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Effects of goat grazing on composition and structure of fire-prone vegetation

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**EFFECTS OF GOAT GRAZING ON COMPOSITION
AND STRUCTURE OF FIRE-PRONE VEGETATION**

A Thesis

Presented to

The Faculty of the Department of Environmental Studies

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Barbara Lee Kluger

May 2003

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ABSTRACT

EFFECTS OF GOAT GRAZING ON COMPOSITION AND STRUCTURE OF FIRE-PRONE VEGETATION

by Barbara L. Kluger

California has fire-prone woodlands, coastal scrub, and grassland ecosystems within urban-wildland interface zones. Research was conducted on the East Bay Municipal Utility District (EBMUD) watershed in Berkeley and Orinda, California, to evaluate potential environmental impacts of goat grazing for fuelbreak maintenance. Random sampling was done on three goat-grazed plots and three ungrazed plots, matched by slope, aspect, and microclimate. Data collection for plant species included taxonomic identification, whether native or non-native, and measurements of vegetation composition and structure, including plant height, percent cover, abundance, and richness. Qualitative data were collected on soil erosion and compaction.

In comparison to the control plots, grazed plots decreased native plant species abundance and richness, increased non-native species abundance and richness, decreased shrub cover by 83%, shrub height by 73%, forb height by 60%, and increased bare soil by 20%,. Results were compared to regional vegetation management guidelines for wildlands fire risk reduction.

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INTRODUCTION

In February 1982, the Blue Ribbon Urban Interface Fire Prevention Committee, from the East Bay in Northern California, issued a report intended to guide public agencies in reducing the incidence and severity of wildland fires near the urban interface (EBRPD, 1982). The members of the committee included natural resource specialists, area residents, fire behavior experts, local fire agency officers, as well as representatives from the East Bay Municipal Utility District (EBMUD), the University of California, and the East Bay Regional Parks Department (EBRPD). One of the committee's primary recommendations was to create and maintain a fuelbreak along the entire 41-kilometer length of the urban-wildland interface zone in the East Bay, within Alameda and Contra Costa counties (EBRPD, 1982; EBHVMC, 1995, Appendix 4). In a fuelbreak, natural vegetation is reduced by thinning, pruning, and selective tree and shrub removal to create a buffer zone where a wildfire can be more easily controlled by fire fighters. Of particular concern was minimizing the potential upward spread of fire from ground fuels to shrubs and trees. Presumably, wildfires burn with lower intensity in a fuelbreak and spread more slowly, both horizontally and vertically. Fuel loads were subsequently reduced within the urban-wildland interface zone by both public and private landowners. However, management efforts by the separate parties were not applied consistently, nor were they coordinated.

The community in the East Bay was galvanized after the catastrophic Oakland Tunnel Fire of October 20, 1991 that destroyed 632 hectares and more than 2,400 structures. A group called the East Bay Hills Vegetation Management Consortium (EBHVMC) prepared an in-depth technical resource guide (East Bay Hills Vegetation Management Consortium, 1995) that outlined their fire hazard reduction program, including a fuel management plan for the East Bay Hills. They supported the 1982 report and again recommended the maintenance of a fuelbreak, the purpose of which is threefold: 1) split large expanses of vegetation into smaller units in order to more easily and safely control a burning fire within them; 2) modify vegetation quantity and structure to create a vegetation zone that can be more effectively defended by fire control efforts; and 3) reduce fire intensity by reducing potential vertical flame lengths (EBHVMC, 1995).

Goat grazing is frequently recommended and used for fuelbreaks and reducing vegetation growth in fire-prone areas along the urban-wildland interface in California (Trout, 1997). Goat grazing appears to be an efficient management technique to significantly reduce fire danger and maintain the health of scrub habitat (Tsiouvaras, et al. 1989). In brushy understories, mechanical or chemical treatments or prescribed burning are seldom conducted because of the high expense and risks involved. Goat grazing is considered a safer and less costly alternative for vegetation reduction because

fewer human workers are required and risks from fire and/or chemical treatments are eliminated. Vegetation managers use goats instead of other grazing animals such as cattle, sheep, or horses on steep hillsides and in sensitive riparian corridors to avoid environmental impacts to the soil and water. Scott Hill, grazing specialist at East Bay Municipal Utility District (EBMUD), believes that goats do not disturb the soil and water quality to the degree that cattle do (Scott Hill, personal communication, May 2000).

Although goats are widely used for reducing vegetation for fire prevention, published data are lacking on other effects of goat grazing on fire-prone habitats. There is no information about the trampling, erosion, soil nutrient changes and vegetation composition changes that goat grazing might cause in native plant communities and wildlife habitat over the long-term. Research results and goatherders' experience have revealed the types of vegetation goats eat. There is also literature about the effects of goat grazing, both continuous and intermittent heavy grazing, on native vegetation, species composition changes, and transitions to and from different successional stages. However, further research is needed to evaluate effects of goat grazing in California where the primary goal is maintaining a fuelbreak in woodland ecosystems. Fuelbreaks are being created and maintained with goat grazing all over California in fire-prone areas within urban-wildland interface zones. Therefore, it is crucial that we evaluate

potential environmental impacts of goat grazing practices. This study provides data that can be used to evaluate and modify goat grazing regimes in urban-wildland interface areas that protect natural resources.

OBJECTIVES

This study was conducted on East Bay Municipal Utility District (EBMUD) watershed land where goat grazing has been conducted annually on several fire-prone sites to control vegetation for fire prevention efforts. The primary objective was to evaluate whether a goat-grazing program can reduce biomass to the extent that high-intensity wildfires are prevented while still encouraging native plant species richness and abundance, minimizing the spread of invasive non-native species, and preventing excessive erosion. Sites were evaluated to determine: 1) whether the fuelbreaks are successfully achieving their fire prevention purposes, and 2) what the other environmental effects of goat-maintained fuelbreaks may be.

For this study, I measured plant composition and vegetation structure in areas where grazing has occurred on an annual basis for four to seventeen years and on control plots with similar topography, slope and aspect that had not been grazed. The results of this research provide useful information and recommendations for evaluating goat grazing programs in this region of California for both fire management and resource protection.

HYPOTHESES

The following hypotheses were tested:

H1: Vegetation composition and structure (as measured by plant species abundance and richness, average plant height and percent cover) on grazed plots are significantly different from ungrazed plots.

H1Ø: Vegetation composition and structure on grazed plots are not significantly different from ungrazed plots.

H2: Abundance and richness of native plant species are significantly lower on grazed vs. ungrazed plots.

H2Ø: Abundance and richness of native plant species are not significantly lower on goat grazed plots as compared to ungrazed plots.

H3: Goat grazing significantly increases the abundance (number of individuals), and richness (number of species) of invasive non-native (exotic) plants over ungrazed plots.

H3Ø: Abundance and richness of invasive non-native species are not significantly increased on goat grazed plots as compared to ungrazed plots.

H4: Goat grazing in fire-prone areas of the EBMUD watershed is an effective method for reducing plant height and cover by key species, which is expected to reduce fire risk by limiting vertical flame length (VFL). VFL is predicted by measuring plant heights and percent cover by key species.

H4Ø: Goat grazing in fire-prone areas has no effect on key plant species and average plant heights.

H5: Erosion potential as measured by the percent of bare soil, soil disturbance, and evidence of erosion (gullies and rills), is significantly higher in goat grazed plots as compared to ungrazed plots.

H5Ø: There is no significant increase in erosion potential in goat grazed plots as compared to ungrazed plots.

LITERATURE REVIEW

This review examines articles that focus on techniques and suggestions for vegetation management in California and in other regions that have a mediterranean climate, generally characterized by wet winters and dry summers. Vegetation management for fire prevention by goat grazing is a primary focus, although research on sheep-grazed sites is also relevant. Topics examined include methods for and concerns about creating fuelbreaks for fire prevention and effects of goat and/or sheep grazing on fuel load, plant species diversity, soil condition, and changes in vegetation and ecology. The articles also elucidate the inherent unpredictability of the effects of any single vegetation management regime, due to the many uncontrollable variables, such as soil types, weather patterns, and available forage.

Coastal Scrub Fire Hazard

In the absence of grazing and fire, succession of grassland to shrublands in open spaces of the urban-wildland interface in the San Francisco (SF) Bay Area has led to a higher fire hazard (Russell and McBride, 2001, 33). These shrublands have higher biomass than grasslands.

In the SF East Bay, dominant species in the coastal scrub plant community include *Baccharis pilularis* (coyote brush), *Rhamnus californica* (coffeeberry), *Rubus ursinus* (blackberry), and *Toxicodendron diversilobum* (poison oak). Russell and McBride (2002) studied successional trends and potential fire

spread in the SF East Bay and other fire-prone shrublands in the region. They calculated surface fuel in terms of tons/hectare of biomass and developed computer simulations to estimate fire spread including average rate of spread, flame length, and fireline intensity (See Table 1). They found that grassland and oak woodlands had the lowest surface biomass, 1.5 tons/ha. and 3.7 tons/ha. respectively. Coastal scrub habitat, and other shrublands dominated by *Baccharis pilularis*, exhibited surface biomass five times greater than oak woodlands and ten times greater than grasslands. The surface biomass of Monterey pine forest was 40.7 tons/ha, 30 times higher than grassland. In the SF Bay Area, Monterey pine forest may include tree species such as *Pinus radiata* and/or *P. muricata* (Monterey pine or Bishop Pine), *Eucalyptus globulus* (Blue gum Eucalyptus), and *Pseudotsuga douglasii* (Douglas-fir), which have a relatively high fireline intensity (Russell and McBride 2001). The computer simulations showed that fire spreads through grasslands at the fastest rate, followed by shrublands, then oak woodlands. However, shrublands exhibited the greatest flame lengths and fireline intensity in comparison to grasslands, oak woodlands, and pine forests.

Fuelbreaks for Fire Prevention

A fuelbreak consists of 75-150 meter-wide strips through brush and trees where vegetation is kept low to prevent wildfires from reaching tree

crowns and to protect homes and other structures. There are several methods of creating a fuelbreak to interrupt the continuity of fuel between wooded and urban areas, including hand clearing, mowing, burning, applying herbicides, bulldozing, and grazing. Grazing has been promoted widely throughout Northern California as an inexpensive, convenient, and environmentally friendly strategy for reducing the risk of fire on public and private lands (Trout 1997). In particular, goat grazing has been adopted because goats can be brought more easily into shrublands, closer to an urban edge than cattle and are usually popular with the public (See Figure 1). Goats negotiate steep slopes with ease and readily eat many types of vegetation, including *Centaurea solstitialis* (yellow star thistle) and *Toxicodendron diversilobum* (Trout 1997).

However, not everyone wants goats to browse vegetation in California's open spaces. There is still much debate about using grazing to control brush. At the center of the controversy are questions about protecting sensitive environmental areas from adverse effects of goats. For example, some environmentalists believe that non-native weeds and grasses are increasing in goat-browsed areas in the canyons in South Laguna Beach, California, due to seed deposition from the feces of the goats (Harris and Nagy 2000). The goats' presence may also be having negative impacts on the activities of wildlife. According to an article in the Los Angeles Times, the city of Laguna

Beach is using 600 goats full-time to maintain a 160-hectare fuelbreak (Harris and Nagy 2000). It is the first city in California to keep a full-time goat herd, though in other cities, such as Oakland and Berkeley, goats graze on an intermittent basis. The Laguna Beach fire prevention officials report trying many vegetation reduction regimes - cattle and sheep grazing, prescribed burning, thinning by hand crews and/or machinery, and chemical herbicides. The officials are satisfied that utilizing goats is the cheapest and safest option. However, no scientific studies have been published that compare results of goat grazing on biomass reduction versus these other measures, nor any that evaluate the effects of goat grazing on natural flora and fauna of Laguna Beach.

Grazing Studies

A small number of studies have documented the effects of goat browsing on fuel loads, goat preferences for different types of forage, and the effects of goat browsing and/or sheep grazing on habitat structures and plant species composition. For example, Tsiouvaras, et al. (1989) conducted a study to determine whether goat grazing on forage at various heights would reduce the fuel load enough to effectively reduce fire hazard in Redwood Regional Park, Oakland, California. Half of the study area was in a *Pinus radiata* (Monterey pine) and *Eucalyptus camaldulensis* (red gum) forest that contained continuous vertical fuel accumulation from coastal shrubs, grasses

and resprouts of *Eucalyptus camaldulensis* in the understory, and had not been previously grazed. The other half was in a fuelbreak that was previously grazed by goats, dominated by grasses and woody shrubs. The study was unreplicated, but the two sites were analyzed both before and after grazing, at three different vegetation heights: 0-0.5m, 0.5-1.5m, and >1.5meters.

Tsiouvarus, et al. (1989) found that goats significantly reduced both live and dead fuels of up to 1.5 meters in height. With higher stocking rates and a greater number of grazing days in the fuelbreak, there was a correspondingly greater reduction in fuel load in that area. In the forested brushland area, the preferred forage plants were *Rubus vitifolius* (California blackberry), *Heteromeles arbutifolia* (toyon), *Baccharis pilularis*, *Lonicera hispidula* (honeysuckle), herbaceous plants and *Arbutus menziesii* (madrone). Goats preferred and utilized recent growth over older, less palatable forage. Coyote brush was browsed heavily, which could potentially be very helpful for reducing fuel loads. The goats were able to break up the vertical and horizontal sequence of fuels, and diminished the litter depth on the ground by 27%, by trampling it into the soil. In the fuelbreak area, invasive woody vegetation was heavily consumed, particularly the native species *Rubus vitifolius* and the non-native *Eucalyptus camaldulensis*.

In another study, Child (et al. 1985) determined that goats adjust their diet to match available forage. In an upland conifer forest of Arkansas, green forage was preferred, but when that was no longer available, the goats' diet abruptly shifted to live pine needles. All pine needles that could be easily reached were consumed; trees up to 2.5 meters high were pushed down by the goats in their efforts to reach the higher branches. Child (1985) recommends removing goats when they begin to eat pine needles to prevent damage to the trees, as this change in diet signals a lack of more appropriate forage.

From their evaluation of several goat studies, most of which were conducted in Texas and California, Green and Newell (1982) assert that properly managed goats under moderate or intermittent stocking rates will reduce brush cover while promoting growth of annual grasses and forbs. When soil became bare in small enclosures where goats were kept, grasses and forbs regenerated in the next growing season. Green and Newell (1982) determined that when land managers stock goats for too long at heavy rates, goats would likely overuse the vegetation. Because goats can forage and survive on plants that other livestock find unpalatable, they are frequently introduced onto land that has been previously mismanaged and severely overgrazed by cattle and/or sheep for decades. While goats may receive the blame for the land's ultimate destruction, Green and Newell (1982) speculate

that their disturbance is only the most recent in a series of impacts caused by grazing animals.

Goats prefer to browse on first-year regrowth following burning or mechanical clearing of brush. They will only eat the older, less palatable woody brush under heavy grazing pressure. To eliminate woody plants from a site, the goats must browse continuously or frequently enough so that foliage cannot accumulate. Over two to four years, the depleted shrubs will die from a lack of stored energy (Green and Newell 1982).

A study by Pettit, et al. (1995) in the temperate Australian farmland found that sheep grazing led to the loss of native plant species and the increase of invasive non-native plant species (Pettit, et al. 1995). Pettit et al. (1995) cite the increased soil erosion, disrupted nutrient cycling, and reduced habitat for wildlife with the associated loss of perennial woody shrubs that result from sheep grazing. Long-term grazing depleted starch reserves in perennials, overshadowing effects such as topography, soil texture, moisture and fertility on the growth and vigor of perennials. Restoring or maintaining a healthy rangeland depended, in part, on using fences to control grazing intensity. Pettit, et al. (1995) also note that if the vegetation management goal is to prevent a complete loss of habitat functioning, one strategy is to first identify key plant species that strongly affect ecosystem functioning. Then, classify those key species within functional groups, such as their

reproductive traits, life histories, and growth forms, so that a management plan can accommodate the requirements of those key species.

In another study Gibson and Brown (1991), conducted research for six years on old British limestone grassland to test the effects of different sheep grazing regimes on plant species turnover. They found, in the early stages of succession, that species initially become randomly established from the seed bank in the soil. Once vegetation is established, grazing can increase both colonization (appearance) and extinction (disappearance) rates of plant species for the first few years. The characteristics of the plant species, the seasonality and intensity of the grazing regimes, and yearly differences in climate, play a dynamic role in habitat diversity and rates of species spread (Gibson and Brown 1991). In general, moderate grazing promoted greater diversity, while grazing in spring and autumn increased rates of extinction, and heavy grazing inhibited the process of succession. Though Gibson and Brown (1991) did not address the value of any particular species or its function in a habitat, such as native plants versus invasive non-native plants, they introduced the practice of tracking rates of colonization and disappearance of species, which can be a useful measure of habitat condition.

Grazing May Change Vegetation Composition and Ecology

An ecosystem will not return exactly to what existed before disturbances occurred (Archer 1996). To maintain a sustainable ecosystem

under a grazing regime, Archer 1996) explains that there must be a diverse assemblage of palatable and unpalatable plant species. Grazing must be controlled to maintain herbaceous cover and growth of palatable perennials while restricting the invasion of unpalatable vegetation. If the grazing regime becomes mismanaged to the extent that there is, for example, soil erosion, expensive restoration efforts may be necessary. Archer (1996) asserts that, to effectively manage an ecosystem, it is important to attempt to account for any impacts that other, less conspicuous animals such as nematodes, insects, rodents and other mammals and invertebrates might have on soil condition and plant species diversity and richness. With heavy selective grazing, palatable plants can be replaced by unpalatable ones, which, in turn, impacts soil chemistry and composition. These soil changes may further encourage the establishment of undesirable plants. Some vegetation shifts may occur relatively quickly while other changes may take many decades, which can be difficult to track. However, Archer (1996) notes that while it is difficult to predict how a habitat's biological and edaphic factors will interact, a closely monitored rangeland may have fewer unfavorable vegetation changes. To better predict how vegetation may change under different management regimes, it can be useful to identify a grazing area's soil type, topography, plant life histories, climate variation, and land-use history (Archer, 1996). To promote greater habitat diversity in

ecosystem reserves, some vegetation managers maintain an open vegetation pattern, which may create a greater variety of habitat types and reduce the incidence of intense fires. Grazing and other methods of active management prevent progressive filling in of the vegetation that would normally occur without that management.

Bartolomé, et al. (2000) studied the relative effect of grazing by sheep versus goats on native vegetation in a mountain reserve in Spain. Three flocks of sheep and goats were studied by doing a micro-histological analysis of their feces to determine their diets over an entire year. The researchers found that sheep ate more herbaceous forage than goats, which prefer more oak browse and shrubs. They also found that grazing alone was apparently not sufficient to maintain the open pattern of vegetation in this region (Bartolomé, et al., 2000). Of importance to the San Francisco Bay Area in California is the finding that greater utilization or removal of biomass could help maintain a partly open landscape, reducing fire hazards and preserving more species diversity over the long term (Bartolomé, et al. 2000).

Seligman (1996) observed that preventing succession in mediterranean-type annual grasslands requires continual disturbances, such as vegetation reduction for fire prevention, cultivation, and grazing. Without those disturbances, the grasslands found in North Africa, Southern Europe, the Near East, Australia, and in California, would be characterized by broad-

leaved, sclerophyllous, evergreen shrubs and trees. Yet today, invasive annual Eurasian grasses have replaced native grasses and forbs in mediterranean climate regions (Seligman 1996). These invasive annual grasses could not continue to dominate over perennial species (thistle, grasses and shrubs) for even a decade without periodic cultivation or disturbance. In California, rangelands on fertile soils are typically maintained by grazing and fire (Seligman 1996). Woody species may persist in heavily grazed annual grasslands by growing in a more prostrate or dense, shrubby form. When grazing is reduced or stopped, the woody species grow taller, sometimes forming dense thickets, presenting a fire danger to adjoining urban areas. Where grassland management has been abandoned and woody or chaparral vegetation subsequently fills in, fire represents significant threat to life, property, watershed, and recreational values. In this situation, undergrazing is the problem, rather than overgrazing (Seligman 1996).

Carmel et al. (1999) studied how topography and traditional grazing practices have played a part in ecological complexity. High-resolution digital maps were produced from both historical and contemporary aerial photographs that spanned more than 28 years for a mountainous region in Israel. This study is a rare example of analysis of long-term vegetation dynamics. Considerable afforestation occurred from 1964-1992, in which the

region went from 2% tree cover to 41%. Herbaceous vegetation decreased over the same period from 56% to 24% cover. Cattle and goat grazing slowed the rate of afforestation, but did not stop the process. In addition to the significant influences on landscape changes by grazing and previous vegetation types, topography was found to have a major impact on vegetation patterns and dynamics, particularly slope and aspect (Carmel et al. 1999). Tree cover increased the least on southeast facing slopes, and increased the most on northwest slopes. Herbaceous vegetation did not show that relationship (Carmel, et al. 1999). Habitat complexity and biodiversity arise in that region from spatial diversity, varied topography and grazing intensities. A more uniform landscape would probably encourage more homogeneous grazing practices, resulting in less biodiversity. In assessing long-term effects of grazing, this study found that while grazing slows succession from herbaceous to woody plants, and then to trees, it does not stop the process (Carmel, et al. 1999).

Species Richness and Diversity as Goals

Conservation biologists agree that preservation and restoration of native species and habitat diversity are desirable goals of land management. Hatch et al. (1999) utilized both prescribed burning and seasonal sheep grazing on California central coast grasslands to test restoration potential of the methods for encouraging the growth of the native bunchgrass species

Nassella pulchra (purple needlegrass) and *Nassella lepida* (foothill needlegrass). Their data revealed that different soil types and weather patterns have significant effects on the restoration of these species and, therefore, on results of the grassland management techniques. They believe that restoration projects would be better managed by encouraging overall species richness and diversity rather than focusing restoration efforts on just one or two species (Hatch et al. 1999).

Lunt and Morgan (1999) introduced prescribed burns as a management tool to assess species compositions of an Australian grassland reserve in which cattle and sheep grazing was excluded for ten years. Their principle finding was that intermittently burning vegetation after excluding stock grazing does not necessarily yield greater species diversity. Their expectation had been that over the course of ten years, the flora would become similar to species-rich remnant populations. Instead, weedy colonizers dominated the landscape and they suspected that the native species in their samples were the more adaptable ones. The more sensitive, less resilient species had likely declined from the area prior to the study. The authors suggest maintaining a portion of land with the status quo management regime(s) before new ones are introduced to use for comparison and analysis of changes/impacts. Before analyses can determine the value of a conservation or management regime, it is important to take species

composition samples from pristine sites for comparisons. Periodic censuses for indicator or target species also might be useful to monitor impacts due to changes in regime. They also asserted that grassland conservation must include frequent removal of biomass and litter to encourage threatened or rare plants to reproduce and add to the habitat biodiversity (Lunt and Morgan, 1999).

METHODS

Study Sites

The three study sites chosen for this research were in Contra Costa and Alameda counties, California. All three are managed by the watershed headquarters of the East Bay Municipal Utility District (EBMUD). (See Figures 2 and 3.) Contra Costa County lies east of the Berkeley Hills (also known as the East Bay Hills or Oakland Hills) and receives less rainfall and fog drip than do the sites in Alameda County. The rolling hills and valleys in this area of Contra Costa County create sharply differing microclimates and plant communities due to differences that include: precipitation, humidity, aspect, temperature, exposure to sun and wind, and slope. Northern coastal scrub plant communities, also referred to as “soft chaparral,” have a very high risk of wildfire that can vary widely in speed of ignition and rate of spread, and produce potential vertical flame lengths (VFL) of 4.2-20.7 meters. The level of wildfire hazard is primarily influenced by the ratio of dead to live plant materials, the amount of soil moisture and annual precipitation (CNPS 1994 and EBHVMC 1995, *Technical Appendices*, App. 9,9). Dry northern coastal scrub, frequently present on hillsides with southern or western exposure, is characterized by *Baccharis pilularis*, *Mimulus aurantiacus* (bush monkey flower), and *Artemisia californica* (California sagebrush), according to the EBHVMC (1995). The site in Contra Costa

Sobrante Ridge, which is east of San Pablo Reservoir. In addition to *Baccharis pilularis*, dominant species in wet northern coastal scrub also include *Toxicodendron diversilobum*, *Ribes californica* or *Ribes quercetorum* (gooseberry), and *Rubus ursinus* and has a VFL of 4.2-9.6 meters. Northern coastal scrub, grassland and savannah plant communities can often be found immediately adjacent to wetlands or riparian zones. Due to a lesser marine influence on the eastern side of the hills, higher temperatures in the dry season create an extreme fire hazard. "Diablo winds," blowing from drier inland areas, intensify the potential for wildfires that can race up the hillsides and to the west (EBHVMC 1995, appendix 7). Two sites were in Alameda County, on San Pablo Ridge, located on the western side of the Berkeley Hills and west of San Pablo Reservoir. Hills and valleys on the western side of the Berkeley Hills are similar to those on the eastern side, but have slightly different microclimates due to the greater amount of rainfall and fog drip. Common plant communities at San Pablo Ridge are wet northern coastal scrub and oak-bay woodland. Oak-bay woodland, referring to *Quercus agrifolia* (coast live oak) and *Umbellularia californica* (California Bay), ranges from a moderate to a high fire hazard, as determined by the structure of the understory (EBHVMC 1995, appendix 7). Along ridgelines of the East Bay Hills, grow trees such as *Pinus radiata* and the non-native *Eucalyptus globulus*, which can carry firebrands long distances when ignited

from flames originating from understory vegetation. For this study, three plots that had been grazed for a minimum of four years each were contrasted with ungrazed control plots that were adjacent to each of the grazed plots and matched by slope, aspect and microclimate (Figures 4 and 5).

Site #1: Sleepy Hollow/Overlook East (SH)

Sleepy Hollow is on Sobrante Ridge, located east of the San Pablo Reservoir and adjacent to Bear Creek Road. This 7.2 hectare site in Orinda, in Contra Costa County, had been goat-grazed annually for 17 years to control weeds and brush. Before then, according to vegetation manager Scott Hill (2000), *Brassica nigra* (black mustard) and *Conium maculatum* (poison hemlock) grew thickly up to approximately 2.5-3 meters, presenting a serious fire threat in the fall when the stalks died and dried out. Danielsen (et al. 2001) reported that if ignited, dry *Conium maculatum* stalks explode from the inside, spreading a fire. Goats apparently eat dry *Conium maculatum* stalks, but it is toxic to many animals (Danielsen, et al. 2001). Sleepy Hollow Elementary School is located at the rear of the valley and at a lower corner of the site (“the hollow”). Private homes are located on the top of the hillside and on the periphery of the site were also at high fire-risk (Scott Hill, personal communication). For at least five years before this study began, local homeowners living at the top of this dry, windy area maintained 30-meter buffer zones around their properties by mowing the tall grasses. Goats

grazed from those buffers down to the fire road that forms the grazing boundary, preventing the process of succession and keeping the vegetation as grassland. A control plot was located east of the grazed area, on land that bordered the EBMUD property, where an understory of dense thickets of *Toxicodendron diversilobum* and *Baccharis pilularis* grew amid coast live oak trees. Because the control plot was matched by slope, aspect, and microclimate, the grazed area might once have had a similar vegetation composition.

Site #2: “KPFA”/Isis Ridge

The KPFA radio tower sits atop the ridge above an especially fire-prone area in the urban-wildland interface of the East Bay Hills on the Oakland-Berkeley border area of Alameda County. Due to the topography that funnels the prevailing winds, fire quickly raced through this area in 1970; this area is located on the eastern side of the East Bay Hills, between the EBMUD watershed land and the residential properties on the western side of the ridge. Three different operators had conducted goat grazing on the four-hectare study site for four consecutive years. Before the introduction of the grazing program, the site was thickly covered with shrubs and eucalyptus, based on the presence of eucalyptus stumps that remain. In addition, the study site was merely one section of a larger fire-prone area;

other sections in the area were mowed, burned and/or cattle grazed, depending on differences in slope and ease of access.

The land, located near Tilden Park, at the corner of Fish Ranch Road and Grizzly Peak, was never used for any commercial purpose. The control plot, in an adjoining section of the hillside below the grazed plot, was left ungrazed by EBMUD because it was less likely to be directly in the path of a wildfire.

Site #3: Lomas Cantatas (below the road) (LC)

Lomas Cantatas Road separates East Bay Regional Park District (EBRPD) land from EBMUD land. The two-hectare parcel of EBMUD land, below Lomas Cantatas Road, lay at the head of a valley that had been managed for four years with goat grazing. The EBRPD section, located between private pastureland and Tilden Park, was above the road. The ungrazed hillside, which served as a control plot, had developed thick brush due to an absence of vegetation management for many years.

Experimental Design

Six plots were sampled: one grazed by goats (treatment) and one ungrazed (control) at each of three sites described above. Controls were matched to treatment plots by slope, aspect (directionality), and microclimate, such as annual precipitation and temperatures. Control plots were adjacent to the grazed plots. Sampling of vegetation and soil condition

was conducted on two occasions for each site. First, samples were collected before the rainy season in October and November of 2001; this was after the goats had grazed to reduce the vegetation for fire prevention. The second sampling was done during February 2002, before low-growing plants were hidden from view by taller non-native grasses. Each transect included 5 1-m² quadrats and 1 16-m² quadrat, that were nested within a larger 100-m² quadrat to simplify data collection, as various strata of vegetation grow within the study sites (See Figure 6).

Data Collection

Vegetation sampling included measurements of plant heights and species, vegetation composition, and structure. Vegetation composition included a plant species list, relative frequency of each species in study quadrats, species density, and the identification of key species in the plant community. Abundance (density) of each species was measured by randomly sampling from each site. All surveys were recorded on data sheets, and photographic records were made to illustrate and reinforce the data.

Plant species information collected included taxonomic identification to the species level, whether the species was native to the region or non-native, and whether the species was rare or widespread. Discussion of potential impacts of sampled invasive plants on a habitat are also included, based on the research by Bossard, Randall, and Hoshovsky (2000). Because non-native

grass species are difficult to identify, particularly in their early stages of growth, they are characterized simply as “non-native grass.” Percent cover of vegetation (not species specific) was estimated with the Braun-Banquet Cover-Abundance Scale with a visual assessment (Mueller-Dombois 1974). According to Bonham (1989), vegetation cover refers to the vertical and horizontal projection of all vegetation on the soil, including plants, plant parts, humus, and litter. Crown cover describes the tree canopy, including branches and leaves. Because trees, shrubs, and forbs were measured separately, these layers of vegetation are expressed as relative cover. The numbers on the Braun-Banquet Cover-Abundance Scale in the table below refer to the crown, leaf, or shoot area projection of a species in a sample quadrat.

Scale	% cover of reference area (Braun-Banquet method)
5	> 75%
4	50-75%
3	25-50%
2	5-25%
1	<5%, and/or scattered
r	Solitary, with small cover

Transects were randomly selected within both control and treatment plots. Because the LC site had two distinct vegetation compositions, e.g. a large grassy area and a shrubby area, stratified random sampling was used to ensure a representative sampling of the site. The stratified sample

included half of the transects in each of the two separate vegetation compositions. A random number table was used to determine the distance in meters from one transect to the next and were then marked with flags. The distance traveled between transects and within each transect were measured in meters with a measuring wheel and/or measuring tapes. According to Mueller-Dombois (1974), sample quadrat sizes within each transect should be large enough to contain all the characteristic species that belong to a given plant community (Bonham, 1989). The sampling sizes for this study measured:

- 1m x 1m (1m^2) for the forb layer, for vegetation under 0.5m;
- 4m x 4m (16m^2) for the shrub layer, for vegetation 0.5-3.0m;
- 10m x 10m (100m^2) for the tree canopy, for vegetation above 3.0m.

Measuring tapes marked the boundaries of each transect. Along one edge of each 100-m^2 transect, five 1-m^2 quadrats were used on the ground to measure forbs within a square meter frame. A 16-m^2 quadrat was nested in one corner of the 100-m^2 transect to sample shrubs, and trees were measured using the entire 100-m^2 quadrat.

Heights were recorded separately for each of the three vegetation layers. Recorded values for vegetation height per quadrat were derived by measuring plant height in each of its four corners plus its center and then calculating the average (mean) of the five measurements.

Percent relative cover was also recorded for the three separate height categories. For the shortest height category (0-49.5cm), the point-intercept method was used to estimate the frequency and percent cover of individual grasses, forbs, and bare soil. The point-intercept method employed a one-meter long point-frequency frame, constructed from PVC pipes and joints, with ten thin rods suspended from it at intervals of ten centimeters (Mueller-Dombois 1974). A total of 50 points were sampled in each 100-m² transect. The 1-m² point-frame was placed every 2 meters on the ground, five times, along one of its 10-meter long sides. Since eight transects were measured at each plot, in both fall and spring, a total of 400 points were recorded (10 points/1m² quadrat x 5 quadrats/transect x 8 transects/plot = 400 points/plot). Percent cover for different plant species were calculated by the number of individuals of each species intercepted by the pins in each transect. Whatever a rod touched first, a living plant, non-living plant parts, or bare soil, was counted for the survey. An individual plant was counted when it was rooted within the quadrat or when greater than 50% of the plant was contained there. In the case of spreading plants, where the roots are not easy to see, the >50% rule applied.

The diameter at breast height, or dbh, of each tree within the 10m x 10m quadrat was calculated from measuring its circumference. To calculate the dbh for trees and large shrubs with multiple trunks, or stems, dbh was

calculated for each stem and added together. Where tree trunks were not contained within the 10m x 10m quadrat, percent cover was recorded, but not the individual tree. For both the shrub and tree level quadrats, individual plants were identified by species and counted. For the shrub layer, individuals between 0.5 meters and 3.0 meters were recorded; the tree layer included individual plants above 3.0 meters high. Percent cover was estimated using the Braun-Banquet Cover-Abundance Scale, which allowed for overlapping foliage and varying degrees of density.

Qualitative soil observations were also recorded for indications of erosion and compaction in each transect. Six terms were used to describe soil condition: mulching effect (**M**), trampling (**Tr**), disturbed (**D**), compaction (**C**), rills (**R**), and gullies (**G**).

Analytic Methods

The following values were calculated:

- 1) plant species richness (# of species)
- 2) % species abundance (% of a species relative to the total number of points sampled);
- 3) total abundance of any one species within one or more transects;
- 4) relative frequency of a species by counting # of quadrats where species is present;
- 5) % bare ground per transect (# pin-points that touched bare soil per 50 points);
- 6) % of transects per plot with rilled or trampled soil.

Statistical analyses compared quantitative data collected on the pairs of randomly sampled grazed (treatment) plots and ungrazed (control) plots

for any possible relationships that test the hypotheses in this study. These analyses indicated whether goat grazing had a significant effect on plant species compositions (richness and abundance), vegetation structure (plant height and/or percent cover) or erosion, compared to the control plots. Indicator and/or key species reported in current ecological literature, were evaluated for significant differences in abundance for grazed vs. control plots. Tests included one-way analysis of variance (ANOVA) with a significance threshold of $p = 0.05$, by means of Systat 9 software (SPSS, Inc. 1999. Chicago, IL), to compare the control and grazed treatment plots and Fall vs. Spring sample dates. Subsamples within each plot were nested within treatments using the following General Linear Model: Treatment (Trt) + Site + date (Fall/Spring) + Trt x Site (subsample) + independent variable = Effect.

Evaluating vegetation structure provides a key to the potential spread of a future wildfire. Qualitative analysis compared fire agency's guidelines for reducing potential vertical flame length and fuel (biomass) to the measurements taken at the grazed (treatment) plots. Flame lengths greater than 2.4 meters, particularly in fire-prone vegetation such as mature *Baccharis pilularis*, can lead to crown fires (in trees) that are more difficult to control. The data give some indication as to whether the EBMUD goat-grazing program is accomplishing the objectives of reducing biomass accumulation and limiting potential vertical flame length for fire prevention

without damaging the watershed, as measured by average heights of vegetation, plant species compositions, and evidence of erosion.

RESULTS

The hypotheses were tested and the results for each are as follow:

H1: Vegetation composition and structure

Vegetation composition and structure are significantly different on grazed plots as compared to control (ungrazed) plots, as measured by plant species abundance and richness, average plant height and percent cover.

H1₀ was rejected, as there were significant differences in overall plant composition and structure in grazed versus control plots.

Plant Species Richness and Abundance

Without exception, there were fewer species found on grazed plots compared to their respective control plots (See Table). The shrub layer (0.5-3.0 meters in height) of the grazed plots showed significantly lower overall species richness compared to the controls (See Figure 7). However, differences in overall species richness in forbs ($p=0.460$) and trees ($p=0.157$) were not statistically significant (See Figure 8). The mean number of shrub species combined per grazed transect was 1.3, versus a mean of 2.7 plant species per control transect (ANOVA, $p=0.001$). Fall and spring data collection revealed very similar values, as most of the shrubs are perennials.

Plant Height

Plant heights were significantly decreased in the forb and shrub layers on all three sites in the grazed plots compared to the control plots ($p<0.05$)

(See Figures 9 and 10). However, tree heights showed more variability, with decreased heights on the LC site and increased heights on KPFC and SH (See Figure 11). In the grazed plots, forb heights showed a decrease of 60 percent compared to control plots; shrub heights were decreased by 73 percent, and tree heights were increased by 11 percent.

The LC control plot had a greater number and abundance of native tree species and greater height of both native and non-native trees. However, the reverse was true at the SH sites; The SH control plot was covered with thick stands of brush that left little light or space available for sapling growth, thereby inhibiting the process of succession. Also, tree height was greatest at the SH grazed plot, where a woodland dominated one section. Grazing apparently did not negatively impact the large native *Quercus agrifolia* and *Umbellularia californica* trees and the two species appeared to be regenerating, as saplings were present. Another exception showed up at the KPFA control plot, where *Baccharis pilularis* comprised the majority of vegetation above 3 meters. Thus, it had a lower average tree height compared to the grazed plot and to the LC and SH control plots.

Percent Cover:

ANOVA results showed significant differences between the grazed and control (ungrazed) plots in the percent vegetation cover of both the forb ($p=0.013$) and shrub layers ($p=0.000$), but not in the tree layer ($p=0.326$) (See

Figures 12 and 13). Because data for this study were gathered in the winter and early spring, forbs and grasses had just started their growth. Many plant species, such as non-native grasses, attain their greatest growth during the summer months. If sampling had occurred during the summer, the forb layer data would likely have produced very different results.

In preliminary observations, before sampling occurred, the LC grazed plot appeared to have quite a lot of vegetative cover in all three height categories, including *Pinus radiata*, *Umbellularia californica*, *Quercus agrifolia*, *Baccharis pilularis*, and annual grasses; the grazing program manager believed that the fuel load was reduced adequately to reduce wildfire hazards while preserving watershed and habitat values. All three grazed plots had significantly less shrub cover than control plots, 15-20% cover versus 85% percent cover at the control plots. On the Sleepy Hollow control plot, the shrubs formed an understory of dense thickets of *Toxicodendron diversilobum* and *Baccharis pilularis* amid *Quercus agrifolia* trees. Because shrubs at these study sites were mostly perennials, percent shrub cover did not vary significantly between fall and spring.

Neither tree heights nor percent tree cover were affected by the time of year that sampling occurred and each site was unique. The LC site had greater cover on the control than the grazed plot; SH had greater cover on the

grazed plot than the control; the KPFA site showed no significant difference between the grazed and control sites.

H2: Abundance and Richness of Native Plant Species

Abundance and richness of native plant species are significantly lower on grazed vs. ungrazed plots.

H2₀ was rejected, as there were significant differences in native plant richness and abundance in grazed versus ungrazed plots.

Native Plant Richness and Abundance

Grazed plots at each site had significantly lower richness (number of species per transect) and abundance (density) of native plant species than ungrazed (control) plots (students t-test and ANOVA, $p=0.000$) (See Table 3). Overall, there was an average of 4 native plant species in grazed transects and 7 native species in control transects (t-Test, $p=0.000$) (See Figure 14). The forb layer had 2.3 native species and 10 individual plants per transect at the grazed plots (See Figures 15 and 16). Control plots had 3.9 species and a density of 21 individual plants per transect. One exception was found at the KPFA grazed plot, where the native perennial bunch grass *Nassella pulchra* was three times more common than at the control plot, on a hillside that the grazed and control plots shared (See Figure 17). From preliminary observations of the KPFA grazed plot, before any vegetation sampling occurred, there appeared to be moderately high plant diversity, including *Nassella pulchra*, *Mimulus aurantiacus*, *Baccharis pilularis*, *Quercus agrifolia*, and *Umbellularia californica*. Grazed plots also revealed a

significant decrease in richness and abundance in the shrub layer (ANOVA, $p=0.000$), where there a mean 1.2 native species and a mean density of 6 individual plants per transect, versus the control plot means, which had 2.6 species and 15 individual plants per transect (See Figures 18 and 19). The tree layer did not reveal a significant difference in grazed vs. control plots for either species richness (ANOVA, $p=0.426$) or abundance ($p=0.575$).

Individual sites showed some variability. In the forb layer, KPFA had greater native plant species richness than LC and SH for both grazed and control plots. SH showed less difference in grazed vs. control plots, but the grazed plot still had lower richness. In fact, *Dirca occidentalis* (western leatherwood), which was sampled on the SH control plot, is listed by the California Native Plant Society (CNPS) as both a rare and a threatened California native plant. According to CNPS (Lake 2001, 26 and CNPS 1994), *Dirca occidentalis* has a limited range in the SF East Bay, where its habitat is also threatened.

H3: Abundance and Richness of Invasive Non-native Species

Goat grazing significantly increases the abundance (number of individuals), and richness (number of species) of invasive non-native (exotic) plants over ungrazed plots.

H3₀ was rejected, as there were a significant increase of invasive non-native plant species on goat grazed plots versus ungrazed plots.

Non-native Plant Species Richness and Abundance

All three grazed plots had significantly greater richness and abundance of non-native species in the forb layer, where there were 2.4 non-native plant species per transect versus 0.8 species per transect at the control plots (See Figure 20 and Table 3). On grazed plots, there was an average abundance of 18 individual non-native plants per transect compared to 4 plants at the control plots (ANOVA $p=0.000$) (See Figure 21). The forb layer at the KPFA grazed plot showed a greater increase of non-native plants than in LC or SH; the smallest increase was in SH. The non-native tree species *Eucalyptus globulus* was present at the ridgetop of the KPFC grazed plot. Non-native species in the shrub layer did not show a significant difference in richness between grazed and control plots ($p=0.399$). Shrubs abundance displayed a statistical difference with a greater non-native abundance at the grazed plots ($p=0.094$). However, the shrub data were contradictory. Overall, there was a greater abundance of non-native shrubs sampled in the

fall than in the spring and the control plots had slightly more abundance than the grazed ones (See Figure 22). For example, the fall samples at the KPFA control plot showed 4-5 species per transect and only 1 species in the spring; the grazed plot in the fall had 2 species per transect and 1 in the spring. If sampling had been done later in the growing season, the data would likely have shown more differences, given that there were plant species in the forb layer that would have been included in the shrub layer. Vegetation above 3.0 meters showed no significant difference between grazed and control plots (ANOVA $p=0.158$).

H4: Goat Grazing for Wildfire Prevention

Goat grazing in fire-prone areas of the EBMUD watershed is an effective method for reducing average plant height and cover by key species, which is expected to reduce fire risk by limiting vertical flame length (VFL). VFL is predicted by measuring plant heights and percent cover by key species.

H4~~0~~ was rejected. *Baccharis pilularis*, a key shrub species in fire-prone northern coastal scrub communities was significantly less abundant in grazed plots and vegetation heights were significantly reduced.

Refer to **H1** *Plant Height* section for plant height data results. Restated briefly, in grazed plots, forb heights were reduced by 60%, shrub heights were reduced by 73%, and tree heights were more variable on different sites, showing a mean increase of 11%. Forb heights were likely shorter for this survey than if data collection had occurred later in the year.

On control plots, the average abundance of *Baccharis pilularis* plants was 6 per transect (4m x 4m quadrat) (See Figure 23). On grazed plots, there were 2, a 67% reduction in the mean number of plants.

H5: Erosion Potential

Erosion potential as measured by the percent of bare soil, soil disturbance, and evidence of erosion (gullies and rills), is significantly higher in goat grazed plots as compared to ungrazed plots.

H5₀ was rejected, as goat grazing does show a significant correlation with trampled and bare soil. Most observed rills and gullies were found on steeper slopes and stream banks (See Figure 25). Some disturbed soil appeared to be caused by gopher activity, rather than goats.

Trampled Soil

Using the point-intercept method, each transect had 50 samples at ground level. Grazed plots revealed trampled soil in 11 out of 50 samples, or 22%; no samples in the control plots showed trampling (ANOVA $p=0.000$) (See Figure 26).

Bare Soil

The ANOVA for bare soil in grazed vs. control plots was also significant ($p=0.003$) (See Figure 27). Bare soil represented 29% of the sampled data points on the control plots and 35% on grazed plots, which shows a 20% increase ($29\% \times 1.20 = 35\%$).

DISCUSSION

Plant Species Richness and Abundance

When considered together, the three control plots had significantly greater richness and abundance of native plant species than the grazed plots.

Because there was less protection from vegetative cover, the grazed plots were more exposed to both wind and sunlight; so native plant species that could survive there would inevitably need to tolerate those edaphic and climatic conditions. Lunt and Morgan (1999) found that less resilient species decline or disappear from a landscape where weedy colonizers dominate. In many parts of the grazed plots in this study, that appeared to be the case.

At the time of this field study, the hillsides at the SH grazed plot were characterized by *Quercus agrifolia* and *Umbellularia californica* woodlands; the narrow valley (the “hollow”) was dominated by annual non-native grasses and *Baccharis pilularis*. Before the goat grazing program had begun, *Brassica nigra* and *Conium maculatum* were pervasive. Little of them had persisted on the grazed plot until the start of the study, but the invasive non-native *Centaurea solstitialis* (yellow star thistle) was widespread.

After years of grazing, the percent tree cover at SH exceeded the control plots. Except for removing the foliage within the goats’ 1.5-meter reach, goat grazing didn’t seem to affect mature trees and *Quercus agrifolia* and *Umbellularia californica* saplings were observed. However, as goats

browse on *Quercus agrifolia* seedlings and saplings; more data would need to be gathered on their rates of regeneration to determine any effects the grazing might have. Regardless of regeneration studies that may be done in the future, a prudent approach would be to protect *Quercus agrifolia* and *Umbellularia californica* seedlings and saplings within a grazing zone whenever possible.

To expect grazed plots to have as high a level of forb species richness as ungrazed plots is unrealistic. However, vegetation managers could accommodate reproductive cycles of some key or threatened plant species, as suggested by Pettit (et al. 1995). Provided that fire hazard does not unduly increase, grazing could be delayed for desirable species that require a certain size or structure to survive over the long term. Waiting until after those species have gone to seed, or by protecting them with modified enclosures and exclosures, might prevent disruption of ecosystem functioning. In addition, provided that desirable species would not be adversely affected, invasive, non-native plant species that do not mature and set seed until the summer could be removed by grazing before that time, e.g. *Centaurea solstitialis*, *Conium maculatum*, *Cirsium vulgare* (bull thistle), *Brassica spp.* (mustard), *Dipsacus fullonum* (wild teasel), and others.

In large grazed areas, remarks Archer (1996), close monitoring of every species is impractical. However, tracking the spread of invasive non-native

species on grazed plots, such as *Anthriscus millefolium* (burr chervil), *Erodium cicutarium* (red-stemmed filare), and several thistle species – *Centaurea solstitialis*, *Cirsium vulgare*, and *Carduus pycnocephalus* (Italian thistle) – and regularly removing them might provide habitat protection for growth of native forbs and shrubs that have beneficial value in the watershed. Also, a sustainable ecosystem might be more effectively maintained with regular monitoring of the balance of palatable (preferred) and unpalatable vegetation (Archer 1996). Though they are indiscriminate browsers, goats will eat the more palatable, foods until they are depleted or inconvenient. Vegetation managers can – and do – instruct goatherders to remove goats once the prescribed reduction of cover is achieved (URS 2002, section 4, page 9). Nevertheless, to minimize further impact to the ecosystem that might encourage the spread of invasive non-native and/or unpalatable species, goatherders should also be instructed to quickly remove the goats as palatable vegetation decreases in relation to unpalatable vegetation,.

Benefits of Goat Grazing

There are indications that goat grazing has ecological benefits. Threatened or rare plants in grasslands have a better chance of survival and reproduction with frequent removal of biomass and litter (Lunt and Morgan, 1999). On both the grazed and control plots of the KPFC site, the native grass *Nassella pulchra* was widespread. The annual grazing prevented the

non-native grasses from choking out that native species, as well as *Eschscholzia californica* (California poppy), which was found only on the grazed plots. On the LC grazed plot, there was a flourishing cluster of *Dirca occidentalis*, a rare shrub, endemic to California, and associated with oak/bay woodlands and riparian zones. The California Native Plant Society includes this species on its list of rare, threatened and endangered plants (Lake 2001, 26 and CNPS 1994). Apparently, goat browsing has not hurt these plants, and might even encourage their growth by annually removing grasses and weeds that could hinder their vigor.

Another benefit is that goats apparently eat and reduce the density of dry *Conium maculatum* stalks, an invasive, non-native species that is toxic to wildlife and horses (Danielsen, et al. 2001). Danielsen (2001) reports that *Conium maculatum* grows in single stalks and forms dense stands that often reach 2 meters high by late spring and could contribute to the upward spread of a wildland fire. Compared to control plots, grazed plots showed lower abundance of *Conium maculatum* (See Figure 24). Though the mean *Conium maculatum* abundance in the control plots appears low, it was unevenly distributed. Only one individual *C. maculatum* plant was sampled on the LC site, but on the KPFA site, *C. maculatum* was sampled at a mean of 17 per control transect and 7 per grazed transect; at SH control plots, there were 14 per control transect and 1 on grazed transects.

Soil Condition and Erosion Potential

Some environmentalists fear that goat grazing programs might introduce the seeds of invasive non-native plants from one area to another, as Harris and Nagy reported (2000). However, it seemed more likely that the increased diversity and abundance of non-native species occurred in grazed plots due to soil disturbance. The non-native plant seeds appeared to be ubiquitous, but did not invade the control plots as readily as the grazed ones.

Gullies and rills were surveyed, but occurred very rarely and mostly on the steeper slopes. In addition, soil disturbance was frequently a sign of rodent activity, rather than direct damage from the presence of goats. Thus, although erosion did not appear to be a serious problem on the grazed plots, there was a significantly higher percentage of trampled and bare soil on the grazed plots. This greater amount of exposed and disturbed soil is a matter of concern, as it provides opportunities for invasive non-native plants to spread. Data would need to be gathered to determine whether goat grazing has an adverse impact on the rate of soil erosion or causes changes in chemistry or composition of the soil.

Fire Risk Management with Lower Percent Cover

Data were gathered in September 2001 through February 2002. Data collected in the fall samples showed that the forb layer in grazed plots had lower percent cover than were in the controls, but in the spring, the grazed

plots had greater percent cover than controls. This was likely due to the greater space and light available to the plants in the grazed plots.

Grassland fires are relatively easier to control than shrubland or tree crown wildfires, as flames produced by low-growing plants (below 0.5 meters) would generate VFLs well below 2.4 meters. Tall grasses and shrubs, particularly where cover is greater than 50%, can generate vertical flame lengths (VFLs) greater than 2.4-meters, which in turn, create a fuel ladder (Russell and McBride 2001). Potentially, a fire then spreads upward to tree crowns, where the ensuing fires are harder to control.

In this study, forbs and grasses that were above 0.5 meters in height were categorized as mid-level vegetation or “shrubs.” Therefore, to evaluate whether a goat grazing program decreases wildfire hazard, the emphasis was on shrub vegetation, as the forb category would not be as meaningful in this context. In the Fuel Management Plan for the East Bay Hills (EBHVMC 1995, app. 9,10), recommendations to mitigate the fire hazards of north coastal scrub communities include the following:

- maintaining a 20% dead to live plant matter ratio by removing dead plant materials and litter;
- either crushing brush to a maximum height of 1 meter, or by creating islands of taller shrubs, surrounded by mulch or low-growing plants;

- regular management of the treatment areas every 3-5 years to minimize buildup of plant litter and to keep the vegetation structure patchy and discontinuous;
- a 30% minimum and 70% maximum reduction of shrub biomass.

In the mediterranean climate that characterizes much of the California coastal region, September and October are the peak months for wildfire hazards. EBMUD vegetation managers usually schedule goat grazing between June and August, when grasses have matured and shrubs, such as *Baccharis pilularis* and *Toxicodendron diversilobum*, contain greater biomass. The key species in shrublands that is known to greatly increase fireline intensity and flame length is *Baccharis pilularis* (Russell and McBride 2001). Current regional guidelines for wildlands fuel reduction aim to reduce the potential for greater than 2.4-meter VFLs. If the control plots in this study were involved in a wildland fire, the dense thickets, dominated by *Baccharis pilularis*, could produce vertical flame lengths greater than 2.4 meters and a higher fire intensity than could the grazed plots.

Tsiouvaras, et al. (1989) suggested that goats could potentially be very helpful for reducing fuel loads because they found that goats browsed *Baccharis pilularis* very heavily and broke up the vertical and horizontal sequence of fuels. As annual non-native grass species frequently grow above 0.5m, and then die, dry out and develop dense layers of thatch in the summer

and fall, the risk of a fire ladder effect would be lower where grazing reduces vegetation height and density.

Percent cover in the shrub layer was significantly lower on all three grazed sites, which had a mean of 15-20% cover, contrasted with 85% shrub cover at the control sites. Further, the mean height and abundance of key chaparral species, such as *Baccharis pilularis*, *Mimulus aurantiacus*, and others, was reduced significantly in goat grazed plots. For example, even where *Baccharis pilularis* abundance was greater than the mean in a grazed transect, the heights were reduced to a mean height of 0.51 meters, which is within the recommendations in the Fuel Management Plan for the East Bay Hills (EBHVMC 1995). This suggests that using goat grazing for managing fire-prone vegetation in the urban-wildland interface appears to be effective in reducing wildland fire hazard by limiting potential fireline intensity and vertical flame lengths in key species.

Further research might include a survey of the sites before the goats graze, in the late spring, to give a more complete picture of the vegetation at its tallest; also, studies need to be done on soil, invertebrates, wildlife, and long-term analyses of the frequency and intensity of fires in these fire-prone areas where goat grazing is done annually.

LIMITATIONS

Though there is a risk that any one year's grazing might have a stronger effect than others, the assumption for this study is that changes in structure and species composition from annual summer grazing occurred over several years' time and yielded adequate data for analysis. Variations in annual precipitation and temperatures also certainly affect vegetation growing on the sample sites. Data collection for this research project was conducted only from October 2001 through February 2002. Consequently, vegetation was sampled before the summer growth, when it develops the thick brush and/or dry forbs and grasses associated with increased wildfire hazard. In addition, goats don't generally graze down to bare dirt, having a preference for vegetation growing between 0.5-1.5 meters high. However, they do eat low-growing plants, so it was difficult to correctly identify some herbaceous plants during the sampling period. However, the lack of thick vegetative cover did yield helpful observational data for indications of soil condition.

Methods and practices for wildfire fighting and its prevention vary from place to place and from one agency to the next. The guidelines that this thesis works with are the commonly accepted ones for East Bay agencies and fire departments (San Francisco Bay area). Conclusions based on those

guidelines may not apply to areas where different guidelines for vegetation reduction for wildfire prevention are used.

Data sampling could not proceed in rainy weather, where brushy vegetation became impenetrable, or terrain was too slippery or steep. In addition, where the risks of injury were excessive or were simply out of reach, some data were sampled by careful visual estimates. Out of necessity, the number of quadrats per plot were reduced because only eight transects could be sampled, rather than ten. These modifications might have reduced, slightly, the randomness and accuracy of the sampling, but results were probably not significantly affected.

SELECTED BIBLIOGRAPHY

- Archer, S. *Assessing and Interpreting Grass - Woody Plant Dynamics*, in. J. Hodgson and A.W. Illius, editors. 1996. *The Ecology and Management of Grazing Systems*. Chapter 4. pages 101-134.
- Bartolome, J., J. Franch, J. Plaixats, N.G. Seligman. 2000. *Grazing alone is not enough to maintain landscape diversity in the Montseny Biosphere Reserve*. in *Agriculture, Ecosystems and Environment* **77**:267-273.
- Bonham, Charles D., *Measurements for Terrestrial Vegetation*. 1989. John Wiley & Sons, Inc. New York
- Bossard, Carla C., John M Randall, and Marc C. Hoshovsky. 2000. *Invasive Plants of California's Wildlands*, UC Press, Berkeley, Calif.
- California Native Plant Society (CNPS). 1994. *Inventory of Rare and Endangered Vascular Plants of California*. 5th edition. Skinner, Mark W. and Bruce Pavlik, editors.
- Carmel, Yohay, and Ronen Kadmon. 1999. *Effects of grazing and topography on long-term vegetation changes in a Mediterranean ecosystem in Israel*. in *Plant Ecology* **145**:243-254. Kluwer Academic Publishers, Netherlands.
- Child, R. Dennis, Byington, Evert K., and Hannah H. Hansen. 1985. *Goats in the Mixed Hardwoods of the Southeastern United States*. in Frank H. Baker and R. Katherine Jones, editors. *Proceedings of a Conference on Multispecies Grazing*. June 25-28, 1985 at Winrock International Institute For Agricultural Development, Morrilton, Arkansas.
- Danielsen Consulting, Inc., East Bay Regional Park District, Ernest Orlando Lawrence Berkeley National Laboratory and Wildland Resource Management, Inc. 2001. *Vegetation Management Almanac for the East Bay Hills*. Hills Emergency Forum, pub. Berkeley and Oakland, CA
- East Bay Hills Vegetation Management Consortium - EBHVMC. May 1995. *Fire Hazard Mitigation Program and Fuel Management Plan for the East Bay Hills*. prepared by Amphion Environmental, Inc. copy available at East Bay Regional Park District.

- East Bay Regional Park District. February 1982. Report of the Blue Ribbon Fire Prevention Committee For The East Bay Hill Area Urban-Wildland Interface Zone.
- Gibson, C.W.D., and V.K. Brown. 1991. *The effects of grazing on local colonisation and extinction during early succession*. Journal of Vegetation Science **2**:291-300. Opulus Press Uppsala, printed in the U.S.A.
- Green, Lisle R. and Leonard A. Newell. 1982. *Using Goats to Control Brush Regrowth On Fuelbreaks*. USDA Forest Service. General Technical Report PSW-59. Pacific Southwest Forest and Range Experiment Station.
- Harris, Bonnie and Sharon Nagy. 2000. for the Los Angeles Times, *Laguna Beach Stuck on Horns of Dilemma*, Special to the Times, published on Monday, May 22, 2000, page A-1
- Hatch, Daphne A., James W. Bartolomé, , Jeffrey S. Fehmi, and Deborah S. Hillyard. 1999. *Effects of Burning and Grazing on Coastal California Grassland*, in Restoration Ecology **7**: no. 4:376-381
- Hill, Scott, goat grazing specialist at the East Bay Municipal Utility District watershed headquarters. July 2000. Contra Costa Co.. Personal communication.
- Lake, Diane. 2001. *Unusual and Significant Plants of Alameda and Contra Costa Counties*. California Native Plant Society, East Bay Chapter.
- Lunt, Ian D., and John W. Morgan. 1999. Vegetation Changes after 10 Years of Grazing Exclusion and Intermittent Burning in a Themada trandra (Poaceae) Grassland Reserve in South-eastern Australia. in Australian Journal of Botany. **47**:537-552
- Mueller-Dombois, Dieter and Heinz Ellenberg. 1974. *Aims and Methods of Vegetation Ecology*, John Wiley & Sons, New York.
- Oakland Fire Department. *The Oakland Tunnel Fire, October 20, 1991*. prepared by Robin Silberman, Technical Writer. This report contains chronologies of time and place of the fire, as well as reports by engine companies and fire officers.
- Pettit, Neil E., Raymond H. Froend, & Phillip G. Ladd. 1995. *Grazing in remnant woodland vegetation: changes in species composition and life form groups*. in Journal of Vegetation Science **6**:121-130. Opulus Press Uppsala.

- Russell, William H., and Joe McBride. *Vegetation Change and Fire Hazard in SF Bay Area Open Spaces*. in Blonksi, K.S., M.E. Morales, and T.J. Morales. 2001. Wildfire Conference: Ten Years After the East Bay Hills Fire; October 10-12, 2001; Oakland, CA. pages 33-44. Technical Report 35.01.462. Richmond, CA, University of Calif. Forest Products Laboratory.
- Seligman, N.G. *Management of Mediterranean Grasslands*. in J. Hodgson and A.W. Illius, editors. 1996. Ecology and Management of Grazing Systems, pages 359-391.
- Trout, Richard, 1997. A Planner's Guide to Vegetation Management Issues and Strategies After California Urban Wildfire, August 1997 Master's Thesis UC Berkeley, Landscape Agriculture Dept.
- Tsiouvaras, C.N., N.A. Havlik and J.W. Batolomé. 1989. *Effects of Goats on Understory Vegetation and Fire Hazard Reduction in a Coastal Forest in California*. in Forest Science Journal for the Society of American Foresters, **35**: no. 4:1125-1131.
- URS Corporation, August 2002. East Bay Regional Park District Vegetation Management Projects Alameda Co, California. Draft Environmental Assessment HMGP #919-515-24, Prepared for FEMA Region IX, Oakland, CA. section 4 and app C:3

FIGURES AND TABLES

Figure 1. Goat grazing is used all over the San Francisco Bay Area for vegetation reduction in fire prevention programs.

Figure 2. San Francisco Bay Area. This road map represents the cities, highways, and major points of interest in the San Francisco Bay Area, in California. Study sites are a short distance from Orinda which is marked east of the East Bay Hills. © *California State Automobile Association, Coast and Valley Section 1997*. Scale: 1.0 cm = 6 km.

Figure 3. East Bay Municipal Utility District (EBMUD) Trails. EBMUD properties are in darker brown. Names of study site locations were chosen for nearby landmarks: KPFA, Lomas Cantatas, and Sleepy Hollow. Scale: 1 cm = 1 km. © EBMUD Trails, 1992.

Figure 4. Study sites are marked. Sleepy Hollow (near Briones Reservoir), Lomas Cantatas (above "Siesta Valley") and KPFA (corner of Fish Ranch Rd. and Grizzly Peak). Scale: 1 cm. = 1.2 km. © California State Automobile Assn., Oakland and Vicinity. 1999

Figure 5. Grazed plots are marked with black dots and names; control plots with lighter dots. Scale: 2.2 cm = 1 km. The Olmstead & Bros. Map Co., Berkeley. © *A Rambler's Guide to the Trails of the East Bay Hills, Northern Section (Third Edition)*. 1995

Figure 6. Sampling grid design for each transect. The shortest vegetation (“forbs”), was sampled within 5 – 1m² quadrats along one 10m edge of the transect. The mid-level (“shrubs”) vegetation was sampled within 1 – 16m² quadrat. The tallest vegetation (“trees”), was sampled within the entire transect, a 100m² quadrat.

Figure 7. Mean shrub species per transect were significantly decreased in the grazed plots (1.5 species) as compared to the control plots (2.7 species).

Figure 8. Mean forb species richness (number of species per transect) was not significantly different between grazed vs. control.

Figure 9. Forb height showed a significant overall decrease of 60 percent in grazed plots compared to control plots (ANOVA, $p < 0.05$).

Figure 10. Shrub height showed a significant overall decrease of 73 percent in the grazed plots compared to the control plots.

Figure 11. Tree heights showed a significant increase of 11 percent overall in grazed plots compared to control plots.

Figure 12. Percent forb cover measured a marginally significant decrease overall of 5 percent in grazed compared to control plots ($p=0.013$).

Figure 13. Percent overall shrub cover showed a significant decrease of 82 percent in grazed plots compared to control plots ($p=0.000$).

Figure 14. Overall native plant richness in grazed plots was significantly lower than in control plots (ANOVA, $p=0.000$). An average of 4 species were in grazed transects and 7 species in control transects.

Figure 15. Native forb richness in grazed plots had a mean of 2.3 native species per transect. Control plots had 3.9 species per transect.

Figure 16. Native forb abundance in the grazed plots was 10 individual plants per transect. Control plots had 21.

Figure 17. *Nassella pulchra* (purple needlegrass) was three times more common on the grazed plot than the control. Goats grazed annually, preventing the non-native grasses from choking out this native species.

Figure 18. Native shrub richness revealed a significant decrease in grazed plots where there were 1.2 species (ANOVA, $p=0.000$) versus the control plots, which had 2.6 species per transect.

Figure 19. Native shrub abundance in grazed plots had a density of 6 individual plants per transect; control plots had 15.

Figure 20. Non-native forb richness was significantly greater at the grazed plots, where there were 2.4 non-native plant species per transect versus 0.8 species per transect at the control plots.

Figure 21. Non-native forb abundance was greater at the grazed plots, which had 18 individual non-native plants per transect compared to the control plots, which had 4 plants (ANOVA $p=0.000$).

Figure 22. Non-native shrub abundance was greater at the grazed plots ($p = 0.094$). Spring data contradicted the data collected in the fall, when control plots had greater abundance than the grazed plots. Overall, however, grazed plots consistently revealed more non-native abundance when compared to the control plots for each study site.

Figure 23. *Baccharis pilularis* mean abundance on control plots was 7 per transect (within 4mx4m quadrats). On grazed plots, there were 5, a 36% reduction. *B. pilularis* is a key species in shrublands that greatly increases fireline intensity and flame length in a wildland fire (Russell and McBride 2001).

Figure 24. *Conium maculatum* is a non-native species that grows in single stalks and forms dense stands that often reach 2 meters high by late spring (Danielsen, et al. 2001). There were fewer *Conium maculatum* plants in the grazed plots, suggesting that goat grazing helps keep this invasive species under control.

Figure 25. Rilled Soil was neither common nor significantly different in control plots compared to grazed plots.

Figure 26. Trampled Soil was only found on the grazed plots (11 data points per 50 sampled, or 22%).

Figure 27. Bare Soil samples in grazed vs. control plots was significant ($p=0.003$). Bare soil represented 29% of the sampled data points on the control plots and 35% on grazed plots, which shows a 20% increase.

Table 1: Biomass and predicted fire characteristics using the FARSITE model. Average flame length is a rating from 0.0-1.0. Shrubs exhibit the greatest fireline intensity and flame lengths, even surpassing Monterey pine forest. *Source: Russell and McBride, 2002, 36*

Biomass and Predicted Fire Characteristics			
Vegetation Type	Surface Biomass tons/ha.	Fireline Intensity (kW/m)	Range of Flame Lengths (m)
Grass: generally considered manageable	1.5	66.5	1-15m - depends on grass length
Shrub	18.7	197.0	6-20m depends on age, slope, moisture
Oak Woodland	3.7	36.0	1-13m - depends on understory
Monterey Pine	40.7	157.9	2-6m depends on understory

Table 2. Each species is listed by site, native or non-native, grazed (Gz) or control (Cntrl), and # of transects out of 16 where species was present.

Species List							
Native Species		Grazed			Control		
Species Name	Common Name	LC	KPFA	SH	LC	KPFA	SH
<i>Achillea millefolium</i>	Yarrow	1	1	1			2
<i>Artemisia californica</i>	California Sagebrush			1			1
<i>Athyrium filix-femina</i>	Lady Fern						15
<i>Baccharis pilularis</i>	Coyote Brush	10	14		12	14	3
<i>Cardamine oligosperma</i>	Bitter Cress					1	3
<i>Chlorogalum pomeridianum</i> var. <i>ledebourii</i>	Soap plant	1		1			3
<i>Claytonia perfoliata</i>	Miners Lettuce			2			
<i>Cynoglossum grande</i>	Grand Houndstongue			1			
<i>Dirca occidentalis</i>	Western Leatherwood						1
<i>Eschscholzia californica</i>	California Poppy	1		2			
<i>Galium</i> spp.	Bedstraw			2			
<i>Heracleum lanatum</i>	Cow Parsnip					4	
<i>Heteromeles arbutifolia</i>	Toyon				1		1
<i>Horkelia californica</i>	Horkelia		1				1
<i>Lichen</i>	Lichen	2			8	6	5
<i>Marah fabaceus</i>	Wild Cucumber						1
<i>Mimulus aurentiacus</i>	Bush Monkey Flower	9	4	1	11		8
<i>Moss</i>	Moss	1			1	6	4
<i>Nassella pulchra</i>	Purple Needle Grass		14		2	4	2
<i>Pentagramma triangularis</i>	Goldback Fern					1	2

(Table 2 continued)

Native Species		Grazed			Control		
<u>Species Name</u>	Common Name	LC	KPFA	SH	LC	KPFA	SH
<i>Polypodium californicum</i>	California Polypody	1					
<i>Pteridium aquilinum</i>	Bracken Fern				1	1	3
<i>Quercus agrifolia</i>	Coast Live Oak	1	1	8	3	2	3
<i>Rhamnus californica</i>	Coffeeberry				10	1	
<i>Ribes quercetorum</i>	Oak Gooseberry					2	
<i>Ribes spp</i>	Gooseberry		1	1		4	
<i>Rubus ursinus</i>	Blackberry		1	0		7	2
<i>Rumex obtusifolius</i>	Bitter Dock		1		5		
<i>Salvia sp.</i>	Sage		1				
<i>Sambucus mexicana</i>	Blue Elderberry			2		4	5
<i>Sanicula crassifolius</i>	Snakeroot			2	1	2	3
<i>Satureja douglasii</i>	Yerba Buena	2	1		11	5	1
<i>Scrophularia californica</i>	California Figwort				1	5	1
<i>Sidalcea malvaeflora</i>	Common Checkerbloom	3	6	5	2		
<i>ssp. malvaeflora</i>							
<i>Stachys bullata</i>	Hedge Nettle		1	2		1	
<i>Symphoricarpus albus</i>	Snowberry			1			
<i>Toxicodendron diversilobum</i>	Poison Oak	6	13	5	4	9	7
<i>Umbellularia californica</i>	California Bay-laurel	5	4	5	6	2	1
<i>Urtica dioica</i>	Stinging Hoary Nettle					3	1
Total # of Native Species		13	15	17	16	21	24

(Table 2 continued)

Non-native Spp		Grazed			Control		
<u>Species Name</u>	Common Name	LC	KPFA	SH	LC	KPFA	SH
<i>Anthriscus millefolium</i> l	Burr Chervil		3	2		1	4
<i>Brassica</i> spp. (<i>nigra</i>)	Mustard (Black)			1			
<i>Carduus pycnocephalus</i>	Italian Thistle		1				
<i>Centaurea solstitialis</i>	Yellow Star Thistle		1	3		1	2
<i>Cirsium vulgare</i>	Bull Thistle	2	4	4	2	1	
<i>Conium maculatum</i>	Poison Hemlock	1	4	2	1	5	6
<i>Dipsacus fullonum</i>	Wild Teasel					2	
<i>Erodium cicutarium</i>	Red-stemmed Filare	2					
<i>Eucalyptus globulus</i>	Blue Gum Eucalyptus		3				
<i>Genista monspessulana</i>	French Broom		3				2
<i>Medicago polymorpha</i>	Calif. Burr Clover	2	4	3			
NNG	Non native Grass	16	8	15	6		1
<i>Pinus radiata</i>	Monterey Pine		3		5		
<i>Rumex obtusifolius</i>	Bitter Dock		1				
<i>Rubus discolor</i>	Himalayan Blackberry				1		
<i>Silybum marianum</i>	Milk Thistle		1	2			
<i>Stellaria media</i>	Common Chickweed			3			
<i>Teraxacum officinale</i>	Dandelion					2	
<i>Vicia</i> spp.	Vetch	2		4			
Total # of Non-native Species		6	12	10	5	6	5

Table 3. For each site, the grazed plots had fewer native species and more non-native species than its corresponding control site.

Richness: Total # of species sampled on each site: Native and Non-native					
	LC		KPFA		SH
	Grazed	Control	Grazed	Control	Grazed
Native species	13	16	15	21	17
Non-native sp	6	5	12	6	10
					24
					5

Richness: Average # of species per transect: Native and Non-native					
	LC		KPFA		SH
	Grazed	Control	Grazed	Control	Grazed
Native species	2.56	5.69	4.19	6.43	2.43
Non-native sp	1.50	0.81	2.13	0.79	2.31
All Species	4.06	6.5	6.32	7.22	4.74
					4.50
					0.94
					5.44