were applied at flexible stocking rates until stubble height reached moderate utilization levels after fence construction in April and May 2004. The 2004 grazing occurred without separation between TUs by one herd due to gates left open. There was no fencing installed to separate TUs 5&6 or TUs 7&8, nor separating Blocks 2&3. Glyphosate herbicide treatments were applied in April and May 2004 by helicopter at 5.3 lbs/acre after removal of the cattle. The Control Treatment Units were left without treatment for comparison to the treatments. A second phase of the grazing treatment only was applied between January 30 and March 23, 2006 (Table 1.B). The 2006 grazing occurred with available gates closed in a sequence of four events. Ten cows and four calves were moved as a group between the blocks and TUs.

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<sup>5</sup> When he designed this study, Mr. Castillo was a biologist with the U.S. Fish and Wildlife Service in Honolulu, Hawaii; he is now owner of Hawaii Natural Resource Services LLC in Kamuela, Hawaii, and a leader of the West Hawaii Wildfire Management Organization; Dr. Weise is with the U.S.D.A. Forest Service, Pacific Southwest Research Station in Riverside, CA; Mr. Nakahara is with the Hawaii Division of Forestry and Wildlife, West Hawaii Office in Kamuela, HI; Mr. Godfrey is with the U.S. Army Hawaii Integrated Training Area Management.

**Table 1.A. Treatment Units and Phase One Application Schedule.**

Treatment Unit	Treatment			
	Control (untreated)	Burn (applied first)	Grazing (applied second)	Glyphosate (applied third)
1	X			
2				X (Apr 04)
3		X (Jan/Feb 04)		
4		X (Jan/Feb 04)		X (Apr 04)
5			X (Apr-May 04)	
6			X (Apr-May 04)	X (May 04)
7		X (Jan/Feb 04)	X (Apr-May 04)	
8		X (Jan/Feb 04)	X (Apr-May 04)	X (May 04)

**Table 1.B. Treatment Units and Phase Two (2006 only) Grazing Application Schedule.**

Treatment Unit	Treatment		
	Grazing		
	Block #1	Block #2	Block #3
1	none	none	none
2	none	none	none
3	none	none	none
4	none	none	none
5	X (Mar 15 - Mar 23)	X (Feb 18 - Mar 5)	X (Feb 18 - Mar 5)
6	X (Mar 15 - Mar 23)	X (Feb 18 - Mar 5)	X (Feb 18 - Mar 5)
7	X (Mar 5 - Mar 15)	X (Jan 30 - Feb 18)	X (Jan 30 - Feb 18)
8	X (Mar 5 - Mar 15)	X (Jan 30 - Feb 18)	X (Jan 30 - Feb 18)

Sampling of the fuel loads and vegetation responses in the Treatment Units was conducted before and after application of the treatments according to the following schedule (Table 2). We have completed all five of the planned samplings.

**Table 2. Sampling Schedule.**

Period	Month/Year	Description
1	January 6-22, 2004	Immediately prior to the application of the treatments
2	February 22-25, March 22-27, May 22-27, 2004	Immediately following completion of the treatments
3	August 2-7, 2004	4 months following the treatments
4	March 16-20, 2005	1 year following the treatments
5	February 27 to March 30, 2006	2 years following the first phase treatments

*Site Preparation.* Prior to commencement of data collection, we subdivided the fuels of the study area into zones corresponding to the treatments that would involve prescribed burning. We repeatedly cut, cleared, and sprayed appropriate herbicide on the fuel breaks to delineate and protect the non-burning Treatment Units and to assist in prevention of accidental spread of fire from the areas to be prescribed burned. The fuel breaks (“buffer areas”) were established by reducing the vegetation height to no more than 4 inches in a 25 feet wide band on all sides around each burn treatment unit. In addition, clearing was conducted within a 25 feet radius around selected native trees to protect their trunks and foliage from damage during the burn treatments. Scott Hawaiian Enterprises (David Scott, owner, Honokaa, HI) was sub-contracted to perform this work, and completed it as planned in the months preceding and including February 2004. His work was completed as well as or better than these specifications, and to the approval of Mick Castillo.

*Potential Confounding Factors.* Potential confounding factors include the variation in substrate, uncontrolled grazing by feral livestock, grazing by non-game animals, non-uniform treatments, weather, and edge effects at each sampling period. No wildfires have occurred in the study area since initiation of the project. Avoiding sampling at the edges of the Treatment Units has minimized edge effects. The grazing treatment was expected to be problematic since fountain grass is poor forage and unpalatable during all but the green growing seasons. Because no fencing separated TUs 5&6 or TUs 7&8, and gates were left open during the 2004 grazing, the grazing treatments were not independent. Consequently, the grazing paddocks contained forage representing different treatments and we expected that grazing preferences and trampling effects would be unequal. A second grazing event was applied to the grazed Treatment Units between January and March 2006 without a systematic sampling prior to that application. That action presents a potential bias, and eliminated an assessment of fuel load growth in the interim of almost two years between grazing events, and fuel reduction caused by the second grazing event. We expected that intra- and inter-seasonal weather patterns the year of the treatments to cause different conditions of plant growth, forage palatability, fuel characteristics, and physiological responses in addition to fire behavior and fire influences (including viability of the soil seed bank, seed germination environment, and growth conditions) in the study area. Precipitation during 2004 through 2006 was greater than average, and thus the grass was greener and grew taller than during average years. It rained in the days before the prescribed burn treatments in January and February 2004, and so probably limited the severity of the burn.

## **2. Fuels and Vegetation Sampling Methods**

*Sampling and Measurements.* Sampling has occurred in each Treatment Unit according to the different protocols for each of the three primary categories of variables: herbaceous fuel (plus non-woody litter), down dead woody fuel, and standing live and dead woody fuel. Table 3 lists the variables measured in each Treatment Unit. Sampling of herbaceous fuel (plus non-woody litter) has been conducted at transient plots because of destructive procedures. Additional details of the sampling procedures are described in Appendix A. We repeated the sampling at the specified times at the locations identified in the field maps.

**Table 3. Variables Measured.**

<ul style="list-style-type: none"><li>• Herbaceous Fuels (plus non-woody litter)—cover, height, biomass, and plant species</li><li>• Downed Dead Woody Fuels (sampled post-treatment only; pre- and post-treatment estimates were very small and not reliable)—biomass by size class</li><li>• Live Woody Fuels (sampled post-treatment only; pre- and post-treatment estimates were very small and not reliable)—biomass</li><li>• Substrate Texture (supplement)</li></ul>
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### **3. Data Analysis**

The data from this study represent one control and seven different treatment combinations with three replicates in a repeated measures design. Data have been collected for the five sampling time periods. We made two measurements of the control Treatment Units (TU #1) for the immediate post-treatment sampling period (Time<sub>2</sub>) to represent the beginning and end of the three-month range (February to May 2004) of that sampling period. These duplicate control data were averaged for each replicate for that Sampling Period, then used in the analyses.

Statistical tests concentrated on the three herbaceous fuel variables (load, height, and cover) because the woody fuels were distributed too broadly and unevenly, with insufficient quantities. The woody fuels measures and results were therefore determined to be unreliable.

To meet assumptions of parametric tests, the variables that exhibited skewed frequency distributions were transformed to induce normality. A log transformation ( $Y' = \log_{10} Y$ ) was performed on herbaceous fuel load and fuel height. Herbaceous fuel cover was measured in 5% classes and those data were transformed using the arcsine transformation ( $\hat{Y} = \arcsin(\sqrt{Y})$ ). Future analysis may require transformations of the data when comparing the past and subsequent sampling.

Each of three variables were analyzed for the effectiveness of treatments on reducing fuels. Treatments were implemented using a 3-way full factorial design with one treatment (herbicides) utilized as a split-plot factor. Each of the three factors consisted of two levels: treatment or no treatment. Measurements were collected over several sampling periods (repeated measures design), once prior and four times after treatments were implemented.

Tests for the effects of burning, grazing, and herbicide treatments on herbaceous fuel variables was performed using repeated measures ANOVA. Included in the model were all three main factors, both 2-way and 3-way interactions, and interactions with the repeated measures factor (time). The blocking factor was included as a random effect and the herbicide treatment was treated as a split plot effect. Differences in herbaceous fuel variables among the TU's were tested using Tukey pairwise multiple comparisons.

To test the probability that conditions at the TUs and corresponding replicates (blocks) were different at the start of the study, we assessed the age of the substrate and correspondence to mapped lava flow history within the study area (Tables 6-8). Using substrate class as an independent variable in a statistical test, we found no significant differences for the herbaceous



fuel load or height, but significant for fuel cover. A separate statistical test (ANOVA) indicated no significant differences between Treatment Units at Time<sub>1</sub> for herbaceous fuel load ( $P = 0.09$ ) and herbaceous fuel height ( $P = 0.11$ ); herbaceous fuel cover was significantly different between Treatment Units ( $P = 0.01$ ). Consequently, the hypothesis that the Treatment Units differed pre-treatment was rejected, and the substrate age variable was excluded as a covariate from the other statistical tests.

As a result of analyzing the results using the split-plot for the herbicide treatment in this final report, the following results tables and discussions show some differences from those provided in earlier annual reports.

#### **4. Photo Records**

As a supplementary record and visual illustration of the treatment effects, we recorded digital photos of each Treatment Unit from the internal access road and from Highway 190. These photos were taken on May 27, 2004, August 7, 2004, March 20, 2005, and March 2, 2006 representing the immediate post-treatment, 4-month post-treatment, one-year post-treatment, and two-year post-treatment sampling periods.

#### **5. Results and Discussion**

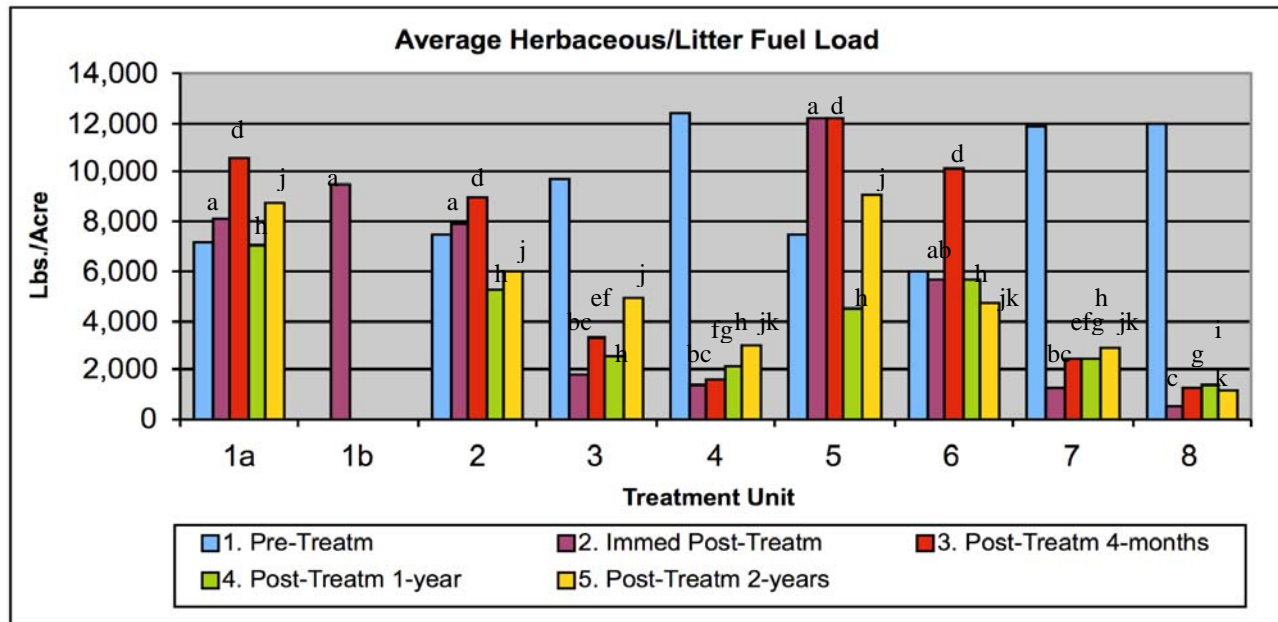
The original data were transferred to spreadsheets and the results were summarized and graphed. These data, spreadsheets, and summaries were distributed to the Project Supervisor (Amanda McAdams) and Principal Investigators after each sampling period for analyses, interpretations, and presentations to local land managers and professional conferences.

The following figures and tables summarize the results from sampling the Treatment Units prior to and following the treatments (up to and including the two-year post-treatment sampling) to compare the treatment effects on the specified variables.

The herbaceous fuel load, height, and cover results are shown in Figures 2, 3, and 4, respectively. The tables below the graphs explain the statistical significance tests. A discussion of the herbaceous fuel loads is included because it is the variable used in fire behavior modeling.

## Herbaceous Fuel Load.

**Figure 2. Herbaceous Fuel Load.**



### Herbaceous Fuel Load Statistically Significant Differences:

Variable	Comparison	Test		P	
Pre-Treatment (T <sub>1</sub> )	Blocks and Treatment Units (TUs)	ANOVA	Blocks	0.310 (no)	
			TUs	0.031 (yes)	
		Tukey Multiple Pairwise Comparison	TUs	0.092-1.0 (no)	
Immediate Post-Treatment (T <sub>2</sub> )	Treatment Units (TUs)	RmANOVA	Between Subjects <sup>1</sup>	burn	0.001 (yes)
				others	no
			Within Subjects <sup>2</sup>	time	0.000 (yes)
				burn*time	0.000 (yes)
				herbicide*time	0.048 (yes)
			others	no	
		Tukey Multiple Pairwise Comparison <sup>3</sup>	Time <sub>2</sub> : 5 <sup>a</sup> 1 <sup>a</sup> 2 <sup>a</sup> 6 <sup>ab</sup> 3 <sup>bc</sup> 4 <sup>bc</sup> 7 <sup>bc</sup> 8 <sup>c</sup>		
4-months Post-Treatment (T <sub>3</sub> )	Treatment Units (TUs)	RmANOVA	Between Subjects <sup>1</sup>	burn	0.001 (yes)
				herbicide	0.033 (yes)
				others	no
			Within Subjects <sup>2</sup>	time	0.000 (yes)
				burn*time	0.000 (yes)
			others	no	
		Tukey Multiple Pairwise Comparison <sup>3</sup>	Time <sub>3</sub> : 5 <sup>d</sup> 6 <sup>d</sup> 1 <sup>d</sup> 2 <sup>d</sup> 3 <sup>ef</sup> 7 <sup>efg</sup> 4 <sup>fg</sup> 8 <sup>g</sup>		
1-year Post-	Treatment Units (TUs)	RmANOVA	Between Subjects <sup>1</sup>	burn	0.000 (yes)
				herbicide	0.026 (yes)

Treatment (T <sub>4</sub> )			Within Subjects <sup>2</sup>	others	no
				time	0.000 (yes)
				burn*time	0.000 (yes)
				others	no
		Tukey Multiple Pairwise Comparison <sup>3</sup>	Time <sub>4</sub> : 1 <sup>h</sup> 2 <sup>h</sup> 6 <sup>h</sup> 5 <sup>h</sup> 3 <sup>h</sup> 7 <sup>h</sup> 4 <sup>h</sup> 8 <sup>i</sup>		
2-year Post- Treatment (T <sub>5</sub> )	Treatment Units (TUs)	RmANOVA	Between Subjects <sup>1</sup>	burn	0.000 (yes)
				herbicide	0.011 (yes)
				others	no
			Within Subjects <sup>2</sup>	time	0.000 (yes)
				burn*time	0.000 (yes)
				herbicide*time	0.015 (yes)
				others	no
		Tukey Multiple Pairwise Comparison <sup>3</sup>	Time <sub>5</sub> : 1 <sup>j</sup> 5 <sup>j</sup> 2 <sup>j</sup> 3 <sup>j</sup> 6 <sup>jk</sup> 4 <sup>jk</sup> 7 <sup>jk</sup> 8 <sup>k</sup>		

<sup>1</sup> Between TUs for all Times; split plots for herbicide treatment.

<sup>2</sup> Between Times for all TUs; split plots for herbicide treatment.

<sup>3</sup> Compare among TUs within the same Time only: TUs with same letter *are not* significantly different ( $P > 0.05$ ); TUs with different letters *are* significantly different ( $P \leq 0.05$ ) for each Time separately. TUs are listed in descending order (largest to smallest) and TUs with the same letter are not significantly different.

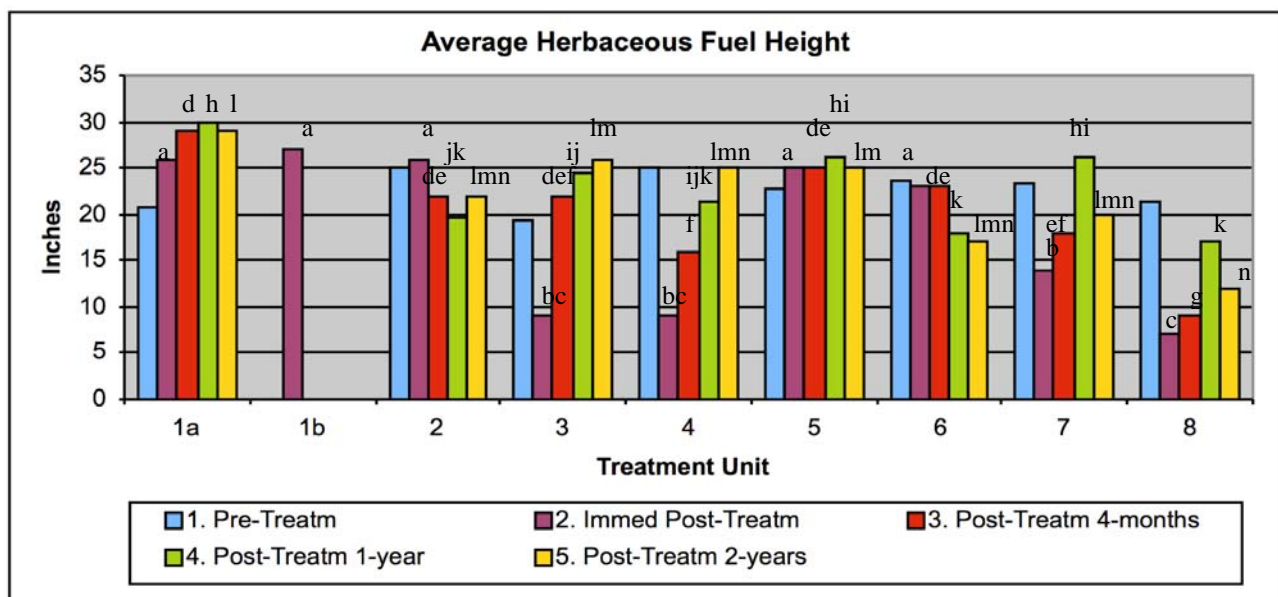
#### *Herbaceous Fuel Load Discussion Summary:*

- The increase in fuel load between January 2004 (pre-treatment) and August 2004 (4-months post-treatment) at the control TUs (#1) indicates there was continual growth of the fountain grass and good growing conditions generally due to the steady precipitation throughout the winter, spring, and summer that year. The drop and then rise in fuel load at the control TUs after the 4-month sampling indicates fluctuations between reduced then better productivity generally between years. Such fluctuation in growing conditions would influence the effectiveness of the treatments in reducing fuel loads.
- The herbicide alone treatment (TU #2) showed the same growth response and no significant reduction of fuel loads compared to the controls (TU #1) at any time since treatment and to the pre-treatment levels (TU #2 at T<sub>1</sub>).
- The dramatic and significant reduction in fuel load in the TUs treated with prescribed burning alone (TU #3) indicates this treatment was effective immediately after treatment (T<sub>2</sub>) through four months later (T<sub>3</sub>) compared to the controls (TU #1) and the herbicide alone treatments (TU #2). But by one year after treatment (T<sub>4</sub>), this effect was no longer significant compared to the controls.
- The apparent increase in fuel load in the TUs treated with cattle grazing alone (TU #5) was *not* significant, and indicates this treatment (as applied) was *not* effective at any time after treatment compared to the controls (TU #1) and the pre-treatment levels (TU #5 at T<sub>1</sub>). Even with the second grazing in 2006, the effect of this treatment was not significant at two years after the start of the study. The cattle grazing alone treatment was not more effective than the herbicide alone treatment (TU #2) and significantly less effective than the prescribed burning alone treatment (TU #3). By one year and two years after the phase one treatments, none of these effects were significantly different from each other or the controls.

- The dramatic and significant reduction in fuel load in the TUs treated with prescribed burning and herbicide (TU #4) and with burning and grazing (TU #7) indicates these treatments (like burning alone—TU #3) were effective immediately after treatment (T<sub>2</sub>) through four months later (T<sub>3</sub>) compared to the controls (TU #1) and the herbicide alone treatments (TU #2), but those effects were reduced to insignificant after one and two years post-treatment. Adding either the herbicide or grazing treatment to the burning treatment did not add significantly to the effect. Adding the second grazing in 2006 did not significantly improve the effect at two years after the start of the study.
- The apparent and delayed increase in fuel load in the TUs treated with cattle grazing followed by herbicide (TU #6) was *not* significant, which indicates this combined treatment was *not* effective at any time after the phase one treatment compared to the controls (TU #1) and the pre-treatment levels (TU #6 at T<sub>1</sub>). Adding the second grazing in 2006 did not significantly improve the effect at two years after initial treatments. This combination was not more effective than either the cattle grazing alone (TU #5) or herbicide alone treatments (TU #2). It was significantly less effective than the prescribed burning alone treatment (TU #3) only at four months after initial treatments.
- The dramatic and significant reduction in fuel load in the TUs treated with prescribed burning, cattle grazing, and herbicide combined (TU #8) indicates this treatment was the most effective of all treatments. It was effective immediately after treatment (T<sub>2</sub>), four months later (T<sub>3</sub>), one year later (T<sub>4</sub>), and two years later (T<sub>5</sub>) compared to the controls (TU #1). This combination was significantly more effective than the prescribed burning alone treatment (TU #3) by four months after treatment (T<sub>3</sub>--but not immediately after treatment, T<sub>2</sub>) and remained so for the remainder of the study. The combination was more effective than the cattle grazing alone (TU #5) and herbicide alone (TU #2) treatments at all times.

### *Herbaceous Fuel Height.*

**Figure 3. Herbaceous Fuel Height.**



**Herbaceous Fuel Height Statistically Significant Differences:**

Variable	Comparison	Test		P	
Pre-Treatment (T <sub>1</sub> )	Blocks and Treatment Units (TUs)	ANOVA	Blocks	0.350 (no)	
			TUs	0.065 (no)	
Immediate Post-Treatment (T <sub>2</sub> )	Treatment Units (TUs)	RmANOVA	Between Subjects <sup>1</sup>	burn	0.000 (yes)
				grazing*herbicide	0.009 (yes)
				others	no
			Within Subjects <sup>2</sup>	time	0.000 (yes)
				burn*time	0.000 (yes)
				herbicide*time	0.048 (yes)
				burn*herb*time	0.035 (yes)
				others	no
		Tukey Multiple Pairwise Comparison <sup>3</sup>	Time <sub>2</sub> : 1 <sup>a</sup> 5 <sup>a</sup> 2 <sup>a</sup> 6 <sup>a</sup> 7 <sup>b</sup> 3 <sup>bc</sup> 4 <sup>bc</sup> 8 <sup>c</sup>		
4-months Post-Treatment (T <sub>3</sub> )	Treatment Units (TUs)	RmANOVA	Between Subjects <sup>1</sup>	burn	0.000 (yes)
				herbicide	0.002 (yes)
				burn*herbicide	0.010 (yes)
				others	no
			Within Subjects <sup>2</sup>	time	0.000 (yes)
				grazing*time	0.001 (yes)
				burn*time	0.000 (yes)
				herbicide*time	0.000 (yes)
				grazing*burn*time	0.001 (yes)
				burn*herbicide*time	0.025 (yes)
				others	no
		Tukey Multiple Pairwise Comparison <sup>3</sup>	Time <sub>3</sub> : 1 <sup>d</sup> 5 <sup>de</sup> 6 <sup>de</sup> 2 <sup>de</sup> 3 <sup>def</sup> 7 <sup>ef</sup> 4 <sup>f</sup> 8 <sup>g</sup>		
1-year Post-Treatment (T <sub>4</sub> )	Treatment Units (TUs)	RmANOVA	Between Subjects <sup>1</sup>	grazing	0.019 (yes)
				burn	0.000 (yes)
				herbicide	0.000 (yes)
				grazing*herbicide	0.008 (yes)
				burn*herbicide	0.039 (yes)
				graz*burn*herbicide	0.007 (yes)
				others	no
			Within Subjects <sup>2</sup>	time	0.000 (yes)
				grazing*time	0.001 (yes)
				burn*time	0.000 (yes)
				herbicide*time	0.000 (yes)
				grazing*burn*time	0.002 (yes)
				burn*herbicide*time	0.000 (yes)
				others	no
		Tukey Multiple Pairwise Comparison <sup>3</sup>	Time <sub>4</sub> : 1 <sup>h</sup> 5 <sup>hi</sup> 7 <sup>hi</sup> 3 <sup>ij</sup> 4 <sup>ijk</sup> 2 <sup>jk</sup> 6 <sup>k</sup> 8 <sup>k</sup>		
		RmANOVA		burn	0.000 (yes)

2-year 2-year Post- Treatment (T <sub>5</sub> )	Treatment Treatment Units (TUs)	RmANOVA	Between Between Subjects <sup>1</sup>	burn	0.000 (yes)
				herbicide	0.000 (yes)
				grazing*herbicide	0.003 (yes)
				burn*graz*herbicid	0.006 (yes)
				others	no
			Within Subjects <sup>2</sup>	time	0.000 (yes)
				burn*time	0.000 (yes)
				grazing*time	0.000 (yes)
				herbicide*time	0.000 (yes)
				others	no
	Tukey Multiple Pairwise Comparison <sup>3</sup>		Times: 1 <sup>l</sup> 3 <sup>lm</sup> 5 <sup>lm</sup> 4 <sup>lmn</sup> 2 <sup>lmn</sup> 6 <sup>lmn</sup> 7 <sup>lmn</sup> 8 <sup>n</sup>		

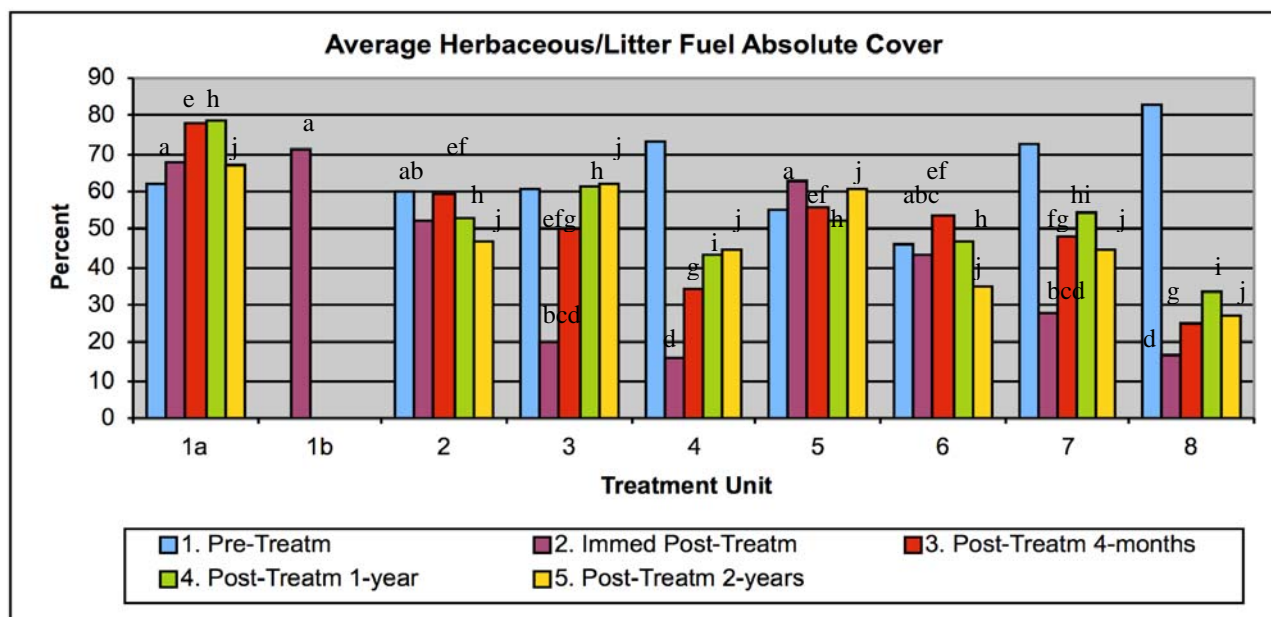
<sup>1</sup> Between TUs for all Times; split plots for herbicide treatment.

<sup>2</sup> Between Times for all TUs; split plots for herbicide treatment.

<sup>3</sup> Compare among TUs within the same Time only: TUs with same letter *are not* significantly different ( $P > 0.05$ ); TUs with different letters *are* significantly different ( $P \leq 0.05$ ) for each Time separately. TUs are listed in descending order (largest to smallest) and TUs with the same letter are not significantly different.

#### Herbaceous Fuel Cover.

**Figure 4. Herbaceous Fuel Cover.**



**Herbaceous Fuel Cover Statistically Significant Differences (Arcsine Transformation of percentage data):**

Variable	Comparison	Test		P	
Pre-Treatment (T <sub>1</sub> )	Blocks and Treatment Units (TUs)	ANOVA	Blocks	0.142 (no)	
			TUs	0.247 (no)	
Immediate Post-Treatment (T <sub>2</sub> )	Treatment Units (TUs)	RmANOVA	Between Subjects <sup>1</sup>	none	
			Within Subjects <sup>2</sup>	time	0.000 (yes)
				burn*time	0.000 (yes)
				herbicide*time	0.008 (yes)
				others	no
		Tukey Multiple Pairwise Comparison <sup>3</sup>	Time <sub>2</sub> : 1 <sup>a</sup> 5 <sup>a</sup> 2 <sup>ab</sup> 6 <sup>abc</sup> 7 <sup>bcd</sup> 3 <sup>bcd</sup> 4 <sup>d</sup> 8 <sup>d</sup>		
		4-months Post-Treatment (T <sub>3</sub> )	Treatment Units (TUs)	RmANOVA	Between Subjects <sup>1</sup>
Within Subjects <sup>2</sup>	time				0.000 (yes)
	burn*time				0.000 (yes)
	herbicide*time				0.000 (yes)
	burn*herbicide*time				0.021 (yes)
others	no				
Tukey Multiple Pairwise Comparison <sup>3</sup>	Time <sub>3</sub> : 1 <sup>a</sup> 6 <sup>ab</sup> 2 <sup>ab</sup> 5 <sup>ab</sup> 3 <sup>abc</sup> 7 <sup>bc</sup> 4 <sup>c</sup> 8 <sup>c</sup>				
1-year Post-Treatment (T <sub>4</sub> )	Treatment Units (TUs)	RmANOVA	Between Subjects <sup>1</sup>	herbicide	0.006 (yes)
			others	no	
			Within Subjects <sup>2</sup>	time	0.000 (yes)
				grazing*time	0.012 (yes)
				burn*time	0.000 (yes)
				herbicide*time	0.000 (yes)
		burn*herbicide*time	0.037 (yes)		
		others	no		
Tukey Multiple Pairwise Comparison <sup>3</sup>	Time <sub>4</sub> : 1 <sup>a</sup> 3 <sup>a</sup> 2 <sup>a</sup> 5 <sup>a</sup> 6 <sup>a</sup> 7 <sup>ab</sup> 4 <sup>b</sup> 8 <sup>b</sup>				
2-year Post-Treatment (T <sub>5</sub> )	Treatment Units (TUs)	RmANOVA	Between Subjects <sup>1</sup>	herbicide	0.003 (yes)
			others	no	
			Within Subjects <sup>2</sup>	time	0.000 (yes)
				burn*time	0.000 (yes)
				grazing*time	0.000 (yes)
				herbicide*time	0.000 (yes)
				burn*grazing*time	0.042 (yes)
		others	no		
		Tukey Multiple Pairwise Comparison <sup>3</sup>	Time <sub>5</sub> : 1 <sup>a</sup> 3 <sup>a</sup> 2 <sup>a</sup> 5 <sup>a</sup> 4 <sup>a</sup> 6 <sup>a</sup> 7 <sup>a</sup> 8 <sup>a</sup> –no differences		

<sup>1</sup> Between TUs for all Times; split plots for herbicide treatment.

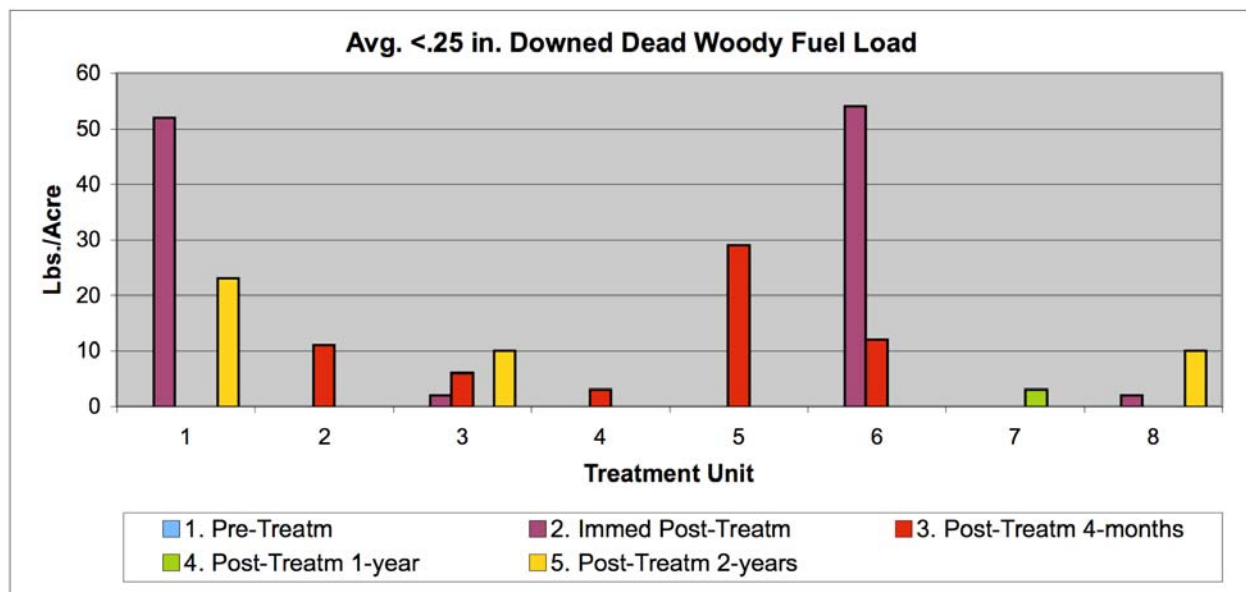
<sup>2</sup> Between Times for all TUs; split plots for herbicide treatment.

<sup>3</sup> Compare among TUs within the same Time only: TUs with same letter *are not* significantly different ( $P > 0.05$ ); TUs with different letters *are* significantly different ( $P \leq 0.05$ ) for each Time separately. TUs are listed in descending order (largest to smallest) and TUs with the same letter are not significantly different.

**Woody Fuels.** The downed dead woody fuel load results for four size classes are shown in Figures 5, 6, 7, and 8. The live woody fuel load results are shown in Figure 9. We determined that both of these sets of results are not reliable because the woody fuels were distributed too broadly and unevenly, with insufficient quantities. These results also do not make sense considering the expected effects on woody loads caused by burning. An entirely different and more costly sampling scheme would have been necessary to effectively sample woody loads in this setting, and the decision to forego such a new method was made with the Principle Investigator early in the project. Therefore the existing woody fuel results are not discussed here, with the exception of the live woody fuels increase in March 2006, which was entirely the result of invasions by two non-native pest plants, tree tobacco (*Nicotiana glauca*) and castor bean (*Ricinus communis*). The latter appeared in herbaceous form immediately after the application of treatments and through the sampling of March 2005. But by March 2006, these plants had matured to tree size with woody stems. Therefore, it was sampled as an herbaceous plant prior to 2006 and as a live woody plant in 2006. See the discussions of these pest plants in the Species Frequency section below.

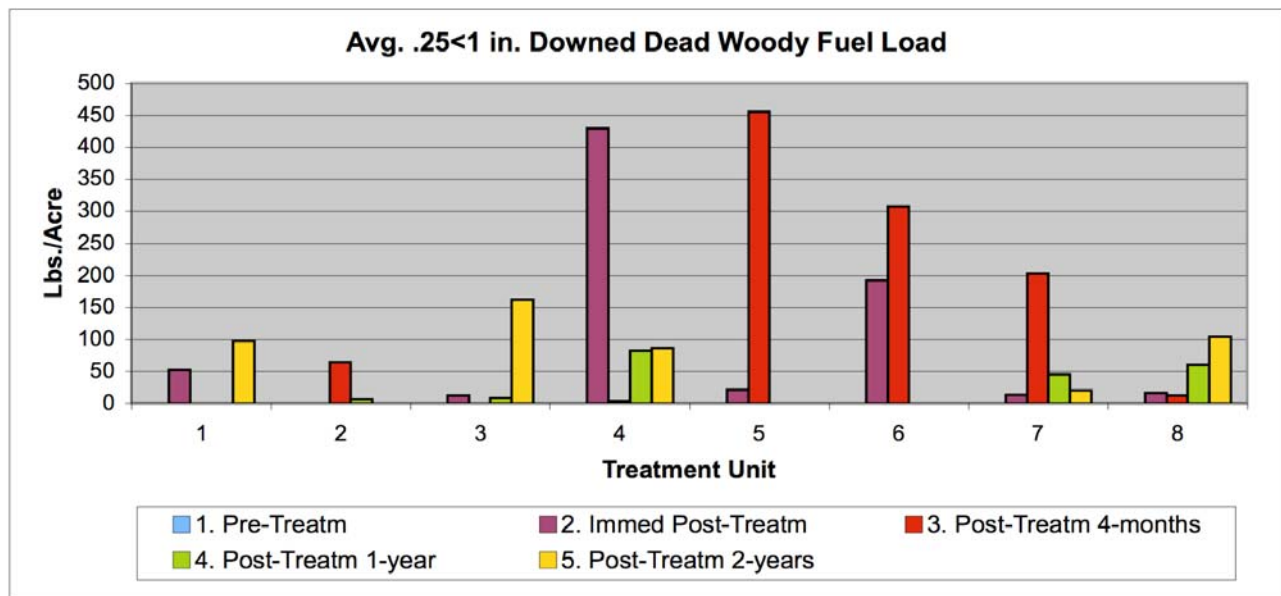
For fuel behavior modeling purposes, the apparent very low amounts of woody fuels indicates such fuels were negligible at the study site during the first through fourth sampling periods of this study. If these woody fuels data are to be used for fire behavior modeling, then we recommend using the fuel amount estimates from the control Treatment Units (TU #1) or averages from the unburned Treatment Units (TUs #1, #2, #5, and #6).

**Figure 5. Downed Dead Woody Fuel Load (<.25 inch diameter).**

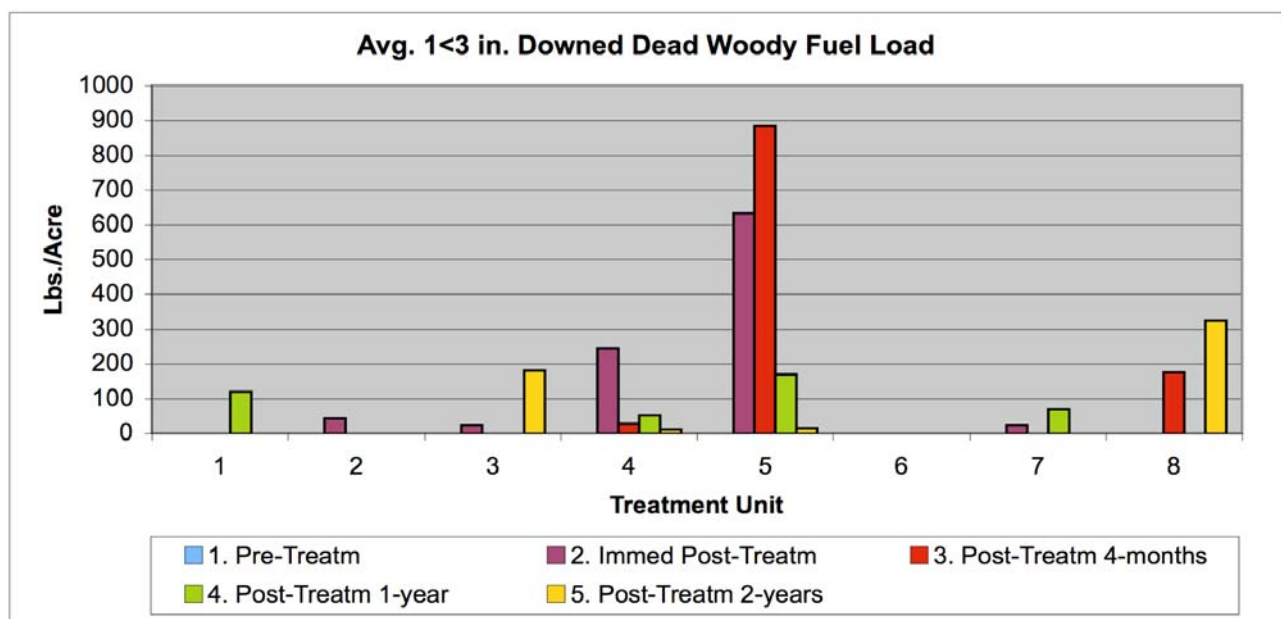




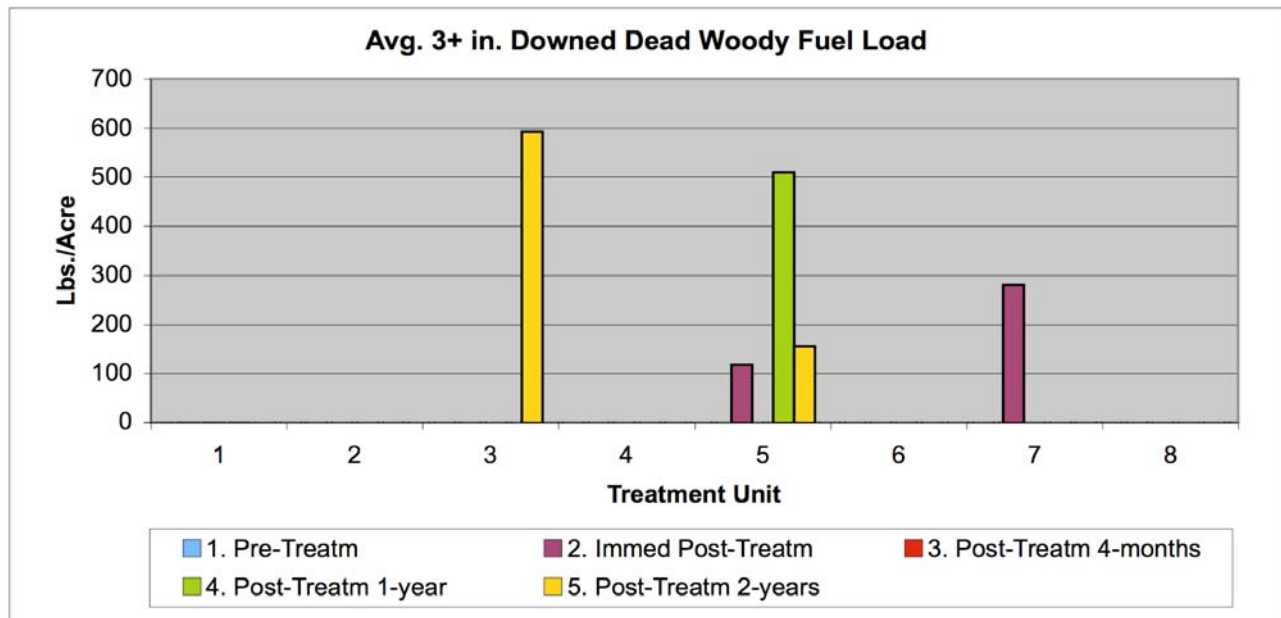
**Figure 6. Downed Dead Woody Fuel Load (.25<1 inch diameter).**



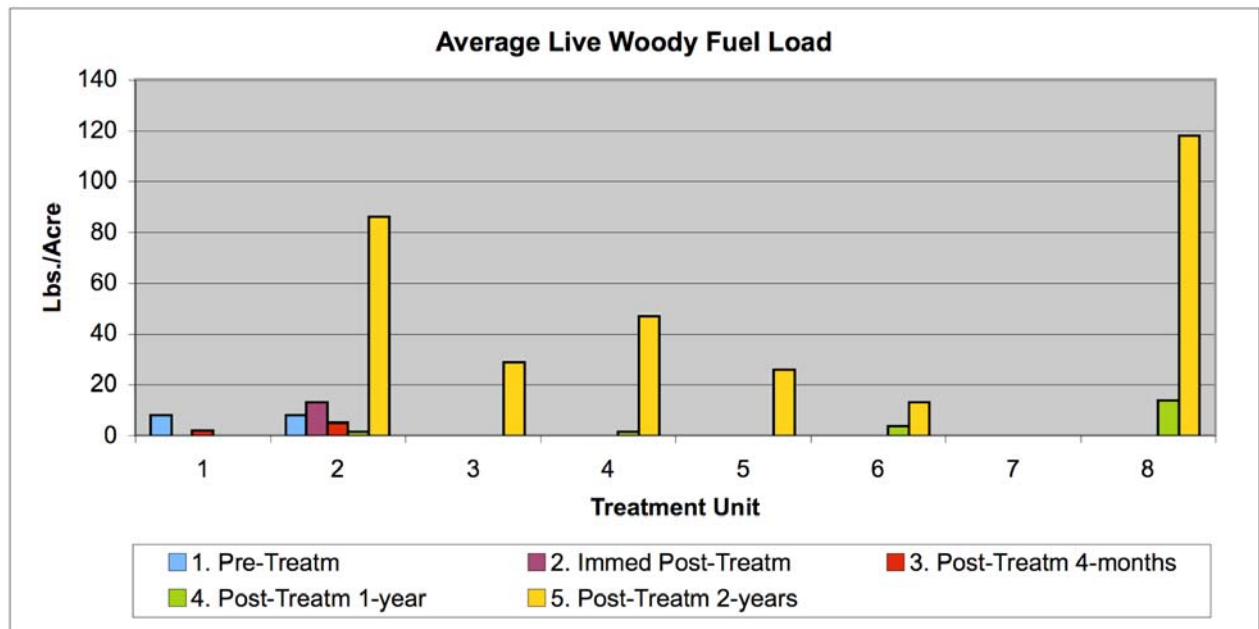
**Figure 7. Downed Dead Woody Fuel Load (1<3 inches diameter).**



**Figure 8. Downed Dead Woody Fuel Load (3+ inches diameter).**



**Figure 9. Live Woody Fuel Load.**



*Species Frequency.* The average frequencies of the herbaceous and live woody species found within the clipping frames in the combined Treatment Units during each sampling period are shown in Tables 4 and 5. No statistical tests or diversity indices were performed. Danielle Frohlich and Mick Castillo confirmed the plant species identifications.

**Table 4. Herbaceous Fuel Species Frequency** (Average Frequency--% occurrence Among 24 Treatment Units--3 replicates of 8 treatment combinations).

Code	Latin Name	Treatment					Affinity <sup>1,2</sup>	Pest <sup>2</sup>
		Pre-	Immed. Post-	4-months	1-year	2-years		
AGCO	<i>Ageratum conyzoides</i>					0.8%	N	x
ASSP	<i>Asclepia sp.</i>				0.8%		N	x
ASTR	<i>Asplenium trichomanes</i>				2.1%	1.7%	I	
BIPI	<i>Bidens pilosa</i>	0.4%		3.8%	6.3%	3.3%	N	x
BRWI	<i>Bromus willdenowii</i>	0.4%					N	
CEER	<i>Centaureum erythraea</i>		3.8%	2.5%			N	
CHCA	<i>Chenopodium carinatum</i>			1.3%	1.3%		N	
CIVU	<i>Cirsium vulgare</i>				0.8%	0.4%	N	?
COTR	<i>Cocculus trilobus</i>		0.8%	0.8%	1.7%	2.1%	I	
DAST	<i>Datura stramonium</i>			0.4%	0.4%		N	x
EMFO	<i>Emilia fosbergii</i>		0.4%		0.4%		N	
GAPA	<i>Galinsoga parviflora</i>	0.4%	0.4%	3.8%	0.4%		N	
GNJA	<i>Gnaphalium japonicum</i>				15.8%	9.6%	N	
HEFO	<i>Helichrysum foetidum</i>					0.4%	N	
LASE	<i>Lactuca serriola</i>		2.1%	0.8%	1.7%	2.1%	N	
LEHY	<i>Lepidium hyssopifolium</i>			2.9%	1.7%	1.3%	N	
MEIN	<i>Melilotis indica</i>		1.7%	0.8%	0.4%	4.2%	N	
MELU	<i>Medicago lupulina</i>					0.4%	N	
MEMI	<i>Melinis miniuiflora</i>	0.8%		4.6%	5.8%	2.5%	N	x
MEPO	<i>Medicago polymorpha</i>		3.3%	5.0%	6.7%		N	
MERE	<i>Melinis repens</i>				1.7%	2.9%	N	x
OXCO	<i>Oxallis</i>	0.4%	2.5%	2.1%	4.2%	0.8%	N	

Code	Latin Name	Treatment					Affinity <sup>1,2</sup>	Pest <sup>2</sup>
		Pre-	Immed. Post-	4-months	1-year	2-years		
	<i>corniculata</i>							
PESE	<i>Pennisetum setaceum</i>	92.5%	95.4%	95.8%	95.8%	95.4%	N	x
PETE1	<i>Pellaea ternifolia</i>				0.8%	0.4%	I	
PETE2	<i>Peperomia tetraphylla</i>					0.4%	I	
PIHI	<i>Picris hieracioides</i>					0.4%	N	
PLPA	<i>Plectranthus parviflorus</i>	0.4%	1.7%	3.3%	5.4%	1.7%	I	
POOC	<i>Portulaca ochraceae</i>				0.4%		?	
POPI	<i>Portulaca pilosa?</i>		0.4%		0.4%		?	
RICO	<i>Ricinus communis</i>		0.8%	5.8%	5.4%	0.8%	N	x
SEMA	<i>Senecio madagascariensis</i>	0.4%	6.7%	26.3%	67.9%	65.0%	N	x
SILA	<i>Sicyos lasiocephalus</i>				0.4%		E	
SOAM	<i>Solanum americanum</i>					0.4%	I?	
SONI	<i>Solanum nigrescens</i>		2.5%	2.1%	2.5%	0.4%	N	
SOOL	<i>Sonchus oleraceus</i>		5.0%	5.8%	21.7%	9.2%	N	
STIC	<i>Sticherus sp.</i>					0.4%	?	
VETH	<i>Verbascum thapsus</i>		1.3%	4.2%	0.8%	0.4%	N	x
WAGR	<i>Wahlenbergia gracilis</i>			0.4%	0.8%		N	
Unknown				0.4%			?	
Unknown				0.4%			?	
Unknown					0.4%		?	
Unknown					0.4%		?	
Species Count		8	16	22	31	26		

<sup>1</sup> Shaw and Castillo 1997: N = Naturalized; I = Indigenous

<sup>2</sup> Motooka et al. 2003: listed as a weed of Hawaii's pastures and natural areas

**Table 5. Live Woody Fuel Species Frequency** (Average Frequency--% occurrence Among 24 Treatment Units--3 replicates of 8 treatment combinations).

Code	Latin Name	Treatment					Affinity <sup>1,2</sup>	Pest <sup>2</sup>
		Pre-	Immed. Post-	4-months	1-year	2-years		
DISA	<i>Diospyros sandwicensis</i>				0.4%		E	
DOVI	<i>Dodonea viscosa</i>					0.8%	I	
LACA	<i>Lantana camara</i>					0.4%	N	x
NIGL	<i>Nicotiana glauca</i>			2.1%	6.3%	5.0%	N	x
OPFI	<i>Opuntia ficus-indica</i>			0.4%			N	
RICO	<i>Ricinus communis</i>					5.0%	N	x
SIFA	<i>Sida fallax</i>			0.4%	3.3%	1.3%	I	
Species Count		0	0	3	3	5		

<sup>1</sup> Shaw and Castillo 1997: N = Naturalized; I = Indigenous; E = Endemic

<sup>2</sup> Motooka et al. 2003: listed as a weed of Hawaii's pastures and natural areas

#### *Species Frequency Discussion Summary:*

- The total number of herbaceous plant species found (in recognizable form) during the study increased from eight before treatment, to 16 immediately after the treatments, to 22 four months after the treatments, to 31 one year following the treatments, and then reduced to 26 two years after treatments. A total of 42 herbaceous plants have been found in at least one sampling period. There were no live woody species found before or immediately after treatment. Three live woody plant species appeared only after four months and one year; five live woody plants were present after two years.
- Three woody and seven herbaceous indigenous plants have been found within the fuels sampling frames for this study. The indigenous plants generally were not found prior to or immediately after treatments, but appeared gradually up to two years after treatment. None of the indigenous species have disappeared, but their frequencies are not generally increasing. The rest (35 herbaceous and four woody plants) are naturalized non-natives.
- Three woody and ten herbaceous non-native plants are considered pests. They have contributed to a shift in species composition and structure of the fuels, and thus in potential fire behavior. This is occurring particularly in the TUs treated with herbicide, which were invaded dramatically by tree tobacco (*Nicotiana glauca*), castor bean (*Ricinus communis*), and fire weed (*Senecio madagascariensis*) by one year after treatment.
- The increasing trend in species richness appeared to level off by the second year.

*Pest Plant Invasions.* Tree tobacco, castor bean, and fire weed have made steady and dramatic advances into the study area during the study period. The first two now dominate the patchy

woody canopy of some Treatment Units, and thus pose the added fire fuel load of a live woody fuel. Tree tobacco is known as an annual or small tree pest throughout the U.S., Mexico, and the African continent. It has been moving toward the study area since before the study began. It first appeared in this study in August 2004, four months after treatments, and has maintained an average frequency of about 5% of samples per TU overall. It was found in all three blocks, but only where herbicide was applied (TUs #2,4,6, and 8). Its greatest frequencies were in the TUs where all three treatments were applied in combination (TU #8). This suggests that tree tobacco seeds were available throughout the study area for invasion upon opening of the herbaceous canopy, and the established plants are able to persist after recovery of the herbaceous canopy to pre-treatment levels. The greatest risk of tree tobacco invasion is with herbicide application. It also suggests that absence of treatments did not allow invasion. Tree tobacco is seriously toxic to livestock.

Castor bean appeared in the study area in the first post-treatment sampling (May 2004), and has maintained an average frequency of about 5% of samples per TU overall. It was found in Block #1 only (TUs 2,3,4, and 5), which suggests that a source population was present only there and invasion was enabled by the opening of the herbaceous canopy (by either herbicides, burning, or grazing alone or in combinations). Its greatest frequencies since August 2004 were in TUs 2 and 4, both of which included herbicide applications, which suggests a greater risk of invasion with that treatment. Castor bean is highly toxic.

Fire weed was present in the study in only one treatment unit prior to application of the treatments. It appeared in gradually increasing numbers of samples and TUs with time since treatments. By March 2005, it was present in all TUs. Frequencies have escalated from an average of about 5% in February 2004 to 25% in August 2004 to 65% of samples in each TU in March 2005 and that frequency persisted to March 2006. This suggests that fire weed seeds were available throughout the study area for invasion upon opening of the herbaceous canopy, and the established plants are able to reproduce and persist in all treatments, including those TU's where the herbaceous canopy recovered to pre-treatment levels as well as in the control units. Its greatest frequencies since August 2004 were in TUs treated with both burning and herbicide (TUs #4 and 8), although they reached high frequencies in all other treatments and moderate frequencies in the control units.

*Substrate.* Two sources were used to estimate the substrate age and corresponding plant growth classes between the Treatment Units—qualitative observations of substrate texture; and the lava flow maps of geologists Wolfe and Morris (1996). Table 6 shows the correspondence between the blocks (replicates), Treatment Units, and mapped lava flows. Table 7 shows the results of a survey of substrate texture at each Sample Point in the fuels sampling areas. Table 8 shows the survey results with corresponding herbaceous fuel loads during the pre-treatment sampling period and summary statistics. These results were used in statistical comparisons of the Treatment Units and replicates (see Section 3 above). As noted, no significant differences between the Treatment Units were detected.

**Table 6. Substrate Age (based on the lava flow maps of Wolfe and Morris [1996]).**

Block	Treatment Unit	Younger ----- Older			
		k3	k2	k1y	k1o/h1o
1	1				x
1	2	x			x
1	3	x			x
1	4	x			x
1	5	x			x
1	6	x			x
1	7	x			x
1	8			x	
2	1			x	
2	2			x	
2	3			x	
2	4			x	
2	5			x	
2	6			x	
2	7			x	
2	8			x	x
3	1			x	x
3	2			x	
3	3			x	x
3	4			x	
3	5			x	
3	6			x	
3	7			x	
3	8			x	x



**Table 7. Substrate Texture and Inferred Age (Qualitative Observations May and August 2004).**

Block	Treatment Unit	Younger ----- Older			
		Rock	Rock with Soil Interspersed	Soil with Rock Interspersed	Fine Sediment/Soil
1	1		x		
1	2			x	
1	3			x	
1	4	x			
1	5		x		
1	6	x			
1	7		x		
1	8		x		
2	1	x			
2	2	x			
2	3	x			
2	4	x			
2	5		x		
2	6	x			
2	7		x		
2	8		x		
3	1			x	
3	2	x			
3	3			x	
3	4	x			
3	5	x			
3	6	x			
3	7		x		
3	8			x	

**Table 8. Surface Texture Survey and Correspondence to Pre-Treatment Fuel Loads\***

Jan 2004 Pre-Treatment Herbaceous Fuels Results Summary

Block	TU	Avg. Fuel Load (lbs/acre)	Avg. Height (inches)	Avg. Absolute Cover (%)	Statistic	Avg. Fuel Load (lbs/acre)	Avg. Height (inches)	Avg. Absolute Cover (%)
1	1	8,698	20	80	A			
1	2	10,970	24	89	Mean	7,860	24	53
1	3	12,793	20	73	SD	3,661	3	18
1	4	14,427	24	78	SEM	1,103.7	0.9	5.4
1	5	6,563	20	50	UpperCL	10,023.5	25.5	63.8
1	6	10,672	26	71	LowerCL	5,696.9	21.9	42.7
1	7	9,201	23	65				
1	8	11,209	21	78	B			
2	1	5,536	21	46	Mean	10,499	22	72
2	2	3,942	22	29	SD	2,636	2	11
2	3	7,185	20	42	SEM	931.9	0.7	3.9
2	4	12,268	22	72	UpperCL	12,325.8	23.4	79.2
2	5	8,535	24	68	LowerCL	8,672.8	20.8	64.0
2	6	3,943	22	34				
2	7	12,480	22	72	C			
2	8	13,541	22	81	Mean	10,312	21	76
3	1	7,158	22	61	SD	2,152	2	13
3	2	7,480	28	64	SEM	962.4	1.0	5.7
3	3	9,321	18	68	UpperCL	12,197.8	23.1	87.2
3	4	10,385	29	69	LowerCL	8,425.3	19.3	64.8
3	5	7,249	24	49				
3	6	3,376	23	34				
3	7	13,766	25	82				
3	8	11,315	21	90				

**Re-arranged by Age Class**

Block	TU	Avg. Fuel Load (lbs/acre)	Avg. Height (inches)	Avg. Absolute Cover (%)
1	4	14,427	24	78
1	6	10,672	26	71
2	1	5,536	21	46
2	2	3,942	22	29
2	3	7,185	20	42
2	4	12,268	22	72
2	6	3,943	22	34
3	2	7,480	28	64
3	4	10,385	29	69
3	5	7,249	24	49
3	6	3,376	23	34
1	1	8,698	20	80
1	5	6,563	20	50
1	7	9,201	23	65
1	8	11,209	21	78
2	5	8,535	24	68
2	7	12,480	22	72
2	8	13,541	22	81
3	7	13,766	25	82
1	2	10,970	24	89
1	3	12,793	20	73
3	1	7,158	22	61
3	3	9,321	18	68
3	8	11,315	21	90

\*Qualitative Observations of Age Class--May and August 2004

A	Rock	Younger	Younger
B	Rock with Soil		
C	Soil with Rocks		Older

## 6. Summary Conclusions

Representative repeat photographs of Blocks #2-3 of the study area are shown in Appendix B.

*Herbaceous Fuel Load.* The most effective fuel load control treatment was prescribed burning (TU #3 and #8). The herbicide alone treatment (TU #2) and cattle grazing alone treatment (TU #5) were *not* effective and adding either the herbicide treatment (TU #4) or grazing treatment (TU #7) to the burning treatment did *not* add significantly to the effect. Adding the second grazing treatment in 2006 did not significantly improve the effects. Adding herbicide to grazing (TU #6) was no more effective than herbicide alone (TU #2). Only the combination treatments of burning with both cattle grazing and herbicide (TU #8) was significantly more effective than burning alone (TU #3), and the effect persisted through all sampling times. By one year after treatment, the fuel loads in the burn alone treatments (TU #3) had recovered to control levels.

*Woody Fuels.* The downed dead woody and live woody fuel loads were distributed very broadly and unevenly, with insufficient quantities for the sampling results to be reliable. Therefore woody results were neither analyzed nor discussed here. Live woody fuels increase dramatically by March 2006, entirely the result of invasions by two non-native pest plants, tree tobacco (*Nicotiana glauca*) and castor bean (*Ricinus communis*).

*Species Richness.* The total number of herbaceous plant species found (in recognizable form) during the study increased from eight before treatment to 31 species one year after the initial treatments, and then 26 species two years after the initial treatments. A total of 42 herbaceous plants were found during at least one sampling period. The total number of live woody species found increased from zero to three species after four months and one year, then increased to five species by two years after the initial treatments. Of these, seven herbaceous and three woody indigenous plants were found by two years after the initial treatments, all of which appeared to be increasing.

*Pest Plant Invasions.* Three woody and ten herbaceous pest plants were found among the naturalized non-natives and all were increasing in frequency by two years after the initial treatments. Tree tobacco, castor bean, and fire weed have made steady and dramatic advances into the study area during the study period. The first two now dominate the patchy woody canopy of some Treatment Units, and thus pose the added fire fuel load of a live woody fuel. These results suggest that tree tobacco seeds were available throughout the study area for invasion upon opening of the herbaceous canopy, and the established plants are able to persist after recovery of the herbaceous canopy to pre-treatment levels. The greatest risk of tree tobacco invasion is with herbicide application, and the least risk is with applying no treatments.

*Treatment Effectiveness.* This study demonstrated that single applications of burning, cattle grazing, and herbicide caused different responses in the herbaceous fuel loads. Annual weather, and the resulting growth and decay of herbaceous phytomass probably had a significant effect on the results observed. Of all the treatments, burning was the

most effective to reduce fuel loads, but this control effect persisted longest with a combination with grazing and herbicide applications. The main fuel component, fountain grass was killed by herbicides and burning, but not thoroughly, and the grass cover returned by regenerating from the perennial bunches or from seed germination after all three treatments, alone or in combination. Burning was least selective and most effective in actually reducing the total fuel load significantly. With practice, and better timing of the burning to coincide with less initial fuel moisture, this treatment could probably be more effective in killing fountain grass plants and seeds, and its effects more persistent.

Herbicide treatments killed the standing phytomass, but left it standing as potential fire fuel through the time of regrowth. Herbicide treatments were probably effective in combination with the other two by killing plants that had been reduced in vigor and viability by the prior burning and grazing. The herbicide alone and combined treatments also opened up the herbaceous canopy best for invasion by the three main pest plants.

The grazing treatments were patchy, and even after a second application in 2006, not effective in reducing overall fuel loads. Grazing on a continuous or short rotation basis, especially after a forage “conditioning” burning treatment would probably be more effective at maintaining a reduced total fuel load. Because cattle herds become familiar with a site over time, continuous grazing with a dedicated cow-calf herd would probably also result in more uniform reduction of fuel loads. The grazing effects of the feral goats and sheep was not studied, but did not appear to be significant, with the notable exception of Block #2-3 TU #8, where these animals were frequently observed and the grazing effects most evident. However, because the terrain was most gentle there, the cattle grazing was probably most uniform.

*Recommendations.* Considering the treatments examined here to reduce fire hazards, I offer the following fuel management recommendations:

- These results suggest an efficient method to maintain a reduced fuel load in a band of fountain grass sites along the drier Mamalahoa Highway--“condition” the forage with a burning treatment and follow with continuous cattle grazing.
- Miles Nakahara stated it succinctly<sup>1</sup>—grazing is the most friendly; it can be adjusted so the fountain grass is reduced, but not cleared (thus reducing pest invasions); and it can be used continuously in contrast to burning and herbicide treatments, which are expensive.
- Repeated herbicide treatments would be most effective as currently used at sites of fire breaks in combination with repeated cutting where the burning and grazing treatments are not feasible.
- The serious problem of pest plant infestations, especially the woody tree tobacco and castor bean, could be reduced by avoiding the broad herbicide applications and triple combination treatments.
- To increase the abundance and persistence of native woody species in this area, it appears that burning and spot herbicide treatments would be effective in opening up the dense herbaceous canopy for selected plantings of desired woody species at

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<sup>1</sup> Personal communication, February 2, 2006; Mr. Nakahara is a Co-Principle Investigator on this research and Wildlife Biologist, Division of Forestry and Wildlife, State of HI, Kamuela, HI.

appropriate sites, followed by regular herbicide or manual clearing of the inevitable invasions of pest plants.

*Additional Research.* Further study is needed to assess:

- The level and heterogeneity of the herbaceous fuels that would effectively reduce wildfire risk.
- The effects of the hypothesized repeated and concentrated grazing on the fuel loads and woody plants.
- The relative contributions of standing live, standing dead, and fallen dead fountain grass to fire fuel loads.
- The relative contributions of the invading woody pest plants to fire hazards and fire behavior.
- The relative contributions of feral goat and sheep grazing in reduction of fuel loads.
- The effectiveness of the hypothesized “conditioning” burning treatments on fountain grass palatability to cattle and feral sheep and goats, and on grass growth.
- The results of varying stocking rates, grazing systems, and stocking density on forage quality and fuel load reduction.

## **Literature Cited**

- Castillo, J.M. 2001. “Effects of prescribed grazing and burning treatments on fire regimes in alien grass-dominated wildland-urban interface areas, Leeward Hawaii.” Proposal by the U.S.D.I. Fish and Wildlife Service, Ecological Services, Pacific Islands Office to the Joint Fire Science Program (RFP 2001-3), submitted to B. Clark, National Interagency Fire Center, April 23, 2001.
- Castillo, J.M. 2004. “Research in the use of burning, grazing, and herbicide in reducing wildfire hazard in Hawaii: the Puuanahulu Wildfire Management Study.” Presentation to the California-Pacific Section of the Society for Range Management fall meeting, November 10, 2004, Kailua-Kona, Hawaii.
- Motooka, P., L. Castro, D. Nelson, G. Nagai, and L. Ching. 2003. Weeds of Hawai’i’s pastures and natural areas. College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa. 184p.
- Shaw, R.B. and J.M. Castillo. 1997. “Plant communities of Pohakuloa Training Area, Hawaii.” Center for Ecological Management of Military Lands, Department of Forest Sciences, Colorado State University.
- Wolfe, E.W. and J. Morris. 1996. Geologic map of the Island of Hawaii. U.S.D.I. Geological Survey.

## APPENDIX A. FUELS AND VEGETATION SAMPLING PROCEDURES

### Puuanahulu Fuels Management Study Fuels and Vegetation Sampling Component

L. Ford (Revised March 17, 2006)

#### SUMMARY

##### Steps:

1. Located Treatment Unit and navigated to the designated Sample Points while minimizing traffic damage and avoid restricted areas.
2. Referred to TU Field Maps.
3. Took measurements, re-labeled the Sample Points (if needed), took notes, and completed field data forms at each Sample Point.
4. Collected and weighed the fuel moisture sub-samples (tared to remove bag weight), and protected them during field day; then stored in a cool dry place; transported the samples to the lab for oven-drying, then *post*-oven weighing (and recording on lab data forms).
5. Before leaving the field or lab at the end of each day, reviewed data forms to assure completion; the original data forms are in the possession of Larry Ford.
6. Processed and analyzed the data, and produced reports.

**Table 1. Variables and Measures**

<i>Variable</i>	<b>Treatment Units Sampled</b>	<b>Number Samples Per TU</b>	<b>Measurement Method</b>	<b>Units of Measure</b>
Herbaceous Fuels (plus non-woody litter)	3 reps x 8 = 24	10	Herbaceous and non-woody litter biomass clipped from one-square-meter frame and weighed in field bag (field weight; tared); separated grasses from forbs in Feb/Mar 06; discard	Avg. height (inches); absolute cover (%); species list; grams (field weight) ~ lbs (tons)/acre
		4 Moisture sub-samples	Representative sub-sample (of clippings) transferred to paper bags, labeled, sealed, weighed in field, saved and later dried in lab oven; separated grasses from forbs in Feb/Mar 06	Grams ( <i>field</i> - and <i>post</i> -drying avg. weight) ~ % moisture (to interpolate oven-dry weights of larger samples)
Downed Dead Woody Fuel	3 reps x 8 = 24	Up to 10	Collect dead woody fuel within 1-square-meter frame—separate by size <0.25 inch, 0.25-<1 inch, 1-<3 inches, and 3+ inches; weigh in field bag (field weight; tared); discard	grams (field weight) ~ Lbs (tons)/acre for each size class (no species distinctions)
		Moisture	Representative sub-sample (of	Grams ( <i>field</i> - and

		sub-samples for each	cuttings) transferred to paper bags, labeled, sealed, weighed in field, saved and later dried in lab oven	<i>post</i> -drying avg. weight) ~ % moisture (to interpolate oven-dry weights of larger samples)
Standing Live Woody Fuel	3 reps x 8 = 24	Up to 10	Collect live woody fuel within 1-square-meter frame—only <0.25 inch stems and foliage; weigh in field bag (field weight; tared); discard	Species list; grams (field weight) ~ Lbs (tons)/acre (no species distinctions)
		Moisture sub-samples for each	Representative sub-sample (of cuttings) transferred to paper bags, labeled, sealed, weighed in field, saved and later dried in lab oven	Grams ( <i>field</i> - and <i>post</i> -drying avg. weight) ~ % moisture (to interpolate oven-dry weights of larger samples)

## PROCEDURES

**Sample Location:** Sample Points were selected in advance by Larry Ford to reflect representativeness of the vegetation and terrain, avoidance of traffic damage and restricted areas, and minimal bias (refer to the Treatment Unit Field Maps). Each Treatment Unit (TU) was subdivided on a map into quarters (NW, NE, SE, SW) of relatively equal size and the Sample Points were distributed proportionately within each quarter. The Sample Points for each TU were identified randomly (using a random number generator) from a mapped grid of approximately 10 meter<sup>2</sup> cells over each TU, and was used as the sampling center point during all subsequent sampling periods. The herbaceous fuel (plus non-woody litter) clipping frames were located randomly (in the same compass direction for each Sampling Period) near each Sample Point in a location that did not overlap prior clipping areas due to the potential effects of destructive sampling. The clipping frames were thus used to sample a different place each Sampling Period. The dead downed woody and live woody samples were taken from within the location of the sampling frame for herbaceous fuels.

**Sample Area Avoidance Rules:** Sample locations were selected to avoid:

- The pie-shaped viewing areas for the Forest Service photographic study
- Peripheral zones of 5 meters width inside the unit boundaries (to avoid edge effects and potential effects of the site preparations)
- Locations that were destructively sampled or trampled excessively by any study investigators during prior visits.
- Sampling areas of other investigators

In general the samplers avoided traffic damage to the vegetation within the TUs. This minimized sampling impacts on the study subjects and any study structures of other investigators as well as the fuel samplers. This also minimized sampling in areas potentially affected by the site preparations (e.g. TU layout, fire break clearing), treatment applications (e.g. prescribed burner traffic, equipment use, fencing construction, cattle herding), and “edge” effects (e.g. blown-in seeds, animal forays from untreated vegetation). When the samplers used their sampling equipment and traversed the sampling area, they minimized traffic. Also the samplers avoided the areas around trees within the burn treatment areas that had been cleared as a site preparation.

**Sample Point Identification:** All the planned Sample Points were marked (approximate location in a grid) on the map for reference by the samplers before entering the TU. The locations were identified with GPS coordinates during the first sampling periods, and subsequently relocated using those GPS coordinates and corrected as necessary. Using the maps (and GPS), the samplers walked to the Sample Points systematically to avoid trampling generally and the restricted areas specifically. During the first sampling (*pre-treatment*) the samplers identified and marked the center of the Sample Point. From the approximate Sample Point, one sampler faced the randomly selected compass direction (for each Sampling Period), and gently tossed a flagged marker over his shoulder. The landing place of the marker (or directly beneath it on the ground, if caught in vegetation) became the center point for the sampling frame. If the location selected in this manner was on an un-vegetated surface, it was accepted, and measurements proceeded. If it was within an area designated for avoidance, then the process was repeated or the location was shifted in a randomly selected alternative compass direction at least one meter outside the area designated for avoidance. Sampling of variables then proceeded as described in Table 1 above.

**Sample Area Marking for Re-location:** The samplers marked the locations of the Sample Points with orange spray painted dots, orange flagging tape on rocks, and aluminum labels (with Block#, Treatment Unit#, and Sample#). Upon revisiting the Sample Points during each Sample Period, the samplers re-marked and labeled the site as needed.

**Post-Treatment Sampling:** The sampling during the four *post-treatment* periods occurred at the same Sample Points as determined and sampled during the first (*pre-treatment*) period. The only change in procedures was the location of clipping and measurements around the Sample Points. Each subsequent herbaceous fuel clipping occurred at adjacent places according to the randomly selected compass direction. The samplers consulted their records and searched the ground for piles of previous clippings to assure that a subsequent sample was not taken in the same place as a previous sample.

**Treatment Unit Field Maps:** Field maps of each TU were used during each Sampling Period to identify sampling locations and make notations.

**Fuel Moisture Sub-Sample Processing:** The sealed and labeled bags of herbaceous and woody fuel moisture sub-samples were protected from moisture and heat during the



sampling and in transport to the drying lab. Labels indicated the source Block#, TU#, Sample Point#, and date of collection. The sealed bags were transported to a central storage location at the end of each Sampling Period. Because fluctuating weather could cause significant shifts in fuel moisture in the field during and between sampling sessions, care was taken to collect all samples and sub-samples within a TU at times as close together as possible.

In the field, the sealed bags were weighed and recorded to insure against future damage or loss of data as well as changes in moisture within the containers. The samples were oven-dried at the lab for up to 48 hours @ 158°F. After oven-drying, the bags were re-weighed. To account for the weight of the empty paper sub-sample bags, an empty bag was weighed each sampling day and during post-drying weighing to tare the scale to yield net field and oven-dry content weights. The resulting average percentage drop in weights of the sample (contents without bag) from field to oven-dry for each sampling day was used to compute dry biomass of fuel samples taken in each TU.

### **Materials and Equipment Used:**

- Sampling—compass, 2-meter small measuring tape, one-meter-square PVC tube clipping frame, clippers, field Pesola scales (5kg for herbaceous samples, 2500g for live and dead woody samples, and 300g for herbaceous and woody fuel moisture sub-samples), nylon fuel weighing bags (large for herbaceous samples, mid-size for woody samples), wood cutting saw, supply of lunch-size paper bags for fuel moisture sub-samples, supply of aluminum labels, supplies of flagging tape and red spray paint, field maps of each TU, Field Data Forms, black Sharpie marking pen, pencils, rain coverings, plant voucher reference book, repair tool kit, GPS (loaded with study coordinates), and cell phone.
- Storage and Drying—secure warehouse for storage, lab scale, secure oven-drying facility, Lab Data Forms, pencils

**Data Forms and Records:** Field and Lab Data forms were provided for recording. At the study site, assignments of clipping, measuring, and recording were repeated to maintain consistency and avoid errors associated with changing roles. The entire data form was filled-in. After sampling at each Sample Point and at the end of the sampling day, the data recorder reviewed the Field Data Forms to assure completion before leaving the study area. In the drying lab, one person performed all tasks--running the drying oven, weighing the samples, recording data, and processing the bags. At the end of each fuel moisture sub-sample drying, that person reviewed the Lab Data Forms to assure completion before leaving the lab.

A complete set of the *original* data forms and other notes was delivered to Larry Ford at the end of each Sampling and Drying Period. Larry Ford processed the data upon receipt, communicated with the sampling and drying teams as needed, and summarized results following the completion of the Sampling Period.

**Supplementary Photographs:** Larry Ford took digital photographs of each Treatment Unit at the end of each Sampling Period. The photographs display representative views of each Treatment Unit for reference by the study investigators and to illustrate study results. He made these photos available by email or CD upon request.

## APPENDIX B. REPRESENTATIVE REPEAT PHOTOGRAHS

**Block #3, TUs #1-4**

May 27, 2004



August 7, 2004



March 20, 2005



March 2, 2006





**Block #2-3, TUs #5-8**  
May 27, 2004



August 7, 2004



March 20, 2005



March 2, 2006



Appendix C. Photographic Plates Showing Changes in Fuel Loading Following the Application of Treatments in Jan-May, 2004.

# **Effects of Prescribed Grazing and Burning Treatments on Fire Regimes in Alien Grass-dominated Wildland-Urban Interface Areas, Leeward Hawaii.**

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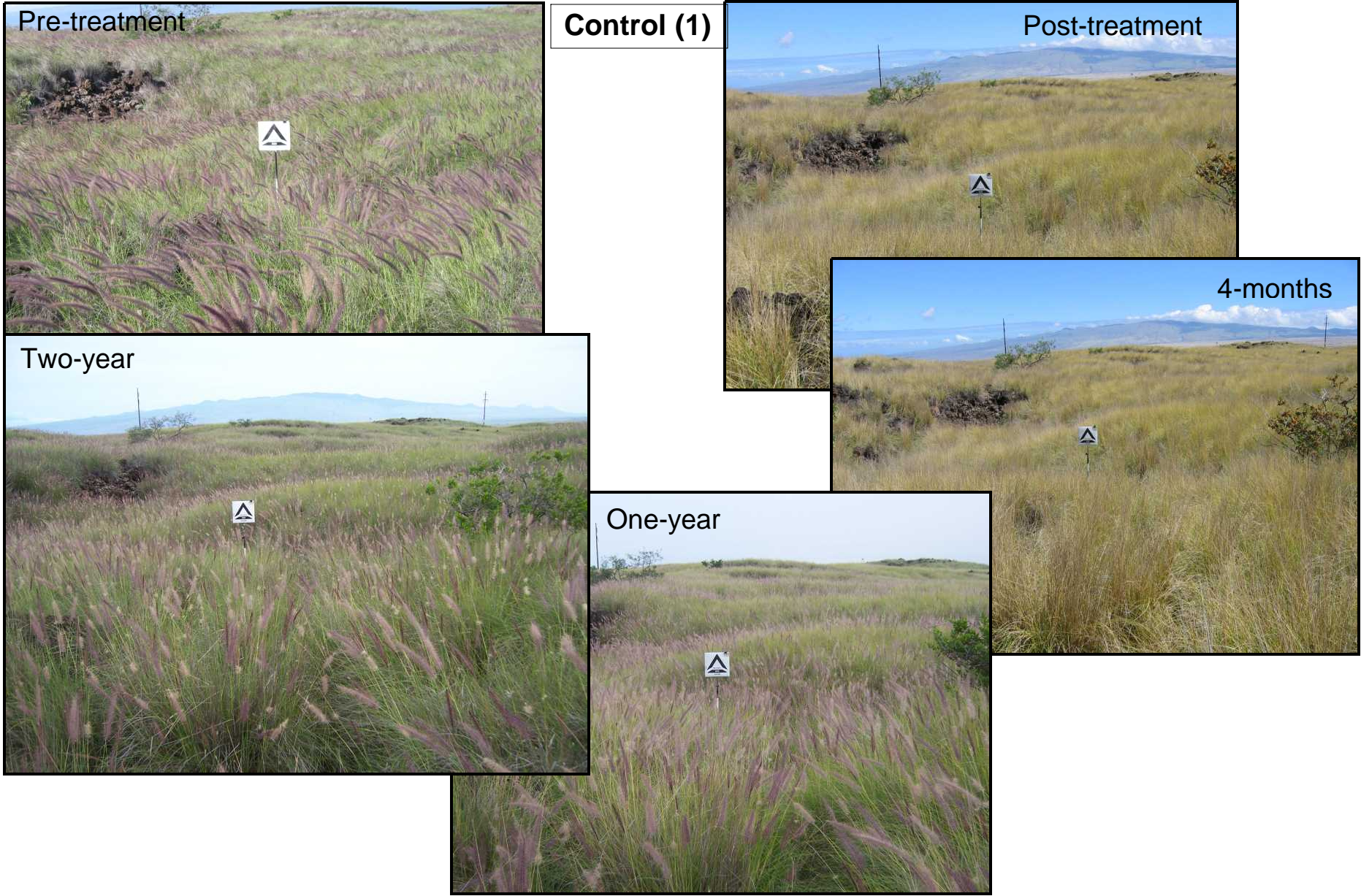
**Final Report to the Joint Fire Science Program**

Project No. 01-3-4-14

## **APPENDIX C: Photographic Plates**



**APPENDIX B.** Photographic plates showing changes in fuel loading for each of 8 treatments applied in Puu Anahulu, Hawai‘i, in Jan – May, 2004-2006.



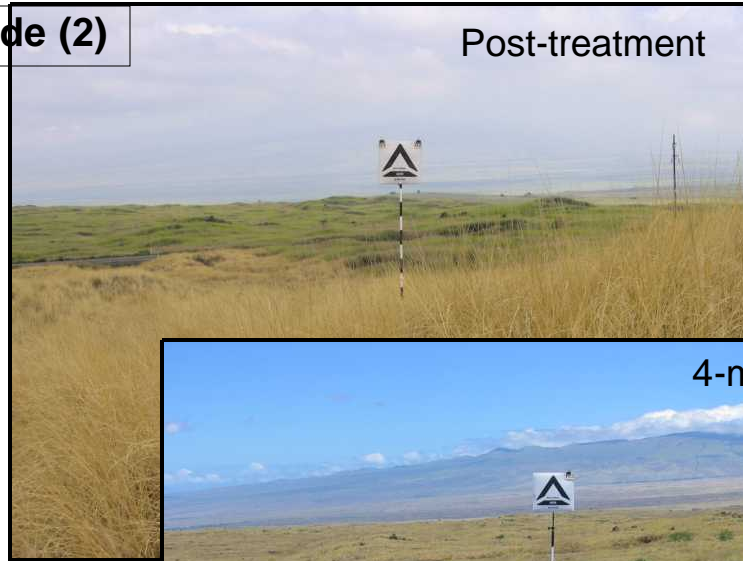


Herbicide (2)

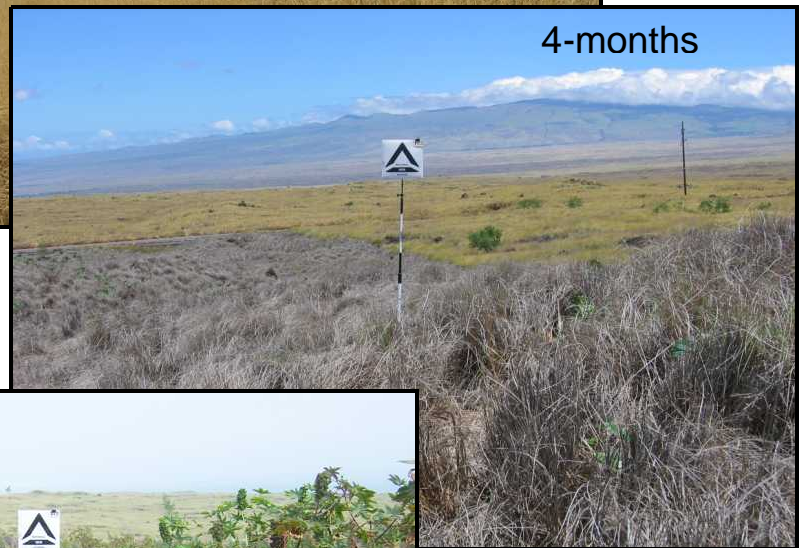
Pre-treatment



Post-treatment



4-months



Two-year



One-year





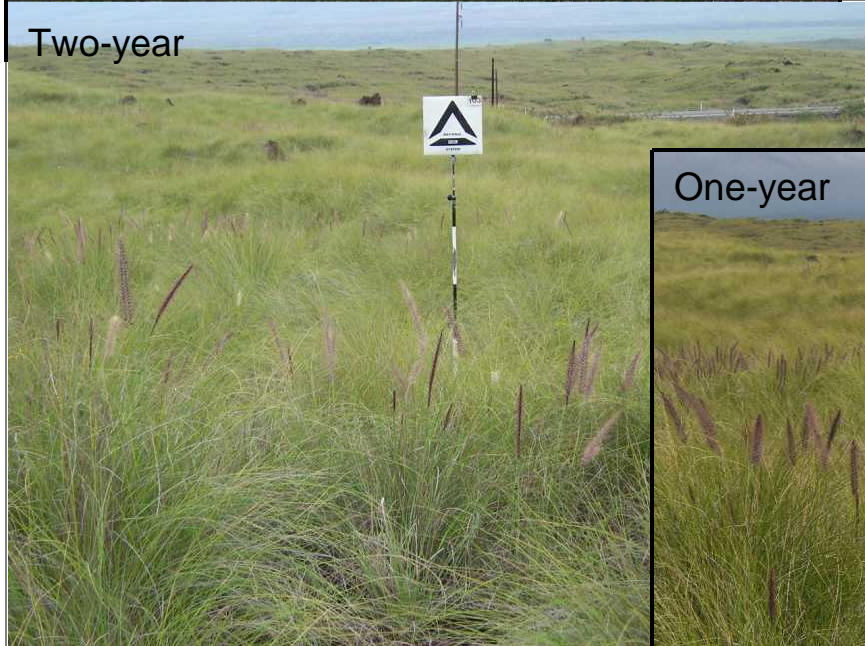
Pre-treatment

Burn (3)

Post-treatment



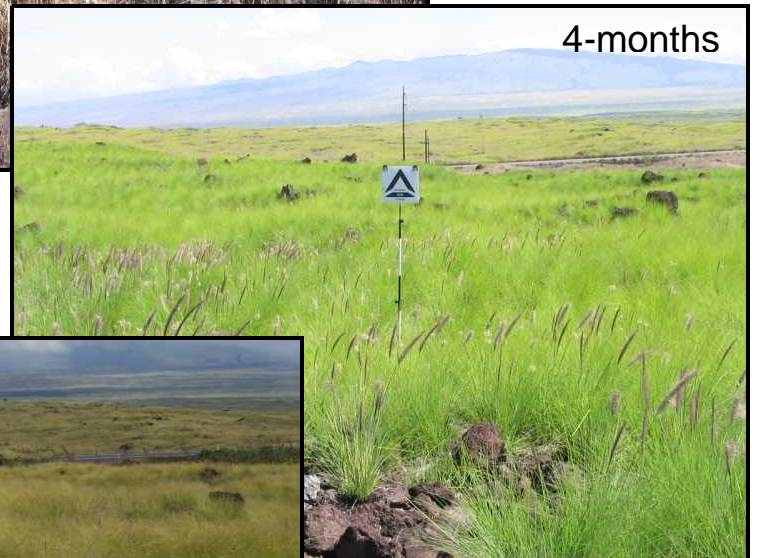
Two-year



One-year



4-months



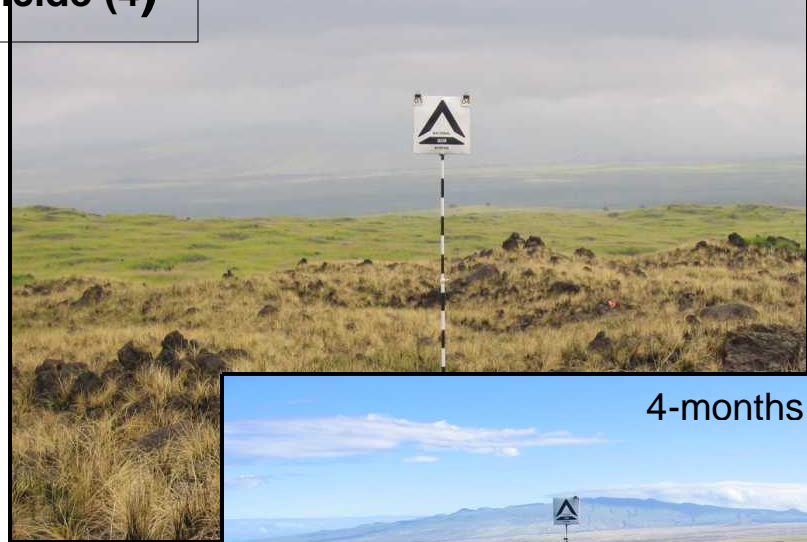


Pre-treatment



Burn & Herbicide (4)

Post-treatment



Two-year



One-year



4-months





Pre-treatment



Graze (5)

Post-treatment



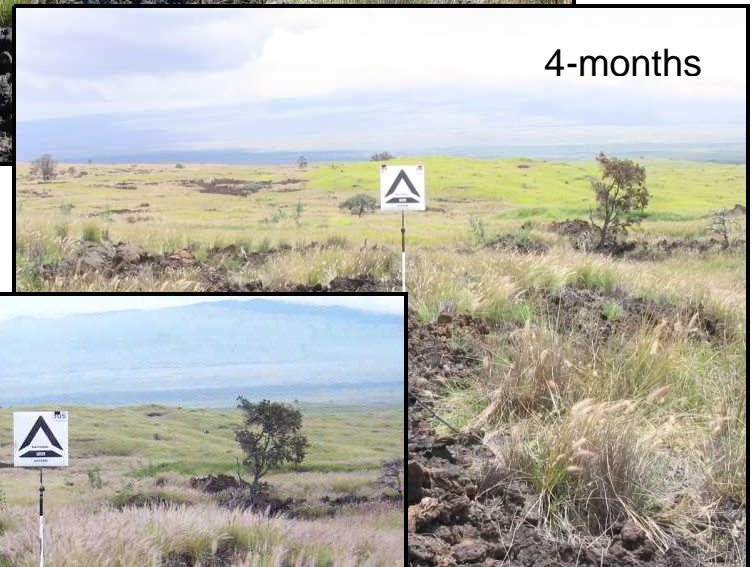
Two-year



One-year



4-months



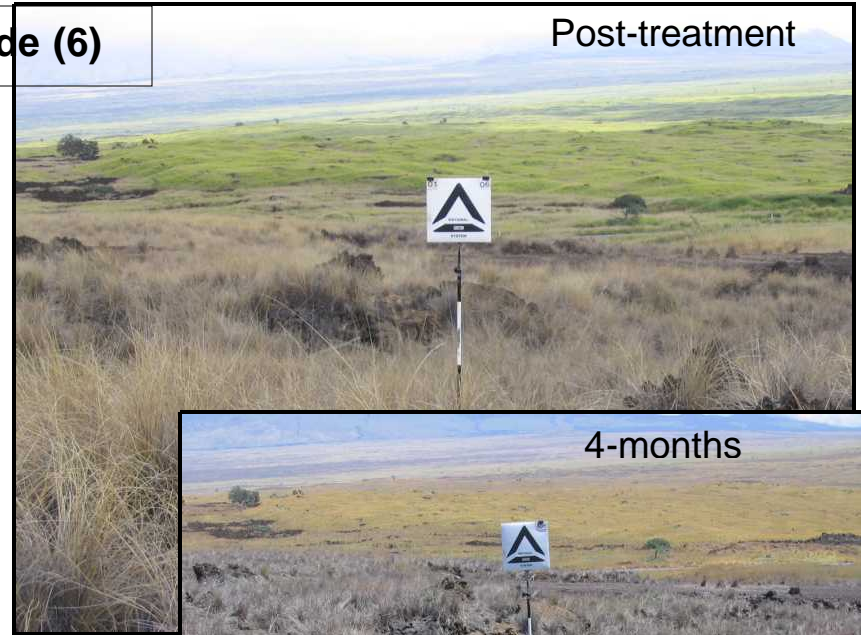


Pre-treatment



Graze x Herbicide (6)

Post-treatment



4-months



Two-year



One-year





Pre-treatment

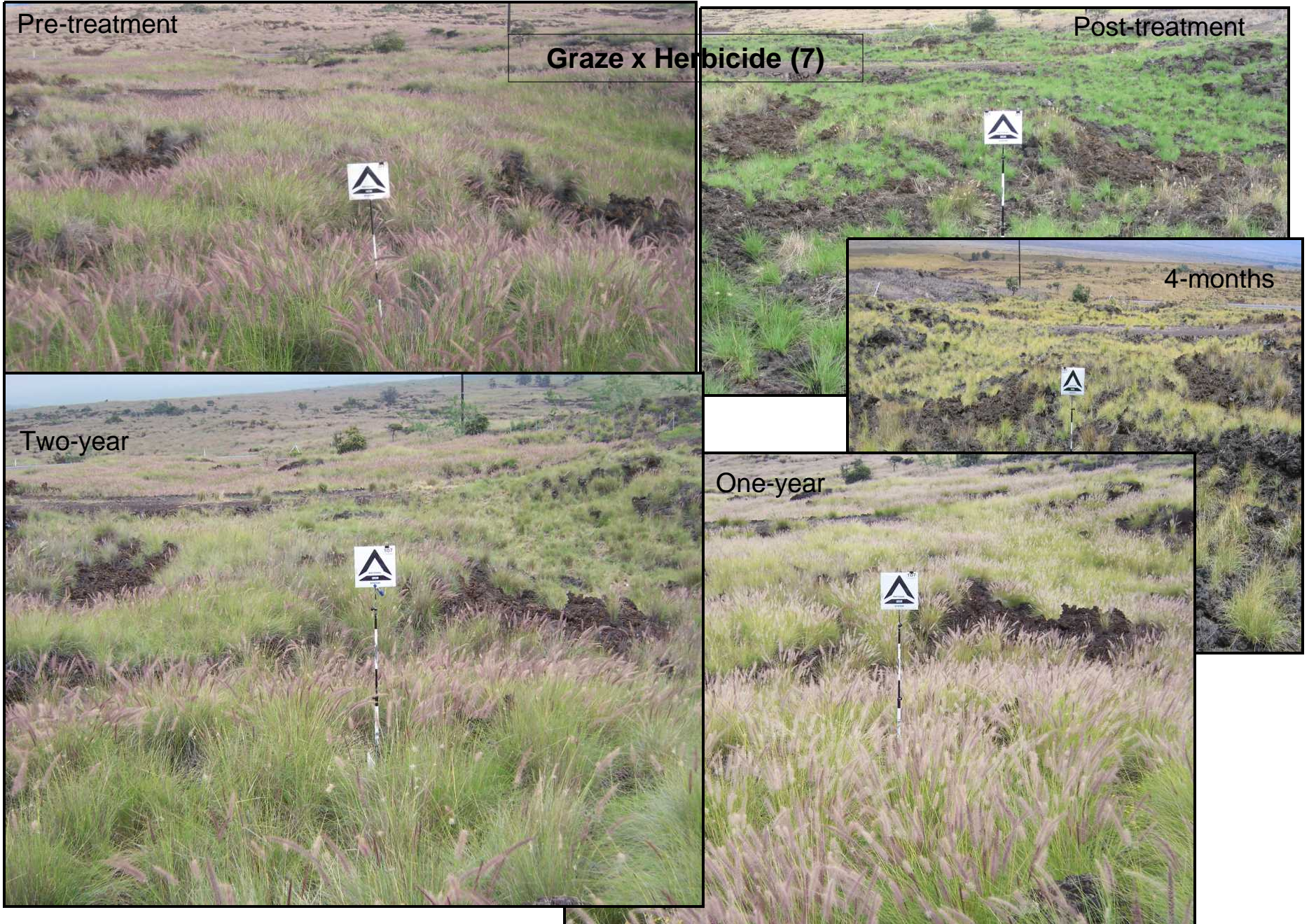
**Graze x Herbicide (7)**

Post-treatment

Two-year

One-year

4-months



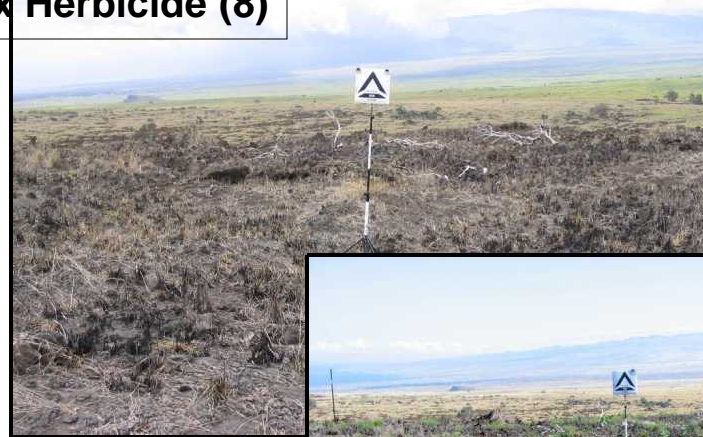


Pre-treatment



**Burn x Graze x Herbicide (8)**

Post-treatment



4-months



Two-year



One-year





## Appendix D. Fuel Modeling Report.

*Draft*

# **Final Report on Fuel Model Methodology and Results**

## *Puu Anahulu Fuels Management Study*



Prepared for:

**The US Fish and Wildlife Service**

Order # 101814M0504

Submitted by:

**Rodrigo Moraga**

**Anchor Point Group LLC**

Boulder, Colorado

April 13, 2006



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# INTRODUCTION

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This project was designed to measure the “Effects of Prescribed Grazing and Burning Treatments on Fire Regimes in Alien Grass-Dominated Wildland-Urban Interface Areas, Leeward Hawaii”. A complete discussion of the project is found in the main body of the full report. This section of the report refers specifically on the results as they relate to fire behavior effects.

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## METHODOLOGY

---

Custom fuel models were developed for each of the treatment units using sampling data provided. In order to create custom models a number of inputs must be provided or default measurements from existing fuel models can be used. The fire behavior software BehavePlus (3.0.1) was decided upon because of the ability to use dynamic fuel models. The fountain grass is best modeled as a dynamic fuel model since the plant has a ratio of dead and live fuel that fluctuates with different relative humidities and moisture contents. Fuel load is transferred from live to dead as a function of the **live herbaceous moisture** entered on the worksheet. This moves a percent of the fuel into the 1 hour fuel load category which is critical for the model to calculate resultant fire behavior. For a more detailed discussion of BehavePlus see the help manual (software included on final project disk).

Two inputs were sampled- **Live herbaceous fuel load** and **fuel bed depth**. Default values for Fuel model gr 9 (Very high load, humid climate grass) were used for all the input variables that were not sampled.

Other inputs (fuel moisture, weather, and slope) were chosen which would represent a reasonable fire scenario. They are not measured values from the prescribed burn as that would only represent weather for that specific day. The same inputs are used for all treatment scenarios ensuring that outputs are comparable.

BehavePlus 3.0.0 (Build 257)

PRE 1

Fri, Jan 21, 2005 at 15:27:16

**Input Worksheet****Modules: SURFACE**

Input Variables	Input Value(s)	Units
<b>Fuel/Vegetation, Surface/Understory</b>		
Fuel Model Type	D	
1-h Fuel Load	0.00	ton/ac
10-h Fuel Load	0.00	ton/ac
100-h Fuel Load	0.00	ton/ac
Live Herbaceous Fuel Load	3.6	ton/ac
Live Woody Fuel Load	0.00	ton/ac
1-h Surface Area/Vol Ratio	1800	ft <sup>2</sup> /ft <sup>3</sup>
Live Herb Surface Area/Vol Ratio	1600	ft <sup>2</sup> /ft <sup>3</sup>
Live Woody Surface Area/Vol Ratio	1500	ft <sup>2</sup> /ft <sup>3</sup>
Fuel Bed Depth	1.8	ft
Dead Fuel Moisture of Extinction	40	percent
Dead Fuel Heat Content	8000	Btu/lb
Live Fuel Heat Content	8000	Btu/lb

**Fuel Moisture**

1-h Moisture	8	percent
10-h Moisture		percent
100-h Moisture		percent
Live Herbaceous Moisture	100	percent
Live Woody Moisture		percent

**Weather**

Midflame Wind Speed (upslope)	6	mi/h
-------------------------------	---	------

**Terrain**

Slope Steepness	10	percent
-----------------	----	---------

**Table 1. Behave Inputs**

By using this dynamic model it will allow the user to input the daily or seasonal profile that most represents the conditions and then run a fire behavior output for that day. This will allow for a reasonable fire behavior expectation for that day.

The custom fuel models developed are specifically for the treatments that were done in association with this project. However, these outputs should be compared to real fire behavior observed on wildfires and calibrated to be more representative.

## RESULTS

The following table represents the outputs calculated. Flame length and Rate of spread are shown graphically, as they are the most tangible outputs used by firefighters. Flame length is directly related to fire intensity. Rate of spread is affected by fuel continuity and by wind speed as much as fuel load.

Output Variable	Value	Units
Surface Rate of Spread (maximum)	7.4	ch/h
Heat per Unit Area	236	Btu/ft <sup>2</sup>
Fireline Intensity	32	Btu/ft/s
Flame Length	2.2	ft
Fuel Load Transfer	22	%
Dead Herbaceous Fuel Load	0.80	ton/ac

**Table 2. Behave Outputs**

### Treatments:

- |                       |                                   |
|-----------------------|-----------------------------------|
| 1. Control            | 5. Grazing                        |
| 2. Herbicide          | 6. Grazing and herbicide          |
| 3. Burn               | 7. Grazing and burning            |
| 4. Burn and Herbicide | 8. Grazing, burning and herbicide |

**Table 3. Treatments**



Figure 1. Rate of Spread

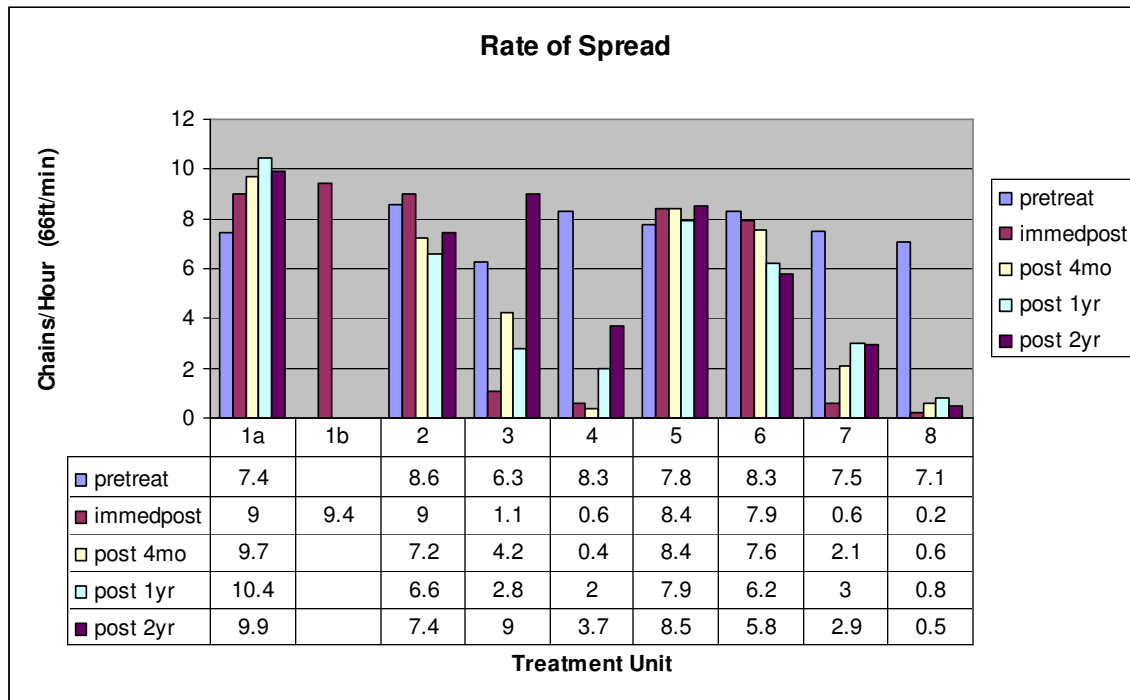
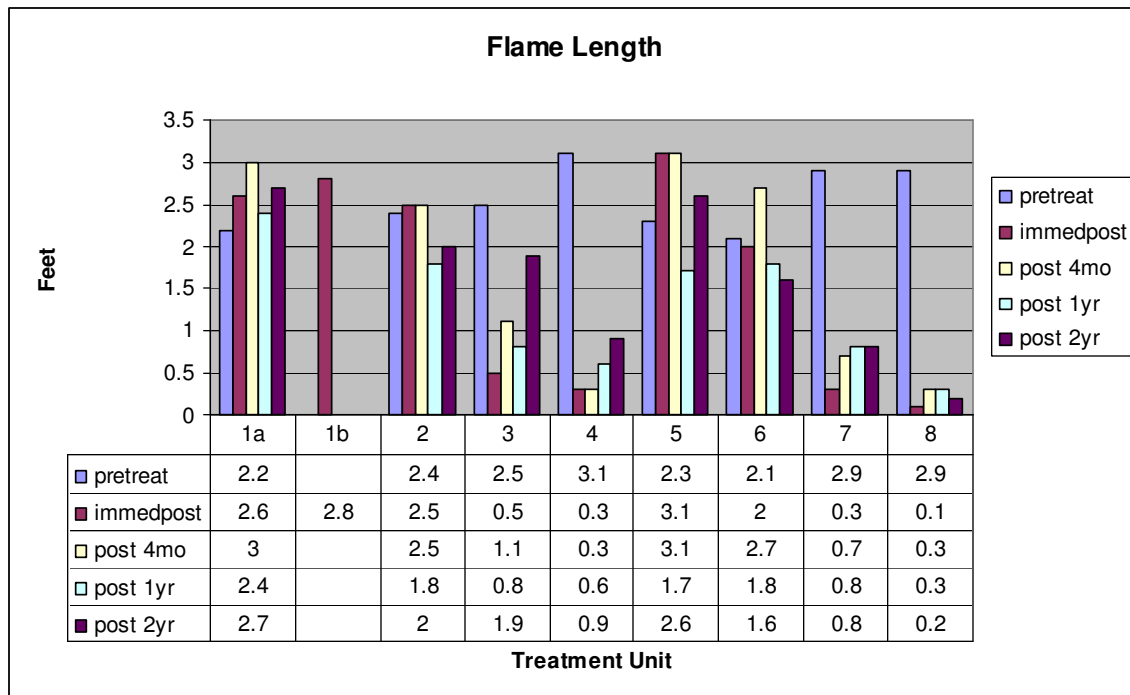


Figure 2. Flame Length



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## CONCLUSIONS

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It would be expected that fire behavior would moderate as fuel loads are reduced. In the units where fire was used there is a drastic decrease in fire behavior. Other treatments have far less effect on fire behavior as the amount of fuel was either not reduced significantly or in some cases increased.

- 1a & 1b. Control unit – fire behavior increased as the grass continued to grow and thus increased available fuel. Fluctuations are based on environmental factors i.e. weather.
1. Herbicide- initially increased by a small amount but then began to decrease. The herbicide takes time to absorb and affect the plant. However, since it does not remove the vegetation and kills the plant, it actually creates more available fuel for burning. The Fluctuations track with the control unit.
  1. Burn- there was initially a very drastic reduction in fire behavior because the available fuel was consumed and removed. Then it began to increase again because thatch was removed allowing more light to the new growth. Also, the seed source is stimulated from nutrient rich ash and more available water.
  1. Burn and herbicide- Initially results were similar to #3. Re-growth was slower then burning alone because the plant was more exposed after burning and the herbicide could better penetrate the plant.
  1. Grazing- There were some timing issues with the grazing blocks and the results may not be accurately represented. Using the results given, it would seem that the grazing was the least effective of the treatments. Fire behavior was increased overall. Fuel loads increased in spite of the fact that the fuel should have been removed by grazing. Fluctuations follow the control unit so it would be assumed that environmental factors influenced growth.
  1. Grazing and herbicide- Little reduction in fuel load was measured. The decrease was also very gradual. There is one spike that does not fit with the trend.
  1. Grazing and burning- A very drastic decline in fire behavior as the fuels were consumed and a much slower re-growth then burning alone. The grazing pulses were done later and helped to limit the growth and thus the fuel load.
  1. Burning, grazing and herbicide- This had the most significant reduction and longest lasting reduction in fire behavior. The burning has the most immediate effect, the herbicide has better penetration to the plant and the grazing helps keep the plant from growing.

---

## RECOMMENDATIONS

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Burning is the most effective short term treatment for reducing fire behavior. However, in order to prevent the rapid re-growth that typically results from burning a secondary treatment must be used. Usually, a grazing regime can help keep the grass in check. The results here do not support that. It may be worth studying the palatability and nutritional value of the grass to cows. The herbicide appears to retard the growth longer but must be used in conjunction with another treatment to help expose the plant to be considered effective in the long term.

The results support that a combination of all three treatments helps reduce and maintain the lowest fire intensity.

Appendix E. September 29, 2005 and June 10, 2006 Fuels Management Workshop Announcements  
and Lists of Attendees.

**APPENDIX E.** West Hawai‘i Fuels Management Workshop Program for September 29, 2005 and Announcement for June 10, 2006.

## **West Hawai‘i Fuels Management Workshop**

September 29, 2005



Lalamilo-Waikoloa Fire, August 2005. JM Castillo

## **Program**

8:45 – 9:00	Registration
09:00 – 9:30	Land use history and fire history in Hawai‘i (Kato and Tomich)
9:30 -- 10:15	The Puu Anahulu Fuels Management Study (McAdams, Castillo, Nakahara, and Weise)
10:15 – 10:30	Break
10:30 – 11:00	Comparison of treatment fuel loads, fire behavior, and treatment costs (Castillo & Nakahara)
11:00 – 11:30	Group discussion / Question & answer
11:30 ---11:45	Federal funding and state and county assistance (Ching and Oliveira)
11:45 – 1:15	Lunch break
1:15 – 2:30	Field site inspection, (Waimea end)
2:30 – 3:15	Field site inspection, (middle section and Kona end)
3:15 – 3:30	Discussion: Where do we go from here?

## Attendees: September 29 West Hawaii Fuels Management Workshop

Mick Castillo	Hawaii Natural Resource Svc	Waimea, HI	<a href="mailto:castillo@hawaii.nrs.net">castillo@hawaii.nrs.net</a>
Heather Cole	Parker Ranch Realty – DFWG	Waikii, HI	<a href="mailto:hcole@parkerranch.com">hcole@parkerranch.com</a>
Rick Hoesbein.	Hosbein Livestock Co.	Waimea, HI	-
Miki Kato	HI DLNR	Puu Waawaa Ranch, HI	<a href="mailto:etkato@aol.com">etkato@aol.com</a>
Curt Kessler	USFWS, Ecological Services	Honolulu, HI	<a href="mailto:Curt_Kessler@fws.gov">Curt_Kessler@fws.gov</a>
Amanda McAdams	USFS (Formerly USFWS)	Dixie-Fishlake NF, UT	<a href="mailto:amcadams@fs.fed.us">amcadams@fs.fed.us</a>
Joe Molhoek	NPS, Hawaii Volcanoes NP	Volcano, HI	<a href="mailto:joe_molhoek@nps.gov">joe_molhoek@nps.gov</a>
Miles Nakahara	HI DLNR	Waimea, HI	<a href="mailto:mnakahara@dofawha.org">mnakahara@dofawha.org</a>
Freddy Rice	F.R. Cattle Co.	Waimea, HI	<a href="mailto:gaile@hawaii.rr.com">gaile@hawaii.rr.com</a>
Mark Thorne	Univ. of Hawaii Coop. Ext. Svc.	Waimea, HI	<a href="mailto:thornem@hawaii.edu">thornem@hawaii.edu</a>
Michael Tomich	HFD	Kona, HI	<a href="mailto:ohiwai@aol.com">ohiwai@aol.com</a>
Steve Troute	US Army Pohakuloa – Ops	Pohakuloa, HI	<a href="mailto:troutes@hawaii.army.mil">troutes@hawaii.army.mil</a>
David Weise	USDA FS Fire Research Lab	Riverside, CA	<a href="mailto:dweise@fs.fed.us">dweise@fs.fed.us</a>
Jerry Williams	USDANRCS	Waimea, HI	<a href="mailto:jerry.williams@hi.usda.gov">jerry.williams@hi.usda.gov</a>
Carolyn Wong	USDANRCS	Waimea, HI	<a href="mailto:carolyn.wong@hi.usda.gov">carolyn.wong@hi.usda.gov</a>
Earl Spence	Kahuku Ranch	Kau, HI	<a href="mailto:earl@whwmo.org">earl@whwmo.org</a>

WEST HAWAI'I WILDFIRE MANAGEMENT ORGANIZATION 501(c)(3)  
Awareness, Planning, and Management

Holomua Center Ste. C-4  
64-1067 Mamalahoa Hwy.  
Kamuela, HI 96743  
(808)885-0900 Tel.  
(808)885-0922 Fax

May 10, 2006

Aloha Land Manager,

You are cordially invited to attend the 2<sup>nd</sup> West Hawaii Wildfire Fuels Management workshop to be held on June 10, 2006 in Waimea (Hawai'i island). The full-day workshop will be hosted by the non-profit 501c3 West Hawai'i Wildfire Management Organization and will focus on evaluating the range of techniques available for managing wildfire fuel loads along roadsides and in other areas. Results from the recently completed 2-year Puu Anahulu Wildfire Management Study will be presented and participants will be encouraged to discuss fuels management issues as they relate to their land management goals and challenges. Specific topics that will be addressed include:

- Factors that contribute to wildfire hazard
- Vegetation and fuel types of fire prone regions of the islands
- Fire behavior in various fuel types
- Techniques and tools available to manage invasive grasses and other fuels

The morning session will be held from 9:00 am to 11:30 at the Waimea Civic Center located across from "Church Row" in Waimea. A luncheon will be provided between 12:00 noon and 1:00 pm, and the afternoon field trip will be held in the Puu Anahulu Game Management Area located along the Mamalahoa Highway 15 miles toward Kailua-Kona. There is no charge to attend the workshop.

Registration for the morning session will start at 8:30 am. Please RSVP via email no later than June 2nd. You may call or e-mail me directly if you have any questions. My office phone number is (808) 884-5909 and my e-mail is castillo@hawaiiinrs.net.

We hope that you will be able to attend!

Sincerely,

*J. Michael Castillo*

J. Michael Castillo  
Board Chair





#### **Attendees:**

NAME	AFFILIATION	LOCATION	EMAIL
• Mick Castillo	Hawai Natural Resource Services	Waimea, HI	<a href="mailto:castillo@hawaiinrs.net">castillo@hawaiinrs.net</a>
• David Clausnitzer	NRCS, Kona	Kona, HI	<a href="mailto:david.clausnitzer@hi.usda.gov">david.clausnitzer@hi.usda.gov</a>
• Jim Dupont	Hawaii Dept. of Hawaiian Hmlds	Waimea, HI	<a href="mailto:jim.w.supont@hawaii.gov">jim.w.supont@hawaii.gov</a>
• Steve Evans	Environ. Pohakuloa Training Area	PTA, Hawaii	<a href="mailto:steven.evahs6@us.army.mil">steven.evahs6@us.army.mil</a>
• Dave Faucette	ITAM, Pohakuloa training Area	PTA, HI	<a href="mailto:dave.faucette1@us.army.mil">dave.faucette1@us.army.mil</a>
• Rod Moraga	Anchor Point Fire Management	Boulder, CO	<a href="mailto:rod@anchorpointgroup.com">rod@anchorpointgroup.com</a>
• Miles Nakahara	Hawaii Div. For & Wildlife	Waimea, HI	<a href="mailto:mnakahara@dofaw.org">mnakahara@dofaw.org</a>
• H.M. Richards Jr.	Kahua Ranch	Waimea, HI	<a href="mailto:hmr4kahua@aol.com">hmr4kahua@aol.com</a>
• Glenn Shishido	Maui Div For & Wildlife	Kahului, HI	<a href="mailto:flenn.n.shishido@hawaii.gov">flenn.n.shishido@hawaii.gov</a>
• Mark Thorne	Univ. of Hawaii, CTAHR	Waimea, HI	<a href="mailto:thornem@hawaii.edu">thornem@hawaii.edu</a>

Appendix F. Copy of the Tri-fold Brochure Interpreting the Outcomes of the Study and Providing Information About how to Access the Study Site.



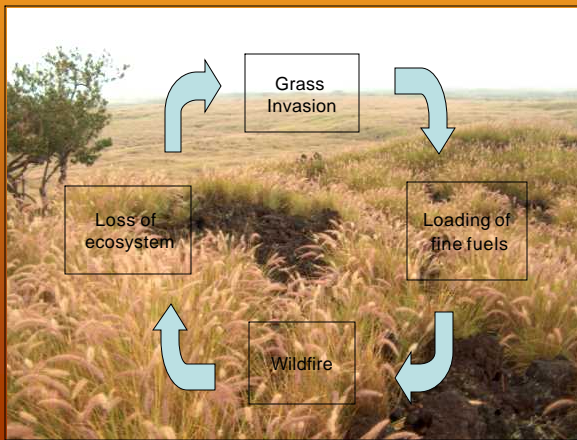
## Wildfires

- Threaten residential communities
- Cause permanent loss of native dry forest and shrub ecosystems
- Degrade rangeland quality
- Decrease available wildlife habitat
- Cause loss of cultural and biological heritage



## Issue/problem

- Invasive grasses such as fountain grass spread in arid natural areas in Hawaii.
- Invasive grasses carry fire easily and are difficult to control.

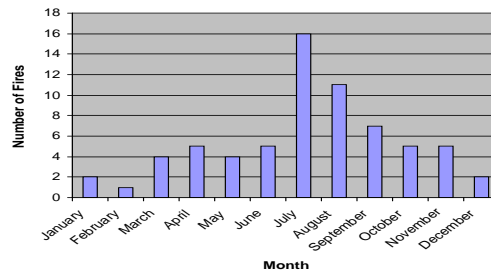


## Ignitions

- Most fires are human-caused
- Most wildfires start along roadsides

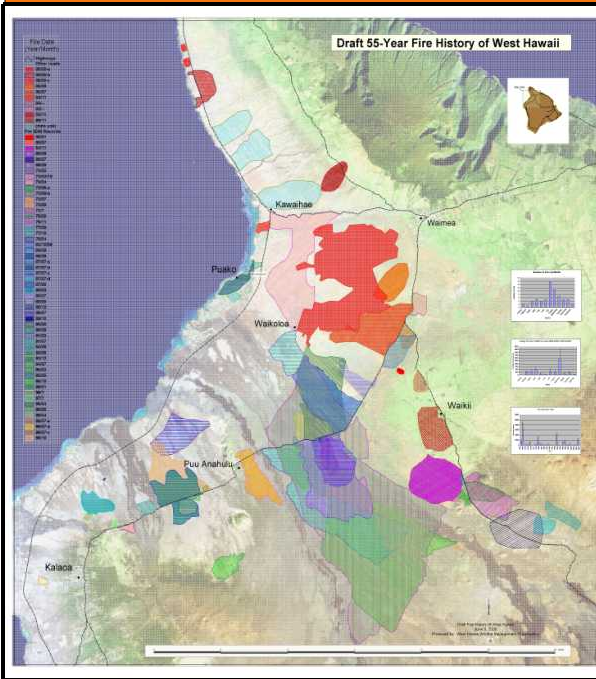


Number of Fires by Month

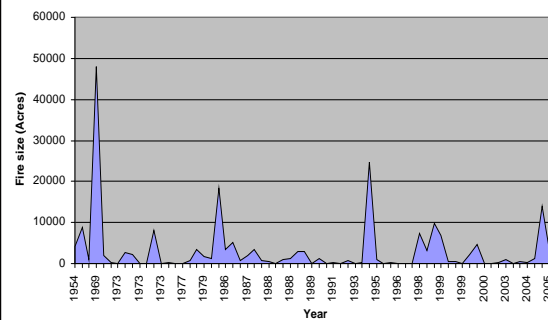


Month

Draft 55-Year Fire History of West Hawaii



Fire Size Over Time



## Things you can do to protect your home and community

- Create defensible space around your home
  - Use fire safe construction materials
  - Apply a Firewise landscaping design



- Participate in community wildfire preparedness planning
- Visit [www.Firewise.org](http://www.Firewise.org) to learn more

## Fine Fuels Reduction Techniques for Landowners and other land managers

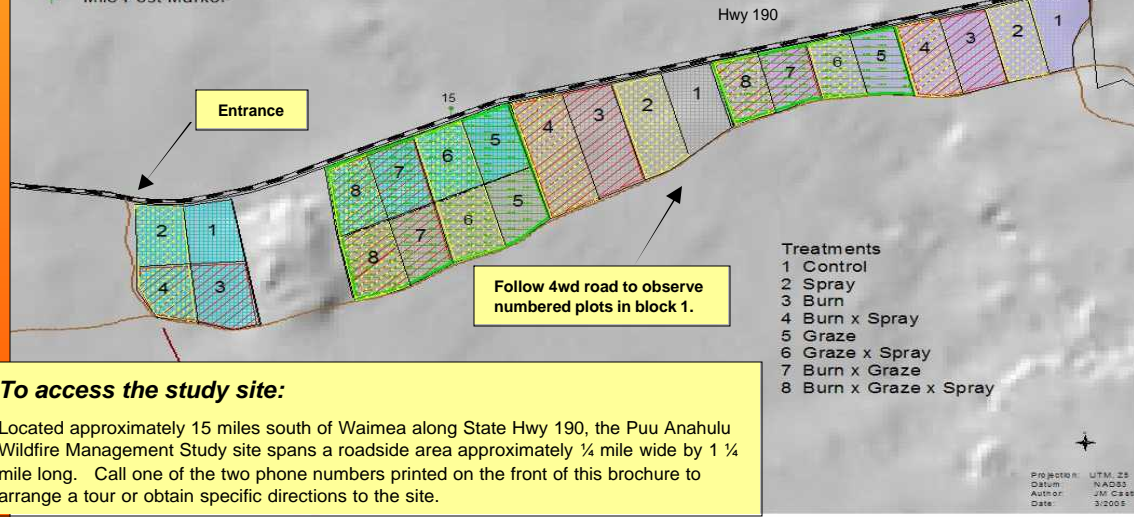
- Focus fine fuels along roadside areas
- Use combinations of prescriptions
- Consider weather patterns



This project was made possible with generous funding from the interagency Joint Fire Science Program.

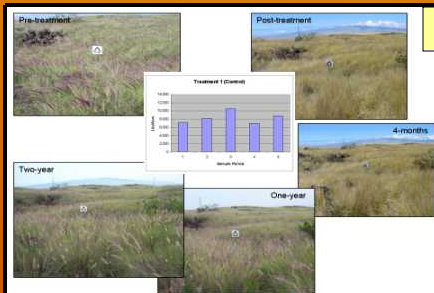
## Puu Anahulu Wildfire Management Study Site

- Treatment Plot Boundaries
- Glyphosate Split-plot Treatments
- Cattle Grazing Paddocks
- Prescribed Burning Treatments
- Treatment Replicates
  - Block 1
  - Block 2
  - Block 3
- Firebreak Road
- Mamalahoa Hwy (190)
- Mile Post Marker



### To access the study site:

Located approximately 15 miles south of Waimea along State Hwy 190, the Puu Anahulu Wildfire Management Study site spans a roadside area approximately ¼ mile wide by 1 ¼ mile long. Call one of the two phone numbers printed on the front of this brochure to arrange a tour or obtain specific directions to the site.

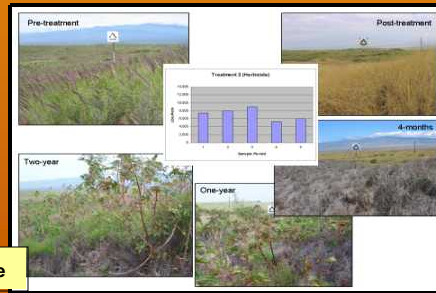


### Control

- Slight annual fluctuations in fountain grass fuel load were observed

- Herbicide killed grass
- Changed composition of fuel type
- Caused a delayed reduction in fine fuel load

### Herbicide

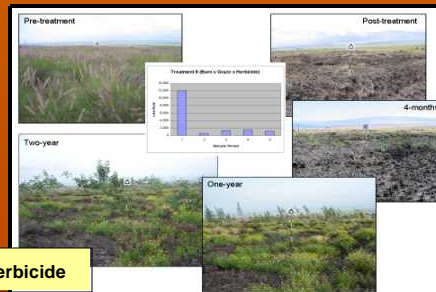


### Prescribed Burn

- Removed fountain grass fuel load
- Did not kill grass
- Grew back slowly (> 2yr)

- Removed grass fuel load
- Created a lasting reduction in fine fuel load
- Changed structure and composition of fuel type

### Burn-Graze-Herbicide



## Wildfire Fuels Management in West Hawaii

# The Puu Anahulu Wildfire Management Study: Techniques for Managing Invasive Grass Fuel Loads



The Puu Anahulu Wildfire Management Study is a collaborative research demonstration study to help identify and evaluate the effectiveness of a range of fine fuels management techniques.

### For more information contact:

The West Hawai'i Wildfire Management Organization 501c3



64-1067 Mamalahoa Hwy, Suite C4  
Kamuela, HI 96743 Tel: (808)885-0900  
or the  
Hawai'i Division of Forestry and Wildlife  
66-1220A Lalamilo Rd.  
Kamuela, HI 97743 Tel.: (808)887-6063



## Appendix G. Soil Seed Bank master's Thesis.

SEED BANK DYNAMICS AND GERMINATION ECOLOGY OF  
FOUNTAIN GRASS (*PENNISETUM SETACEUM*)

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF THE  
UNIVERSITY OF HAWAI'I IN PARTIAL FULLFILLMENT OF THE  
REQUIREMENTS FOR THE DEGREE OF

**MASTER OF SCIENCE**

IN

**BOTANY**

December 2005

By

Edith D. Nonner

Thesis Committee:

Donald R. Drake, Chairperson  
Susan Cordell  
Curtis Daehler  
Clifford Morden



## ABSTRACT

In Hawaii, fountain grass (*Pennisetum setaceum*) is an aggressive, fire prone invader that out-competes native flora and forms monotypic stands with large amounts of dead mass that fuels fires. Wildfires eliminate native dry forest species and contribute to further spread of alien grasses, creating a grass/fire cycle. The presence of a fountain grass seed bank can increase the possibility of the reestablishment of this alien grass. Alternatively, restoration efforts can benefit from the presence of native seeds in the seed bank. The goals of this study were: 1. Test the basic germination requirements of *P. setaceum*, 2. Determine the seed bank composition in a degraded dry forest site, 3. Test the effectiveness of prescribed fire and large-scale aerial herbicide treatment in removing/suppressing fountain grass seed banks. Laboratory germination trials showed that *P. setaceum* does not require light for germination and seedlings can emerge from at least 5 cm soil depths. However, awns on the dispersal unit imply fountain grass may form predominantly surface layer seed banks. The soil seed bank at the study site is dominated by non-native species. Of the 23 species germinated from the seed bank, 3 native species and 20 alien species emerged; 3 of the alien species are grasses, 14 are herbaceous weeds, and 3 are woody species. *Pennisetum setaceum* forms a patchy seed bank with a maximum density of 2040 seeds/m<sup>2</sup>. Field and lab tests show that fire and heat, respectively, are effective in killing fountain grass seeds. However, the heterogeneity of lava fields on which fountain grass occurs may provide refugia for seeds during fire events. While not statistically significant, some trends are evident in the data. The *P. setaceum* seed bank is reduced after the passage of fire, and input of seeds into the seed bank is suppressed by herbicide treatment. The sampling methodology employed is not robust enough to show differences in the seed bank after treatment. Smaller sub plots within the research site may be more appropriate to show treatment effects. Given the paucity of native species present in the seed bank, native seed augmentation will be necessary for restoration.

