The Effects of Building Shadow and Human Disturbance of Ponderosa Pine Forest Herbaceous Understory

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Abstract

Human activity displaces species and harms ecosystems, but to what degree? Little focus has been placed on the effects of human and building shadow disturbance on herbaceous understory in the northern Arizona ponderosa pine (Pinus ponderosa) *forest. At a newly built research station, this experiment used transects to examine percent cover of herbaceous vegetation at three different levels of disturbance surrounding a research station. I expected that herbaceous cover would be greatest at intermediate level of disturbance following the intermediate disturbance hypothesis that states an intermediate amount of disturbance will create high diversity in species. However, this hypothesis was not supported, rather the control and the disturbed sites were not significantly different from each other. The experiment is a good base-line study for the disturbed area. It should be conducted yearly to witness over time how the area is affected by disturbance. In general, more studies need to be conducted in order to determine the consequences of human and building shadow disturbance on herbaceous understory.*

Introduction

The ponderosa pine forest of northern Arizona has seen many changes over the past century and a half. The changes include fire suppression, domestic animal grazing, lumber industry, climate changes, felling, drought, and, recently, there has been a large increase in development within National Forest property. Studies conducted on the ponderosa pine forest have researched the larger effects of these issues, but few have documented changes in the understory, even though the understory greatly influences the ecosystem.

It is expected that human interference will immediately displace and disrupt the understory. Researchers need to have access to areas where they can study disturbance, but this in itself creates disturbance. For example, research stations, which house scientists working on experiments, ironically, impact the surrounding area with trampling and moving seeds by means of equiptment and clothing.

This study focuses on one disturbed plot one month after the construction of a research station at the Flagstaff Arboretum, Flagstaff, Arizona (*Figure 1(a) and 1(b)*) . It is within the Coconino National Forest. Comparing this disturbed area to an undisturbed plot can help us witness how human introduction and disturbance impacts understory regeneration. This will contribute to finding better management practices for preserving ponderosa pine understory in this region.

Ponderosa Pine History and Ecosystem

In northern Arizona, ponderosa pines thrive from about 6000 to 8000 feet in elevation (CP-LUHNA, 2007). The pine forest of northern Arizona is the largest Ponderosa Pine forest on the continent at 1.3 million hectares (CP-LUHNA, 2007 and Van Hooser and Keegan, 1987) (*Figure 2*). This particular forest is an open forest where naturally there is a large amount of space between trees. This space allows for the growth of a diverse mix of grasses, forbs, and shrubs in the ponderosa pine understory.

The most abundant grasses are Arizona fescue (*Festuca arizonica)*, mountain muhley (*Muhlenbergia montana)*, mutton grass (*Poa fendleriana)*, and squirrel-tail (*Sitanion hystrix)* (White et al., 1991). These four species are important because they make up 88-93% of the total grass cover (White et al., 1991). These four grasses range in growth periods (i.e. late spring, high summer, etc) providing a large source of food for wildlife, and stabilizing the dry soil (White et al., 1991). Grasses flourish in conditions where ponderosa pines are spread widely apart, like in the stands which were found over 100 years ago (White et al., 1991).

Fire is an important aspect of this ecosystem, and naturally occurred every two to twenty years before suppression (Fule et al., 1997). European settlers moved into the area suppressing fire since the 1880s. Natural fire maintains the natural open stand forest by regulating the density of stands, burning off accumulating biomass, and promoting nutrient cycling (Fule et al., 1997). Low-intensity fires stay at the understory level, killing small seedling and saplings to help maintain the open forest structure. These fires burn off biomass every so often, but when fire does not occur in its regular cycle, biomass accumulates creating more fuel (Fule et al., 1997).

Fire suppression has caused many problems for this forest ecosystem. Pine density has increased in the past several decades. Early National Forest inventories found that the pre-settlement pine density ranged from 7-116 pines/ha (Fule et al., 1997). In

1992, the average reached over 3000 trees/ha (Mast et al., 1999). In the mid 1900s, scientists found that numerous patches of pine seedlings were evident, while the herbaceous vegetation was still dense (Fule et al., 1997). By 1995, those patches of seedlings had turned into a site dominated with young pines, and herbaceous vegetation had decreased dramatically in density (Fule et al., 1997).

Shifts in weather have also placed extra stress on the forest. From the sixteenth to twentieth century, evidence shows that the area was cooler (Pierce, et al., 2004). Data shows that colder periods experienced more frequent low-severity fires. The intensity of these fires was most likely managed by an increase in understory growth (Pierce et al., 2004). Currently, there is a ten year drought occurring. Drought periods allow fires to burn faster and at higher intensity. Fire suppression has increased the biomass in the area, and combined with drought, the number of high-intensity crown fires has also increased.

An all these issues combined have caused the natural fires to turn crown fires, which are quick burning and extremely destructive. The effects of fire suppression have had large implications for forest composition, as well. Consequently, herbaceous understory is less productive (Fule et al., 1997). With an increase of trees came a denser shade canopy, making it more difficult for understory species to grow. As a result, "trees are now growing in areas where grasses once thrived" (NEPA, 2007). The increase of pine litter from a lack of fire has decreased grass growth by smothering seedlings (Hobbes and Huenneke, 1992). Humans have also increased the amount of invasive plant species. Introduction of invasive species result in areas being overtaken by species that wildlife cannot use as forage. Invasives also out-compete native species.

A very common invasive species of grass is cheat grass (*bromus tectorum*). It grows easily in over-grazed land (Springer et al., 2005). Sheep and cattle were introduced to this area for grazing by the European settlers starting as early as the 1880s for food and other resources. With over-grazing comes available space for invasive species growth. Many species now considered invasive were introduced for livestock forage and erosion prevention (D'Antonio and Vitousek, 1992).

Invasive species are a serious issue for any ecosystem. Silversheath knotweed (*Polygonum argyrocoleon)* and cheat grass are just a few of the sixty-five noxious weeds on the United States Department of Agriculture's list for Arizona (USDA, 2006). Invasive species out-compete natives and reduce plant populations. They can reduce, or even displace, native species to the extent where the function of the ecosystem is affected (Hobbs and Huenneke, 1992). On the northern edge of Yellowstone National Park, heavy grazing has caused exotic grasses, like cheat grass, to out-compete the native grasses (Patten, 1993). Clothing, shoes, and equipment easily transport seeds of invasive species. This is something to consider for this particular site since the research station houses scientists while doing field studies. Detrimental effects, like invasives out-competing native grasses, create a decrease in available food for native animals. As a result, invasives threaten biodiversity and ecosystem stability (Malakoff, 2002).

Though many of these are a result of large scale human impact, light disturbance appears to keep invasive species away in some situations. Understory disturbance studies suggest areas with low plant species diversity are invaded easier than areas with high plant diversity (Stohlgren et al., 1999). Therefore, it is important to have at least minimal disturbance to increase diversity in order to prevent invasives becoming predominant in the area. Yet, some studies claim that disturbance can increase the invasionability of a community (Hobbs and Huenneke, 1995).

Intermediate Disturbance Hypothesis

The northern Arizona ponderosa pine ecosystem has evolved to be accustomed to intermediate disturbances by fires and by native mammal herbivory. Natural disturbances can actually increase species diversity by decreasing dominant species competition. The intermediate disturbance hypothesis suggests that intermediately disturbed areas are better suited to support higher diversity, even more than disturbance categorized as lower or greater intensity (Rambo, 1999). Disturbance levels that are higher or lower than intermediate allow the dominance of only a few species, but intermediate disturbance produces an increase in both species evenness and number of niches (Arim et al. 2002). In addition, only a few species can exist without disturbance. Disturbance can eradicate individuals that appropriate common resources preventing competitive exclusion (Miller, 1982). This allows out-competed species, or rare species, the opportunity to thrive. When high disturbance occurs, colonization species (plant species which have high growth or high dispersal rates) have the capabilities to push through the rapid colonization process, while some of the more competitive species are excluded (Miller, 1982). Some species can live and thrive in patches at different stages of recovery (Roberts and Gilliam, 1995). Varying stages of regeneration allow both early and late succesional species to harmonize (Rambo, 1999). Species diversity will reach its maximum at an intermediate time interval past initial disturbance (Collins, et al., 1995). Diversity is at peak during "intermediate stages of succession" which would allow enough time to elapse so diversity is high, but nothing is at the point of domination (Roberts and Gilliam, 1995). One important point to note is the research station's disturbed area may have a slow recovery rate. Plant ecosystems recovering from a disturbance that affects a main resource (i.e. space) has a slower recovery rate than an intermediately disturbed ecosystem (Mackey, 2001).

For example, an experiment focusing on disturbance in the form of cattle grazing gives interesting insights to the issue of intrusive non-native disturbance. Sites were set-up with long-term grazing, short-term grazing, short-term control, and long-term control. At two of the three long-term grazed sites plant species' diversity increased, in comparison with the un-grazed sites (Rambo and Faeth, 1999). In addition, in one of the short term and enclosed sites, the grazed areas had greater plant diversity compared with the un-grazed areas (Rambo and Faeth, 1999). This suggests that reducing dominant and competitive plants will allow less competitive plants to endure (Rambo and Faeth, 1999). A second study in a longleaf pine-wiregrass ecosystem where fire is a natural component of the ecosystem found that more frequent fires (hence more frequent disturbance) resulted in a greater species richness of the understory compared to areas maintained with less frequent fire (Kirkman et al., 2004). Similarly, after trampling in a tall-grass prairie, species' diversity reached a maximum at the intermediate time interval since the last disturbance (Collins et al., 1995). While species' diversity decreased as disturbance became more frequent (Collins et al., 1995). These experiments show the diversity of issues that are raised from unnatural disturbance, which relates to the present study.

Felling and Development Disturbance

Recently there has been large human disturbance on ponderosa pine forest around Flagstaff from felling and development. A current project with the National Forest Service is felling, which is a mechanical thinning of trees. As stated, there has been a large increase in stand density from fire suppression. The National Forest Service is doing this project in order to bring the forest back to its natural stand. A lumber company hired by the National Forest Service is working area by area to cut out the small trees from the stands. Yet, after an area is finished, what is left is woodchips, piles of wood and litter, and destruction of vegetation. The heavy machinery and consistent trampling rips out vegetation, leaving mud and tire tracks behind. It is a very destructive technique. There has been minimal research on the effects of felling on the herbaceous understory.

Development in, and adjacent to, a wildlife interface will greatly affect the biological diversity by remodeling, isolating, disturbing native vegetation, simplifying vegetation structural diversity, and by introducing invasives and non-natives (Marzluff and Bradley, 2003). Development creates barriers which disrupts ecosystem functions like nutrient cycling, soil formation, and water cycling (Marzluff and Bradley, 2003). From development disruptions ecosystems see increased wind, exposure to invasives, clearing, pruning, trampling, and decreased humidity (Marzluff and Bradley, 2003).

The study presented here was executed in northern Arizona at the Flagstaff Arboretum's new Miriam Powell Research Station. The Arboretum is within the Coconino National Forest. Ponderosa pine understory is an essential component of the ecosystem. It is extremely important to study disturbances, and learn about the consequences. The area was cleared for the building, and according to the IDH, this would give rare and out-competed species an opportunity to thrive, therefore increasing species richness. Based on the amount of disturbance within the disturbed site, 0-15 meters ("inner" area) from the building is expected to have lowest diversity because of consistent disturbance caused by trampling, in comparison to the disturbed "outer" area. The 15-30 meters ("outer") area from the research station will have the greatest amount of diversity because of its initial disturbance, and now relatively little disturbance This will give us a better idea of how disturbance impacts herbaceous understory vegetation.

Figure 1 (a): *Arizona (http://www.destination360.com)*

Figure 1 (b): *Flagstaff, Arizona (http://www.arizona-mapsite.com/flagstaff_maps.html)*

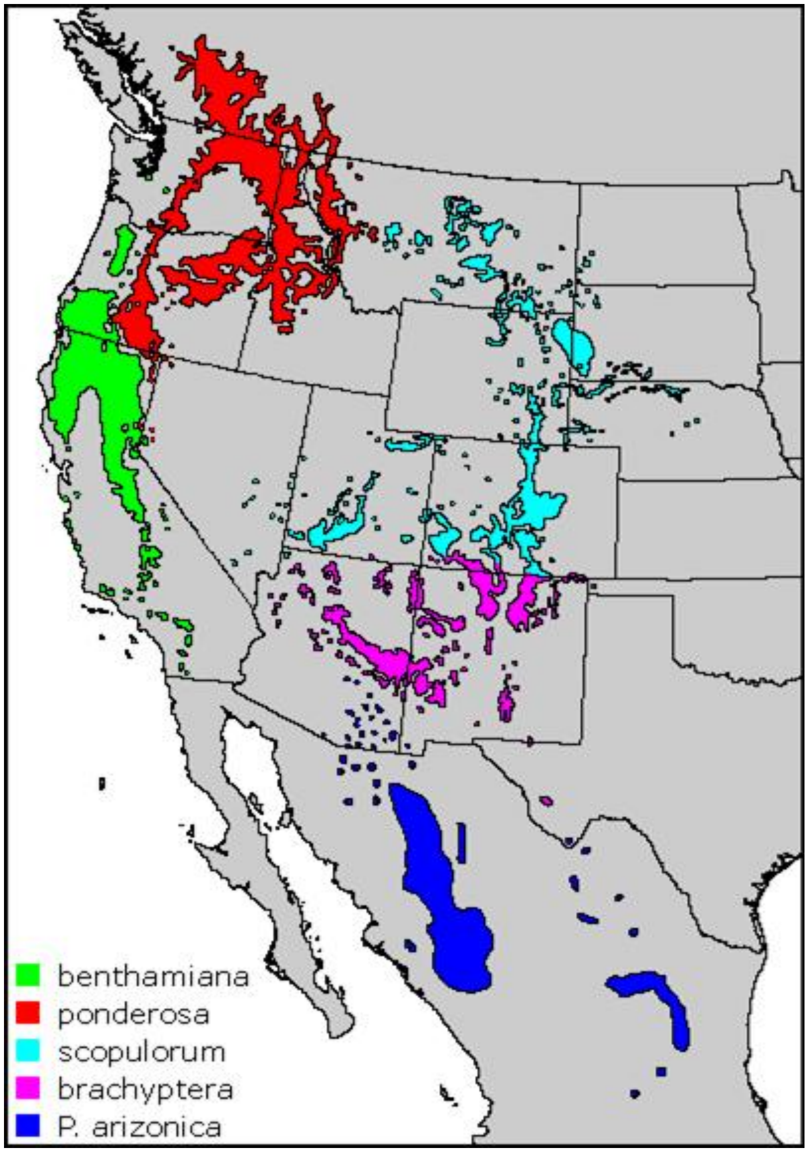

***Figure 2**: Map of ponderosa pine distribution*

Methods

Flagstaff is on the Colorado Plateau. The land is around 7,000 feet in elevation. The plot of land (0433093, 3890866) was originally undisturbed until a house and parking lot were constructed for a research station (*Figure 3*). Neither sites experienced the felling until after the data was taken. And it had not been felled until after the data was taken. Important to note is that these areas did not have particularly dense tree stands. Only large pines were in the area.

In the disturbed site, the house measures about 30 meters by 70 meters. On the east side of the house is a gravel parking lot, which measures around 40 meters by 20 meters. The construction caused a large radiating disturbance area, that varies depending on the side of the house. On the north side, disturbance reached about 20 meters, while on the south side, disturbance reached about 50 meters. Mulch was placed around the house to cover the mud that the construction disturbance created (*Figure 3*). The house, completed in early June 2007, and development disturbance has not affected the area before this.

The control site is located in Coconino National Forest land. The site is next door to the house lot, around 500 meters south/southwest. The area does not have a road going through it, and a barbed-wire fence is maintained on the north side facing the house lot. The only unnatural disturbances it could receive are campers, ATVs, and cattle grazing. Visually, the area looks undisturbed in the sense that rotting trees laid where they fell, grass was not matted or pulled out, and there were no ATV tire marks. On the south and west side of the control area is an open field or "park".

To collect the vegetation data, transects with quadrats were set-up. The transects ran 30 meters for all twenty transects, and every point of origin was taken by GPS (*Table 2*). In the disturbed area, the transects were divided in half. The first 15 meters is "inner", and the second 15 meters is "outer". Therefore, there is an inner rectangle, and outer rectangle around the house (*Figure 3*). Transects radiated from the house. Degrees were chosen randomly, then some were changed in order to assess all aspects of the house. A compass was used in order to pick the direction of the transect, and make sure that it laid straight.

In the control, transects were randomized. A point of origin was chosen, and radiated in any direction as long as it did not cover an area previously assessed by another transect. Unlike the disturbed site, these transects were not halved.

Quadrats were use to create a fixed area. The quadrat measured 1-by-1 meters. A twine grid made 100 squares so percent cover could be taken easily. Each quadrat percentage equaled 100%, and vegetation was estimated as percent cover within the quadrat.   First, the quadrat was place at 2 meters on the right of the transect tape, then 4 meters on the left, then 6 meters on right, etc. The quadrat was placed 1-meter from the line every time so the trampled plants next to the transect were not taken into account.

Disturbed Transect Number	GPS	Degree	Control Transect Number	GPS	Degree
T1	0433093 3890866	54	T1	0432983 3890810	158
T2	0433087 3890854	340	T2	0432974 3890835	89
T3	0433075 3890846	252	T3	0432950 3890958	207
T4	0433079 3890337	212	T4	0432945 3890990	132
T5	0433099 3890839	102	T5	0432942 3891015	226
T6	0433086 3890867	352	T6	0432907 3890941	128
T7	0433089 3890838	140	T7	0432895 2890925	322
T8	0433090 3890850	76	T8	0432888 3890910	22
T9	0433057 3890837	80	T9	0432952 3890958	202
T10	0433095 3890829	164	T10	0432869 3890916	258

Table 1: *Transect degrees and GPS points for both the disturbed and control site transects.*

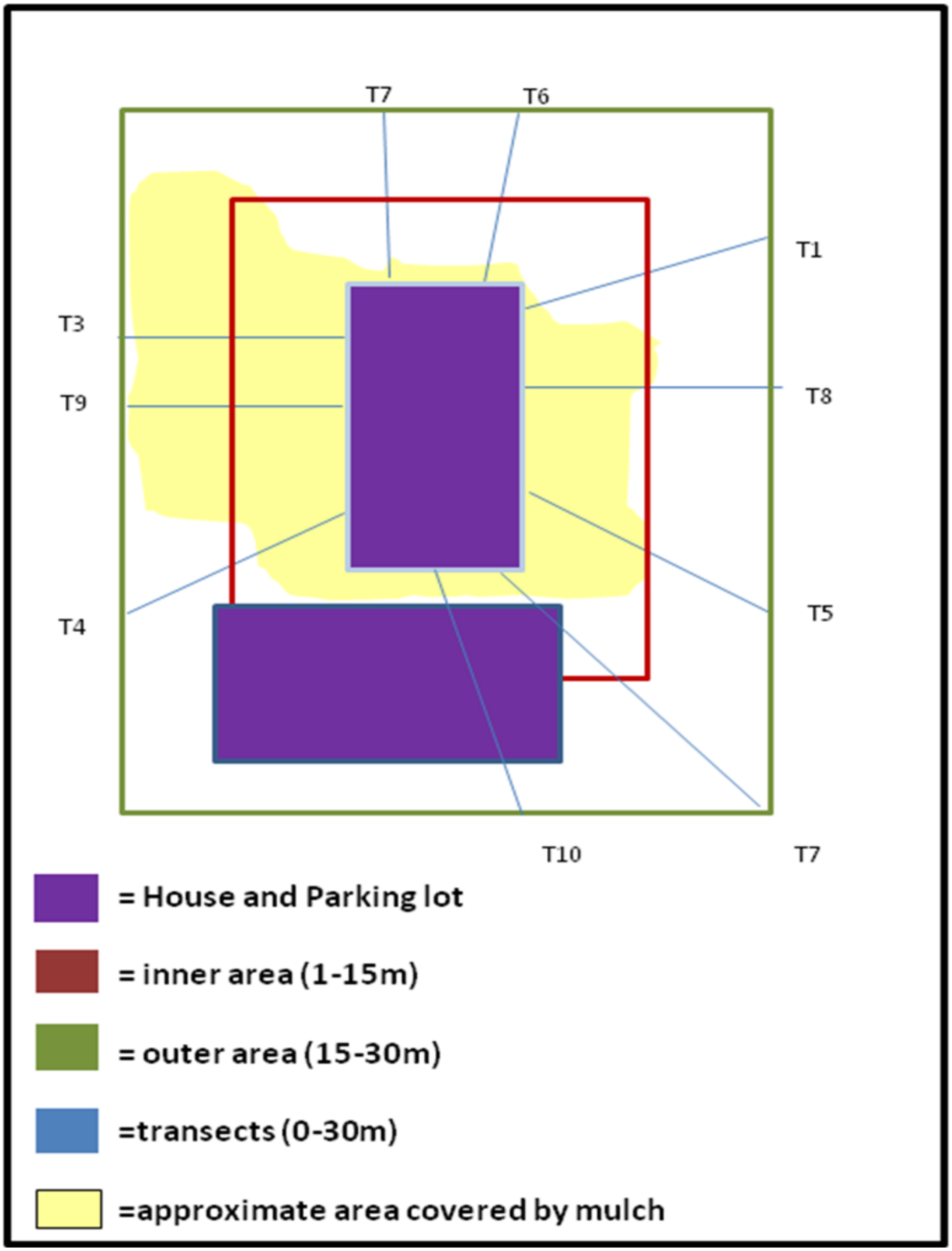

Figure 2: *map of disturbed site with "inner" and "outer" areas represented*

Results

Average number of species per transect does not vary much between the control and disturbed, and between the inner and outer. In comparing the control and disturbed sites, average number of species per transect is 10.2 for the control, and 9.0 for the disturbed site (*Figure 4(a) and Table 2*). The control site had only three more plant species than the disturbed ($p = 0.43$). When comparing the disturbed inner and outer area, the inner area has on average 4.6 species per transect, and the outer has 4.4 species per transect ($p = 0.87$) (*Figure 4(b)* and *Table 2*).

When looking at the species, it is important to notice the invasive species present since they are an issue for this ecosystem. The control has five invasive species, which are burclover (*Medicago polymorpha*), rubber rabbitbrush (*Chrysothamnus nauseosus*), cheat grass, silversheath knotweed, and toad flax (*Linaria vulgaris*).

The disturbed (inner) has four invasive species including silversheath knotweed, cheeseweed (*Malva parviflora*), Chinese elm (*Ulmus pumila*), and cluster dock (*Amsinckia intermedia*). The disturbed (outer) area also has four species which include Chinese elm, crabgrass (*Digitaria sanguinalis*), kings lupine (*Lupinus kingii*), and silversheath knotweed.

For non-invasive, non-native species, the control site has two including western yarrow (*Achillea millefolium)* and common mullin (*Verbascum thapsus*). In the disturbed (inner) and disturbed (outer) there is only one species in each site which is alsike clover (*Trifolium hybridum).*

One pattern explored is the top three most dominant species per site, and per area. The three most abundant plants in the control site are Arizona fescue at 17.2%, squirrel-tail at 4.4%, and mutton grass at 2.2% (*Figure 5(a)* and *Table 3(a)*). These top three species added together cover 23.8% of the control site.

The top three most abundant species for the disturbed site is Arizona fescue at 17.2%, squirrel-tail at .71%, and both mutton grass and foxtail barley (*Hordeum jubatum*) come in third at .28% (*Figure 5(a)* and *Table 3(a)*). Together, they equal 9.5% of the whole site, compared to the 23.8% of the top three species in the control site ($p = .44$).

When the disturbed site is broken up into the two areas, the most abundant in the disturbed (inner) area are Arizona fescue at 2.1%, mutton grass at .14%, and alsike clover at .14% (*Figure 5(b) and Table 3(b)*). These three equal 2.4% of the inner transects.

The three most abundant species in the disturbed (outer) area is Arizona fescue at 10.6%, squirrel-tail at .71%, and foxtail barley and mutton grass both come in at .28%. The outer's top three most abundant species is 11.6% of the outer transects (p = .42) (*Figure 5 (b) and Table 3(b)*).

Number of Transect	Control	Disturbed (inner)	Disturbed (outer)	Disturbed (inner and outer)
1	13	6	6	12
2	4	10	2	12
3	10	4	2	6
4	14	3	4	7
5	10	2	9	11
6	9	8	4	12
7	15	4	7	11
8	10	3	8	11
9	7	3	0	3
10	10	3	2	5
mean (number of species)	10.2	4.6	4.4	9
standard deviation	1.03138452	0.819804187	0.945844379	1.000671141

Table 2: *Average number of spcies per transect, mean number of species per area, and standard deviation*

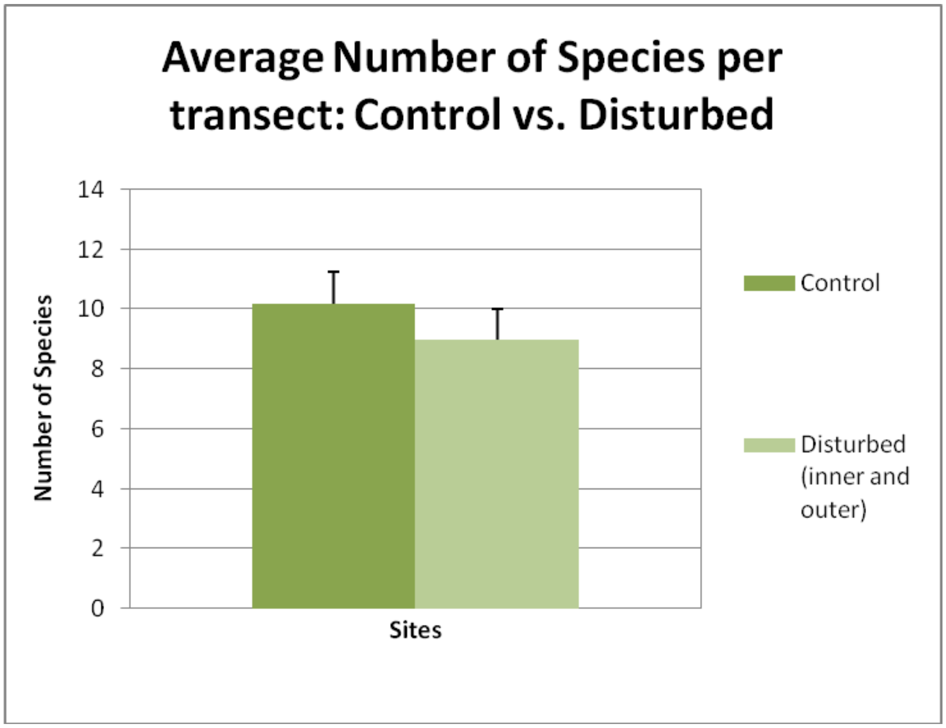

Figure 4(a)

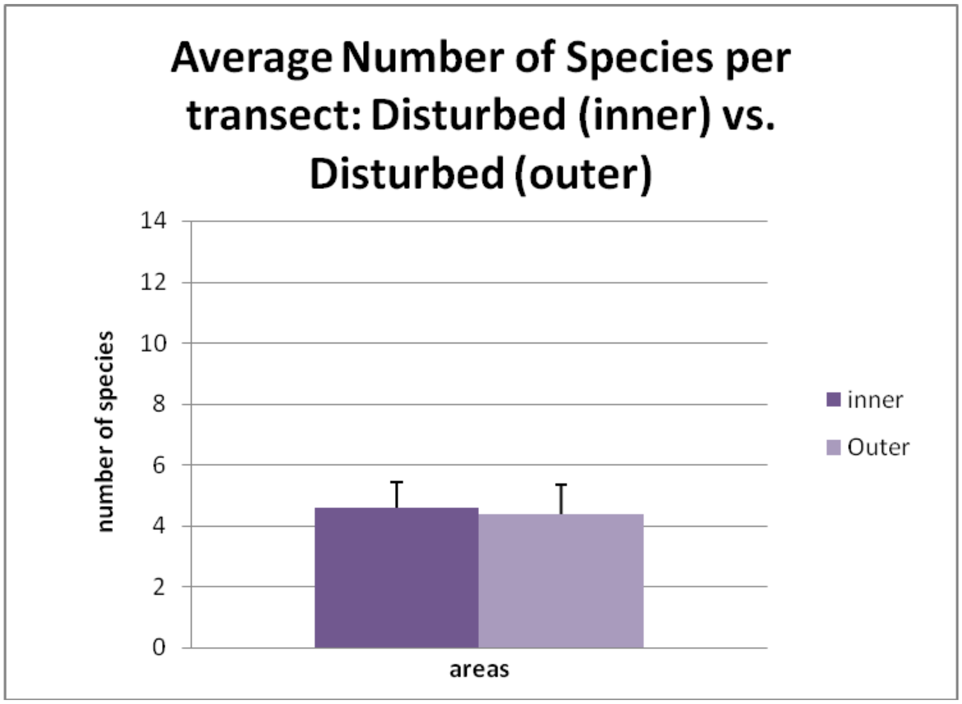

Figure 4(b)

Control	**Disturbed (inner and outer)**
Festuca arizonica (17.2%)	*Festuca arizonica* (8.9%)
Sitanion hystrix (4.4%)	*Sitanion hystrix (.71%)*
Poa fendleriana (2.2%)	*Hordeum jubatum* and *Poa fendleriana* (.28%)

Table 3(a)

Inner	**Outer**
Festuca arizonica (2.1%)	*Festuca arizonica* (10.6%)
Poa fendleriana (.14%)	*Sitanion hystrix* (.71%)
Trifolium hybridum (.14%)	*Hordeum jubatum* and *Poa fendleriana* (.28%)

Table 3(b)

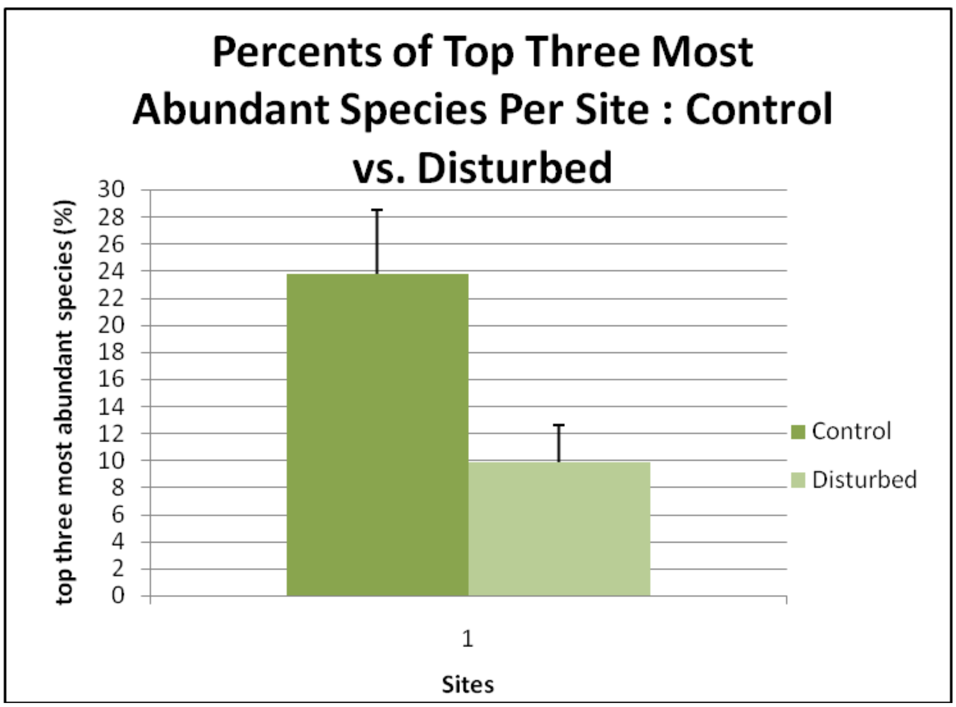

Figure 5(a)

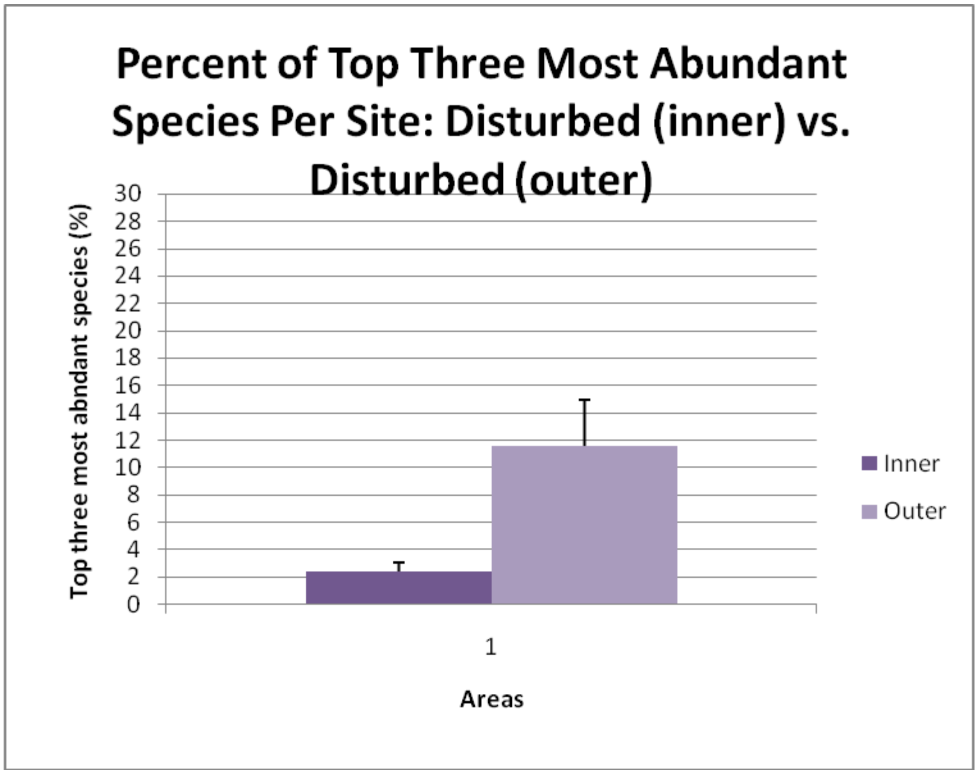

Figure 5(b)

Discussion

The hypothesis of intermediate disturbance producing higher diversity was not supported for this location. There was no significant difference between the control and disturbed sites. It was also hypothesized that the disturbed (outer) would have more species than the disturbed (inner) considering that it had initial disturbance, but now is receiving little disturbance. The outer and the inner areas were also not significantly different with the other area having one more species than the inner.

With the top three most abundant species comparison, the control has much higher percentages than the disturbed. It makes sense that the control would have higher populations per species because it is at a later succession period. Although there is a stark difference in percentage, the control and disturbed (inner and outer) sites have all three species in common. These species are Arizona fescue, mutton grass, and squirrel-tail, which are three of the four most common grass species in this ponderosa pine forest

(White, Cook, and Vose, 1991). Although the percentages are not as high as the control, these species are present. That is important because it shows what should be there is there. Had weedy species been in the top three, maybe it would show that the invasionability of the site has increased, and this would be a concern. Within the disturbed site, the inner and outer have two of the three species in common. Both of which are two species in the top four most abundant in this ecosystem. One of the inner's top three species is alsike clover. It is not invasive, but is a non-native.

There are four possible reasons for the outcome of the hypothesis. It is possible that the data was taken too soon after initial disturbance, the mulch prevented plants from growing, or that there is no classification for disturbance levels making it difficult to tell if disturbance is intermediate, low, or high. In addition, the intermediate disturbance hypothesis has some drawbacks.

One problem with the Intermediate Disturbance Hypothesis is that it does not specify what exactly "intermediate" disturbance is. There is no classification system for what is low, intermediate, or high. In addition, mulch was placed over the bare dirt around the house (*Figure 1*). The mulch was placed there to prevent erosion, and possibly to keep weeds at bay. Yet, this mulch could have had a large effect on the ability for plants to grow. A study done by Greenly and Rakow (1995), suggests that a mulch depth greater than 7.5cm can greatly affect plant growth through temperature, soil oxygen levels, and moisture aspects (Greenly and Rakow, 1995). Another study is currently looking at treated wood mulch to determine if chemical leaching can effect growth (McLaurin, unpublished report). It is also possible that the area was not given enough time post-disturbance to regenerate. The site was most likely not at the point of intermediate stages of succession, which typically produces the highest diversity (Roberts and Gilliam, 1995). Important to note is that a majority of the data was collected before and during the monsoon season. September 1st is the highest point of growth for the season because it is at the end of the monsoon season (McLaughlin, 1978).

However, intermediate levels of disturbance do not always result in peak diversity (Mackey and Currie, 2001). For example, in a review of 197 papers, Mackey and Currie (2001) found that non-significant disturbance-diversity relationships were most common (Mackey and Currie, 2001). Their point is that other hypotheses may be related to the

IDH, and that the IDH is not strong when standing on its own. There are many components to species diversity to the point that some researchers believe the IDH is incomplete by itself.

The non-equilibrium models, including the IDH, are useful in improving our understanding of diversity, but there are issues because of the hypothesis' generality (Roberts and Gilliam, 1995). The hypothesis does not address variations in site quality, or forecast differences in community diversity (Roberts and Gilliam, 1995). It is also unclear whether the Intermediate Disturbance Hypothesis is applied to the patch, stand, or landscape levels, or to all three (Roberts and Gillian, 1995). The IDH does not take into consideration different ecosystems, and range of disturbances including frequency, intensity, and sizes, which are important and vital aspects of an ecosystem (Roberts and Gilliam, 1995). The hypothesis also assumes that species maintain a "trade-off" between their competition and tolerance abilities (Collins, et al., 1995). Although there are faults with the IDH, it is a commonly used tool for looking at post-disturbance growth, and works for the Flagstaff Arboretum research station study.

All of the plants of the top three most abundant species, both in the control and disturbed (inner and outer), are grasses (*Figure 5*). This is healthy compared to if invasive species had been in the top three. Although, when looking at the disturbed (inner and outer) apart, the inner's most abundant species includes one non-native/non-invasive species, alsike clover. This area should be watched in the future to see if this high disturbance area would become more susceptible to invasives. Over time, this may become an issue for the disturbed area because of seed transportation through clothing and equipment.

Restoration would be the next step for the Flagstaff Arboretum. A small amount of plants were saved from the site and replanted, but more work could be done to regenerate the area. It would be a good idea to bring in more plants raised from the greenhouses to the site since container plants often have a higher survival rate than distributing seeds (Korb and Springer, 2003). In addition, container plants propagate quicker and tend to be larger specimens (Korb and Springer, 2003). Assessments would need to be done with soil, precipitation, light, fuel loading, fire history, aspect and slope, and climate (Korb and Springer, 2003). Out of all these components, it is most important that soil and precipitation are assessed (Korb and Springer, 2003). When planting, it is essential to examine seed source, soil seed bank density, species composition, plant community composition, grazing, and human impacts (Korb and Springer, 2003). It would be best to plant and seed in this area prior to or during monsoon season and even during the dormant season (Korb and Springer, 2003). Applying needles, organic debris, and rock mulch would prevent the soil from drying around the plants (Korb and Springer, 2003). Plants should also be planted in "random spacial arrangements" and in close arrangements which "create moderate microclimates" (Korb and Springer, 2003). Protecting the area from grazing and recreational impacts for 2-5 years would be ideal (Korb and Springer, 2003). Although around the research station there are cement paths, it would be a good idea to make a path from the north porch door to the main outer arboretum path for when researchers need to go to the main arboretum buildings. It would also be encouraged to create some more paths around the house, and remind researchers to stay on gravel paths, or away from regenerating areas. Placing fencing around plant spacial areas would also help protect the plants from trampling and herbivory. The area would regenerate quicker and healthier if more effort was put into the regeneration process.

This study and its results are important because it can help conservation techniques as one example of how disturbance affects the understory. This study could produce better results if conducted year after year. By repeating this study, a clearer idea would be produced of how disturbance affects this particular area. In addition, it can indicate over time how a disturbed area reacts to building shadow development. New development is occurring everywhere in the Flagstaff area with very little knowledge on how this change will affect the grasslands and forest.

Disturbances caused by felling and development are issues that need to be research as soon as possible. Researching this more in depth can show scientists which species grow back, many invasives are present, and how fast the understory replenishes itself. As ecologists, we need to further explore how understory disturbance affects its relationship with the thousands of insects, birds, and mammals that depend on this ecosystem.

Species List – Disturbed Area

Annual Sunflower (*Helianthus annuus)*
Alsike Clover (*Trifolium hybridum*)
Arizona Fescue (*Festuca arizonica*)
Astralagus sp. 1
Biennial Cinquefoil (*Potentilla biennis)*
Blue Grama (Bouteloua gracilis)
Buckbrush (*Ceanothus fendler)*
Calliopsis (*Coreopsis tinctora)*
Canadian Horseweed (*Conyza canadensis*)
Cheeseweed (*Malva paraviflora*)
Chinese Elm (*Ulmus pumila*)
Cirsium sp. 1
Cirsium sp. 2
Cluster Dock (*Amsinckia intermedia*)
Common Clover (*Trifolium sp.)*
Crabgrass *(Digitaria sanguinalis)*
Deervetch *(Lotus wrightii)*
Duckweed (not aquatic)
Erigeron sp. 1
Erigeron sp. 2
Erigeron sp. 3
Fernbush (*Chamaebatiaria millefolium*) **T**
Foxtail Barley (*Hordeum jubatum)*
Gambel Oak (*Quercus gamelii)*
Giant Sunflower (*Helianthus giganteus)*
Groundcover Milkvetch (*Astragalus hymistratus*)
Horseweed (*Erigeron canadensis)*
Kings Lupine *(Lupinus kingii)*
Longleaf mock thelypody (*Pennellia longifolia)*
Mountain Rue (*Ruta montana*)
Mutton Grass (*Poa fenderiana*)
Narrow Goldenrod (*Solidago canadensis*)
New Mexico Fleabane (*Erigeron neomexicanus)*
Orange Gooseberry (*Ribes pinetorum*)
Palmer's Lupine (*Lupinus palmeri*)
Pepper Grass (*Lepidium densiflorum*)
Platte River Cinquefoil (*Potentilla plattensis*)
Ponderosa Pine (*Pinus ponderosa)*
Rayless Gumweed *(Grindelia aphanaetis)*
Sheep Fescue (*Festuca ovina)*
Silver's Milkvetch *(Astragalus subcinereus)*
Silversheath knotweed (*Polygonum argyrocoleon)*
Spineless Horsebrush (*Tetradymia canescens)*

Spreading Fleabane *(Erigeron divergens)*
Squirrel-tail (bottlebrush) *(Sitanion hystrix/Elymus elymoides)*
Toadflax *(Linaria genistifolia)*
UNI Grass 2
UNI Grass 3
UNI Grass 4
UNI Grass 5
UNI Grass 6
UNI Grass 7
UNI Grass 10
UNI Woody plant
Varileaf Cinquefoil (*Potentilla diversifolia*)
Wheeler Thistle (*Cirsium wheeleri*)
Whipple Penstemon (*Penstemon whippleanus)* **T**
White Sweet Clover (*Melilotus albus)*
Woody Whitestem Gooseberry (*Ribes sp.*) **T**

Notes:

There are some plants that were not on the Arboretum's species list which were present at the site.

All the species within the designated disturbed area were collected. That is why there is more species on this list than used in the data.

Sitanion hystrix, *Elymus elymoides*, bottlebrush and squirrel tail were combined in different ways in depending on the resource. Therefore, I combined them together.

Key:

T = Transplanted

Species List (Control Site)

Arizona Fescue (*Festuca arizonica*)
Asteraceae sp. 1
Asteraceae sp. 2
Astragalus sp. 2
Bearded Cinquefoil (*Potentilla crinita*)
Biennial Cinquefoil (*Potentila biennis*)
Blue Grama (*Bouteloua gracilis*)
Burclover (*Medicago polymorpha*)
Cheat Grass (*Bromus tectorum*)
Circium sp. 3
Circium sp. 4
Common Mullin (*Verbascum thapsus*)
Deervetch (*Lotus wrightii*)
Erigeron sp. 2
Erigeron sp. 3
Erigeron sp. 4
Eyed Gilia (*Giliaophthalmoides*)
Mutton Grass (*Poa fendleriana*)
Little Pussytoes (*Antennaria rosulata*)
Foxtail Barley (*Hordeum jubatum*)
Pine Dropseed (*Blepharoneudron tricholepis*)
Narrow Goldenrod (*Solidago canadensis var. scabra*)
Palmer's Lupine (*Lupinus palmeri*)
Pepper grass (*Lepidium densiflorum*)
Potentilla sp. 1
Potentilla sp. 2
Ribes sp. 1
Richardson's Goldenweed (*Hymenoxys richardsonii*)
Rocky Mountain Pussytoes (*Antennaria parvifolia*)
Rubber Rabbitbrush (*Chrysothamnus nauseosus*)
San Fransisco Peaks Ragwart (*Packera franciscana*)
Silver's Milkvetch (*Astragalus subcinereus*)
Silversheath Knotweed (*Polygonum argyrocoleon*)
Spineless Horsebrush (*Tetradymia canescens*)
Spreading Fleabane (*Erigeron divergens*)
Squirrel-tail (bottlebrush) (*Sitanion hystrix/Elymus elymoides*)
Sweet Clover Vetch (*Vicia pulchella*)
Toad flax (*Linaria vulgaris*)
UNI Species 1
UNI Species 2

UNI Species 3
Varileaf cinquefoil (*Potentilla diversifolia*)
Western Yarrow (*Achillea millefolium* var. *occidentalis*)
Wheeler Thistle (*Cirsium wheeleri*)

Notes:

Unlike the disturbed site, this site was too large in order to collect all species within the area. All the species included are the ones collected during experiment.

References

"An Illustrated Guide to Arizona Weeds." *The University of Arizona Press*.

Arim, Martias, Olga Barbosa, Jean-François Molino, and Daniel Sabatier. "Humped Pattern of Diversity: fact or fiction?" *Science*, Vol. 297, No. 5588, (Sept.2002) pp.1763(1).

"Biotic Communities of the Colorado Plateau". *Colorado Plateau LUHNA Project*. (Sept. 2007). http://www.cpluhna.nau.edu/Biota/ponderosa_forest.htm

Boucher, Paul; J.M. Rominger; A. Neas; Joanne Baggs; Jan Busco. "Flora of The Arboretum at Flagstaff." (Updated May 2000).

Buckley, Steve. Plants of Northern Arizona: A Comprehensive Field Guide for the Mogollon Plateau Coniferous Forest bioregion in Arizona. *The University of Northern Arizona* (2005).

Collins, Scott L.; Susan M. Glenn; David J. Gibson. "Experimental Analysis of Intermediate Disturbance and Initial Floristic Composition: decoupling cause and effect." *Ecology*, Vol. 76, No. 2, (Mar.1995) pp. 486(7).

Cooper, Charles F. "Pattern in Ponderosa Pine Forests". *Ecology*, Vol. 42, No. 3. (July 1961) pp. 439-499.

D'Antonio, Carla M. and Peter M. Vitousek. "Biological Invasions by Exotic Grasses, the Grass/Fire Cycle, and Global Change." *Annual Review of Ecology and Systematics* , Vol. 23, (1992) pp. 63-87.

"Fire History and Ecology". United States Geological Survey. (Sept. 2007). http://www.mesc.usgs.gov/resources/spotlight/lace/place_firehistoryecology.asp

"Flora of Flagstaff Arboretum". Compiled by the Horticulturalists at the Flagstaff Arboretum (2005).

"Figure 2: Ecotone Shift." United States Geological Survey, (Sept, 2007). www.mesc.usgs.gov/resources/spotlight/place/place_ecotone.asp

Fule, Peter Z.,; W. Wallace Covington; Margaret M. Moore. "Determining reference conditions for Ecosystem Management of Southwestern Ponderosa Pine Forests." *Ecological Applications,* Vol.7, No. 3. (Aug. 1997) pp. 895-908.

Greenly, Katrina M. and Donald A. Rakow. "The Effect of Wood Mulch type and depth on weeds and tree growth and certain soil parameters." *Journal of Arboriculture,* Vol. 21,No. 5. (Sept. 1995).

Hobbs, Richard J. and Laura F. Huennecke. "Disturbance, Diversity, and Invasion: Implications for Conservation." *Conservation Biology,* Vol. 6, No. 3, (Sept. 1992) pp 324-337.

"Ideas for Change: Chapter 2-Background, Trends, and Needs." *United States Forest Service: Coconino National Forest.* (Sept. 2007). http://wwwfs.fed.us/r3/coconino/nepa/flea2_health.html.

Kirkman, L.K.; P.C. Goebel; B.J. Palik. "Predicting Plant Species Diversity in a Longleaf Pine Landscape." *Ecoscience,* Vol. 11, No. 1, (2004) pp. 80-93.

Korb, Julie E. and Judith D. Springer. "Understory Vegetation". <u>Ecological Restoration of Southwestern Ponderosa Pine Forests</u>. Ed. Peter Friederici. Washington D.C. : Island Press. (2003).

Mackey, Robin L. and David J. Currie. "The Diversity-Disturbance Relationship: Is it Generally Strong and Peaked?" *Ecology*, Vol. 82, No. 12, (2001) pp. 3479-3492.

Malakoff, David. "Arizona ecologist puts stamp on forest restoration debate." *Science,* Vol. 298, No. 5590, (Sept. 2002) pp 2194.

Mast, Joy Nystrom; Peter Z. Fule; Margaret M. Moore; W. Wallace Covington; Amy E.M. Waltz. "Restoration of Pre-settlement Age Structure of an Arizona

Ponderosa Pine Forest". *Ecological Applications*, Vol. 9, No. 1, (1999) pp. 288 239.

Marzluff, John M. and Gordon A. Bradley. "Wild Interface". Ecological Restoration of Southwestern Ponderosa Pine Forests. Ed. Peter Friederici. Washington D.C.: Island Press. (2003).

McLaughlin, Steven P. "Determining Understory Production in Southwestern Ponderosa Pine Forests."*Bulletin of the Torrey Botanical Club*, Vol. 105, No. 3. (Jul-Sept. 1978) pp. 224-229.

McLaurin, Wayne J. "Evaluation of Potential Effects on Plant Growth of Engineered Wood Products and Dimensional Lumber." University of Georgia; Department of Horticulture. (no date). http://www.canr.org/02010.pdf

Moore, Margaret M.; W. Wallace Covington; Peter Z. Fule. "Reference Conditions and Ecological Restoration: A Southwestern Ponderosa Pine Perspective." *Ecological Applications*, Vol. 9, No. 4 (Nov. 1999), pp. 1266-1277.

Parker, Kittie F. "An Illustrated Guide to Arizona Weeds." *The University of Arizona Press*. (Nov. 2007). http://www.uapress.arizona.edu/onlinebks/weeds/species.htm

"Plants Database." United States Department of Agriculutre: Natural Resources Conservation Service.(Nov. 2007). http://www.plants.usda.gov.index.html.

Rambo, Jennie L. and Stanley H. Faeth. "Effect of Vertebrate Grazing on Plant and Insect Community Structure." *Conservation Biology*, Vol. 13, No. 5, (Oct. 1999) pp. 1047-1054.

Stohlgren, Thomas J.; Dan Binkley; Geneva W. Chong; Mohammed A. Kalkhan; Lisa D. Schell; Kelly A. Bull; Yuka Otsuki; Gregory Newman; Michael Bashkin; Yowhan Son. "Exotic Plant Species Invade Hot Spots of Native Plant Diversity." Ecological Monographs, Vol. 69, No. 1. (Feb. 1999) pp. 25-46.

Van Hooser, D. D., and C. E. Keegan. "Distribution and Volumes of Ponderosa Pine Forests" Symp. on Ponderosa Pine: The Species and Its Management. (October, 1987) pp. 1

White, Alan S.; James E. Cook; James M. Vose. "Effects of Fire and Stand Structure on Grass Phenology in Ponderosa Pine forests." *American Midland Naturalist*, Vol. 126, No. 2, (Oct. 1999) pp. 269-278.