Department of Defense
Legacy Resource Management Program

PROJECT NUMBER 07-362

Removal of Invasive Fire-Prone Grasses to Increase Training Lands in the Pacific

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September 2008

Removal of Invasive Fire-Prone Grasses to Increase Training Lands in the Pacific

Marine Corps Training Area Bellows
Oʻahu, Hawaiʻi

PREPARED FOR

Department of Defense
Legacy Resources Management Program
Project 07-362
Under
US Army Corps of Engineers
Cooperative Agreement W912DY-07-2-0008

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1.0 EXECUTIVE SUMMARY

This report represents the final deliverable for the 2007 Legacy Resource Management Program project number 07-362 (Cooperative agreement W912DY-07-2-0008), titled '*Removal of Invasive Fire-prone Grasses to Increase Training Lands in the Pacific*'. This project was developed and carried out by SWCA Environmental Consultants (SWCA) to determine the effectiveness of three different methods in reducing the surface fuel loads in a guinea grass (*Panicum maximum*) dominated community, thereby reducing susceptibly to sustained fires. Three control treatments were tested including mechanical removal, herbicide application and grazing using cattle to reduce the fuel loads at Marine Corps Training Area Bellows (MCTAB), on the island of O'ahu, Hawai'i. Information on the cost of the various control treatments and their long-term effectiveness in maintaining reduced fuel loads would also benefit land and resource managers in the Pacific Islands where guinea grass and frequent fires are problematic.

This experimental fuel treatment project was carried out at the Marine Corps Training Area Bellows (MCTAB), O'ahu. Twelve experimental plots were established during the summer of 2007 in the northwestern part of MCTAB and the following four treatments were applied in replicates of three: mechanically removing guinea grass, herbicide application, cattle grazing and control. Data were collected on the following parameters: live herbaceous fuel loads, fuel loads in the 1 hr, 10 hr and 100 hr moisture classes, fuel and litter bed depths and various vegetation characteristics such as percent cover of ground vegetation and percent of open canopy. The first set of data, prior to application of the treatments was collected during September and October of 2007. The experimental treatments were applied in December 2007. Two sets of post treatment data were collected. The first was in January 2008, directly after the application of the treatments and the second in May 2008, 5 months after the application of the treatments. Evidence supporting the effectiveness of the treatments was based on post-treatment reduction of fuel loads in the various fuel categories, reduction of total fine fuel loads and fuel bed depths, as well as informal observations of fuel continuity of the different treatments.

The total fine fuel load at MCTAB was found to average 6 tons/acre. Results also indicate that grazing by cattle is most effective in lowering the fuel bed depths of guinea grass on MCTAB. Effect of treatment on reduction of guinea grass fuel loads varied with time. Mechanical treatment was the most effective in rapidly reducing guinea grass; however, the grazing treatment was most effective in *maintaining* low fuel loads over 5 months post application of treatment. At the end of the experiment, fuels in the grazing plots also appeared to be less continuous than other treatments and; therefore, not expected to carry fast moving fires. Grazing treatment also appears to be most effective in maintaining lower total fine fuel loads, 5 months post application of treatments.

The total cost of applying the experimental treatments was $23,940. A cost analysis was done to estimate the cost of applying these treatments on a larger scale of 500 acres at MCTAB on both annual and 10-year cycles. The estimated cost of applying mechanical and herbicide treatments over 10 years would be $240,000 and $520,000, respectively. In contrast, if MCTAB adopted an agricultural out-lease program for cattle grazing, the analysis suggests that an *income* in the range of $72,150 to $161,135 over 10 years is possible.

Based on the relative cost effectiveness of the grazing treatment together with its effectiveness in reducing and maintaining low fuel loads at MCTAB, SWCA recommends the use of cattle grazing as a control method to maintain low fuel loads and reduce the fire hazard on MCTAB and surrounding lands. SWCA also recommends that MCTAB use this fundamental fuels data to model site specific fire behavior for the training areas under different treatment and weather conditions. Such an exercise would further help consolidate fuel treatment decisions on MCTAB. Fuel reduction will be an ongoing battle to keep the fire hazards low. Finally, SWCA recommends that MCTAB consider implementing a fuel conversion program to a fuel reduction program. Fuel conversion would involve replacing fire prone guinea grass with more fire resistant native/non-invasive species that can also support the various military training activities on MCTAB.

2.0 INTRODUCTION

Invasive grasses pose a major threat to dry land forest ecosystems in Hawai‘i by converting natural forested habitats to fire-driven grassland systems (Hugh et al. 1991, Smith and Tunison 1992). Non-native, invasive grasses that are susceptible to and promote continued fire regimes have also become the dominant ground cover on military installations in the Pacific, such as the Ulupa‘u Crater Weapons Range at Marine Corps Base Hawaii (MCBH), Marine Corps Training Area Bellows (MCTAB), Army installations Makua Valley, Schofield Barracks, Pohakuloa Training Area, the Hawaii Army National Guard facility at Diamond Head Crater, and at the Naval Magazine on the Island of Guam. Invasive, fire-prone grasses in Hawai‘i and Guam diminish natural ecosystem function and compromise the availability of suitable military training lands. Fire-prone grasses have aggravated fire risk to weapons firing training and increased the threat to the federally-protected resident colony of red-footed boobies (*Sula sula)* in Ulupa‘u Crater, and to the endangered plants at the Army Makua Range on O‘ahu. Destructive brush fires have spread when sparks from ricocheted bullets hit the dry grass resulting in loss of training time, and the destruction of wildlife and their habitats. These military installations have invested millions of dollars to manage and minimize fire risk to optimize military training opportunities and to protect species and their habitats. The high cost of fire management on military installations will continue to be an issue unless a cost effective means of controlling or eliminating invasive grass cover and cyclical fires can be found.

2.1 Guinea Grass and Marine Corps Training Area Bellows (MCTAB)

Guinea grass, native to Africa, is widely introduced and naturalized throughout the tropics. It was probably introduced to Hawai‘i as a forage grass in mid 1800’s and has naturalized on all the main Hawaiian Islands from 0 to about 800 m elevation (Wagner et al. 1990). It is a coarse perennial grass that can grow to a height of about 4 m. Ranging from warm temperate dry to moist through tropical very dry to wet forest life zones, guinea grass is reported to tolerate annual precipitation of 6.4 to 42.9 inches, annual temperature of 12.2 to 27.8°C, and pH of 4.3 to 8.4 (Duke 1978, 1979). Its seeds are passively dispersed by wind, birds, mammals, and flowing water. It is a prolific seeder and can survive long periods of drought. Hence, it can spread rapidly in a given habitat. Guinea grass can also tolerate some shade and can grow under trees and in stands of low bush. Beavers (2001a) conducted tests at Makua Military Reservation and Schofield Barracks and demonstrated that guinea grass “has a propensity for fast moving, high intensity grass fires” which can be “uncontrollable in a wildland suppression situation” even in low wind conditions. Guinea grass burns readily and re-grows more rapidly following fire than do woody plants, thereby establishing a pattern of frequent fires.

The majority of guinea grass at MCTAB is concentrated in the north section adjacent to the Enchanted Lake and Lanikai communities. In 2003, a fire ignited and carried through the guinea grass dominated stands in the north of MCTAB coming very close to the residences located on the ridge. Because MCTAB is adjacent to urban development, such fires could have had major consequences if they caused structural damage or human injury. Such fire could potentially lead to temporary restrictions or closing military activities on the training areas. For this reason, MCBH tasked Geo Insight (2003) to evaluate fire risks from guinea grass and other invasive plant species at MCTAB.

Although a high fire risk, guinea grass is considered an important warm-season forage grass because of its high productivity and nutritional value. Livestock grazing has been used successfully in other areas of the world to reduce fine fuel loads and thereby reduce the risk of fire (Goldammer 1988, Yoder 2004). In Hawai‘i, cattle and sheep are known to forage on guinea grass (Warren et al. 2007). The use of livestock grazing in Hawai‘i to reduce grass biomass that is a fire risk can be a two-edged sword. Grazing might minimize the fire risk by reducing grass biomass, but cattle can also consume and damage native plant seedlings, trample them and impede recruitment (Blackmore and Vitousek 2000). However, due to the absence of native vegetation in guinea grass abundant areas on MCTAB, livestock grazing to minimize the fuel loads could serve as an effective fuel load reduction tool.

2.2 Rationale

Stand structure and wildland fire behavior are clearly linked (Rothermel 1991). Weather conditions, topography, and fuels all play a role in the hazard, severity and size of wildland fires (Agee and Skinner 2005, Pinol et al. 2005). Among these, altering the fuel loads which also affects the fuel bed depths and fuel continuity is the most feasible and important factor in reducing fire hazard and severity (Vaillant et al. 2006).

Land managers are constantly faced with the challenge of implementing fuel treatments that are effective and achievable within a reasonable amount of time. Traditionally, mechanical removal of fuels and prescribed fire has been the primary tool for reducing the risk in fire prone communities. In Hawai'i, prescribed fire is used by the military in the west and south ranges of Schofield Barracks and on the Makua Military Reservation (Beavers 1999, 2001a). However, several factors limit the application of prescribed fire as a fuel reduction treatment on MCTAB. Because MCTAB shares its west and north borders with urban landscapes, smoke, air quality restrictions and liability associated with escaped burns are major concerns. Second, limited burn windows and the lack of trained fire fighters on staff make prescribed burning efforts a challenge. Given such limitations, MCTAB personnel and land managers in the Pacific seek alternative fuel reduction treatments such as mechanical, herbicide and grazing to reduce guinea grass fuel loads; however, very little information is available.

2.3 Objectives

The fuel loads of grasses, shrubs, litter and wood that are in contact with ground surface on MCTAB were not known at the beginning of this study. The overarching objective of this study was to develop site-specific data on guinea grass fuel loads in order to strengthen the scientific foundation of fuel treatment decisions by land and resource managers at DoD installations in the Pacific. Specific goals included:

1) Quantification of the types of surface fuel loads on MCTAB
2) Evaluate which of the following three alternative fuel treatments is most effective in reducing and maintaining the fuel load of guinea grass on MCTAB:
    a. Mechanical removal
    b. Herbicide application
    c. Cattle grazing

2.4 Determining the Effectiveness of Treatments

Due to the difference in the relative influence of fuel and weather between forest ecosystems, it is difficult to develop precise quantitative guidelines for fuel treatments (Agee 1997, Peterson et al. 2005). For temperate woodland forests, such as the ponderosa pine forests, the majority of the scientific literature supports the effectiveness of fuel treatments in reducing the probability of crown fires (Agee 1996, Pollet and Omi 2002). The evidence supporting such effectiveness of fuel treatments is based on informal observations (Brown 2002, Carey and Schuman 2003), post-fire inference (Pollet and Omi 2002) and simulation modeling (Stephens 1998, Finney 2001).

Scientists are only beginning to understand fire behavior in guinea grass systems in subtropical places like Hawai'i. Fire in guinea grass communities could not be modeled accurately based on temperate tall-grass grassland fire models developed by the National Forest Fire Laboratory (Andrews 2001). Therefore, custom fire models for guinea grass in Hawai'i were created using fuels data from the Makua and Schofield Barracks military installations on O'ahu (Andrews 1999, 2001). There is no set guideline to determine what constitutes 'low' guinea grass fuel loads in Hawai'i. However, the reduction of surface fuel loads is widely accepted as an effective measure of reducing fire intensity and increasing the probability of timely fire suppression in guinea grass systems in Hawai'i (Beavers 1999, 2001, Warren et al 2007).

In this experimental application of fuel treatments, the results from the first set of data collected in January 2008, taken directly after treatment application in December 2007, represent the immediate effectiveness of the applied treatments without consideration of subsequent changes with time. The effectiveness of the December 2007 treatments were evaluated based on a combination of reduction of total fine fuel loads and other fuel categories, reduction in fuel depths, maintenance of high percent moistures in live herbaceous fuels, and informal estimates of the continuity of fuels. The nature of the fuel treatments is known to affect the vegetation and microclimatic conditions in the post treatment environment and therefore also influence the length of effectiveness of the treatments (Graham et al. 2004). Hence, the results from the second set of data taken in May 2008 will be discussed in terms of the length of effectiveness of the treatments over the 5 month period, January to May 2008.

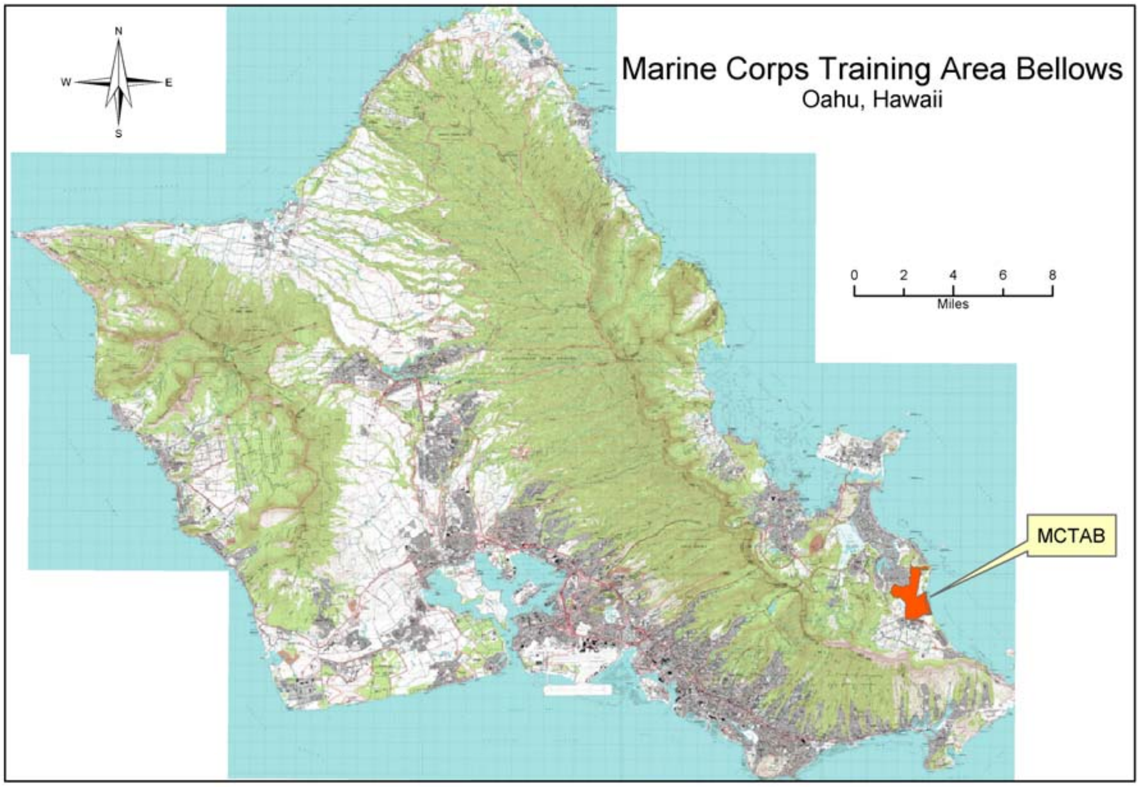

Figure 1. Location of Marine Corps Training Area Bellows on O‘ahu (from SWCA, MCTAB Vegetation Management Strategy, 2006).

3.0 METHODS

3.1 Study Site

SWCA conducted this fuel treatment experiment on Marine Corps Training Area Bellows (MCTAB) on the Island of O‘ahu, Hawai‘i. MCTAB encompasses 1,078 acres on the coastal plain of the Waimanalo Ahupua‘a within the Ko‘olaupoko district in east O‘ahu (Drigot et al. 2001, Figure 1). The landscape at MCTAB has been highly altered by humans. In late 1800’s, the land was used for planting sugarcane. During the First World War in 1917, the land was set aside for military operations and remains actively used for various military training exercises today.

Nearly 85% of the vegetation on MCTAB consists of non-native and invasive species (Char 1995). A recent study used remote sensing and image-processing technologies in concert with ground-truth studies to create an accurate digital geo-database of vegetation cover on MCTAB (Geo InSight 2003). This study found that koa haole (*Leucaena leucocephala*)-guinea grass community dominated MCTAB. Koa haole was the most abundant (80% cover) tree species and guinea grass was the most abundant understory species, covering about 61% of MCTAB. In about 36% of the area covered with guinea grass on MCTAB, the percent cover of this grass was 80% or more (Figure 2).

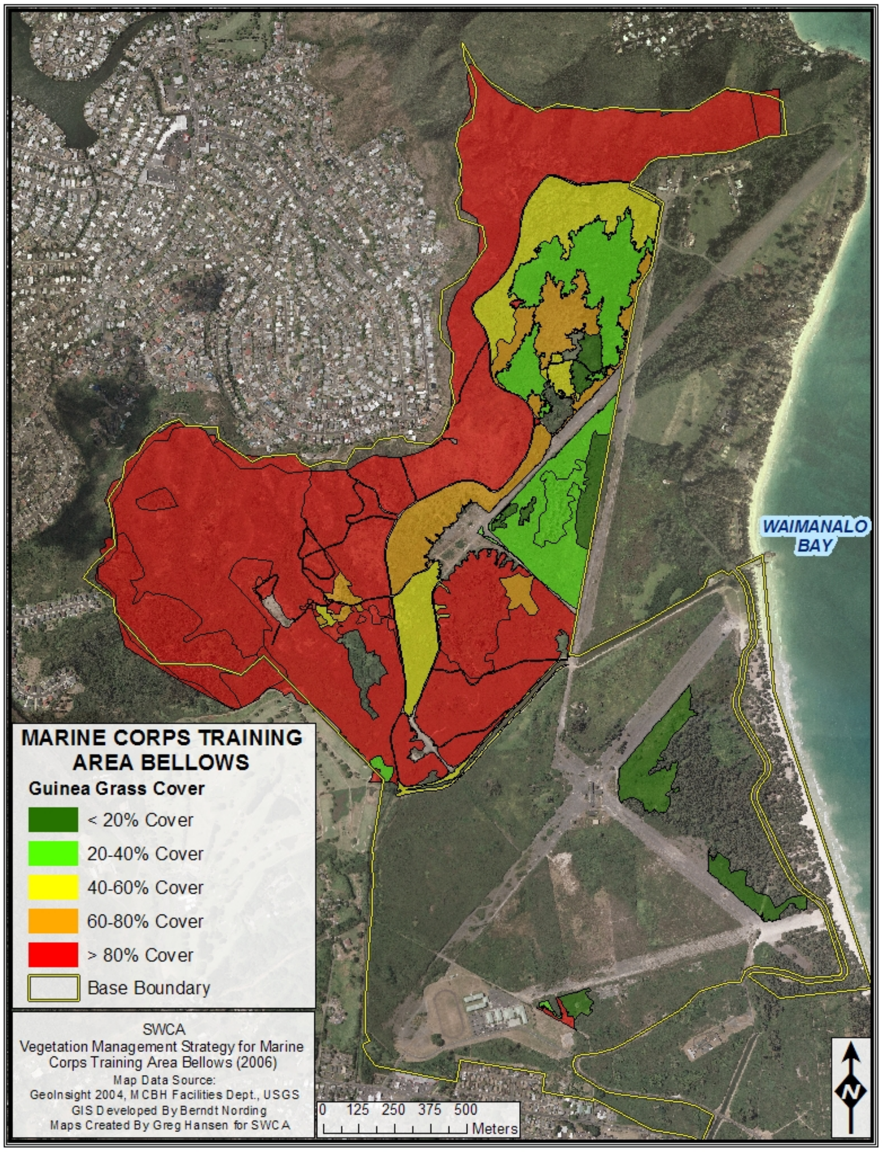

Figure 2. Guinea grass cover on MCTAB (modified from Geo InSight International 2003).

SWCA biologists conducted the experiment in the northwestern sector of MCTAB (Figure 3), which represents a typical koa haole-guinea grass community of Oʻahu. Although the west and south facing slopes of Keolu hills and the central portion of MCTAB comprise over 80% cover of guinea grass, this area could not be used due to the logistical difficulty of establishing plots and applying the treatments on slopes greater than 30% and because portions of this hillside had burned during a fire in the year 2003. The actual location of our plots was further limited to this area because of ongoing military construction and training activities in the central portion of MCTAB. Within this northwestern area, the test plots were set up in areas with more than 60% guinea grass cover to the extent possible and in locations that did not have any significant populations of native plant species. Cultural resource locations and potential remediation sites were also avoided.

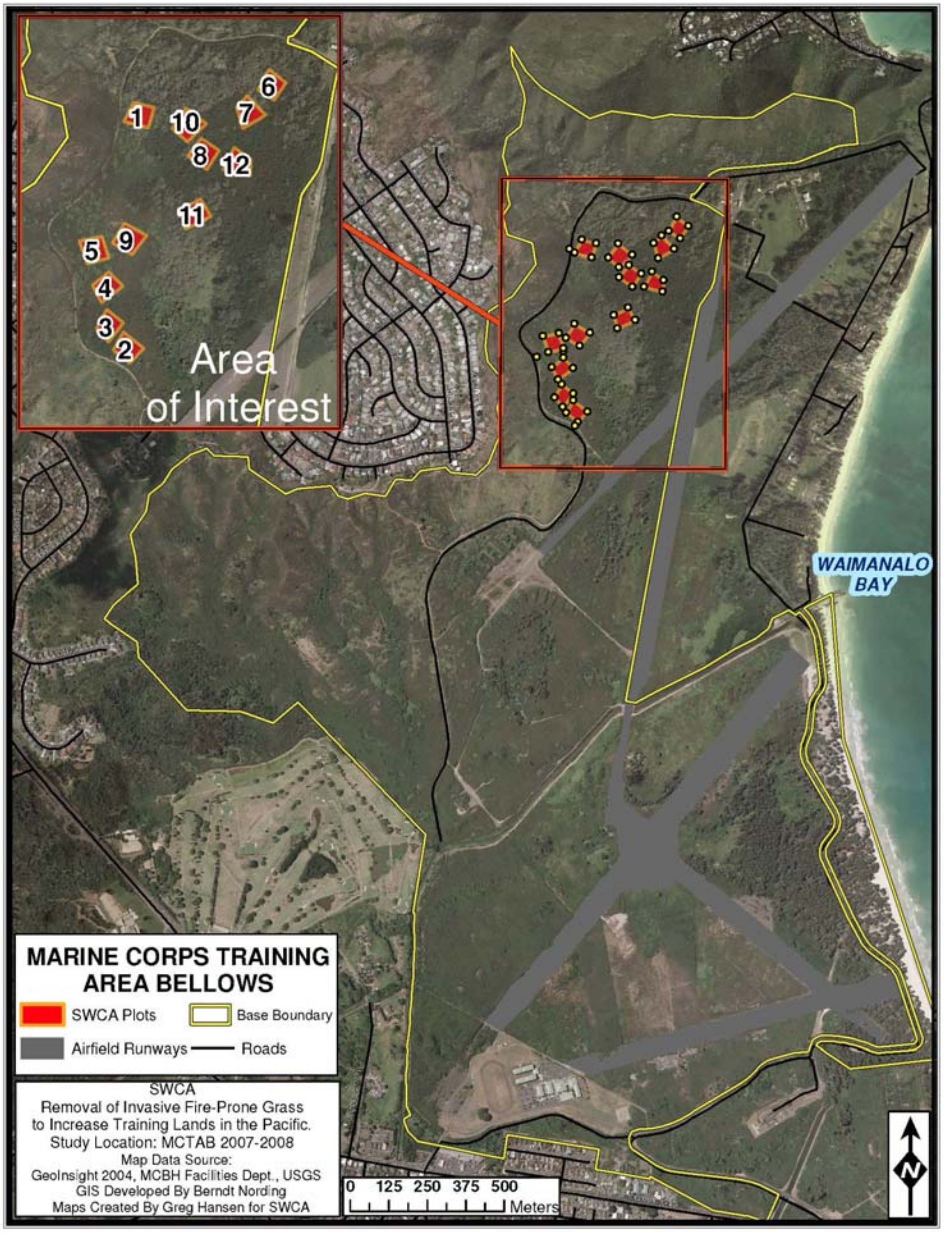

Figure 3. Location of the 12 experimental fuel treatment plots at MCTAB**.**

3.2 Experimental Design and Data Collection

In May and June of 2007, SWCA biologists established twelve 50 m^2 plots in the northwestern area of MCTAB (Figure 3). For each plot, four directions were randomly selected from 12 potential directions ranging from 0 to 330 degrees, spaced 30 degrees apart and radiating out from the center. Then, four 25 m long transects we set-up along randomly selected directions radiating out from the center of the plot (Figure 4).

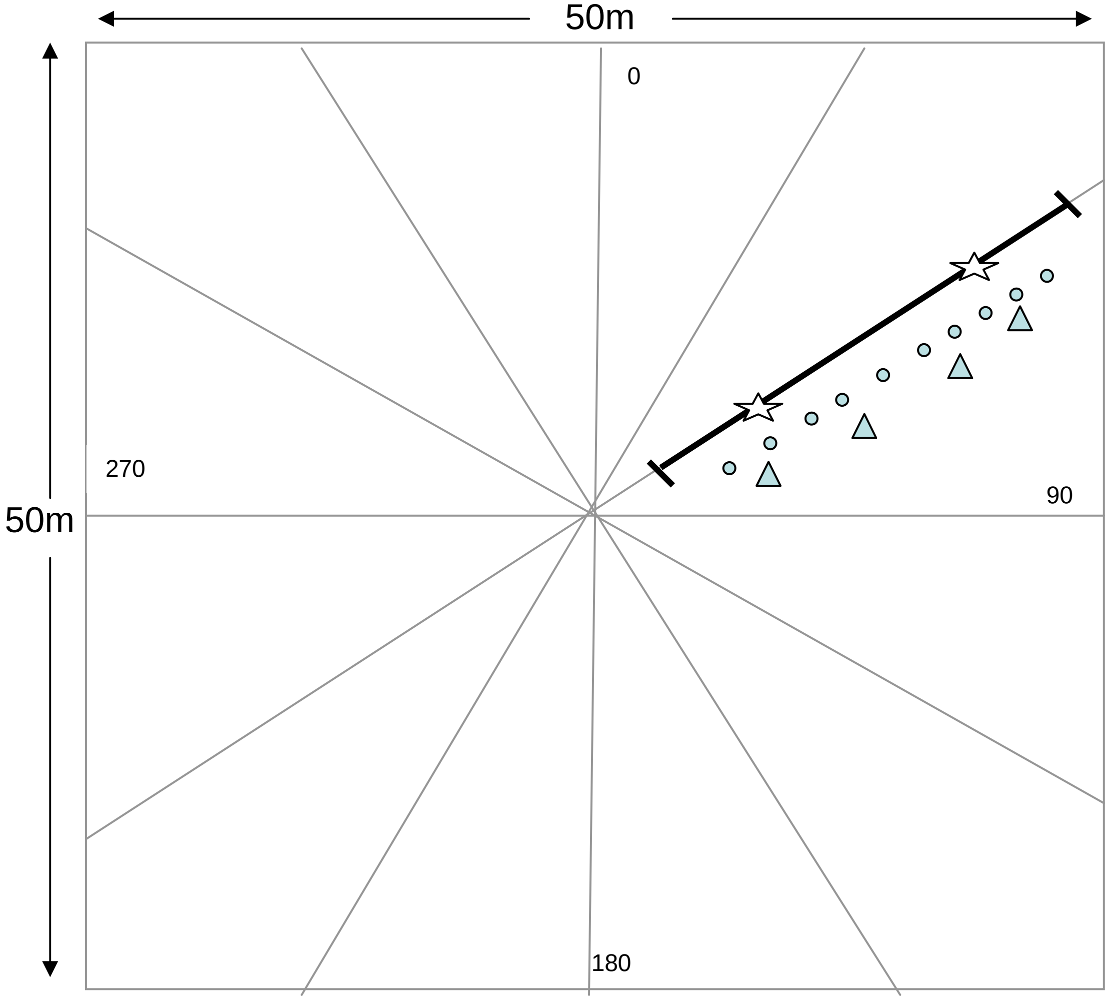

Figure 4. Experimental Design. Not to scale. One of the four transects at 60 degree orientation is shown. Circles represent points for fuel bed depth measurements (n =10/transent, 40/plot). Triangles represent points for biomass collection (n=4/transect, 16/plot). Both ground vegetation and canopy cover (location denoted by star) were read on the transect. Data for downed woody fuels was also collected on the transect.

Data for the following fuel and vegetation parameters were collected:

1. Live herbaceous fuel loads – All above ground herbaceous biomass (which was mainly guinea grass) was sampled at the 5, 10, 15 and 20 m mark at a distance of 2 m to the right side of the transect (n= 4 subplots/transect, 16 subplots/plot), (Figure 5). The biomass was clipped and placed in zip-lock plastic bags and weighed within 12 hours from

collection to obtain the wet weights. The biomass was then transferred from each sub-plot into paper bags for drying in a convection oven at 100º C. The samples were checked for completeness of drying and were considered totally dry if the dry weight of the sub-samples did not change over two consecutive weighing sessions.

Figure 5. Collection of all herbaceous biomass before (L), and after (R).

2. Downed woody debris (DWD) - The downed woody fuels were sampled using Brown's (1974) planar intercept method. For each transect, 1-hr fuels (0 to 0. 6 cm) and 10-hour fuels (0.6 to 2.5 cm) were sampled from the 2 to 4 m mark, 100-hour fuels (2.5 to 8 cm) were sampled from 2 to 7 m mark and 1000-hour fuels (>8 cm) were sampled from 2 to the 22 m mark.

3. Fuel bed and litter depths - The surface fuels were expected to be trampled and disturbed while deploying the transect and reading percent cover of vegetation along the transect. Instead of reading the fuel and litter bed depths along the transect, the fuel and litter bed depth data were recorded prior to collecting the biomass at 10 points starting from the 4 m mark, 2 m to the right side (going clockwise) of each transect (n=10/transect, 30/plot) (Figure 4).

4. Cover of ground vegetation - The pole or point intercept method was used to read cover of ground vegetation. A 0.25 inch diameter pole was dropped at every 25 cm along each transect from 2 to 22 m mark and all plant species that touched the pole was recorded.

5. Canopy cover - The amount of light received by each plot was estimated by indirectly reading the amount of open space within the canopy. A spherical densitometer was used to read the percent of canopy that was open. Canopy cover was read at the 5 and 15 m marks (n = 2/transect, 8/plot) along each transect.

3.3 Treatment Application

Data for the above fuel and vegetation characteristics were collected during October and November 2007. In November 2007, the perimeter of all plots was flagged to ensure that the treatments were uniformly applied without missing the corners. In December 2007, the following four treatments were applied in replicates of three:

1. Mechanical removal of guinea grass (Figure 6). Mechanical removal of guinea grass was accomplished using a Bob Cat – skid steer. Guinea grass was pushed over, run-over, and the shovel end was run over the grubs. Koa haole trees were not intentionally removed while removing the guinea grass; however, in the process of removing the grass some koa haole trees, branches and twigs also broke. The fallen grass and shrub was pressed and somewhat tilled in with the dirt inconsistently throughout the plot. The large kiawe (*Prosopis pallida*) trees that occurred at the study location were not removed. The grubbed material was left in place or distributed over the plot for decomposition. It took a total of three days to apply the mechanical treatment to the three plots.

Figure 6. Mechanical treatment before treatment application (L), and immediately after treatment application (R).

2. Herbicide application (Figures 7 to 10). A 2% solution of the herbicide 'Honcho' (EPA Reg No. 524-445) was used to spray the three herbicide plots. The chemical was hauled on site in a tanker and since all the plots were relatively close to the dirt road a long hose was used to evenly spray all ground vegetation. A total of 450 gallons of solution was used over 1.8 acres. It took a total of 1.5 days to spray three herbicide plots. Herbicides were used only by trained and certified herbicide applicators.

3. Cattle grazing (Figures 11 to 13). Due to the logistic difficulties in maintaining herds of goats or sheep and due to their plant selectiveness, cattle were determined to be the most suitable ungulates for grazing guinea grass on MCTAB (Mark Thorne, personal communication). The stocking rate of cattle for each of the three treatment plots was determined based on the stocking rate calculations in Thorne and Stevenson (2007). Due to logistic and budget constraints, SWCA could not apply the grazing treatment beyond 10 days. For this reason, the two fixed factors while calculating the stocking rate for each plot was the number of days (10 days) and the amount of herbaceous biomass available in each plot. Sixteen cows were used - four mature cows were introduced in plot 6, six mature cows were introduced in each of plot 1 and plot 2. The cattle were transported to the plots and allowed to graze continuously for a period of 10 days. Temporary 'field fences' were established around each of the plots to keep the cattle enclosed within the

plot. A strand of barbed-wire was run around and on top of the ‘field fence’ to keep the cattle from pushing down on the fence. Water troughs for the cattle were provided via potable water trucked to the plots.

4. Control. The control plots did not receive any of the above treatments.

Figure 7. Experimental plot prior to spraying herbicide**.**

Figure 8. Application of herbicide.

Figure 9. Yellowing of guinea grass leaves 9 days after spraying herbicide.

Figure 10. Dead guinea grass leaves 16 days after spraying herbicide.

Figure 11. Introducing cattle into the experimental plot.

Figure 12. Plot # 1 prior to grazing.

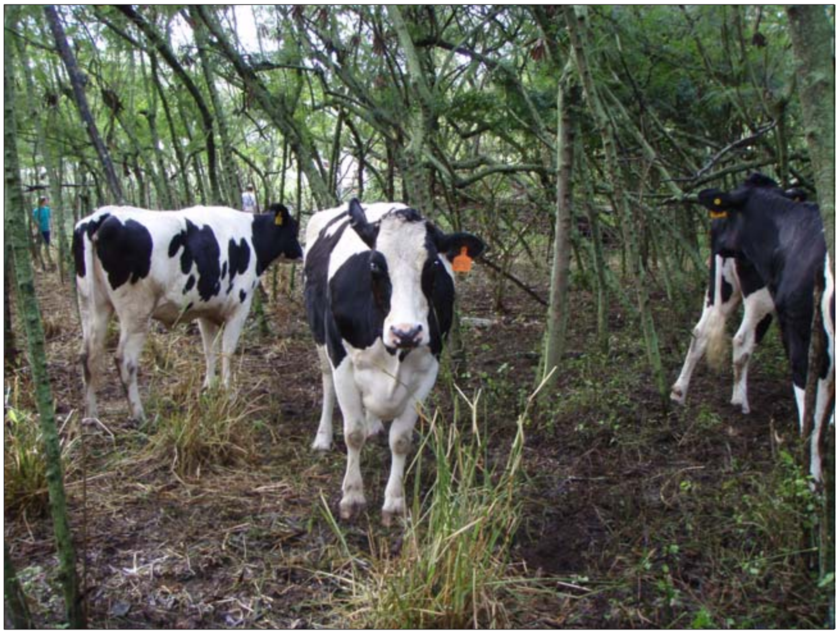

Figure 13. Plot # 1, 9th day of grazing.

The peak effectiveness of the mechanical and grazing treatments was considered to be immediately following the application, while the peak effectiveness of the herbicide treatment was considered to be a few weeks following spraying when the chemical had taken full effect and killed the grass. Thus, the application of the treatments and post-treatment data collection was staggered accordingly in order for the first set of data to be collected from each plot to coincide with the peak effectiveness of the treatments.

The first set of post treatment measurements was taken in January 2008 to measure the quantity of surface fuel loads removed as a result of the treatments. The second set of measurements was taken five months after the treatment applications, in May 2008, and was expected to indicate length of effectiveness of the treatments. All post-treatment fuel sampling and cover data measurements followed that of pre-treatment method, except that the post-treatment biomass were collected from the opposite (left) side of the transect (n=4/transect and 16/plot).

4.0 DATA ANALYSES

All statistical analyses were performed using SYSTAT 12.0 software (SPSS, Inc., Chicago). The distribution of the fuel loads data was skewed to the right and was log transformed. The transformed data were normally distributed as determined by a normal probability plot. The ground vegetation cover data also had a skewed distribution and were transformed using the arcsine square root. The transformed data were normally distributed, as determined by a normal probability plot. Data collected on all the fuel and vegetation parameters were then analyzed using a repeated measures ANOVA with time as the repeated measure, treatment as a fixed factor and either fuel loads, canopy cover, ground vegetation cover, fuel bed and litter depths as the dependent factor. One-way-ANOVAs were performed to determine the differences among treatments within a given time. Where differences were detected post hoc comparison of means was performed using Tukey’s multiple comparisons.

Downed fuel loads for the 1-hr, 10-hr and 100-hr moisture classes were calculated based on the equations from Brown (1974):

$$\text{Tons/acre} = \frac{11.64 * n * d^2 * s * a * c}{Nl}$$

Where n = the number of intersections over all the sample points for each of the fuel moisture classes.
d^2 = the squared average diameters for each size class on the computation sheet.
s = specific gravity of koa haole (Specific gravity of the predominant tree species of haole koa, as taken from Sharma and Venkaiah (1992).
a = weight correction factor. The weight correction factor adjusts for the fact that all particles do not lie horizontally as assumed in the planar intersect theory.
c = average slope correction factor for all sampling planes.
Nl = total length of the sampling line = number of sampling points multiplied by the length of the sampling plane.

All dry weights obtained were converted to tons per acre (t/a).

5.0 RESULTS

5.1 Fuel Loads

Prior to application of the treatments, total fine fuel loads on MCTAB ranged from 1 to 16 tons/acre and averaged 6 tons/acre (±1SE = 0.416). Average fuel loadings by fuel and treatment type are summarized in Appendix 1.

Live herbaceous fuel loads varied over time (Table 1). In January 2008, all plots treated appeared to have lower amounts of live herbaceous fuel loads, with the mechanical plots averaging the lowest (mechanical 0.09 t/a, herbicide 0.17 t/a, grazing 0.17 t/a and control 0.19 t/a). But only the differences between the mechanical and control plots were statistically significant ($P < 0.001$, Figure 5). In May 2008, five months following application of the treatments, the three treatment plots again had lower average live herbaceous fuels (grazing 0.143 t/a, mechanical 0.145 t/a, herbicide 0.16 t/a) compared to the control (0.17 t/a), but this difference was only significant for the grazing plots (Figure 14).

Table 1. Repeated measures ANOVA for live herbaceous fuel loads.

Between subjects					
Source	*SS*	*df*	*MS*	*F*	*P*
Treatment	0.323	3	0.108	3.081	0.029
Error	5.967	171	0.035		
Within subjects					
Source	*SS*	*df*	*MS*	*F*	*P*
Time	1.439	2	0.720	45.368	<0.001
Time*Treatment	0.175	6	0.029	1.842	0.090
Error	5.425	1652	0.016		

Both 1-hr and 10-hr fuels varied over time and there was a significant interaction effect of treatment and time (Tables 2 and 3). In January 2008, the three treatment plots averaged higher 1-hr (mechanical 0.58 t/a, herbicide 0.62 t/a, grazing 0.46) and 10-hr (mechanical 2.95 t/a, herbicide 2.10 t/a, grazing 3.06 t/a) fuel loads than the control (1 hr 0.36t/a, 10 hr 1.68t/a); however, none of these differences were significant (Figures 15 and 16).

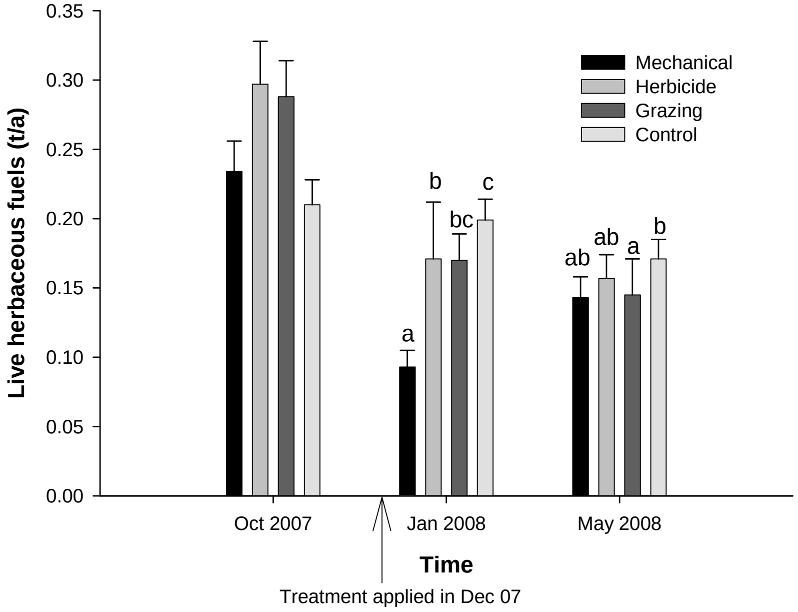

Figure 14. Live herbaceous fuel loads before and after application of the fuel treatments. Different letters within a time period denote significant differences among treatments.

Table 2. Repeated measures ANOVA for 1 hr fuel loads.

Between subjects					
Source	*SS*	*df*	*MS*	*F*	*P*
Treatment	1.122	3	0.374	2.099	0.114
Error	7.835	440	0.178		
Within subjects					
Source	*SS*	*df*	*MS*	*F*	*P*
Time	0.609	2	0.350	4.670	0.012
Time*Treatment	2.025	6	0.338	5.175	<0.001
Error	5.741	88	0.065		

Table 3. Repeated measures ANOVA for 10 hr fuel loads.

Between subjects					
Source	*SS*	*df*	*MS*	*F*	*P*
Treatment	0.829	3	0.276	1.347	0.273
Error	8.204	440	0.205		
Within subjects					
Source	*SS*	*df*	*MS*	*F*	*P*
Time	8.438	2	4.174	67.00	<0.001
Time*Treatment	1.080	6	0.180	2.889	0.013
Error	4.984	80	0.062		

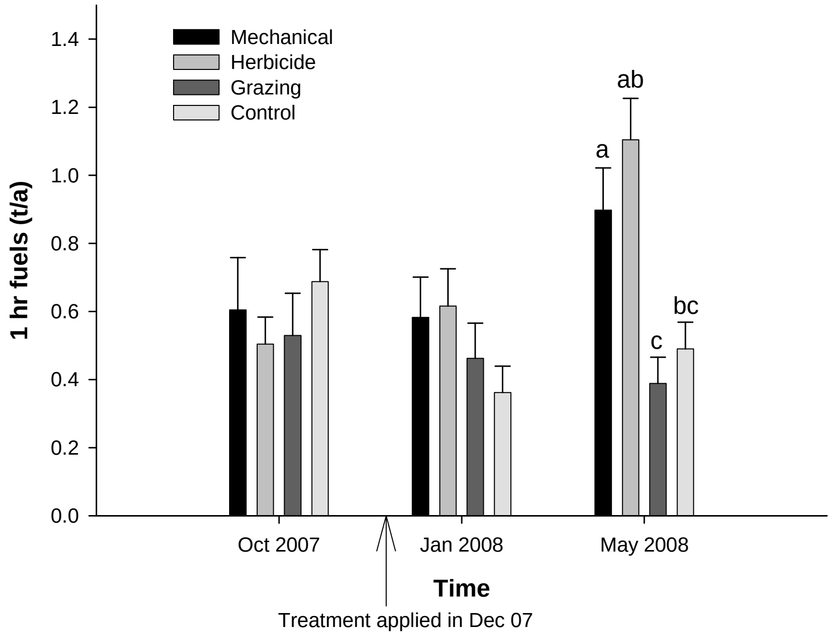

Figure 15. 1-hour fuels before and after application of the treatments. Different letters within a time period denote significant differences among treatments.

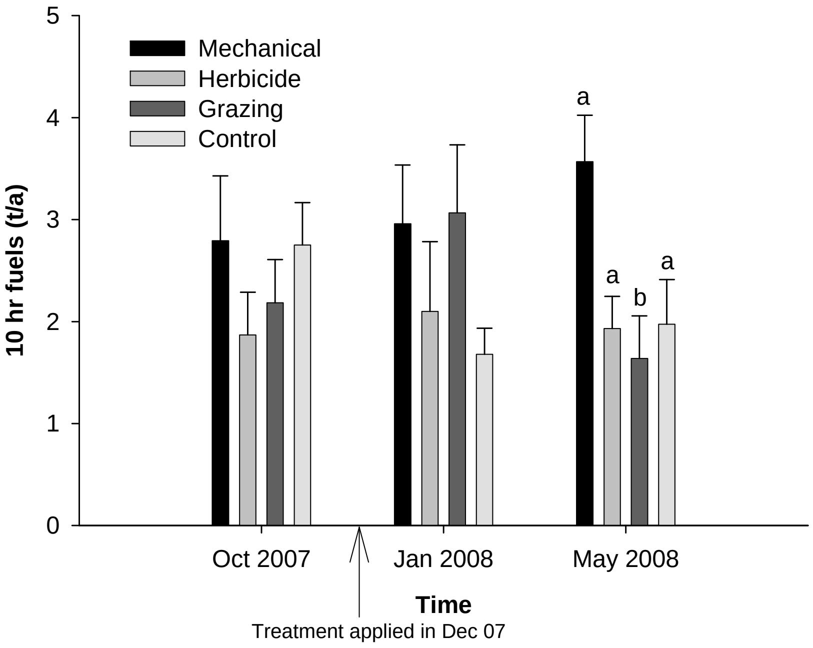

Figure 16. 10-hour fuels before and after application of the treatments. Different letters within a time period denote significant differences among treatments.

In May 2008, the grazing plots (0.38 t/a) averaged the lowest 1-hr fuels compared to the other treatment plots (mechanical 0.90 t/a, herbicide 1.10 t/a, control 0.49 t/a) and were significantly lower compared to the mechanical and herbicide plots (Figure 15). In May 2008, the 10-hr fuels in the grazing plots were the lowest (1.67 t/a) compared to all other plots (mechanical 3.57 t/a, herbicide 1.93 t/a, control 1.97 t/a) (Figure 16).

The 100-hr fuels also varied over time and there was a significant interaction effect of treatment and time (Table 4). Following treatment in December 2007, the three treatment plots (mechanical 6.73 t/a, herbicide 1.70 t/a and grazing 3.80 t/a) averaged higher 100-hr fuel loads, but only the mechanical plots had significantly (P=0.001) higher 100-hr fuel loads than the control (1.40 t/a) (Figure 17).

Table 4. Repeated measures ANOVA for 100 hr fuel loads.

Between subjects					
Source	*SS*	*df*	*MS*	*F*	*P*
Treatment	2.973	3	0.990	10.87	<0.001
Error	1.731	190	0.091		
Within subjects					
Source	*SS*	*df*	*MS*	*F*	*P*
Time	0.398	2	0.199	3.694	0.034
Time*Treatment	1.537	6	0.256	4.756	0.001
Error	2.047	38	0.054		

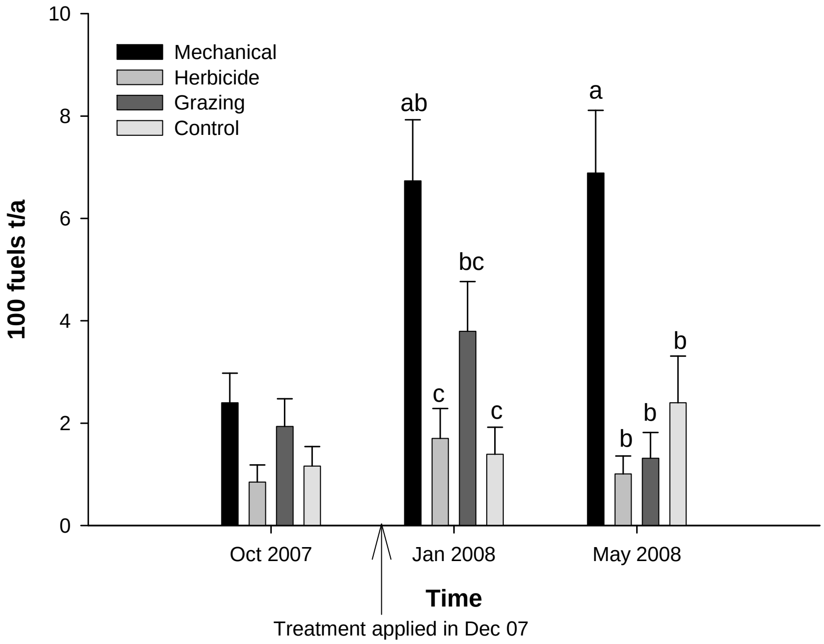

Figure 17. 100-hour fuels before and after application of the treatments. Different letters within a time period denote significant differences among treatments.

Five months after treatment application, the mechanical plots (6.89 t/a) had the highest 100-hr fuels compared to all other treatment plots (herbicide 1.01 t/a, grazing 1.32 t/a and control 2.40 t/a) (Figure 17).

The live herbaceous, 1-hr, 10-hr and 100-hr fuel loads were combined to obtain the total fine fuel loads. The total fine fuel loads did not vary over time. However, there was a significant effect of treatment on the differences in the total fine fuel loads within a given time (Table 5).

Table 5. Repeated measures ANOVA for total fine fuel loads (live herbaceous+1hr+10 hr+100hr).

Between subjects					
Source	*SS*	*df*	*MS*	*F*	*P*
Treatment	2.909	3	0.970	5.517	0.003
Error	7.733	440	0.176		
Within subjects					
Source	*SS*	*df*	*MS*	*F*	*P*
Time	0.111	2	0.056	0.952	0.390
Time*Treatment	1.605	6	0.268	4.587	<0.001
Error	5.133	88	0.058		

In January 2008, the three treatment plots (mechanical 10.36 t/a, herbicide 0.90 t/a, grazing 7.50 t/a) averaged higher total fine fuel loads than the control plots (3.63 t/a) (Figure 18). However, only the mechanical plots were significantly higher fuel loads than the herbicide (P=0.017) and the control (P=0.007) (Figure 18). By the end of the experiment in May 2008, grazing plots (3.47 t/a) averaged the least total fine fuel loads compared to other treatments (mechanical 11.50 t/a, herbicide 4.20 t/a and control 5.03 t/a), but this difference was only significantly (P<0.001) lower than the mechanical plots (Figure 18).

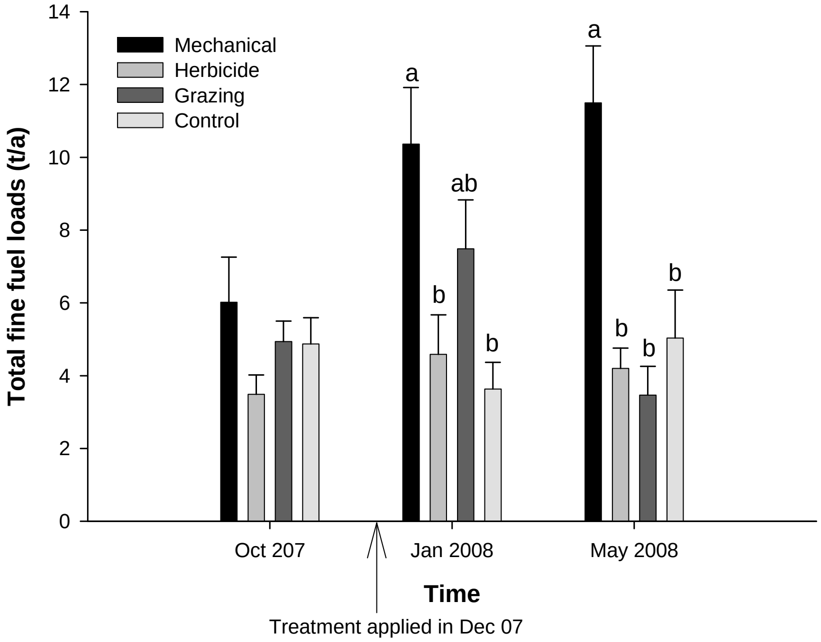

Figure 18. Total fine fuel loads before and after application of the treatments. Different letters within a time period denote significant differences among treatments.

5.2 Fuel and Litter Bed Depth

Data for fuel and litter bed depths were pooled together to give a total measure of 'fuel and litter bed depths'. Fuel bed depths varied over time and there was a significant interaction of treatment and time on the fuel bed depths (Table 6).

Table 6. Repeated measures ANOVA for fuel bed depths.

Between subjects					
Source	SS	df	MS	F	P
Treatment	8.871	3	2.957	30.875	<0.001
Error	45.491	475	0.096		
Within subjects					
Source	SS	df	MS	F	P
Time	12.915	2	6.485	116.921	<0.001
Time*Treatment	66.520	6	11.087	200.733	<0.001
Error	52.469	950	0.055		

Following treatment application, cattle grazing plots in January 2008, had the lowest fuel bed depths (27 cm, 0.8 ft) compared to all other treatments (mechanical 39 cm, 1.3 ft; herbicide 138 cm, 4.5 ft and control 68 cm, 2.2 ft). However, in May 2008, the mechanical treatment (89 cm, 2.9 ft) had the highest and herbicide treatment (20 cm, 0.6 ft) had the lowest fuel bed depths compared to all other treatments (Figure 19, Appendix 1). Prior to application of the treatments, there were already differences in the mechanical, herbicide, and control plots in fuel bed depths. The pattern of these differences remained the same after application of the treatments and hence the relative effect of these treatments on changes in fuel bed depths in January 2008 is not clear (Figure 19).

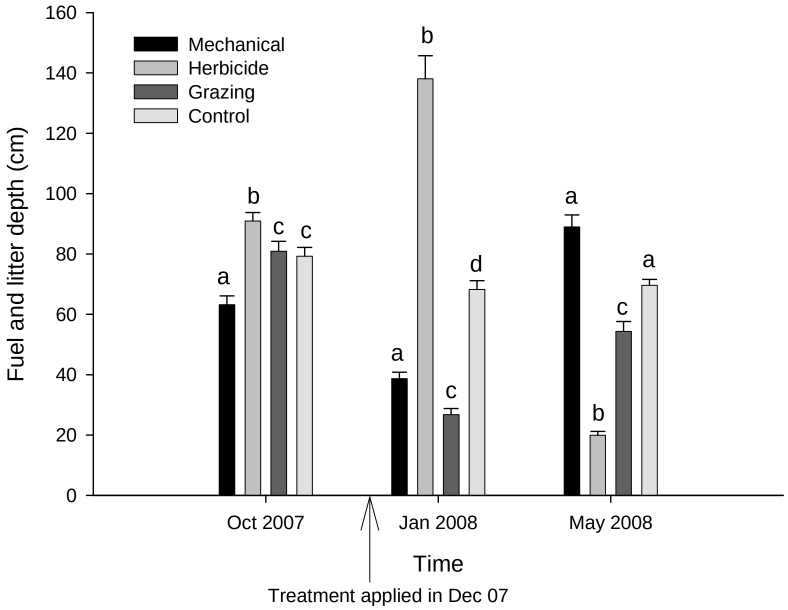

Figure 19. Fuel bed depths before and after application of the treatments. Different letters within a time period denote significant differences among treatments.

5.3 Percent Moisture

Percent moisture of live herbaceous fuels varied over time and there was a significant interaction effect of treatment and time (Table 7).

Table 7. Repeated measures ANOVA for percent moisture of live herbaceous fuels.

Between subjects					
Source	*SS*	*df*	*MS*	*F*	*P*
Treatment	18,566.8	3	6,188.9	27.27	<0.001
Error	36,756.4	162	226.8		
Within subjects					
Source	*SS*	*df*	*MS*	*F*	*P*
Time	38,100.4	2	19,050.2	106.3	<0.001
Time*Treatment	34,420.6	6	5737.7	32.01	<0.001
Error	58,058.9	324	179.2		

Prior to the application of treatments, the percent moisture of the mechanical (36%) and grazing (33%) plots was significantly lower compared to the percent moisture of the herbicide (43%, P=0.015 for mechanical, P<0.001 for grazing) and control (44%, P=0.005 for mechanical and P<0.001 for grazing) plots (Figure 20). After application of treatments in January 2008, as well as in May 2008, herbicide plots had significantly lower percent moisture (43% in January and 28% in May) compared to all other treatments (January: mechanical 52%, grazing 71%, control 70%; May: mechanical 64%, grazing 51%, control 51%) (Figure 20).

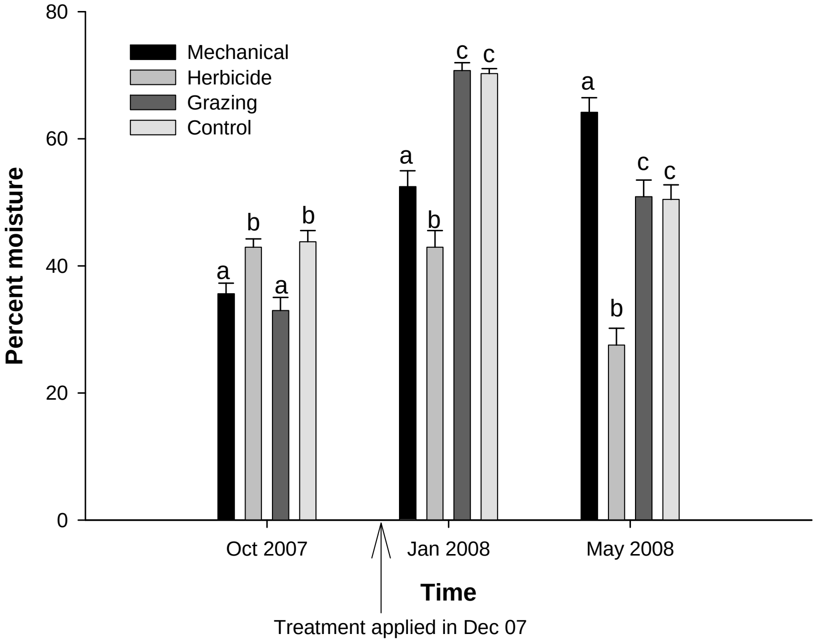

Figure 20. Percent moisture of live herbaceous fuels before and after application of the treatments. Different letters within a time period denote significant differences among treatments.

5.4 Percent Cover of All Other Species Excluding Guinea Grass

Percent cover of all other species pooled together, excluding guinea grass, varied over time and there was a significant interaction effect of treatment and time (Table 8).

Table 8. Repeated measures ANOVA for percent cover of other species excluding guinea grass.

Between subjects					
Source	*SS*	*df*	*MS*	*F*	*P*
Treatment	0.783	3	0.263	3.687	0.019
Error	2.997	42	0.071		
Within subjects					
Source	*SS*	*df*	*MS*	*F*	*P*
Time	1.382	2	0.691	29.387	<0.001
Time*Treatment	3.184	6	0.531	22.568	<0.001
Error	1.975	84	0.024		

Prior to treatment application, percent cover of all other species averaged highest in herbicide plots (33%) compared to all other treatment plots. However, this difference was only significantly higher than the mechanical (11% P=0.05) and grazing (8% P=0.014) plots. In January 2008, the three treatments had significantly lower percent cover (mechanical 9% P=0.04, herbicide 1% P=0.001, grazing 6% P=0.028) than the control (19%); however, there were no significant differences in the pooled percent cover of all species among the three treatment plots (Figure 21). At the end of the experiment in May 2008, mechanical treatment plots had significantly greater percent cover (59%) of all other species than all other treatments (herbicide 6% P<0.001, grazing 15% P<0.001 and control 17% P<0.001) (Figure 21).

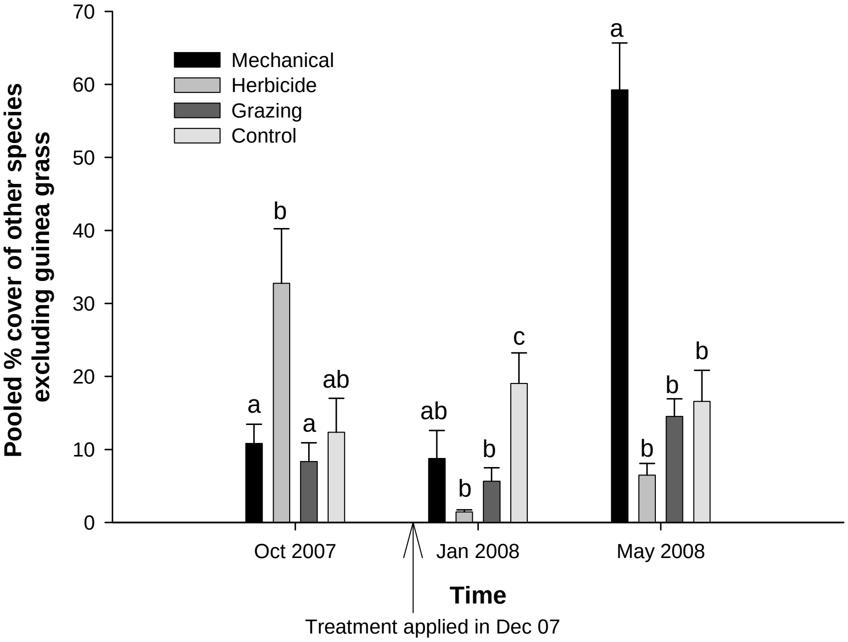

Figure 21. Pooled cover of all other species excluding guinea grass before and after application of the treatments. Different letters within a time period denote significant differences among treatments.

5.5 Percent Cover of Bare Soil Available

Percent cover of bare soil available did not vary over time; however, there was a significant influence of treatment on the differences in percent bare soil cover within a given time (Table 9).

Table 9. Repeated measures ANOVA for percent cover of bare soil.

Between subjects					
Source	*SS*	*df*	*MS*	*F*	*P*
Treatment	0.582	3	0.194	3.687	0.022
Error	2.285	42	0.054		
Within subjects					
Source	*SS*	*df*	*MS*	*F*	*P*
Time	1.382	2	0.691	29.387	<0.001
Time*Treatment	3.184	6	0.531	22.568	<0.001
Error	1.975	84	0.024		

In January 2008, following application of the treatments, percent bare soil available averaged lowest in the mechanical treatment (24%) compared to the other treatment plots (herbicide 6%, grazing 11% and control 8%). This difference was only significant for the herbicide (P=0.005) and control plots (P=0.021). Five months after the application of the treatments, in May 2005, there was a similar trend in the percent bare soil available, but the herbicide plots had the lowest percent bare soil (2%) available compared to all other treatments (mechanical 14%, grazing 13%, control 10%) (Figure 22).

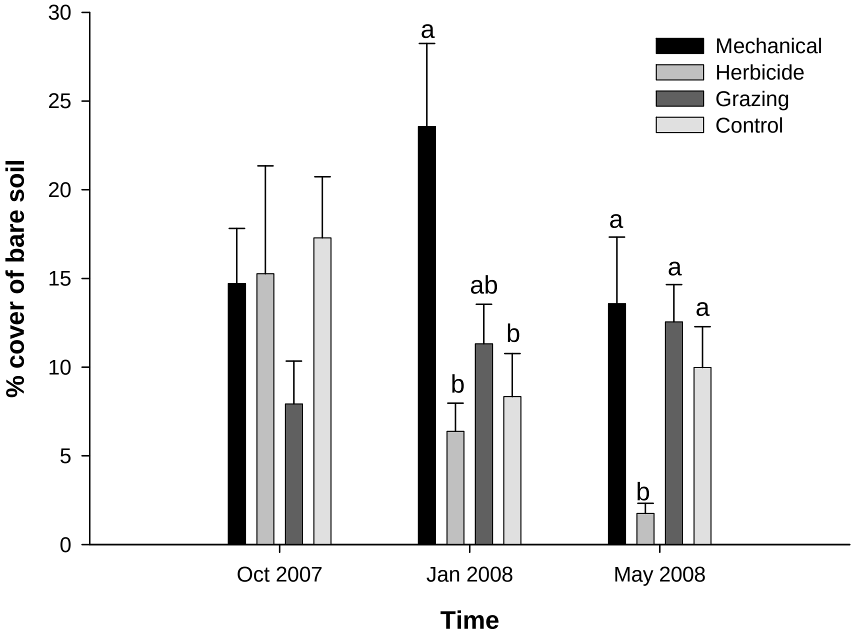

Figure 22. Percent moisture of bare soil available before and after application of treatments. Different letters within a time period denote significant differences among treatments.

5.6 Percent of Canopy Open

Prior to application of the treatments in September 2007, the percent of open canopy in grazing plots (53%) averaged higher than all other treatment plots (mechanical 41%, herbicide 39%, control 37%).

However, this difference was only significant (P=0.03) for the control plots. In January 2008, the differences in the treatments had a similar pattern to that prior to the treatment application. The percent of canopy open in grazing (41%) averaged greater than all other plots (mechanical 39%, herbicide 33%), but was only significantly higher than the control plots (35%). In May 2008, grazing plots still averaged higher percent of open canopy than other plots; however, there were no significant differences among the treatments (Table 10, Figure 23).

Table 10. Repeated measures ANOVA for percent of open canopy.

Between subjects					
Source	*SS*	*df*	*MS*	*F*	*P*
Treatment	1409.5	3	469.84	3.641	0.021
Error	4903.2	38	129.03		
Within subjects					
Source	*SS*	*df*	*MS*	*F*	*P*
Time	841.7	2	420.87	7.428	<0.001
Time*Treatment	619.6	6	103.28	1.823	0.106
Error	4306.5	76	56.66		

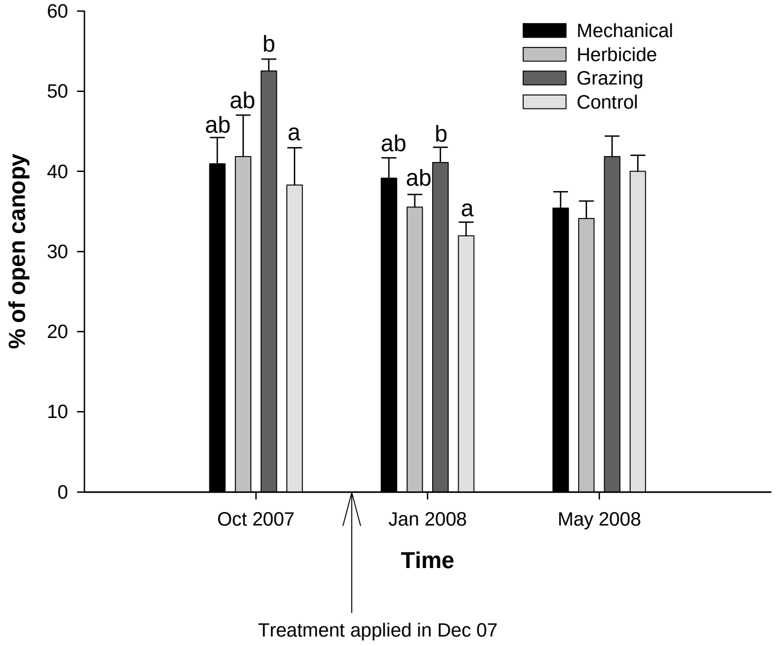

Figure 23. Percent of open canopy before and after application of the treatments. Different letters within a time period denote significant differences among treatments.

5.7 Horizontal Continuity of Fuels

Following application of the treatments, in January 2008, unlike the control and herbicide treatments (Figure 10), the process of removing guinea grass mechanically (Figure 6) and through cattle grazing (Figure 13) created several patches of bear ground and broke up the continuity of fuels. By the end of the experiment in May 2008, the grazing plots continued to have relatively more open patches of bare soil (Figure 24), while guinea grass had grown back and occupied all the bare patches created in the mechanically treated plots (Figure 25). The herbicide plots also had a continuous mass of dead guinea grass five months after treatment application in May 2008 (Figure 26).

5.8 Treatment Costs

The total cost of applying the treatments in this experimental study was $23,940. The breakdown for each treatment is as follows:

Mechanical - $5200. The cost of renting the skid steer machine and labor for each 0.6 acre plot was approximately $1,733. Thus the total for 3 mechanically treated plots $1,733 x 3 = $5,200.

Herbicide – $4870. Cost of herbicide was $370. Labor cost for each 0.6 acre plot was $1,500; so for 3 plots $1,500 x 3= $4,500. The total cost of applying the herbicide treatment = $4,500 + $370 = $4,870.

Grazing - $13,870. The bulk of the cost ($4,950 + $7,920 = $12,870) in applying the grazing treatment was in erecting the fences to keep the cattle enclosed within the study plot.

Table 11. Grazing treatment costs.

Fence material-	@ $2.5/ ft for 660 ft	$4,950
Labor for fencing -	@ $4/ ft for 660 ft	$7,920
Cost of renting 16 cows -	@ $25 per cow	$400
Cost of hauling the cows to & from the study site -	@ $200/ trip	$400
Labor cost for monitoring and providing water to cows -	-	$200
Total cost of grazing treatment		$13,870

Figure 24. In May 2008 cattle grazing plots still had patches of bare soil that broke up the continuity of guinea grass fuels.

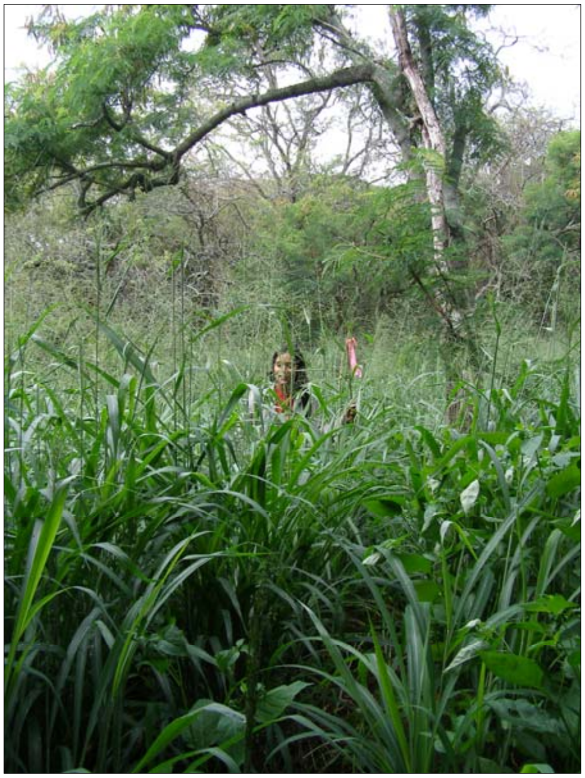

Figure 25. Continuity of fuels in mechanical plots in May 2008.

Figure 26. Continuous mass of dead guinea grass in the herbicide plots in May 2008.

6.0 DISCUSSION

6.1 Fuel Loads

SWCA conducted this experimental fuel treatment analysis at MCTAB with the objective of quantifying the amount of guinea grass fuel loads and determining which treatment (mechanical removal, herbicide application or cattle grazing) would most effectively reduce them. The average surface fuel loads of 6 t/a in the guinea grass-koa haole systems on MCTAB appear to be considerably lower that those at the Makua Military Reservation and Schofield Barracks. Beavers (1999, 2001) found that in a guinea grass dominated community, average surface fuel loads at Makua ranged from 1.5 to 25 t/a and averaged 9 t/a while those at Schofield Barracks ranged from 8 to 18 t/a and averaged at 14 t/a. Warren et al. (2007) reported the herbaceous fuel loads from a koa haole- guinea grass community in Makua Military Reservation to be around 5.5 t/a.

In this experiment, SWCA found that guinea grass was the dominant ground cover in the experimental plots and thus comprised the bulk of live herbaceous fuels loads at MCTAB. Mechanical treatment was the fastest method of reducing guinea grass fuel loads (Figure 14). However, in May 2008, guinea grass fuel loads decreased by 6%, 15% and 24% in the herbicide, control and grazing plots respectively, but increased by 56% in the mechanical plots. Thus, it seems that the ***long term effectiveness*** of cattle grazing over the 5 months (January to May 2008) post application of treatment was better than other treatments in maintaining low guinea grass fuel loads. At the end of the experiment in May 2008, cattle grazing plots also had the lowest 1-hr and 10-hr fuel loads and although not statistically significant, the total fine fuel loads also averaged the lowest in the cattle grazing plots.

In January 2008, in spite of guinea grass being removed, the cattle grazing plots did not show a statistically significant reduction in guinea grass (live herbaceous) fuel loads compared to the herbicide and control plots (Figure 14). This may be due to several reasons, among them: 1) over the 10 days of grazing, cattle broke the fence and got out of one of the plots (plot # 1) twice, though they were then returned to the plot later that same day; 2) the second time the cattle escaped the plot on the 9th day, it was not possible to return them that same day;

therefore, plot # 1 received at least one less day of grazing and trampling pressure compared to the other plots. It is conceivable that the effect of the grazing treatment in lowering the guinea grass fuel loads would have been more obvious if plot 2 had received the full grazing treatment.

Unlike the other treatments, the texture and palatability of guinea grass affected uniform application of the grazing treatment. Prior to application of the treatment, plot 2 had significantly taller (110 cm/ 3.6 ft) guinea grass compared to plots 1 (71 cm/ 2.3 ft) and 6 (1.9 ft), ($P<0.001$ for plots 1 and 6). These taller grasses were coarse and therefore less palatable to cattle. As such, cattle removed significantly lower amounts of guinea grass in plot 1 (34% $P=0.007$) and plot 2 (39% $P<0.001$) compared to plot 6 (58%). In spite of applying appropriate stocking rates of cattle, it is likely that differences in the texture / palatability of guinea grass among the grazing plots induced considerable variability in the application of the grazing treatment and therefore made it less likely to detect statistically significant differences.

Results indicate that mechanically removing guinea grass in December 2007 led to a significant increase in the total fine fuel loads on MCTAB in January 2008 (Figure 18). Mechanically removing guinea grass significantly increased (by 180%) the 100-hr fuels (Figure 6 and 20) which probably led to an overall increase in the fine fuel loads of the system. Even five months after the treatment, the total fuel loads in the mechanical plots remained higher than the other treatment plots. During the process of mechanically removing guinea grass, small branches and twigs of koa haole trees broke and fell to the ground which probably contributed to the observed increase in the total fuel loads (Figure 6). A similar trend was also found in other studies of temperate woodland ecosystems: mechanical removal led to an increase in surface fuel loads due to conversion of canopy fuels to surface fuels (Alexander and Yancik 1977, Graham et al. 2004). ***This suggests that unless the slashed vegetation is removed after mechanically treating the area, it undermines the effectiveness of the mechanical fuel treatment.***

6.2 Fuel Bed Depth

Lower fuel bed depths contribute to reducing the intensity of grassland fires. The grazing treatment was the most effective in reducing the fuel bed depths in January 2008. The fuel bed depths in the herbicide plots remained higher compared to the other treatments following application. In contrast, the herbicide plots had the lowest fuel bed depths in May 2008, five months after the application of the treatments. The drying, wilting and decomposition of vegetation in sprayed plots probably led to this decrease in the fuel bed depths over time; whereas, the re-sprouting and re-growth of vegetation in the mechanical and grazing plots led to an increase in the fuel bed depths over time. In spite of the observed increase in May 2008, grazing plots still had 22% lower fuel bed depths than the control; whereas, the mechanical plots had 22% higher fuel bed depths than the control. ***This suggests that the overall effectiveness of grazing treatments in reducing and maintaining fuel bed depths is higher than the mechanical plots.***

6.3 Percent moisture

Fuel moisture affects all aspects of fire behavior, but it is affected by past and present weather conditions as well as biological processes. Fuel moisture changes in all time scales: abruptly, daily, seasonally, and annually (Pyne et al 1996). The effect of experimental treatments on percent moisture of the fuels cannot be determined at MCTAB because it rained prior to and while collecting data for some of the experimental plots. However, in general, guinea grass fuel moistures averaged 44%, 70% and 50% in October 2007, January 2008, and May 2008, respectively. In creating custom fuel models of guinea grass, Beavers (2001) considered a 26% fuel moisture to be high and an 8% fuel moisture to be low and pose high fire threat. Compared to the Makua Military Reservation on O‘ahu, the fuel moisture of guinea grass on MCTAB could be considered relatively high. This is not surprising as MCTAB is located on the windward side of the island that receives higher rainfall compared to MMR and Schofield on the leeward side of the island.

6.4 Percent Cover of All Species Excluding Guinea Grass and Percent Bare Soil

The increase in the percent cover of all other species in the mechanical plots measured in May 2008 (Figure 25) might be explained by the combination of differences in climatic conditions and the dynamics of the vegetation in the post treatment environment. The process of mechanically removing guinea grass significantly increased (by 38%) the amount of bare soil available. This availability of bare soil also overlapped with the peak rainfall season in Hawai'i which ranges from around December to February (Juvik and Juvik 1998). SWCA observed a rapid increase in the abundance of several weedy species such as popolo (*Solanum americanum*), *Rivina humilis*, and Chinese violet (*Asystacia ganetica*) within a month following application of the mechanical treatment. It is possible that the other plant species in the mechanical plots took advantage of this availability of water and bare soil in combination with the temporary release of competition from the grasses which brought about an increase in the cumulative percent cover of these weedy species.

6.5 Percent of Open Canopy

Fuel treatments did not influence the percent of open canopy, that is, the amount of light reaching the forest floor. After several branches of koa haole trees were knocked over during mechanical removal of guinea grass, the amount of canopy opened up in these plots increased, thereby increasing the light levels in these plots. A spherical densitometer was used to read the canopy cover to the nearest 25%. Perhaps reading the amount of light directly at a finer scale would have better captured the differences of the treatments on the canopy cover.

6.6 Horizontal Continuity of Fuels

Horizontal continuity of fuels is an important factor in the behavior of fuels and directly affects fire behavior. Areas with patchy fuels are likely to burn less intensely than those with continuous fuels, and offer better opportunities for fire suppression during an event of fire. Because the mechanical and grazing treatments involved actual removal of guinea grass, they appeared to be more effective than the herbicide treatment in creating open patches of bare soil. In less than two months; however, the vegetation in the mechanical plots grew back and essentially covered all the bare soil available. At the end of the experiment in May 2008, cattle grazing plots still had more discontinuous vegetation compared to the other treatment plots. ***This suggests that in the event of a wildland fire, areas grazed by cattle will probably not burn as intensely as the other treated plots.***

6.7 Treatment Costs

It could be misleading to simply extrapolate the cost of experimental treatments to treatment applications at a larger scale. Table 12 summarizes the costs of applying the experimental treatments and the estimated cost of (mechanical removal, herbicide application and cattle grazing) at the larger scale of approximately 500 acres comprising Training Area 3 of MCTAB. Training Area 3 was selected for estimating the costs because almost all of the guinea grass on MCTAB is limited to this region (Geo Insight International 2003). Estimates were made after consulting with Matt Shirman of Hui Ku Maoli Ola Native Plant Nursery and Darrell Bueno of the 'Cattle Company' whose services were contracted to perform the experimental treatments. The mechanical treatment is estimated to be applied at least three times a year for it to be effective.

7.0 CONCLUSIONS AND FUEL TREATMENT RECOMMENDATIONS FOR MCTAB

1) Cattle grazing was the most effective in reducing the fuel bed depths in the guinea grass / koa haole plant community on MCTAB over the long-term.
2) The effectiveness of the treatments in reducing the guinea grass fuel loads varied with time. Mechanical treatment was the most effective in the short-term reduction of guinea grass (live herbaceous) fuels; however, grazing treatment was the most effective in maintaining low quantities of guinea grass fuels loads for a period of five months post-treatment.

3) Cattle grazing treatment was the most effective in maintaining the discontinuity (patchiness) of guinea grass fuels for a five month period post-treatment.
4) The process of mechanically removing guinea grass converted canopy fuel to surface fuel and led to an increase in the total fine fuel loads in the koa haole-guinea grass community on MCTAB.

Table 12. Estimated cost of applying fuel reduction treatments on 500 acres of Training Area 3 (TA 3) on MCTAB on an annual and 10 year basis.

Treatment	Estimated annual cost for 500 acres of TA 3	Estimated cost over 10 years
Mechanical removal ➢ Crushed grass and debris left on site.	$8000 for one time removal. Based on the results of the study the treatment would need to be applied at least 3 times a year. Hence total cost	
Total cost	**$24,000**	**$240,000**
Herbicide – this includes only application and not removal of the dead grass.		
➢ Herbicide cost	$50,000	
➢ Labor	$2050	
Total cost	**$52,000**	**$520,000**
Grazing		
➢ Initial and one time cost of fencing the perimeter	Part of TA 3 is already fenced. Depending on topography the remainder of the perimeter to be fenced ranges from 20,000 to 44,000 ft.* Hence cost of fencing perimeter @ $4/ ft ranges from $80,000 to $176,000.	It would take from 3.3 yrs ($80,000/$24,050) to 6.3 yrs ($151,950/$24,050) to recover the cost after which there could be a gain in the range of $24,050 per year. So income could range from $72,150 ($24,050 x remainder of 3.7 years) to $161,135 ($24,050 x 6.7 yrs)
➢ Ag/Cow income	Stocking rate is ~1 cow/3 acres year round, so ~ 167 cows for 500 acres. If Ag outlease starts the same year – then income @ $12/head/month for 167 cows is ~ $24,050 would range from: $55,950 ($176,000 - $80,000) to $151,950 ($176,000 - $24,050)	
Total income	**$80,000 to $151,950**	***Annual Income range $72,150 to $161,135***

* The actual location of the perimeter fence will depend upon how much slope the cattle can handle while grazing on the east facing slopes of Keolu hills in TA 3. The perimeter to be fenced was estimated to range from 20,000 to 44,000 ft.

Based on the overall effectiveness of cattle grazing in lowering and maintaining low fuel loads on MCTAB, as well as the cost effectiveness of this treatment over a 10 year period, SWCA recommends that MCTAB consider establishing a formal grazing program to remove and maintain low guinea grass fuel loads. The initial cost of setting up a perimeter fence will be high compared to the mechanical or herbicide removal, but the costs would be recovered in less than 10 years and the income thereafter could be channeled back into fence maintenance and/or other environmental work on MCTAB.

Although mechanical treatment is effective in reducing live herbaceous fuel loads, it significantly adds to the 100-hr fuels thereby increasing the amounts of total fine fuel loads on MCTAB. Mechanical fuel reduction treatments should probably not be applied for fuel reduction as they tend to increase the fine fuel loads on MCTAB. Furthermore, dense stands of koa haole without the grass are considered suitable for the various training activities. The process of mechanically removing guinea grass also removes some koa haole trees and increases the amount of fallen stems. Unless the fallen logs and other vegetation is mulched in place or removed from the site, the mechanically treated areas may not be conducive to training exercises. Mechanically removing the fuels also exposes a lot of bare soil which most likely will become a germinating ground for new invasive plant species.

This experimental study by SWCA provides the baseline data on fuel loads under different fuel treatments. It is recommended that this data be used to construct site specific fire behavior models for MCTAB under different treatment and weather conditions. Fire models could lend further insight into the effectiveness of each of the treatments by predicting the likelihood of fire ignition, how the fire would carry, and the ease of fire suppression under each fuel treatment and weather condition on MCTAB.

Finally, fuel reduction requires constant effort on MCTAB in order to minimize the risk of fast moving, high intensity fires sweeping through the training areas. When fuel treatment efforts cease overtime the system reverts to being a fire prone grass dominated plant community. SWCA recommends that MCTAB consider fuel conversion as an alternate strategy to fuels reduction. This involves replacing the existing fire prone guinea grass in the understory with vegetation that is less fire prone and also supports the current land use at MCTAB. While the original research project as first conceived had intended to plant suitable native/non-invasive fire resistant species on one of the treated, the project fell short of funding. Before attempting large scale restoration, it is recommended that MCTAB conduct vegetation restoration or fuel conversion experimental tests to determine what suite of species are suitable for replacing guinea grass while supporting the various training exercises conducted.

8.0 ACKNOWLEDGEMENTS

SWCA acknowledges the support and input received for this project from the following individuals and/or agencies.

Dr. Diane Drigot. Senior Natural Resource Manager. Marine Corps Base Hawaii.

Lance Bookless. Natural Resource Manager. Marine Corps Base Hawaii.

Daniel Geltmacher. Marine Corps Base Hawaii.

Andrew Beavers. Centre for Environmental Management of Military Lands. Colorado State University.

Dr. Mark Thorne. College of Tropical Agriculture and Human Resources. University of Hawaii at Manoa.

Dawn Greenlee. U.S. Fish and Wildlife Service. Honolulu. HI.

Kapua Kawelo. Oahu Army Environmental.

Dr. James Leary. Department of Plant and Environmental Protection Sciences. University of Hawaii at Manoa.

Dr. Boone Kauffman. U.S. Forest Service. Pacific Northwest Research Center. Hilo. Hawaii.

SWCA also acknowledges Amy Brown Curtis and Shantel Keuma, two students who volunteered to help on this project as part of their school environmental program. We are also grateful to Victor Bovino for all his help with data collection and other logisitical support on this project.

Most importantly, SWCA acknowledges the DoD Legacy Resource Management Program and the support staff in allowing this project to take place.

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APPENDIX 1

Mean values of fuel loading by size class, fuel and litter bed depths, and other vegetation parameters for pre and post treatment dates.

Treatment	Fuel class t/a or Parameter	Pre-treatment (October 2008)		Post treatment (Jan 2008)		Post treatment (May 2008)	
		Mean	SE	Mean	SE	Mean	SE
Mechanical	1 hr	0.61	0.15	0.58	0.12	0.90	0.12
Herbicide	1 hr	0.50	0.08	0.62	0.11	1.10	0.12
Grazing	1 hr	0.53	0.12	0.46	0.10	0.39	0.08
Control	1 hr	0.69	0.09	0.36	0.08	0.49	0.08
Mechanical	10 hr	2.79	0.64	2.96	0.57	3.57	0.45
Herbicide	10 hr	1.87	0.42	2.10	0.68	1.93	0.32
Grazing	10 hr	2.18	0.42	3.06	0.67	1.64	0.42
Control	10 hr	2.75	0.42	1.68	0.26	1.97	0.44
Mechanical	100 hr	2.40	0.58	6.73	1.19	6.89	1.22
Herbicide	100 hr	0.85	0.33	1.70	0.58	1.01	0.35
Grazing	100 hr	1.93	0.54	3.79	0.97	1.32	0.50
Control	100 hr	1.16	0.38	1.39	0.53	2.40	0.91
Mechanical	Live herbaceous	0.23	0.02	0.09	0.01	0.14	0.02
Herbicide	Live herbaceous	0.27	0.03	0.17	0.04	0.16	0.02
Grazing	Live herbaceous	0.29	0.03	0.17	0.02	0.13	0.02
Control	Live herbaceous	0.27	0.02	0.20	0.02	0.17	0.01
Mechanical	Total fine fuels	6.02	1.24	10.36	1.56	11.50	1.56
Herbicide	Total fine fuels	3.49	0.53	4.59	0.72	4.20	0.56
Grazing	Total fine fuels	4.94	0.56	7.49	1.34	3.47	0.79
Control	Total fine fuels	4.87	0.72	3.63	0.73	5.03	1.32
Mechanical	Fuel bed depth	63.22	2.91	38.70	2.14	88.97	3.95
Herbicide	Fuel bed depth	90.91	2.84	138.05	7.60	19.94	1.26
Grazing	Fuel bed depth	80.90	3.27	26.78	2.02	54.33	3.29
Control	Fuel bed depth	79.22	2.95	68.24	2.92	69.58	2.01
Mechanical	% moisture	35.59	1.67	52.47	2.48	64.14	2.29
Herbicide	% moisture	42.92	1.32	42.92	2.63	27.53	2.65
Grazing	% moisture	32.98	2.06	70.70	1.25	50.87	2.62
Control	% moisture	43.79	1.76	70.26	0.78	50.46	2.28
Mechanical	% cover veg	10.80	2.65	8.75	3.84	59.26	6.41
Herbicide	% cover veg	32.75	7.48	1.44	0.30	6.48	1.59
Grazing	% cover veg	8.33	2.58	5.66	1.84	14.51	2.42
Control	% cover veg	12.35	4.65	19.03	4.18	16.56	4.28
Mechanical	% bare soil	14.72	3.10	23.56	4.68	13.58	3.75
Herbicide	% bare soil	15.26	6.09	6.38	1.59	1.75	0.58
Grazing	% bare soil	7.92	2.42	11.32	2.23	12.55	2.10
Control	% bare soil	17.28	3.45	8.33	2.43	9.98	2.30
Mechanical	% open canopy	40.95	3.28	39.14	2.55	35.41	2.05
Herbicide	% open canopy	41.86	5.16	35.53	1.57	34.12	2.19
Grazing	% open canopy	52.53	1.47	41.10	1.90	41.86	2.55
Control	% open canopy	32.28	4.65	31.96	1.70	40.00	2.00