Determination of Fire Impacts on Vegetative Communities of the Upper Sonoran Desert Using Terrestrial Ecological Unit Inventory Data

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Introduction

Fire frequency in this upper subdivision of the Sonoran Desert has increased significantly since 1955, correlating both to population growth and winter precipitation trends (Alford et al., 2005). Historically, the effects of fire as a disturbance agent in desert systems has been minimal due to low fuel loads that would not be capable of sustaining fire on a landscape (McLaughlin and Bowers, 1982; Brooks and Pyke, 2001; Engel and Abella, 2011). Anthropogenic augmentation of the desert communities has resulted in increased fire frequencies. Introduced exotic annuals have increased the canopy of fine flashy fuels in desert systems facilitating the spread of fire across the landscape (Brooks and Pyke, 2001). Native vegetation of the upland Sonoran desert is a diverse mixture of cacti and desert shrubs, most notably Saguaro cactus (*Carnegiea gigantean*), trees like yellow and blue palo verde (*Parkinsonia microphylla*, and *Parkinsonia florida*), common desert shrubs include triangle bursage (*Ambrosia deltoidea*), jojoba (*Simmondsia chinensis*), creosotebush (*Larrea tridentate*), wolfberry (*Lycium berlandieri*), brittlebush (*Encelia farinose*). The Native vegetation evolved without frequent fire and thus often times lack fire-adapted characteristics to survive a high intensity fire regime (Esque et al., 2004).

A third of the Tonto National Forest, approximately 750,000 acres, is comprised of the upland subdivision of the Sonoran Desert. Of that area roughly 470,000 acres has burned in the Tonto National Forest since 1970. While successional response to fire is well documented in most grass, woodland, and forested systems there are still questions remaining about the nature of vegetative response to fire in arid landscapes. Determining the indicators for long term departure in the Sonoran desert system could help land managers anticipate whether or not management intervention is needed to prevent long term departures across the desert landscape.

The USDA Forest Service, Southwestern Region, Terrestrial Ecological Unit Inventory was initiated on the Tonto National Forest in the 1980 and continues to present day. Data collection is based on an integrated approach where ecological components (climate, soils, geology, geomorphology and vegetation) are described collectively and simultaneously at a location where the ecological type is stable, functioning, and diverse (USDA Forest Service, 1986). The data collection process results in data on vegetation communities' species composition and abundance in addition to surface cover and soil pedon characteristics. Due to the ongoing nature of the survey the result is a sweet of data pre and post fire over a diverse assemblage of map units in the Sonoran Desert.

Objectives

- Establish trends for post fire vegetative recovery in the Upland Subdivision of the Sonoran Desert.
- Provide metrics for land managers to utilize when determining restoration strategies and timelines for recovery.

Conclusions

The rate of recovery for Sonoran Desert plant communities is a much slower process for areas that had moderate to high burn severity. Previous studies have modeled Sonoran desert plant community recovery on TSF gradients that suggest canopy cover recovery within 28yrs (Alford et al., 2005). However, our analysis suggests that while canopy cover might have improved species richness and diversity is altered due to the decrease in common native cactus and tree species and an increase in annual forb and graminoid canopy cover. Based on our data we have concluded that from 25-35 years there is a shift in state toward a more representative vegetative community but not a complete recovery.

Sonoran Desert soils are often susceptible to erosion, evidence of increased rill, gully, and sheet erosion is often noted as a visual observation in previously burned areas. Many cactus species, especially *Carnegiea gigantean*, require a stable rooting environment, the increased erosion due to disturbance could easily be associated with reduced return of cactus species in our study area. It is reasonable to suggest that in areas that have experienced moderate severity burn disturbance land managers should consider limiting intrusions into the burned area in order to avoid exacerbating stability issues. In areas with extensive moderate to high burn severity the loss of viable seed sources for native species might require management intervention to re-introduce species like *Carnegiea gigantean.*

Methods

A digital polygon layer was obtained from the Tonto National Forest's digital database, it included all mapped fire perimeters for fires post 1970. In addition to this data we obtained raster data on burn severity for fires recorded post 1984 (MTBS data, 2015). The Terrestrial Ecological Unit Inventory began on the Tonto National Forest in the 1980s. Field data from the upper Sonoran Desert was identified and compared to fire data to determine if site data could reflect impacts of recent fire history. Analysis was conducted by map unit and only for those units that had data in pre and post fire landscapes. In some instances older data was not used in analysis of species diversity due to changing data collection protocol. Sample sites consist of tenth acre circular plots, a complete species list with canopy cover values are measured in addition to a full taxonomic soil description.

Vegetative species richness and Shannon's diversity index (based on canopy cover) was summarized with pc-ord software version 6.19 (McCune and Mefford, 2011). To determine whether specific species distinguished community state change we looked at TSF (time since fire) and burn intensity category using indicator species analysis and Monte Carlo randomizations to assess significance at $P=0.1$ (McCune and Mefford, 2011). To determine if community composition was recovering we conducted non-metric multidimensional scaling (NMS, with Sørensen distance) of plant communities in each map unit distinguished by TSF.

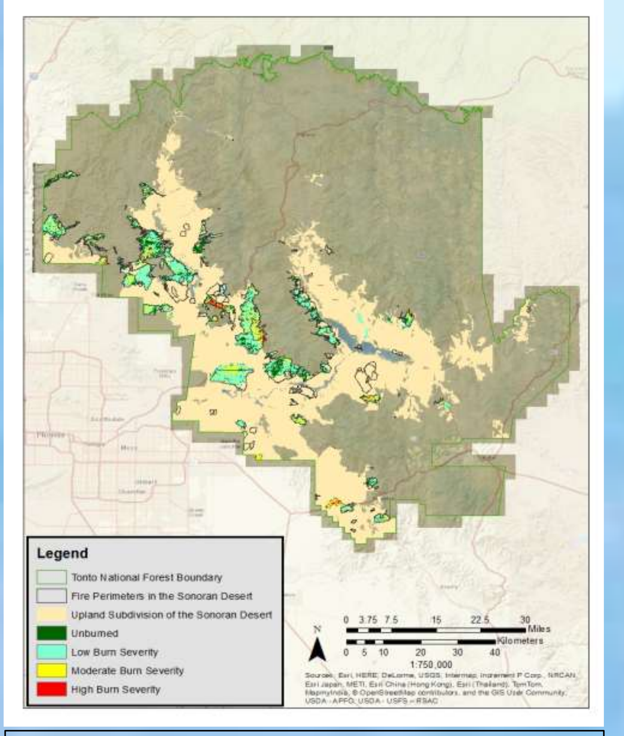

Figure 1. Map displaying the extent of the Upper subdivision of the Sonoran Desert ion the Tonto National Forest. Historic burn perimeter (post 1970) and burn severity data (post 1984) displayed for this ecological subdivision.

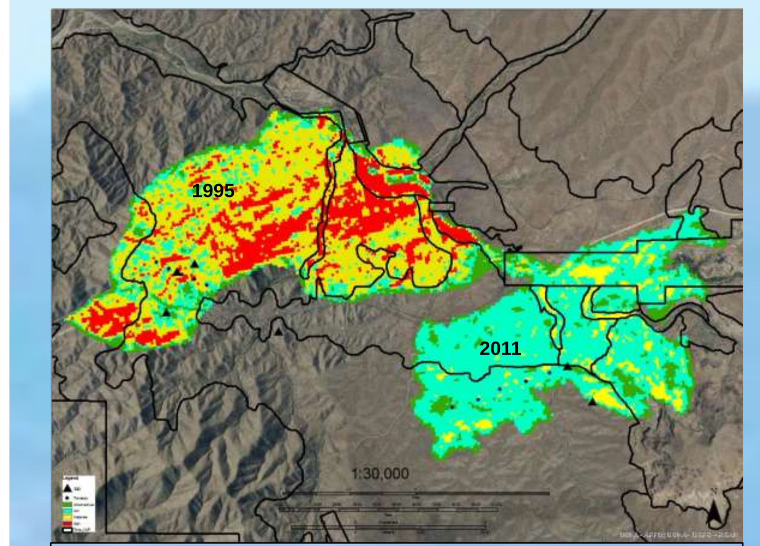

Figure 2. Map displaying TEUI data point in map unit 238 with burned area severity for two burns, one occurring in 1995 the other in 2011.

Results and Discussion

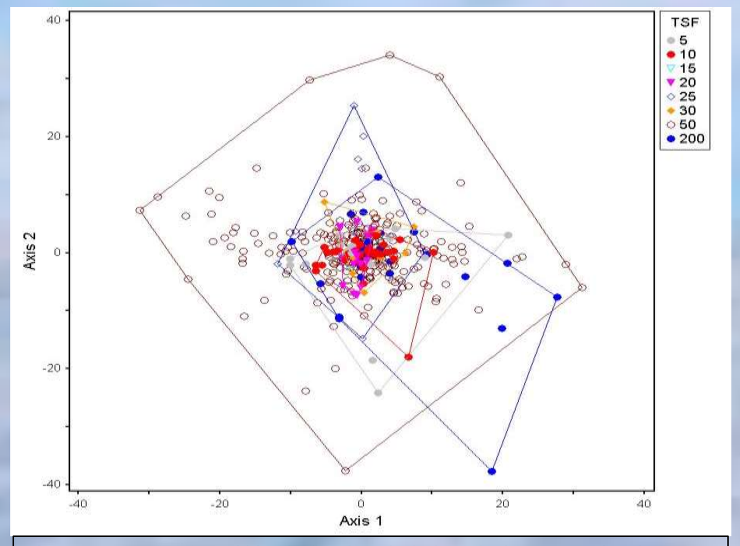

Figure 3. Non-metric multideminsional analysis (NMS) of TEUI species data at different TSF groupings. TSF=50 represents TEUI data collected at observations and transect stops and are considered to represent current conditions. TSF=200 represents TEUI ecological site data from areas that are considered to be fully functioning, stable, and representative of potential natural vegetation for that map unit. All data recorded within a burn perimeter at sometime after a fire event was grouped in 5 year increments. The oldest digitally recorded fire with data collection within the perimeter on the Tonto NF was at TSF=30.

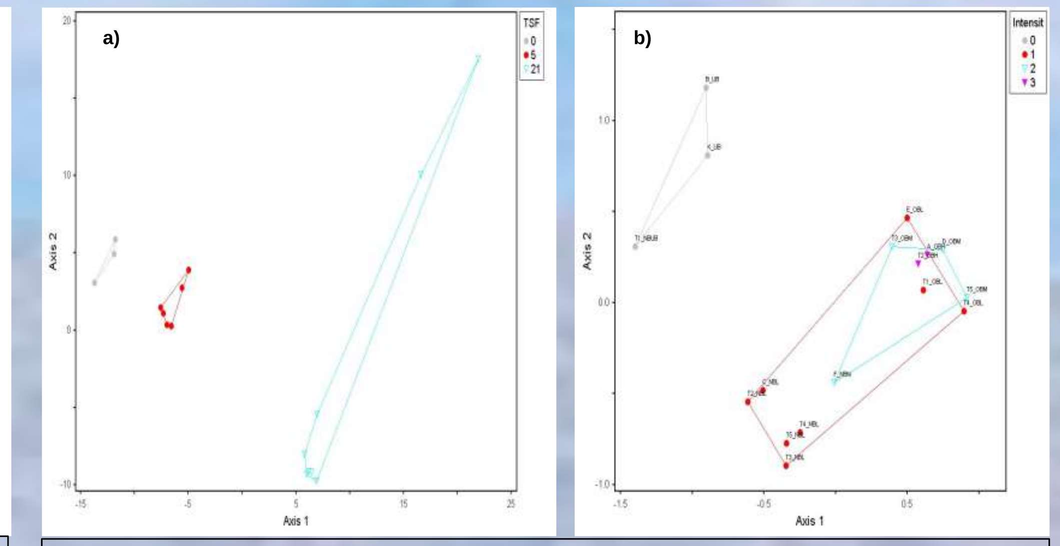

Figure 4. Non-metric multideminsional analysis (NMS) of TEUI species data in Map Unit 238. (a) Ordination is grouped based on TSF with TSF=0 representing the unburned plot data and TSF=5 and TSF=21 representing data from areas that burned in 1995 and 2011 respectively. (b) Ordination is grouped based on fire severity data; 0-unburned, 1-low intensity, 2-moderate intensity, 3-high intensity. Site ID labels can help identify TSF within the burn intensity groupings; UB-unburned, NB-new burn (2011), OB-old burn (1995).

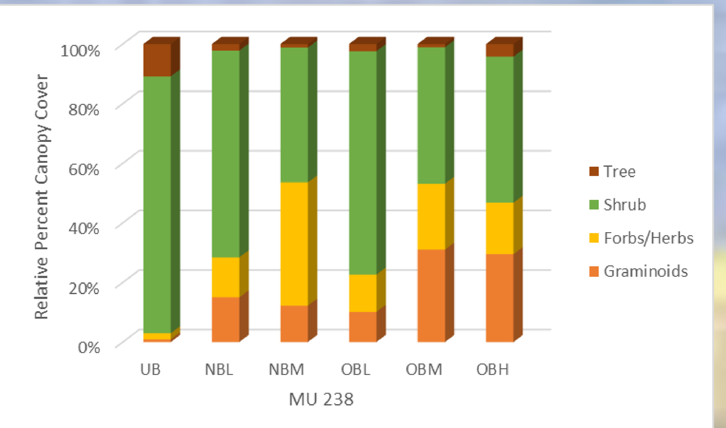

Figure 5. TEUI data from MU 238 compares the relative canopy cover for each site based on lifeform. (*UB-Edaphic unburned reference state; NBL-low intensity new burn; NBM-moderate intensity new burn; OBL-low intensity old burn; OBM-moderate intensity old burn; OBH-high intensity old burn*)

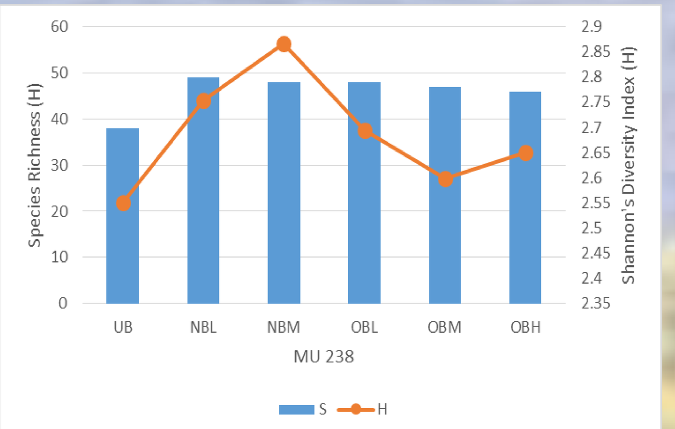

Figure 6. TEUI data summary of MU 238 of the species richness (S) on the left axis and the Shannon's diversity index (H) on the right axis. (*UB-Edaphic unburned reference state; NBL-low intensity new burn; NBM-moderate intensity new burn; OBL-low intensity old burn; OBM-moderate intensity old burn; OBH-high intensity old burn*)

NMS ordination of plot data was conducted on 11 TEUI map units within the Sonoran Desert of the Tonto NF. When the data is lumped together and grouped based on TSF the larger grouping represents the unburned data (TSF=50 &TSF=200). Burned data clusters toward the center but as TSF increases the clusters expand, a possible indication that areas at TSF=25 and 30 are progressing to a state that is starting to resemble unburned data (Figure 3). Because of the diverse environmental habitat factors within the Tonto National Forest we then looked at individual map units. Map Unit 238 presented a unique opportunity because we had data from unburned areas in close proximity to two different burn areas of different TSF states. MU 238 is a schist hills unit with slopes ranging from 0-45%, elevation approximately 750m, mean annual precipitation at 36cm, major soil components are a complex of Lithic Ustic Haplargids and Ustic Haplargids. NMS ordination of MU 238 data showed distinct groupings based on TSF with the older (TSF=21yrs) burn data located farther away from the unburned and new burn (TSF=5yrs) (Figure 4a). This could possibly indicate that the area within this 1995 burn is not yet recovered to the unburned state. Looking at the MU 238 ordination based on burn severity groupings burned versus unburned is clearly different but there is less distinction between the burn severity groupings (Figure 4b). This could possibly be explained by the extent of the mapped burn severity. The older burn has a greater extent of moderate to high intensity burn while the newer burn is mostly low intensity with some moderate and no high intensity (Figure 2). The increased area of disturbance to a greater severity is evident by visual signs of increased sheet erosion and benching along the slopes of the older burn area making the lack of stability a limiting factor for many cactus species (Figure 7). Species richness and Shannon's diversity index showed an increase from unburned plots (Figure 6), this is likely due to the increase in annual forbs and graminoids associated with the burn areas. Figure 5 looks at the breakdown of canopy cover based on lifeform relative to the site. Notice that shrub and tree canopy cover is reduced in favor of increased forb and graminoid cover in burn sites. Indicator species analysis in PC-ORD was conducted with the data grouped on burn severity in addition to TSF. None of the indicator values (IV) for MU 238 where significant at $p<0.1$ for burn severity groupings but there is notable trends for decline in IV scores with increased burn severity for *Carnegiea gigantean*, *Echinocereus engelmannii*, *Opuntia engelmannii,* and *Parkinsonia microphylla*, native cactus and tree species with little fire adaptability (Table 1). When grouped based on TSF two notable IV scores that where significant where *Bromus rubens* (red brome) and exotic annual grass that increased as an indicator with increased TSF and *Parkinsonia microphylla* which decreased as an indicator with increased TSF (Table 1).

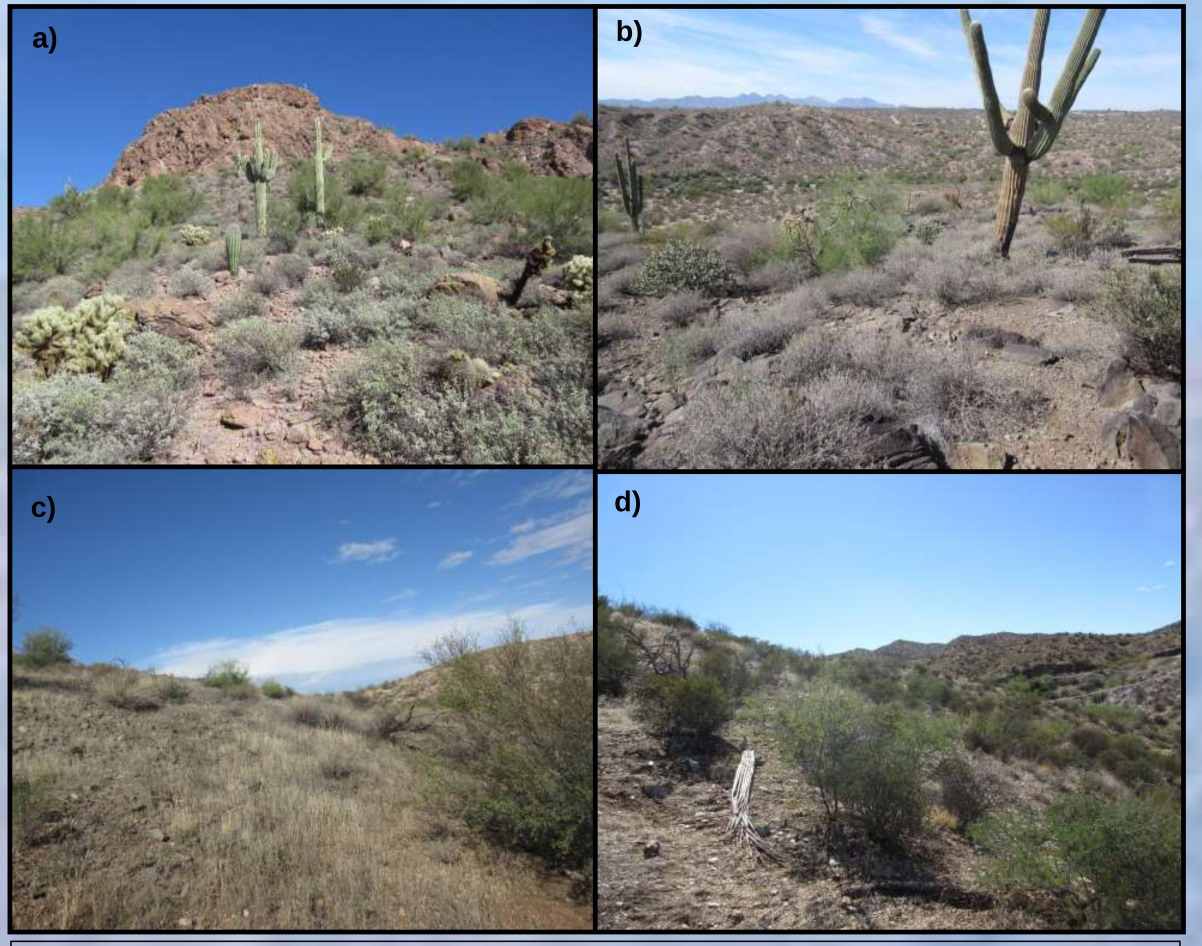

Figure 7. Landscape pictures from data collection stops in burned area perimeters on the Tonto National Forest. (a) Unburned Sonoran Desert landscape with multiple size classes of *Carnegiea gigantean* and *Parkinsonia microphylla*, dominant shrub cover with rocky interspaces between shrubs. (b) This is a low intensity burn (TSF=21 years), notice large *Carnegiea gigantean* survived with scaring at the base, shrub cover is dominated by *Encelia farinose* a common early colonizer of disturbance areas, and *Simmondsia chinensis,* a species that is capable of root crown regeneration after fires. (c) A moderate intensity burn (TSF=21 years), *Carnegiea gigantean* are greatly reduced as is relative shrub canopy cover, cover of annual plant species is increased. (d) A high intensity burn (TSF= 21 years), *Carnegiea gigantean* are greatly reduced shrub cover in this photo is dominated by *Simmondsia chinensis* and annual cover is increased.

Table 1. Table displays PC-ORD Indicator Values of selected plant species as percent of perfect indication (perfect = 100) based on combining values for relative abundance (based on species canopy cover) and relative frequency (presenence/absence). MU 238 was analysised with two different groupings, Burn Severity and TSF. Monte Carlo test of significance to test significance of observed max IV for the groupings from random permutations is also listed. (McCune and Mefford, 2011) *(* = p<0.1)*

Species	Indicator Values							
	MU 238							
	Burn Severity				TSF			
	Unburned	Low	Moderate	*p*	Unburned	5 years	21 years	*p*
Bromus rubens	3	20	77	*0.34*	3	18	79	*0.08**
Carnegiea gigantean	53	47	0	*0.59*	57	14	5	*0.34*
Echinocereus engelmannii	86	7	0	*0.39*	85	7	0	*0.33*
Encelia farinose	43	41	16	*1.00*	44	45	10	*0.87*
Eriogonum fasciculatum	27	44	1	*0.70*	31	8	10	*0.86*
Opuntia engelmannii	95	5	0	*0.70*	96	3	1	*0.64*
Parkinsonia microphylla	94	5	2	*0.20*	93	2	5	*0.01**
Simmondsia chinensis	33	28	39	*0.79*	34	25	41	*0.27*

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