The Effects of Abandoned Mines on Tree Health in Boulder Canyon, CO and an Analysis of Abandoned Mine Lands Mitigation Policies

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ABSTRACT

This thesis examines the effects of abandoned mines on tree health in Boulder Canyon, CO and also analyses national and state policy regarding abandoned mine lands mitigation. Abandoned mines are a prevalent issue throughout the nation and in the state of Colorado. Research has shown that abandoned mines leak heavy metal pollutants that can have an adverse effect on ecosystems. I used a line intercept sampling method to determine the mean diameter at breast height and percentage of dead trees at 13 mined and 13 control areas. The results showed that the presence of a mine had no effect on either the mean diameter at breast height or the percentage of dead trees. For the policy analysis I focused on mitigation success rates of both the EPA Superfund and the Colorado Division of Reclamation Mining and Safety (DRMS) as well as how these organizations are funded. The DRMS had a higher success rate of mitigation which can be partially contributed to stable revenue from taxes on the coal and nonrenewable industry. The EPA Superfund will not be able to effectively mitigate abandoned mine Superfund sites if a polluter pays tax on the non renewable sector is not reinstated.

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Introduction:

The two research questions I worked to answer for this thesis are “What effects have abandoned mines had on tree health in Boulder Canyon?” and “How effective are national and state abandoned mine mitigation policies?” This research looked at populations of trees at thirteen different mine sites within Boulder Canyon as well as thirteen control sites within the same region. For this research I have defined tree health by using two factors: 1) the average diameter at breast height of the control and; 2) mined areas and the percentage of dead trees in each area. My research was funded through CU - Boulder’s Undergraduate Research Opportunities Program and took place during the summer months of 2016.

Abandoned mines are a very important issue in Colorado as they are scattered through much of our state. The purpose of this research is to better understand what the consequences of these abandoned mines are on the natural environment. This research provides insight into what environmental damage has been done, and provides initial steps for remediating any environmental effects affects of these mines. Additionally this project analyzes policy regarding the mitigation and reclamation of abandoned mines. There are a multitude of organizations that are tasked with ensuring abandoned mines are not actively harming humans or the environment. These organizations have certain policies set in place, sometimes created by them and other times created by higher government authorities that are supposed to guide the mitigation process. I examined whether or not these policies are effective and the reasons behind their success or failure. This principally I analyzed budget and funding data and the ratios of the number of mines declared hazardous to the number of mines reclaimed. I ask if policies are being funded properly and receiving the priority that many scientists argue abandoned mines should have.

Abandoned mines and the possible negative impacts associated with them are an important issue in the west and throughout the nation. Boulder Canyon is an outdoor recreational hotspot, as well as the location of many people's homes. This research will benefit those who use or live in Boulder Canyon by providing insight on how we may reclaim these abandoned mines and return the land back to its natural or healthy ecosystem. The policy analysis provides information on how to improve our current mitigation policies so that mines are reclaimed in a safe and timely manner with all stakeholders' inputs being respected. The policy analysis will also provide an in-depth look at the funding available for reclaiming abandoned mines and how that funding is being collected, appropriated, and used.

Background:

Abandoned mines are a nationwide issue with an estimated 500,000 abandoned mines throughout the nation, and 23,000 of those mines located in the state of Colorado alone. The majority of these mines were established after an 1872 federal mining law that encouraged the development of mines and allowed people to lay claim to areas for these mines (Brown et al, 2015). Mining has been a significant environmental problem in the Western United States for a long time now (Seymour, 2004). After several years of operating, many of these mines fell victim to the boom-bust cycle and ended up closing their doors, years before any real environmental protection laws were in place. Although no longer operating, these mines leave behind vast amounts of arsenic, lead, radionuclides, and many other heavy metals. Highly acidic waters leached from the mines carry away heavy metals that leak into our watersheds and streams, affecting all organisms that use that water as a source of life, including humans. Many of these mines have also left behind large piles of toxic tailings, the waste material created from processing ore. These tailings are a combination of ground up rock, heavy metals, and chemicals that can continue to leach toxins for up to 100 years (Bale, 2014). Reports have shown that down slope of these toxic piles there is often little to no vegetation growth due to heavy metals that have migrated through the soil. This migration of heavy metals into the soils effectively sterilizes the soil and stunts the growth of vegetation *(Lyon, 1993).*

Because of these adverse effects there are now extensive regulations on how a mine stores its waste. Most of the abandoned mines were closed during a time when there was little environmental regulation, causing the mines to be closed in a potentially detrimental way to the environment. The main issue, however, is not lack of knowledge of the past and potential effects of abandoned mines, but instead the amount of time and money that must go in to reclaim these sites. This process is still in the works and does not guarantee the removal of all threats. The reclamation of just a few mines in Colorado can cost millions of dollars and that does not even cater to the fact that many heavy metals have already been released from the mines. The EPA has estimated that the cleanup and reclamation of abandoned mines nationwide is anywhere between $20 billion and $54 billion, and that estimate does not include coal mines (Brown et al, 2015). More research around the effects of abandoned mines on ecosystems as well as research looking into mitigation techniques will hopefully reduce the costs of reclamation of these mines. Research around this topic is ever more pertinent and necessary for protecting our natural lands.

In 1997 a framework was developed by the Environmental Protection Agency to help them implement a multi-statute and multi-policy approach to dealing with the environmental concerns associated with abandoned mines. This framework was created with input from multiple stakeholders including other Federal agencies, States, Tribes, local governments, industry, and environmental groups *(EPA, 1997)*. The Bureau of Land Management has also created a similar framework that provides guidance for abandoned mine land remediation on their lands. There are many agencies at the national level that work in collaboration to reclaim mines. The Bureau of Land Management works with multiple other organizations within the Department of the Interior including the Office of Environmental Policy and Compliance (OEPC), Office of Surface Mining Reclamation and Enforcement (OSMRE), U.S. Geological Survey (USGS), and National Park Service (NPS) as well as other federal agencies such as the Forest Service, Environmental Protection Agency (EPA), U.S. Army Corps of Engineers (USACE), and state and local entities *(BLM, 2007)*.

The Office of Surface Mining Reclamation and Enforcement is a particularly important organization with regards to abandoned mine reclamation nationwide. The OSMRE oversees and enforces the Surface Mining Control and Reclamation Act of 1977 (SMCRA). The SMCRA is a federal law that regulates the environmental effects of coal mining in the United States. SMCRA attached a per ton fee to all extracted coal to create a fund for the reclamation of abandoned mine lands. *(Demeritt, 2009)* Through this act the OSMRE was able to create two programs, one for monitoring existing mines and a second dedicated to reclaiming abandoned mine lands.

The EPA defines abandoned mine lands as "those lands, waters, and surrounding watersheds where extraction, beneficiation or processing of ores and minerals has occurred" *(EPA - AML Main, 2016).* The EPA has an abandoned mine lands program which identifies ways to protect human health and the environment by using both regulatory and non-regulatory approaches. These approaches include:

- Voluntary cleanups
- Agency managed emergency responses
- Involvement of Brownfields partners
- Cleanups based on redevelopment/revitalization
- Agreement on Consent remediation
- Superfund Alternative Site designation
- NPL listing
- Innovative reuse/remediation

The abandoned mine lands program is coordinated through the agency's National Mining Team and Abandoned Mine Lands Team *(EPA - Basic Info, 2016).*

A large proportion of the funds used to reclaim abandoned mine lands comes from the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, otherwise known as the Superfund Act. By definition a Superfund Site is “any land in the United States that has been contaminated by hazardous waste and identified by the EPA as a candidate for cleanup because it poses a risk to human health and/or the environment” *(HHS, 2016)*. These sites are placed on the National Priorities List (NPL), established in 1982. According to the EPA, as of April 7th, 2016, 139 abandoned mine sites have been proposed for or listed on the National Priorities List *(EPA, 2016)*. There are 4 different designations that each site can fall under, explained by the following:

- **Proposed:** Site proposed (by the EPA, the state, or concerned citizens) for addition to the NPL due to contamination by hazardous waste and identified by the Environmental Protection Agency (EPA) as a candidate for cleanup because it poses a risk to human health and/or the environment.

- **Withdrawn**: Site removed from the NPL because EPA has determined that it poses no real or potential threat to human health and the environment.

- **Final**: Site determined to pose a real or potential threat to human health and the environment after completion of HRS screening and public solicitation of comments about the proposed site.

- **Deleted**: Site deleted from the NPL by the EPA (with state concurrence) because site cleanup goals have been met and no further response is necessary at the site. *(HHS, 2016)*

Mines can also fall under a non-NPL designation and are cleaned up using the Superfund Alternative Approach. This is not an alternative to the Superfund process but instead an alternative to listing the site on the NPL, which can be a costly and time intensive process.

Funding to reclaim these abandoned mine superfund sites comes from a trust fund that was established through CERCLA. This trust fund was financed primarily by a polluter pays tax on crude oil and certain chemicals as well as an environmental tax based on a corporation's income and other smaller sources such as cost recovery, penalties, income taxes, and interest incomes. The authority for these taxes expired in 1995 when congress allowed for the tax to expire, however, some funds have continued to accrue as tax audits have shown some corporations still owe money. In addition the trust fund has continued to receive some revenue from the various other sources *(GAO-08-841R, 2008).*

In Colorado specifically, until 1976 there were virtually no regulations requiring mines to be reclaimed after their use. This is what has led to the overwhelming number of unclaimed abandoned mines in the state. To help solve this issue the Colorado Division of Reclamation Mining & Safety (DRMS) was created in 1976 under our Department of Natural Resources to regulate non-coal mining operations. In that same year a Mined Land Reclamation Board was created as an administrative capacity and the Colorado Mined Land Reclamation Act was passed *(History, n.d.)*. Under this act the board was able to require owners of mines to reclaim the mine when the extraction was complete. The Mined Land Reclamation Board still exists today and consists of seven members: two from the mining industry, two experts in ecology and conservation, an expert in agriculture, a representative of the Soil Conservation Board, and a representative of the Department of Natural Resources. Since their creation these two programs have been amended to include more environmental protections as well as property and water resource protections. The Division of Reclamation Mining & Safety receives the majority of its funding through federal funds, severance taxes, and fees. The Inactive Mine Reclamation Program is a subset of the DRMS and its main priority is to identify hazards and environmental problems that arise from abandoned mines. They then design appropriate closures and reclamation techniques to reclaim and safeguard abandoned mines and the surrounding lands.

Literature Review:

This section examines and reviews literature that has already been published about abandoned mines and their effects. I have focused on research that falls under two major categories: Environmental Impact and Reclamation of Mines.

Environmental Impact

Research has been done around the environmental impacts of abandoned mines for decades now. Roberts and Johnson *(1978)* studied the effects of abandoned mines on the environment and published their findings back in 1978. Their work shows that this is in no way a new issue. In their research they found that soil around abandoned mine complexes was heavily contaminated with metals that largely reflect the composition of mine waste. Though their research could not find conclusive evidence on the effect this contamination had on wildlife, recent studies have been researching the same topic. A large portion of this research is looking at how the heavy metals and other toxins are affecting organisms that live around these abandoned mines. Research has found that there is extreme acid-rock drainage and that extensive remedial efforts are now required *(King, 1996).* This same study also found that contamination from mines had affected water quality and fish habitats. King does, however, discuss that there is no significant evidence that there are short term effects on agriculture from abandoned mine waste leaking into the watershed. King calls for the need of scientific information in predicting, assessing, and remediating the environmental effects of mining. Larison *(2000)* examined the cadmium toxicity among wildlife in the Colorado Rocky Mountains. Larison argues that cadmium is a naturally occurring element that is a trace constituent, but when in larger quantities can be extremely toxic. Larison’s research found that ingestion of even trace amounts of cadmium can affect distribution of species as well as health and physiology. The research also found that cadmium concentration is higher in vertebrates than expected. Other research has also been done that is similar but with different conclusions. Custer *(2009)* studied the exposure of insects and insectivorous to metals and other abandoned mine tailings. Custer also stated that these metals are often times found in small concentrations naturally occurring in the organisms. For this reason some of the results did not have significant differences and could not be fully concluded. Custer did, however, conclude that at two separate drainage sites there was an increase in the concentration of 25 different metals in insects and insectivorous birds between mining impacted sites and unaffected sites. Many of these environmental effects are due to the contamination of water from the heavy metals leaking from abandoned mines. There is research being done on the pollution and acidification of water from mine waste. Young *(1997)* argues in a research paper that pollution from abandoned mines in a serious and increasing problem. Cowie *(2014)* specifically focuses on stream waters in the Western United States and argues that the water quality is being continuously degraded by acid mine drainage. The U.S. Geological Survey has studied the impacts of abandoned mine lands on watersheds in both Colorado and Montana. The studies found that the Colorado watershed was greatly affected, more so than the Montana watershed. The report states that the primary effect of mining is degraded water quality and aquatic habitat. This degradation consequently affects aquatic and fishery resources, with some streams completely devoid of fish. The study confirms that these streams are affected through direct discharge of acid drainage and other pollutants associated with mining *(Buxton et al, 1997)*. Research has also been focused around colloid formation and metal transport through stream mixing zones in Colorado. The study's purpose was to measure stream discharges as well as concentrations of dissolved and colloidal metals through two mixing zones in the Animus River. The research found that upstream of the mixing zone the Animus River had high zinc concentrations. The mixing zones from the two separate creeks, Mineral Creek and Cement Creek, inputted large concentrations of other heavy metals such as aluminum, iron, copper, and lead. These creeks were also found to be acidic due to the runoff of acid mine drainage *(Schemel et al, 2000).*

Reclamation of Mines

It is clear that the research focused on abandoned mines shows that there are environmental impacts due to these mines. These reports often times call for the reclamation of the mines to limit future environmental impacts. There is a lot of research being done on the reclamation process due to the fact that it can be very costly and acts more as a short term fix than a long-term solution. For reclamation to be successfully completed it is important to understand the hydrologic connections between surface water, groundwater, and mine workings *(Cowie, 2014)*. Cowie worked on better understanding this connection and also focused research around source identification. To do this research Cowie used natural and applied tracers to track the movement of contaminants through the watershed. The results found that water travels relatively easy through the mine workings with little obstructions. This research is incredibly important because it sets a model for targeted remediation efforts for acid mine drainage from abandoned mines. Similar research has been done in Colorado with similar research techniques. Hazen and colleagues *(2001)* argue that traditional remediation of abandoned mines through the treatment of acid mine drainage is not feasible for the thousands of abandoned mines located in Colorado, as well as difficult and expensive. Hazen and colleagues are looking for ways to create new tools to identify sources of metal pollution within a mine, very similar to Cowie's work using natural and applied tracers. The researchers in this study used hydrogen and oxygen isotopes of water in combination with solute analysis and hydrometric techniques. The researchers were able to find that 79% of flow in a high Zinc concentrated stream was from a new source of water. This finding led researchers to believe that some mine reclamation projects can be focused on a single area within the mine. The idea is that if the source of new water flow can be identified, then it can be diverted or isolated. The researchers also believe that it may be possible to dewater contamination sites.

Mine reclamation sites are important targets for ecological restoration, yet are difficult to restore. Many researchers are experimenting to find ways to restore habitats that have been affected by mine pollution. Francis and colleagues *(2009)* evaluated the importance of nursery nutrient loadings as a new approach to restore forests on abandoned mine lands. Their work included nitrogen loading seedlings in a laboratory for 18 weeks before transferring the seedlings to a reclaimed mine site. Their results show that the nitrogen-loaded seedlings had increased survival rates as well as greater dry mass production. This research paves a way for exponential nitrogen loading to be used as a viable technique for the restoration of forests on abandoned mine affected lands. Other research has shown that other science based approaches are very effective when dealing with landscapes highly disturbed by mine pollution *(Rieder et al, 2013).* Rieder and colleagues argue that restoration of disturbed landscapes can have a favorable trajectory when well planned treatments are implemented. Their research included a greenhouse experiment to screen 36 growth medium treatments, and a field experiment to test a subset of best performing treatments. Through their experiments they were able to find the best treatment for reclaiming lands lost to mining. They found that 30 cm of waste rock amended with lime and mushroom compost and covered with 15 cm of limed, fertilized stockpiled topsoil was the best treatment for reclaiming lost lands. Again, this is another example of a model that can be replicated not only in Colorado, but also around the world for the reclamation process of abandoned mines. There has been other work done to try and restore ecosystem habitats where abandoned mines have affected the land. There is a particular problem with successfully re-establishing aspen forests on mine affected lands. Many attempts have failed due to the seedling's lack of extensive root systems. One study has been done that examined and identified factors that limit the survival and growth of aspens on reclaimed mine land. The study was able to find a technique using transplanted trees, soil from aspen stands, and controlled vegetation to work well for re-establishing aspen forests on reclaimed abandoned mine land.

Methods

For my research on the effects abandoned mines have on forest health I first determined a specific region in which all of my test sites would be located. I decided to choose Boulder Canyon as the region. I chose Boulder Canyon for a two primary reasons: The extensive history of mining that has occurred in the canyon and the canyon's is recreational value as a hotspot for climbers, mountain bikers, hikers, and other outdoor enthusiasts who I believe would appreciate keeping a healthy ecosystem in the canyon. I hoped that my research could provide more information to keeping that healthy ecosystem a reality. After choosing the region I then had to determine which mine sites I would study. To do this I used the website http://www.westernmininghistory.com/mines to obtain the exact longitude and latitude of different mines in the canyon. When selecting the mine sites I ensured that the mines were spread over an elevation range of 6,000 - 8,000 ft and also ensured that I selected mine sites on both the north and south slopes of the canyon. I also had to take into account the accessibility of the mines, looking at whether the mines were on private property or not and how difficult it would be to get to them. To determine the control sites I made sure that each site was not within a 500 ft radius of a mine opening. Once I selected a site to use as a control I recorded the elevation and longitude and latitude of the site. As with the mine sites, I made sure the control sites were spread over an elevation range of 6,000 - 8,000 ft and on both the north and south slopes of the canyon.

To look at the health of trees I used the line intercept sampling method to show the number and species of tree, diameter at breast height, and whether the tree was dead or alive. I chose this method because I had experience using it before in some of my EBIO lab classes and it is an effective but easy method for one to two people to accurately execute. I chose to look at these variables because they are indicators of forest health. Whether the trees were alive or dead shows how healthy a population of trees is while the diameter at breast height is a way of showing the size of a tree, with larger sizes being attributed to healthier tree growth. I typically spent eight hour days in the field for approximately two weeks recording data. For this method I performed the following steps:

1. Determine the testing area. Control areas were randomly selected throughout Boulder Canyon and were at least 500 ft from any mine opening. Mine areas were predetermined using a map of abandoned mines in Boulder Canyon.
2. Once the area is determined, record the latitude, longitude, and elevation of the site.
3. For mine areas, measure a 150 ft radius from the opening of the mine. For control areas, select a tree and measure a 150 ft radius from the tree. This set equally sized testing areas.
4. Lay out a one hundred ft measuring tape across a random portion of the land.
5. Record each tree that is touching or within a one foot radius (including the canopy) of the measuring tape.
6. Measure and record the species of tree and whether alive or dead of each individual tree that is touching/within the radius of the tape measure.
7. Measure and record the diameter at breast height:
    1. To do this I used a DBH measuring tape and wrapped it around the tree 4.5 ft above the ground, the DBH tape automatically equates the circumference to the diameter.
    2. When the trunk is at an angle I measured at a right angle to the trunk 4.5 ft along the center axis of the tree.

3. When the trunk split at a point lower than 4.5 off the ground I measured the smallest circumference below the lowest branch.
4. When the tree was a multi-stemmed tree I determined the size by measuring the DBH of each trunk and then adding the total diameter of the largest trunk to one-half the diameter of each additional trunk.

2. Repeat steps 4-7 seven more times for a total of 8 line intercepts per site.

To analyze the data that I collected in the field I used the program R to run a statistical analysis. I identified my predictor variable as the presence or absence of a mine. I then assigned a one for all locations with a mine and a zero for all locations without a mine. My response variables were identified as the size of the tree and whether the tree was dead or alive. At first I ran a Welch Two-Sample T-test to compare the means of my response variables. I then created a model by defining each of the predictor variables that could affect the results and the potential interactions between the variables. I ran this model through a variance analysis and found the best-fit model, which would show me which variables had the most effect on the results.

For the policy analysis portion of my research I first had to determine the scope of the analysis. I decided to look at both national and state level abandoned mine mitigation policies for a more holistic understanding of the process. I decided to go with both national and state level policies because abandoned mines are often reclaimed with funding and organizations from both levels of government. For the national level I mostly focused on the EPA and Superfund sites. After determining the scope of my analysis I then used the resources available to me through the University of Colorado to obtain as much information as I could surrounding abandoned mine reclamation, mitigation processes, and funding. I then used this information to determine what policies are already in place, what priorities are in place, why certain organizations are not getting the resources they need, and how various stakeholders are being affected. After getting information on these questions I focused on what is working and what is not working and attempted to come up with possible solutions to fix the issues within the abandoned mine policy realm. I also looked at what is being done now to ensure that corporations that own mines have the financial stability to reclaim the mine when they are done with it so that more abandoned mines are not being created.

Results

For this section I present the raw data that I obtained through my research. I have categorized the data into two different sections: Tree Health Data and Mitigation Policy Findings.

Tree Health Data

The data collected for the effects of abandoned mines on tree health was taken from 13 different areas including a mine (Affected) and 13 control areas not including a mine (Control). The raw data can be found in Appendix A. After collecting all of the data it was found that the mean diameter at breast height of the affected group is 14.72 cm. The mean diameter at breast height of the control group is 18.89 cm. A Welch two-sample t-test found a 95% confidence interval in the difference of means to be between -5.32 and -3.03. This test found that a null hypothesis stating "the difference in means is zero" to be false and was proven statistically significant with a p value of 1.297e-12.

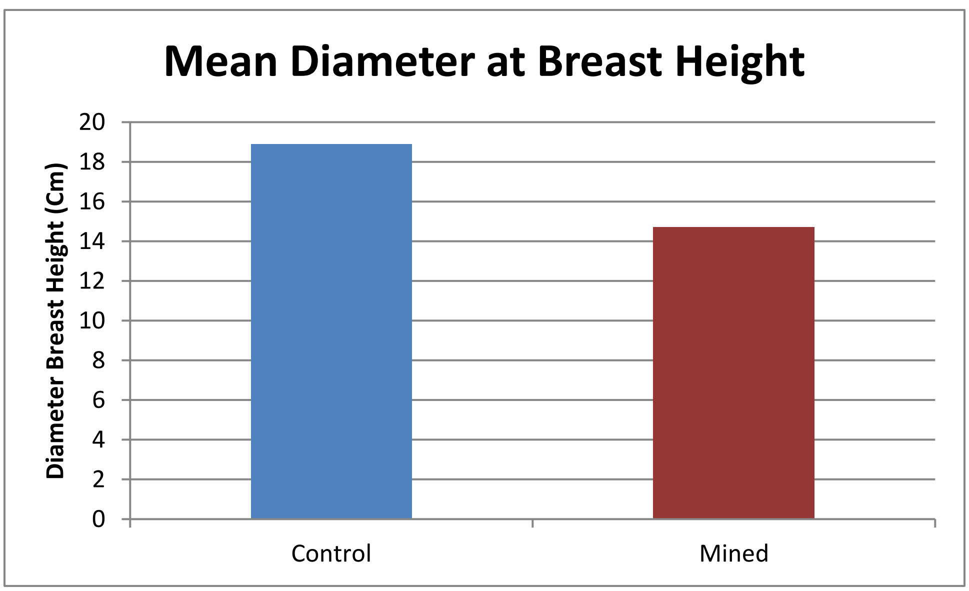

Figure 1: Mean diameter at breast height for the mined and control areas.

However, although it has been determined that the mean diameter breast height of trees in the affected areas is smaller than the mean diameter breast height of trees in the control areas, further analysis had to be done to determine whether this difference is due to the presence of mines or other factors. To do this we needed to create a model with all predictor variables (site location, mine effect, tree type, alive or dead) and the potential interactions among pairs of variables (i.e. does location influence tree type?). To do this we first defined each variable we are working with:

- x1 = location
- x2 = mine effect
- x3 = tree type
- x4 = alive
- y = response variable

We then created the following model with all potential interactions:

- y~x1+x2+x3+x4+x1*x2+x1*x3+x1*x4+x2*x3+x2*x4+x3*x4

We ran an analysis of this variance model and then used an approach that found the best model (i.e. which variables are important). The final model was determined to be:

- y~ x1 + x3 + x4

Note that the final model does not include mine effects meaning that the other three variables (site location, tree type, alive/dead) explain most of the variation in diameter. What this data is showing is that the diameter breast height of the trees is influenced by locality, the type of tree, and whether the tree is dead or alive. The presence or absence of a mine has no effect on the diameter breast height of the trees. The R code used to run this variance model can be found in Appendix B.

Analysis of the data found that in the affected mine areas 2.85% of the trees were dead. In the control area it was found that 2.53% of the trees were dead. By running a Welch Two Sample t-test a p-value of 0.7068 was determined. At a 5% significance level, this number shows that these two percentages are not statistically significant from each other. Therefore, the presence or absence of a mine has no effect on the percentage of dead trees in the area.

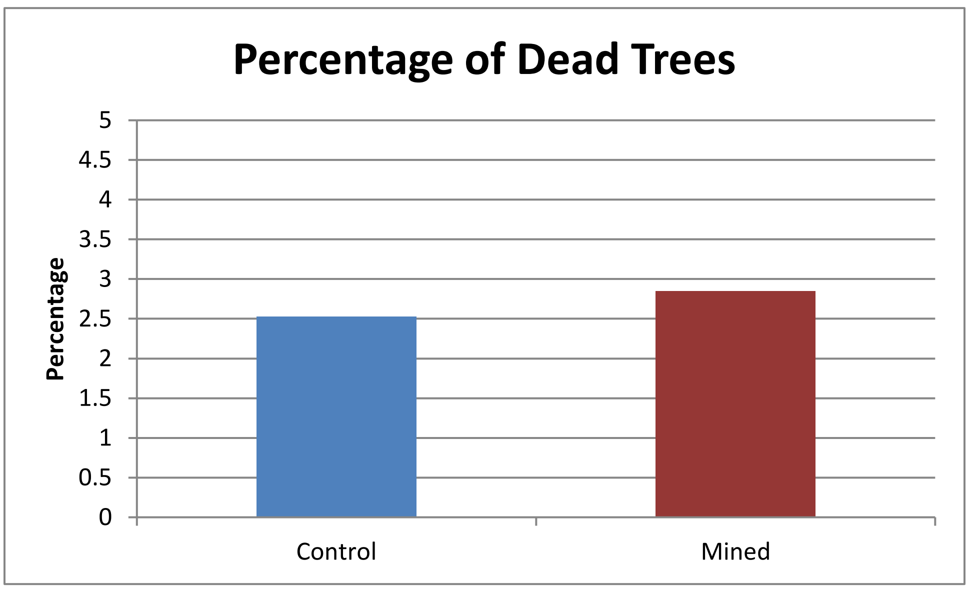

Figure 2: Percentage of dead trees at mined and control areas.

Mitigation Policy Findings

According to the EPA, as of April 7th, 2016, 139 abandoned mine sites have been proposed for or listed on the National Priorities List *(EPA, 2016)*. Overall there are a total of 1,782 sites that have been proposed or listed on the National Priorities List. Of these 1,782 sites, 53 of them are proposed and 392 of them have been deleted *(EPA National Priorities List, 2016)*. This indicates that out of the finalized sites (1,729) 22.67% of them have been properly mitigated. As mentioned before, there are four different designations that a site can fall under. These designations are *proposed, withdrawn, final,* and *deleted.* Sites can also fall under a non-NPL status. A description of these designations can be found in the background section (Page 6). The 139 abandoned mine sites were designated in the following way: Final - 102, Deleted - 19, Proposed - 11, Non-NPL - 7. Of these 139 sites, 128 of them were determined to pose a serious risk to human health or the environment. Out of those 128, nineteen were cleaned up to the point where they could be determined as no longer a threat. This indicates that only 14.84% of abandoned mines on the superfund list have been properly cleaned up. In Colorado specifically, there are an estimated 23,000 abandoned mines; the Colorado Division of Reclamation, Mining, and Safety states that 6,127 of them have been made safe by their efforts. This indicates that approximately 26.6% of abandoned mines in Colorado have been properly cleaned up. The DRMS states that due to their efforts 1,539 acres of abandoned mine lands have been reclaimed by their efforts.

The following table shows the number of abandoned mine superfund sites that were deleted each year:

Year	**Number of Sites Deleted**
1996	5
1997	1
1998	1
1999	1
2000	1

2001	1
2002	1
2003	1
2004	1
2009	2
2011	2
2012	1
2015	1

Figure 3: Number of abandoned mine superfund sites deleted each year *(EPA, 2016).*

The Colorado Division of Reclamation, Mining, and Safety is under the Colorado Department of Natural Resources (CDNR). The CDNR has a total budget of $262,617,572. Of that budget the DRMS has a budget of $7,746,999. Funding comes from the Department of the Interior - Office of Surface Mining Reclamation and Enforcement (OSM) through reclamation fees paid by current coal mine operators under the Surface Mining Control and Reclamation Act of 1977. Additional funding for safeguarding activities comes from the U.S. Bureau of Land Management, the U.S. Forest Service, as well as state severance tax. The DRMS' total budget funding is broken down in the following way:

- Federal Funds - $3,318,057
- Cash Funds/Severance Taxes - $3,347,272
- Cash Funds/Fees - $1,051,670
- Reappropriated funds - $30,000

The Inactive Mine Reclamation Program is a subset of the DRMS that focuses on safeguarding abandoned mines and is responsible for the 6,127 abandoned mines that have been mitigated.

This program specifically has a budget of $2,403,544. The funding for this budget is broken down in the following way:

- Federal Funds - $1,243,800
- Cash Funds/Severance Taxes - $1,129,744
- Reappropriated funds - $30,000

The DRMS has a total of 68.9 full time equivalents (FTE) and of that 68.9 FTE, 17.8 FTE are appropriated to the Inactive Mine Reclamation Program. The rest of the funds and FTE go to the Coal regulatory program, minerals regulatory program, and mine safety/blasters certification.

When the Superfund Trust Fund was created in 1980 it was authorized at $1.6 billion. In 1986 Superfund amendments authorized it at $8.6 billion and a third authorization in 1990 added an additional $5.1 billion *(EPA, 1990).* Since 1981, Superfund appropriations have totaled over $32 billion in nominal dollars, or about $1.2 billion annually through 2007 *(GAO-08-841R, 2008).* The revenue that the trust fund receives comes from the multiple sources mentioned earlier and fall into four major categories: taxes on crude oil and certain chemicals, as well as an environmental tax based on a corporation's income; appropriations from the general fund; fines, penalties, and recoveries from responsible parties; and interest accrued on the balance of the fund. For fiscal years 1981-1995, while the superfund taxing still had authority, the funds were received in the following proportions:

- Taxes: 68%
- General Fund Appropriations: 17%
- Interest: 9%
- Fines, Penalties, and Recoveries: 6%

For fiscal years 1996-2007, after the taxing authority had expired, the funds were received in the following proportions:

- Taxes: 6%
- General Fund Appropriations: 59%
- Interest: 16%
- Fines, Penalties, and Recoveries: 19%

The large increase in general funds appropriations is coming from the tax payer's dollar and is appropriated by congress. The balance of the trust fund has declined dramatically over recent years from $4.7 billion at the start of the 1997 fiscal year to $173 million at the start of fiscal year 2007. During the period of fiscal years 1999 through 2007 overall Superfund program expenditures declined nearly 30% in constant dollars which was mostly due to a decline in expenditures for remedial activities *(GAO-08-841R, 2008).* The EPA's annual costs to conduct remedial construction for all nonfederal superfund sites were estimated at $335 million to $681 million for fiscal years 2010 through 2014. These annual cost estimates far exceed annual funding allocation for such actions. Remedial construction costs for the fiscal years 2011 and 2012 were $253 million and $414 million greater than the annual funding the EPA allocated for remedial action in fiscal year 2009 *(GAO-10-857T, 2008).*

Discussion

This section reports analysis and conclusions from the data. In this section I focus on three different categories to draw a conclusion: Tree Health, Mitigation Policy, and Current Mines.

Tree Health

This research worked to answer the question "What effects have abandoned mines had on tree health in Boulder Canyon?". For the purposes of this research tree health was defined by two different factors: the average diameter breast height of the control and mined areas and the percentage of dead trees in each area. Initial analysis of the data found that the average diameter at breast height was larger in the control areas than in the mined areas, 18.89cm and 14.72cm respectively. Although these results were statistically significant, supported by a p-value of 1.297e-12, more data analysis had to be run to support a claim that the decreased average diameter breast height is due to the presence of a mine. What the data analysis showed is that the average diameter at breast height of the trees is influenced by locality, the type of tree, and whether the tree is dead or alive. The presence or absence of a mine has no effect on the diameter at breast height of the trees. The data analysis also found that there was no significant difference in tree mortality between the mined and control sites. The mined areas had an average of 2.85% dead trees while the control area had 2.53% dead trees. A t-test comparing this data found a p-value of 0.7068, well above a 5% significance level. This evidence supports the claim that abandoned mines have had no effect on tree health, as defined in this project, in Boulder Canyon.

Although there is extensive research showing that the lands around abandoned mines are contaminated with heavy metal pollution *(Navarro et al, 2008; Roberts et al, 1978)*, this seems to not have an effect on tree health in Boulder Canyon. This is congruent with other research done on the relationship between tree health and heavy metals. While there is little research done on the effects of heavy metals on the trees studied in this research, other research has found that trees have the ability to show a high tolerance level without damage to growth and perplexing low mortality rates when exposed to heavy metals *(Watmough et al, 1995; Hashemi, 2013)*. Since the majority of the damage that comes from abandoned mines is onset by the introduction of heavy metals to the ecosystem, it is understandable that the trees in Boulder Canyon showed no resulting effects from this pollution. These results are important for the reclamation process of these abandoned mine lands. There are two parts to abandoned mine reclamation: the safeguarding and closure of the mine to prevent further contamination and the restoration of the surrounding ecosystem. While organizations like the DRMS, EPA, and OSMRE work to close and safeguard the mines from leaking more contaminants, it is left to environmental groups, researchers, and state and local authorities to restore the ecology of the area. The restoration of mined lands can be looked at as ecosystem reconstruction through the reestablishment of the capability of the land to capture and retain fundamental resources. It is guided by ecological principles and promotes the recovery of ecological integrity *(Cooke et al 2002).* Understanding that there is no effect on tree health can allow restoration and future research to be focused on other aspects of biodiversity such as vegetation growth or wildlife, both of which have been shown to be affected by abandoned mines *(Larison, 2000; Custer, 2009; Zhang et al, 2014)*. By not having to focus on restoring native trees to the area, groups working on restoration will be able to save time and money while narrowing their focus allowing them to be more effective at restoring the natural ecosystem.

I believe it is important to mention that while collecting the data for this research I also looked at vegetative ground coverage. Although due to computer issues the data that I collected was unfortunately lost. I cannot say conclusively that there was a difference in the ground coverage between the mined and control areas because I was not able to run statistical analysis on the data. However, I can say that I could visually see a difference between the two areas. The mined areas had, from what I could tell, much more area that was bare ground than in the control areas. This is congruent with other research done on the effects of mined lands on vegetative growth. A prominent example of this is phosphate mining on the small Pacific Island of Nauru which has lead to an 80% decrease in vegetation and soil *(Gowdy et al, 1999).* These observations along with research already published on the issue should be of great importance for ecological restoration of abandoned mine lands.

Mitigation Policy

In an attempt to answer the question "How effective are national and state abandoned mine mitigation policies?" I have analyzed the efforts of the EPA and the Colorado DRMS. My findings have shown that of the 128 abandoned mine superfund sites, only 14.84% of them have been reclaimed by the EPA. This is a slightly lower percentage than the percentage of overall superfund site mitigations which is 22.67%. As seen in Figure 3 the rate at which these abandoned mine superfund sites are being deleted has slowed considerably. In the 21 year period (1996-2016) that this data was collected, thirteen of the deletions occurred in the first ten years (1996-2005), while only six deletions occurred in the eleven years that followed (2006-2016). These results are congruent with other research done on the effectiveness of the EPA Superfund program. Research has found that although the total number of sites on the NPL has remained relatively constant over recent years, the number of remedial action project completions and construction completions has generally declined *(GAO-15-812, 2015).*

This decrease in the number of remedial action project completions can be attributed greatly to the rapid decrease in funding. The decrease in funding is due to the tax on crude oil and other chemicals, as well as the environmental tax on corporation's incomes being halted. In the years that the trust fund tax had authority, 68% of the revenue came from this tax. In the 12 years that followed only 6% had come from the tax. This decrease in the percentage of revenue coming from taxes can be attributed to the staggering 96.32% decrease of money in the Superfund trust fund between the fiscal years 1997 and 2007. The EPA's annual cost estimates for remedial actions far exceed their budget for such projects and are the number one reason why the mitigation of abandoned mine Superfund sites has declined over the past two decades. The data has also shown that not only are funds decreasing but the amount being allocated for remedial actions is decreasing as well. This decrease in funding for remedial actions can be attributed to the shear deficit in revenue for these projects. The EPA does not want to start reclamation construction on a site knowing they will most likely not have enough money to finish the construction. So instead they put the little revenue that they do have to other aspects of the Superfund, such as administration.

It is evident that increasing funding is the most important aspect to increasing reclamation of abandoned mine Superfund sites. Revenue coming into the trust fund must be increased significantly to the point where enough money is being allocated to remediation projects so that annual remediation cost estimates fall within the budget. Over the past two decades it is clear that general fund appropriations are not enough revenue for the EPA to properly mitigate these Superfund sites. The only way to increase the revenue to a high enough amount that the EPA can start remediation projects and stay under budget is by bringing back the tax on crude oil and chemicals, or a tax similar to this that works as a polluters pay tax. This tax has been proven to work before and a similar federal tax has been working since 1977 and continues to offer revenue to this day. As mentioned earlier the Surface Mining Control and Reclamation Act of 1977, which is overseen by the Office of Surface Mining Reclamation and Enforcement, imposes a per ton tax on coal extracted in the United States. This tax is redistributed to states that have an approved abandoned mine reclamation program. This tax is the revenue that the Colorado DRMS receives from federal funds, accounting for 42.83% of their total annual budget. The Colorado DRMS also receives a large portion of their total annual budget (43.2%) from Colorado severance taxes. The Colorado Severance Tax is a tax imposed upon nonrenewable natural resources that are removed from the earth within the state of Colorado. This equates to a total revenue proportion from taxes of 86.03% of the total budget.

As shown in the results, the DRMS has a higher success rate than the EPA of completed mitigation projects. Now this can be due to factors such as easier reclamation projects which generally mean lower remediation costs, we have to remember that Superfund sites are the worst of the worst. However, there is no arguing that the DRMS would have successfully mitigated nearly as many mines as they have today if their budget was cut by more than 86%. The taxes on the coal, oil, and nonrenewable industries work and allow for states to mitigate the hazardous abandoned mines in their boundaries. During Obama's 2008 campaign he promised to restore the Superfund program to its former glory by reinstating the polluter pays tax. An attempt was made to bring some more funding to the superfund in 2009 with the American Recovery and Reinvestment Act *(Taylor, 2011)*. This act was able to allocate an extra $600 million to Superfund for the cleanup of sites. Throughout his campaign, however, Obama was not able to fulfill this promise of reinstating the tax. In 2010 the EPA lobbied for and sent a letter to congress urging for the reinstatement of the tax on crude oil and other chemicals. The EPA stated that this tax will ensure that parties who benefit from the extraction or sale of substances that commonly cause environmental degradation and adverse health effects bear the cost of cleanup, instead of the American tax payer. Mathy Stanislaus, assistant administrator for EPA's Office of Solid Waste and Emergency Response, stated that "Our taxes should be paying for teachers, police officers and infrastructure that is essential for sustainable growth -- not footing the bill for polluters" *(Petteway, 2010).* The data is clear for the need of the polluters pay trust fund tax and the EPA fully supports its reinstatement. The trust fund tax must be brought back in similar fashion so that the EPA will have funding to properly mitigate abandoned mines for the safety of our health and the environment.

The DRMS is currently the only program in the state of Colorado to address past mining hazards and minimal funding is available for environmental projects. While they have had a very high number of proper mitigations and safe closures of abandoned mines, more money needs to be allocated to the ecological restoration of the abandoned mine lands in Colorado.

Current Mines

Section 108(b) of CERCLA gives the EPA the authority to require that facilities contributing to what is defined as hazards to humans or the environment, to establish and maintain evidence of financial responsibility. Financial responsibility demonstrates that the owner of the facility has the ability/funds to cover any costs associated with the release of hazardous materials from their facility. In 2009 the EPA identified hardrock mining facilities as the first priority for the development of financial stability under CERCLA. The EPA identified hard rock mining classes of facilities, and defined "hardrock mining" for purposes of the notice as the extraction, beneficiation or processing of metals (e.g., copper, gold, iron, lead, magnesium, molybdenum, silver, uranium, and zinc) and non-metallic, non-fuel minerals (e.g., asbestos, phosphate rock, and sulfur) *(EPA, 2009).* This requirement of financial responsibility on mines will decrease the likelihood for the need for hazardous waste cleanup by outside parties and therefore allocate more funds within the EPA and DRMS to remedial action programs.

On the state level in Colorado, mining operations must apply for a Mined Land Reclamation Board Permit to legally operate a mine. This permit requires a mine operator to have a reclamation plan set for when the mine is closed. The permit also requires that once an operator has completed a phase of mining, that operator has 5 years to complete the reclamation process for that phase. Each operator must submit a yearly report and fee to the DRMS to ensure that the permit is being upheld. The minerals program, another program within the DRMS, also completes inspections of each permitted mine site at least once every four years. High priority hardrock sites are often inspected annually and operations that use hazardous materials may be inspected monthly. The sites are inspected to ensure that the operator is in compliance with their permit. If it is found that the operator is not in compliance with their permit, a case is made in front of the Mined Land Reclamation Board in which a decision can be made to suspend or cancel the permit *(DRMS Minerals Program Permitting).*

Conclusion

This study found there is no effect on tree health, as defined in this project, in Boulder Canyon, CO, from abandoned mines. While the data showed a statistically significant difference of approximately four cm in the mean DBH between the control and mined areas, further statistical analysis found that this difference was due to variables other than the presence of a mine. This data is important for projects working to restore the ecosystem of abandoned mine lands. Restoration groups with an understanding of these results can focus their attention on restoring vegetative ground cover and species habitats.

My analysis of policies relevant to abandoned mine lands mitigation has shown that the primary factor in the success rate of remedial action projects is funding. Without a tax on the nonrenewable sector, the EPA does not have the funds to properly mitigate abandoned mine superfund sites to make them safe for human health and the environment. The loss of the tax on crude oil and other chemicals, and the loss of environmental tax on corporation's incomes have resulted in a decreased number of remedial action projects while the number of sites being added to the National Priorities List continues to increase. A tax of similar structure has shown to be efficient and reliable on the state level, specifically in Colorado. To improve the success rate of abandoned mine remedial action projects on the national level, the tax on crude oil and other chemicals, as well as the environmental tax on corporation's incomes must be reinstated. If not the original tax, a similar "polluter pays" tax on the nonrenewable sector must be created to provide revenue for the Superfund Trust Fund while also holding those industries responsible for paying for the negative environmental externalities their operations create.

This research can be continued by examining the effects of abandoned mines on vegetative growth in Boulder Canyon. As mentioned before, I had attempted to collect data for this but unfortunately lost the data due to computer issues. By looking at the native vs. non-native plant composition as well as the overall proportion of bare ground vs. vegetative cover we will be able to better understand the impacts that abandoned mines have had on ecological health in Boulder Canyon. Another avenue to further this research is to study the effects of heavy metals on the conifer trees that were examined in this study. As discussed in this paper, the heavy metal accumulation from abandoned mines had no effect on the diameter breast height or mortality of the trees in Boulder Canyon. By researching the effects of known pollutants from abandoned mines on the trees in this study, we can better understand the relationship between abandoned mines and trees in Boulder Canyon, as well as Colorado as a whole.

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Appendices

This section contains all appendices referred to in this thesis

Appendix A

Raw data for mine sites:

Key:

P = Ponderosa Pine
D = Douglass Fir
A = Aspen
J = Rocky Mountain Juniper
1 = Alive
0 = Dead

SITE - AFFECTED	CROSS CUT #	TREE TYPE	DIAMETER (Cm)	ALIVE?
Jay	1	P	6.885	1
Jay		P	23.49	1
Jay		P	48.6	1
Jay		D	13.77	1
Jay		D	33.21	1
Jay		P	4.05	1
Jay		P	5.67	1
Jay		D	22.68	1
Jay		D	18.63	1
Jay		D	23.085	1
Jay		P	6.885	1
Jay	2	P	9.72	1
Jay		D	4.05	1
Jay		D	3.24	1
Jay		D	8.505	1
Jay		P	17.01	1
Jay		D	8.1	1
Jay		P	2.43	1
Jay		D	8.1	1
Jay		D	4.05	1
Jay		P	1.62	1
Jay	3	P	9.72	1
Jay		P	8.1	1
Jay		D	5.67	1
Jay		P	8.1	1
Jay		P	5.265	1
Jay		P	10.53	1
Jay		P	6.075	1
Jay		P	19.44	1
Jay		D	15.39	1
Jay	4	D	13.77	1
Jay		P	18.225	1
Jay		D	18.63	1
Jay		D	8.505	1
Jay		P	3.645	1
Jay		P	5.265	1
Jay		P	3.24	1
Jay		D	10.53	1
Jay		P	6.48	1
Jay		D	26.73	1
Jay	5	D	16.2	1
Jay		D	15.795	1
Jay		D	8.1	1
Jay		P	4.455	1
Jay		P	8.91	1
Jay		D	25.11	1
Jay		P	26.73	1
Jay		D	10.125	1
Jay		P	12.15	1
Jay		P	27.54	1
Jay		P	7.29	1
Jay		P	24.705	1
Jay	6	D	6.48	1
Jay		D	17.01	1

Jay		D	25.515	1
Jay		P	16.2	1
Jay		P	17.01	1
Jay		D	43.74	1
Jay		P	47.79	1
Jay	7	D	21.06	1
Jay		D	19.44	1
Jay		D	25.11	1
Jay		P	15.39	1
Jay		P	15.795	1
Jay		P	3.24	1
Jay		P	5.265	1
Jay		D	12.15	1
Jay	8	P	15.39	1
Jay		P	18.225	1
Jay		P	6.48	1
Jay		P	13.77	1
Jay		P	35.64	1
Jay		D	22.275	1
Jay		P	12.96	1
Unknown 4	1	P	10.5	1
Unknown 4		P	5.5	1
Unknown 4		P	3.5	1
Unknown 4		P	11.5	1
Unknown 4		D	23	1
Unknown 4		P	6	1
Unknown 4		P	3	1
Unknown 4		D	17.5	1
Unknown 4		P	10.5	1
Unknown 4		D	15.5	1
Unknown 4	2	P	4	1
Unknown 4		D	1.5	1
Unknown 4		D	0.5	1
Unknown 4		D	11	1
Unknown 4		D	0.5	1
Unknown 4		P	41.5	1
Unknown 4	3	D	13	1
Unknown 4		P	37.5	1
Unknown 4		D	22	1
Unknown 4		P	5	1
Unknown 4		P	4	1
Unknown 4		P	9	1
Unknown 4		P	5	1
Unknown 4		P	3.5	1
Unknown 4		D	29	1
Unknown 4		P	13.5	1
Unknown 4		D	2	1
Unknown 4		P	10	1
Unknown 4		P	22.5	1
Unknown 4		P	15	1
Unknown 4		D	31	1
Unknown 4	4	P	19	1
Unknown 4	5	P	7.5	1
Unknown 4		P	7	1
Unknown 4		P	46.5	1
Unknown 4		D	4	1
Unknown 4		P	14	1
Unknown 4		D	16	1
Unknown 4		P	13.5	1
Unknown 4		D	25	1
Unknown 4	6	P	17	1
Unknown 4		P	21.5	1
Unknown 4		D	3.5	1
Unknown 4		P	31	1
Unknown 4		D	3	1
Unknown 4		P	19	1
Unknown 4		B	6.5	1
Unknown 4		D	5	1
Unknown 4		P	33	1
Unknown 4	7	D	0.5	1
Unknown 4		D	23	1
Unknown 4		P	25.5	1
Unknown 4	8	D	0.5	1
Unknown 4		D	0.5	1
Unknown 4		P	26.5	1
Unknown 4		D	2	1
Unknown 4		D	0.5	1
Unknown 4		D	0.5	1
Unknown 4		P	16	1
Unknown 5	1	P	12.5	1
Unknown 5		P	30	1
Unknown 5		D	24.5	1
Unknown 5		P	8.5	1
Unknown 5		P	26	1
Unknown 5		P	9	1
Unknown 5		D	12	1
Unknown 5		D	17	1
Unknown 5		D	25	1
Unknown 5	2	P	21	1

Unknown 5		P	13	1
Unknown 5		D	0.5	1
Unknown 5		P	20.5	1
Unknown 5		D	33.5	1
Unknown 5		P	13	1
Unknown 5		P	16	1
Unknown 5		P	10	1
Unknown 5		D	36.5	1
Unknown 5		P	5.5	1
Unknown 5		P	15.5	1
Unknown 5		D	21	1
Unknown 5		P	8.5	1
Unknown 5		P	22	1
Unknown 5	3	P	15	1
Unknown 5		P	21.5	1
Unknown 5		P	24	1
Unknown 5		D	2	1
Unknown 5		D	4.5	1
Unknown 5		P	23	1
Unknown 5		D	0.5	1
Unknown 5		D	0.5	1
Unknown 5		D	3.5	1
Unknown 5		D	12	1
Unknown 5	4	D	0.5	1
Unknown 5		P	7	1
Unknown 5		P	16	1
Unknown 5		P	7.5	1
Unknown 5		D	5	0
Unknown 5		P	22	1
Unknown 5		D	22.5	1
Unknown 5		P	10	1
Unknown 5	5	P	16	1
Unknown 5		D	0.5	1
Unknown 5		D	36	1
Unknown 5	6	P	23	1
Unknown 5	7	P	25	1
Unknown 5		D	0.5	1
Unknown 5		J	18	1
Unknown 5		D	20	1
Unknown 5		D	53	1
Unknown 5		P	4	1
Unknown 5		P	5	1
Unknown 5		D	37.5	1
Unknown 5		P	9	1
Unknown 5		P	16.5	1
Unknown 5	8	D	18	1
Unknown 5		D	24.5	1
Unknown 5		D	21	1
Unknown 5		D	13	1
Unknown 5		D	0.5	1
Unknown 5		P	37	1
Unknown 5		D	0.5	1
Unknown 5		D	2	1
Unknown 5		D	1	1
Unknown 5		D	0.5	1
Unknown 5		D	1	1
Unknown 5		P	36	1
Unknown 5		D	31	1
Sister	1	P	27	1
Sister		P	26	1
Sister		D	1.5	1
Sister		P	19.5	0
Sister		D	19	1
Sister		P	4	1
Sister		P	14.5	1
Sister		P	12	1
Sister		D	7.5	1
Sister		P	11.5	1
Sister	2	P	19	1
Sister		P	24	1
Sister		P	27	1
Sister		D	3.5	1
Sister	3	P	23.5	1
Sister		D	47	1
Sister		P	23	1
Sister		P	17	1
Sister		P	11.5	1
Sister		P	38	1
Sister		P	31.5	1
Sister	4	D	17.5	1
Sister		D	8	1
Sister		P	44.5	1
Sister		D	10	1
Sister		D	20	1
Sister		D	3.5	0
Sister		P	5.5	1
Sister		P	23	1
Sister		P	36	1
Sister		D	3	1

Sister		P	23.5	1
Sister	5	D	4.5	1
Sister		D	22	1
Sister		D	29.5	1
Sister		P	17	1
Sister		P	24	1
Sister		P	11	1
Sister		D	31.5	1
Sister		P	16	1
Sister		P	12	1
Sister		P	6	1
Sister		P	32	1
Sister	6	D	2	1
Sister		D	19.5	1
Sister		P	18	1
Sister		P	11	1
Sister		P	4	1
Sister		D	3.5	1
Sister		D	4.5	1
Sister		P	20	1
Sister		D	2.5	1
Sister	7	D	7	1
Sister		D	32	1
Sister		J	0.5	1
Sister		P	8	1
Sister		P	17.5	1
Sister		P	16.5	1
Sister	8	D	33	1
Sister		P	34	1
Sister		P	20.5	1
Sister		D	21	1
Sister		D	9	1
Unknown 6	1	P	22.5	1
Unknown 6		P	18	1
Unknown 6		P	17.5	1
Unknown 6		P	19	1
Unknown 6	2	D	0.5	1
Unknown 6		P	8.5	1
Unknown 6		D	24	1
Unknown 6		P	34	1
Unknown 6		D	14.5	1
Unknown 6		P	14	1
Unknown 6		P	17	1
Unknown 6		D	10	1
Unknown 6		D	7.5	1
Unknown 6		D	5.5	1
Unknown 6		P	28	1
Unknown 6	3	D	2.5	1
Unknown 6		D	0.5	1
Unknown 6		D	18	1
Unknown 6	4	D	6.5	1
Unknown 6		D	3.5	1
Unknown 6		D	7	1
Unknown 6		P	21.5	1
Unknown 6		P	10	1
Unknown 6		P	24.5	1
Unknown 6		D	7	1
Unknown 6		D	6.5	1
Unknown 6		D	5.5	1
Unknown 6	5	P	26	1
Unknown 6		P	32	1
Unknown 6		P	29.5	1
Unknown 6	6	P	4	1
Unknown 6		P	28.5	1
Unknown 6		P	23	1
Unknown 6		P	30.5	1
Unknown 6		P	21.5	1
Unknown 6		D	0.5	1
Unknown 6	7	D	2	1
Unknown 6		P	17.5	1
Unknown 6		P	23	1
Unknown 6		J	8	1
Unknown 6		J	9	1
Unknown 6		J	7.5	1
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Unknown 6		P	32	1
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Unknown 6		P	19	1
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Unknown 6		J	13	1
Unknown 6		J	11	1
Unknown 7	1	D	3.5	1
Unknown 7		P	23	1
Unknown 7		D	6	1
Unknown 7		D	34	1

Unknown 7	2	D	16	1
Unknown 7		P	13.5	1
Unknown 7		P	19	1
Unknown 7		P	18.5	1
Unknown 7		P	19.5	1
Unknown 7		D	15	1
Unknown 7		P	16.5	1
Unknown 7		P	14	1
Unknown 7		P	21.5	1
Unknown 7		P	27	1
Unknown 7		P	29.5	1
Unknown 7		D	0.5	1
Unknown 7		D	22	1
Unknown 7		P	25	1
Unknown 7	3	P	28	1
Unknown 7		P	6	1
Unknown 7		D	2.5	1
Unknown 7		P	20	1
Unknown 7		P	31.5	1
Unknown 7		D	24	1
Unknown 7		D	32.5	1
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Unknown 7		D	12	1
Unknown 7		P	17.5	1
Unknown 7		P	25	1
Unknown 7		D	10.5	1
Unknown 7		P	21	1
Unknown 7		P	15	1
Unknown 7		P	22	1
Unknown 7	6	P	2	1
Unknown 7		D	16	1
Unknown 7	7	P	25	1
Unknown 7		P	30.5	1
Unknown 7		P	12.5	1
Unknown 7		P	6.5	1
Unknown 7		P	17	1
Unknown 7		P	19.5	1
Unknown 7	8	P	9.5	1
Unknown 7		D	17	1
Unknown 7		D	26.5	1
Unknown 7		D	5.5	1
Unknown 7		P	0.5	1
Unknown 8	1	P	1	1
Unknown 8		D	0.5	1
Unknown 8		D	0.5	1
Unknown 8		D	1	1
Unknown 8		P	7	1
Unknown 8		P	11.5	1
Unknown 8		P	8.5	1
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Unknown 8		P	14	1
Unknown 8		D	1	1
Unknown 8		D	1	1
Unknown 8		D	2	1
Unknown 8	2	P	8	1
Unknown 8		P	6.5	1
Unknown 8		P	1	1
Unknown 8		P	7	1
Unknown 8		P	7	1
Unknown 8		P	6.5	1
Unknown 8		D	5	1
Unknown 8	3	P	10	1
Unknown 8		P	4	1
Unknown 8		P	3	1
Unknown 8		P	8	1
Unknown 8		P	3.5	1
Unknown 8		P	3.5	1
Unknown 8		P	2.5	1
Unknown 8		P	32	1
Unknown 8		D	4	1
Unknown 8		P	5.5	1
Unknown 8		P	1	1
Unknown 8		P	5	1
Unknown 8	4	P	16	1
Unknown 8		D	7	1
Unknown 8		D	8	1
Unknown 8		D	2.5	1
Unknown 8		P	7.5	1
Unknown 8		P	9.5	1
Unknown 8		P	1	1

Unknown 8		P	6.5	1
Unknown 8	5	P	5.5	1
Unknown 8		P	7	1
Unknown 8		P	39.5	1
Unknown 8		P	10.5	1
Unknown 8		P	1	1
Unknown 8		P	6.5	1
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Unknown 8	6	D	15	1
Unknown 8		D	9	1
Unknown 8		P	11	1
Unknown 8		P	8	1
Unknown 8		P	3	1
Unknown 8		A	6	1
Unknown 8		A	3	1
Unknown 8		P	15.5	1
Unknown 8		P	18	1
Unknown 8		A	10	1
Unknown 8		A	6	1
Unknown 8		A	6.5	1
Unknown 8		A	8	1
Unknown 8	7	P	12	1
Unknown 8		P	9	1
Unknown 8		D	5	1
Unknown 8		D	3.5	1
Unknown 8		P	11	1
Unknown 8		D	1	1
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Unknown 8		D	1	1
Unknown 8		P	6	1
Unknown 8		P	4	1
Unknown 8		A	12	1
Unknown 8		D	10.5	0
Unknown 8		A	12	1
Unknown 8		A	7.5	1
Unknown 8		A	7.5	1
Unknown 8		P	13.5	1
Unknown 8		D	4	1
Unknown 8	8	P	2.5	1
Unknown 8		P	10.5	1
Unknown 8		A	4.5	1
Unknown 8		A	3.5	0
Unknown 8		A	3.5	1
Unknown 8		A	8.5	1
Unknown 8		A	11	1
Unknown 8		P	15	1
Unknown 9	1	D	6	1
Unknown 9		P	33.5	1
Unknown 9		P	4.5	1
Unknown 9		P	4.5	1
Unknown 9		P	15.5	1
Unknown 9		P	10.5	1
Unknown 9	2	D	23.5	1
Unknown 9		D	25.5	1
Unknown 9		P	6	1
Unknown 9		P	7.5	1
Unknown 9		D	4	1
Unknown 9		P	29	1
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Unknown 9		P	27	1
Unknown 9		D	2.5	1
Unknown 9		P	2	1
Unknown 9		P	7.5	1
Unknown 9		P	6.5	1
Unknown 9	4	P	28.5	1
Unknown 9		P	29.5	1
Unknown 9		P	16.5	1
Unknown 9		P	7	1
Unknown 9		P	4.5	1
Unknown 9	5	P	24	1
Unknown 9		P	26	1
Unknown 9		P	35.5	1
Unknown 9		D	1	1
Unknown 9	6	P	1	1
Unknown 9	7	P	10.5	1
Unknown 9		P	3.5	1
Unknown 9		P	3	1
Unknown 9		P	2.5	1
Unknown 9		P	0.5	1
Unknown 9		P	0.5	1
Unknown 9		P	3	1
Unknown 9		P	28	1
Unknown 9		P	10.5	1
Unknown 9	8	P	2	1
Unknown 9		P	32	1
Unknown 9		P	11.5	1
Unknown 9		P	3.5	1
Unknown 9		P	2	1
Unknown 9		D	20.5	1

Unknown 10	1	P	32	1
Unknown 10		P	31	1
Unknown 10		P	40.5	1
Unknown 10		P	10.5	1
Unknown 10	2	P	48	1
Unknown 10		P	39.5	1
Unknown 10	3	P	34.5	1
Unknown 10		P	36	1
Unknown 10		P	14.5	1
Unknown 10		P	31.5	1
Unknown 10		P	15	1
Unknown 10		P	22	1
Unknown 10		P	23.5	1
Unknown 10	4	P	14	1
Unknown 10		P	27.5	1
Unknown 10		P	30.5	1
Unknown 10		P	12.5	1
Unknown 10		P	19	1
Unknown 10		P	35	1
Unknown 10	5	P	12	1
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Unknown 10		P	10	1
Unknown 10		P	26	1
Unknown 10	7	P	11.5	1
Unknown 10		P	28	1
Unknown 10		P	2.5	1
Unknown 10		P	3	1
Unknown 10		P	3	1
Unknown 10		P	0.5	1
Unknown 10		P	5	1
Unknown 10		P	4	1
Unknown 10		P	3.5	1
Unknown 10		P	3.5	1
Unknown 10		P	1.5	1
Unknown 10	8	P	23.5	1
Unknown 10		P	34.5	1
Unknown 11	1	P	25.5	1
Unknown 11		P	16.5	1
Unknown 11		P	3	1
Unknown 11		D	18	1
Unknown 11		A	13.5	1
Unknown 11	2	P	28.5	1
Unknown 11		P	9	1
Unknown 11		P	34	1
Unknown 11	3	D	7	1
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Unknown 11		P	25.5	1
Unknown 11	4	P	27.5	1
Unknown 11		P	19	1
Unknown 11		P	24.5	1
Unknown 11		D	1.5	1
Unknown 11		P	25	1
Unknown 11	5	D	31.5	1
Unknown 11		D	15	1
Unknown 11		D	23	1
Unknown 11		D	2	1
Unknown 11		D	2	1
Unknown 11		P	30	1
Unknown 11		D	16	1
Unknown 11		P	15	1
Unknown 11		D	22	1
Unknown 11		D	0.5	1
Unknown 11		P	23	1
Unknown 11		P	16	1
Unknown 11		P	34	0
Unknown 11		P	17.5	1
Unknown 11	6	P	29	1
Unknown 11		P	24	1
Unknown 11		P	29.5	1
Unknown 11		D	25.5	1
Unknown 11	7	P	20	1
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Unknown 11		D	27	1
Unknown 11		D	6	1
Unknown 11		D	13	1
Unknown 11		D	9	1
Unknown 11	8	P	11	1
Unknown 11		D	28.5	1

Unknown 11		D	18.5	1
Unknown 11		A	19	1
Unknown 11		D	7.5	1
Unknown 11		A	9	1
Unknown 11		J	6.5	1
Unknown 11		A	12	1
Unknown 12	1	D	11	1
Unknown 12		P	8	1
Unknown 12		D	27	1
Unknown 12		P	33.5	1
Unknown 12		D	14.5	1
Unknown 12		P	6.5	1
Unknown 12		P	19.5	1
Unknown 12	2	P	14	1
Unknown 12		P	22.5	1
Unknown 12		D	3	1
Unknown 12		D	16.5	1
Unknown 12		D	9	1
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Unknown 12		D	4.5	1
Unknown 12	3	P	41	1
Unknown 12		D	7	1
Unknown 12		D	9.5	1
Unknown 12		P	26	1
Unknown 12		P	21	1
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Unknown 12	4	P	7	1
Unknown 12		P	10.5	1
Unknown 12		P	6	1
Unknown 12		D	13	1
Unknown 12		P	12.5	1
Unknown 12		D	20	1
Unknown 12		P	13.5	0
Unknown 12		P	6.5	0
Unknown 12		P	12	1
Unknown 12		P	7	1
Unknown 12		P	5.5	1
Unknown 12		P	15.5	1
Unknown 12		D	11.5	0
Unknown 12		D	24.5	1
Unknown 12		D	23	1
Unknown 12		P	7	1
Unknown 12	5	J	6	1
Unknown 12		P	25	1
Unknown 12		P	14	1
Unknown 12		P	31	1
Unknown 12		P	20	1
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Unknown 12		D	19.5	1
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Unknown 12		P	21.5	1
Unknown 12	6	P	24.5	1
Unknown 12		D	2.5	1
Unknown 12		A	20	1
Unknown 12		D	0.5	1
Unknown 12		D	0.5	1
Unknown 12		D	0.5	1
Unknown 12		A	10	1
Unknown 12		D	4.5	1
Unknown 12		A	23.5	0
Unknown 12		D	15	1
Unknown 12	7	D	0.5	1
Unknown 12		P	29	1
Unknown 12		P	4	1
Unknown 12		D	11	1
Unknown 12		D	3.5	1
Unknown 12		P	5.5	1
Unknown 12		D	3	1
Unknown 12		D	5	1
Unknown 12		D	4.5	1
Unknown 12	8	P	23.5	1
Unknown 12		P	7	1
Unknown 12		P	37	1
Unknown 12		P	9	1
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Unknown 13		D	21.5	1
Unknown 13		D	24	1
Unknown 13		P	12	1
Unknown 13		D	4	1
Unknown 13		D	33	1
Unknown 13	2	D	1	1

Unknown 13		P	48	1
Unknown 13		D	0.5	1
Unknown 13		D	9	1
Unknown 13		D	11.5	1
Unknown 13		D	3	1
Unknown 13		P	11	1
Unknown 13		P	16	1
Unknown 13		D	2.5	1
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Unknown 13		P	28	1
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Unknown 13	3	D	1	1
Unknown 13		D	2.5	1
Unknown 13		P	23	1
Unknown 13		P	27	1
Unknown 13		D	2.5	1
Unknown 13	4	D	24	1
Unknown 13		P	16.5	1
Unknown 13		P	12	0
Unknown 13		P	5.5	1
Unknown 13		P	6	0
Unknown 13		P	10	1
Unknown 13		P	7.5	0
Unknown 13		P	10.5	1
Unknown 13		P	17.5	1
Unknown 13		D	5	0
Unknown 13		P	18	1
Unknown 13		P	16	1
Unknown 13	5	D	27.5	1
Unknown 13		D	16.5	0
Unknown 13		D	9.5	0
Unknown 13		D	15.5	1
Unknown 13		D	24.5	1
Unknown 13		D	23	1
Unknown 13	6	D	10.5	1
Unknown 13		D	26	1
Unknown 13		D	17	1
Unknown 13		D	8	0
Unknown 13		D	12	0
Unknown 13		D	3	0
Unknown 13		D	22.5	1
Unknown 13		D	10.5	0
Unknown 13		D	25	1
Unknown 13		P	15	0
Unknown 13		D	19	1
Unknown 13		P	10	1
Unknown 13		D	3	1
Unknown 13	7	D	0.5	1
Unknown 13		D	0.5	1
Unknown 13		P	0.5	1
Unknown 13		P	14	0
Unknown 13		P	3	1
Unknown 13		P	3.5	1
Unknown 13	8	P	14.5	1
Unknown 13		D	7	1
Unknown 13		D	6	1
Unknown 13		P	3	1
Unknown 13		D	2	1
Unknown 13		P	43	1
RED	1	D	12.5	1
RED		D	17	1
RED		D	46	1
RED		P	7	1
RED	2	P	19	1
RED		P	11.5	1
RED		P	11	1
RED		P	14	1
RED		P	19.5	1
RED	3	P	20	1
RED		D	5	1
RED		D	26	1
RED		P	7	1
RED	4	P	23.5	1
RED		P	24.5	1
RED		P	25	1
RED		P	15	1
RED		P	9	1
RED		P	8	1
RED		P	21	1
RED		P	12	1
RED		P	21	1
RED		P	23.5	1
RED	5	P	9	1
RED	6	P	26	1
RED		P	9	1
RED		P	5.5	1
RED		P	18.5	1
RED	7	P	13	1
RED		P	17.5	1

RED		P	19	1
RED	8	P	15.5	1
RED		P	27	1
RED		D	52	1
RED		D	24	1
RED		D	19	1
RED		P	11	1
RED		D	21	1

Raw data for control sites:

SITE - CONTROL	CROSS CUT #	TREE TYPE	DIAMETER (Cm)	ALIVE?
AAA	1	P	20.25	1
AAA		D	23.49	1
AAA		D	14.58	1
AAA		D	11.34	1
AAA		D	6.48	1
AAA		P	25.92	1
AAA		P	19.44	1
AAA		P	37.26	1
AAA		D	1.215	1
AAA		D	1.62	1
AAA		D	9.72	1
AAA		P	21.87	1
AAA		P	4.455	1
AAA		D	14.985	1
AAA	2	D	23.895	1
AAA		P	8.91	1
AAA		P	29.16	1
AAA		D	21.06	1
AAA		D	10.935	1
AAA		P	12.96	1
AAA		P	4.455	1
AAA		D	0.81	1
AAA		D	0.405	1
AAA		D	0.405	1
AAA		D	1.215	1
AAA	3	P	36.45	1
AAA		D	21.87	1
AAA		P	10.935	1
AAA		P	26.73	1
AAA		P	15.795	1
AAA		P	14.175	1
AAA		P	12.555	1
AAA		P	14.58	1
AAA		P	20.25	1
AAA		D	17.82	1
AAA		D	25.515	1
AAA		P	9.315	1
AAA		P	7.29	1
AAA		P	19.845	1
AAA		P	17.82	1
AAA		P	22.68	1
AAA	4	P	14.985	1
AAA		P	11.34	1
AAA		P	23.895	1
AAA		P	18.63	1
AAA		D	12.96	1
AAA		P	14.175	1
AAA		P	12.96	1
AAA		P	14.985	1
AAA		P	7.29	1
AAA		P	12.15	1
AAA		D	0.81	1
AAA	5	D	16.2	1
AAA		P	30.375	1
AAA		D	1.62	1
AAA		D	0.6075	1
AAA		D	8.1	1
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AAA		P	18.63	1
AAA		P	2.43	1
AAA		P	13.77	1
AAA		P	8.1	1
AAA		P	2.43	1
AAA		P	10.125	1
AAA		P	18.63	1
AAA		D	0.81	1
AAA		D	0.81	1
AAA		P	12.96	1
AAA		P	12.15	1
AAA		P	12.96	1

AAA	7	D	12.15	1
AAA		D	5.67	1
AAA		P	12.96	1
AAA		P	14.58	1
AAA		P	9.72	1
AAA		P	8.1	1
AAA		P	7.695	1
AAA		P	8.1	1
AAA		D	6.885	1
AAA		D	4.05	1
AAA		D	16.2	1
AAA		D	8.91	1
AAA		P	17.82	1
AAA		D	8.91	1
AAA		P	16.2	1
AAA		P	11.34	1
AAA		A	1.62	1
AAA		A	7.695	1
AAA	8	D	3.645	1
AAA		P	9.315	1
AAA		D	17.82	1
AAA		D	1.62	0
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AAA		P	9.72	1
AAA		P	6.075	1
AAA		P	6.48	1
AAA		D	19.845	1
AAA		D	29.16	1
AAA		P	23.49	1
AAA		P	9.72	1
AAA		P	7.29	1
BBB	1	D	14.175	1
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BBB		D	34.83	1
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BBB	2	D	13.77	1
BBB		D	19.845	1
BBB		D	17.01	1
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BBB		D	25.11	1
BBB		D	23.49	1
BBB		D	19.44	1
BBB		D	21.87	1
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BBB		D	8.91	0
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BBB		D	19.44	1
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BBB		D	16.605	1
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BBB		D	19.44	1
BBB		P	36.45	1
BBB		D	21.87	0
BBB		D	23.49	1
BBB	5	D	17.82	1
BBB		D	12.96	1
BBB		D	17.01	1
BBB		D	25.92	1
BBB	6	D	8.1	1
BBB		D	24.705	1
BBB		D	8.505	1
BBB		P	9.72	1
BBB		P	6.075	1
BBB		D	6.48	1
BBB		D	14.58	1
BBB	7	D	12.96	1
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BBB		D	29.97	1
BBB		D	22.68	1
BBB	8	D	12.96	1
BBB		D	4.455	0
BBB		D	12.96	1
BBB		D	6.48	0
BBB		P	10.935	1
CCC	1	D	12.15	1
CCC		P	3.24	1
CCC		D	23.085	1
CCC		D	42.12	1
CCC		D	29.16	1
CCC		D	55.08	1
CCC		P	0.405	1
CCC		D	0.81	1
CCC		D	0.405	1

CCC		D	0.405	1
CCC	2	D	1.215	1
CCC		P	3.645	1
CCC		D	17.82	0
CCC		D	23.49	1
CCC		D	15.795	1
CCC		D	7.695	1
CCC	3	D	14.175	1
CCC		D	34.83	1
CCC		D	10.125	1
CCC		D	25.515	1
CCC		D	10.125	1
CCC	4	D	11.34	1
CCC		D	11.34	1
CCC		D	14.175	1
CCC		D	12.15	1
CCC		D	6.885	1
CCC		D	14.175	1
CCC		D	8.505	1
CCC		D	8.1	0
CCC		P	17.82	1
CCC		D	17.01	1
CCC		P	25.515	1
CCC	5	D	17.82	1
CCC		D	29.16	1
CCC		D	24.3	1
CCC		D	6.885	0
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CCC	6	D	14.985	1
CCC		D	53.46	1
CCC		D	22.275	1
CCC		D	30.375	1
CCC		D	21.06	1
CCC	7	P	14.58	1
CCC		D	11.34	1
CCC		D	20.25	1
CCC		D	11.745	1
CCC		P	21.06	1
CCC		D	19.44	1
CCC		P	4.86	1
CCC		D	18.225	1
CCC		P	8.91	1
CCC	8	D	5.265	0
CCC		D	16.2	1
CCC		D	7.29	1
CCC		D	2.43	1
CCC		D	2.025	1
CCC		D	3.24	1
CCC		D	12.15	1
CCC		P	33.21	1
DDD	1	D	19.5	1
DDD		D	20.5	1
DDD		D	8.25	1
DDD		D	9	1
DDD		D	8	1
DDD		D	15	1
DDD		D	15.5	1
DDD		D	16.5	1
DDD		D	6	1
DDD		D	45	1
DDD		D	19	1
DDD	2	D	16.5	1
DDD		D	25	1
DDD		D	11	1
DDD		D	12.5	1
DDD		D	10	1
DDD		D	19.5	1
DDD	3	D	24	1
DDD		D	23	1
DDD		D	23.5	1
DDD		D	15	1
DDD		D	21	1
DDD		D	24.5	1
DDD	4	D	21	1
DDD		D	7.5	0
DDD		D	7.5	0
DDD		D	21	1
DDD		D	31	1
DDD		D	8	0
DDD		P	25.5	1
DDD		D	10	1
DDD	5	D	20.5	1
DDD		D	17	1
DDD		D	26.5	1
DDD		D	22	1
DDD		D	14.5	1
DDD		D	27	1
DDD		D	24	1
DDD	6	D	27	1

DDD		D	34	1
DDD		D	27.5	1
DDD	7	D	19.5	1
DDD		D	16	1
DDD		D	16	1
DDD		D	15.5	1
DDD		D	19.5	1
DDD		D	13	1
DDD		D	17.5	1
DDD		D	26	1
DDD	8	D	14	1
DDD		D	10	1
DDD		D	10.5	1
DDD		D	15	1
DDD		D	11.5	1
DDD		D	8	1
DDD		D	33.5	1
EEE	1	P	15	1
EEE		D	20.5	1
EEE		D	2.5	1
EEE		D	2	1
EEE	2	D	12.5	1
EEE		D	20.5	1
EEE		P	23	1
EEE	3	D	14.5	1
EEE		D	10	1
EEE		D	17	1
EEE		D	35	1
EEE		P	29.5	1
EEE		D	16.5	1
EEE	4	D	24.5	1
EEE		D	23.5	1
EEE		P	22	1
EEE		D	29	1
EEE		D	27	1
EEE		D	26	1
EEE		D	20	1
EEE		D	17	1
EEE	5	D	26.5	1
EEE		J	9.5	1
EEE		D	8	1
EEE		D	20	1
EEE		D	3	0
EEE		D	21	1
EEE		D	4	1
EEE		D	19	1
EEE	6	P	23.5	1
EEE		P	18	1
EEE		D	6.5	1
EEE		D	23	1
EEE		P	31.5	1
EEE		D	32	1
EEE		D	6	1
EEE		D	11	1
EEE		D	20.5	1
EEE		D	12	0
EEE	7	J	7	1
EEE		D	19	1
EEE	8	D	29	1
EEE		D	15	1
EEE		D	9	1
EEE		D	23.5	1
EEE		D	19	1
FFF	1	P	33.5	1
FFF		P	32	1
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FFF		P	34	1
FFF		P	24	1
FFF		P	9	1
FFF		P	28.5	1
FFF		P	33.5	1
FFF	2	P	22	1
FFF		P	22	1
FFF		P	10	1
FFF		D	0.5	1
FFF		P	26	1
FFF	3	P	21.5	1
FFF		P	17.5	1
FFF		P	22	1
FFF		P	6	1
FFF		P	19	1
FFF		P	15	1
FFF		P	11	1
FFF		P	19	1
FFF	4	P	26	1

FFF		P	16	1
FFF		P	23	1
FFF		P	10.5	1
FFF		P	11	1
FFF		P	10	1
FFF		P	20	1
FFF		P	26	1
FFF		P	16.5	1
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FFF		D	61.5	1
FFF		P	28.5	1
FFF	6	P	36.5	1
FFF		P	12.5	1
FFF		P	34.5	1
FFF		P	25	1
FFF		P	6.5	1
FFF		P	7	1
FFF		P	16.5	1
FFF	7	P	12	1
FFF		P	24	1
FFF		P	6	1
FFF		P	24	1
FFF		P	24.5	1
FFF		P	28	1
FFF		P	23	1
FFF	8	D	13	1
FFF		P	40	1
FFF		P	3.5	1
FFF		D	2.5	1
GGG	1	P	20	1
GGG		P	23	1
GGG		P	19.5	1
GGG		P	2	1
GGG		P	26.5	1
GGG	2	P	8.5	1
GGG		D	27	1
GGG		P	30.5	1
GGG		P	45.5	1
GGG		P	37.5	1
GGG	3	D	4	1
GGG		P	20.5	0
GGG		P	23.5	1
GGG		P	28	1
GGG		P	3.5	1
GGG	4	P	1	1
GGG		P	15	1
GGG		P	0.5	1
GGG		P	25.5	1
GGG		P	24.5	1
GGG		P	21	1
GGG		P	0.5	1
GGG		P	35	1
GGG	5	J	7	1
GGG		J	25	1
GGG		J	12	1
GGG		J	6	1
GGG		P	13	1
GGG		J	13.5	1
GGG		J	19	1
GGG		P	22.5	1
GGG		P	21	1
GGG		P	31	1
GGG	6	P	29.5	1
GGG		P	25.5	1
GGG		P	27	1
GGG		P	14	1
GGG		P	19	1
GGG		P	15	1
GGG		D	21.5	1
GGG		P	17	1
GGG		P	21	1
GGG	7	P	36.5	1
GGG		P	20	1
GGG		P	36.5	1
GGG		P	0.5	1
GGG		D	17.5	1
GGG		P	12	1
GGG		P	26	1
GGG		P	12	1
GGG		P	23	1
GGG	8	P	8.5	1
GGG		P	19	1
GGG		P	1	1
GGG		P	27	1
GGG		P	19.5	1
GGG		P	43	1
GGG		P	19	1

HHH	1	D	8.5	1
HHH		D	0.5	1
HHH		D	10	1
HHH		P	21	1
HHH	2	D	23	1
HHH		P	26	1
HHH		P	38	1
HHH		P	17.5	1
HHH		P	46	1
HHH		P	11	1
HHH		P	39	1
HHH		P	43.5	1
HHH	3	P	10.5	1
HHH		P	11	1
HHH		P	8.5	1
HHH		P	2	1
HHH		D	0.5	1
HHH		P	16	1
HHH		D	5	1
HHH		D	2	1
HHH		P	35	1
HHH		P	2.5	1
HHH		P	28.5	1
HHH		P	9.5	1
HHH		P	25.5	1
HHH		P	19	1
HHH		P	10.5	1
HHH	4	P	2.5	1
HHH		D	7	1
HHH		D	31	1
HHH		P	7	1
HHH	5	P	17.5	1
HHH		P	7	1
HHH		D	0.5	1
HHH		D	4	1
HHH		D	0.5	1
HHH		P	11.5	1
HHH	6	D	6	1
HHH		P	4.5	1
HHH		P	11.5	1
HHH		P	15.5	1
HHH		D	0.5	1
HHH		P	24.5	1
HHH		P	21	1
HHH		P	27	1
HHH		D	6.5	1
HHH		P	8.5	1
HHH		P	19	1
HHH	7	P	21.5	1
HHH		P	11	1
HHH		P	16	1
HHH		P	1.5	1
HHH		P	4.5	1
HHH	8	P	11.5	1
HHH		P	3	1
HHH		P	11.5	1
HHH		P	16.5	1
HHH		D	44.5	1
HHH		P	7.5	1
III	1	P	26.5	1
III		P	40	1
III		P	11	1
III		P	31	1
III	2	P	13	1
III		P	39	1
III		P	19	1
III		P	22	1
III		P	36	1
III		P	38	1
III	3	P	48.5	1
III		D	5	1
III		P	33.5	1
III		P	13	1
III		P	7.5	1
III		D	9.5	1
III		D	10	1
III		D	9.5	1
III		P	37	1
III		D	46	1
III		P	36.5	1
III	4	P	19	1
III		P	21.5	1
III		P	10.5	1
III		D	13.5	1
III		P	17	1
III	5	P	27.5	1
III		D	6	1
III		P	35	1
III		P	26	1

III		P	9	1
III		P	13	1
III	6	D	16.5	1
III		P	38	1
III		P	28	1
III		P	30	1
III		P	20	1
III		P	32	1
III		P	38	1
III	7	P	28.5	1
III		P	40	1
III		P	32.5	1
III		P	38.5	1
III	8	P	36	1
III		P	33	1
III		P	31.5	1
III		P	18.5	1
III		P	25.5	1
III		P	20.5	1
III		P	30.5	1
III		P	28	1
JJJ	1	P	24	1
JJJ		P	26	1
JJJ	2	P	25	1
JJJ		P	25	1
JJJ		P	13	1
JJJ	3	P	24	1
JJJ		P	26	1
JJJ	4	P	16	1
JJJ	5			
JJJ	6	P	26.5	1
JJJ		P	38	1
JJJ		P	29	1
JJJ	7	P	24.5	1
JJJ		P	20	1
JJJ		P	25	1
JJJ	8	P	31	1
JJJ		P	37.5	1
JJJ		P	43	1
KKK	1	P	11	1
KKK		P	34.5	1
KKK		P	21.5	1
KKK		P	38.5	1
KKK	2	P	48	1
KKK		P	30.5	1
KKK		P	24	1
KKK		P	29.5	1
KKK		P	25	1
KKK		P	25.5	1
KKK	3	P	22	1
KKK	4	P	14.5	1
KKK		P	16	1
KKK		P	19.5	1
KKK	5	P	16.5	1
KKK		P	10	1
KKK		P	13	1
KKK		P	37	1
KKK	6	P	20	1
KKK		P	28.5	1
KKK		P	22.5	1
KKK	7	P	28	1
KKK		P	7.5	1
KKK			37	1
KKK	8	P	18	1
KKK		P	12	1
KKK		P	24.5	1
KKK		P	10.5	1
KKK		P	17	1
KKK		P	8.5	1
KKK		P	7	1
KKK		P	17.5	1
KKK		P	31	1
KKK		P	40.5	1
LLL	1	P	38.5	1
LLL		P	26.5	1
LLL		P	42.5	1
LLL		P	12	1
LLL		P	19	1
LLL		P	20	1
LLL		P	13	1
LLL		P	23.5	1
LLL	2	P	32.5	1
LLL	3	P	26.5	1
LLL	4	P	31.5	1
LLL	5	P	16.5	1
LLL		P	32	1
LLL		P	24	1

LLL	6	P	25.5	1
LLL		P	30	1
LLL	7	P	34	1
LLL		P	32	1
LLL	8	P	35.5	1
MMM	1	P	44.5	1
MMM		P	41.5	1
MMM	2	P	7	1
MMM		P	21	1
MMM		P	27	1
MMM		P	22	1
MMM		P	15	1
MMM	3	P	52.5	1
MMM		P	18	1
MMM		P	42.5	1
MMM		P	29	1
MMM		P	26	1
MMM	4	P	22.5	1
MMM		P	16	1
MMM		P	17	1
MMM		P	16.5	1
MMM		P	30.5	1
MMM		P	21	1
MMM	5	P	29.5	1
MMM	6	P	25.5	1
MMM		P	30.5	1
MMM		P	48	1
MMM		P	20	1
MMM	7	P	24.5	1
MMM		P	18	1
MMM		P	29.5	1
MMM	8	P	36	1
MMM		P	34	1
MMM		P	27	1

Appendix B

Code used to run analysis of variance model:

```
#define the variables we are working with
x1 <-  Site   #location
x2 <-  Mine   #mine effect
x3 <-  Tree   #tree type
x4 <-  Alive  #alive
y <- Diameter   #response variable

#we need a model with all predictor variables x1, x2, x3, and x4 and the potential interactions among pairs of variables
library(MASS)  #this is a library that does some statistics
fit <- aov(y~x1+x2+x3+x4+x1*x2+x1*x3+x1*x4+x2*x3+x2*x4+x3*x4)  #this is the analysis of variance model

#use an approach that finds the best model (i.e. which variables are important)
step <- stepAIC(fit, direction="both")
step$anova #display results

final_model1 <- aov(y~x1+x3+x4)
summary(final_model1)
```