THESIS

SPATIAL COMPONENT FOR THE DECISION SUPPORT SYSTEMS OF COLORADO'S FOREST PRODUCTS INDUSTRY — INDUSTRY CLUSTER ANALYSIS ON SAWMILLS IN NORTHERN COLORADO

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ABSTRACT

SPATIAL COMPONENT FOR THE DECISION SUPPORT SYSTEMS OF COLORADO'S FOREST PRODUCTS INDUSTRY — INDUSTRY CLUSTER ANALYSIS ON SAWMILLS IN NORTHERN COLORADO

The Colorado State Forest Service (CSFS) has received numerous requests for a resource that provides a consolidated, up-to-date spatial representation of facilities and contractors associated with Colorado's forest products industry (CFPI). The overall purpose of this project was to provide methods for creating the spatial component to be used in the decision support systems (DSS) of CFPI. The spatial component provides visual aids and decision-making assistance in order to locate potential biomass sources, plan future forest management, estimate transportation costs, understand the accessibility of a potential treatment site, understand which processing facilities are located in closest proximity to treatment sites to maximize efficiency, find prime facility candidates for woody biomass conversion and more. The first part of this study provides methods for obtaining the necessary data and creating a series of maps to be used in the tool. State-wide trends and relationships discovered by combining various map layers are discussed. The second part of the study demonstrates the potential and utility of the decision-making tool by performing an industry cluster analysis that investigated spatial interactions of sawmills and their feedstock in northern Colorado. Variables included in the industry cluster analysis were: sawmill capacity (annual production volume in board feet), species being processed, feedstock ownership origin, distance to recent forest management activities and competition (number of sawmills occurring within a 50-mile radius of a sawmill). The analysis

attempted to discover any significant relationships between these independent variables and working distance (distance sawmills are willing to travel for log procurement), the dependent variable. Information was collected through spatial analysis using the mapping tool in addition to telephone or in-person interviews with sawmills in the industry cluster area.

All sawmills in the industry cluster analysis region were contacted and 12 responded to the interviews, representing over 90% of the sawmill capacity in the cluster analysis region. Two significant relationships were found, though R-squared values were around 50%, indicating weak correlations. A statistically significant relationship was found between maximum working distance and annual production volume. Another significant relationship was found between annual production volume and the number of sawmills occurring within a 50-mile radius (competition). No significant relationships were found between working distance and proximity to treatments, feedstock origin, species being processed or competition.

The tool was valuable for collecting spatial information such as proximity to recent forest management sites and the number of sawmills that occur within a 50-mile radius. The industry cluster analysis provided insight for general trends of sawmills in northern Colorado and helped to recognize where further research is needed. Additionally, the data collected in the study contributes in the effort to collect sawmill data state-wide.

Mapping Colorado’s forest products facilities and contractors using ArcGIS software proved to be a very useful way to visualize the data and discover meaningful relationships that can be used in the decision support systems of Colorado’s forest products industry. This tool provides aid as forest management becomes more complex with insistent factors like wildfire, insects and disease, product availability in the market and wood biomass utilization. It provides a resource for a diverse set of stakeholders with many different DSS objectives including sustainability, future forest management, identifying industry hotspots and biomass availability.

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1. INTRODUCTION

1.1. General Overview

Personal insights from past knowledge and experience can be important in decision-making; however, spatial representations serve as very useful tools to strengthen and support this process. The term "decision support system" (DSS) is used commonly when referring to situations such as these, where information generated by computer software systems is used in conjunction with the decision maker's intuitions to come to a conclusion (Varma et al., 2000). The final verdict is left to the decision-maker, though spatial aids play a large role in the process.

Geographic information system-based software (GIS) has become a conventional tool used in the DSS of numerous disciplines. Because of the multifaceted nature of forest management and forest products industries, multiple-criteria decision-making (MCDM) is innate, and GIS is particularly useful in capturing and comparing numerous influential variables, being economic, social and ecological (Varma et al., 2000; Pereira and Duckstein, 1993). GIS allows for a broader perspective, better visual representations, multi-criteria analyses, side-by-side comparisons, prioritizing and revealing relationships otherwise unseen.

The overall purpose of this project was to provide methods for creating the spatial component to be used in the DSS of Colorado's forest products industry. The spatial component provides visual aids and decision-making assistance in order to locate potential biomass sources, plan future forest management, estimate transportation costs, understand the accessibility of a potential treatment site, understand which processing facilities are located in closest proximity to treatment sites to maximize efficiency, find prime facility candidates for woody biomass conversion and more. The first part of this study focused on methods for obtaining the necessary data and creating a series of maps to be used as a universal decision-making tool. State-wide trends and relationships discovered by combining various map layers are discussed.

The second part of the study focused on demonstrating the potential and utility of the decision-making tool by performing an industry cluster analysis to take a closer look at spatial interactions of sawmills and their feedstock in northern Colorado. Feedstock characteristics greatly influence the forest products industry. Location, accessibility, species type, health and ownership are all characteristics that play a large role for agencies, processing facilities, contractors and biomass users. The cluster analysis looked particularly at the proximity of feedstock to processing facilities as it is a key bidding factor and overall influential factor for treatment cost and efficiency (Lynch and Mackes, 2003; Lynch, 2001).

1.2. Background

The inspiration to create a decision-making tool for Colorado's forest products industry resulted out of necessity for an updated, consolidated and accessible spatial data source. CSFS has received numerous requests for a resource that provides the spatial distribution of wood processing facilities throughout Colorado. The project was initiated in response to these requests, in addition to the need in the forest products industry for a collected, up-to-date spatial tool that shows detailed wood processing facility interactions. This chapter outlines important background information impacting Colorado's wood products industry that further justifies the need for this mapping resource.

1.2.1. Timberland and Land Ownership

Colorado has approximately 24.4 million acres of forest and woodland, the majority of which occurs in the western half of the state paralleling the Rocky Mountains. The National Gap

Analysis Program (GAP) Data Portal (2011) provided Colorado land cover data, as shown in Figure 1.1.

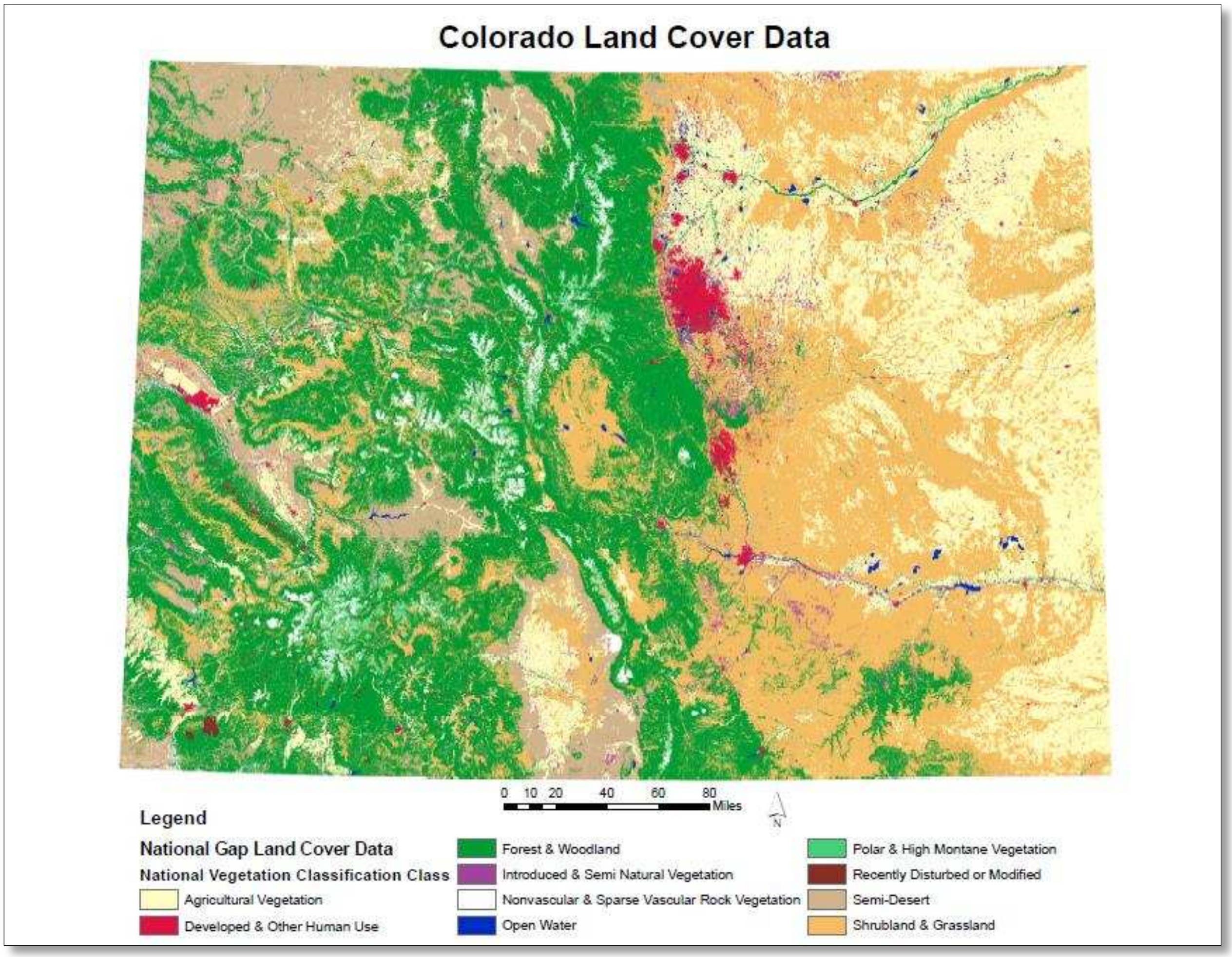

Figure 1.1. Colorado's National Gap Landcover Data by national vegetation classification class.

Pinon-juniper (*Pinus edulis*, *Juniperus scopulorum* and *Juniperus monosperma*) and aspen (*Populus tremuloides*) forests make up about 40% of Colorado's woodlands. The top timber-producing forest types, spruce-fir (*Picea engelmannii* and *Abies lasiocarpa*), ponderosa pine (*Pinus ponderosa*) and lodgepole pine (*Pinus contorta*), make up about 35% (Sorenson et al., 2012). The CSFS (2010) has compiled a list of forest acreage types for the state of Colorado, as shown in Table 1.1.

Table 1.1.
Colorado's forest acreage by type, reproduced from the 2010 Colorado State Forest Service's Statewide Forest Resource Assessment.

Forest Type	Acres
Pinon-Juniper	5,177,926
Aspen	5,065,277
Spruce-fir	4,571,066
Ponderosa pine	2,527,660
Oak Shrubland	2,365,998
Lodgepole pine	1,662,750
Montane Riparian	934,666
Plains Riparian	246,493
Introduced Riparian Vegetation	116,899
Total	24,452,476

According to the University of Montana's Four Corners Timber Harvest report (Sorenson et al., 2012), approximately half of Colorado's entire timber harvest consisted of lodgepole pine. This species was mainly used for sawlogs, posts, poles, fiber and fuelwood. Spruce followed as the second top producer at 19% of the entire harvest. It was used for mainly sawlogs and house logs. Ponderosa pine made up about 13% of the harvest and was used mainly for sawlogs but also for furniture, fiber and fuelwood (Sorenson et al., 2012).

Land ownership across Colorado is a discontinuous matrix of public and private land of various proportions. Land ownership data for Colorado was obtained from the COMaP dataset (Lavender et al., 2011), shown in Figure 1.2. Items in the legend of Figure 1.2 include United States Forest Service (USFS), Private (PRI), State (STA), Bureau of Land Management (BLM), National Park Service (NPS), Bureau of Indian Affairs (BIA), Bureau of Reclamation (BOR), Department of Defense (DOD), Municipalities (Local), United States Forest Service Land Utilization (USFS_LU), United States Forest Service National Grassland (USFS_NG) and United States Fish and Wildlife Service (USFW).

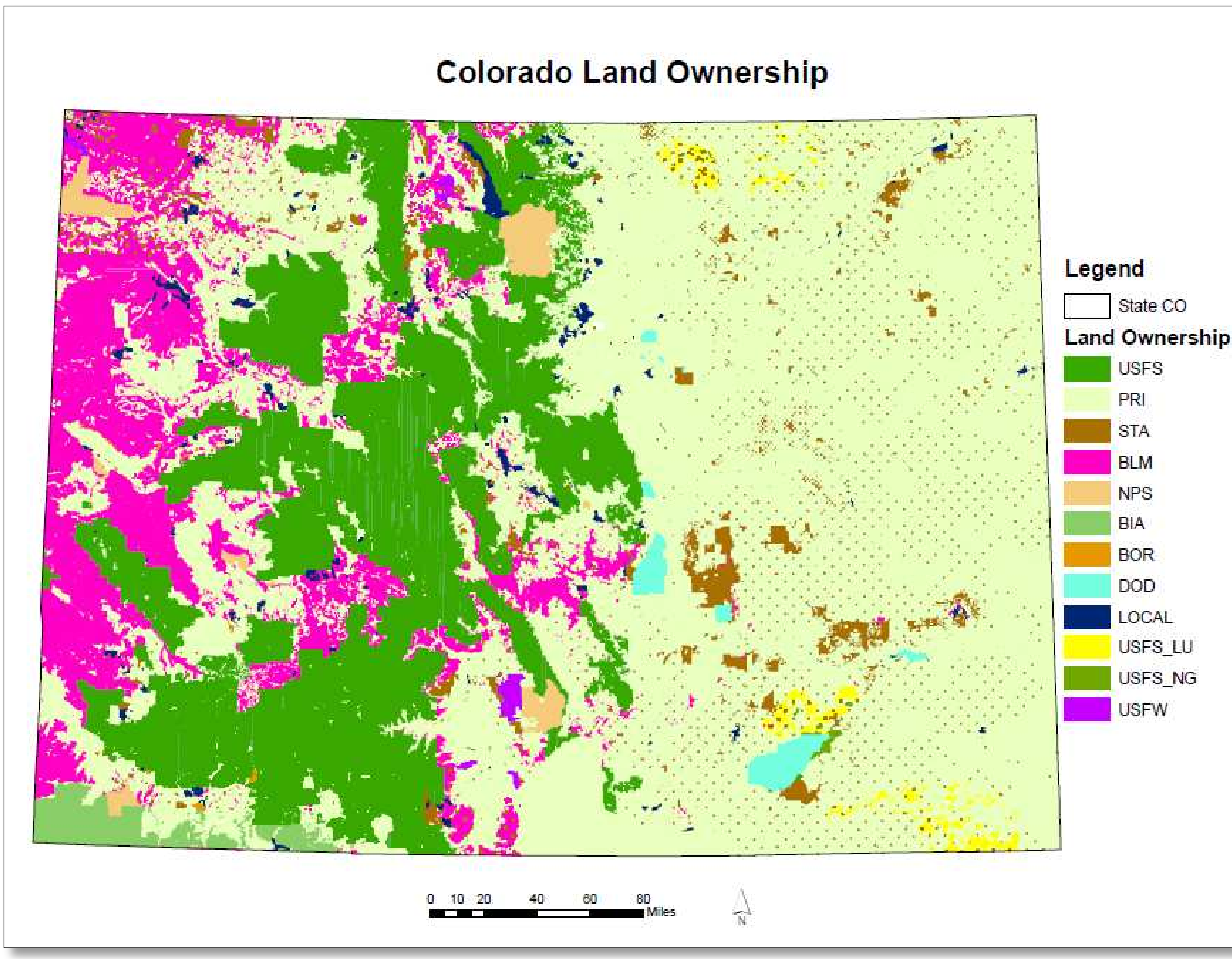

Figure 1.2. Map of Colorado's Land Ownership by Agency.

The largest percentage of Colorado's forested land is federally owned at nearly 70%. The other 30% is owned by numerous state agencies, tribal governments, private landowners and other non-federal personnel (CSFS, 2010). Two thirds of the entire 2012 harvest originated from national forests (Sorenson et al., 2012). For this reason, the wood products industry is greatly dependent upon the management plans and actions set forth by these agencies. Additionally, fragmentation due to ownership inconsistency creates barriers for much needed large-scale forest health objectives such as state-wide fuels reduction and beetle-kill mitigation.

1.2.2. Forest Health Concerns

Wildfire, pests and diseases were highlighted as forefront concerns in CSFS's annual report on Colorado's forest health (2015). Fire conditions in Colorado became more severe around the turn of the 21st century. During this time, devastating fires burned hundreds of thousands of acres and caused millions of dollars in losses, many of which occurred on federal lands. Years of successful suppression, increased fuel loading, prolonged drought conditions and the development of the wildland-urban interface (WUI) attribute to Colorado's heightened wildfire risk (Calkin et al., 2005).

Conditions and losses have worsened with time. On record, 2012 was a particularly bad fire year. There were a total of 1,498 fires and 246,445 acres that burned, a high percentage of which occurred on forested land (NIFC, 2015). The Waldo Canyon fire and the High Park fire were the most notorious fires of 2012. Colorado continues to be at risk of severe wildfires. In 2013 the Black Forest Fire burned over 14,000 acres in El Paso County. Four hundred and eighty nine homes were destroyed and two lives lost (El Paso County, Colorado Sheriff's Office, 2014). The total cost associated with this fire was estimated at over $500 million (Mackes, 2014). Wildland firefighting currently consumes over 50% of the entire Forest Service budget. As a result, other responsibilities have been neglected, one being preventative fuels reduction (USDA, 2015).

Lynch (2000) shed some light on the costs and benefits of prevention treatments with a study focused in southwestern Colorado. By comparing the costs and profits acquired from the restoration treatments of five different project sites in the southwest to what was spent just on fire suppression in that area, he was able to show that restoration treatments are economically and ecologically advantageous. The Disappointment fire occurring in Dolores, Colorado in 1996 cost $992,000 to suppress, approximately two to three times more than what it cost to perform restoration treatments on similar units in the area. Furthermore, the treated areas retained large, healthy trees and were considered esthetically pleasing and ecologically healthy. The burned area lost tree cover, wildlife habitat, esthetics and required additional treatment to replant and prevent erosion (Lynch, 2000).

In response to several bad fire years there has been a surge in national, state-wide and community-level initiatives working to reduce wildfire risk. The National Fire Plan was developed in 2000 to provide national support in reducing wildfire risk at the community level and to ensure that there are appropriate firefighting efforts for the future (US Department of the Interior and USDA Forest Service, 2002). The Healthy Forests Restoration Act (HFRA) was passed in 2003 which initiated several community-based programs that worked to decrease fire risk specifically in the wildland urban interface (WUI). Mandated under the Forestry Title of the 2008 Farm Bill, the Forest Action Plan was created by CSFS in collaboration with the National Association of State Foresters (NASF) with the overall purpose of protecting Colorado’s forests. This program works to educate and provide support to landowners and communities promoting fire-adapted communities through forest management.

Other programs have ensued in Colorado, such as the Front Range Fuels Treatment Partnership (FRFTP). The FRFTP was initiated in 2002 for the purpose of reducing wildfire risk by performing sustained fuels treatments throughout the 10 Colorado Front Range counties: Boulder, Clear Creek, Douglas, El Paso, Gilpin, Grand, Jefferson, Larimer, Park and Teller. CSFS, the National Park Service (NPS), the Rocky Mountain Research Station and the United States Department of Agriculture Forest Service (USDA FS) are some of the agencies associated with this partnership (FRFTPR, 2006). They initially estimated 1.5 million acres in need of treatment within the Front Range region (Addington et al., 2014). Approximately 292,000 acres have been treated as of 2012 (FRFTP, 2012).

The massive amount of forested land that has been affected by pests and diseases intensifies the already severe wildfire conditions across the state. For the case of pine beetle infestations in Colorado, wildfire behavior is expected to be the most severe in areas that have not been treated (Collins et al., 2011). The mountain pine beetle (MPB), or *Dendroctonus ponderosae*, has been one of the most detrimental pests to infect Colorado’s forests. Since 1996 approximately 3.4 million acres have been affected across the state. Only 15,000 additional acres were added in 2015, which is the lowest level since its outbreak, though overall impact on Colorado’s forests remains significant (CSFS, 2015). The MPB is partial to two of the top timber-producing species in Colorado; lodgepole pine and ponderosa pine (CSFS, 2015; Sorenson et al., 2012).

The spruce beetle (*Dendroctonus rufipennis*) has affected 1.5 million acres of Engelmann spruce, Colorado’s second top timber-producing species. Other detrimental pests getting increasingly worse over the last few years are the western spruce budworm (*Choristoneura freemani*), the Douglas-fir tussock moth (*Dendroctonus pseudotsugae*) and the emerald ash borer

(*Agrilus planipennis*). Altogether, about 5.5 million acres have been affected thus far in Colorado (CSFS, 2015; CSFS, 2014)

1.2.3. Available Markets and Woody Biomass Utilization

A common obstacle for fuels reduction and beetle-kill mitigation is offsetting the cost of surveying, treating and transporting the materials. There must be a need in the marketplace for the material in order to make these treatments practical and profitable for agencies, contractors and processors. Removal of the infected wood to reduce wildfire risks and further infestation, on top of finding a way to make it profitable has proven to be difficult. As a result of weak timber markets in Colorado and inaccessibility, Collins et al. (2011) estimates that no more than 15% of beetle-killed forests will receive treatment.

The MPB typically targets mature pine trees as hosts. Potential products for this material were investigated by Byrne et al., (2005). While these trees can be processed for lumber, this proves difficult on the basis that dry logs tend to cause de-barkers to become less efficient and require more energy to saw causing blades to blunt faster. Checking occurs and blue stain can also degrade the lumber. Though some value loss occurs, strength and stiffness properties of wood from beetle-killed trees were not significantly affected (Forintek, 2003). An additional study was performed by Mackes and Eckhoff (2015) that investigated the utilization of beetle-killed lodgepole pine harvested in Colorado and Wyoming. They reported potential for some of these trees to be used for cut stock. Tree diameter was a greater indicator of cut stock maximization, not time standing dead. Other outlets for this material include fence posts, utility poles, decking, log home material and fuelwood (Byme et at., 2005).

Material harvested during fuels treatments is generally small diameter so potential products tend to have less value. These include posts, poles and fuelwood. Utilizing this wood for bioenergy is one potential outlet for both beetle-kill mitigation and fuels treatments. Woody biomass as a source for heat and electricity is gaining recognition nation-wide as it is a renewable, clean and carbon neutral source of energy when used properly. In 2013, the Statewide Wood Energy Team Cooperative Agreement (SWET) was established in Colorado; its main goal being to increase awareness and utilization of woody biomass as an energy source. Colorado is one of 16 wood energy teams thus far in the United States. There are currently around 12 facilities in Colorado that use biomass for heat, electricity or both.

Proximity of processing facilities to treatment location is a key indicator for project efficiency and overall costs. Six sawmills have closed down in Colorado since the year 2000 (Reader, 2010), which indicates that co-locating treatments to facilities in close proximity may prove to be challenging or impractical. Finding ways to become more efficient is crucial. Prior to spending money on pre-sale actions for timber sales or forest management activities, there is need for a tool that provides general information about where Colorado's processing facilities are located, as well as other information that will help in deciding whether a stand is likely to be managed, such as current road networks, terrain, species distribution, wildfire risk and ownership.

1.3. Project Importance

CSFS and Colorado's forest products community as a whole, has revealed the need for a consolidated, up-to-date, spatial representation of Colorado's forest products facilities to be used in DSS. This tool has the ability to be used at a very diverse scale. Federal and state forest management agencies and their associated programs can use this map as a decision support tool. Facility managers, local communities, renewable energy advocates, non-profit organizations, various stakeholders across the state, private business owners, county/city planners, development planners, those interested in feedstock and facility relationships and organizations applying for grants for fuels treatments are just a few entities that could also benefit.

The resource created in this project fills a large gap in understanding Colorado's forest products industry and offers a decision-making tool for various stakeholders. It allows these entities to analyze the distribution of Colorado's forest product facilities and how they relate to other influential variables to aid in better decision-making.

The purpose of the industry cluster analysis was to not only demonstrate the usefulness of the mapping tool, but also to expand our knowledge of Colorado sawmills using the mapping tool for spatial analysis and telephone interviews for supplementary sawmill information. The data collected in this study on northern Colorado sawmills, along with studies reporting on sawmills in other parts of the state work towards a state-wide sawmill inventory. This can be used for further research on Colorado's forest products industry or it can be used in comparison studies for looking at different parts of the state. Overall, this project provides a valuable resource to a diverse set of decision-makers across the state and elsewhere, and helps to better understand Colorado's forest products industry.

The industry cluster analysis also provides an investigation of the factors that influence a sawmill's haul or working distance. This helps to understand the factors that have the greatest impact on feedstock interactions and identify gaps in the processing chain where there is abundant feedstock but no facilities close to economically be able to process it. The gaps reveal areas where future facility placement would be ideal. Overall, this project provides a valuable resource to a diverse set of decision-makers across the state and elsewhere, and helps to better understand Colorado's forest products industry.

1.4. Project Objectives and Scope of Work

The first objective was to develop an up-to-date spatial resource that revealed the geographic footprint of Colorado's forest products facilities. This entailed obtaining basic information for wood processing facilities across the state and using this data to create a point layer in ArcMap that displays their geographic footprint. The next step was to collect associated data layers whose incorporation influenced the forest products industry in some way, aided in the process of evaluating relationships throughout data layers or helped with orientation and clarification. Examples of additional data layers include transportation systems (e.g., interstates, highways, railways), recent forest treatment locations, county boundaries, land ownership, demographics (e.g., population distribution and density), facility density, fire risk across the state and location of the wildland urban interface (WUI).

This collection of data was organized into one geodatabase and serves as the backbone of the spatial resource. In order to display information contained in the geodatabase, the next step was to over-lay various combinations of the data to illuminate existing, state-wide trends and relationships. A series of maps were constructed and used as tools for better decision-making. Procedures taken to acquire the necessary data are outlined subsequently, as well as how the data was manipulated and displayed for the final map products. The decision-making tool encompasses the total collection of data layers into one geodatabase and the final map outputs, all of which can be used as the spatial component of decision support systems.

The second objective was to demonstrate the utility of this tool by performing an industry cluster analysis on sawmills occurring in a selected set of counties in north-central Colorado: Routt, Jackson, Grand, Larimer and Boulder. The cluster analysis provides an example of how the decision-making tool can be used to better understand certain aspects of Colorado's forest products industry; in this case, investigating sawmill feedstock interactions.

Sawmills consider a multitude of factors when making decisions regarding their feedstock. Each sawmill might have different objectives, opinions or experiences that influence their decisions and can be hard to quantify. Other factors that are considered include the location of the sawmill or the species they target. The market that is available to them at the time also plays a large role in their decision-making, and conditions can rapidly change.

A sawmill's working radius, or the distance they are willing to travel for log procurement, provides insight as to which areas of the state can and cannot be practically logged or managed. When haul distance is reduced, transportation expenditures are minimized which can improve sawmill efficiency. This begs the question, are sawmills co-located to feedstock? Is there a higher density of sawmills in areas with more potential timberland so as to minimize transportation costs? What factors influence a sawmill's maximum working radius? The industry cluster analysis looked into five variables: sawmill capacity (annual production volume in board feet), species being processed, feedstock ownership origin, distance to recent forest management activities and competition (number of sawmills occurring within a 50-mile radius of a sawmill). These were the independent variables. Significant relationships were sought out between independent variables and working distance (distance sawmills are willing to travel for log procurement), the dependent variable. Information was collected through spatial analysis using layers created for the mapping tool in addition to telephone or in-person interviews with sawmills in the industry cluster region.

- Null Hypothesis 1: There is no relationship between sawmill capacity, or annual product volume, and working distance for log procurement.

- Null Hypothesis 2: There is no relationship between a sawmill’s proximity to recent forest management treatments and working distance.
- Null Hypothesis 3: There is no relationship between those whose feedstock origin is federal and working distance.
- Null Hypothesis 4: There is no relationship between the tree species being used by sawmills and working distance.
- Null Hypothesis 5: There is no relationship between the number of sawmills occurring in a fifty mile radius of a sawmill (competition) and working distance.
- Null Hypothesis 6: There is no relationship between the number of sawmills occurring in a fifty mile radius of a sawmill (competition) and annual product volume.

Further discussion of the hypotheses and associated statistical analyses is presented subsequently in Chapter 5.

2. LITERATURE REVIEW

Information required for this study has been of interest to other organizations and agencies. Certain environmental, social and economic data already exist though needs to be collected and unified into one source. This section provides a review of literature similarly using GIS to create decision-making tools. Sources of existing mapping data necessary for the creation of this tool are also reviewed.

2.1. GIS-based Decision Support Tools in Forestry

The decision-making support systems (DSS) of forest management-related entities require the incorporation of a diverse set of ecological, economic, social and temporal variables. GIS is commonly used to evaluate and assist in forestry-related MCDM systems, therefore, available research on this topic is vast. It is used at the local, state and federal level and has been widely accepted as a conventional tool in forestry.

Making its first appearances in forestry in the early 1970's, MCDM remains an important tool for forestry planning. Decision support systems become quite complex upon consideration of all associated criteria, wherein GIS can be used to store, organize, manipulate, display and analyze the many factors that influence educated decision-making. Every decision impacts other key variables. The best scenario is pursued and a compromise must be reached between economic factors such as timber and forage, environmental factors such as soil erosion and carbon sequestration and social factors such as recreation and employment (Diaz-Balteiro and Romero, 2008; Varma et al., 2000). Decision support systems have evolved through the years as issues in forest management have become greater and more complex due to factors like climate change, air quality and discontinuous land ownerships. Maintaining a balance between the complexity of DSS and its user-friendliness may prove difficult as the demand for DSS increases (Vacik and Lexer. 2013; Diaz-Balteiro and Romero, 2008).

Objectives drive the criteria that appear in each DSS. They vary greatly depending upon the individual, agency or organization in question. For example, tourism and recreation would be main criteria in a national park's DSS but would not be applicable to a private landowner. They may vary greatly in their objectives and specific criteria but each DSS goes through the same process of first defining their objectives, then organizing them by order of importance (Diaz-Balteiro and Romero, 2008; Varma et al., 2000).

Literature on the integration of GIS into forestry-related DSS is vast in European countries (Dalemans et al., 2015, Sacchelli et al., 2013; Vacik et al., 2013; Zambelli et al., 2012; Phua et al., 2005; Voivontas et al., 2001). One of the more recent developments in Europe was the creation of a specialized DSS tool, called Sim4Tree, in Flanders, Belgium (Dalemans et al., 2015). Sim4Tree is referred to as a multipurpose toolbox that allows for the comparison of different forest management scenarios and incorporates different temporal and climatic situations. The scenarios can be ranked for optimization to result in better- informed forest management decisions. The tool is fairly new and has shown little merit thus far. Nonetheless, it provides a new and different spatial technology to be incorporated into forestry DSS for use at a diverse scale.

Sustainability, though difficult to define, is an objective that holds precedence in most all forest management DSS as it is the livelihood and backbone of forest management and the forest products industry. Forest health, conservation of biodiversity, soil and water, timber production, harvesting schedules and reforestation are criteria commonly seen with a sustainability objective (Vacik et al., 2013, Diaz-Balteiro et al., 2008 and Varma et al., 2000).

An additional sustainability criterion that has rapidly gained recognition in recent years is woody biomass utilization. Spatial tools are being used more frequently to take inventory of forest biomass availability and to aid in decisions that maximize its potential for energy (Sacchelli et al., 2013, Zambelli et al., 2012, Voivontas et al., 2001). A sustainable supply of biomass is required for successful bioenergy systems, which necessitates detailed inventories of potential feedstock. GIS can be used to become more familiar and confident with feedstock supply chains (feedstock location, quantity and cost). One recent publication authored by Zambelli et al. (2012), used GIS to extract potential areas of biomass supply in the Italian Alps. Once the potential supply was located, they queried only feedstock that was considered to be suitable and accessible. This tool was designed to be incorporated with DSS of Italy's bioenergy sector for policy makers at the administrative level.

Literature specific to the United States is less common, though several articles have been released in recent years that incorporate GIS into their DSS. Phillips et al. (2006) reported their methodology and experience with implementing a DSS while doing a financial analysis of South Carolina's state forests. GIS was a main component of their DSS plan where it was used for gathering inventories, recent management activities and other relevant information into one centralized database management system. Their conclusions reported the use of a GIS-based DSS being worthwhile despite initial start-up costs and the up-keep that is required. This approach proved to be less subjective than previous methods and aided in organizing and justifying their decision-making process.

GIS has also been used in the United States for DSS with reclamation objectives such as the study of revegetating old mining lands near Butte, Montana (Hickey, R and Jankowski P. 1997) and the reforestation of old sugarcane plantations in Hawaii (Phillips et al., 1996). A more recent article by Peikielek et al. (2015) provided a perfect example of how GIS in DSS can aid in forest management planning. This article outlined the process of using GIS software in coordination with species distribution and global climate modeling software to help plan for climate change in Yellowstone National Park. With these models they anticipated future species distributions occurring at higher elevations. This kind of change has the potential to create significant complications as the new species distributions are projected to occur where active management is currently prohibited (Peikielek et al., 2015). Having this knowledge gives agencies the ability to alter management before the change happens and justify their reasoning.

2.1.1. Spatial Resources for Forestry-Related DSS in Colorado

CSFS has provided several spatial resources to aid in the state's forest management decisions. The most recent Report on the Health of Colorado's Forests (2015) provided a great deal of spatial information on things like insect and disease progression and restoration and mitigation grants throughout the state. The CSFS (2010) also published a statewide spatial resource assessment to support strategic forest management decisions across the state by showing where resources would be most intelligently allocated.

Hughes and Mackes (2006) performed a spatial analysis on the available biomass resources in Larimer County, Colorado. Information was collected from the CSFS Fort Collins District, the United States Forest Service's (USFS) Canyon Lakes Ranger District and the Rocky Mountain National Park. It was then stored in a geodatabase file and displayed using ArcGIS software to investigate feedstock availability and sustainability for potential biomass plants in Colorado.

An online spatial resource was created for the southwestern part of the state in 2015 (Licata et al., 2015). General characteristics of the sawmills, contractors and available timber in

Archuleta, Dolores, La Plata, Montezuma and San Juan counties were collected and reported on. The community feature in Google Earth was used to share spatial information about sawmills and contractors in the areas as well as information on recent agency treatments and wildfire events. The Forest Inventory Data Online (FIDO 1.5.1) website estimated nearly 2.7 million acres of combined forestland and timberland in these 5 counties, the majority of which occurred on public lands (USDA Forest Service, 2015). The conclusions were that a significant amount of available timber for the region occurred on USFS lands; therefore, timber industry success in the southwest region is heavily dependent upon USFS making their timber supply available.

2.2. Sources of Mapping Data

The overall goal of this study was to provide Colorado's forest products stakeholders and decision-makers with a spatial tool that displayed the distribution of Colorado's wood processing facilities and contractors in relation to factors such as demographics, transportation, timberland, previous forest management treatments, etc. The intended use was for this information to be used as the spatial component in the DSS of Colorado's forest products industry. An extensive search for existing data initiated the process and provided many of the layers used for the creation of this tool.

All businesses affiliated with Colorado's forest products industry or users of Colorado's forests were sought out to be incorporated into this spatial tool. This included processing facilities such as sawmills, cabinet or flooring manufacturers, firewood businesses, forestry contractors or those using woody biomass for heat or electricity. Over the past ten years, several research efforts have been released that provided spatial information concerning Colorado's forest products facilities and contractors.

The University of Montana's Bureau of Business and Economic Research (BBER) in partnership with the Interior West-Forest Inventory and Analysis (FIA) created the Forest Industries Data Collection System (FIDACS). Approximately every 5 years, FIDACS does a census of major forest products manufacturers in the 4 corner states: Arizona, Colorado, New Mexico and Utah. The 2012 Four Corners Timber Harvest and Forest Products Industry Report (Sorenson et al., 2012) is their most recent publication providing information on Colorado's forest products industry. This includes spatial information for Colorado's timber-processing and residue-utilizing facilities.

CSFS provided several valuable sources of mapping information. The Colorado Forest Products Program (CFP) collected spatial and product information from many of Colorado's wood processing facilities in 2011. The Colorado Wildfire Risk Assessment Portal (CO-WRAP) was created in 2012 in response to increasingly severe wildfire conditions in Colorado. This resource was made available by CSFS as an interactive spatial web tool (http://www.coloradowildfirerisk.com/map). The goal was to aid in wildfire preventative measures at the community and government level by providing scientific information to be used in planning. The wildfire risk factor represents both the likelihood of a fire happening as well as an area's likelihood of being most negatively affected by wildfire. A risk layer was also created for assessing the wildland-urban interface (WUI). This takes WUI housing density and combines it with flame length to show where greatest harm to homes and people is probable.

Information on Colorado's forestry contractors was collected in a study performed by Vaughn and Mackes (2015). Upon evaluation it was determined that contractor capacity is lacking, and at its current state will not be able to handle the workload required for Colorado's needed forest mitigation and fire prevention.

The University of Tennessee (UT) Center for Renewable Carbon, funded by the U.S. Endowment for Forestry and Communities Inc., produced a large database of industrial facilities that either produce a wood product or utilize the wood as a fuel source. This is referred to as the Wood2Energy database (2015). Spatial information for facilities was provided by state.

3. METHODOLOGY

3.1. Data Acquisition

3.1.1 Data Format and Study Site

Data were collected or created in a geodatabase format, which stores geographic information as well as tables organizing certain characteristics of the data called attributes. ArcInfo10.2 GIS software was used to manage, manipulate and project this data. Some were already in geodatabase format and some needed to be pooled together and translated. A projected Universal Transverse Mercator (UTM) coordinate system was used in the 1983 North American Datum (NAD), Zone 13. The state of Colorado was considered to be the study site. Certain pieces of data occurring near the state border were considered based on their potential to impact Colorado's forest products industry. For example, some sawmills in southern Wyoming used wood from Colorado's forests as their feedstock and for that reason they were included.

3.1.2. Facility Data

To provide the most comprehensive prognosis of the industry as possible, locations for all types of facilities associated with wood products were pursued. Data collection initiated with a broad search for various agencies, programs or personnel already possessing Colorado wood products facility location data that were willing to share information. CSFS's utilization and marketing forester, Tim Reader, provided valuable insight as to where this information could be found. The following sources (Table 3.1) were contacted with requests for facility information: the University of Montana's Bureau of Business and Economic Research, CSFS's Colorado Forest Products (CFP) Program, the University of Tennessee's Wood2Energy Program, CSFS's Colorado Wildfire Risk Assessment Portal (Co-Wrap) and Damon Vaughan, CSFS forester. Additional facilities were added based on internet searches and guidance provided from experienced CSFS personnel with knowledge of the industry and of chief facilities across the state. Facility data were organized into four main groups: bioenergy producers, solid wood producers, contractors and users.

Any facility using wood from Colorado's forests to produce a form of biomass that could be used directly in a cordwood boiler, wood/pellet stove or fireplace were grouped into bioenergy producers. Only businesses whose main product was firewood were included in this group. Examples of such businesses in Colorado include Confluence Energy and Renewable Fiber. Many businesses produced firewood in addition to their primary log processing, but firewood was not their primary product, therefore, they were not included here. Solid wood producers included all major processing facilities in Colorado such as sawmills, post and pole producers, log home builders as well as furniture and cabinet manufacturers. Many of these facilities also produced other products like firewood and wood chips, but not as their primary product. Forestry contractors include only those whose primary product was the service they provided (e.g., logging, mitigation or consultation services). They harvest the material but do not process it. There are several facilities that both log and mill their product for which they were considered to be solid wood producers.

The users group encompassed existing and potential facilities/businesses that use or are prime candidates for using biomass for heat, power or both. Examples of existing users in Colorado include the Boulder County Jail and the Salvation Army High Peak Camp. Potential users were grouped here based on a set of characteristics known to make them good candidates for converting their heating or power systems to biomass. Good candidates are generally large facilities that already have a centralized heating system in place, have large utility bills and are currently using a more expensive means to power and heat their building than biomass would be

(Becker and others, 2014). For example schools, hospitals, jails, or ski resort lodges. Some facility locations were provided as geographic coordinates though the majority of the data were addresses. In this case, geographic coordinates were obtained by performing an individual address search using Google Earth software.

Information from all of these resources was organized into one master Excel sheet containing facility name, geographic coordinates and, if available, information on the products they provide. Where information was not provided from the resources, it was added if available on facilities' websites, otherwise, it was left blank. Any duplicate facilities were removed. The final master Excel sheet was uploaded into ArcMap as a point layer based on facility geographic coordinates. The data was then transformed into UTM NAD83 Zone 13 to allow for better measurement capabilities. This was done by using the Projection Data management tool in ArcMap. Separate layers were created for each of the four facility categories. The collection of facility data layers were saved into one master geodatabase folder.

3.1.3. Treatment Data

A geodatabase containing agency treatment data was obtained upon request from CSFS via Pete Barry, GIS technician. This included vector polygon data layers outlining treatments performed by USFS, CSFS, BLM, and NPS. The agency treatment data sources differ and are outlined in Table 3.1. All of the data was queried using ArcMap's Extract and Select Data Analysis tool to represent only treatments providing feedstock occurring from 2010 to 2014 (or the most recent date available depending on what the agency provided). All data was re-projected into UTM NAD83 Zone 13 if not already in this format.

3.1.4. Associated Reference Data

In addition to treatment and facility data, a variety of additional data layers were collected to support or clarify relationships in the data and allow for better orientation. All of the associated reference layers were re-projected into UTM NAD83 Zone 13 and added to the tool's master geodatabase folder. The complete collection of data used in this project with the associated source information is outlined in Table 3.1.

Table 3.1.
Data theme and source information for the complete collection of data layers used in this study.

Data Theme	Data Source	Original Data Type, Structure
Bioenergy producers	1. Sorenson et al., 2012 (http://www.bber.umt.edu/) 2. CFP Database, 2011(http://csfs.colostate.edu/cowood/cfp/)	Vector, Shapefile
Solid wood producers	1. Sorenson et al., 2015 (http://www.bber.umt.edu/) 2. CFP Database, 2011 (http://csfs.colostate.edu/cowood/cfp/)	Vector, Shapefile
Current users	Wood2Energy Database, 2015 (http://www.wood2energy.org/Database%20Connection.htm)	Vector, Shapefile
Potential users (Schools and Hospitals)	CO-WRAP, 2012 (http://www.coloradowildfirerisk.com/map)	Vector, Shapefile
CSFS Treatment Data	CO-WRAP, 2012 (https://www.coloradowildfirerisk.com/map/Pro)	Vector, Shapefile
BLM Treatment Data:	Colorado Bureau of Land Management (BLM) Geospatial Data, 2014 (http://www.blm.gov/co/st/en/BLM_Programs/geographical_sciences/gis.html)	Vector, Shapefile
NPS Treatment Data:	National Park Service (NPS) Integrated Resource Management Applications, 2012 (https://irma.nps.gov/Portal)	Vector, Shapefile
UFSF Treatment Data:	USDA FSGeodata Clearinghous, 2014 (http://data.fs.usda.gov/geodata/edw/datasets.php)	Vector, Shapefile
Boundary Layers (state shape (cdot) counties)	Colorado Department of Transportation (CDOT) Online Transportation Information System (OTIS) (http://dtdapps.coloradodot.info/otis/catalog)	Vector, Shapefile
Cities	CDOT OTIS, 2014 (http://dtdapps.coloradodot.info/otis/catalog)	Vector, Shapefile
Transportation (railways, interstates, highways, local roads and Forest Service roads)	CDOT OTIS, 2014 (http://dtdapps.coloradodot.info/otis/catalog)	Vector, Shapefile
Temperature	Natural Resource Conservation Service (NRCS) Geospatial Data Gateway (GDG), 2010 (https://gdg.sc.egov.usda.gov/)	Vector, File Geodatabase Feature Class
Insect and Disease Damage	United States Department of Agriculture (USDA) Forest Service Aerial Detection Survey, 2012, 2015 (http://www.fs.usda.gov/detail/r2/forest-grasslandhealth/?cid=fsbdev3_041629)	Vector, Shapefile

Land Ownership	COMaP dataset (Lavender et al., 2011) (http://ibis.colostate.edu/WebContent/WS/Centroid/comap.html)	Vector, File Geodatabase Feature Class
Gap Landcover	National Gap Analysis Program (GAP) Data Portal (2011) (http://gapanalysis.usgs.gov/gaplandcover/data/download/)	Raster, GRID
Digital Elevation Model (DEM)	NRCS GDG, 2013 (https://gdg.sc.egov.usda.gov/)	Raster, TIFF
Urban Areas	CDOT OTIS, 2010 (http://dtdapps.coloradodot.info/otis/catalog)	Vector, File Geodatabase Feature Class
Population by County	State of Colorado's Information Marketplace; Colorado Population Projections, 2015 (https://data.colorado.gov/browse?category=Demographics&utf8=%E2%9C%93)	.XLS
Per Capita Personal Income by county	State of Colorado's Information Marketplace; Income Data for Colorado's Counties, 2014 (https://data.colorado.gov/browse?q=income%20data&sortBy=relevance&utf8=%E2%9C%93)	.XLS
Census Populated Places	U.S. Bureau of the Census, Population Estimates Program (PEP), 2015 (http://www.census.gov/popest/)	.CSV
Schools and Hospitals	CO-WRAP, 2012 (https://www.coloradowildfirerisk.com/map/Pro)	Vector, Shapefile
WUI Risk	CO-WRAP, 2012 (https://www.coloradowildfirerisk.com/map/Pro)	Raster, File Geodatabase Feature Class
Wildfire Risk	CO-WRAP, 2012 (https://www.coloradowildfirerisk.com/map/Pro)	Raster, File Geodatabase Feature Class

3.2. Layer Pairings and Map Creation

To display this data in a meaningful way, individual maps were created that combined various layers with the intention of providing visual aids that increase the understanding of the forest products industry and can be used as decision-making aids for those associated with the industry. The tool is made up of a master folder containing all of the data necessary to the project and the maps that were created to display this information. This section outlines layer manipulation and the procedures taken to combine data for individual map creation. The facility and contractor layers were paired with layers that provide insight on their relationships with population data, potential future forest management treatments and biomass utilization.

3.2.1. Distribution of Colorado's Wood Processing Facilities and Contractors

A facility category map was created by over-laying all of the facility types (bioenergy and solid wood producers, users and contractors) with state shape and county boundary layers for orientation. The Kernel Density Spatial Analyst tool in ArcMap was used to create a facility density map. This tool revealed where facility density was highest across the state on a weighted scale by calculating a magnitude per unit area from point features (in this case the features are the locations of facilities and contractors) using a kernel function to fit a smoothly tapered surface to each point. The data were classified using the Natural Breaks classification method with 5 classes. For the purposes of this study, all default settings were used for the Kernel Density tool. The same process was followed to create separate density layers for contractors and each different type of facility in Colorado (Figure 3.1). A side-by-side comparison map was created using these different density layers.

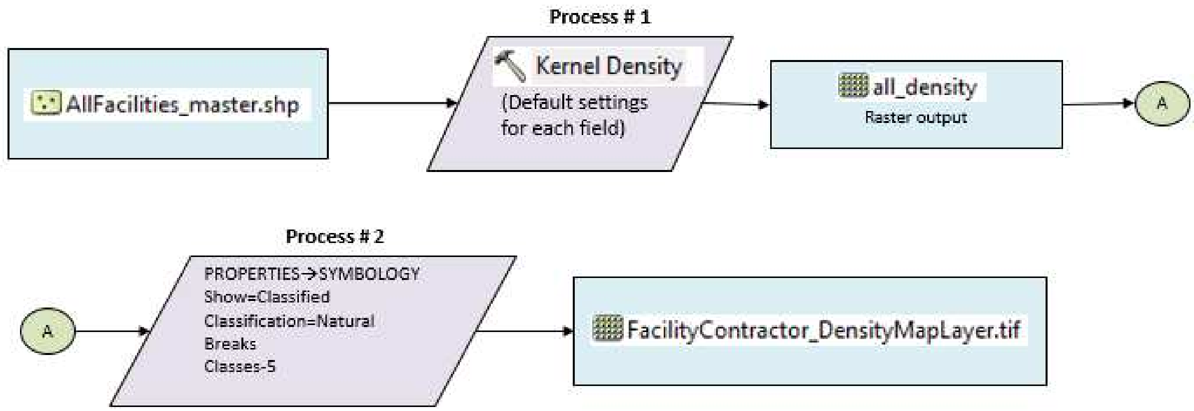

Figure 3.1. Data manipulation process taken to create a density map layer for all wood products facilities and contractors in Colorado using ArcMap10.

Primary transportation systems in Colorado were obtained from the Colorado Department of Transportation's Online Data Catalog. The data were queried to represent only I-70, I-25, I-76 and railways. These were then over-laid with contractor and facility density and county boundaries for orientation.

The next maps paired contractor and facility layers with Colorado demographic factors; Population by county, per capita personal income by county and urban area populations (major cities in Colorado). County population and total person income were downloaded in .xls format from the State of Colorado's Information Marketplace (2015, 2014). 2015 population estimates and 2014 per capita income data were displayed. Both sets of data were added to the original County layer by adding new fields to the attribute table, entering numbers manually and creating separate layers for each. The data were shown with graduated colors using the Natural Breaks classification method with 4 classes for population and 5 classes for income. Urban population was obtained from the U.S. Bureau of the Census Population Estimates Program from the 2010 census year. This data was displayed with graduated colors and classified using Natural Breaks with 4 classes. These demographic layers were then shown with contractor and facility layers.

3.2.2. Future Treatment and Biomass Utilization Investigation

In an attempt to show how facilities are located in relation to where treatments are likely to occur across Colorado, several maps were created showing how facilities matched up with factors that influence future forest management treatment sites. These included land ownership, species distribution, wildfire risk, WUI regions, slope, road availability, insect and disease damage, and previous treatment locations.

Land ownership (COMap dataset, Lavender et al., 2011) and forest type (National Gap Analysis Program, 2011) were over-laid with contractors and facilities. Wildfire and WUI risk layers were downloaded from CSFS's CO-WRAP website (2015). Originally, wildfire risk was displayed using five categories ranging from lowest risk to highest risk. The three highest risk categories were extracted and displayed. WUI risk was originally displayed using nine categories ranging from least negative impact to most negative impact. The four most negatively impacted categories were extracted and displayed. The Extract by Attributes spatial analyst tool was used for these processes.

A DEM was obtained from the Natural Resource Conservation Service Geospatial Data Gateway (2010). From this layer, slope and hillshade layers were created. The slope surface spatial analyst tool in ArcMap was used to identify the gradient from each cell of the raster data to create a slope model (Figure 3.2).

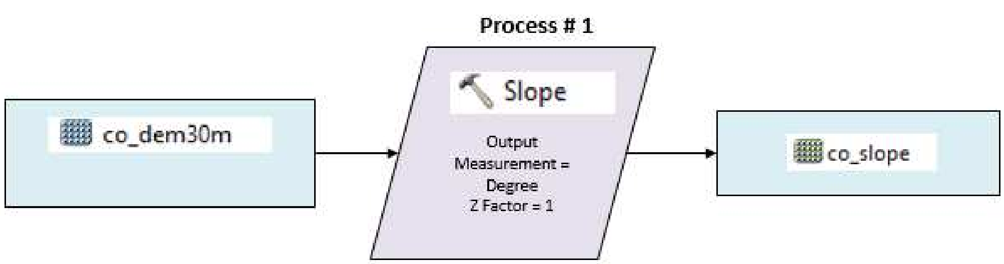

Figure 3.2. Data manipulation process taken to create a slope layer for Colorado using ArcMap10.

The Hillshade surface spatial analyst tool was used to create a shaded relief from the DEM surface raster by taking shadows and an illumination source angle into account (Figure 3.3). The hillshade layer display was manipulated to have 50% transparency and was combined with the original DEM to allow for better topographical visualization.

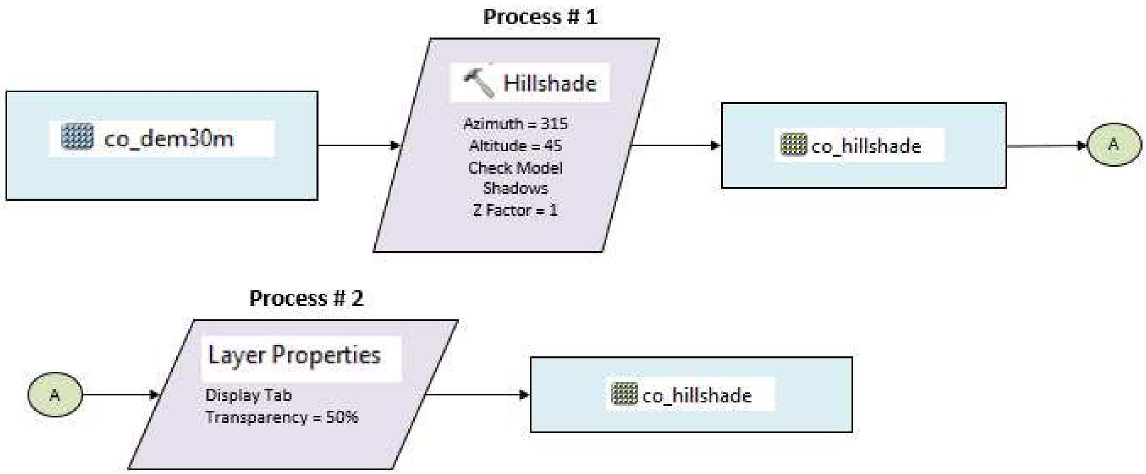

Figure 3.3. Data manipulation process taken to create a hillshade layer for Colorado using ArcMap10.

The slope layer was re-classified to represent areas with extreme slopes, meaning heavy machinery would be hard to use in these areas if at all (Figure 3.4). For the purposes of this map, anything exceeding a slope reclassification value of 5 or above was colored red, indicating areas that were at or over a 50% slope (~30 degree angle). This layer was over-laid with tree species distribution.

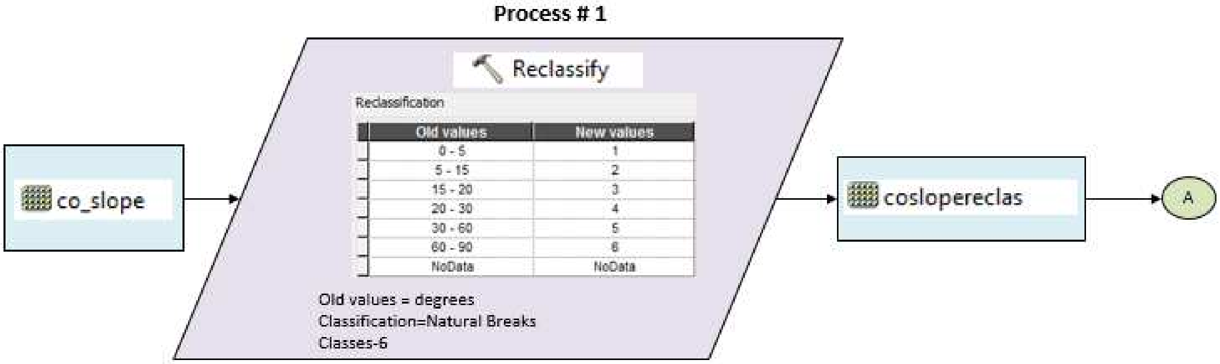

Figure 3.4. Data manipulation process taken to reclassify the Colorado slope layer into 6 unique values signifying degree classes.

A series of ArcMap tools were used to pinpoint areas with high potential of being treated based on the following factors: wildfire risk, WUI risk, insects and disease damage and previously treated forest management sites. The Extract by Attributes spatial analysis tool was used to select only high wildfire and WUI risk areas. This was then intersected with areas that have been damaged by insects and disease using the Intersect analysis tool. The erase overlay analysis tool was used to exclude areas that have already been treated (Figure 3.5).

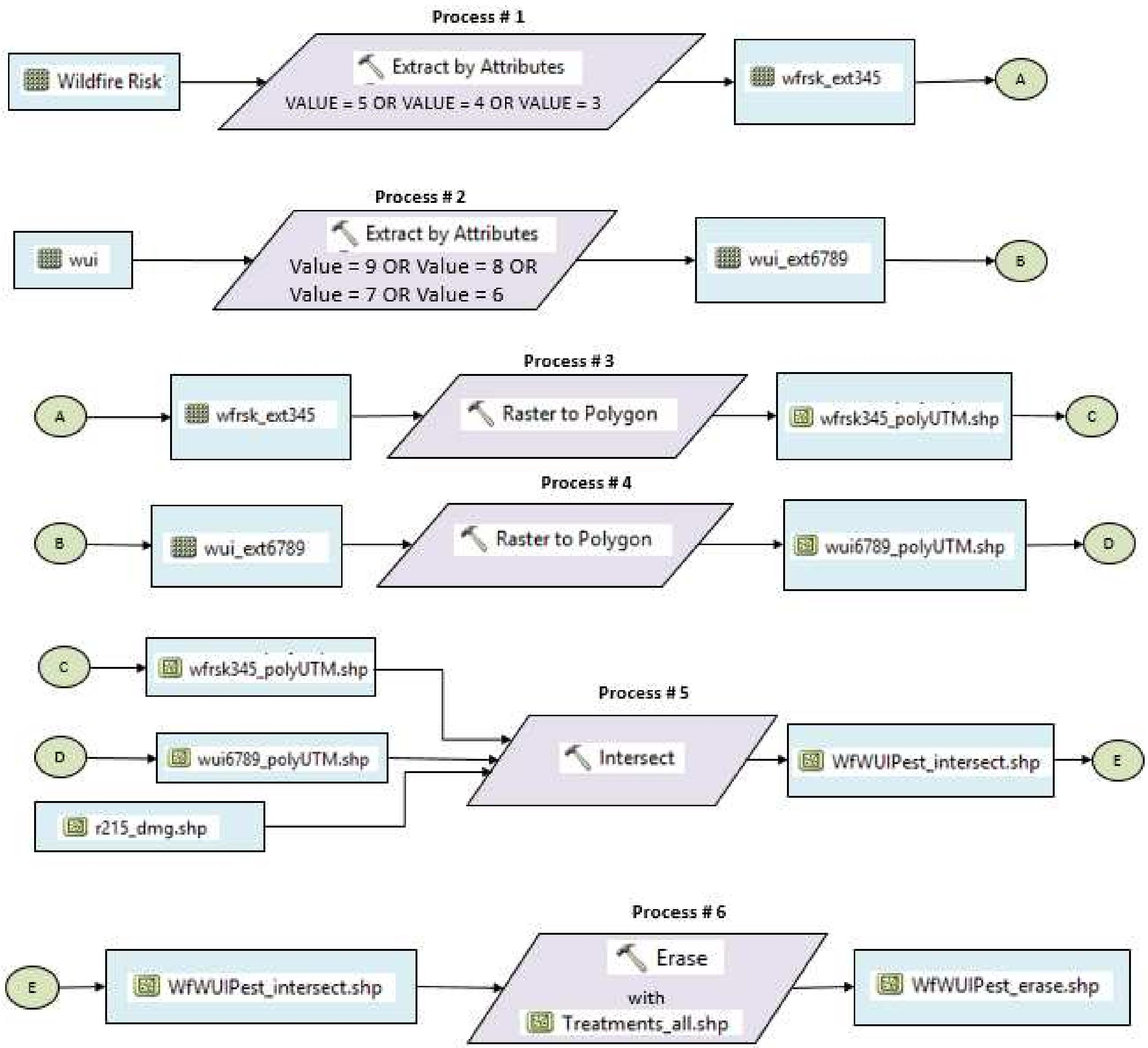

Figure 3.5. Data manipulation process taken to display places in Colorado occurring in high WUI and wildfire risk areas that have been affected by insects and disease and have not previously been treated.

For investigating Colorado's biomass utilization, the Kernel tool was used to create a layer showing the density of schools and hospitals which represented potential biomass users. This layer was then over-laid with bioenergy producers, solid wood producers and current users. The overall facility and contractor density layer was over-laid with the school and hospital density layer to investigate existing or potential spatial relationships. The layer displaying the intersect of WUI risk, wildfire risk and insect and disease impact, excluding previously treated areas, was over-laid with all contractors, facilities and users. The final map created in this series showed the average minimum temperatures across Colorado from 1981 to 2010.

3.3. Industry Cluster Analysis on Northern Colorado Sawmills

Sawmills were extracted from the overall solid wood producer facility layer and projected as a separate data layer referred to as Industry Cluster Sawmills. The sawmills were asked a series questions that sought to address the hypotheses listed in Chapter 1. The interviews were performed either via telephone or site visits. All data collected from interviews and spatial analyses were initially tabulated in Microsoft Excel 2013. Simple descriptive statistics (e.g., means, percentages) were used to summarize the data and show basic relationships. Quantitative data was analyzed by means of interactive statistical analysis via regression analysis using Minitab17 statistical software.

4. RESULTS AND DISCUSSION

The first part of this study required a great deal of data collection, assemblage and manipulation. This was accomplished by first gathering all the necessary data, creating data layers with ArcMap GIS software, managing them to be in one compatible format, then combining various data layers to discover and display meaningful relationships. This chapter reports the findings of these efforts, provides a discussion of applicability and addresses certain limitations within the study. The potential of the mapping resource is not limited to the maps presented here; rather there are many possible data combinations with the potential to provide decision-making assistance.

4.1. Data and Mapping Results

4.1.1. Facility and Contractor Density, Demographics, Transportation

The authors of the University of Montana's FIDACS 2012 Timber Harvest and Forest Industry report provided spatial information on the facilities they contacted in Colorado, mainly bioenergy and solid wood producers were obtained from the Montana data (Sorenson et al., 2012). The CSFS's Colorado Forest Products Program's database provided location and product information for both bioenergy and solid wood facilities (Colorado Forest Products Database, 2011). Contractor information was provided from a survey performed in 2015 by Damon Vaughan, CSFS Forester (Vaughan and Mackes, 2015).

Current biomass users were obtained from the Wood2Energy database developed by the University of Tennessee (Wood to Energy User Facility Database, 2015). Potential users were collected from the CSFS's COWRAP website, which provided point data for schools and hospitals in Colorado (Colorado Wildfire Risk Assessment Portal, 2015).

Orientation data layer sources included CSFS's CO-WRAP website, the Colorado Department of Transportation (CDOT) Online Transportation Information System (OTIS), the Natural Resource Conservation Service (NRCS) Geospatial Data Gateway (GDG) and the COMaP dataset (Table 3.1). These included the state shape of Colorado, county boundaries, cities, interstates, highways, local roads, forest service roads, railways, temperature data, ownership boundaries and landcover data.

Facilities and contractors located in Colorado were displayed in Figure 4.1. A large cluster of facilities and contractors occur in the north-central part of the state, specifically Gilpin, Boulder, Denver, Jefferson and surrounding counties. To locate statistically significant clusters of facilities and contractors, a density map was created which verified that the highest densities occurred in the Front Range Region around Boulder, Gilpin, Denver and Jefferson counties. Other significant clusters were found in the Montrose and Delta county region as well as in the southwestern part of the state in Montezuma and La Plata counties (Figure 4.2).

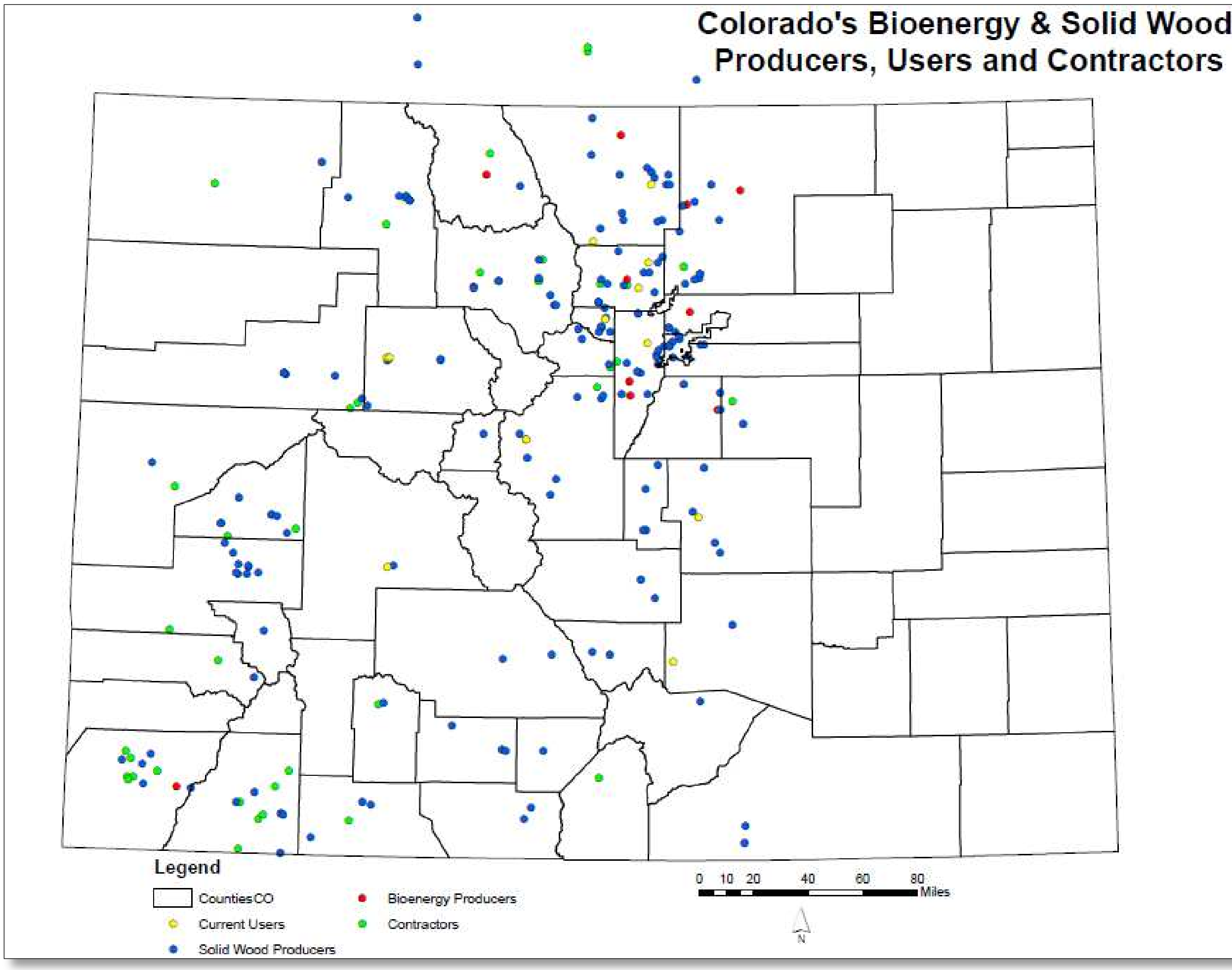

Figure 4.1.Colorado’s bioenergy, solid wood and current wood processing facilities and contractors by county.

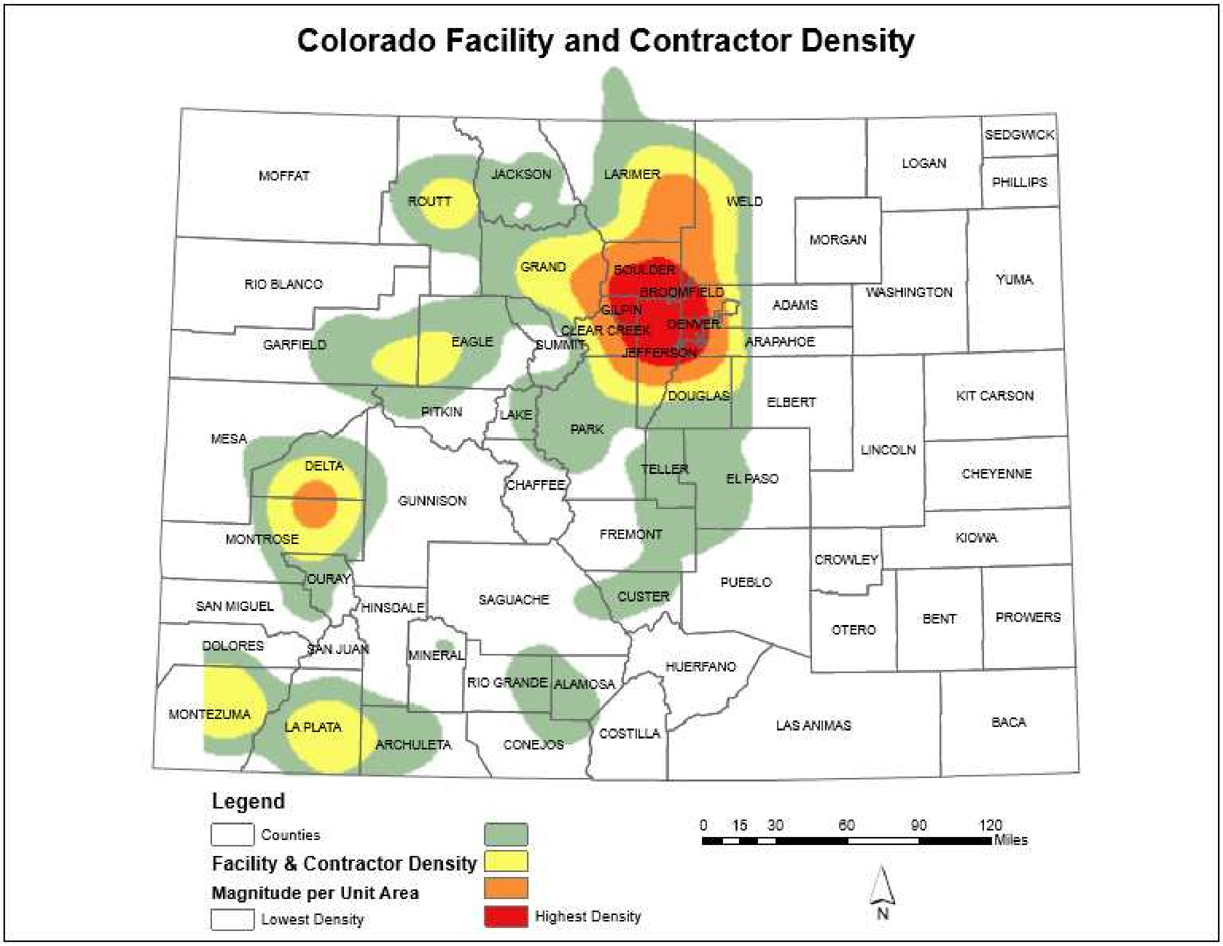

Figure 4.2. Density of wood products facilities and contractors across Colorado via ArcMap10 Kernel Density tool using Natural Breaks classification with five classes.

The next map provided a side-by-side comparison of how different facility types are distributed across the state (Figure 4.3). Solid wood producers were further subdivided into sawmills and value-added producers such as furniture, cabinet and flooring manufacturers. By comparing the density clusters of different types of facilities and contractors it was evident that the distributions were different, though for each category the highest density magnitudes were found in the same area; clustered around Jefferson, Boulder, Broomfield, Denver and Gilpin counties. The solid wood producer category contained the highest number of facilities (this included sawmills and furniture, cabinet and flooring manufacturers). These figures also demonstrated the absence of wood processing facilities, contractors or biomass users along the eastern plains.

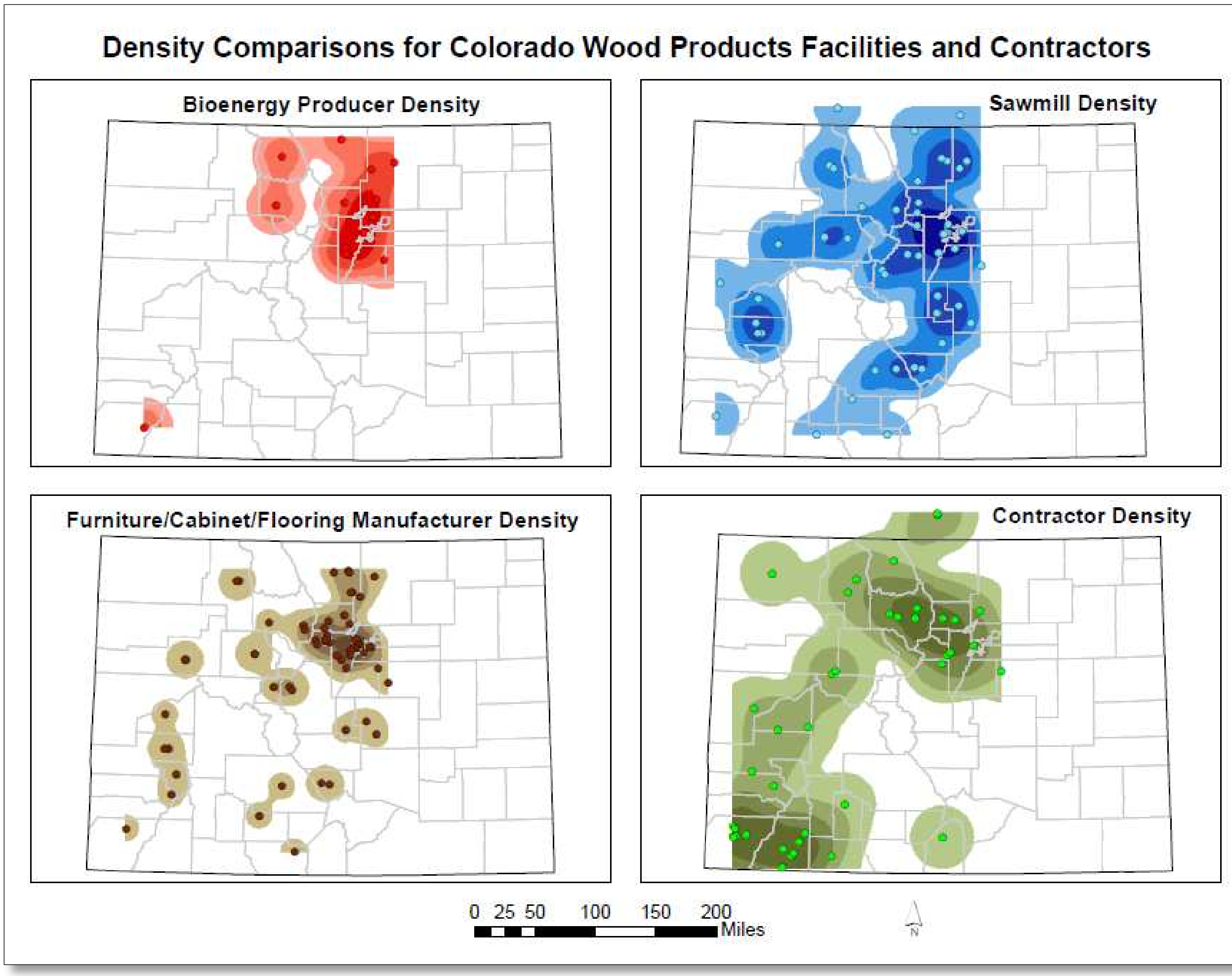

Figure 4.3. Comparison of bioenergy producer, sawmill, furniture/cabinet/flooring manufacturer and contractor densities in Colorado (darker color represents higher density

Demographic relationships were investigated using the next several figures. Population, per capita income by county and total personal income by county was provided by the State of Colorado's Information Marketplace (2015, 2014). This data originated from the Bureau of Economic Analysis and Census for the State of Colorado. The 2015 county population data was estimated by the Census Bureau's Population Estimates Program (PEP) building from the 2010

U.S. census data (U.S. Bureau of the Census Population Estimates Program, 2015). The urban population layer represents populations of major cities from the U.S. census data for 2010 (Figure 4.4).

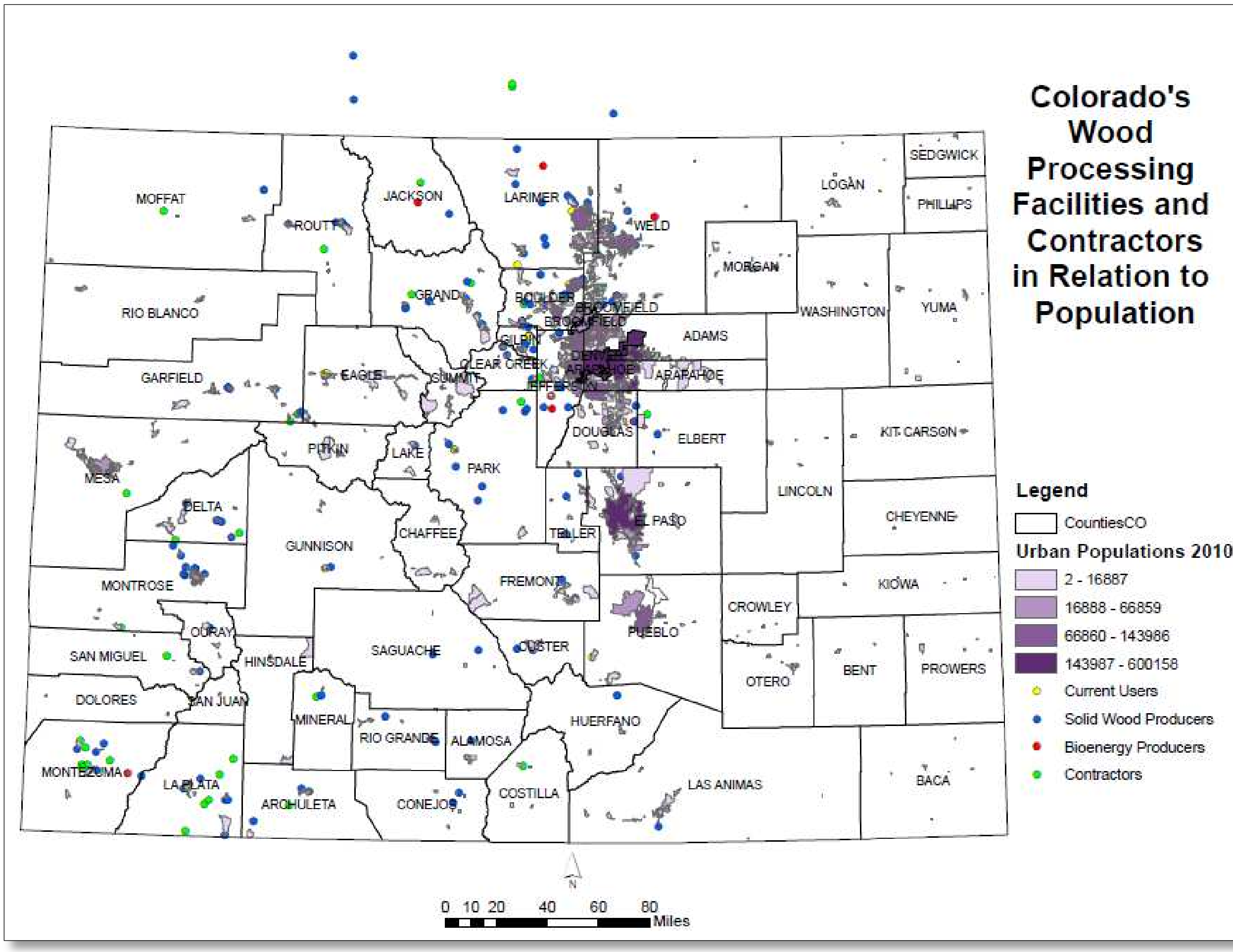

Figure 4.4. Distribution of Colorado’s wood products facilities and contractors in relation to 2010 urban population.

2014 was the most recent data available for per capita and total personal income. Per capita income is the average personal income within each county divided by county population (U.S. Bureau of the Census Population Estimates Program, 2015) (Figure 4.5). Total personal income is the income received by an individual from all sources (U.S. Bureau of the Census Population Estimates Program, 2015) (Figure 4.6).

An intuitive trend was illustrated by the demographic maps, which was that Colorado's facilities occurred in the highest density where human population was also the highest. The greatest facility density was seen throughout the Front Range region in Gilpin, Boulder, Denver, Broomfield, Jefferson, Adams and Arapaho counties (Figures 4.1 and 4.2). The locations of heavily populated areas were shown in Figure 4.4 as urban areas. The highest facility density occurred proximate to Colorado's largest urban areas. This association suggested that population may be a major indicator of facility placement.

Pitkin County had the highest per capita income and Jefferson, Broomfield, Arapaho and El Paso counties had the highest total personal income. Very little to no facilities or contractors occurred within Pitkin county even though it had the highest per capita income. While some of the north-central clustered facilities occurred in the second highest per capita income bracket, the facilities clustered in the southwest occurred in the lower brackets (Figure 4.5). Few associations were found between Colorado's wood products facilities and contractors and per capita income by county.

Counties with the highest total personal income were all counties that contained the highest density of facilities and contractors. The smaller clusters of facilities occurring in the mid-southwester part of the state had slightly higher incomes than the majority (Figure 4.6). The facility and contractor density layer more closely aligned with total personal income in Colorado than per capita income.

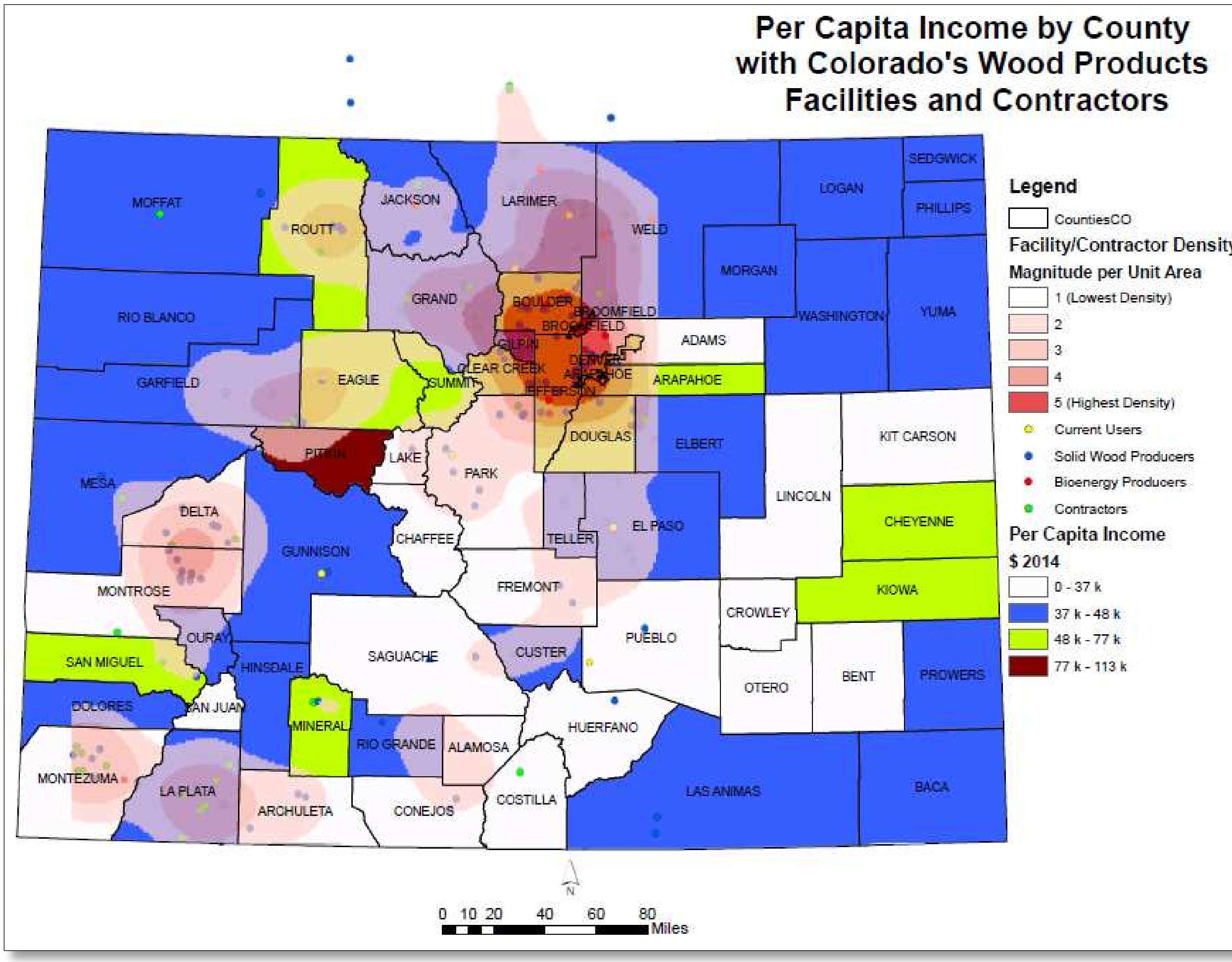

Figure 4.5. Distribution of Colorado's wood products facilities and contractors in relation to Per Capita Income by county.

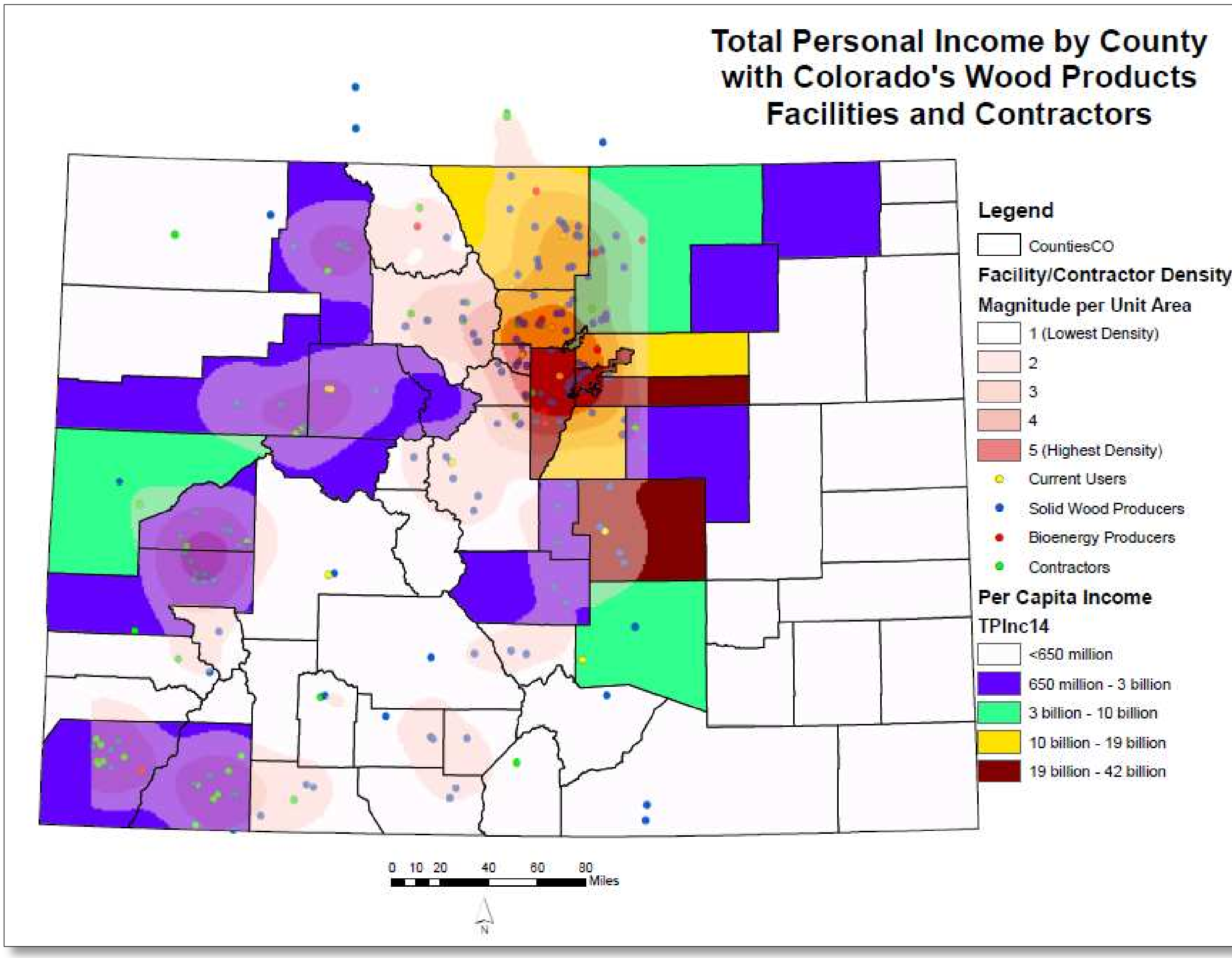

Figure 4.6. Distribution of Colorado’s wood products facilities and contractors in relation to Total Person Income by county.

Main thoroughfares showed a substantial relationship with facility placement (Figure 4.7). The main facility hotspot contained the intersection of all the major interstates of Colorado (I-76, I-70 and I-25) and a multitude of railway systems. Each area clustered in any magnitude with facilities was connected to major interstates, railways, or both. This map suggests that transportation systems may be an indicator of wood products facility and contractor placement.

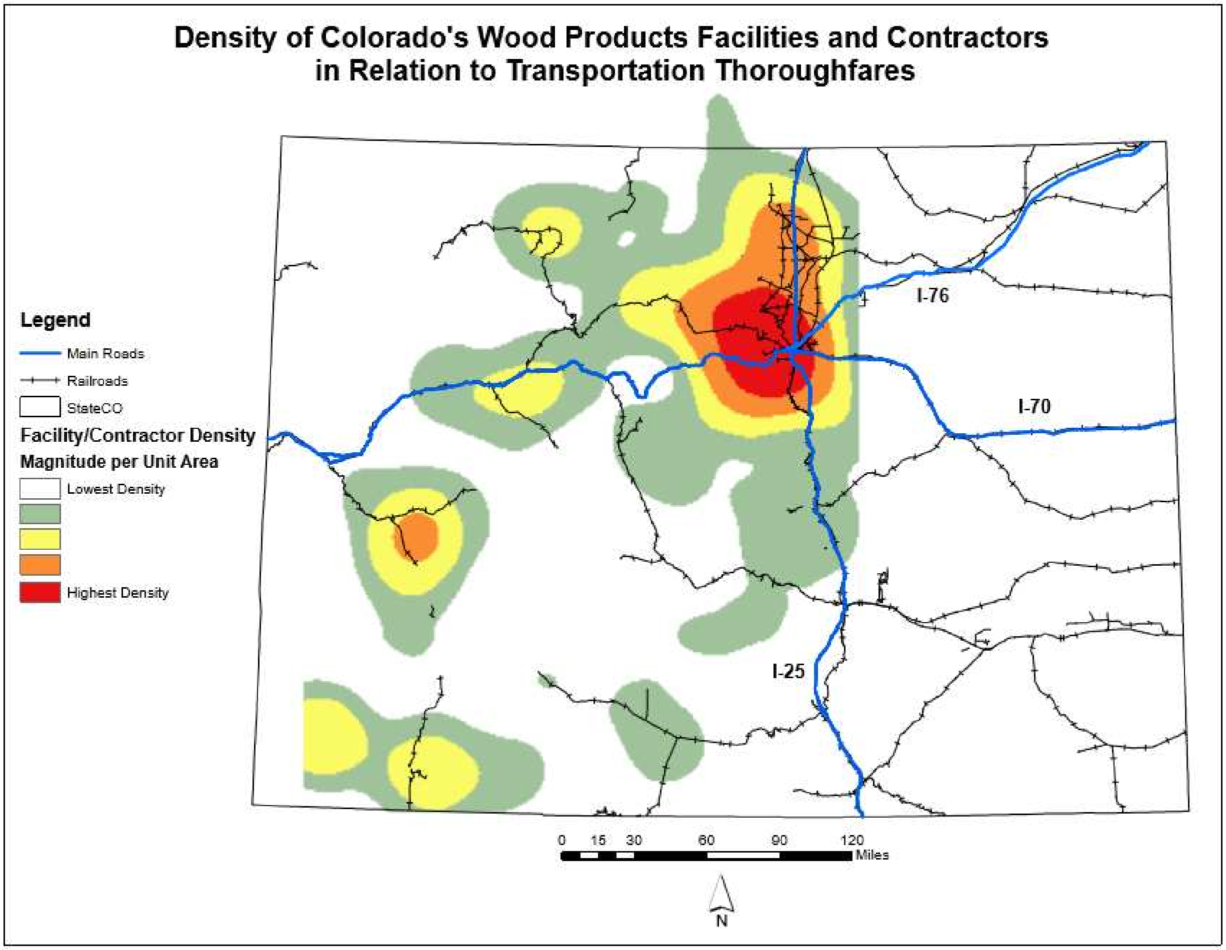

Figure 4.7. Relationship between main transportation thoroughfares (I-76, I-70, I-25, railways) and the density of facilities and contractors in Colorado.

4.1.2. Investigation of Future Forest Management and Biomass Utilization Potential

The next series of maps were created to provide those associated with the forest products industry of Colorado with a visual representation of where forest management is needed across the state. Need for treatment was based on wildfire risk, WUI regions, and insect and disease damage. Accessibility factors were added for users to be able to rudimentarily consider the feasibility of treating these areas based on slope and presence of pre-existing roads.

Knowledge of where forest management is needed indicates where treatments have a high likelihood of occurring in the future. Although this information has the potential to be useful to all those associated with the forest products industry, it is particularly useful to those interested in utilizing woody biomass for heat and/or electricity. A major obstacle for converting facilities to a biomass system is establishing a consistent feedstock supply. These maps enable users to visually analyze different parts of the state for optimal biomass site locations.

The ownership and species type of feedstock in Colorado was shown with facility distribution (Figure 4.8 and 4.9). Owing to the fact that most of Colorado's available timberland is federally-owned in the western half of the state, many wood processing facilities and contractors were surrounded by federal land. The Front Range Region, which contained the highest facility and contractor density, was surrounded by USFS lands, private lands and some NPS lands (Rocky Mountain National Park). Facilities and contractors in the far west were in closest proximity to BLM and private lands. Neighboring land owners to the southwestern facility and contractor clusters included USFS, private, BLM and BIA (Figure 4.8). This demonstrated how dependent the wood products industry is on the management actions set forth by USFS, BLM and other government agencies in Colorado. While this may not always be true, facilities likely worked with agencies in the closest vicinity so as to keep the costs of transportation down.

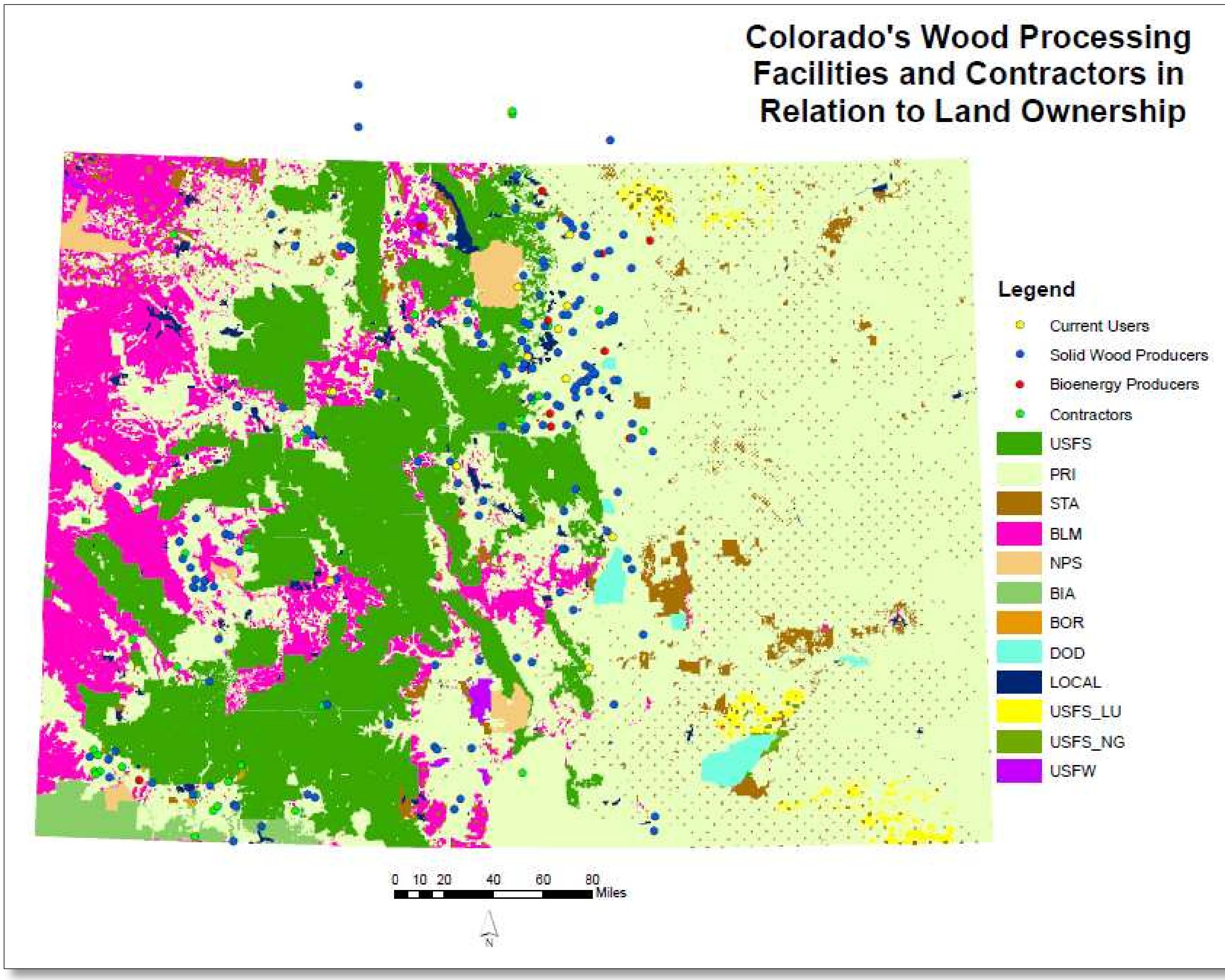

Figure 4.8. Distribution of Colorado's wood processing facilities and contractors in relation to land ownership.

Similarly, facilities and contractors may be limited to working with the species type that is in closest proximity to minimize transportation costs. The next figure showed how facilities and contractors were distributed when over-laid with tree species distribution across Colorado. The far west was dominated by mainly pinon-juniper with some mixed conifer and aspen. Lodgepole pine occurred more in the norther part of the state and ponderosa pine more in lower elevations. Species that occurred nearest to the Front Range density cluster of facilities and contractors included mixed conifer, lodgepole pine, spruce-fir and ponderosa pine (Figure 4.9). Species in the mixed conifer forest type are Douglas fir (*Pseudotsuga menziesii*), white fir (*Abies* *concolor*), bristlecone pine (*Pinus aristata*), limber pine (*Pinus flexilis*) and Rocky Mountain juniper (*Juniperus scopulorum*) (CSFS, 2010).

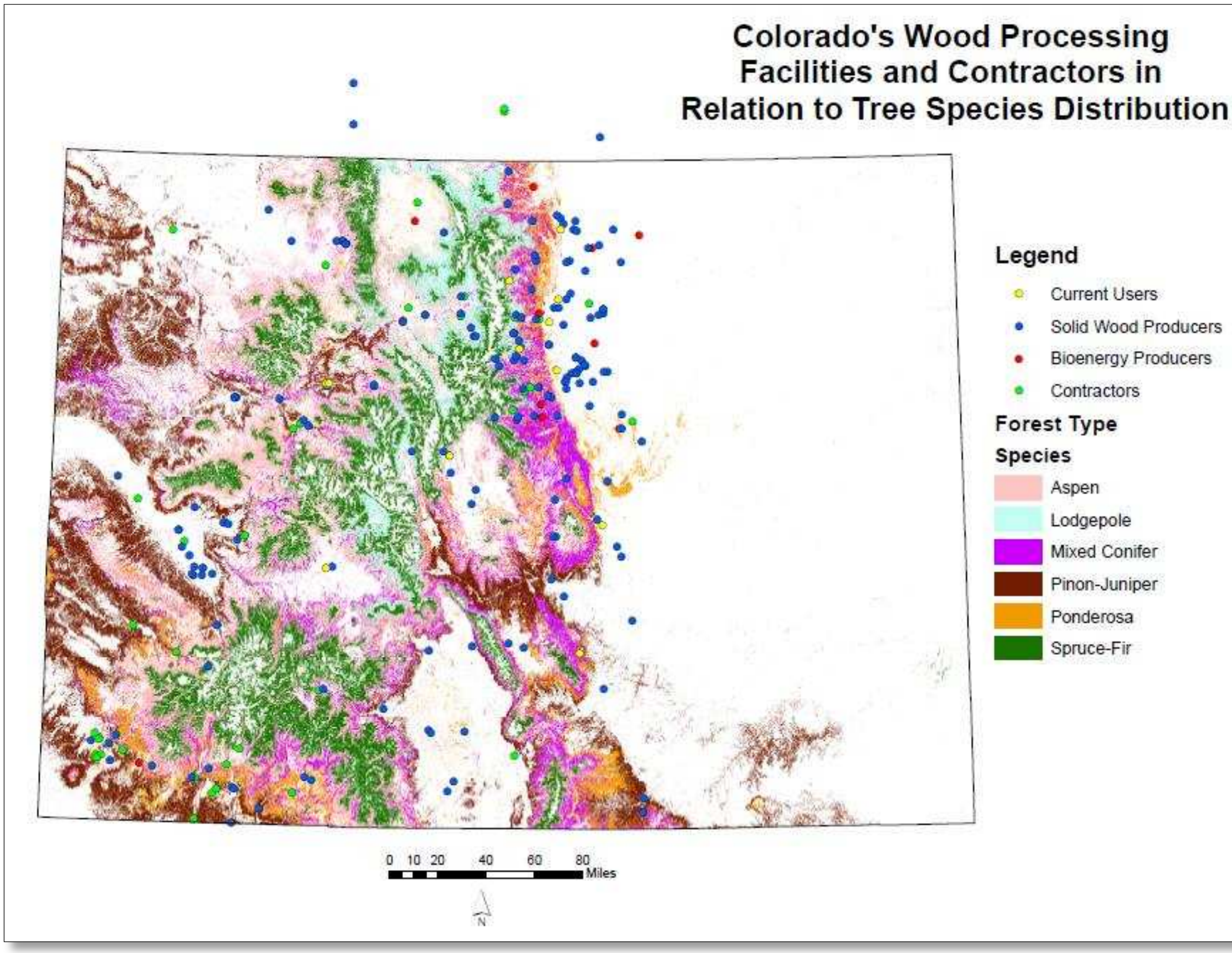

Figure 4.9. Distribution of Colorado's wood products facilities and contractors in relation to tree species distribution.

Figure 4.10 provided the distribution of areas in Colorado at high risk of wildfire and areas that occurred within the highest WUI risk zones. The wildfire risk layer showed the possibility of loss or harm occurring from a wildfire by orders of magnitude. The WUI risk data layer showed the measure of potential impact wildfire has on people and their homes within the

WUI, shown as a scale of potential negative impact (Colorado Wildfire Risk Assessment Portal, 2015).

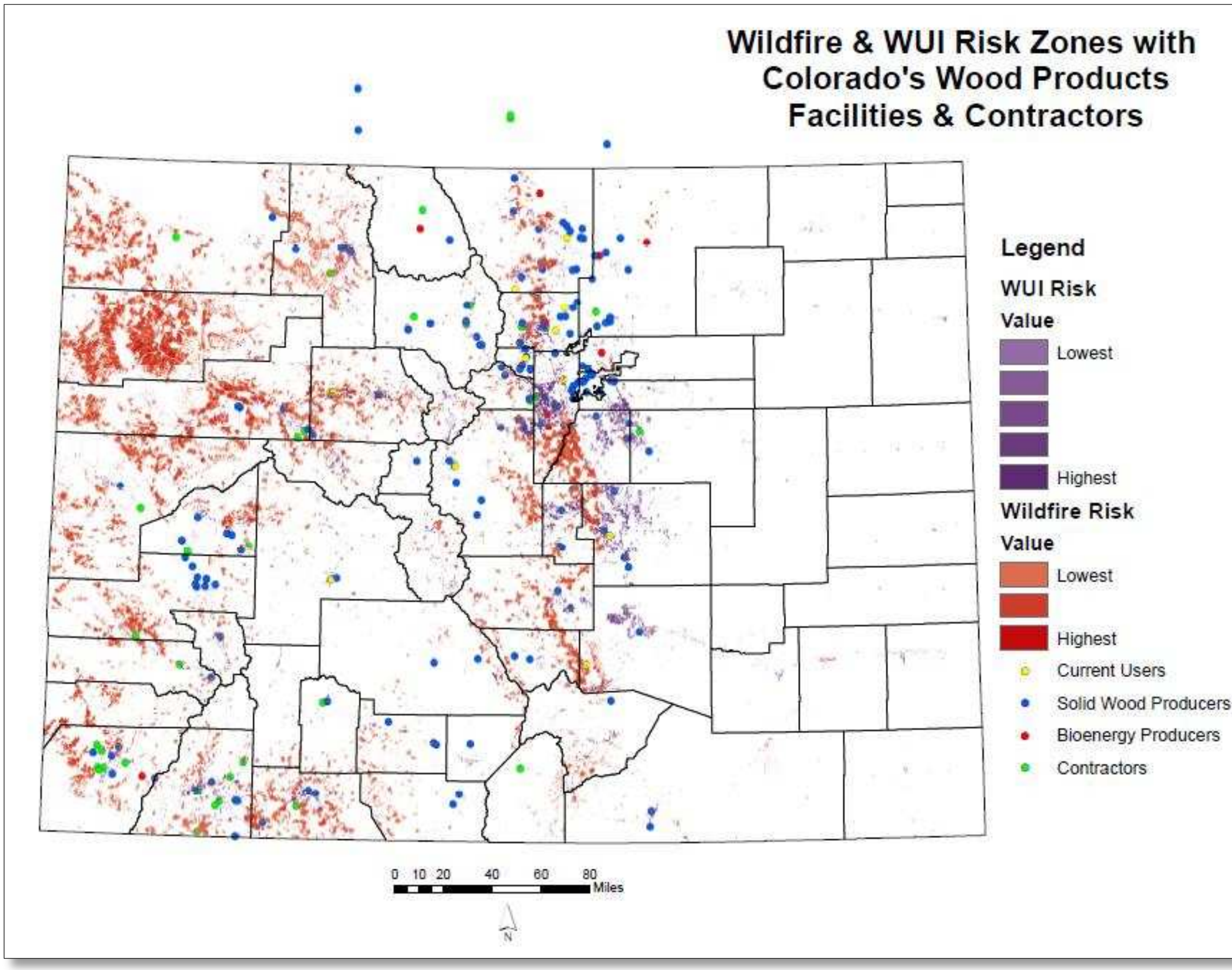

Figure 4.10. Distribution of Colorado’s wood products facilities and contractors in relation to high wildfire and WUI risk areas.

These two factors are good indicators of where future fuels treatments are likely to occur and where future biomass feedstock could be available in the future. The proximity of facilities and contractors to treatment areas has the potential to provide those performing the treatments with an idea of who would be best positioned to use for contracting and processing so as to minimize transportation costs. Estimation of treatment costs could be performed based on distances. Current biomass users could use this map for locating potential biomass supply and ensuring a consistent supply for the future.

Along with wildfire and WUI risk, insect and disease damage increases the likelihood of an area being treated due to the increased susceptibility to wildfire and because utilization of this wood is time-limited. The areas affected by insects and diseases were shown by pathologic agent in relation to wood products facilities and contractors in Figure 4.11.

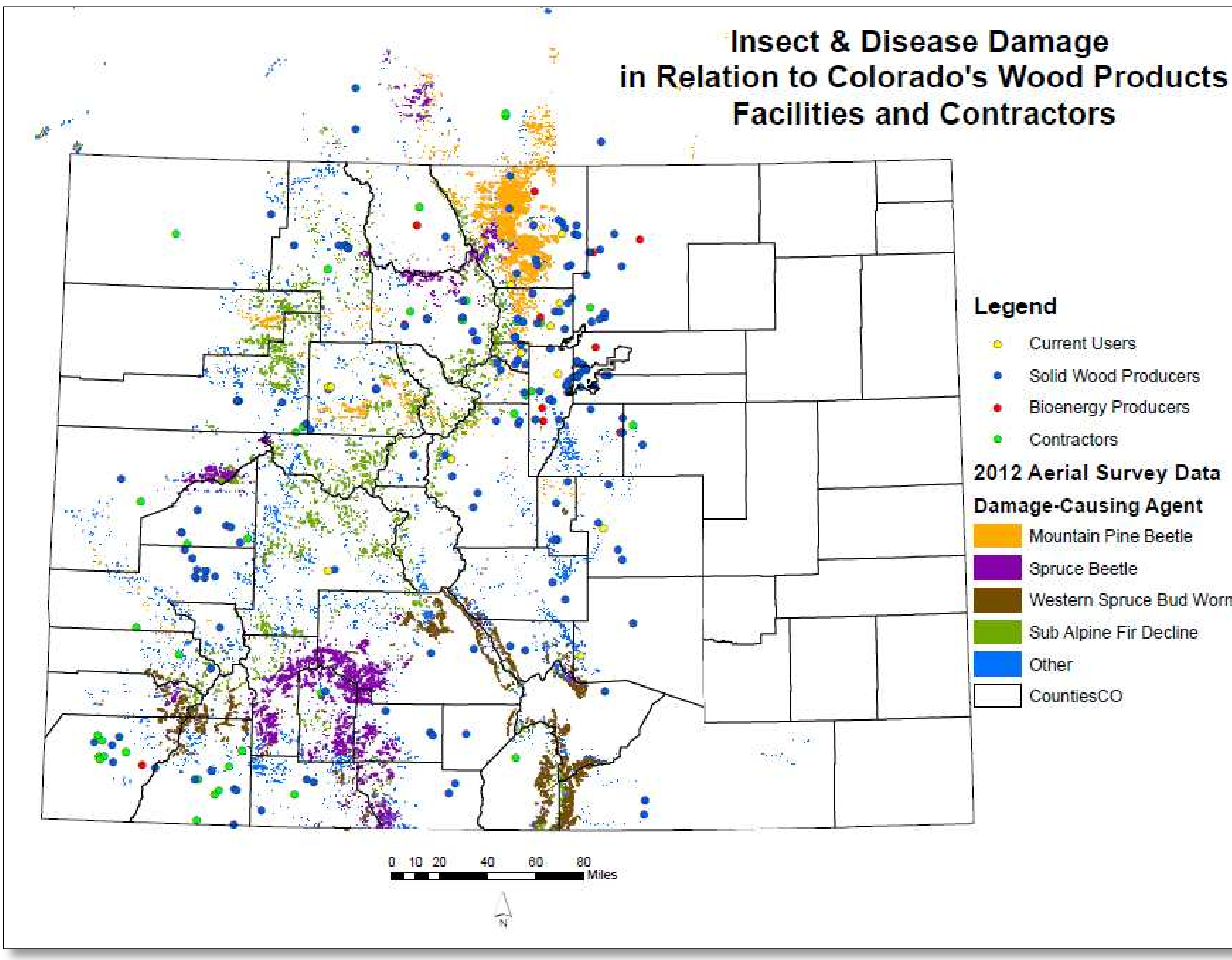

Figure 4.11. Distribution of Colorado's wood products facilities and contractors with insect and disease damage through 2012.

To further investigate where potential treatments may occur, a map was created to pinpoint areas with a high likelihood of being treated by using the intersect tool in ArcMap to isolate and display only the areas that occur within the WUI and wildfire risk zones that have been affected by insects or disease (Figure 4.12). Areas that have already been treated (Figure 4.13) were removed using the Erase tool to exclude agency treatment polygons. Figure 4.13 shows areas that have been treated from 2012 to 2014 (or 2015 depending on the agency). This map can be used to grasp the amount and location of treatments that have been occurring recently across Colorado, as well as the agency performing them and how the treatments are located in relation to forested land and wood products facilities and contractors.

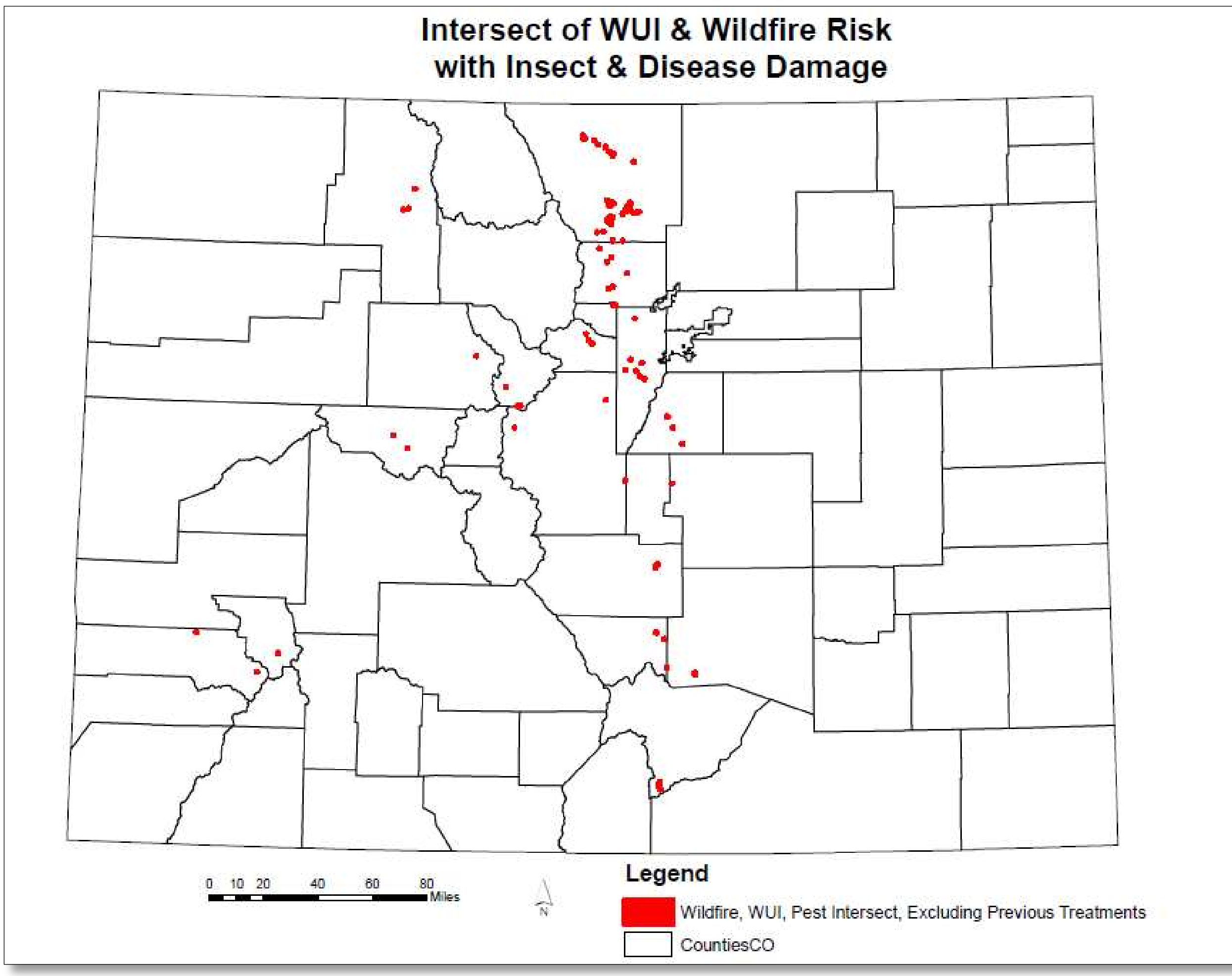

Figure 4.12. The intersect between WUI and wildfire risk zones with areas that have been affected by insects or disease, excluding previous treatment areas.

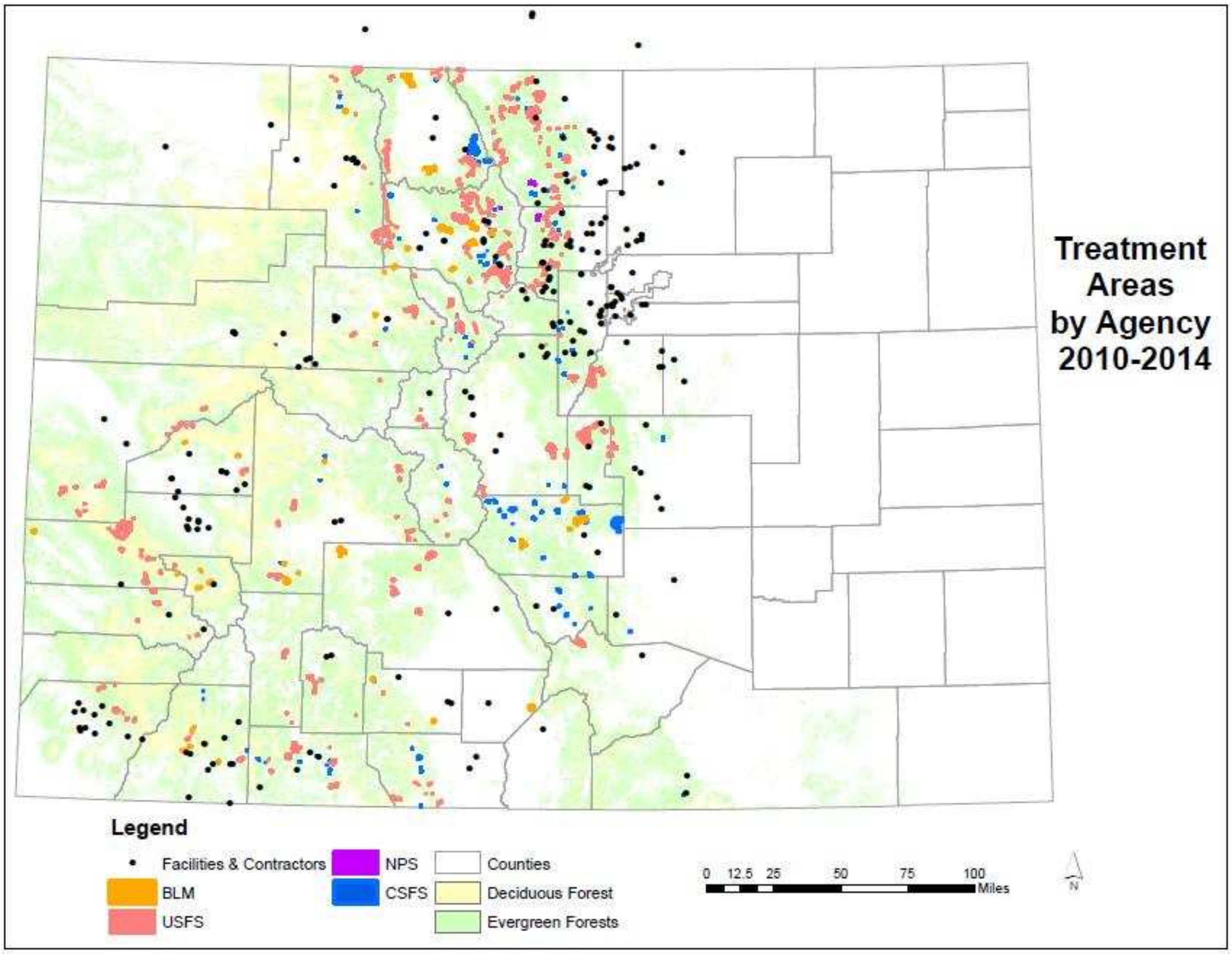

Figure 4.13. Distribution of Colordo's wood products facilities and contractors with previous agency treatment locations.

The majority of areas with high wildfire and WUI risk that have been affected by insects and disease occurred on federal land (Figure 4.14). These maps provide insight as to how much treatment and feedstock is likely to come from different land ownerships and which facilities are in closest proximity for processing.

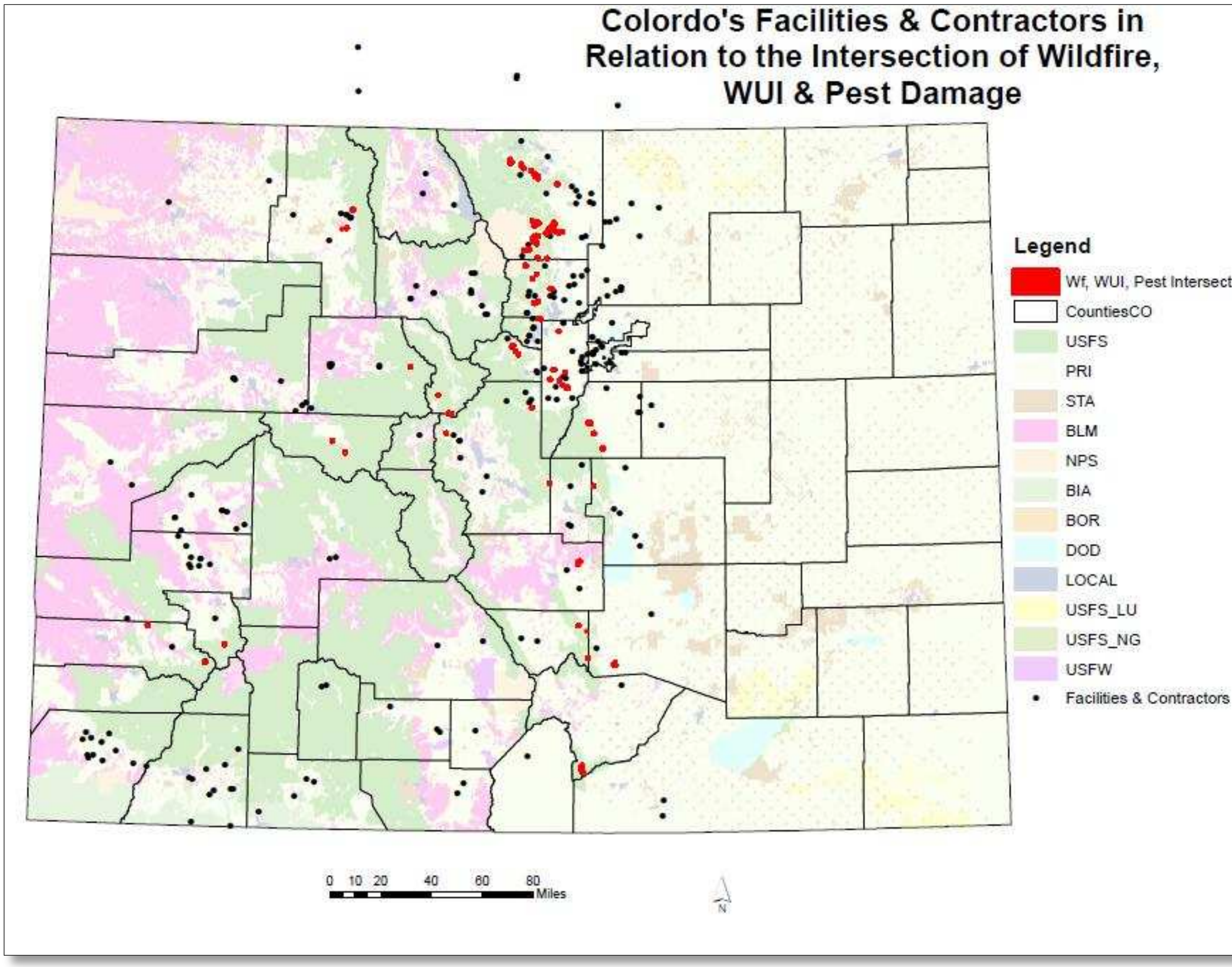

Figure 4.14. Intersect of wildfire risk and WUI risk zones that have been damaged by insect and disease with land ownership and Colorado's wood products facilities and contractors.

Larimer county contained the greatest area in need of treatment. Ownership for this area included USFS and NPS (Figure 4.14). The Mountain Pine Beetle was the major damage-causing agent here (Figure 4.11) and mainly lodgepole pine with some ponderosa pine were the species affected (Figure 4.9).

The purpose of subsequent maps was to provide insight as to furture treatment accessibility for users to perform cost estimations based on slope and pre-existing roads. Certain areas with extreme slopes may be inaccessible for heavy machinery. Cost of treatment increases for difficult areas such as these, if treatment is possible at all. Whether or not contractors will have to build in roads prior to treatment is another factor that influences the cost of treatment (Figure 4.15). These maps provide users with a resource to perform initial site evaluations.

The red areas in Figure 4.16 and Figure 4.17 represent areas with a 50% slope or greater. This slope was chosen because it is the maximum slope limitation for ground-based harvesting systems. This type of terrain would require either doing the treatment without heavy machinery or using more expensive yarding systems such as cable yarding or helicopter (Windell and Bradshaw, 2000). This map provides agencies, contractors and planners with a better idea of what to expect as far as accessibility and the cost of treating an area prior to visiting the site. For example, initial investigation of a site by using this map could display a large proportion having extreme slopes, meaning they could expect harvesting costs to increase.

The magnified view in Figure 4.14 indicated that some lodgepole pine, aspen and spruce-fir stand unsuitable for use because of limited accessibility and the increased cost of treatment as a result of hazardous slopes.

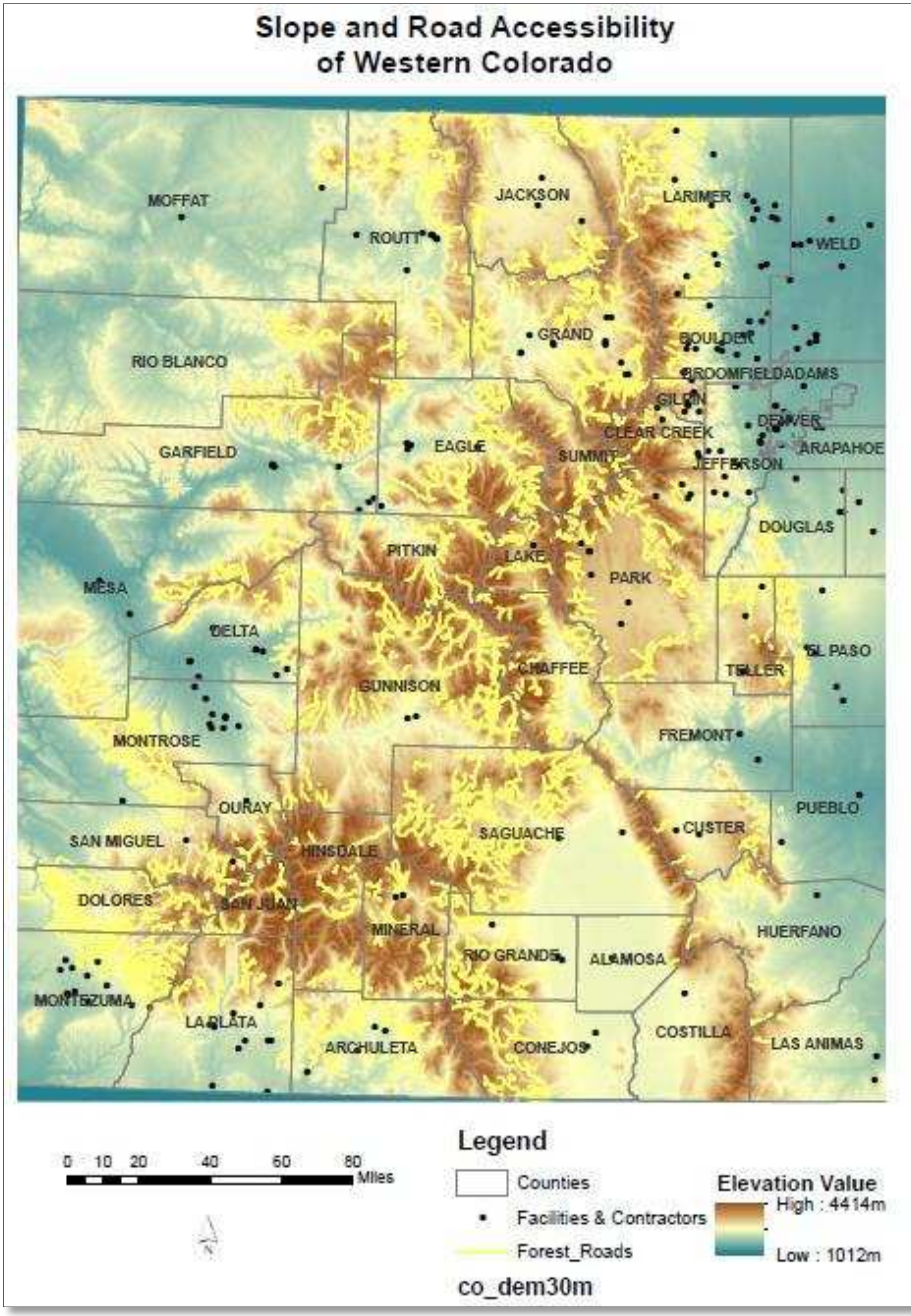

Figure 4.15. Colorado DEM with pre-existing forest roads.

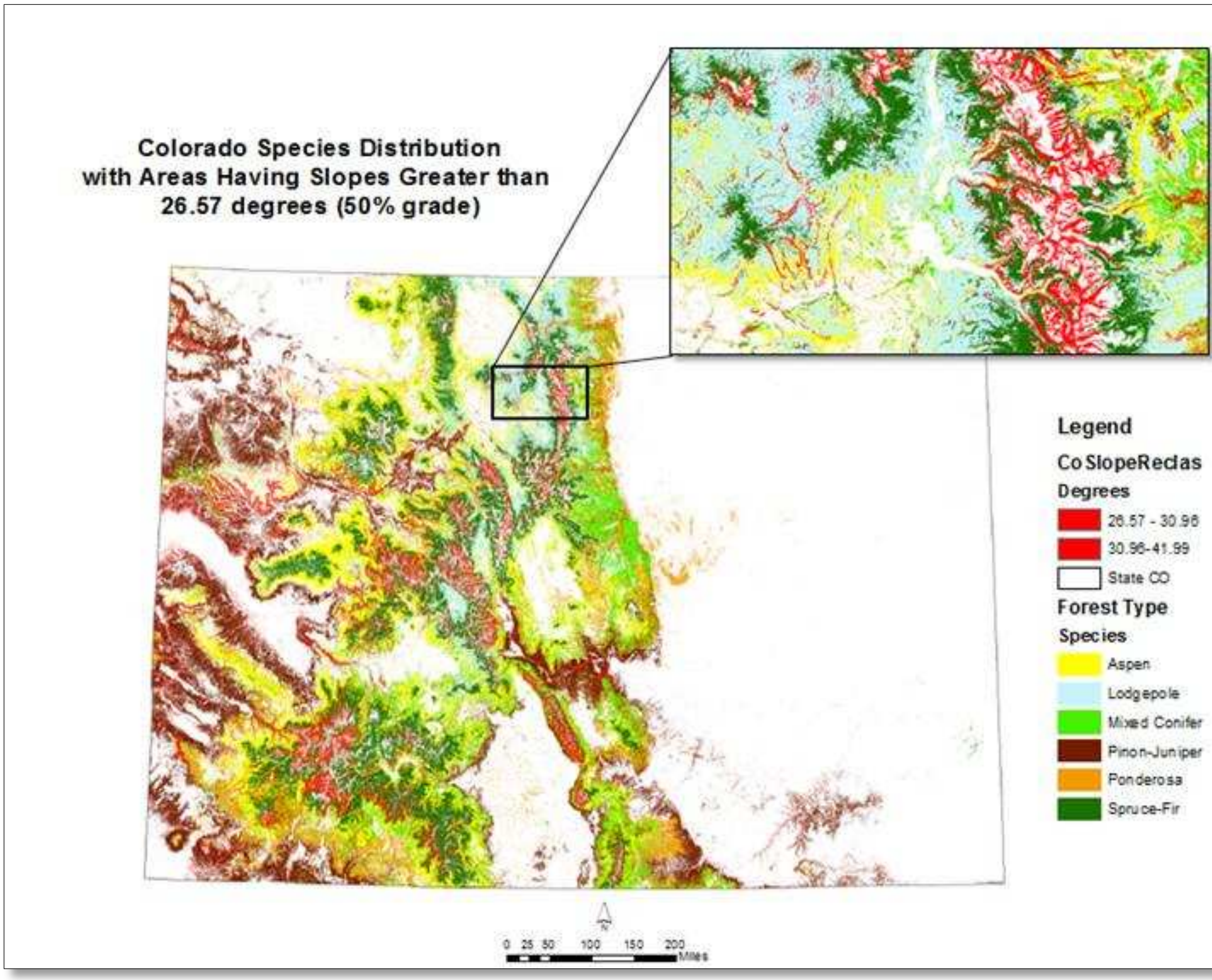

Figure 4.16. Areas of timberland in Colorado with slopes greater than 26.57 degrees, or a 50% grade.

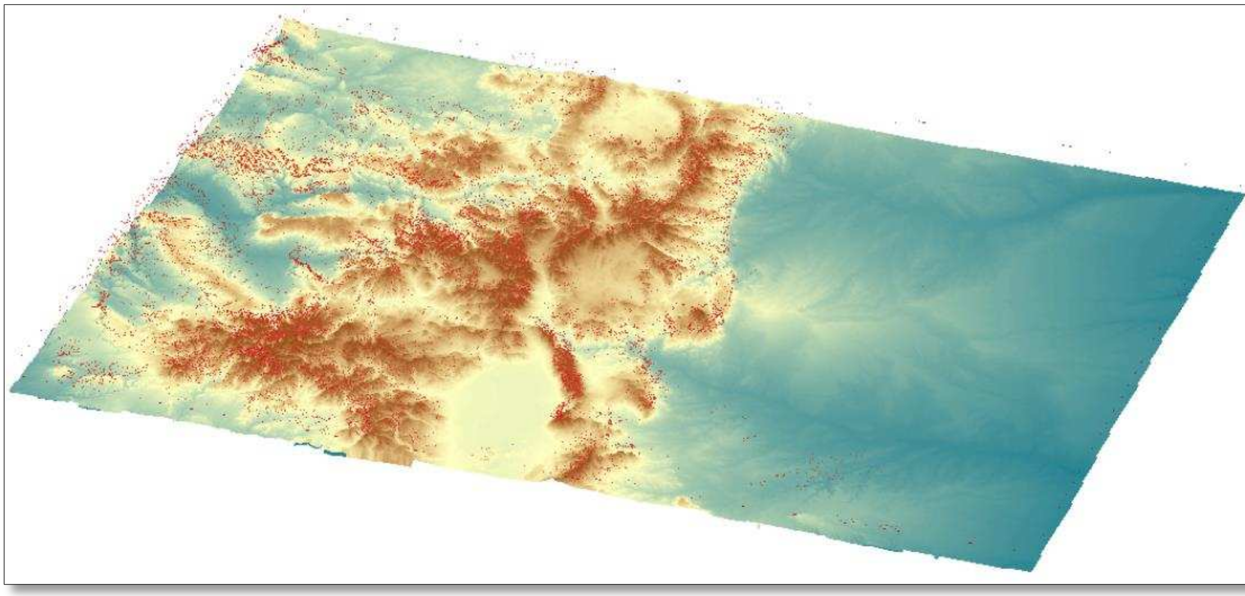

Figure 4.17. 3D DEM of Colorado with slopes greater than 50% shown in red.

Those interested in biomass utilization can use the future treatment maps for investigating biomass supply based on areas in need of treatment. Solid wood producers often sell byproducts such as shavings or sawdust that have the potential to be used by the facilities in the current users category. Insight was provided for potential relationships between facilities that require biomass and facilities that produce it.

Figure 4.18 combined bioenergy and solid wood producers with current and potential biomass users with the intention being to associate groups of producers with current users to locate where potential relationships could be initiated to maximize biomass utilization. These associations are important because they allow producers to maximize utilization of their waste and better offset their transportation costs. Users benefit by having a consistent and reliable biomass supply. Colorado only has about 12 facilities currently using biomass for heat, electricity or both. About half are spread throughout the Front Range region averaging 30 miles away from each other. The others are more widely spaced throughout the western half of the state and south of the Front Range region. They are located anywhere from 50 to 100 miles away from one another.

For the purposes of this study, a school and hospital density layer was created to represent potential biomass users. Generally, schools and hospitals are prime biomass candidates as they are usually large facilities requiring year-round heating or electricity with a centralized heating system already in place. These attributes can lessen the costs associated with converting to biomass. Other good candidates might be ski resorts or facilities with heated pools. This study investigates schools and hospitals as potential biomass candidates.

Intuitively, the highest densities of schools and hospitals were located similarly to the most populated regions in the state. Denver County contained the highest density magnitude of schools and hospitals. Both potential users and wood products facilities had the highest densities in the Denver Metro area, with separate smaller clusters occurring in Larimer, Boulder, Weld, El Paso, La Plata, Montezuma and Montrose counties (Figure 4.18).

These biomass maps can also be used to locate facilities that would be optimal candidates for converting to biomass heat and/or electricity based on their proximity to areas in need of treatment and their proximity to solid wood producers that yield a material suitable for use in a biomass system. Certain parts of Colorado that require more heating on average would be good places to start (Figure 4.19).

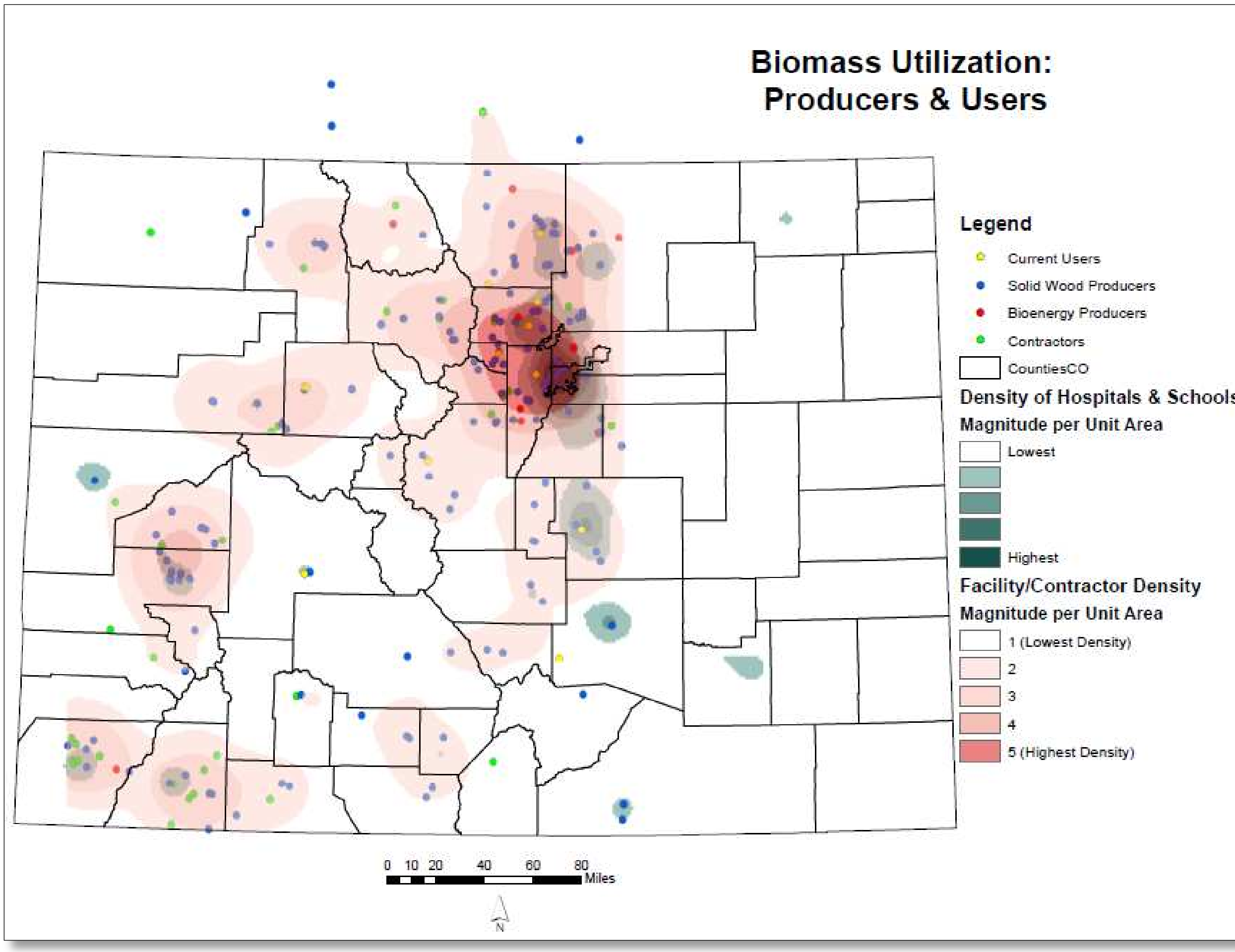

Figure 4.18. Distribution of wood products facilities and contractors with current users and the density of schools and hospitals (potential biomass users) in Colorado.

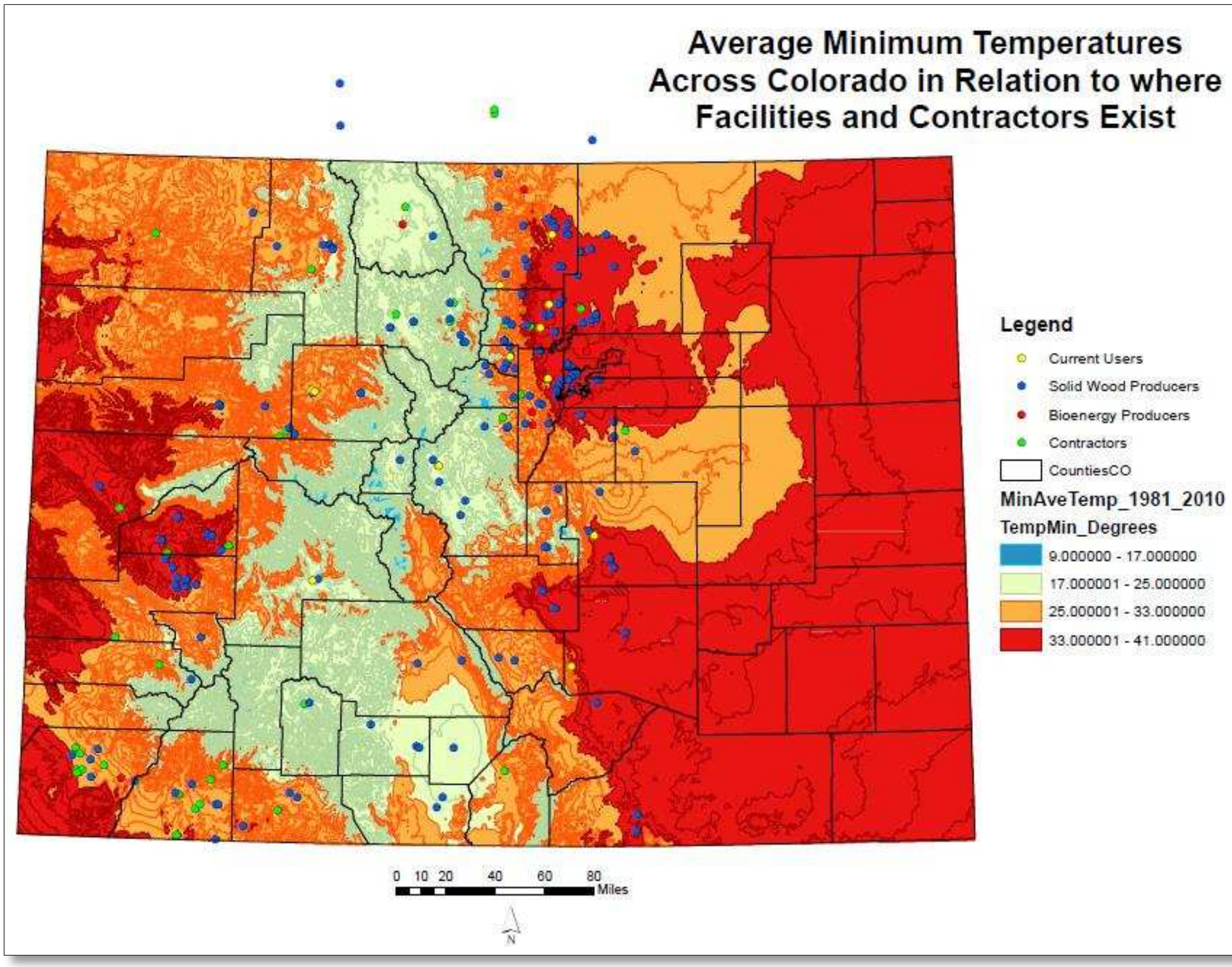

Figure 4.19. Distribution of wood products facilities and contractors with the average minimum temperature across Colorado from 1981 to 2010.

4.2. Limitations

4.2.1. Data Limitations

This part of the study required a great deal of data accumulation, which involved data collection from a multitude of sources. Before making assumptions based off these maps it is important to remember what the data represents and when it was collected. The most recent data were used where possible but certain layers represent different years.

Facility and contractor locations were obtained from several different sources (Sorenson et al., 2012; Vaughan and Mackes, 2015; Colorado Forest Products Database, 2011; Wood to

Energy User Facility Database, 2015). Some coordinates were obtained by searching individual addresses in Google Earth. Accuracy can only go so far as Google Earth allows. The only way to have completely accurate locations would be to do site visits, a task that would be out of the scope of this project.

Previous agency treatment layers included polygon data layers outlining treatments performed by USFS, CSFS, BLM, and NPS. The two attributes of interest within these data sets were the years of treatment completion and the type of treatment that was executed. Only recent years of treatments have the potential to provide feedstock to the industry so anything prior to 2010 was queried out. The most recent data were used, though it varies among agencies. Similarly, only the types of treatments that have the potential to provide a feedstock were of use in this study. Treatments such as burning, planting, piling, yarding or pesticide application were removed from the data leaving only timber sales, thinnings, cuttings or any other projects that removed material with the potential to be used as feedstock.

It is important to recognize several limitations to the treatment data. The framework and process of treatment data documentation varies greatly between agencies. Within agency documentation may vary as well. Depending on the year and the specific treatment area the data may have been collected by different people. Some of the datasets had missing entries periodically or contained missing fields entirely. In situations such as these, the data were not used for the final mapping product. To remain as accurate and conservative as possible, the only data used in the mapping of this project were clearly stated as occurring between the years specified for each agency and the type of treatment specified for each agency. Therefore, it can’t be assumed that the treatment data used in the mapping of this project is completely and exactly accurate. Rather, it is a representation of what was likely to have occurred, encompassing only the information clearly and comprehensively made available.

The USFS provided data up through 2014. They represented their treatment periods by documenting the year the treatment was planned and the year it was accomplished. The data were queried to only represent commercial or restoration thinning, all types of cuttings, fuel breaks, and permanent land clearing accomplished between 2010 and 2014. NPS provided data as recent as 2012. The information was queried to only represent non-fire treatments that were completed between 2010 and 2012.

There were several imprecisions in the BLM dataset. The date of treatment was not identified in some of the fields, and many of the entry dates were extraneous. For example, the date of treatment read 1/1/9999 repeatedly. This date might have significance to the agency, it could be due to collector error or it could also represent a “null” value. Regardless, these entries were excluded due to uncertainty. Many of the descriptions of the fields that were excluded were unrelated to this study so it is likely that their exclusion had little effect on the outcome. Additionally, some of the description fields were blank, leaving no way to know the type of treatment that occurred. These fields were also excluded. The data was queried to represent only removal treatments completed between 2010 and 2015.

Some of the CSFS dataset also contained empty fields making it unclear when and what treatments were performed. This could be due to backlog; the agency could be working with this data currently to fill in these fields. Regardless, they were excluded from analysis.

The treatment data represented in this resource does not contain information about the species that was harvested or the volume that was obtained. This is a major limitation as the data can only provide information for performing spatial analysis and cannot provide information for economic analysis. More detailed treatment data does exist and can be obtained from agencies and organizations given more time granted that they approve of its use. This task was beyond the scope of the study but would prove very useful for furthering this research and performing economic estimations in coordination with the spatial component.

5. INDUSRY CLUSTER ANALYSIS ON NORTHERN COLORADO SAWMILLS

The industry cluster analysis was performed with the intention of demonstrating the potential of the maps and layers which make up the spatial resource. This section contains methods and a discussion for one example of how the tool can be used. Another objective of the cluster analysis was to expand our knowledge of some Colorado sawmills using the mapping tool for spatial analysis, supplemented with telephone interviews and statistical analysis for additional sawmill information. Because feedstock characteristics (e.g., location, species type, ownership) play such a large role in the wood products industry chain, these characteristics were of primary focus, particularly how feedstock characteristics relate to sawmill characteristics (e.g., output volume, distance traveled to obtain feedstock).

5.1. Population and Study Site

To create the most accurate representation of the geographic footprint of Colorado's wood products facilities for the decision-making tool, data collection encompassed all associated facilities including sawmills, log home producers, furniture manufacturers, biomass producers and forestry contractors. The population of interest for the cluster analysis was narrowed to only sawmills. Doing a complete survey of Colorado's sawmills would be a rather arduous and time-consuming task and was out of the scope and time frame of this project. For this reason, only sawmills occurring within these five north-central counties were considered: Routt, Jackson, Larimer, Grand and Boulder. Sawmills located just beyond county and state lines were included based on their potential to use wood as feedstock from counties considered in the industry cluster region. One additional sawmill located outside the five county area was included based on prior knowledge that its feedstock originates from those five counties and the fact that it is one of the largest sawmills in Colorado and its exclusion would leave a gap in the study's representation of key wood processors obtaining feedstock from the industry cluster area. The decision to study this area stemmed from its high proportion of forested land, its dense human population, its presence of numerous sawmills and the fact that the northern Front Range region is in need of a more comprehensive information source on its sawmills and feedstock.

While this cluster analysis only provides northern Colorado sawmill data, it sets the framework and aids in the effort to obtain sawmill data state-wide. Licata et al. (2015) provided some feedstock to sawmill/contractor data for the southwestern part of the state and some sawmill and harvest data was collected in the 4-corner states (Arizona, Colorado, New Mexico and Utah) by Sorenson et al. (2012). Contractor data was collected state-wide via Vaughan and Mackes (2015). The sawmill data collected in this industry cluster analysis supplements existing data and provides opportunities to further this research for other parts of the state. Additionally, some of the findings in this industry cluster analysis can roughly be applied to other sawmills or areas in the state provided that they have similar circumstances.

Sawmills included in the survey were selected based on their location. There are limitations to the industry cluster findings for this reason. The industry cluster analysis cannot accurately represent the entire population as a whole (all sawmills in Colorado) because the only area surveyed was the north-central part of Colorado. This area may differ greatly from all other parts of the state. The available timberland and timber species may differ as well as land ownership, land use, road networks, population and available markets. The industry cluster findings only reflect trends and relationships occurring within the study site area.

5.2. Methodology

5.2.1. Sample Development and Hypotheses

Sawmills were extracted from the overall solid wood producer facility layer and projected as a separate data layer referred to as Industry Cluster Sawmills (Figure 5.1).

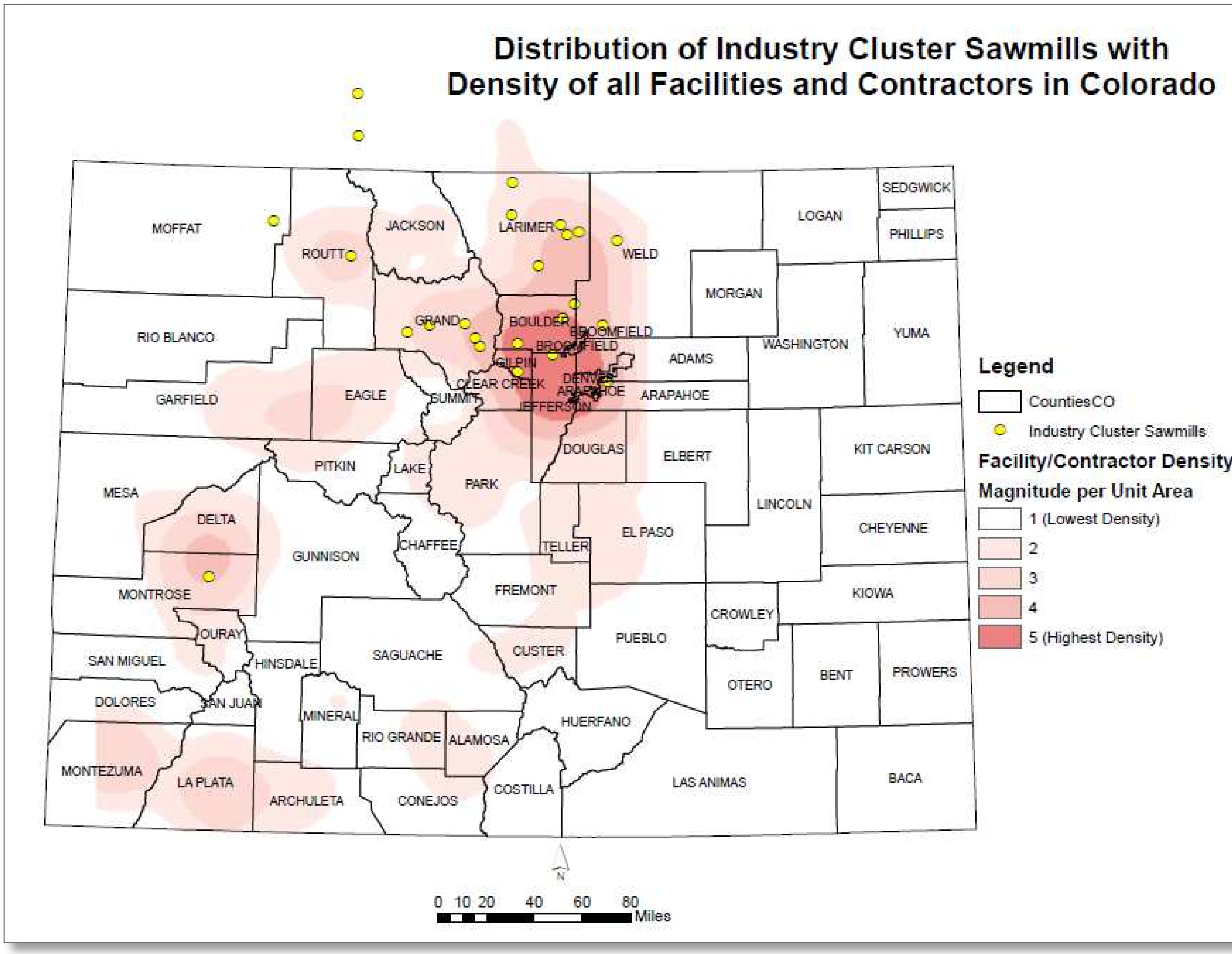

Figure 5.1. Distribution of industry cluster study sawmills with the overall density of Colorado's wood products facilities and contractors.

The sawmills shown in Figure 5.1 were asked a set of pre-determined questions that sought to address the hypotheses listed in chapter 1. Interviews were performed via telephone or site visits. This entailed attempting to contact a total of 27 potential sawmills and asking them questions which involved sawmill and feedstock characteristics.

These questions were based off a timber processing survey performed in 2015 for a report on the timber economy in Southwest Colorado (Licata et al., 2015). Some questions were changed or added to better suit the objectives of this study. The first questions ensured that the facilities were in fact sawmills, and that some or all of their feedstock came from Colorado. Those meeting these criteria were included in the analysis and those who didn't were not.

Interview Questions:

1. What type of processing facility are you?
2. What is your annual production volume in board-feet?
3. What states do you obtain feedstock from? What percentage from each state if more than one?
4. If Colorado, which counties are your logs from? What forests are your logs from?
5. Feedstock ownership origin (%)? (State, USFS, BLM, other Public, own forest lands, other forest industry lands, Tribal?)
6. What is the average and maximum distance you reach out to obtain feedstock?
7. Which species do you utilize and about what percentage does each species make of your total production?

All data collected from interviewing or doing spatial analyses were initially tabulated in Microsoft Excel. Simple descriptive statistics (e.g., means, percentages) were used to summarize the data and show basic relationships within it. Quantitative data was analyzed by means of interactive statistical analysis via linear regressions using Minitab17 statistical software. A critical alpha level of $P<0.05$ was adopted for all significance tests. The independent variables were sawmill capacity (annual production volume in board feet), species being utilized, feedstock ownership origin, distance to recent forest management activities and number of other sawmills occurring within a 50-mile radius. The dependent variable was working distance, or the distance sawmills reach out for log procurement.

5.2.2. Data Collection

The first hypothesis tests if larger sawmills with greater annual production volumes, given in board-feet (BDFT), have larger working distances, given in miles. This relationship was investigated by doing a linear regression using Minitab17 statistical software which determined if there was a statistically significant relationship between these two variables or if the results were more likely due to chance.

The second hypothesis required spatial analysis prior to statistical analysis to obtain values for representing proximity of sawmills to forest management treatments. Several layers were required to obtain measurements: transportation layers (interstates, highways, local roads and forest roads), imagery basemap layer, Industry Cluster Sawmills layer and all treatment layers. While often times a sawmill's harvest range is depicted as a radius with the sawmill at the center of a circle, the actual working distance is more typically an irregular area driven mainly by road networks. For this reason, the Measurement tool in ArcMap was used to estimate the mileage between sawmills and treatments by following along roadways rather than just measuring a straight line from sawmill to treatment (Figure 5.2). The transportation layers were mainly followed but in cases where these layers didn't provide roads needed for connection, the imagery basemap was used to find direct routes and measure accordingly. For each sawmill, the top three closest treatment sites were measured. In order to obtain a conservative number, the farthest point for each of the treatments was used. An average of the three sites was taken and then put into a linear regression to discover if there was a significant relationship between sawmill distance to forest management sites and working distance, or if the results were simply due to chance.

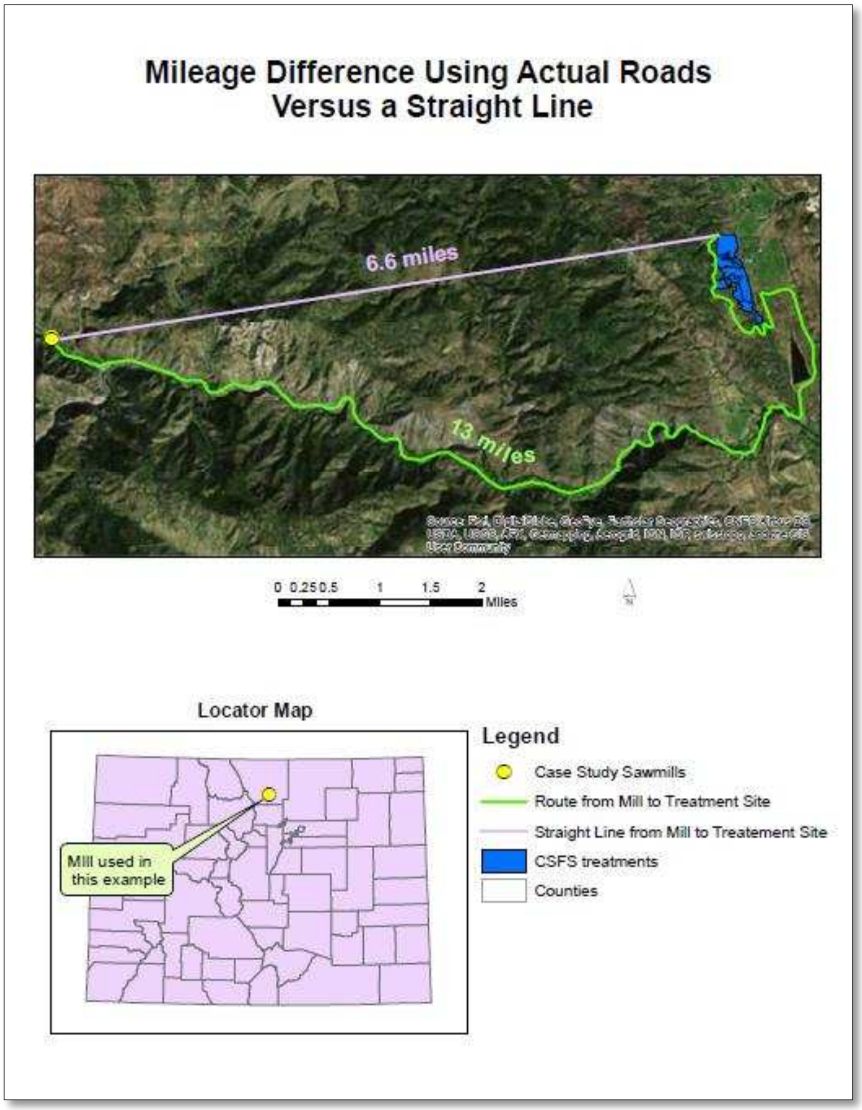

Figure 5.2. Example of differing distances between measuring a straight line (radius) and following along roads

The third hypothesis tests if there is a relationship between federally owned feedstock and working radius. This hypothesis stemmed from the fact that the USFS is the largest timberland holder in the 5 county cluster analysis area (Table 5.1). Figure 4.8 displayed that a large majority of Colorado's facilities are surrounded by USFS land.

Table 5.1.
Area of timberland for north-central Colorado (5 County Area: Routt, Jackson, Grand, Larimer, Boulder) by Forest Type Group from Forest Inventory Data Online (FIDO 1.5.1) website, inventory year 2014.

	Ownership Group (acres)						
Forest-type Group	National Forest	National Park Service	Bureau of Land Management	State	Local (county, municipal, etc.)	Private	Total
Pinyon / juniper	0	0	0	0	0	0	0
Douglas-fir	77937	0	8678	9954	6380	66183	169131
Ponderosa pine	106790	0	0	4673	0	124087	235550
Fir / spruce / mountian hemlock	593451	0	15135	6230	0	48923	663740
Lodgepole pine	382786	0	33788	0	6503	40729	463807
Other western softwoods	7144	0	0	0	0	0	7144
Elm / ash / cottonwood	0	0	0	746	0	3286	4032
Aspen / birch	285574	0	48840	31008	0	184238	549660
Woodland hardwoods	0	0	0	0	0	0	0
Nonstocked	58570	0	0	4673	0	28111	91354
Total	1512252	0	106441	57284	12883	495557	2184418

Feedstock ownerships and working distances were collected during sawmill interviews. The ownership variable was coded as 1, signifying use of federally owned timber (in any amount), and 0, signifying no use of federally owned timber at all. A regression analysis was performed to determine if this relationship was significant or if it was just due to chance. Similarly, the fourth hypothesis was addressed by doing a regression analysis to discover significant relationships between the main species used by sawmills and their working distance.

The Buffer Spatial analysis tool in ArcMap was used to investigate competition. A fifty mile buffer was placed on each sawmill and the number of other sawmills occurring within that radius was tallied. A linear regression was used to discover any relationship between working distance and competition.

5.3. Results

Twelve of the 27 businesses contacted responded to the interview, the rest either could not be contacted, were out of business, were contractors rather than sawmills, weren't willing to participate or weren't willing to answer certain interview questions. The average maximum working distance for those who responded to the interview was 125 miles. The distribution was skewed right with the majority between 50 and 100 miles. The histogram and box plot reveals that one sawmill is willing to travel much farther than the majority (Figure 5.3).

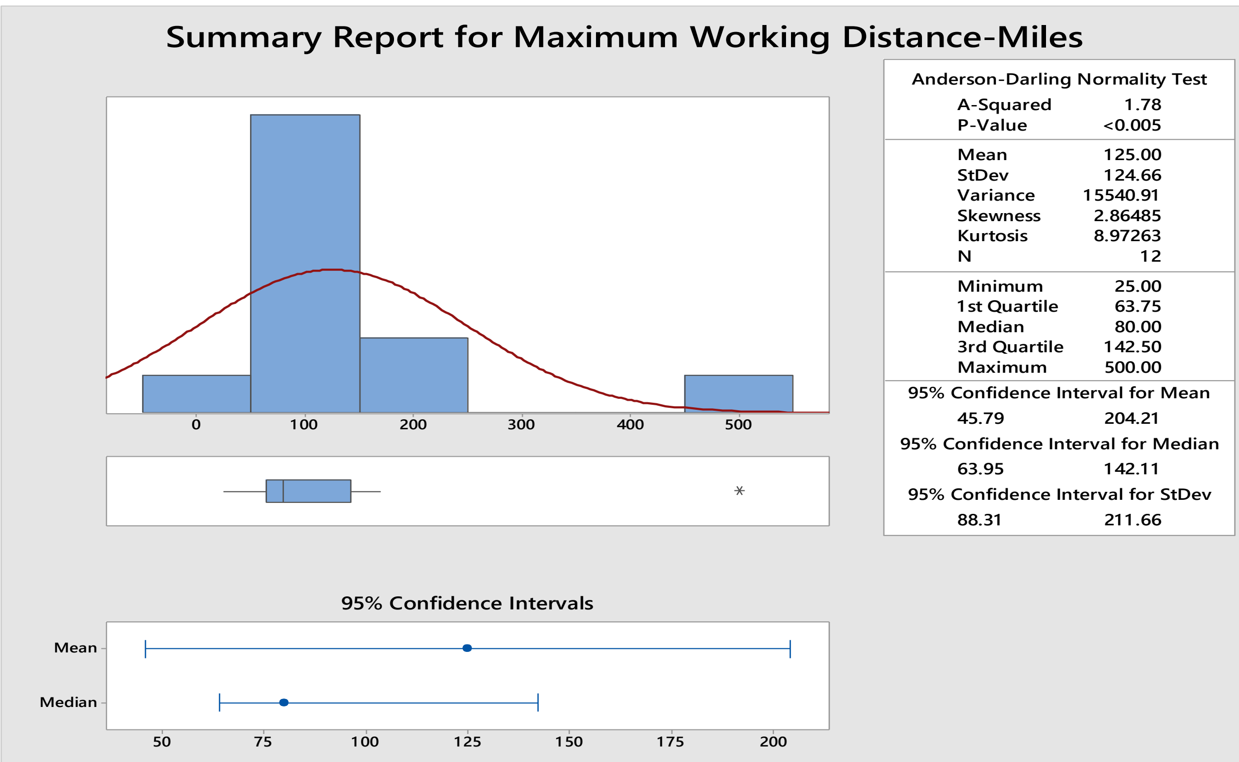

Figure 5.3. Basic summary statistics report for the working distance of sawmills that responded to the interview.

Sawmills were also asked their average working distance. This variable was more normally distributed than maximum working distance. The mean average working distance was 74.583 miles. The median value was 60 miles. Again, the Figure shows that one sawmill traveled farther on average for log procurement (Figure 5.4).

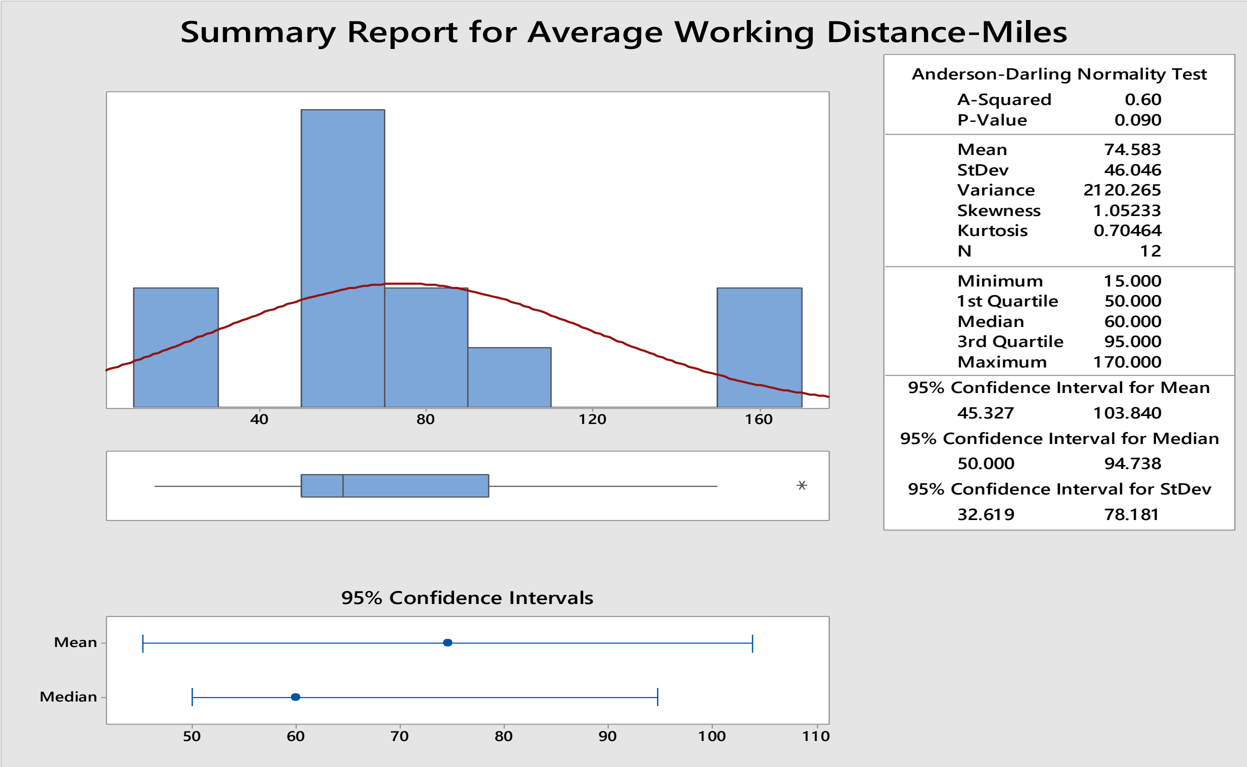

Figure 5.4. Basic summary statistics report for average working distance of sawmills that responded to the interview.

The mean annual production volume of industry cluster sawmills was about 12.6 million board-feet per sawmill. The distribution was heavily skewed to the right. The majority of sawmills that responded to the interview were small, producing 500,000 or less board-feet annually. Only three were in the mid-range, producing between 3-5 million board-feet annually. Figure 5.5 shows two sawmills produced a good deal more than all the rest; between 50-80 million board-feet annually.

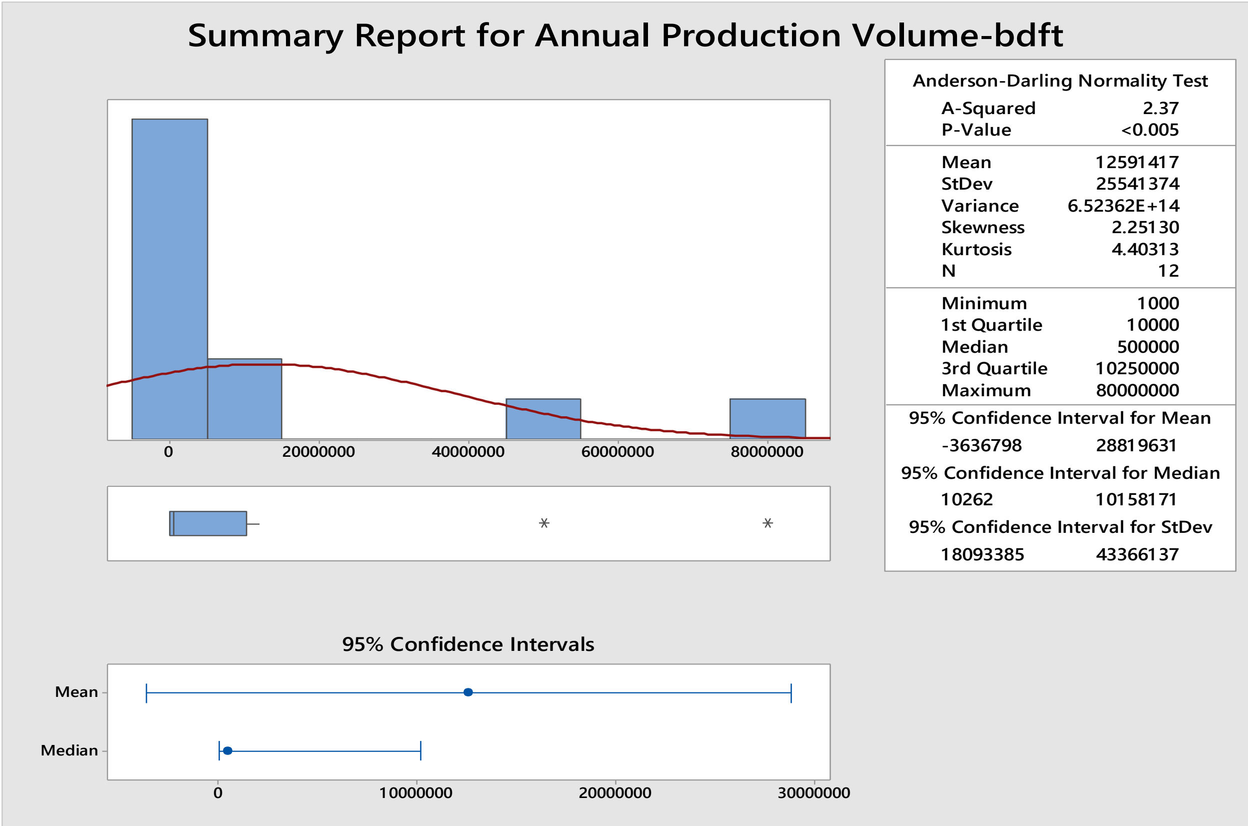

Figure 5.5. Basic summary statistics report for the annual production volume of mills that responded to the interview.

The first hypothesis suggested that larger sawmills with greater annual production volumes would be willing to reach out farther for log procurement. Figure 5.6 shows the regression model for maximum working distance with annual production volume. A P-value of 0.008 indicates that there is a significant relationship, but with an adjusted R-square value of 53.0%, the correlation between maximum working distance and annual production volume is weak. Figure 5.7 shows the regression model for average working distance with annual production volume. A P-value of 0.235 indicates that annual production volume is not a meaningful predictor variable.

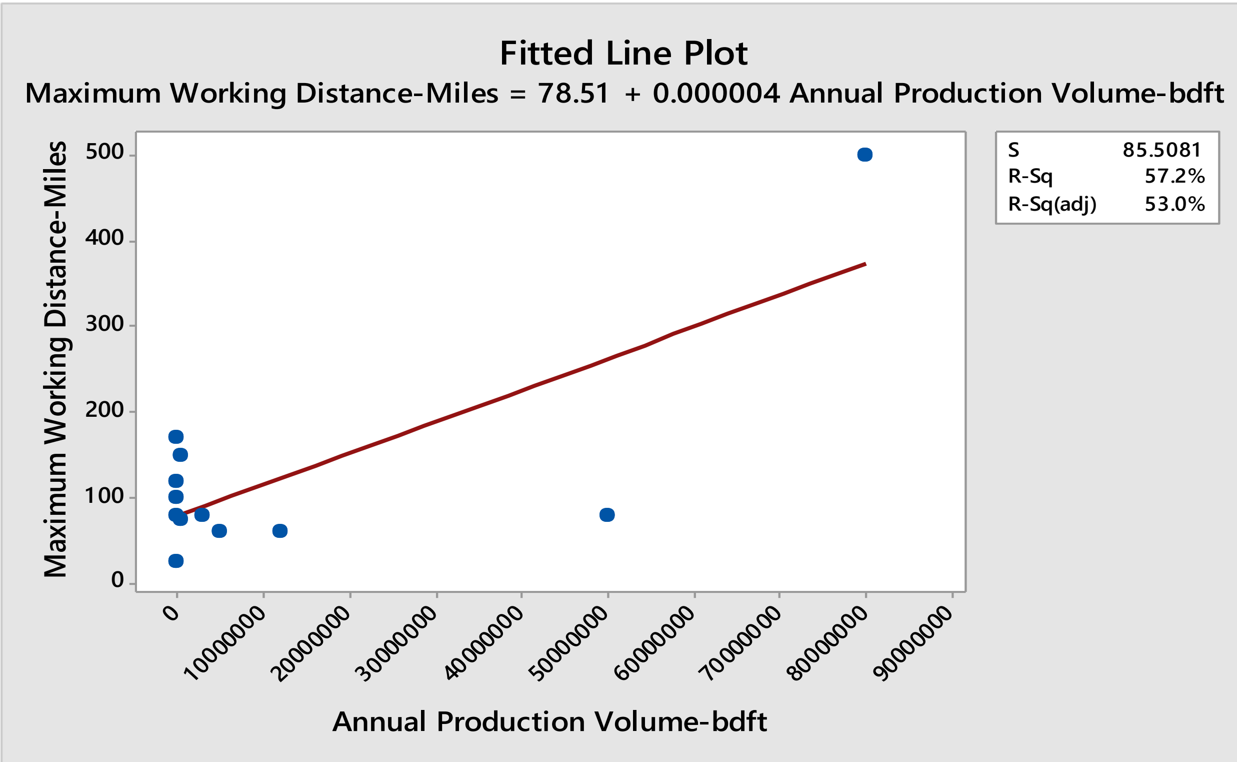

Figure 5.6. Regression model for maximum working distance, the response variable, and annual production volume, the predictor variable, P-value 0.008.

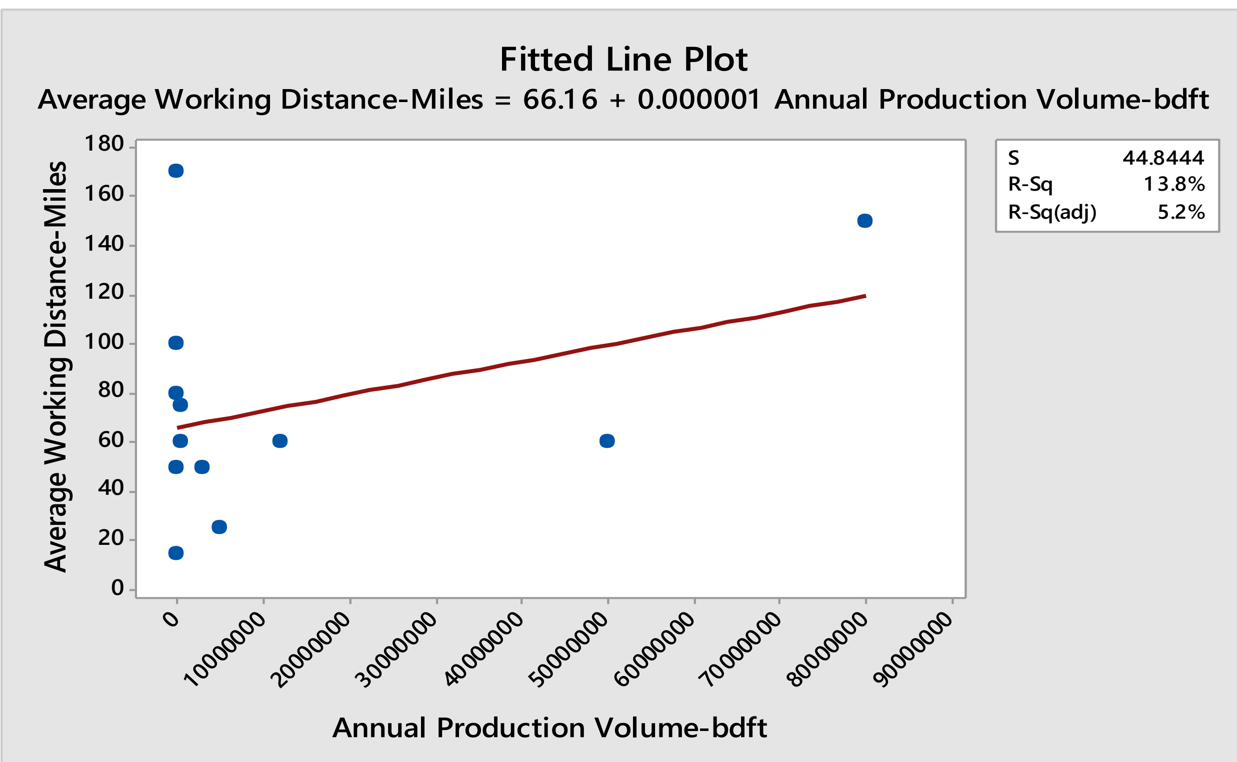

Figure 5.7. Regression model for average working distance, the response variable, and annual production volume, the predictor variable, P-value 0.235.

On average, sawmills participating in this study were about 26 miles from the closest forest management occurring in the last 6 years. The majority of sawmills reported that they work with feedstock from both private and public land ownership. Four strictly worked with private, two strictly worked with public. All but three sawmills used lodgepole pine in the greatest proportion for their feedstock species. No significant statistical relationships were found by performing linear regressions for working distance with proximity to treatments, feedstock ownership origin or the tree species being processed.

The fifth hypothesis suggested that increased competition would cause sawmills to reach out farther for feedstock. The next two figures show the relationship between sawmills occurring within a 50-mile radius with maximum working distance (Figure 5.8) and average working distance (Figure 5.9).

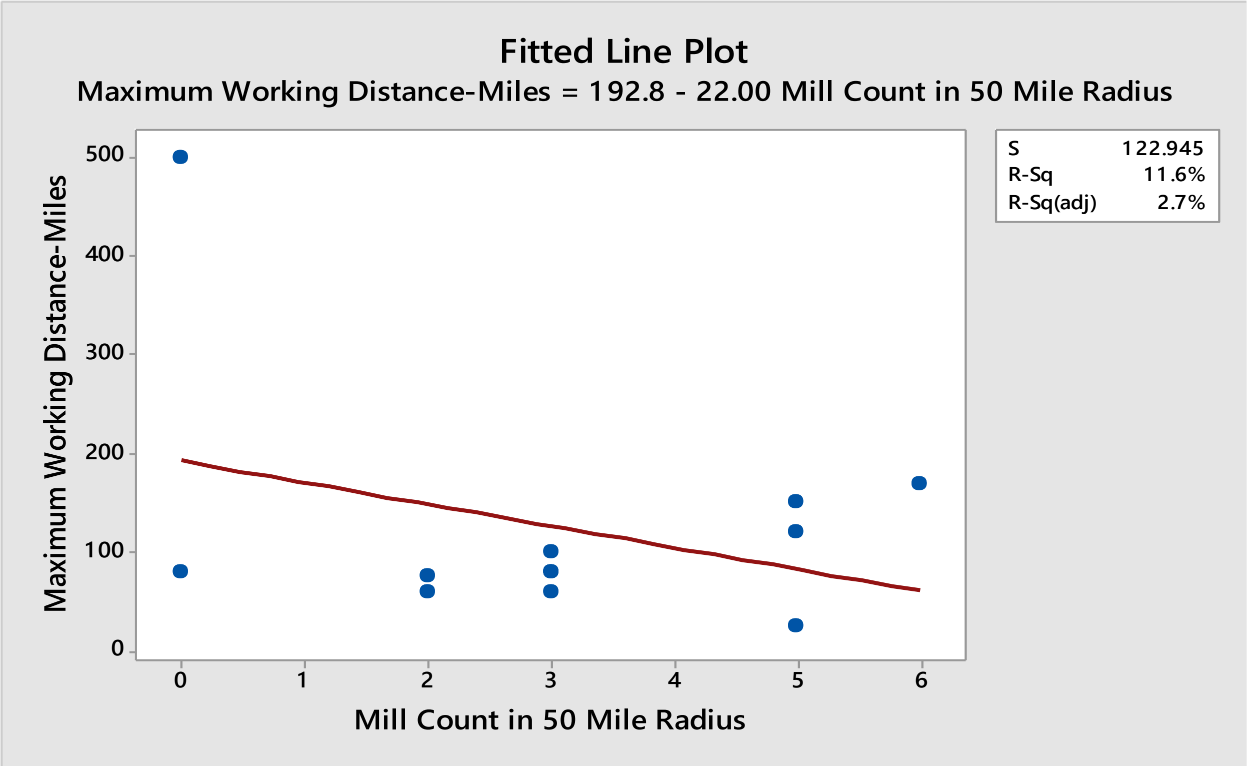

Figure 5.8. Regression model for maximum working distance, the response variable, and the number of sawmills occurring in a 50-mile radius, the predictor variable, P-value 0.406.

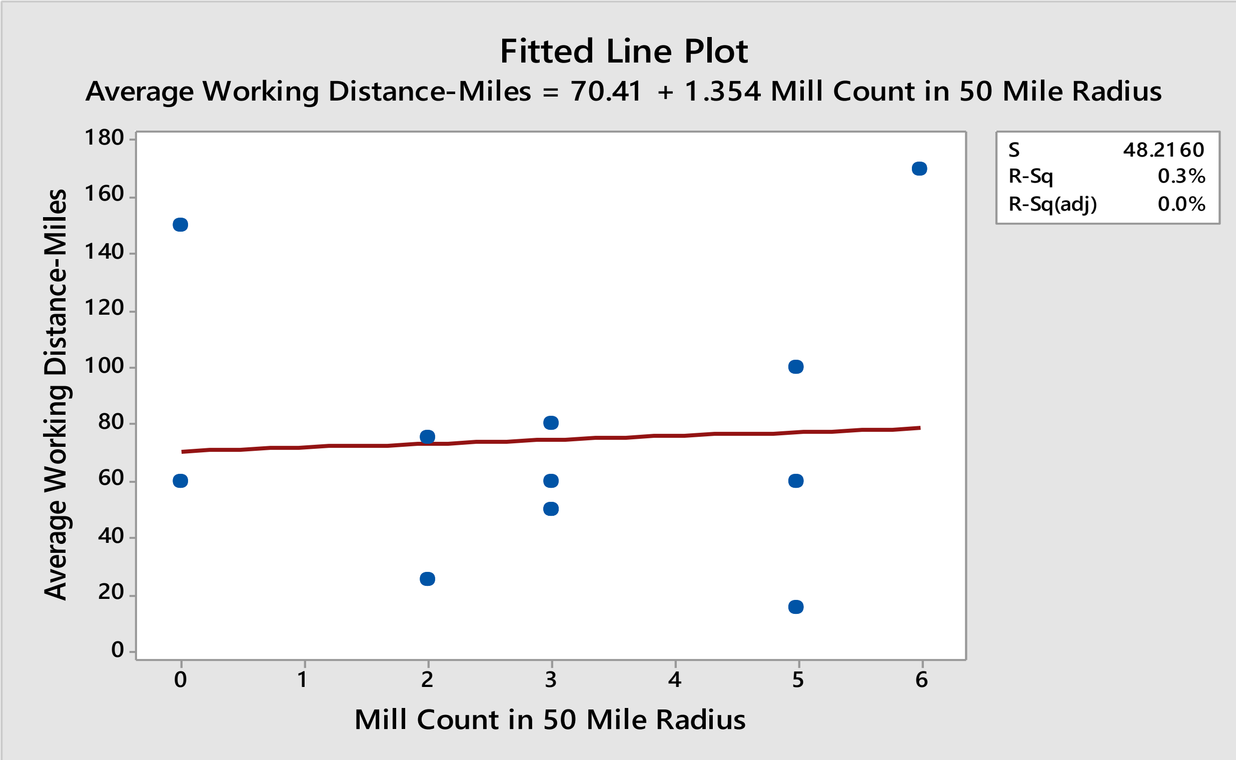

Figure 5.9. Regression model for average working distance, the response variable, and the number of sawmills occurring in a 50-mile radius, the predictor variable, P-value 0.861.

Insignificant P-values indicate that competition is not a useful predictor of maximum working distance or average working distance in these models.

The final hypothesis suggested that competition is inversely related to annual product volume. The regression model in figure 5.10 indicates that sawmills occurring within a 50-mile radius was a significant predictor variable for annual production volume (P-value 0.008), but with an adjusted R-square value of 52.0%, the correlation is weak.

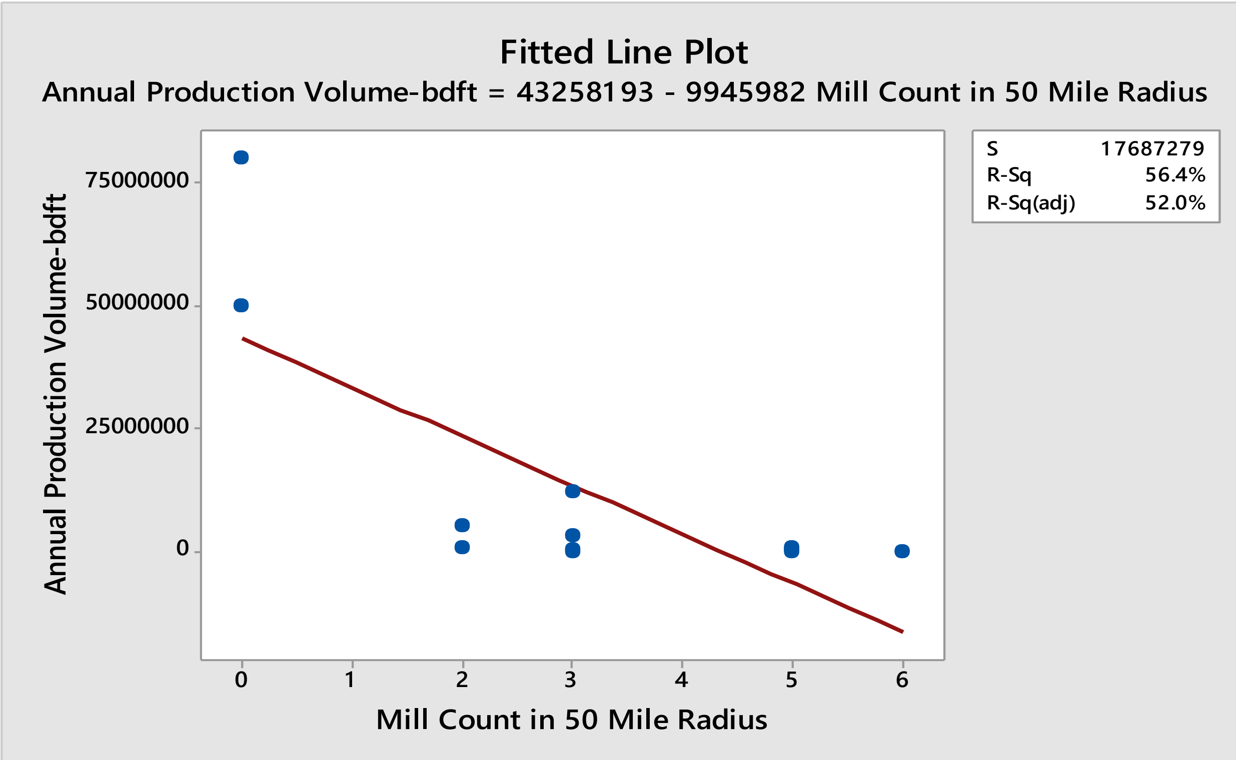

Figure 5.10. Regression model for maximum working distance, the response variable, and the number of sawmills occurring in a 50-mile radius, the predictor variable, P-value 0.008.

5.4. Discussion

The industry cluster analysis interviews returned sample size of 12 sawmills for statistically analyzing quantitative data. Although this sample size was smaller than anticipated, it represented a high percentage of the sawmill capacity (>90%) in the cluster analysis area and the data collected provided insight for general trends in northern Colorado and helped to recognize where further research is needed.

Colorado had 84 sawmills in 1982. Only 31 remained as of 2012. The smaller sawmills, though far greater in number, produced very little of the total volume produced. 90% of the total harvest was processed by larger sawmills (Table 5.2).

Table 5.2.
Colorado lumber production by sawmill size, reproduced from the Four Corners Timber Harvest and Forest Products Industry 2012 report (Sorenson et al., 2012).

Size class[a]	Number of sawmills	Volume (MBF[b])	Percentage of total	Average per sawmill
Over 2 MMBF	8	86,507	91	10,813
Under 2 MMBF	23	8,887	9	386
Total	31	95,394	100	3,077

[a] Size class is based on reported lumber production. MMBF denotes million board feet lumber tally.
[b]MBF = thousand board feet lumber tally.

Similar results were found in the cluster analysis data, where there was a lack of mid-sized sawmills. Basic summary statistics revealed that 7 mills produced 500,000 or less board-feet annually, two produced over 50 million board feet annually and only two sawmills produced an amount somewhere in between. A greater number of sawmills of varying output volumes in the sample would likely express more significant trends, but would also require expanding the study area. Performing a complete survey of Colorado's sawmills would be a potential opportunity for future research. Some of the sawmill data has already been collected in this study and the methods for collection and analysis are already outlined.   A greater sample size would provide greater opportunity for identifying trends and relationships.

About half the sawmills included in the cluster analysis worked with both public and private land ownership. Feedstock origin was a difficult factor to analyze because it changes frequently and is greatly dependent on forest management activities of agencies in the region. Several sawmills explained how their feedstock ownership origin has changed through the years depending upon what is available at the time. Personal experiences and opinions can also impact feedstock origin regardless of proximity. Two sawmills worked only with public and four worked only with private. More than one of the four individuals who worked strictly with private feedstock related that the reason for exclusively working with private timber was due to bad personal experiences and lack of work on public land in close proximity to them.

Almost all sawmills in this study were currently utilizing beetle-kill lodgepole pine so the regression was insignificant. Lodgepole is a prominent species in this area so it is intuitive that it is being processed it in largest proportion. Species used by sawmills is greatly dependent upon the work that is available at the time, so feedstock species often change for sawmills. Again, agency forest management is a main driver of what species are made available. Currently there is a big push in Colorado to treat the areas affected by beetle kill as well as treat areas at high fire risk. Once these areas are treated, the amount of lodgepole pine being processed by sawmills may decrease as a result.

There was not a significant statistical relationship between the species being used and the distance sawmills travel for log procurement. This could be due to insufficient sample size. Several sawmills very clearly indicated that they travel farther for timber of greater value which depends on both species and size. The largest sawmill in the study, producing 80 million board-feet annually, does not process lodgepole pine in the greatest proportion, rather spruce-fir species which are known to hold greater value. This sawmill reported traveling the farthest distance for log procurement.

Proximity of sawmills to the recent treatment areas had no significant statistical effect on distance traveled for log procurement. There was no practical means of confirming that the sawmill closest to a treatment area was actually the one processing it. In other words, just because a sawmill is closest to a given treatment area it does not mean that it was under contract with that sawmill, which is a definite limitation when considering this factor. Nonetheless, the treatment data was used to show a facility's proximity to where recent forest management has been occurring and where timber has been available in the past 6 years.

Some sawmills produced very little annually but were still willing to travel long distances. The smallest sawmill in the study was willing to travel almost twice as far as one of the largest. It is possible that sawmills are willing to travel farther to stay open even if the costs aren't exactly in their favor. Additionally, some data may not have been precise estimates of distance traveled. Some estimates may have been traveling distance from several years ago or in some cases, people being interviewed either didn't know or had a difficult time coming up with an accurate estimate of annual board-feet production and/or working distance.

Another factor was competition. The regression models for maximum and average working distance with number of sawmills in a 50-mile radius were not significant (Figure 5.8; Figure 5.9). With a greater sample size these trends might be better defined.

The most significant relationship of the study was shown in the regression of annual production with the number of sawmills occurring in a 50-mile radius (Figure 5.10). A P-value of 0.008 indicates strong evidence against the null hypothesis, meaning that competition is inversely related to annual production volume. In other words, sawmills have a higher production volume where competition is minimized. The two largest sawmills in the study had zero competition within a 50-mile radius.

6. SUMMARY AND CONCLUSIONS

In this study a mapping tool was created to be used as the spatial component of DSS for Colorado's forest products industry. The data was created and manipulated using ArcGIS software. The resource shows how Colorado's forest products facilities and contractors are distributed in relation to demographics, transportation thoroughfares, land ownership, wildfire risk, insect and disease damage and recent forest management treatments. Finding current and accurate data was essential to this tool's validity and proved to be the largest task.

Altogether about 230 facilities and contractors were collected. The maps displayed the distribution of bioenergy and solid wood producers, current and potential biomass users and contractors. Knowing the location of different types of processing facilities or contractors across the state is useful information for many end-users. These maps can be useful to agencies when making decisions prior to cruising for forest management or timber sales. If an area requiring treatment is far from any processing facility it may be hard for contractors to bid. Having spatial information on potential facilities prior to cruising and bidding allows for better-informed decisions prior to spending money on cruising.

These maps can also be used by contractors when looking into general logistics related to site species, slope, road availability, terrain, etc. before bidding on a job. Those interested in obtaining feedstock supply for heating or powering their facility can use these maps to investigate where potential, sustainable feedstock supplies exists and for existing producers to collaborate with existing users to increase utilization. Those interested in converting their facility to use woody biomass for heat or electricity can also use these maps to better understand the candidacy of their facility's location.

The purpose of the industry cluster analysis was to utilize the spatial resource for collecting data to find trends as well as contribute in the effort to collect sawmill data state-wide. While the results were lacking due to limited sample size, the industry cluster analysis was useful for demonstrating how the tool can be used to collect spatial information such as proximity to recent forest management sites and the number of sawmills that occur within a 50-mile radius.

A sample size of 12 sawmills, representing over 90% of sawmill capacity in the cluster analysis area, were included in the analyses. The initial results provided evidence which failed to reject the first null hypothesis, showing a statistically significant relationship between maximum working distance and annual production volume. Although, an adjusted R-squared value of 53.0% represented a weak correlation. The results provided evidence which rejected the second, third, fourth and fifth null hypotheses. No significant relationships were found between working distance and proximity to treatments, feedstock origin, species being processed or the number of sawmills occurring within a 50-mile radius. While a relationship was not found between working distance and competition, results provided evidence which failed to reject the sixth null hypothesis, showing a statistically significant relationship between annual production volume and competition. The R-squared value for this model was 52.0% which indicates a weak correlation.

A definite limitation to the industry cluster analysis findings was sample size. Given more time, a complete survey of sawmills state-wide would have been beneficial. A greater sample size would provide more statistical capabilities and more robust findings. An opportunity for future research exists in taking the data already collected in the northern region by this study, and the data already collected in the southwest region in the Licata et al. (2015) study, and filling in the gaps with the rest of the state to find significant relationships associated with sawmill product volume.

This study provides many opportunities for future research. Currently the tool is limited in its economic capabilities. Obtaining more detailed treatment data that incorporates the species and volumes harvested from each treatment would allow for greater economic evaluations of the forest products industry, relationships between sawmill and feedstock and transportation feasibilities.

Another area where opportunity exists for future research is improving upon the working distance and proximity to treatment variables used in the cluster analysis. Working distance was obtained by asking sawmills the maximum and average distance they reach out for log procurement. This approach leaves room for a lot of variability. These numbers were estimations provided from sawmill owners who were asked on the spot to provide answers off the top of their head. The actual distance they travel may be very different from the number provided in this cluster analysis interview. Measuring sawmill proximity to nearest treatments also had limitations. While intuitively it would make sense that the closest treatments to a sawmill would be processed by that sawmill, this is not always the case. Proximity to treatments was used to show how close sawmills were to where timber has been available in recent years, not necessarily where they pulled logs from. Taking a sample of logs coming into a sawmill would address these limitations. The species, size and origin could be recorded for each log so as to better understand the distance sawmills go depending on timber value and what timber is being made available at the time.

One overall limitation is the format in which the data is displayed. A limited amount of detail is provided which might not be sufficient depending upon the users' objectives. The ability to over-lay layers based on individual needs as well as zoom to areas of interest would allow for the greatest potential of this resource. An interactive format would be particularly useful such as the interface provided by the CO-WRAP mapping tool (2012). This tool allows for more detail and the ability to combine data layers based on individual objectives. Another limitation is that the data's current format requires some prior knowledge of GIS and ArcMap software. An opportunity for furthering this research would be to create an interface that is more readily available and does not require GIS experience.

Mapping Colorado's forest products facilities and contractors proved to be a very useful way to visualize the data and discover meaningful relationships that can be used in the DSS of Colorado's forest products industry. This tool aids stakeholders with many differed DSS objectives including sustainability, future forest management, identifying industry hotspots and biomass availability.

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