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AN ANALYSIS OF SMALL DIAMETER FOREST BIOMASS AVAILABILITY AND REMOVAL COSTS IN RAVALLI COUNTY, MONTANA

By

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Traditionally small diameter forest biomass, a by-product of timber harvests, was disposed of by either pile-and-burn, lop-and-scatter, or broadcast burn methods. This thesis has determined the net economic effect that collection and delivery of biomass to a newly established market center has upon a comprehensive ecological forest restoration treatment designed to return lower elevation forests of Ravalli County, Montana to historical fire interval conditions. All lands in the county available for this treatment have been identified using GIS technology, and harvest and delivery costs calculated per acre. There are approximately 69,000 acres in Ravalli County identified via GIS as low elevation frequent fire interval forests. On average, each acre will produce 14 tons per acre of biomass using a whole tree system and 12 tons per acre using a cut-to-length system, at 50% moisture content.

It has been demonstrated that on average positive economic returns result if using either a whole tree or cut-to-length system with biomass collection. Including delivery, whole tree systems will yield from $707 to $1,007 per acre in net revenue; cut-to-length systems yield $289 to $418 per acre in net revenue. Similarly, positive economic returns result without biomass collection and delivery. Including pile and burn costs of $175/acre for small diameter forest biomass, whole tree systems result in $253 to $553 per acre in net revenue and cut-to-length systems generate $140 to $245 per acre in net revenue.

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CHAPTER I

Introduction

1.1 Biomass for Energy

Utilization of biomass for energy purposes is common throughout the world, and the potential to expand its use is believed to be substantial (Sedjo 1997). Fluctuations in fossil fuel prices and increasing environmental controls will continue to provide opportunities for growth in the biomass power industry. Also, the changing nature of the United States electricity industry offers opportunities for non-conventional power sources such as wood (NREL 1998). For decades waste from the forest products industry has been used for energy purposes, and the industry is a major supplier of biomass for energy (bioenergy) in most of the developed world (Sedjo 1997). Traditionally wood-processing facilities, such as sawmills, pulpmills, and plywood mills provided the majority of wood waste used for bioenergy. More recently however, interests of the energy industry have shifted to other types of biomass supply, such as agriculture and plantation-style biomass production (Roos et al. 1999; Lunnan 1997; Downing and Graham 1996) and timber harvest waste (Emergent Solutions 2003; Fiedler et al. 1999; Han et al. 2002; Han, Lee, and Johnson 2004; Keegan et al. 2003). However, collection, delivery and use of timber harvest waste, commonly called slash, were long believed economically un-feasible, and in many regions of the United States, this is still the case.

The estimated cost to generate electricity from biomass ranges from 5.2 to 6.7 cents per kilowatt-hour in the Northwest. In contrast, the cost of generating electricity from a new natural gas-fired power plant is 2.8 cents per kilowatt-hour (OR DOE 2004). And when compared to crude oil, it has been estimated that timber harvest slash and mill residues contain only 46% of the energy content of crude oil (Aden and Ibsen 2004); consequently, electricity and thermal energy industries have largely ignored timber harvest slash as a potential source of energy in favor of fossil fuels. With the price of the next best energy alternative, typically fossil fuels, lower per energy unit, there is little surprise utilizing timber harvest slash for energy is largely considered economically unfeasible. However, the amount of power generated nationally from all biomass, including timber harvest slash, increased 3,500% from the late 1970's to the mid-1990's, overall net power efficiency increased, and current cost estimates of forest biomass in the U.S. are less than $50 per delivered ton (Aden and Ibsen 2004). Accordingly, timber harvest slash as a potential source of biomass for energy is gaining more attention, specifically in heavily forested regions of the country such as western Montana where large-scale timber harvests still occur on private and public lands.

Furthermore, timber harvest slash collection and utilization technology is advancing at a rapid pace. Heavy equipment such as the slash-bundler can collect and package timber harvest slash into compact bundles, which are easily loaded and transported to utilization centers. Equipment such as this, which processes the timber harvest slash into easily handled and storable form, allow for increased efficiency of slash utilization. Other notable timber harvest slash utilizing technologies include thermal energy distribution systems such as boilers and co-generation facilities that produce electricity in conjunction with thermal energy. And when these boilers and co-generation facilities are located at or near the source of their feedstocks, the potential for efficient utilization of this material increases. With increasing efficiency of timber harvest slash use there are a number of effects, one of which is to expedite the reduction of fuel loadings in many overstocked forests, thus resulting in decreased potential for disease, insect infestation, and catastrophic wildfire.

1.2 The Effects of Wildfire, and Lack of, in Western Montana

Throughout the west, and specifically in western Montana, much of the new attention given to small diameter forest biomass is a result of several recent years of severe wildfire activity and a growing portion of the State's residents supporting forest management activities that reduce the potential for catastrophic wildfires. Wildfires burn millions of acres every year in the United States, and on average thousands of acres are burned every year in Montana. The Forest Service's long-lived policy of "out by 10 a.m." and its Smokey the Bear campaign have contributed immensely to the public's perception that all wildfires are bad. However, it is now widely recognized that wildfire is a natural part of forest ecosystems, with many ecosystems directly dependent on wildfire (Sampson, Clark and Morelan 1995). It has been estimated that prior to industrialization (~ 200 – 500 years before present) approximately 86 to 212 million acres burned 584 to 1,355 million tons of aboveground biomass every year in the United States (Leenhouts 1998). The number of acres burned in wildfires in recent years accounts for approximately 5% of the pre-industrial acreages burned. And this lack of wildfire in fire-dependent ecosystems has in many places resulted in ecologically imbalanced forests prone to destructive wildfires.

Historically in many lower elevation forest types of western Montana wildfire occurred approximately every ten to twenty years, burning fuels on the forest floor, recycling nutrients, and killing small trees. Wildfires were and are part of the equilibrium between biotic production and decomposition, and are the primary oxidation mechanism in many western forest ecosystems due to their relatively slow decomposition rates (Leenhouts 1998). Over time, forests of large fire-tolerant trees, such as pine and larch, dominated much of the area (Sampson, Clark and Morelan 1995) but due to a century of rapid and successful wildfire suppression, many ecosystems that have adapted to wildland fire have become increasingly unstable. Without the effects of natural wildland fire, many western Montana forest ecosystems are now plagued with overstocking, excessive fuel accumulation, stagnation, and factors that encourage disease and insects (Leenhouts 1998). Because of so many years of fire exclusion, re-introducing fire via prescribed burning or allowing wildfire to return naturally could be disastrous, as evidenced in many of the west's recent wildfire seasons, and particularly the Montana wildfires of 2000.

It has been estimated that approximately 60% of federal forestlands in Idaho and Montana are currently subject to lethal or stand replacing fires (O'Laughlin 2002). Of Montana's 22.3 million acres of forestland, 82% are deemed to have a high (stand replacing) or moderate fire hazard rating. Previous research has shown that approximately 9.3 million acres of Montana forestlands are short interval, fire-adapted ecosystems (Fiedler et al. 2001a) that historically relied on frequent, low intensity ground fires to naturally dispose of forest floor accumulations, such as down woody debris, and seedlings and saplings. Of these, about 7.6 million acres are rated high or moderate for fire hazard. This means that when fire does occur in forests with excessive fuel loads, aside from the potential loss of human life and property, the effects can be devastating to the forest ecosystem. Wildfires typical in this kind of situation often cost millions of dollars to suppress, require an extraordinary amount of resources that cannot be used in suppression efforts of wildfires elsewhere, and leave in their wake what appears to be a thoroughly destroyed landscape. And this is in addition the potential for human fatalities and destruction of property where forested wildland areas are adjacent to human development.

1.3 Wildfire in the Wildland-Urban Interface

Much of this desire for minimal wildfire activity is due to the rural nature of many of Montana's towns. Ravalli County, the area of concern in this thesis, is located in west central Montana on the eastern border of Idaho and the Selway-Bitterroot Wilderness, and is home to the Bitterroot Valley (Figure 1.1). Of the county's 1.53 million acres, 1.11 acres, or approximately 72%, are in the Bitterroot National Forest, which surrounds the Bitterroot Valley on three sides. Due to the overwhelming abundance of National Forest, every city and town in Ravalli County is located in the wildland-urban interface. Commonly defined, the wildland-urban interface (WUI) "exists where humans and their development meet or intermix with wildland fuel" (Federal Register 2001). While the populations of these cities and towns in Ravalli County are low, many high value residences and vacation homes exist in the wildland-urban interface and receive a significant portion of total firefighting resources when wildfires occur, as demonstrated in the extraordinary Ravalli County wildfires of 2000.

Although no estimates of wildfire protection and suppression costs are currently available for the wildland-urban interface, estimates of fuels treatment costs do exist (GAO 2003). This suggests government agency knowledge of high value property located in these areas and the need to mitigate destructive wildfires that threaten the structures located in the WUI. But mechanically thinning the forests of Ravalli County to reduce excessive fuels would of course result in massive quantities of timber harvest slash, which because of current collection technology, and more notably distance from

Figure 1.1 – Area of concern - Ravalli County, Montana.

utilization centers, presents a marginal economic opportunity for collection and utilization of this material.

1.4 Wildfire Threat Reduction: Economic Incentives for Fuel Treatments

Due to public interest in reducing the potential for wildfire in forested areas in or near the WUI coupled with advances in timber harvest slash collection and utilizing technology, there is a growing interest in small diameter forest biomass availability and delivered costs. The national Fuels for Schools program, sponsored largely by the USDA Forest Service and several western State Foresters, is a primary proponent of using timber harvest slash as an alternative to traditional heating methods in public schools. These agencies believe that financial incentives for hazardous fuels treatments are created when slash utilizing systems are located in areas adjacent to overstocked public forests. Additionally, timber harvest slash utilizing facilities in the northern Rockies need to be near the harvesting sites to make bioenergy financially feasible (Han et al. 2002). Under the tenets of the Fuels for Schools program, the USDA Forest Service, Forest Products Laboratory located in Madison, Wisconsin, in conjunction with USDA Forest Service State and Private Forestry, provided much of the funding necessary for the first timber harvest slash utilizing facility operated at a public school in Montana, thus creating a 'market center' near the feedstock. The installation of this facility at the Darby School District occurred largely because it was believed that the costs of acquiring local timber harvest slash feedstocks would be low and economically justifiable. Some of the effects of installing this heating system in Darby are 1) the cost of heating with timber harvest slash is approximately one-third annually of the alternative heating method, oil (Scheele 2003), 2) the feedstock is locally derived, providing income and employment to the Bitterroot Valley area community, 3) there is utilization of what was traditionally waste material, and 4) pollutants emitted from open slash burning are reduced.

Following the successful installation of a timber harvest slash utilizing system in Darby, Montana, nearly one dozen other western Montana school districts are exploring opportunities for a similar system. These school districts range geographically from Eureka, located in the northwest corner of Montana, to Big Timber located in central Montana. Two other facilities are currently under construction in Montana, with one in Ravalli County, and are both scheduled to begin operating in Autumn 2004 (U.S. Congress, House 2004). There is also an electricity and thermal energy co-generation facility very near Ravalli County in Frenchtown, Montana that is capable of utilizing a substantial amount of timber harvest slash. The proximity of these market centers in and near the Bitterroot Valley and the Bitterroot National Forest provide newfound opportunities for timber harvest slash collection and utilization.

Furthermore, previous research conducted at the state level has concluded that on average, a comprehensive forest restoration treatment (Fiedler et al. 1999, 2001a), designed to return the low elevation fire adapted forest ecosystems of western Montana to sustainable conditions, results in a per-acre quantity of timber harvest slash stock sufficient to support a modest level of slash utilizing facilities (Fiedler et al. 1999; Keegan et al. 2003). This comprehensive forest restoration treatment also generally provides a per acre quantity of merchantable timber that results in positive operational net revenue if the timber harvest slash is left on site (Fiedler et al. 1999). So with the combination of soon to be three timber harvest slash utilization centers, a known abundance of slash stock, which clearly fuels destructive wildfires, and a silvicultural prescription that produces significant quantities of timber harvest slash and generally results in positive net financial returns, there is now an interesting connection between wildfire mitigation and the economically efficient collection and use of this natural resource.

1.5 Analysis Objectives

With the application of the comprehensive prescription, negative impacts of wildfires are reduced, and cleaner, less expensive fuels become available for rural Montana communities and school districts. But because the economic impact that collection and delivery of timber harvest slash, or small diameter forest biomass, may have upon the overall costs or revenues associated with implementing the comprehensive restoration treatment in Ravalli County are yet unknown, so is its real world application. Therefore, knowing the impact on the overall costs of this treatment of collecting and delivering the small diameter forest biomass in Ravalli County would provide valuable information for land managers considering the treatment for fuel reduction and/or forest restoration.

This analysis has determined the net economic impact that collection and delivery of small diameter forest biomass will have upon the comprehensive forest restoration treatment (Fiedler et al. 1999, 2001a) when applied to selected lands in Ravalli County, Montana. Additionally, the likely volume of small diameter forest biomass made available as a by-product of the comprehensive prescription has been estimated. These objectives were accomplished through 1) examination of forest inventory data, 2) computer modeling the application of the comprehensive prescription on the forest inventory data to develop a representative list of harvested products, 3) identification of low elevation fire-adapted forestlands in Ravalli County suitable for the prescription via Geographic Information System (GIS) technology, and 4) estimation of harvest and delivery costs with and without the collection of small diameter forest biomass. From steps one and two above, an average 'product list' consisting of timber harvest slash, pulplogs, and sawlogs was derived from the implementation of the comprehensive prescription on forest inventory records. As a result of step three, delivery costs were estimated using GIS technology for product delivery to three market centers, which together comprise the likely buyers of all harvested material. From step four above, harvest costs associated with the treatment were estimated for two harvest systems – whole tree and cut-to-length – and overall net revenues or costs associated with harvest and delivery of the materials in the representative 'product list' were determined using product values that reflect current western Montana product values.

It is believed that the results of this analysis have established not only realistic stump to market net costs and/or revenue estimates for the implementation of the prescription in Ravalli County, but also a sound methodology from which subsequent locally oriented analyses can be based. Land managers on the Bitterroot National Forest will find the results of this analysis useful for prioritizing lands for treatment based upon number of acres found in varying land statuses such as Wildland Urban Interface (WUI), Fire Regime Condition Class (FRCC), ownership, and/or forest type. The harvested product estimates derived in this thesis will further provide land managers with harvestable merchantable and sub-merchantable volumes, costs, and values associated with the comprehensive forest restoration treatment, and may assist in timber sale evaluation and/or budgetary planning.

CHAPTER II

Review of the Comprehensive Ecological Restoration Treatment

2.1 Introduction

As previously stated, some low elevation forest types of western Montana have experienced almost a century of wildfire exclusion that has disrupted the pattern and effects of historic wildfire regimes. In addition, in some cases high grade logging took the largest trees that are the most resistant to wildfires, insects, and disease. Consequently, many forest ecosystems are altered and potential for severe wildfire, as well as insect and disease problems, has increased. To mimic the effects of historic wildfires in fire-dependent ecosystems, previously land managers often used prescribed fire. However, due to various social and political obstacles of prescribed fire (Manfredo et al. 1990), and more importantly considering that fuel loads in many of these areas are too high to use prescribed fire, it is believed that mechanically thinning these forests may be the only means to reduce excessive fuels (O'Laughlin 2002). Following is a review of the literature related to the ecology-based forest restoration treatment, or comprehensive prescription, used in this thesis, which is designed to return the low elevation fire-adapted forests of western Montana to pre-fire suppression conditions.

2.2 Ecological Imbalances in Western Forests and "New Forestry"

Historically, ponderosa pine forests were the most common forest types throughout the low elevations of the northern Rockies and Inland West. Research has shown that wildfires are a natural part of forest ecosystems, but because fires have been excluded from forest ecosystems for the past century due to rapid and successful suppression efforts, it has become increasingly clear that many western forests require fuel reduction (Fiedler et al. 2001b). The suppression of natural wildfire activity, as well as the effects of widespread grazing and logging, has significantly altered the composition of many wildland forests, ponderosa pine included (Fiedler et al 2001a). According to Dr. Carl Fiedler (U.S. Congress, House 2000), in a statement to Congress:

> "The most dramatic changes have occurred in the ponderosa pine forests that historically experienced frequent, low-intensity fires. Stands today are much denser, often with twice the cross-sectional stem area as pre-fire suppression stands. Previously open stands have filled in with small and medium-sized trees, sometimes ponderosa pine, but more often shade-tolerant species such as Douglas-fir, true firs, or incense cedar. Small trees serve as "ladder" fuels, allowing normally low-intensity surface fires to torch into the overstory and become intense crown fires. These gradual but directional changes in forest conditions since the early 1900s have created a regional tinderbox -- catastrophic fire potential over millions of acres of the western landscape, with associated threats to human life and property. Hazardous conditions in pine forests have gained national attention because ponderosa pine and pine/fir forests are the most extensive forest type in the West, occupying nearly 40 million acres."

Initially called "New Forestry" by Franklin (1989), the treatment is described as a "kinder and gentler forestry that better accommodates ecological values, while allowing for the extraction of commodities." The New Forestry approach to forest management, which focuses on the maintenance of complex forest fauna and flora ecosystems and habitat and not simply tree removal, stems from the idea that "forestry needs to expand its focus beyond wood production to the perpetuation of diverse forest ecosystems"

(Franklin 1989). Others have stressed that: “Alternatives to traditional silvicultural systems are urgently needed to meet such objectives [as described by Franklin (1989)] and to address strident public criticism. Ultimately, this will be the responsibility of the silviculturists” (Long and Roberts 1992). And while Franklin concedes that many of the concepts embodied in New Forestry are not new, the focus of New Forestry – the maintenance of complex ecosystems and not just the regeneration of trees – is a fresh approach that distinguishes his recommendations from those of traditional forestry practices.

Keegan, Fiedler and Stewart (1995) examined New Forestry as modified versions of traditional prescriptions, both ecologically and operationally. Traditionally, timber harvest objectives were not influenced much by concerns for fauna or flora habitat; rather the emphasis had typically been on the financial success of the operation. Modified versions of New Forestry have placed increasing emphasis on ecological conditions versus financial success. Prescriptions designed to consider contemporary social demands for environmental qualities, such as resource sustainability, as well as those geared to return western conifer forests to pre-interrupted fire interval conditions, are now somewhat generally referred to as ecology based treatments, ecosystem restoration treatments, or more simply, forest restoration treatments. The new attitude toward forestry was a function of “previous experience implementing the principals of ecosystem management [having] shown that forest management should focus more on what is left on the landscape than what is removed” (Missoulian [Missoula], 27 January 2004). This included leaving some large live trees in areas that would other wise be clear-cut, scattered groups of understory trees in selected areas, and standing dead trees as a source of down woody material and organic matter as potential habitat for forest fauna. Fiedler et al. (1999) later described ecosystem restoration and management as "an evolutionary offshoot of New Forestry on national forests in the Inland Northwest" where "The emphasis in restoration treatments is to address fire hazard and forest pest problems, with timber production a by-product of these activities." Keegan, Fiedler and Stewart (1995) believed that responses to the changes set forth by New Forestry practices would take years to evaluate. This due to the length of time required for tree re-generation and observations of wildlife habitat alterations where the impacts of New Forestry were not initially observable.

2.3 Thin-From-Below Treatment

Initially a popular approach to fuel reduction was implementing the thin-from-below treatment. This restoration prescription calls for the removal of all or most small-diameter trees that constitute the forest understory, generally trees less than nine to ten inches in diameter. These small-diameter trees are known to serve as ladder fuels that transport non-severe forest floor fires to the overstory, where fire expansion rapidly occurs. The removal of these small-diameter ladder fuels promotes vigor and growth potential for the remaining larger diameter trees. Thinning-from-below was a somewhat popular first start to fuels reduction, but the high costs, low timber value, and minimal reduction of crown fire spread potential, quickly became an obstacle to widespread application. However, thinning-from-below is still conducted in a typically pre-commercial activity environment.

2.4 The Comprehensive Ecological Restoration Treatment

After the establishment of the thin-from-below prescription in modern forestry, Fiedler et al. (1999, 2001a) proposed an ecologically based treatment to deal with conditions in low elevation Inland Northwest ponderosa pine forests. As part of these treatments the removal of low value medium-size and/or shade tolerant species was incorporated into prescriptions previously designed to remove only the ladder fuels. In addition to its fundamental purpose as an ecological restoration tool this comprehensive prescription can also address the financial concerns that the thin-from-below prescription could not. According to Fiedler (U.S. Congress, House 2000):

> "The comprehensive approach removes ladder fuels, reduces composition of late-successional species (if present), and lowers overall stand density enough to induce regeneration of ponderosa pine and spur development of large-diameter trees. A fundamental difference between the [comprehensive prescription and the thin-from-below prescription] becomes clear during prescription implementation. Rather than focus on the trees to be cut -- as is the case with the thin-from-below prescription, the approach we recommend is to mark the trees to be left in the number, species, size, and juxtaposition that best approximate (or set the stage for) the desired sustainable stand of the future. All trees not designated for leave are cut, which is a diametrically different way of approaching long-term sustainable management than the thin-from-below approach."

This comprehensive prescription is designed to leave approximately 40 – 60 ft^2 of basal area[1] per acre consisting primarily of large trees. Therefore, nearly all trees less than 9-inches diameter at breast height (DBH) are removed with the intended purpose of creating relatively open forests dominated by large trees. Here, cutting is implemented as a means of removing trees that could not be "specifically targeted and killed in a prescribed burn" (Fiedler et al. 2001a). There is in addition to the target basal area described above, an allowable amount of selection cutting that may include leaving some

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[1] The cross section area of the stem or stems of a plant/tree or of all plants/trees in a stand, generally expressed as square units per unit area.

of the healthy small diameter trees in order to allow a new age class of ponderosa pine and/or western larch that in the long run creates a mixed age forest (Fiedler et al 1999). More specifically, the comprehensive prescription calls for trees less than 5-inches DBH to be cut, slashed, piled and burned; virtually all trees 5 to 9-inches DBH are cut and removed for products, while discretionary selection cutting is applied to the trees greater than 9-inches DBH.

To estimate the per acre wood fiber volume that are potentially available from the comprehensive prescription in Montana, Keegan et al. (2003) conducted a review of forest inventory data. The comprehensive prescription was then applied to the forest inventory data to estimate potential removed volumes at the statewide level, which resulted in large-scale timber harvest slash estimates for specified Montana forests that have a high or moderate risk of spreading wildfire. The researchers found that on average, 37.3 oven-dry tons per acre of total harvested material could be expected from those acres west of the continental divide. Of this amount, roughly 9.0 oven-dry tons per acre was identified as best allocated to energy production (i.e. non-merchantable small diameter forest biomass) while the remaining amount consisted of merchantable bole wood. Of the estimated 9.0 tons per acre, 2.5 tons per acre were potentially available from whole trees less than 5-inches DBH, and 6.5 tons per acre were derived from the tops and limbs of the merchantable material greater than 5-inches DBH (Keegan et al. 2003). The researchers did not assume the 5 to 9-inch bole material, which amounts to approximately 7.0 tons per acre, would be used for energy but rather sold as either break even or profitable products.

2.5 The Economics of the Comprehensive Prescription

Harvesting timber with value as a result of implementing the comprehensive prescription has two primary impacts. The first, as described above, is to return Inland west forests to sustainable forest conditions, a condition generally desired by the public and land managers. The second is to offset the costs of the treatment application to either reduce or eliminate any required subsidy or generate net revenue. As stressed above and in the literature (Fiedler et al. 1999), valuable timber is cut only as a function of the comprehensive ecological restoration treatment, and is never done so solely in an effort to reduce treatment costs or increase revenues. As it turns out, often times the value of removed timber can offset treatment costs and will generally result in net revenue for the treatment areas. Following is a brief discussion of the economics associated with the implementation of the comprehensive prescription.

Fiedler et al. (1999, 2001a) used Forest Service inventory records (FIA) from low elevation ponderosa pine forests to evaluate the economics of the comprehensive prescription and the thin-from-below prescription. Forest conditions from frequent fire interval forest types in the Inland West, including Montana, were identified for evaluation. Prescriptions were then applied to each stand under two harvest system alternatives – tractor ground and cable ground – with the results consisting of net revenue per acre by harvest system.

The net revenues associated with the comprehensive prescription were determined from harvest costs derived from a previous study (Keegan et al. 1995) using an expert opinion survey of western Montana loggers and log processors and product prices that reflected western Montana conditions at the time of the analysis. No mention was made of how the transportation costs were derived, which therefore makes comparison with the transportation results in this thesis difficult. Average net revenues range up to $950 per acre with the comprehensive prescription using either harvest system, with or without a pulp market. Again the researchers note that while the comprehensive prescription may very likely produce "substantial" amounts of merchantable timber on average, this should be considered a by-product of the activity and not the driver (Fiedler et al. 1999).

Later, Keegan et al. (2003) estimated harvest costs by product associated with the comprehensive prescription applied in western Montana with a harvest cost model developed for both whole tree and skyline systems (Keegan et al. 2002). Harvest costs included delivery, and this time assumed a 75-mile one-way transportation distance. Implicit in the harvest cost calculations was the notion that the cost of acquiring tops and limbs of trees with merchantable boles is "negligible" due to the "free ride" to the landing this material receives as part of the larger objective of processing those trees for delivery to the mill (Keegan et al. 2003). It was found this component costs from $10 to $20 per bone dry ton. However, it was also found that timber harvest slash could cost up to $70 per bone dry ton if limbing and bucking were done in the woods.

2.6 Timber Harvest Slash Disposal Under the Comprehensive Treatment

Aside from merchantable trees, Fiedler et al. (1999) recommend that from a cost standpoint piling and burning in the woods or at the landing would best deal with the sub- and non-merchantable trees. However, they did not include cost estimates for any method of slash disposal in their cost and revenue calculations. Estimates of prescribed fire on National Forest lands range from $92 per acre for management-ignited burns (USFS 2003a) to $175 per acre for slash reduction burns (Cleaves, Martinez, and Haines 2000). Considering that the comprehensive prescription will produce, on average, a substantial amount of timber harvest slash, it seems clear that the later estimate would represent more accurately the additional costs required for complete forest restoration. But because the Fiedler et al. analysis did not consider the cost of slash collection and delivery, the impact that timber harvest slash disposal has upon the overall financial results of the comprehensive prescription are yet unknown.

Furthermore, social and environmental externalities of widespread slash burning are too great to be ignored. Piling and burning slash in Ravalli County, Montana, and most likely anywhere is going to have associated costs that are not dealt with formally in this thesis, and could very likely impact not only the economic analysis of the Fiedler et al. study, but also the decision of whether or not the prescription would be realistically applied. It would be inappropriate to generically expect public acceptance of such burning activities. And, as Han et al (2004) note, leaving large amounts of dry untreated fuels on the forest floor increases both fire risk and intensity. Therefore the harvest operation must either completely remove the slash or carefully burn the fuels with prescribed fire, both of which require direct expenditures. Burning of course would require community approval and social acceptance of the pollution externality. And because the in-woods residue has the potential to be significant in terms of fire hazard, as well as countering the intended purpose of the prescription, which is to reduce forest floor fuel loadings, leaving the slash would not justify the operation. In this thesis, harvest cost estimates without slash collection and delivery will include the $175 per acre cost shown by Cleaves, Martinez, and Haines (2000) to be the average for slash burning on National Forest lands.

CHAPTER III

Review of Small Diameter Forest Biomass Availability and Associated Harvest and Delivery Cost Estimation Methods Under Alternative Fuel Reduction Treatments

3.1 Introduction

Prior to selecting the timber harvest cost estimation model used in this analysis, a number of harvest cost and production models found in the literature were reviewed. Most models are either region specific, system specific, or even machine combination specific. A large number of the logging harvest cost models require substantial knowledge of specific harvest systems (LoggerPC4, Helipace, LogCost 5.0), components of harvest systems (Falling and Bucking Appraisal) and/or hauling (Log Truck Haul Cost Appraisal, Network 2000) (PNW 2004). In fact, many of these models require extensive knowledge of harvest systems, operators and equipment, and location layout and attributes. However, found in the literature are also harvest cost models that require substantially less operation-specific knowledge.

Other than the research previously discussed related to the comprehensive prescription (Fiedler et al. 1999, 2001a; Keegan et al. 2003), at the time of this analysis there had been no additional studies that analyzed the financial aspects of the comprehensive prescription at the local or regional level. However, a number of studies using alternative silvicultural prescriptions, also designed to reduce forest fuels in varying locations around the western United States, have been conducted. Following is a review of literature that has addressed the issues of small diameter forest biomass availability from silvicultural prescriptions different from the comprehensive prescription, as well related estimates of harvest and delivery costs. First is a review of the some harvest cost estimation models, including the harvest cost model used in this thesis. Then methods for calculating transportation costs, and following that, some previously determined harvest costs and net revenue and/or cost results, and finally methods of small diameter forest biomass volume estimates available from fuel reduction treatments are described.

3.2 Models of Harvest Cost Estimation Found in the Literature

Hartsough et al. (1997) compare the productivity relationships of three different harvest systems, which include whole tree and cut-to-length systems, on naturally regenerated ponderosa pine and mixed conifer stands in the Sierra Nevada region of California to produce thirty-seven model equations. Each of these production functions estimates a single component of a harvest system using specifically defined machinery (i.e. traveling, loading, unloading). Hartsough et al. then combined the hourly productivity estimates with the results of a previous study that estimated hourly equipment costs which resulted in per acre cost estimates for each system activity. From this Hartsough et al. have described a method to estimate per acre harvest costs for whole tree and cut-to-length systems that produce small sawlogs and slash chips.

However, applying this method has its limitations as well. It would be tremendously time consuming to identify and apply the correct activity equation for each product using specific machinery required for each harvest system analyzed. There are undoubtedly numerous factors that influence hourly cost estimates, such as equipment replacement costs, depreciation, salvage value, equipment life, scheduled hours per year, supply and expense costs, maintenance and repair, labor rates, and benefit rates (Hartsough 1997). These are key assumptions that would have to be made by those knowledgeable in these areas, and time necessary spent 'fine-tuning' either of the harvest system modeling procedures would be inhibitive.

Keegan et al. (2002) estimated stump to loaded truck harvest cost estimates for a whole tree system using cost data derived from expert opinion via survey of timber-processing companies and independent logging contractors in Montana. Harvest scenarios that were presented in the survey were based upon an ecological restoration treatment; this model takes the form:

3.1. $Y_i = 28.04 - 1.272X_{1i} - .058X_{2i} - .0069X_{3i}$

In equation 3.1, Y_i = stump to loaded truck costs per green ton expressed in 1998 dollars, X_{1i} = average diameter at breast height, X_{2i} = volume per acre removed, and X_{3i} = average skidding distance.

Utilizing this harvest cost estimation model would have yielded cost estimates that were based on the expert opinion of contractors that have likely conducted harvest operations in the study area. Harvest cost estimates would reflect operating conditions, 1998 wage and benefit rates, and productive machine hour rates, which include operating and maintenance costs. Unfortunately, the model was not intended to estimate harvest costs of trees with average diameters less than 6-inches diameter at breast height (DBH) or larger than 10.5-inches DBH. Additionally, there is no harvest cost estimating procedure within the Keegan et al. (2003) study for a cut-to-length harvest system. Keegan et al. further state that:

> "if the cost of gathering data were not a factor, an industrial engineering approach involving detailed time-and-motion studies might provide data and models with somewhat greater accuracy than achieved here . . . Time-and-motion studies may also be the most precise method to analyze specific operations for factors that affect productivity. For example, how might modest changes in slope influence the productivity of a specific piece of skidding equipment?"

As described by Hartsough et al. (2001), many timber harvest models have been developed ranging from a single harvest activity to stump to mill operations. Some models require minimal input (Keegan et al. 2003) while others may require over a dozen variable inputs (Randhawa, Scott, and Olsen 1992). However, the complexities of some of these models may potentially make them impractical to use in long term planning (Hartsough et al. 2001). Therefore, the combination of information from numerous previous harvest cost studies into a single model that would estimate costs for typical harvest systems was produced requiring minimal data inputs and operation knowledge.

Described by Hartsough et al. (2001), the approach of incorporating existing machine productivities found in the literature into a single harvest cost model was eventually embedded in the stand-alone program STHarvest (Fight, Zhang, and Hartsough 2003). This public domain program is used to estimate the stump to truck cost of harvesting small diameter timber for six common types of harvest systems over a range of stand conditions. Primary variable inputs are common and are 1) trees per acre cut, 2) average cubic foot volume per tree, and 3) green wood density[2]. Other variables include harvest system, partial cut or clearcut, skidding or yarding distance, slope, move-

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[2] The weight of green wood and bark per cubic foot of bole wood, measured in pounds per cubic foot.

in distance, number of acres harvested, and machine costs. Harvest costs are estimated in 1998 dollars per hundred cubic feet and dollars per green ton.

Much like the Keegan et al. (2002) model, this model provides a simple and practical approach to estimating harvest costs, but for six different harvest systems. The model requires minimal user input and is rather easily localized by manipulating hourly machine and labor costs, green wood densities, and volume of tops and limbs removed with the bole. However, STHarvest does not incorporate slash bundling time-and-motion studies into its algorithms, making it necessary to refer to other loading and forwarding models to estimate the costs of collecting and delivering to the landing the slash bundles. It would also be difficult to identify and separate costs for the trees that would be harvested and whole tree chipped (here, trees less than 5-inches DBH) from those that would be processed and loaded onto log trucks for mill delivery.

3.2.1 Fuel Reduction Cost Simulator

At the time of this analysis, work to install diameter class separation ability and slash bundling cost estimates within the STHarvest spreadsheet model was underway by Dr. Roger Fight, Principal Economist, at the USDA Forest Service Pacific Northwest Research Station and Dr. Bruce Hartsough, Professor of Biological and Agricultural Engineering, University of California, Davis. The result was the Fuel Reduction Cost Simulator (FRCS) timber harvest cost model (Hartsough and Fight 2003) which was used in this analysis to estimate stump to loaded truck harvest costs across all diameter classes cut via the comprehensive prescription. FRCS contains all the features of STHarvest, discussed above, but with diameter class separation and slash bundling capability, and was selected for use in this thesis because of this ability. Table 3.1 below displays the variable inputs for the FRCS harvest cost model as well as variable descriptions.

3.3 Delivery Cost Estimation Methods

Transportation cost of forest products to a market location where the product has value is a crucial component of total cost and can often eliminate the financial feasibility of timber harvests. Therefore, estimating product delivery costs was also essential to determine the impact that timber harvest slash collection and delivery has upon the comprehensive prescription. Methods for estimating transportation costs vary from simple assumptions of one-way haul distances (Han et al. 2002; Keegan et al. 2003) to uniform cost per mile (USFS 2003a) to ignoring transportation costs altogether (Keegan et al. 1995). Others have used more sophisticated techniques that involve Geographical Information System (GIS) data to estimate haul costs. For example, the transportation component of the BioSum model (Fried et al. 2003) consisted of a GIS road layer that contained likely rates of road speed, generating a cost per ton-mile of traveling any road segment within the study area. Every unit of analysis in the study area was then mapped to a market center. Fried et al. found transportation costs averaged $1,438 per acre and small diameter forest biomass transportation costs alone averaged $293 per acre, or $17.50 per green ton.

Table 3.1 – Fuel Reduction Cost Simulator (FRCS) harvest cost model input variable description.

Variable Model Inputs	Description of Model Inputs
Operational Inputs	
YardDist, ft one way slope distance	Skidding distance for the ground based skidder system or the forwarding distance for the CTL system; it refers to the average one-way distance measured along the slope.
Slope, %	Average fall line slope for the harvest unit; 22% assumed for this analysis.
PartialCut	Choice of 'Partial Cut' or 'Clearcut.'
CollectOptionalResidues	Engages model estimations of chipping slash at the landing for whole tree system and bundling, forwarding, and loading slash bundles for the cut-to-length system.
Inputs from Cut Tree List	
Removals, trees/acre	Number of harvested trees per acre; variable.
TreeVol, ft3	Average volume in cubic feet to the merchantable top (whole tree bole for chip trees); variable.
User-SpecDBH, in	Average diameter at breast height for the harvest unit; variable.
User-SpecTreeHeight, ft	Average tree height in feet; optional, has default function built in.
User-SpecWoodDensity, green lb/ft3	Pounds per cubic foot of green wood; allows localization and variable.
User-SpecResidueWt, fraction of bole wt	Weight of unmerchantable tops and limbs, as a fraction of the bole weight; variable.
Other Assumptions	
MoistureContentFraction, wet basis	Difference of green wood weight less dry wood weight divided by green wood weight, expressed as a fraction; allows localization and variable. 50% used in this analysis.
LoadWeight, green tons (logs)	27 tons
LoadWeight, green tons (chips)	15 tons
CTLTrailSpacing, ft	50 feet; default setting
ResidueRecoveryFraction for WT systems	Fraction amount of slash from harvest unit collected via whole tree system; .80 used in this analysis.
ResidueRecoveryFraction for CTL	Fraction amount of slash from harvest unit collected via cut-to-length system; .65 used in this analysis.
Machine and Labor Inputs	
Faller or Bucker	Dollars per hour per person employed as faller or bucker, which includes wages and benefits; $33.21/hour used in this analysis.
All Others	Dollars per hour per person for all employees which are not fallers or buckers, which includes wages and benefits; $21.78/hour used in this analysis.

3.4 Estimation of Harvest Costs and Net Revenues Associated with Fuel Reduction Treatments

In addition to outlining some methods for estimating harvestable merchantable products and timber harvest slash volumes, as well as methods for estimating harvest and transportation costs associated with those products, a brief discussion of the net revenues estimated by the analyses previously discussed are in order. Han et al. (2002) calculated net revenues of a fuel reduction treatment in southwest Idaho using the spreadsheet harvest cost model STHarvest and market product prices available at the time their analysis. Estimated harvest costs averaged $717 per acre, with $432 per acre attributable to clean chip and timber harvest slash. They showed a net loss of up to $548/acre, before transportation costs were included. Removing only sawlogs resulted in a net gain of $21/acre before transportation costs were included; therefore any activity taking place that seeks to remove products other than sawlogs would require a subsidy of some kind before transportation costs are factored into the total net gain or loss.

Estimates of harvest cost per acre from a USDA Forest Service (USFS 2003a) analysis range between $400/acre and $1630/acre depending on forest type and terrain, and were also derived using STHarvest. The costs were estimated for fuel reduction treatments in western states. Estimated net revenues ranged from a $100 loss to a $1,560 gain depending primarily on forest type and merchantable products available from that particular portion of the study area. The USDA Forest Service researchers also describe the effects that transportation costs can have upon the economic viability of any given operation used in this study, stating, "As much as half the cost of [biomass] delivered to a manufacturing facility may be attributed to transportation" (USFS 2003a). The authors assumed a chip transportation cost of $0.35/mile for each oven-dry ton. Furthermore, transportation cost and distance to markets, they suggest, may preclude recovery of most of the merchantable and non-merchantable material analyzed.

The authors of the BioSum model concluded that nearly every acre analyzed resulted in net losses for fuel reduction treatments in western Oregon and northern California. Their conclusion is mostly due to transportation costs of $17.50 per green ton and the assumption that the value of delivered timber harvest slash, or biomass, was $18.00 per green ton. Therefore, in contrast to the Healthy Forest Initiative, "biomass never pays its own way out of the woods" (Fried et al. 2003). However, the researchers are careful to mention that product quality and volumes vary per acre, as do per acre distances from market centers, and this can make it very difficult to estimate per acre net revenue or loss including transportation costs for regional areas.

3.5 Biomass Available Under Differing Fuel Reduction Treatments

There exists in much of the literature common methodology for estimating merchantable timber and harvest slash yields. This commonality is the use of a USDA Forest Service sponsored and maintained database of forest inventory records: the Forest Inventory and Analysis (FIA) database. That is, the data that many of the following researchers have analyzed to estimate potential timber harvest slash available from a specific treatment for a particular area or region are from the same source. This data source was used in this thesis and is discussed in detail in the 'Data and Methods' section of this document. The following is a sample of studies conducted to estimate potential harvest slash yields using FIA data under a variety of (1) scenarios, (2) locations, and (3) objectives.

When the Darby, Montana Fuels for Schools project was initiated, the Bitter Root Resource Conservation and Development (RC&D) program conducted an informal evaluation of the area's ability to provide enough fuel for the Darby Consolidated School District's boiler system. Tom Coston, former USDA Forest Service Region 1 Regional Forester and now a participating member of the Bitter Root RC&D, made an inquiry into the potential availability of timber harvest slash useable for fuel from State owned and privately owned lands in Ravalli County. According to Coston, this was done through verbal contact with Charles Keegan, Bureau of Business and Economic Research, and Dr. Carl Fiedler, College of Forestry and Conservation, both at The University of Montana, Missoula (Coston 2004). Personnel contact with Keegan and Fiedler yielded informal assurances that their analysis of Montana FIA data showed a per acre quantity of stock sufficient to supply the biomass system; the Keegan and Fiedler results were previously discussed.

In addition to verbal contact with these University researchers, Coston also initiated personal contact with Plum Creek Timber Company, Inc., which owned 6,916 acres of private industrial forestland in Ravalli County as of April 2002 (Sorenson 2004). Because Plum Creek often and consistently conducts logging activity in Ravalli County and chips residues for clean chips and hogfuel, the information obtained by Coston from these two sources provided useful insight into potential availability of timber harvest slash for fuel from privately owned lands. Coston's personal contact yielded the information that those industrial forestlands in Ravalli County will provide approximately twenty-six green tons per acre. As far as slash estimation with respect to State and private lands in Ravalli County is concerned, Coston's inquiry was the only attempt at estimating timber harvest slash available at the time of this analysis, and this quasi-official inquiry produced no published results.

Additionally, Emergent Solutions (2003) evaluated sources of local feedstock supply for a potential co-generation facility that would be located at the Milltown, Montana hydroelectric dam if the electricity distribution structure was left behind if the dam were removed. A co-generation facility would produce electricity and thermal energy in a single system. Milltown is located approximately eight miles east of Missoula, Montana; therefore local industrial wood product residues as well as wood products from the local forests were considered among the potential sources of feedstock supply. The researchers note that the supply of industrial residues and slash from local-area forests was "considered to be tight." For example, the Smurfit-Stone Corporation plant that has a co-generation facility used to receive its supply of hogfuel and industrial wood residue for free, but must now pay for hogfuel or residues (Emergent Solutions 2003).

The researchers assumed that because mill residues would be allocated elsewhere any new facility would require new sources of biomass material to be identified – namely biomass removed from local forests. These researchers also analyzed FIA data and conducted personal interviews to estimate potential timber harvest slash available under several harvest scenarios. The lands considered in the Emergent Solutions, Inc. assessment as the most likely sources of slash were limited to those within a 60-mile radius of the Milltown, Montana dam. The lands were restricted by slope to accommodate ground based harvest systems, were non-reserved, and within proximal distance of a road. The FIA database was used as the basic source for estimating potential timber harvest slash for feedstock based on the above criteria. From the FIA data plots that met the above criteria, estimates of potential slash availability ranged from 1.9 to 15.0 bone-dry tons per acre, depending on harvest goals. The researchers also cite Dr. Carl Fiedler as indicating western Montana lands are capable of providing 14.5 to 15.0 bone-dry tons per acre once every 35 years. Harvest slash from traditional commercial logging could provide on average 4.7 bone-dry tons per acre. If only slash generated from pre-commercial thinnings (i.e. thin-from-below) were considered then an average of 3.9 bone-dry tons per acre could be expected.

The Emergent Solutions, Inc. researchers assumed that a threshold of 2 to 3 times the biomass feedstock necessary to supply an electricity generation facility for one year would have to be available locally as feedstock. If a 10 megawatt plant would consume 2.94 million bone-dry tons of biomass every 35 years, then the assumed sufficient supply of biomass feedstock necessary for the co-generation facility would be 6.0 to 9.0 million bone-dry tons every 35 years. Therefore, it was suggested that National Forest lands, which comprise the majority of federally owned lands considered in the analysis, would not provide enough feedstock for the co-generation facility. Conversely, if the assumed quantities of potential feedstock were applied to privately owned lands, it was found these lands alone could provide the necessary amounts of biomass to the facility. However, the researchers noted that there is a severe lack of information as to the condition or potential of biomass supply from privately owned lands.

Similarly, a study which used methodology most closely associated with that used in this thesis, researchers at the USDA Forest Service Pacific Northwest Research Station devised a geographically explicit modeling framework to utilize FIA data to assess and summarize biomass production opportunities in California and Oregon (Fried et al. 2003). With the intended purpose of identifying locations with sufficient accumulation of forest biomass to justify investment in a processing facility capable of generating 50 megawatts each, forest inventory data that represented 22.2 million acres in California and Oregon were collected and analyzed. Analyzed plots were restricted to slopes that accommodate ground-based systems, and were proximal to a road. A computer model was used to simulate fuel treatment prescriptions under a variety of different treatment scenarios and led researchers to the conclusion that there is enough biomass to supply four 50-megawatt power plants for decades but "supply under the most conservative scenarios [that minimizes merchantable timber yield] would be far more limited." Depending upon the treatment, biomass estimates range from 10.9 green tons per acre up to 20.6 green tons per acre (Fried et al. 2003).

Another report produced by the USDA Forest Service (USFS 2003a) used similar methodology for fifteen western States. The intent of the USDA Forest Service report was to "characterize, at a regional scale, forest biomass that can potentially be removed to implement the fuel reduction and ecosystem restoration objectives of the National Fire Plan for the western U.S." (USFS 2003a). Forest inventory data were used as a snapshot of forest stand conditions to model a harvest prescription that differs from the comprehensive prescription. Specifically, the researchers chose to reduce the Stand

Density Index (SDI)[3] to 30% of the maximum SDI. Montana was estimated to have 19 bone-dry tons per acre available under this scenario.

In a broad report that discussed how general energy issues can be tied to western forest health and the role they play in potentially enlarging the biomass energy industry, Samson, Smith, and Gann (2001) cite two eastern Oregon case studies. The researchers still believe that "there is ample supply to sustain an energy facility in each county, based on the small or uneconomic trees that need to be removed" (Samson, Smith, and Gann 2001). The researchers further conclude that without a guaranteed source of biomass from federal lands, feedstock supplies that would ensure the continued success of a biomass energy facility located in Grant or Wallowa County, Oregon would be inadequate. Samson, Smith, and Gann believe that the political climate and constraints in eastern Oregon are largely to blame for the lack of biomass harvesting activity to reduce the dense undergrowth of pine and fir that exists in that region. Additionally, in Grant County, local landowners are observed to be 200 miles from the Columbia River pulpwood markets, which would impact net revenues significantly under a fuels reduction scenario.

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[3] Stand density index (SDI) is a relative measure of stand density that converts a stand's current density into a density at a reference size.

CHAPTER IV

Data and Methods

4.1 Introduction

As described in the Literature Review chapters, previous research estimated potential small diameter forest biomass and merchantable timber available from an ecology-based fuel reduction prescription designed to return the lower elevation fire-adapted forests of western Montana to pre-interrupted fire interval conditions (Fiedler et al. 1999, 2001a; Keegan et al. 2003). Furthermore, the establishment of small diameter forest biomass utilizing technology in Ravalli County, Montana, in addition to interest throughout the region in acquiring similar technology, necessitates thorough and accurate county level analysis of timber harvest slash – or biomass – collection and delivery to local market centers. An analysis such as this would additionally provide land managers and school districts with decision tools that might aide in budgeting or prioritizing land management practices. However, evaluation of the economic impact that biomass collection has upon the comprehensive prescription, as well as estimates of biomass volume, has not occurred at the county level.

This thesis used methodology similar to that of Fiedler et al. (1999, 2001a) and Keegan et al. (2003) pertaining to fuel reduction treatment selection and use of forest inventory data. Also similar to previously mentioned analyses, a computer spreadsheet model, the Fuel Reduction Cost Simulator (FRCS) timber harvest cost model was used to estimate the impact that biomass collection has on the economics of the comprehensive prescription. This was done for two harvest systems – whole tree (WT) and cut-to-length (CTL). Extrapolating beyond similar research, delivery costs were estimated using sophisticated computer software and remotely sensed data that aided in selecting lands appropriate for the prescription, and assignment of delivery cost values to every parcel of selected study area land. Delivery costs are a function of distance to market center and surface type of roads traversed in transit. With previous research having described ponderosa pine, Douglas fir, and dry lower mixed conifer forests as the most common type of forest throughout lower elevations of western Montana and Ravalli County (Fiedler et al. 1999, 2001a, 2001b; Keegan, Fiedler and Stewart 1995; Keegan et al. 2003; O'Laughlin 2002), these forest types are focus of this thesis as well.

The organization of this chapter is as follows: first the methodology used to derive the product list of merchantable timber and biomass harvested is described. A description of the harvest cost modeling process used to estimate stump to loaded truck costs associated with the harvested materials then follows. Third is a description of the study area lands selection process, and lastly the methods used to derive delivery cost estimates for the harvested materials are described.

4.2 Estimation of the Product List - Forest Inventory Data and Methods

Forest Inventory and Analysis (FIA) data were used to estimate the potential small diameter biomass and merchantable material available from the implementation of the comprehensive prescription via two harvest systems. The data were acquired from the U.S. Department of Agriculture Forest Service Forest Inventory and Analysis (FIA) National Program Online Database Retrieval System (USFS FIADB 2003). FIADB contains extensive data on forest area attributes and on the status of live and standing dead trees collected from one-acre sample stands and are a statistical representation of forest conditions in the surrounding areas. FIADB provides sampled forest data for all regions of the nation. Data collection is carried out in accordance with sampling methods, procedures and time frames described in The Forest Inventory and Analysis Database: Database Description and User's Manual Version 1.0 (USFS FIADB 2003). According to FIADB:

> "FIA plots are designed to cover a 1-acre sample area; however, not all trees on the acre are measured. Recent inventories use a national standard, fixed-radius plot layout for sample tree selection. Various arrangements of fixed-radius and variable-radius (prism) subplots were used to select sample trees in older inventories. . . For all plots, several observations are recorded for each sample tree, including its diameter, species, and other measurements that enable the prediction of the tree's volume, growth rate, and quality. These tree measurements form the basis of the data on the tree records in the FIADB (USFS FIADB 2003)"

According to USFS FIADB (2003), FIA data provide reliable estimates for volume where sampling error does not exceed 5% per 1 billion cubic feet of growing stock on timberland. Therefore, the FIA data served to approximate 'merchantable' material – sawlogs, pulplogs – and 'non-merchantable' material – biomass – produced from the comprehensive prescription.

4.2.1 Initial Selection of the Forest Inventory Data

Selecting the forest inventory data from the vast FIA database began by determining which 'forest types' in FIADB would be representative of those in the study area – Ravalli County, Montana. In conjunction with the relevant literature, forest types were selected in consultation with Dr. Carl Fiedler, Research Associate Professor of Silviculture, and Charles Keegan, III, Director of Forest Industry Research, both of the University of Montana, Missoula. The selected forest types are Douglas fir (DF), Ponderosa pine (PP), and dry lower mixed conifer (DLMC, which represents a non-majoral mix of low elevation species).

According to Fiedler and Keegan, FIA data from Ravalli County alone would likely have been insufficient for estimates of small diameter forest biomass due to the low number of FIA data available from the county for the three forest types under evaluation. It was Fiedler's opinion however that forest stand conditions of the three forest types in Lake, Mineral, and Missoula counties were similar enough to those in Ravalli County of the same forest types, and represent stand conditions of the same forest type in Ravalli County[4]. Therefore, FIA data from those four counties were evaluated.

4.2.2 Fire Regime Condition Class and Final Selection of the Forest Inventory Data

In addition to selecting FIA data from forestlands representative of the study area, the FIA data needed to be from sample plots in a state of moderate or high departure from historical fire patterns. Forest managers evaluate a forest's departure from historical fire patterns using Fire Regime Condition Classes (FRCC):

> Fire-regime condition class (FRCC) is an approximation of ecosystem departure resulting from a change in fire regimes. FRCC serves as a proxy to ecological fire effects. That is, the greater the departure, the greater the probability that the status of some ecosystem component will decline if a fire occurs. Severe fire effects are those that are considered

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[4] See Figure 1.1 for the precise locations of these counties.

to be outside those effects characteristic of the historical range of variability (USFS 2003b).

Following are the formal definition of Fire Regime Condition Class as described in the National Fire Plan[5], and are those used in this thesis:

1. FRCC 1 (Low departure): Fire regimes are within their historical range and the risk of losing key ecosystem components is low;
2. FRCC 2 (Moderate departure): At least one fire interval has been missed, or exotic species have altered native species composition (e.g. cheat grass and blister rust). There is a moderate risk of losing key ecosystem components should a fire occur;
3. FRCC 3 (High departure): Several fire intervals have been missed, or exotic species have substantially altered native species composition (e.g. cheat grass and blister rust). There is a high risk of losing key ecosystem components should a fire occur.

Only FIA data plots with a status of FRCC 2 or FRCC 3 (moderate or high departure) were selected for evaluation. However, FRCC is not recorded in FIADB, thus requiring a means to determine the FRCC value of each FIA sample plot. In order to accomplish this task, the U.S. Forest Service Interior West Forest Inventory and Analysis staff located at the Forestry Sciences Laboratory in Ogden, Utah was contacted to assign an FRCC status to each FIA sample data plot via GIS and remotely sensed data[6]. Only

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[5] The National Fire Plan is a cooperative, long-term effort among various governmental agency partners.

[6] Although the fine scale GIS data used for this designation had been deemed appropriate for analyses of areas greater than about 10,000 acres, such as Ravalli County, its validity for FRCC designations at the one-acre stand level is questionable, and any decisions based on these data should be supported with field verification, especially at scales finer than 1:100,000 (USFS 2003b). Therefore, using the fine scale GIS data to describe the number of FRCC acres countywide is appropriate while assigning a single acre in the county an FRCC designation should be ground-truthed for verification. But because the FIA data come

FIA sample plots with an FRCC status of 2 or 3 were at this point considered for use in this analysis.

Additionally, FIA sample plot data were further selected from only two groups of owners that represent the majority of land ownership in Ravalli County: private and USDA Forest Service. Data from the third largest land owning entity – the State of Montana – were not used. Table 4.1 displays the study area in Ravalli County by ownership, and as can be seen, Montana State owned lands comprise just over 2.0% of the total acreage available for the comprehensive treatment in Ravalli County. According to Paul Moore of the Montana Department of Natural Resources and Conservation, the state agency responsible for the administration of Montana State owned lands, State lands in Ravalli County will provide approximately 2.5 million board feet of salable timber in the next four years. The largest portion of State land in the study area – the Sula State Forest – currently has no pre-commercial thinning opportunities and will only provide approximately one-half million board feet of salable timber in the near future (Moore 2004). Furthermore, the majority of the Sula State Forest is within the area burned in the catastrophic wildfires of 2000, which consumed most, if not all, of the small diameter

Table 4.1 - Ravalli County, Montana study area by primary land ownership.

	Ownership	
Agency	Acres	Percent of Total
Forest Service	49,777.64	72.37%
State	1,592.17	2.31%
Private	17,408.01	25.31%
Sum	68,777.82	100.00%

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from four contiguous counties, it was assumed that the proportion of FIA data with FRCC designations of 2 or 3 constitute a representative portion of the actual FRCC designations placed on the landscape in the four counties.

timber in the forest, thus crippling the State Forest's short-run potential as a source of biomass. Figure 4.1 displays the perimeter of the Sula State Forest and shows the fire burn severity within the State Forest boundaries in 2000.

Using the above-described criteria, the final set of FIA data used in this analysis fall into one of the following categories:

1. Ponderosa Pine sample plot, FRCC 2 or 3, National Forest or private ownership;
2. Douglas-fir sample plot, FRCC 2 or 3, National Forest or private ownership;
3. Other (Dry Lower Mixed Conifer/Non-lodgepole) sample plot, FRCC 2 or 3, National Forest or private ownership;

Unfortunately, however, FIADB does not include the forest type 'Dry Lower Mixed Conifer;' in its place the FIA data were queried for all forest types that were non-lodgepole and temporarily assigned the forest type label 'Other.' Discussed in the 'Forest Types' (section 4.4.2) of this chapter is the transformation of the 'Other' forest types to 'Dry Lower Mixed Conifer' (DLMC).

4.2.3 Application of the Comprehensive Prescription to the Forest Inventory Data

After the FIA sample plot data were selected as described above, Dr. Carl Fiedler at The University of Montana, College of Forestry and Conservation modeled the comprehensive prescription given the selected FIA data. Previously developed algorithms simulated the application of the prescription using the tree list associated with each FIA sample data plot selected for evaluation (Fiedler et al. 2003). From the tree list, individual tree attributes such as species, diameter, height, and crown ratio were

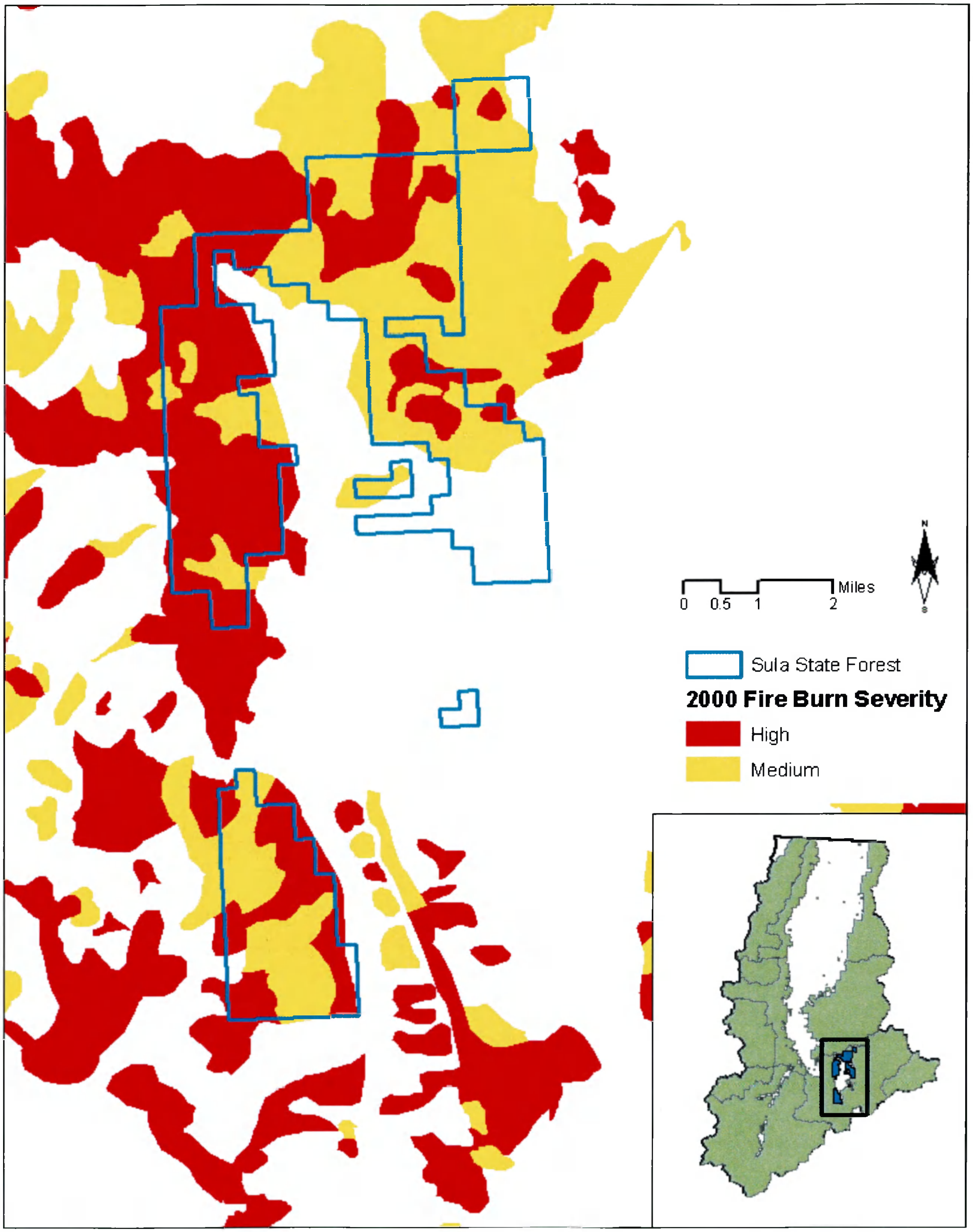

Figure 4.1 – Sula State Forest boundary and 2000 fire burn severity.

evaluated for marking the tree for 'leave'. All trees that were not marked for leave were cut and added to the 'cut tree' or 'product list.' This process of marking trees for leave, and subsequently cutting the remainder, was conducted in order from shade intolerant and fire resistant species, namely ponderosa pine and western larch, to shade tolerant species, like Douglas fir. This modeling process resulted in the product list, which is a plot-level summarized listing of selected attributes of the trees cut in the modeling process, and was further used to determine cost of the prescription and average net revenues. The prescription modeling process was conducted for each of the FIA sample data plots selected and the data received from this process is described by variable in Table 4.2. Of particular importance are the variables: quadratic mean diameter (QMD)[7], cubic foot volume, oven-dry biomass, and trees per acre cut. Values for each variable listed in Table 4.2 were computed for three size classes from each FIA plot: less than 5-inches diameter at breast height (DBH), 5.01-inches to 9-inches DBH, and greater than 9-inches DBH.

There were 161 FIA sample plots for which the comprehensive treatment was modeled. Of these 161 plots, 50 yielded no harvested products and Fiedler explained this as the FIA sample plots being one of the three correct forest types, but simply not having the minimum basal area necessary to implement the comprehensive prescription. Therefore, these fifty sample plots were removed from the analysis because it is highly unlikely that forestlands not having the minimum basal area requirements would be

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[7] Quadratic mean diameter (QMD) = $\sqrt{\frac{\sum_{i=1}^{n} DBH_i^2}{n}}$

Table 4.2 – Variable definition of summarized cut tree data received from Fiedler via modeling the comprehensive prescription.

Variable	Description
Owner	Ownership group class code. A broader group of landowner classes.
Forest type from Fiedler	Forest type as defined by Dr. Carl Fiedler.
QMD of trees < 5"	Quadratic mean diameter of trees less than 5-inches DBH.
QMD of trees 5" to 8.9"	Quadratic mean diameter of trees 5 to 8.9-inches DBH.
QMD of trees 9" and larger	Quadratic mean diameter of trees greater than 9-inches DBH.
Cubic foot volume per acre of trees < 5"	Total cubic foot volume of harvested trees less than 5-inches DBH.
Cubic foot volume per acre of trees 5"- 8.9"	Total cubic foot volume of harvested trees 5 to 8.9-inches DBH.
Cubic foot volume per acre of trees 9" and larger	Total cubic foot volume of harvested trees greater than 9-inches DBH.
Oven-dry biomass (tons/acre) of trees 1"- 4.9" plus tops and limbs of trees > 4.9"	Bone dry weight (tons/acre) of all trees less than 5-inches DBH plus tops and limbs of trees greater than of equal to 5-inches DBH.
Oven-dry weight of boles 5"- 8.9" (tons/acre)	Bone dry bole weight (tons/acre) of trees 5 to 9-inches DBH.
Oven-dry weight of boles 9" and larger (tons/acre)	Bone dry bole weight (tons/acre) of trees greater than 9-inches DBH.
TPA CUT < 5"	Trees per acre cut less than 5-inches DBH.
TPA CUT 5" - 8.9"	Trees per acre cut 5 to 8.9-inches DBH.
TPA CUT >= 9"	Trees per acre cut 9-inches DBH and greater.

considered for harvest activity. Of the remaining 111 FIA sample plots, Fiedler identified 2 as lodgepole forest types and 8 as western larch forest types and these were removed. Next, visual data inspection was performed to identify any sample plots with harvested products that were suspicious or appeared to be aberrations. The data were inspected for average size (QMD) of trees per acre cut greater than 20-inches[8] and/or total cubic feet harvested greater than 4,000 ft^3 per acre, an unlikely characteristic of these types of stands. Also, sample plots with greater than 1,000 trees per acre cut were

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[8] The comprehensive prescription targets the largest trees for leave.

examined closely to determine the likelihood of this removal number, with respect to diameter class, and all but one plot were retained for the analysis. Therefore, the number of FIA data plots acceptable for use in this analysis is one hundred (n=100). The summary statistics of all the trees cut, or final product list, are displayed below in Table 4.3.

Table 4.3 - Summary statistics of selected variables from the final product list.

Variable	n	Mean	Median	Std. Deviation
QMD <5	100	1.87	2.10	1.53
QMD 5 - 9	100	5.98	6.80	2.64
QMD <>9	100	12.91	12.45	3.48
CubicFt <5	100	90.39	33.15	168.45
Bole CubicFt 5 - 9	100	353.26	236.00	388.50
Bole CubicFt >9	100	1,145.49	898.00	918.61
Biomass Tons (Dry)	100	6.66	6.06	4.26
Bole Tons 5 - 9 (Dry)	100	4.55	3.07	4.97
Bole Tons >9 (Dry)	100	16.62	13.22	13.39
Trees per Acre Cut <5	100	175.99	60.00	248.88
Trees per Acre Cut 5-9	100	75.48	53.60	78.77
Trees per Acre Cut >9	100	56.51	48.50	42.07

4.3 Application of the Harvest Product and Cost Model to the Forest Inventory Data

After Dr. Fiedler modeled the comprehensive prescription for the one hundred FIA sample data plots, several of the variables provided in the resulting product list from each FIA plot were then entered into the harvest cost estimation model Fuel Reduction Cost Simulator (FRCS) (Hartsough and Fight 2003) discussed in section 3.2.1. Again, FRCS is an elaborate spreadsheet application that allows for alteration of fixed and variable costs to 'localize' the model; Table 3.1 lists all the required FRCS inputs. The output from each FIA data plot harvest simulation is an estimate of the average cost of that unit, and the average of the one hundred estimates derived from the harvest simulation of each FIA plot with FRCS was used to estimate overall average harvested products and costs in Ravalli County.

FRCS provided estimates for total per acre harvest costs given variable inputs listed below for each of three diameter classes of trees under evaluation. However, only two diameter classes in FRCS were used in this analysis: 'chip trees' and 'small log trees'. In this thesis, the chip tree class consists of all harvested trees less than or equal to 5-inches diameter at breast height (DBH) and the small log tree class consists of all other trees harvested (> 5-inches DBH). Following are the required FRCS variable inputs for each of the two diameter classes, their respective sources (in parentheses), and a description of how each variable was derived. The variables are:

1. Trees per acre removed (Fiedler product list);
2. Quadratic mean diameter of each FIA sample plot (Fiedler product list);
3. Average per tree cubic foot bole volume (Fiedler product list);
4. Green wood density, pounds per cubic by species; at 50% moisture content these are:
    a. Douglas fir = 60 lbs/ft^3 (Brown, Snell and Bunnell 1977; Brown 1978; Snell and Brown 1980);
    b. Ponderosa pine = 50 lbs/ft^3 (Brown, Snell and Bunnell 1977; Brown 1978; Snell and Brown 1980);
    c. Dry lower mixed conifer = 65 lbs/ft^3 (equals the moisture content of western larch) (Brown, Snell and Bunnell 1977; Brown 1978; Snell and Brown 1980);

5. Ratio of tree slash weight to bole weight (Fiedler product list; Brown 1978);

Additional required model inputs that do not vary across diameter classes:

1. Wages and benefit rates for:
    a. Fallers or buckers (ACINET 2003);
    b. All others (ACINET 2003);
2. Ground slope (%) (GIS);
3. Skidding/Forwarding distance (feet) (Chung 2003).

Two tree diameter classes were used in FRCS for this analysis (<=5-inches and >5-inches) but the product list provided by Fiedler contained three diameter classes (<=5-inches, 5.01 to 9-inches, and >9-inches, DBH). It was therefore necessary to collapse the three diameter classes from the Fielder product list down to two diameter classes. This was accomplished fairly easily for some of the required model inputs. For example, determining trees per acre harvested and harvested bole volume for the greater than 5-inch diameter class for FRCS was accomplished by summing across the two largest diameter classes in the Fiedler product list. Greater than 5-inch QMD for FRCS was calculated as a volume weighted value across the two largest diameter classes in the Fiedler product list as shown in equation 4.1 below.

$$\textbf{4.1}\quad VolumeWeightdQMD = \left[\left(\frac{B_2}{B_2 + B_3}\right) * QMD_2 + \left(\frac{B_3}{B_2 + B_3}\right) * QMD_3\right]$$

In equation 4.1, B_2 = total harvested bole weight (tons) of the 5 to 9-inch diameter class, B_3 = total harvested bole weight (tons) of the greater than 9-inch diameter class, QMD_2 =

quadratic mean diameter of the 5 to 9-inch diameter class, and QMD_3 = quadratic mean diameter of the greater than 9-inch diameter class.

Average per tree cubic foot bole volumes were calculated by simply dividing the harvested bole volumes by trees per acre cut for each of the two diameter classes. Green wood densities were determined by applying the appropriate bone-dry weight per cubic foot for each of three species (Douglas fir, ponderosa pine, western larch[9]) obtained from Brown, Snell, and Bunnell (1977), Brown (1978), and Snell and Brown (1980) that correspond with the forest type from which the FIA plot data were drawn. The bone-dry weights were then transformed to 50% moisture content necessary for the harvest cost estimation, as shown below in equation 4.2.

$$4.2 \quad MoistureContent = \frac{W_g - W_o}{W_g}$$

In equation 4.2 W_g = the green weight of wood and W_o = the bone-dry weight of wood. The difference between the green weight and the dry weight divided by the green weight provided moisture content on a wet basis.

To calculate per tree ratio of slash weight to tree bole weight for the 1 to 5-inch diameter class, Brown's (1978) regression estimates were employed. Three separate regression equations, one for each species (e.g. Douglas fir, ponderosa pine, western larch), were used to estimate bone-dry per tree live crown weight and three additional regression equations were used to estimate bone-dry per tree bole weight[10]. The six

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[9] Bone-dry cubic foot weight of western larch was used for dry lower mixed conifer.

[10] Equations for estimating bole weights are for trees less than or equal to 4-inches DBH. It was assumed that extrapolating the models upward by an increment of 1 would be of minor consequence. There is

regression equations are displayed in Table 4.4. For all six equations, d = DBH and in its place QMD was substituted. The exercise of dividing per tree slash weight by its bole weight was performed for the 1 to 5-inch diameter class for each FIA sample plot.

Table 4.4 – Regression equations used to estimate per tree slash as a fraction of bole, in weight.

Species	Live crown weight (w)	Bole weight (w)
Douglas fir	$w = e^{(1.1368 + 1.5819*\ln(d))}$	$w = .74 + 1.591*d^2$
Ponderosa pine	$w = e^{(.268 + 2.074*\ln(d))}$	$w = 1.08 + .9361*d^2$
Western larch	$w = e^{(.4373 + 1.6786*\ln(d))}$	$w = .96 + .6532*d^3$

Source: Brown, James. 1978. Weight and Density of Crowns of Rocky Mountain Conifers. USDA Forest Service Research Paper INT-197.

It was deemed acceptable for the 1 to 5-inch diameter class fraction to be in the neighborhood of 1.0 (Hartsough 2004), which the majority of FIA sample plots were.

To calculate slash to tree bole weight for trees greater than 5-inches in diameter, first the total cubic feet of harvested material 1 to 5-inches was multiplied by the bone-dry cubic foot weight of the species that corresponds with the forest type, and then divided by 2,000 resulting in tons per acre of harvested material. This number is then subtracted from biomass tons per acre yielding biomass tons per acre excluding the weight of 1 to 5-inch diameter trees, essentially producing total per acre slash of trees greater than 5-inches[11]. Then by simply dividing this result by the bole weight of the greater than 5-inch diameter class, reasonable estimates of tree slash to tree bole weight fractions were produced. According to Dr. Bruce Hartsough (2004), these fractions for

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essentially zero literature that applies to a strictly 5-inch DBH with the input variables at hand for this analysis.

[11] Because of the proprietary nature of Fiedler's modeling process and inherent expense, the 'tops and limbs' of trees 5-inches and less were not calculated separately, and it is assumed that cubic foot volume of trees less than or equal to 5-inches includes the slash.

trees larger than 5-inches DBH should range between approximately .25 and .45, as did the majority of those computed in this manner.

To further localize the FRCS harvest cost model average wage and benefit rates of employees in the Montana forestry industry were utilized. FRCS required two different wage and benefit rates to be entered, one for fallers and buckers, and another for all other workers. The median 2002 wage for fallers and buckers was $24.60/hour in West Montana, which includes Ravalli County, as compared with a national average of $13.64/hour. The median wage for logging equipment operators in West Montana was $16.13/hour, as compared with a national average of $12.88/hour (ACINET 2004). The logging equipment operator's hourly wage was used in the 'all others' category in the harvest cost model. But because benefit rates specific to Montana are not currently published, the model default rate of 35% was accepted.

Other variable inputs that localize the model include utilizing a ground slope of 22.4% that was calculated from the GIS portion of this analysis and is the average slope of the lands in the study area. Additionally the model required skidding/forwarding distances. Because choosing one harvest unit distance from a road to represent all lands within 1,500 feet was thought to be too limited, three incremental harvest unit areas of less than 500 feet, 500 to 1,000 feet, and 1,000 to 1,500 feet from the landing were chosen for the harvest cost analysis. Consultation with Dr. Woodam Chung (2003), Assistant Professor of Forest Operations, University of Montana, Missoula, Montana, indicated that during harvest activities, the average skidding distance in a given unit is approximately 60% of the linear distance from the point of the unit nearest the landing to the point of the unit furthest from the landing. Therefore, 60% of the maximum distance for each increment was specified and entered into the model for evaluation. These distances are 300 feet, 800 feet, and 1,300 feet. Figure 4.7 displays these incremental distances.

As previously stated, FRCS was designed so that all trees in the 'chip trees' diameter class are whole tree chipped, and so the appropriate variables from the Fiedler product list derived from trees less than 5-inches DBH were entered in this category. The model further provides that all trees in the diameter class of 5.01-inches or greater, labeled 'small log trees,' will be either whole tree skidded and processed at the landing for the whole tree system, or felled, de-limbed and forwarded for the cut-to-length system, and of course the appropriate variables from the Fiedler product list for this category were entered into the model. The 'Collect Optional Residues' feature of the model allows cost estimates for all slash piled at the landing to be chipped and blown onto vans for the whole tree system, or bundled with a slash bundler and forwarded and loaded onto log trucks for delivery.

Table 4.5 displays the product and harvest cost variables and brief definitions of each variable. Of particular importance in the 'Product recovered/acre' category are the 'bole weight' and 'optional residue recovered' variables. These product variables show the per acre volumes of merchantable timber and biomass recovered, e.g. bole weight and optional residue recovered, respectively. Using the model inputs derived from the Fiedler product list, the values in the FRCS product list were nearly one to one matches with the values corresponding to Fiedler product list for that particular acre[12] (each FIA sample

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[12] Bole volume estimates for the greater than 5-inch diameter class were exact matches for all FIA plots; biomass estimates were nearly one to one matches after adjusting for moisture content. It was assumed the difference between the two product lists was caused by differing bone-dry weights of species harvested. Fiedler was aware of every species cut; FRCS only allows one green weight entry per analysis unit.

plot equals one acre). Therefore, the product list this analysis is based upon was derived from FRCS, but variable stand attributes acquired from Fiedler's modeling of the prescription on the forest inventory data were used as model inputs. Also important in this analysis are the '$/acre' variables.

Table 4.5 – FRCS harvest model product and cost output variables.

Variable	Description
Product recovered/acre	
Bole weight, GT/acre	Products recovered by category (primary = merchantable, residue = biomass) per acre
WT residue recovered as part of primary product, GT/acre	
Primary Products, GT/acre	
Optional residue recovered, GT/acre	
For Optional Residues, $/GT of additional residue recovered	
Bundle: CTL Residues	Cost per green ton of handling slash/residue (biomass)
Forward: CTL Residues	
Chip Loose Residues: from log trees <=80 cubic feet	
Chip Bundled Residues: from all trees <=80 cubic feet	
For All Products, $/acre	
Fell&Bunch: trees <=80 cubic feet	Cost per acre by activity for the entire harvest operation for whole tree and cut-to-length harvest systems
Harvest: trees <=80 cubic feet	
Skid Bunched: all trees	
Skid Unbunched: all trees	
Forward: trees <=80 cubic feet	
Yard CTL: trees <=80 cubic feet	
Process: log trees <=80 cubic feet	
Load: log trees	
Load CTL: log trees <=80 cubic feet	
Chip: chip whole trees	
Chip: chip tree boles	
Chip CTL: chip tree boles	
Bundle: CTL Residues	
Forward: CTL Residues	
Chip Loose Residues: from log trees <=80 cubic feet	
Chip Bundled Residues: from all trees <=80 cubic feet	
$/acre	
Stump-to-Truck for Primary Products w/o Move-In	Cost per acre summarized by product, assuming no move-in (set up) costs
Onto-Truck for Residues w/o Move-In	
Total, $/acre	
$/GT of all products	
Stump-to-Truck for Primary Products w/o Move-In	Cost per green ton summarized by product, assuming no move-in (set up) costs
Onto-Truck for Residues w/o Move-In	
Total, $/GT of all products	

This shows the cost per acre associated with merchantable timber harvest as well as biomass collection.

Tables 4.6 and 4.7 display the summary statistics resulting from the harvest cost and product modeling process using the selected FIA data. The FIA data show the mean quantity of biomass produced from the implementation of the comprehensive prescription is 14 tons per acre using a whole tree system and 12 tons using a cut-to-length system, at 50% moisture content. The difference in recovered biomass volumes between the two harvest systems is attributable to the variable model input 'ResidueRecoveryFraction' which specifies the amount of biomass each harvest system will recover. Cut-to-length systems will recover approximately 65% of cut small diameter biomass due to the nature of the equipment involved, breakage, etc. Whole tree systems will recover approximately 80% of all possible small diameter biomass cut. For both harvest systems, harvest costs are the costs of cutting all trees <9-inches DBH and selectively cutting trees >9-inches DBH until the target basal area of remaining trees is 40 – 60ft^2. A whole tree system skids all cut trees to the landing where trees >5-inches DBH are processed for loading and trees <5-inches DBH are whole tree chipped. A cut-to-length system is very similar except that the tops and limbs of trees >5-inches DBH are collected with a slash bundler, forwarded to the landing, and then loaded for delivery.

Table 4.6 - Total harvested green tons per acre and associated harvest costs with biomass collection, by harvest system and skidding/forwarding distance.

Mean Harvest Costs With Biomass Recovery (n=100)

	Whole Tree			**Cut-to-Length**		
Skidding Distance	**Mean Tons/Acre**	**Mean $/Acre**	Std. Deviation	**Mean Tons/Acre**	**Mean $/Acre**	Std. Deviation
300	**56.47**	**$1,085.73**	$720.61	**54.33**	**$1,622.88**	$1,096.51
800	**56.47**	**$1,245.74**	$820.85	**54.33**	**$1,684.65**	$1,130.01
1,300	**56.47**	**$1,386.30**	$906.80	**54.33**	**$1,752.12**	$1,166.16

Table 4.7 – Total harvested green tons per acre and associated harvest costs without biomass collection, by harvest system and skidding/forwarding distance.

Mean Harvest Costs Without Biomass Recovery Including Pile and Burn Costs (n=100)

	Whole Tree			**Cut-to-Length**		
Skidding Distance	**Mean Tons/Acre**	**Mean $/Acre**	Std. Deviation	**Mean Tons/Acre**	**Mean $/Acre**	Std. Deviation
300	**42.34**	**$1,197.83**	$699.04	**42.34**	**$1,506.03**	$958.14
800	**42.34**	**$1,357.84**	$799.12	**42.34**	**$1,555.89**	$984.14
1,300	**42.34**	**$1,498.40**	$884.97	**42.34**	**$1,611.47**	$1,012.87

As seen, a whole tree harvest system results in approximately 14 green tons per acre of biomass with harvest costs between $1,086 and $1,386, depending on skidding distance. Without biomass collection, a whole tree system costs between $1,198 and $1,498 per acre including a $175 per acre pile and burn cost. Similarly, implementing the prescription using a cut-to-length system results in approximately 12 green tons of biomass per acre at a cost ranging from $1,623 to $1,752 if biomass is slash bundled, forwarded to the landing, and loaded for delivery. If biomass is left in the woods, harvest costs range from $1,506 to $1,611 per acre including an equivalent pile and burn cost.

4.4 Selection of Study Area Lands Using GIS

Simultaneous to analyzing forest inventory data to determine the volume of products generated from the comprehensive prescription, as well as associated harvest costs, Geographic Information System (GIS) technology and data were used to identify those lands in Ravalli County suitable for the prescription and distance from market centers. Simply put, GIS allowed for spatial identification and representation of those lands in Ravalli County that met the criteria for harvest activity that are described below.

These data were used to depict and stratify lands in Ravalli County by land features, attributes and forest conditions. GIS technology was further employed to calculate product delivery costs to the market centers as a function of distance. Thus, expressing biomass availability as a function of spatially explicit land features such as distance from road and distance to market enabled a more accurate estimate of delivered market cost.

Specifying candidate lands in Ravalli County considered for the comprehensive prescription was a lengthy and intricately detailed process. As is discussed in detail below, lands were selected based primarily upon the following criteria:

1. USDA Forest Service or privately owned;
2. Douglas fir, ponderosa pine, or dry lower mixed conifer forest type;
3. Ground slope less than or equal to 35%[13];
4. Fire Regime Condition Class (FRCC) 2 or 3;
5. Within approximately 1500 feet of operation grade road.

The selection of forest types and ownerships has previously been discussed. Following are the additional criteria for land selection.

4.4.1 Study Area Boundary and Land Ownership

The GIS data used to determine National Forest land ownership in Ravalli county were provided by Jim Fears, GIS Specialist, Bitterroot National Forest, USDA Forest Service. This GIS data layer was used to derive National Forest, State, and other major federally owned land boundaries within Ravalli County, Montana. The original data

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[13] 100% = 45 degrees.

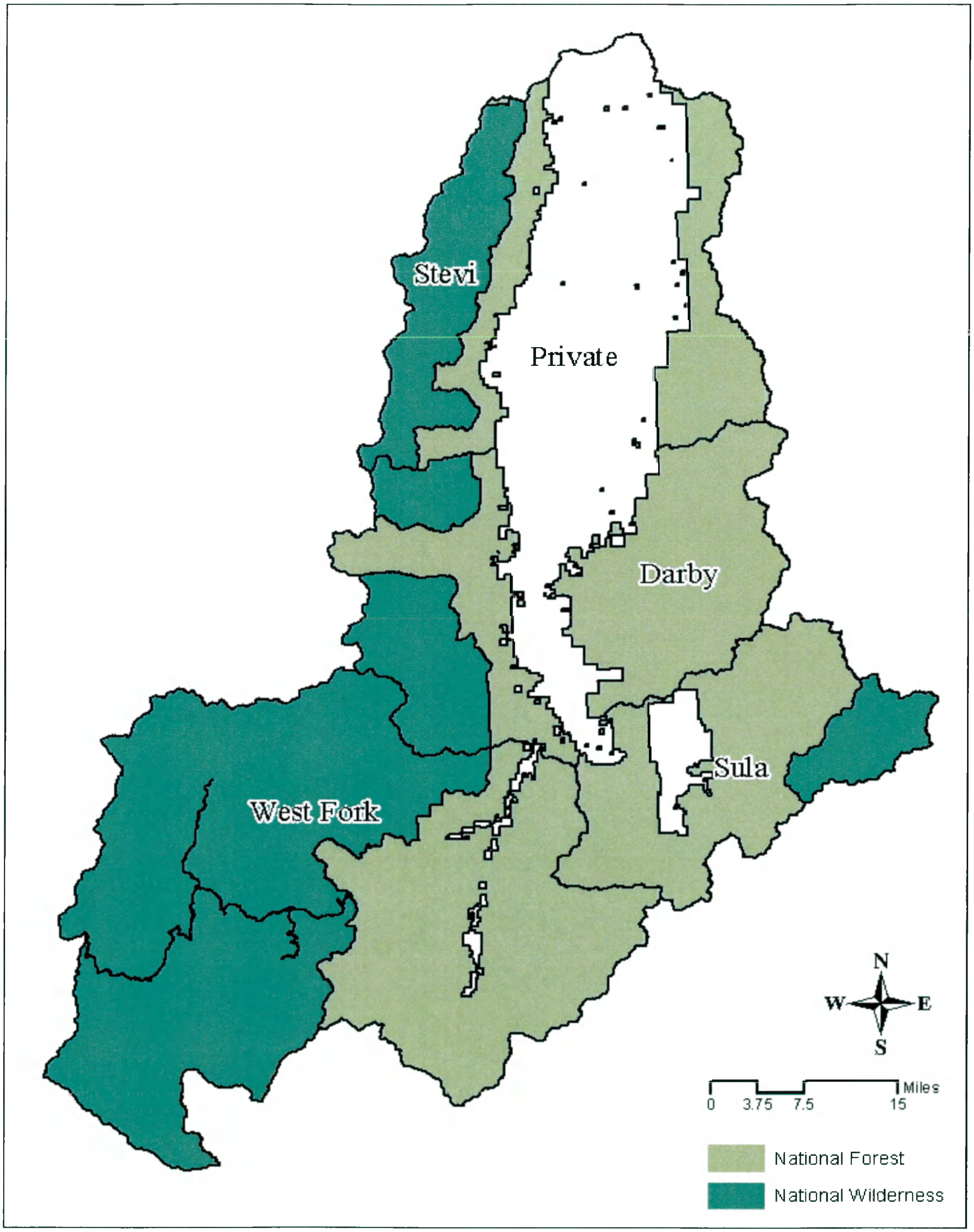

Figure 4.2 – Bitterroot National Forest boundaries, by Ranger District.

layer, as received from Fears is shown in Figure 4.2, and is labeled by Ranger District. While the Bitterroot National Forest GIS data provided fairly accurate information regarding the boundary locations of various federal and state owned lands, locating a GIS data set that explicitly defined piece-by-piece private landownership within Ravalli County was necessary. Specifically, GIS raster data from the Montana Cadastral Mapping Project acquired from the Montana Natural Resource Information System (NRIS) was used (2004). This data layer is displayed in Figure 4.3 and shows all of the land ownerships by major landowner. As seen, the USDA Forest Service controls the majority of land in Ravalli County, with private land ownership a distant second.

4.4.2 Forest Types

Much like the selection of the forest inventory data (FIA), the forestlands identified for analysis using GIS must have been Douglas fir, ponderosa pine, or dry lower mixed conifer. The GIS data provided by Fears had previously been altered by the Ecology and Management of Northern Rocky Mountain Forests Research Work Unit 4151(RWU 4151) of the USDA Forest Service, Forestry Sciences Lab, Missoula, Montana in a manner that defined forest type. These GIS data were processed for the modeling purposes of Simulating Patterns and Processes at Landscape Scales (SIMPPLLE), and are comprised of USDA Forest Service Region Timber Stand Management Record System (TSMRS) data and Satellite Image Landcover Classification (SILC) data. The RWU 4151 modeling process essentially resulted in 'forest typing'

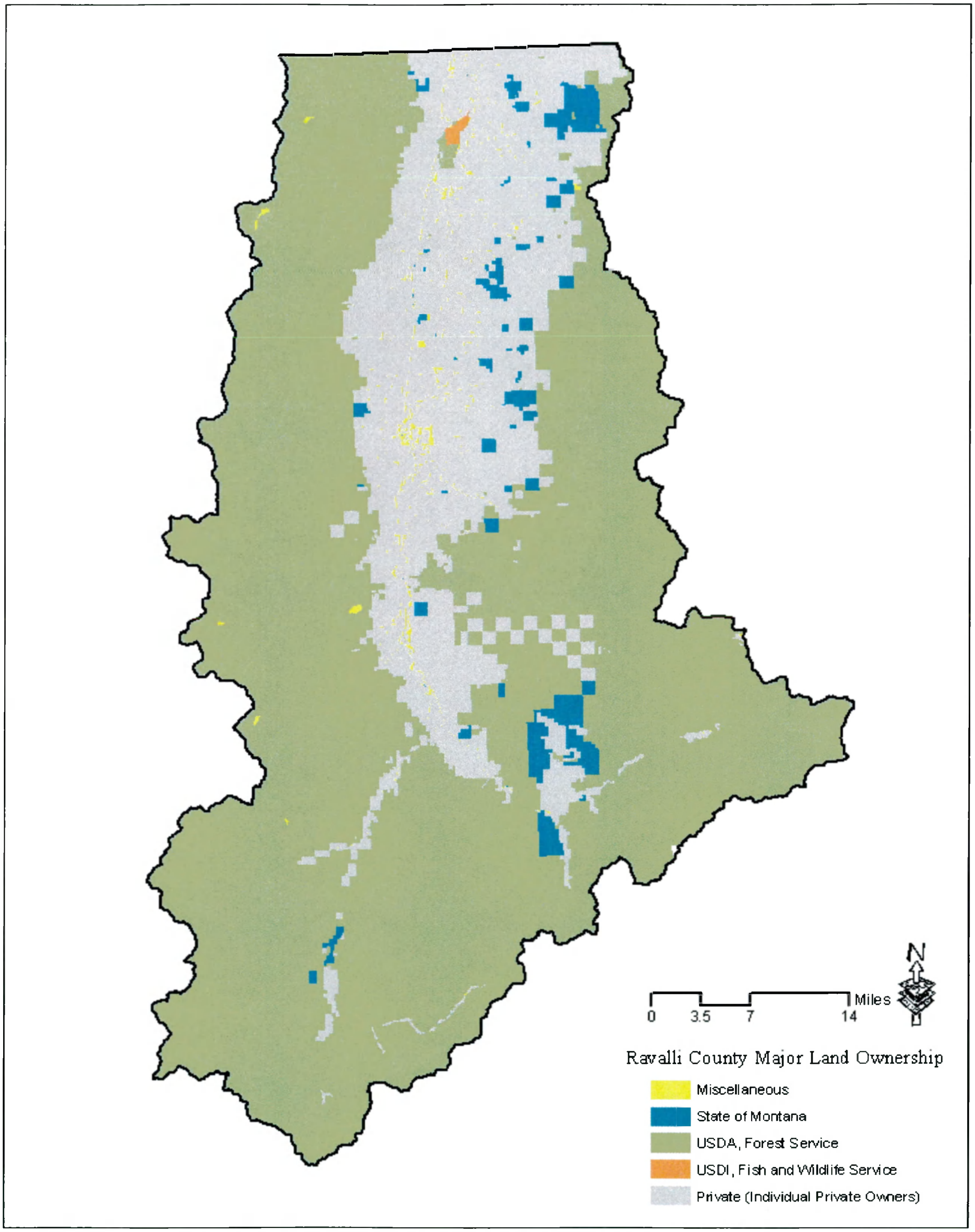

Figure 4.3 - Land ownership in Ravalli County by major landowners.

each GIS data polygon; it was from those forest type assignments that Bitterroot National Forest landscape level forest types used in this thesis were derived.

A list of the many forest types identified and defined by RWU 4151 is displayed in Table 4.8. Also displayed beside the list of RWU 4151 forest types are those forest types that Fiedler would consider Douglas fir, ponderosa pine, or dry lower mixed conifer. The result of this was to create a useable crosswalk between the FIA data, selected by the forest types appropriate for the prescription, and the GIS data, similarly selected. Fiedler's forest typing the RWU 4151 data should in no way be mistaken for a literal translation of one entity's definition of forest type to the other's definition of forest type. It was simply Fielder's professional opinion the forest types defined by RWU 4151 were similar enough to the forest types he would define as Douglas fir, ponderosa pine, or dry lower mixed conifer for the crosswalk. It should further be noted that Fielder insisted that knowledge of habitat type of the area in question is necessary for a more accurate definition of forest type. Therefore, the FIA data were selected based primarily upon forest type, and this crosswalk then allowed for GIS identification and selection of Ravalli County lands using the similarly defined forest types. Figure 4.4 shows the three forest types identified from the RWU 4151 list by Fiedler for the majority of Ravalli County and the entire Bitterroot National Forest. Technical difficulties with the GIS coverage obtained from RWU 4151 prevented displaying these for only Ravalli County. Figure 4.4 displays all lands that are Douglas fir, ponderosa pine, or dry lower mixed conifer and is a visual representation of Table 4.8.

Table 4.8 – Crosswalk between RWU 4151 forest types and those defined by Dr. Carl Fiedler.

Forest Type Code	RWU 4151 Defined Forest Type	Fiedler's definition of the RWU 4151 forest types
AF	Alpine fir	
AL	Alpine larch	
AL-WB-AF	Alpine larch-White bark pine-Alpine fir	
CW	Cottonwood	
CW-MC	Cottonwood-Mixed Conifers	
DF	Douglas fir	Douglas fir
DF-AF	Douglas fir-Alpine fir	
DF-GF	Douglas fir-Grand fir	
DF-LP	Douglas fir-Lodgepole	
DF-LP-AF	Douglas fir-Lodgepole-Alpine fir	
ES-AF	Engleman Spruce-Alpine fir	
GF	Grand fir	
L	Larch	
L-DF	Larch-Douglas fir	Dry lower mixed conifer
L-DF-AF	Larch-Douglas fir-Alpine fir	
L-DF-GF	Larch-Douglas fir-Grand fir	
L-DF-LP	Larch-Douglas fir-Lodgepole	
L-DF-PP-LP	Larch-Douglas fir-Ponerosa pine-Lodgepole	Dry lower mixed conifer
L-LP	Larch-Lodgepole	
LP	Lodgepole	
L-PP	Larch-Ponderosa pine	Dry lower mixed conifer
L-PP-LP	Larch-Ponderosa pine-Lodgepole	Dry lower mixed conifer
NF	Non-forested	
NS	Non-stocked	
PP	Ponderosa pine	Ponderosa pine
PP-DF	Ponderosa pine-Douglas fir	Ponderosa pine
QA	Quaking aspen	
QA-MC	Quaking aspen-Mixed conifers	
WB	White bark pine	
WB-ES-AF	White bark pine-Engleman spruce-Alpine fir	

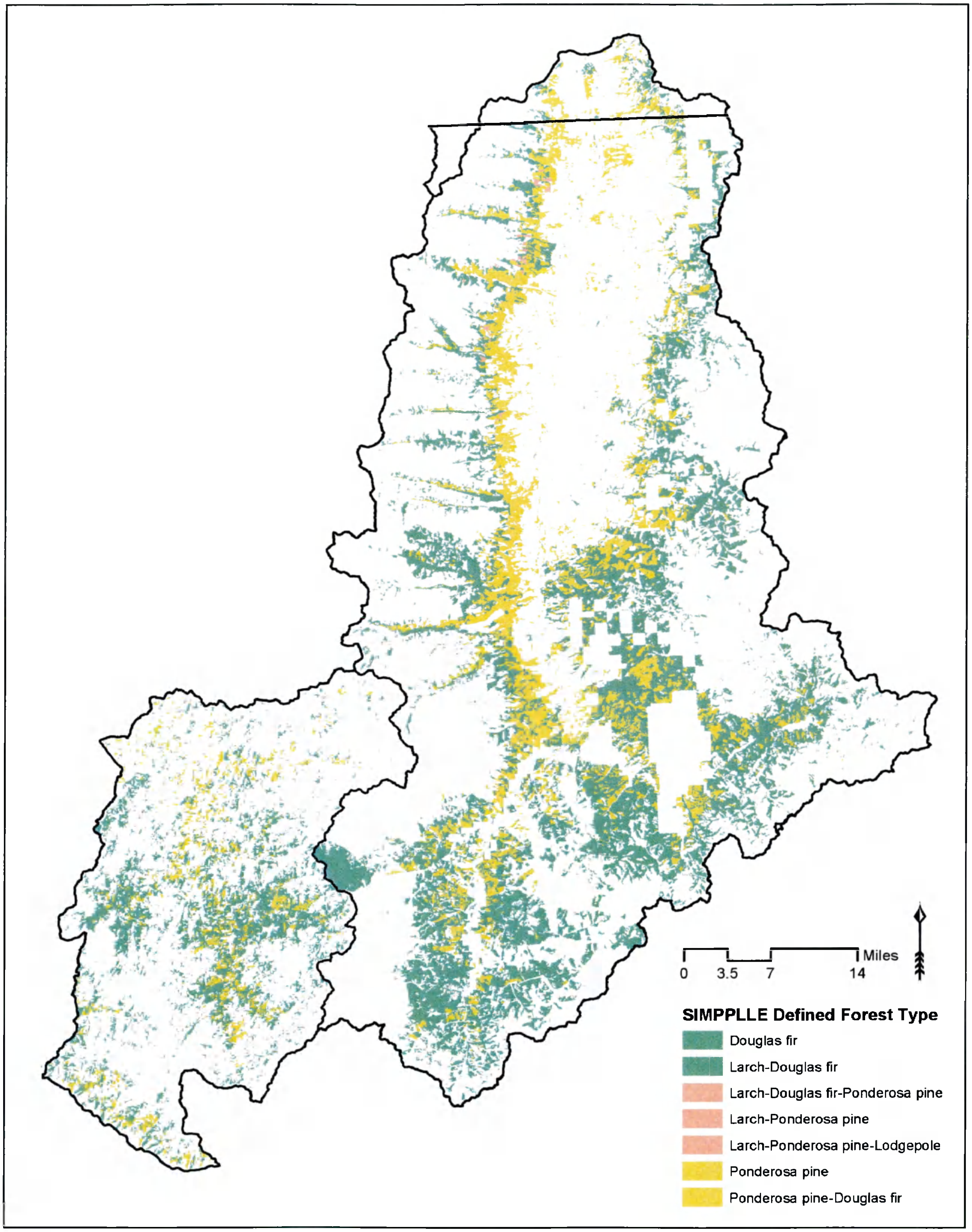

Figure 4.4 - Selected forest types of the Bitterroot National Forest.

4.4.3 Ground Slope

Ground based harvest systems – such as whole tree and cut-to-length – are limited to areas where slopes are less than approximately 35%. Ground based systems cause less damage to reserve trees (i.e. leave trees) than aboveground systems and are typically less expensive. Therefore it was necessary to identify lands in Ravalli County where ground based systems could be utilized to implement the comprehensive prescription using only the two ground based systems chosen for this analysis. The data used to produce the GIS landscape 'slope' data layer to meet this criterion were derived from the Digital Elevation Model (DEM) component of the Bitterroot National Forest GIS data. A DEM is a "digital data file containing an array of elevation information over a portion of the earth's surface. This array is developed using information extracted from digitized elevation contours from Primary Base Series maps" (BNF GIS Metadata). Figure 4.5 shows the slope of the lands in Ravalli County and the entire Bitterroot National Forest with slope less than or equal to 35%. Landscape level slopes were produced within the ArcMap software using the Spatial Analyst feature in conjunction with the DEM. Similar to the map of forest types, technical difficulties with the raster DEM prevented conversion to a polygon coverage or shapefile that would have allowed a clip of the county to be created. Nevertheless the county boundaries are visible.

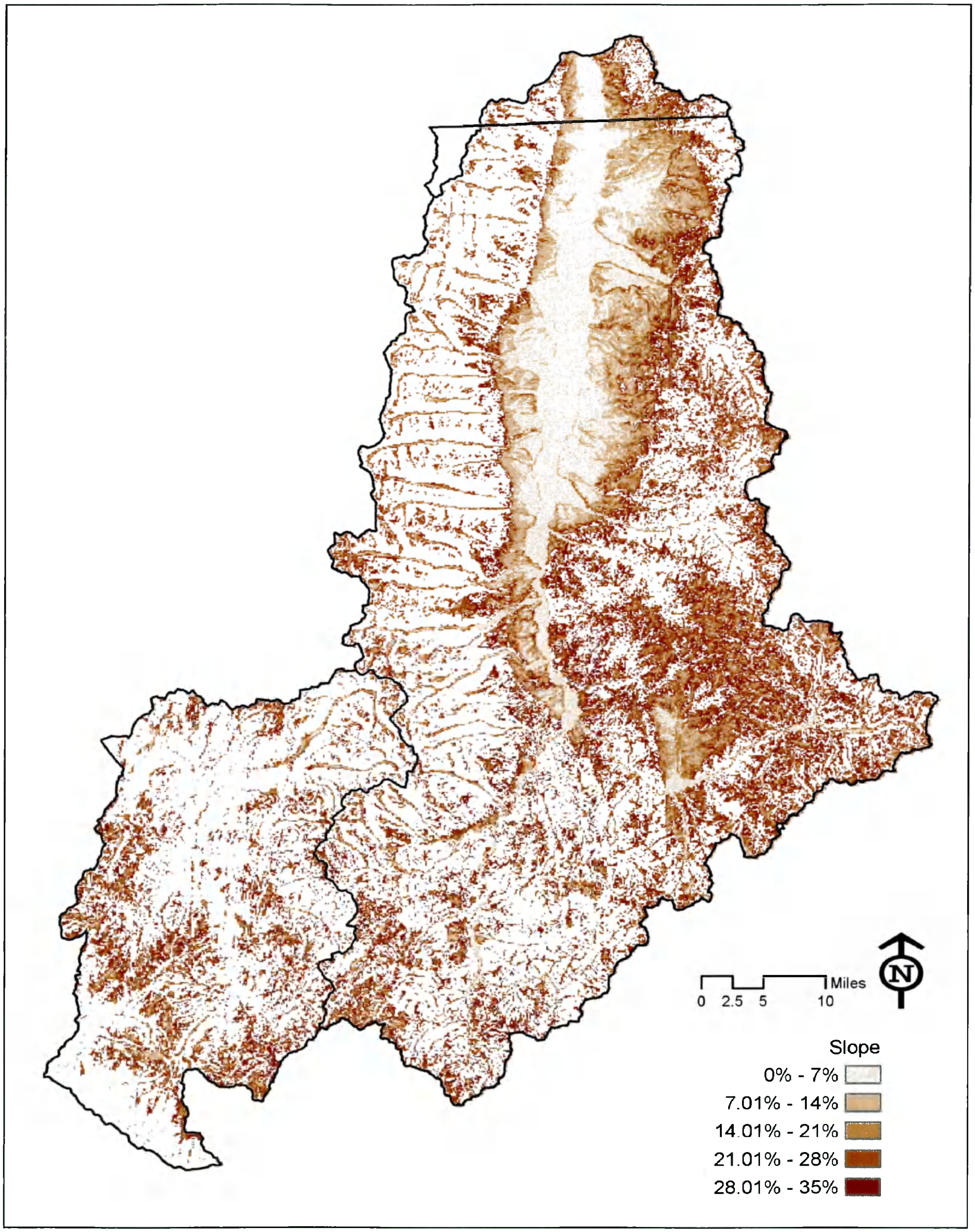

Figure 4.5 – Percent slope of lands in Ravalli County and the Bitterroot National Forest.

4.4.4 Fire Regime Condition Class

Only lands with Fire Regime Condition Class (FRCC) values of 2 or 3 were evaluated in this thesis due to the likelihood these areas would receive mechanical thinning, as preferred to prescribed fire, for fuel reduction. In order to identify the lands in Ravalli County most likely to receive the comprehensive prescription given a status of FRCC 2 or 3, data from the USDA Forest Service Northern Region National Fire Plan Cohesive Strategy Geospatial Database were obtained (USFS 2003b). As previously discussed, these data were used to assign FRCC's to the FIA sample plots used to derive the product list. Here the data were employed to identify lands in Ravalli County that are of moderate and high (FRCC 2 or FRCC 3, respectively) departure from historic fire regimes. Figure 4.6 shows the lands within Ravalli County with FRCC designations of 1, 2 or 3.

These data exist in 90 square meter resolution cell size, and according to the Northern Region Cohesive Strategy Team, "Although the resolution of the FRCC theme is 90 meter cell size, the expected accuracy does not warrant their use for analyses of areas smaller than about 10,000 acres" (USFS 2003b). Because Ravalli County is approximately 1,534,711 acres in size, this of course confirms that the data are correctly applied in this analysis. Further confirmation of this data's appropriateness in this analysis was verbally provided by Don Krogstad, GIS Coordinator, Flathead National Forest, USDA Forest Service (Krogstad 2004).

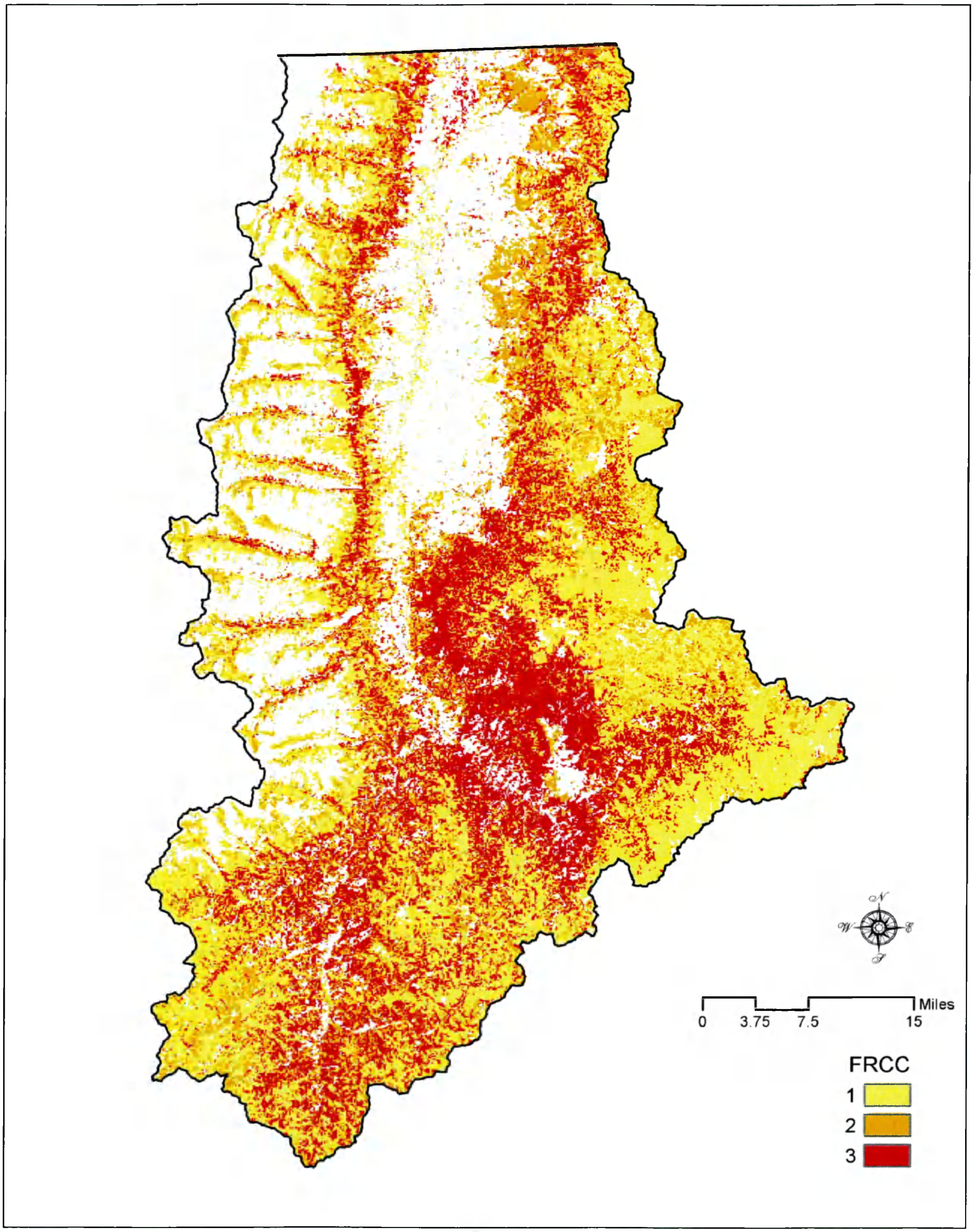

Figure 4.6 – Current fire regime condition class of Ravalli County.

4.4.5 Skidding/Forwarding Distances

Skidding or forwarding distance has been shown to have a significant impact on the total cost of an operation (Fight, Zhang and Hartsough 2003; Hartsough, Zhang and Fight 2001; Hartsough et al. 1997; Keegan et al. 2002; Kellogg and Bettinger 1994). Skidding distances were chosen based upon the assumption that a 1,500-foot distance away from existing roads would be approximately the maximum skidding/forwarding distance of ground-based harvest operations. Figure 4.7 shows an example of an area in Ravalli County where lands have been limited to 1,500 feet from a road. Also displayed in Figure 4.7 are the incremental distances from the landing that the harvest units were assumed to have for the harvest cost modeling process.

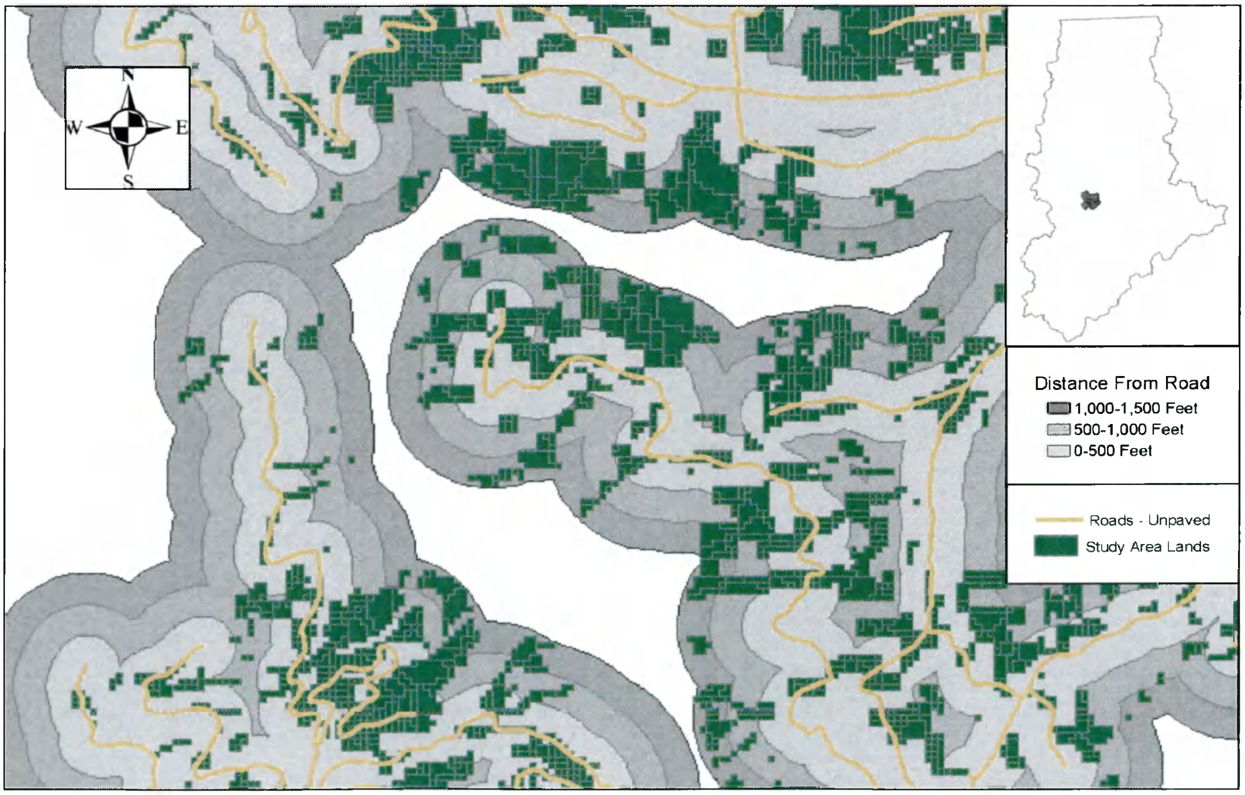

Figure 4.7 – Incremental distances used for skidding/forwarding cost evaluation.

4.4.6 2000 Fire Burn Severity

The extraordinary Montana wildfire season of 2000 hit Ravalli County especially hard. A total of 356,000 acres were burned in areas ranging from National Wilderness to the WUI. 48% of the acres burned were either Moderate or High burn severity (discussed below) and it was believed that removing these areas from the analysis was appropriate due to the likelihood that overstocked fuels were consumed in the wildfires.

The data used to produce the GIS '2000 Fire Burn Severity' data layer were received from the Bitterroot National Forest. This data set "is a polygon coverage showing delineations of [Burned Area Emergency Response] BAER burn severity classes for the Bitterroot BAER teams analysis areas" (BNF GIS Metadata). Within this base data layer each polygon is categorized into a burn severity class; these are:

1. H = High – More than 40% of the polygon exhibits soil or watershed features likely to significantly increase runoff and erosion;
2. M = Moderate – Less than 40% of the polygon exhibits high severity indicators, but a majority of the area is more highly impacted than low severity;
3. L = Low – A majority of the polygon exhibits low burn severity or unburned area within the fire perimeter. Areas mapped as Low severity commonly contain significant unburned areas intermingled with low severity burn, and generally not feasible to map separately for the BAER assessment;
4. U = Unburned – Larger areas of unburned lands within the fire perimeter that can be mapped separately from Low for the BAER assessment;
5. OUT – The unburned island identified by ICS (Incident Command System) fire perimeter mappers in the Rye Creek watershed. This is a donut hole of unburned

island contained within the outer fire perimeter, but considered by ICS to be outside the fire perimeter for purposes of acreage calculations.

All areas categorized as High or Moderate burn severity were removed form this analysis. It was assumed small diameter material would not have survived the fires of 2000 after having experienced High or Moderate fire burn severity. As confirmed by Paul Moore (2004) of the Montana Department of Resources and Conservation, little merchantable sawtimber in the Sula State Forest survived the fires of 2000 for salvage with basically zero timber below 9-inches DBH surviving at all. And as can be seen in Figure 4.1, the Sula State Forest was pummeled by High and Moderate burn severity during these fires. Figure 4.8 displays the High and Moderate burn severities of the 2000 wildfires, which were removed from the analysis.

4.4.7 Wildland Urban Interface

Wildland-Urban Interface (WUI) status is not a landscape condition for receiving the comprehensive prescription. However, identification and inclusion of these areas is believed to provide valuable information for land managers and environmental organizations that have recently listed WUI areas as those that should receive top priority for fuel reduction treatments, and therefore may base management decisions and/or allocate resources based upon WUI status. As a result from including WUI data, it was possible to produce the number of acres in the WUI areas of Ravalli County and estimate volumes of small diameter biomass potentially available from these areas (Table 4.9). The Bitterroot National Forest WUI zone is defined as the lands within one mile

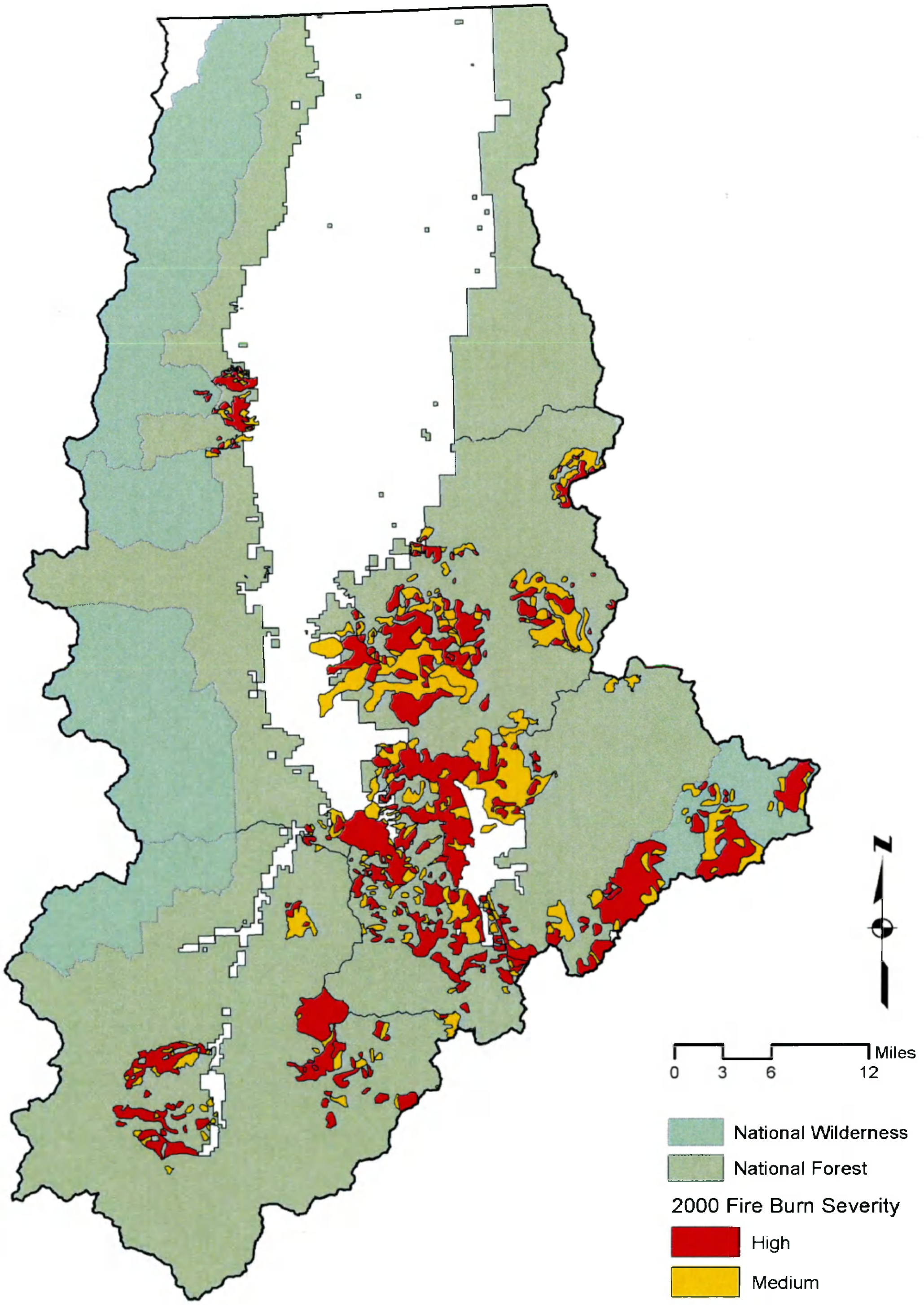

Figure 4.8 – Bitterroot National Forest fire burn severity of 2000 wildfires.

mile inside the perimeter of the National Forest. However, it should be mentioned that the USDA Forest Service's formal definition of WUI, as defined in the Federal Register (2001), is:

> "'the urban wildland interface community exists where humans and their development meet or intermix with wildland fuel.' There are three categories of communities that meet this description. Generally, the Federal agencies will focus on communities that are described under categories 1 and 2. For purposes of applying these categories and the subsequent criteria for evaluating risk to individual communities, a structure is understood to be either a residence or a business facility, including Federal, State, and local government facilities. Structures do not include small improvements such as fences and wildlife watering devices."

Categories 1 and 2 are thusly defined in the Federal Register:

> Category 1 - Interface Community
>
> The Interface Community exists where structures directly abut wildland fuels. There is a clear line of demarcation between residential, business, and public structures and wildland fuels. Wildland fuels do not generally continue into the developed area. The development density for an interface community is usually 3 or more structures per acre, with shared municipal services. Fire protection is generally provided by a local government fire department with the responsibility to protect the structure from both an interior fire and an advancing wildland fire. An alternative definition of the interface community emphasizes a population density of 250 or more people per square mile.
>
> Category 2 - Intermix Community
>
> The Intermix Community exists where structures are scattered throughout a wildland area. There is no clear line of demarcation; wildland fuels are continuous outside of and within the developed area. The development density in the intermix ranges from structures very close together to one structure per 40 acres. Fire protection districts funded by various taxing authorities normally provide life and property fire protection and may also have wildland fire protection responsibilities. An alternative definition of intermix community emphasizes a population density of between 28–250 people per square mile.

It should also be mentioned that due to the vagueness of these Category definitions, verbal communication with National Forest personnel has verified that each National Forest in the National Forest System has significant control over its interpretation and definition of WUI. Further verbal communication revealed that there is within the Bitterroot National Forest a significant level of control over the WUI definition given to each Ranger District within the National Forest, thus making a county wide definition that exactly fits the district level definitions difficult. Therefore the formal definition of WUI by way of the Bitterroot National Forest was used. Figure 4.9 displays the data layer depicting the lands one mile in from the boundary of the Bitterroot National forest.

4.4.8 Road Identification and Definition

Another crucial component of timber harvest activity necessary to estimate the net economic impact on the comprehensive prescription that collection and delivery of small diameter biomass to a market center are of course delivery costs. In order to derive delivery cost estimates, GIS road data for Ravalli County were employed and it was determined that the following criteria were required of the road data:

1. A current set of GIS data containing each and every road legally accessible by the public;
2. A current set of GIS data describing the surface type of each and every road legally accessible by the public. These road surface types are:
    a. Paved (consisting of asphalt, bituminous, or concrete surface types);
    b. Unpaved (consisting of road mix, gravel, graded, or bladed surface types).

Unfortunately these GIS data were not readily available from a single source, so therefore a total of four sources of GIS data were individually contacted, and each entity's contribution to the final GIS road layer is described below.

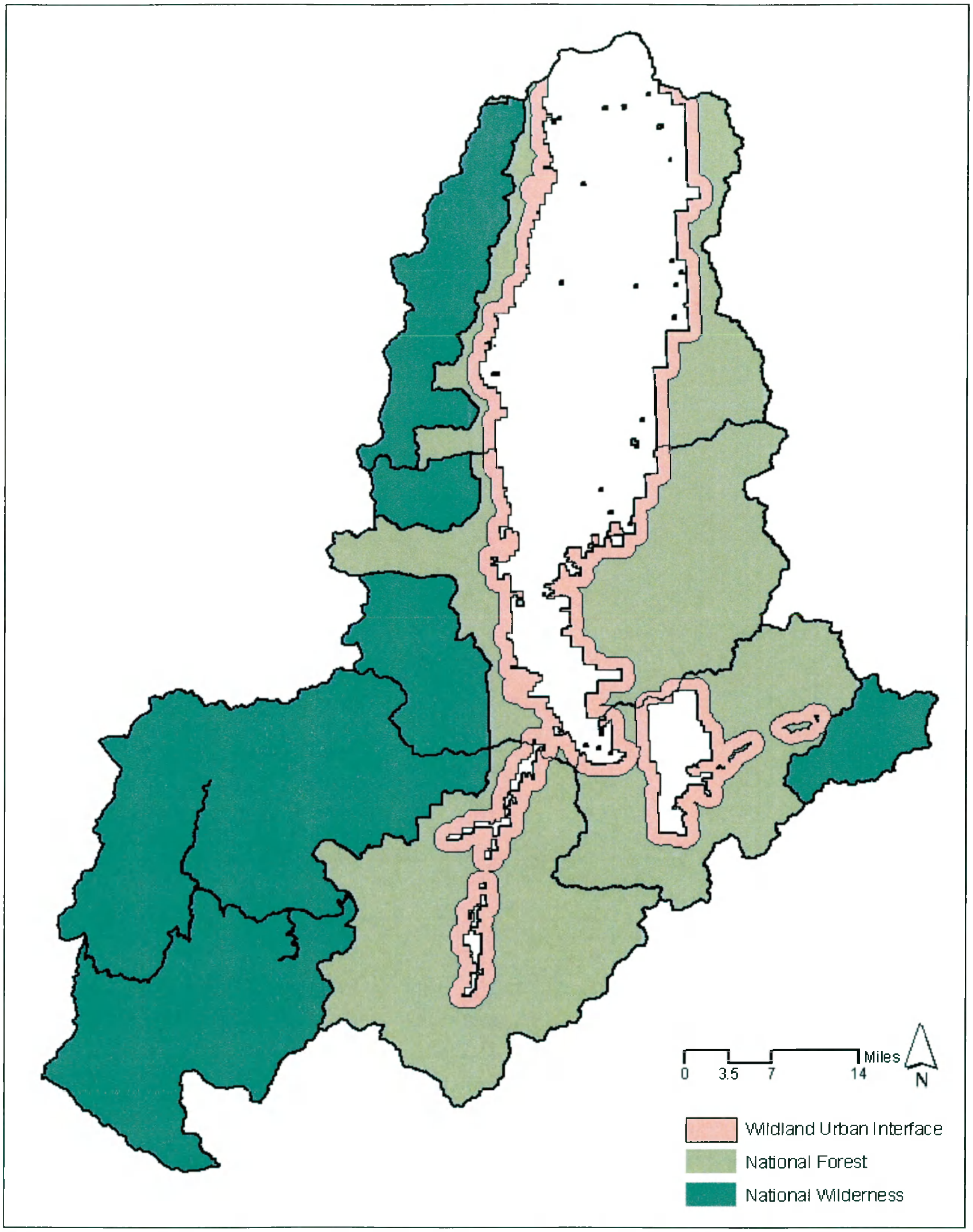

Figure 4.9 - Wildland Urban Interface in the Bitterroot National Forest, as defined by the Bitterroot National Forest.

The process of defining road surface types for the many roads in Ravalli County began with inspection of Montana Natural Resource Information System (NRIS) GIS data. NRIS provided a complete set of road data for Ravalli and Missoula Counties but unfortunately did not contain road surface types. The NRIS data layer was used as the base map to which all other surface type data were eventually transferred. That is, NRIS supplied a complete map (i.e. data layer) of county roads, but without surface type. As described below, the remaining three data sources were able to provide surface type data, but each for limited portions of county roads only.

The GIS data acquired from the Bitterroot National Forest contained a layer of: "Roads wholly or partly within, or adjacent to, and serving the National Forest system and which are necessary for the protection, administration, and utilization of the National Forest System and the use and development of its resources" (BNF GIS Metadata). It was used primarily for the roads within the Bitterroot National Forest and contained little data for roads outside the National Forest. The Bitterroot National Forest road data layer is displayed in Figure 4.10. To determine surface type for roads outside the National Forest, visual inspection of a Bitterroot National Forest map was performed. Although not updated since 1992, this map provided a basis for defining the surface types of roads in the county. Mapped roads are categorized into several surface types, among them, 'hard surface' and 'paved.' The breaks in surface type from paved to unpaved identified on the map were then manually transferred from the Bitterroot National Forest map onto the NRIS GIS data layer via visual interpretation. In Figure 4.10, the paved roads outside the National forest boundary were assumed to be transportation corridors outside the forest boundary for all harvest activity. And, all further definition of surface type from

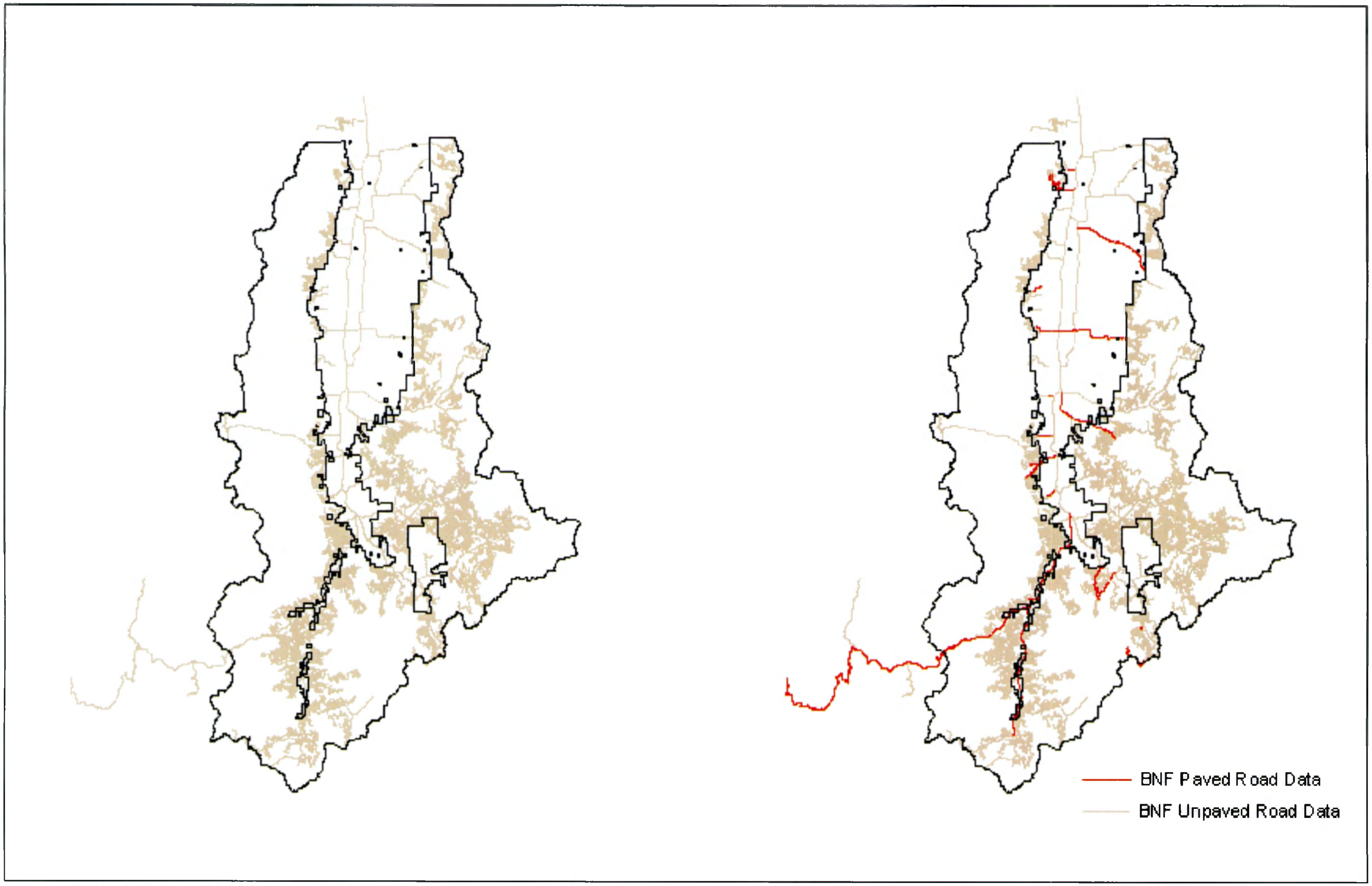

Figure 4.10– Bitterroot National Forest GIS road data, by surface type.

other data sources was performed only for those roads that adjoin privately owned lands selected for analysis.

Next, the Montana Department of Transportation (MDOT) was contacted in order to fill in the surface type gaps in Ravalli County not defined by the Bitterroot National Forest. MDOT provided a GIS data set of Ravalli County roads and an additional text file that described surface type. These two files were joined together in order to ascertain the surface types of its portion of county roads. Figure 4.11 displays this original GIS data layer as received from MDOT after the text file was joined with the GIS data. The data consist primarily of unpaved roads and the surface types derived from MDOT were subsequently joined with the NRIS data layer.

In order to locate the remaining road surface type data necessary, the Ravalli County Department of Transportation (RCDT) was contacted. Although RCDT did not house GIS data, the agency provided a current list of county maintained roads and their respective surface types. In order to match the RCDT list of road surface types with roads on or adjacent to selected study area lands, ESRI ArcMap software was employed. Having previously identified surface types of roads within the Bitterroot National Forest, it was only necessary to define surface types near selected private lands outside the National Forest at this point. A list of several hundred roads outside the forest boundary were identified as unknown surface type and sent to RCDT. From this list RCDT was able to identify county maintained roads as well as their surface type and approximately where those surface types began and ended. This information was then manually transferred to the NRIS GIS data layer. Visual inspection of the data (when displayed as

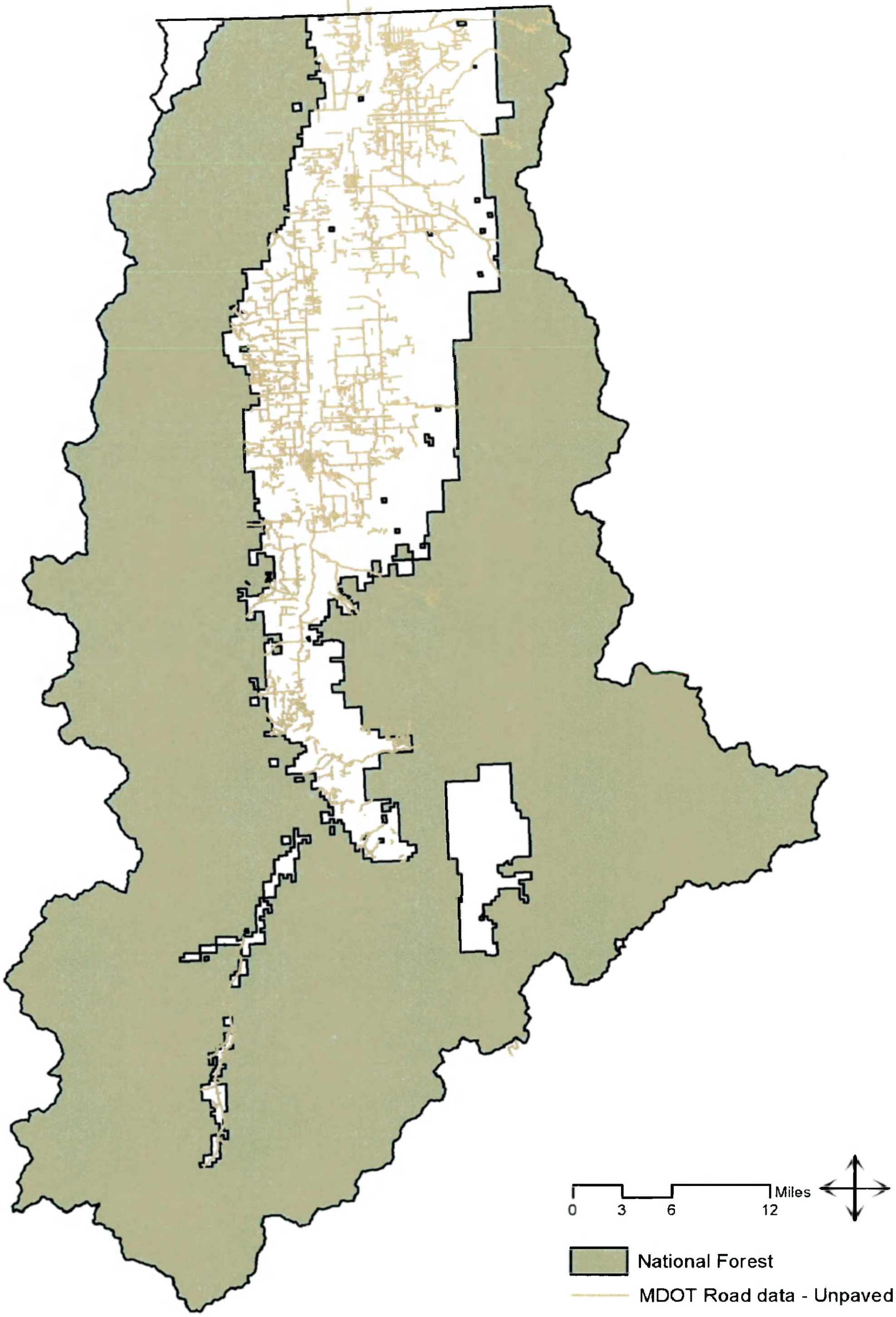

Figure 4.11 – GIS road data supplied by the Montana Department of Transportation (MDOT).

a map), as well as utilizing the measuring tool within ArcMap allowed for accurate definitions of road surface types and breaks of surface types.

From these four sources and using the methods described, a complete set of GIS road data, and equally important, road surface type, was produced. The single vector GIS road data layer constructed for this analysis is displayed in Figure 4.12; as can be seen, the majority of the roads in Ravalli County are unpaved and the eastern portion of the county has an almost uncountable number of unpaved forest access roads. The insert shows the level of detail the GIS software can display.

4.5 Definition of the Final Study Area

Using the above-described data and methodology, the areas of Ravalli County that were of the correct forest type, condition class, ownership, slope, and distance from a road were identified. Robin Silverstein, a Biologist with the Economic Aspects of Forest Management on Public Lands Research Work Unit 4802 of the USDA Forest Service Rocky Mountain Research Station, Missoula, Montana conducted the majority of the data manipulation using ESRI ArcMap and related software. Silverstein was able to identify the lands in Ravalli County that met the above-described criteria using the forest type definitions provided by Dr. Carl Fiedler and SIMPPLLE, Fire Regime Condition Class (FRCC) provided by the USDA Forest Service Northern Region, ownership from the NRIS Montana cadastral mapping project, slope and distance from operation grade road as determined by the Bitterroot National Forest Digital Elevation Model (DEM). The

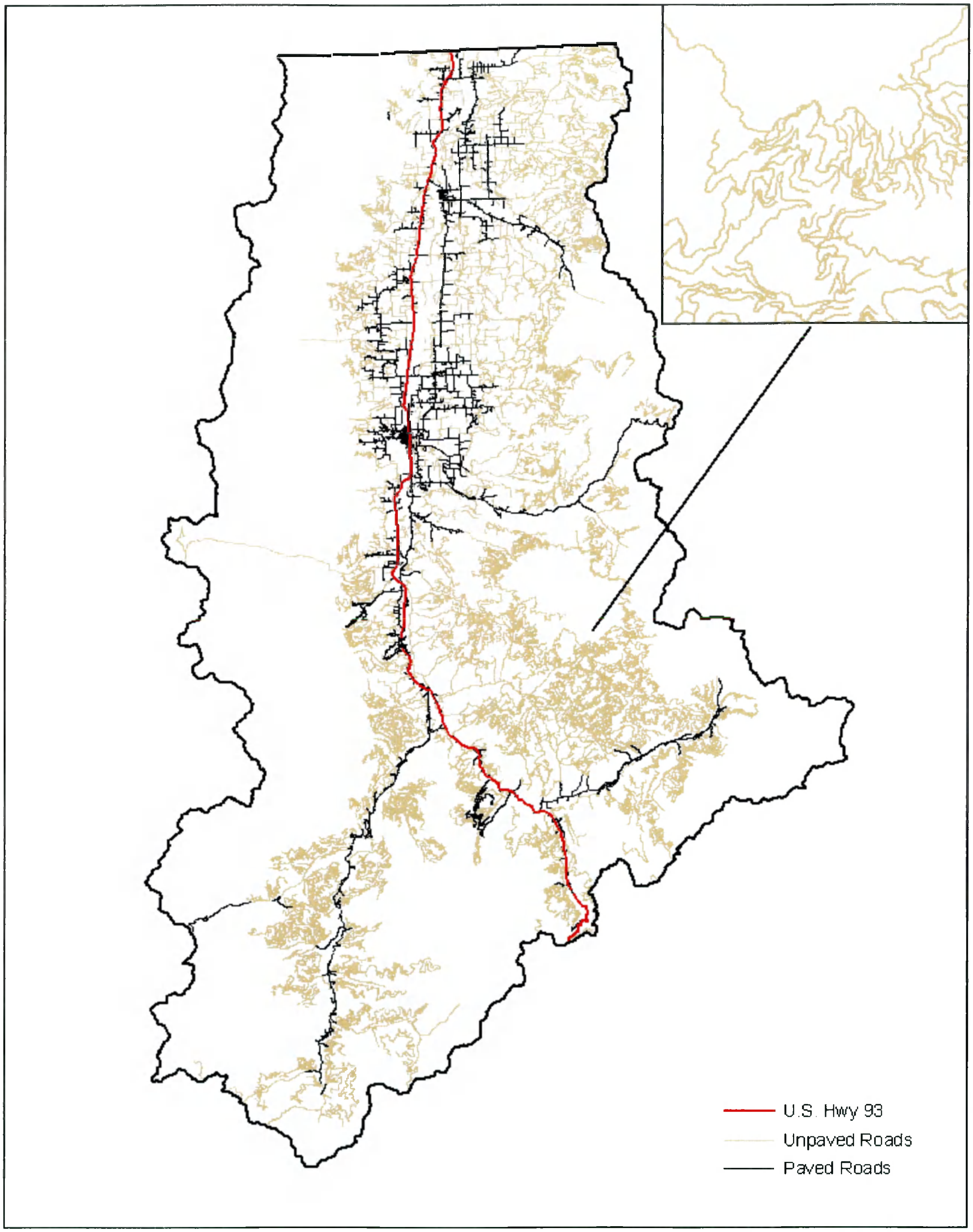

Figure 4.12 – All roads in Ravalli County by surface type.

study area that was derived from the above-described data and methods is displayed in Figure 4.13 (enlargement in Appendix I). This figure represents the final set of spatially explicit data that met all the criteria outlined in this chapter. Table 4.9 numerically represents the number of study area acres displayed in Figure 4.13 broken down by forest type, ownership, condition class, and WUI status. Therefore, the lands in Ravalli County displayed in Figure 4.13 were those found to be most suitable for the comprehensive prescription.

4.6 Delivery Costs: Calculation of Distances and Delivery Costs To the Selected Market Centers

After the road and surface type data for Ravalli County had been identified and formatted, it was necessary to calculate distances and delivery costs to three market centers identified as likely buyers of merchantable materials or small diameter forest biomass. The three market centers for all materials harvested (in parentheses) are:

1. Darby Public School, Darby, Montana (Biomass);
2. Smurfit-Stone, Inc., Frenchtown, Montana (Pulplogs);
3. Stimson Lumber Company, Bonner, Montana (Sawlogs).

These three market centers (Figure 4.14) were chosen because of their proximity to the study area and utilization capacity. According to Tom Coston (2003), the biomass facility located at the Darby Public School in Darby, Montana at southern end of Ravalli County is estimated to require approximately 650 tons of biomass for fuel each year to supply heat to the school facility. Rick Franke of Smurfit-Stone, Inc., located in Frenchtown, Montana 14 miles west of Missoula in Missoula County, estimates up to 500

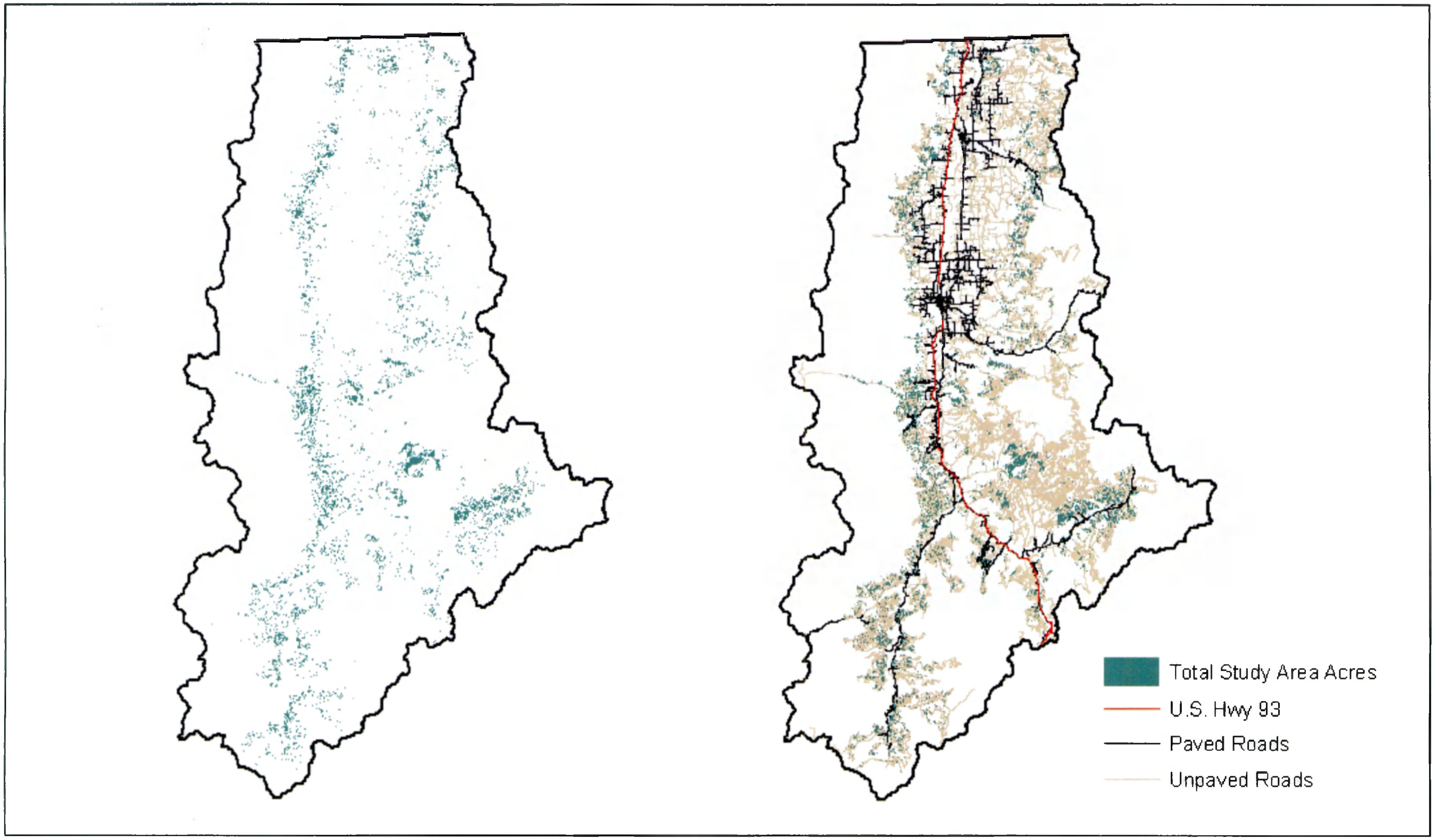

Figure 4.13 – All lands in Ravalli County study area.

Table 4.9 – Total study area acres in Ravalli County by condition class, ownership, WUI status, and forest type.

Forest Type	Ownership	Condition Class	Wildland Urban Interface Status	Number of Acres
DLMC	Forest Service	2	NONWUI	30.69
DLMC	Forest Service	2	WUI	215
DLMC	Private	2	NONWUI	7
DLMC	Forest Service	3	NONWUI	31
DLMC	Forest Service	3	WUI	298
DLMC	Private	3	NONWUI	52
DLMC	Private	3	WUI	2
DLMC	State	3	NONWUI	2
Douglas Fir	Forest Service	2	NONWUI	3,451
Douglas Fir	Forest Service	2	WUI	1,971
Douglas Fir	Private	2	NONWUI	1,065
Douglas Fir	Private	2	WUI	36
Douglas Fir	State	2	NONWUI	156
Douglas Fir	State	2	WUI	9
Douglas Fir	Forest Service	3	NONWUI	15,016
Douglas Fir	Forest Service	3	WUI	9,795
Douglas Fir	Private	3	NONWUI	2,842
Douglas Fir	Private	3	WUI	208
Douglas Fir	State	3	NONWUI	388
Douglas Fir	State	3	WUI	92
Ponderosa pine	Forest Service	2	NONWUI	1,381
Ponderosa pine	Forest Service	2	WUI	2,614
Ponderosa pine	Private	2	NONWUI	5,871
Ponderosa pine	Private	2	WUI	145
Ponderosa pine	State	2	NONWUI	294
Ponderosa pine	State	2	WUI	34
Ponderosa pine	Forest Service	3	NONWUI	6,582
Ponderosa pine	Forest Service	3	WUI	8,393
Ponderosa pine	Private	3	NONWUI	6,943
Ponderosa pine	Private	3	WUI	239
Ponderosa pine	State	3	NONWUI	592
Ponderosa pine	State	3	WUI	24
Sum				68,778

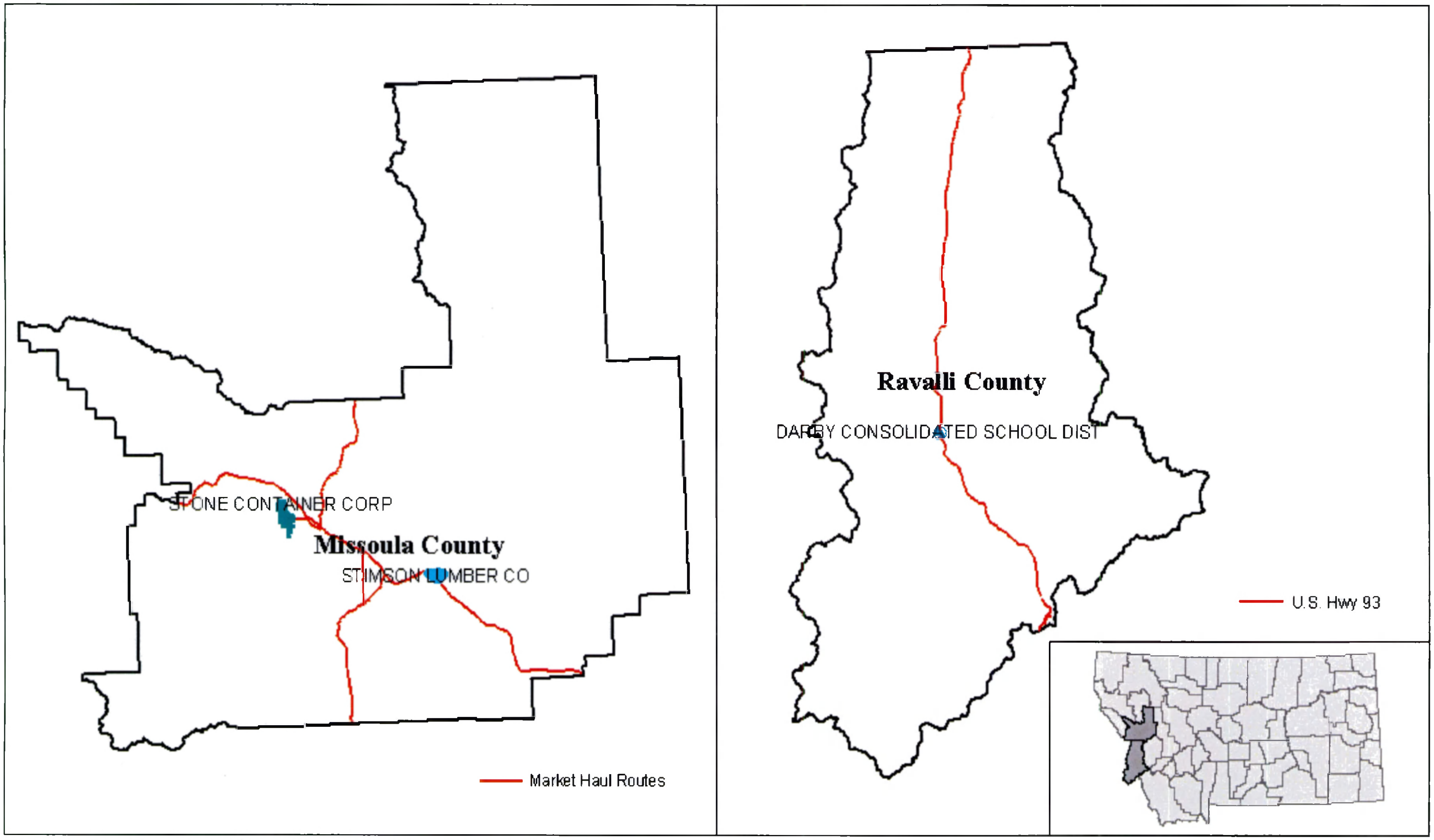

Figure 4.14 – Location of assumed analysis markets and haul routes, by real property ownership.

bone-dry units of hogfuel are consumed each day at this facility (2004), where one bone-dry unit equals 2,400 oven-dry pounds. Smurfit-Stone, Inc. is also a regional buyer of pulplogs with a minimum diameter of 2.5-inches inside bark and maximum diameter of 28-inches inside bark. So with pulplogs in this analysis being between 5.01 and 9-inches diameter at breast height (DBH), the smallest 32 foot log (assuming 5.01-inches DBH) in this diameter category would taper down to no less than 2.5 inches inside bark. Smurfit-Stone, Inc. accepts all conifers except cedar and juniper. Therefore, it is reasonable to assume that Smurfit-Stone would be a willing purchaser of either delivered pulplogs or hogfuel. Additionally, Stimson Lumber Company located in Bonner, Montana 6 miles east of Missoula in Missoula County is a purchaser of sawlogs; this company accepts logs with minimum diameter of 4.6-inches and maximum diameter of 29.5 inches.

Calculating the distances that selected lands in the county are from the three markets was accomplished using ESRI ArcMap GIS software and the Ravalli County road data previously discussed. Delivery costs were determined on a per mile basis through consultation with Don McKinnon, USDA Forest Service Appraisal Specialist, and using a private contractor's bid on a local stewardship contract in 2002 (McKinnon 2003). The per mile delivery cost estimates (in 2002 dollars) provided by McKinnon are:

1. $4.68 per loaded truck mile on a <u>gravel</u> road ($.18 per mile per ton);
2. $2.28 per loaded truck mile on a <u>paved</u> road ($.0875 per mile per ton).

It is believed that using these costs reflect local western Montana conditions and all fixed and variable costs of transporting logs and chips/biomass and provide accurate and reasonable delivery cost estimates.

ESRI ArcMap software was used to calculate distances in miles and delivery costs as the shortest and least cost distance from each study area analysis unit to the market center respectively. Therefore, it was assumed that any log truck going north out of Ravalli County to either of the two market centers in Missoula County would take the shortest paved road route to its destination. It is further assumed that the shortest paved route is also the least cost route. Figures 4.15 and 4.16 show all the study area lands as a gradient colored distances and costs from the three market centers, respectively. As can be seen, most of the lands in the study area show little difference in cost or distance between Smurfit-Stone, Inc. and Stimson Lumber Co. Appendix II shows distributions of the distances and costs displayed in Figures 4.15 and 4.16. Table 4.10 shows the statistics by delivery cost and distance to the market centers. Costs are those for one truck going one-way. Converting the one-way per truck delivery costs to dollars per acre, using mean delivery costs, was accomplished by simply calculating the ratio of tons per acre to tons per truck and multiplying by mean delivery costs. For sawlog delivery this ratio is 1.22, and for pulplog delivery the ratio is .33 (assuming a load capacity of 27 tons). For biomass delivery this ratio for a whole tree system is .93 and for a cut-to-length system the ratio is .80 (assuming a 15 ton capacity).

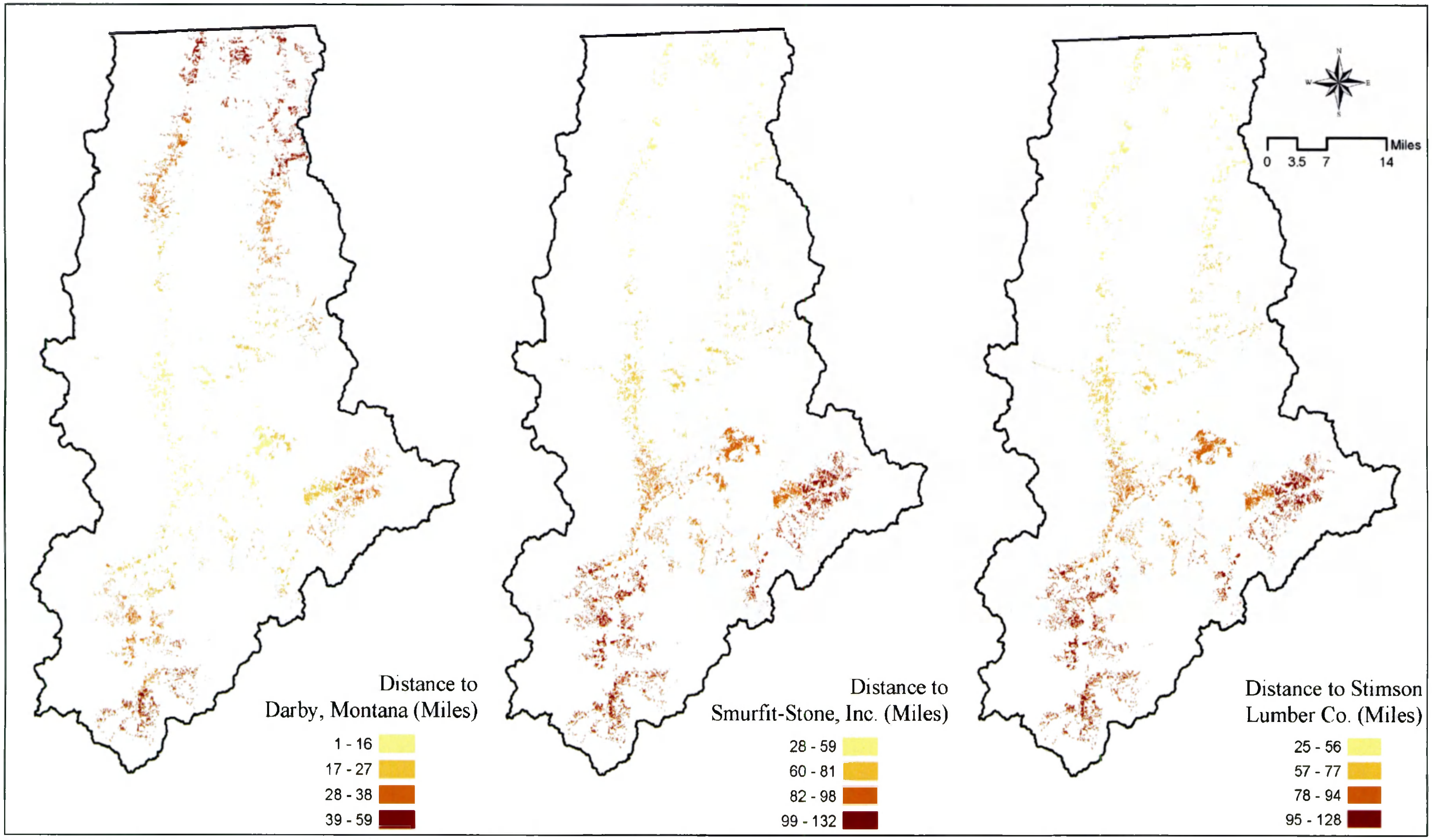

Figure 4.15 – Study area distance in miles to the three market centers.

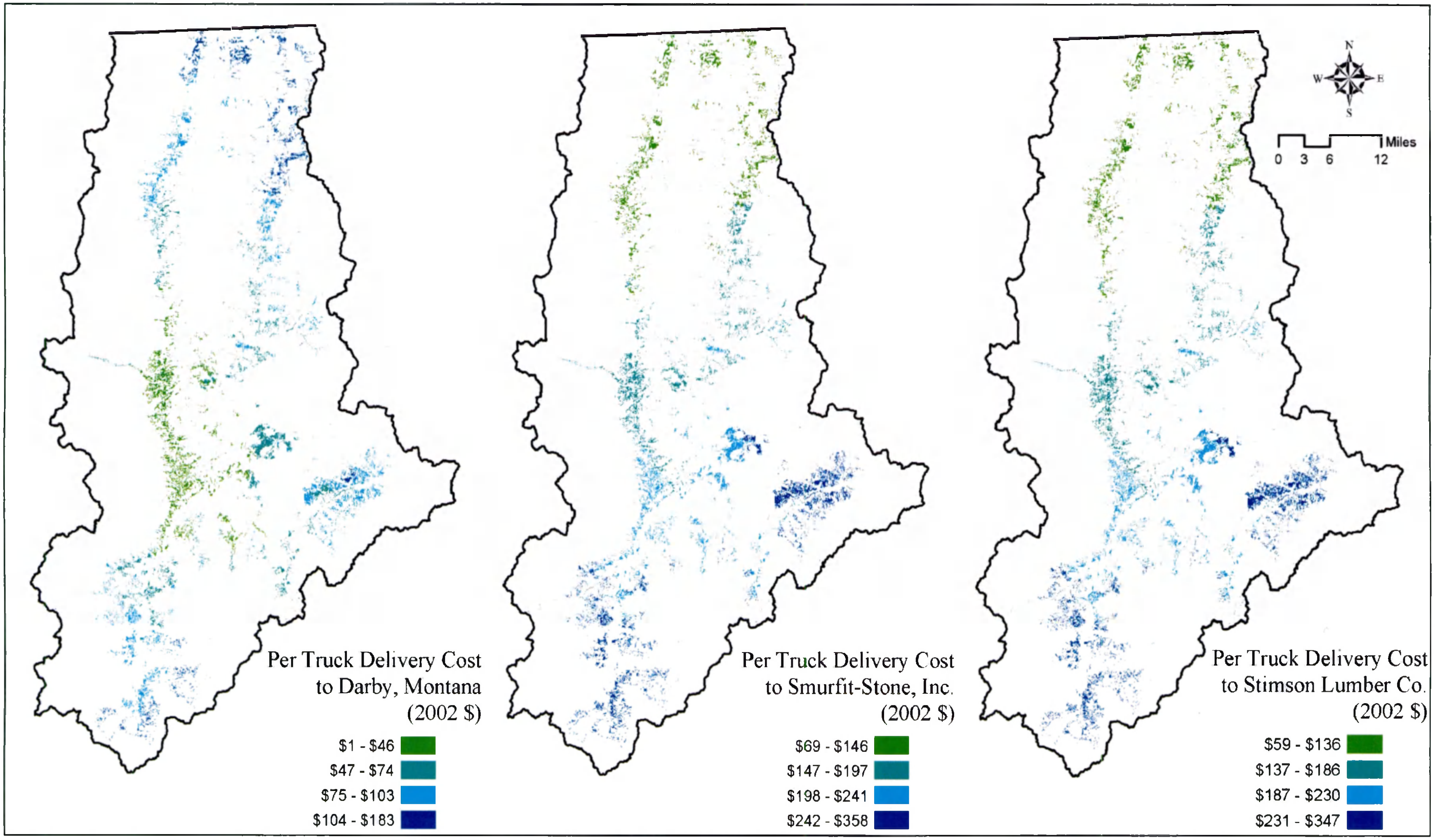

Figure 4.16 - Study area delivery cost in 2002 dollars to the three market centers.

Table 4.10 – Summary statistics of per truck and per acre delivery cost and distance to the analysis market centers.

	Distance to Stimson Lumber Co. (miles)	Distance to Darby School District (miles)	Distance to Smurfit-Stone, Inc. (miles)	Per truck cost to Stimson Lumber Co. (2002 Dollars)	Per truck cost to Darby, Montana (2002 Dollars)	Per truck cost to Smurfit-Stone, Inc. (2002 Dollars)
Mean	77.80	26.26	81.37	$192.21	$72.14	$202.44
Median	81.01	26.83	84.51	$200.13	$74.28	$210.36
Std. Deviation	23.12	12.09	23.00	$55.32	$30.59	$55.32
Minimum	24.57	.59	28.07	$58.56	$1.76	$68.79
Maximum	128.28	59.41	131.78	$347.47	$183.00	$357.70
$/Acre – Whole Tree	---	---	---	$236.16	$66.96	$66.66
$/Acre – Cut-to-Length	---	---	---	$236.16	$57.60	$66.66

Appendix III shows the number of acres in the Ravalli County study area as a function of distance in miles from the three market centers, the number of acres within incremental transportation cost distances from the three market centers, and the number of green product tons per acre for each harvest system as a function of transportation cost distance from the three market centers.

4.7 Estimation of Delivered Product Values

In addition to defining the study area, delivered values of all products harvested were required in order to determine the net economic effects of biomass collection on the prescription. To estimate the delivered value of harvested sawlogs, data collected and housed at the Forest Industry Research Program, Bureau of Business and Economic Research, University of Montana, Missoula (BBER 2004) were used. Table 4.11 shows a two-year average of 2002 and 2003 western Montana mill delivered prices. According to the BBER:

> "The following [prices (Table 12) are] a summary breakdown of recent past average prices reported by primary wood processors for logs of the various species listed. These prices are not necessarily a reflection of current market prices. Fair market prices may vary a great deal based on log size, length, quality, contract size and terms, and a number of other factors. All information reported is recent average price per thousand board feet (MBF), Scribner Decimal rule, delivered to the mill site."

The thousand board feet (MBF) prices were transformed to per ton prices using a local conversion factor acquired from Ed Hayes, a Timber Sale Preparation Supervisor for the Bitterroot National Forest (Equation 4.3).

4.3 $Tons = .1466 * MBF$

Delivered product values for the 5 to 9-inch diameter class (pulplog) to market were obtained from Rick Franke of Smurfit-Stone, Inc (2004). According to Franke, the current delivered value of pulplogs at Smurfit-Stone in Frenchtown, Montana is $27 per green ton. And while the pulplog market may vary from low demand to high demand, this value was assumed for all harvested pulplogs and it was indicated by Franke that this price had been relatively stable over the past several months. The delivered value of chipped biomass to Darby, Montana was estimated by Tom Coston (2003) to range between $25 and $35 per ton (at any moisture content). The delivered value of $29 per green ton was chosen, and not coincidentally is currently the same delivered value of chipped hogfuel at Smurfit-Stone, Inc

Table 4.11 – Product prices for selected species used to determine net revenues in Ravalli County.

	Price per thousand board feet (MBF Scribner) by year and quarter										
Species	2002-1	2002-2	2002-3	2002-4	2002 average	2003-1	2003-2	2003-3	2003-4	2003 average	**2-year average**
Ponderosa pine					$363.88					$346.25	**$355.06**
yellow	$394.00	$425.00	$450.00	$363.00		$368.00	$383.00	$367.00	$430.00		
bull	$335.00	$300.00	$336.00	$308.00		$276.00	$309.00	$314.00	$323.00		
Douglas fir	$381.00	$364.00	$379.00	$367.00	$372.75	$361.00	$377.00	$367.00	$388.00	$373.25	**$373.00**
Western larch (DLMC)	$380.00	$409.00	$380.00	$372.00	$385.25	$374.00	$377.00	$366.00	$388.00	$376.25	**$380.75**

	Price per green ton (1 MBF = 6.82 tons) by year and quarter										
	2002-1	2002-2	2002-3	2002-4	2002 average	2003-1	2003-2	2003-3	2003-4	2003 average	**2-year average**
Ponderosa pine					$53.35					$50.77	**$52.06**
yellow	$57.77	$62.32	$65.98	$53.23	$0.00	$53.96	$56.16	$53.81	$63.05		
bull	$49.12	$43.99	$49.27	$45.16	$0.00	$40.47	$45.31	$46.04	$47.36		
Douglas fir	$55.87	$53.37	$55.57	$53.81	$54.66	$52.93	$55.28	$53.81	$56.89	$54.73	**$54.69**
Western larch (DLMC)	$55.72	$59.97	$55.72	$54.55	$56.49	$54.84	$55.28	$53.67	$56.89	$55.17	**$55.83**

Source: Bureau of Business and Economic Research, University of Montana, Missoula, Montana

Table 4.12 shows the delivered values of harvested products expected from the implementation of the comprehensive prescription for both harvest systems per acre. Using average products harvested, which are outlined in Tables 4.6 and 4.7, we see that the average per acre value of biomass with a whole tree system is approximately $410, and $348 with a cut-to-length system, pulplogs are valued at $246 and sawlogs are valued at $1,813 using either system, resulting in a grand total of $2,457 per acre of gross revenue per acre using a whole tree system and $2,395 using a cut-to-length system.

Table 4.12 - Delivered per acre product values of average harvested products.

Product (Diameter Class)	Average Tons per Acre	Per Ton Delivered Product Value	Average Product Value per Acre - Whole Tree	Average Product Value per Acre - Cut-to-Length
Biomass				
Whole Tree	14.13	$29.00	$409.77	---
Cut-to-Length	11.99	$29.00	---	$347.71
Pulplogs (5.01 - 9-inches)	9.11	$27.00	$245.97	$245.97
Sawlogs (> 9-inches)	33.24	$54.20 (Average)	$1,801.61	$1,801.61
Sum			$2,457.35	$2,395.29

From Table 4.12 we also see that average per acre delivered product values are higher than harvest costs shown in Tables 4.6 and 4.7, assuming any skidding/forwarding distance. But depending on the harvest unit's location in Ravalli County, there exists potential for net revenue loss, attributable to delivery, utilizing a cut-to-length system. This is due to the higher overall harvest costs associated with biomass collection, the number of trucks that must deliver the harvested material and the harvest unit's distance from the markets (Appendix II).

4.8 Calculation of Net Economic Effects of Biomass Collection

Estimating the economic effect that biomass collection has on the comprehensive prescription was conducted using current product values and estimates of harvest and delivery costs. The effects were modeled with and without the collection of biomass for each harvest system and skidding/forwarding distances of 300, 800, and 1,300 feet, where the difference (i.e. with biomass collection versus without biomass collection) represents the cost of availability. Again, whole tree harvest costs associated with the prescription <u>without</u> biomass collection include harvest of all trees less than 9-inches DBH and selected harvest of trees greater than 9-inches DBH. Trees less than 5-inches DBH were harvested, removed to the landing, and piled for disposal. Trees greater than 5-inches DBH were harvested and removed to the landing, processed and merchantable material loaded onto a log truck for delivery. Whole tree harvest costs for the prescription <u>with</u> biomass collection include all harvest costs associated with the activities just stated, as well as the costs of chipping all trees less than or equal to 5-inches DBH that are removed to the landing as part of the prescription, and chipping tops and limbs of harvested trees greater than 5-inches DBH that resulted from processing merchantable material at the landing.

Harvest costs for the cut-to-length system include, similar to the whole tree system, cutting all trees less than 9-inches DBH and selected harvest of trees greater than 9-inches DBH. There are additionally the costs of forwarding and loading the harvested merchantable material. However, because all trees less than 5-inches DBH are left scattered in the woods along with the tops and limbs of the merchantable material, cost estimates of in-woods slash bundling and forwarding to the landing biomass were produced and included in total per acre harvest costs with biomass collection. Slash bundling costs are excluded without biomass collection. Appendix IV shows the distributions of net revenues associated with each FIA data plot. Included in the calculations without biomass collection and delivery is a $175 per acre pile and burn cost. Mean delivery costs to the three market centers were used in all calculations that included biomass whereas mean delivery costs to Stimson Lumber Co. and Smurfit-Stone, Inc. only were included in the calculations without biomass collection and delivery.

In order to calculate the net economic results with and without biomass collection for Ravalli County, the mean per acre harvest costs for each system and skidding/forwarding distance (Tables 4.6 and 4.7) were added to the delivery costs determined for each selected unit on a per acre basis, using GIS and outlined in section 4.6. A weight derived from each polygon's ratio of size in acres to total study area acres was then applied to each polygon's total cost of harvest and delivery. The sum of these weights across all polygons is the mean cost of availability determined for each acre in the study area. These weighted averages were then subtracted from the value of delivered materials outlined in section 4.7 (Table 4.12). These calculations are displayed below in equations 4.4 through 4.8. Delivery costs were adjusted according to type and volume of material harvested from each acre. That is, on average each acre is expected to yield 33 green tons of sawlogs, 9 green tons of pulplogs, and either 12 or 14 green tons of biomass, depending on harvest system. Therefore, because log trucks can only carry approximately 27 tons of material, 1.23 trucks are needed per acre to deliver harvested sawlogs, .34 trucks to deliver pulplogs, and either .93 or .80 trucks to deliver biomass (the use of small chip vans, which carry 15 tons, was assumed), depending on harvest system.

4.4 $$w_i = \frac{a_i}{\sum_{i=1}^{n} a_i}$$

4.5 $$\overline{Y}_{weighted} = \sum_{i=1}^{n} w_i tc_i$$

4.6 $$S^2_{weighted} = \frac{\sum_{i=1}^{n} w_i tc_i^2 - (\sum w_i) * \overline{Y}^2_{weighted}}{\sum_{i=1}^{n} w_i}$$

4.7 $$Net\,Revenue_{WT} = TPV_{WT} - \overline{Y}_{weighted}$$

4.8 $$Net\,Revenue_{CTL} = TPV_{CTL} - \overline{Y}_{weighted}$$

In equation 4.4 w_i is the weight applied to each polygon's cost of availability, where a_i equals each polygon's size in acres. In equation 4.5, $\overline{Y}_{weighted}$ is the weighted mean cost of availability, and tc_i is the total cost of availability for polygon i that includes harvest and delivery cost. Equation 4.6 shows the calculation of variance for the weighted mean, and of course the standard deviation is simply the square root of the variance. In equations 4.7 and 4.8 TPV_{WT} equals the total product value for a whole tree system and TPV_{CTL} equals the total product value for a cut-to-length system (Table 4.12). Using equations 4.7 and 4.8, net revenue for each acre selected in Ravalli County was calculated, and the results are outlined in the following chapter.

CHAPTER V

RESULTS: THE ECONOMICS OF BIOMASS AVAILABILITY, COLLECTION AND DELIVERY

5.1 Introduction

The economic impact that collection and delivery of small diameter forest biomass has upon the comprehensive forest restoration prescription on selected lands in Ravalli County was determined for a whole tree and cut-to-length harvest system using the methods and data previously described. Following are the results of the analysis that include costs of availability[14] associated with biomass collection and delivery, net revenue generated from each selected acre in Ravalli County, and biomass volumes made available from the prescription.

5.2 Biomass Cost of Availability

Harvest costs for the prescription were estimated with and without the collection of biomass, and the difference between the two cost estimates plus delivery is the marginal cost of adding the estimated quantities of biomass to total harvest production. Tables 4.6 and 4.7 show mean harvest costs per acre, excluding delivery, with and without biomass recovery from the comprehensive prescription for both harvest systems. Again, the harvest cost estimates in Table 4.7 include a $175 per acre pile and burn cost,

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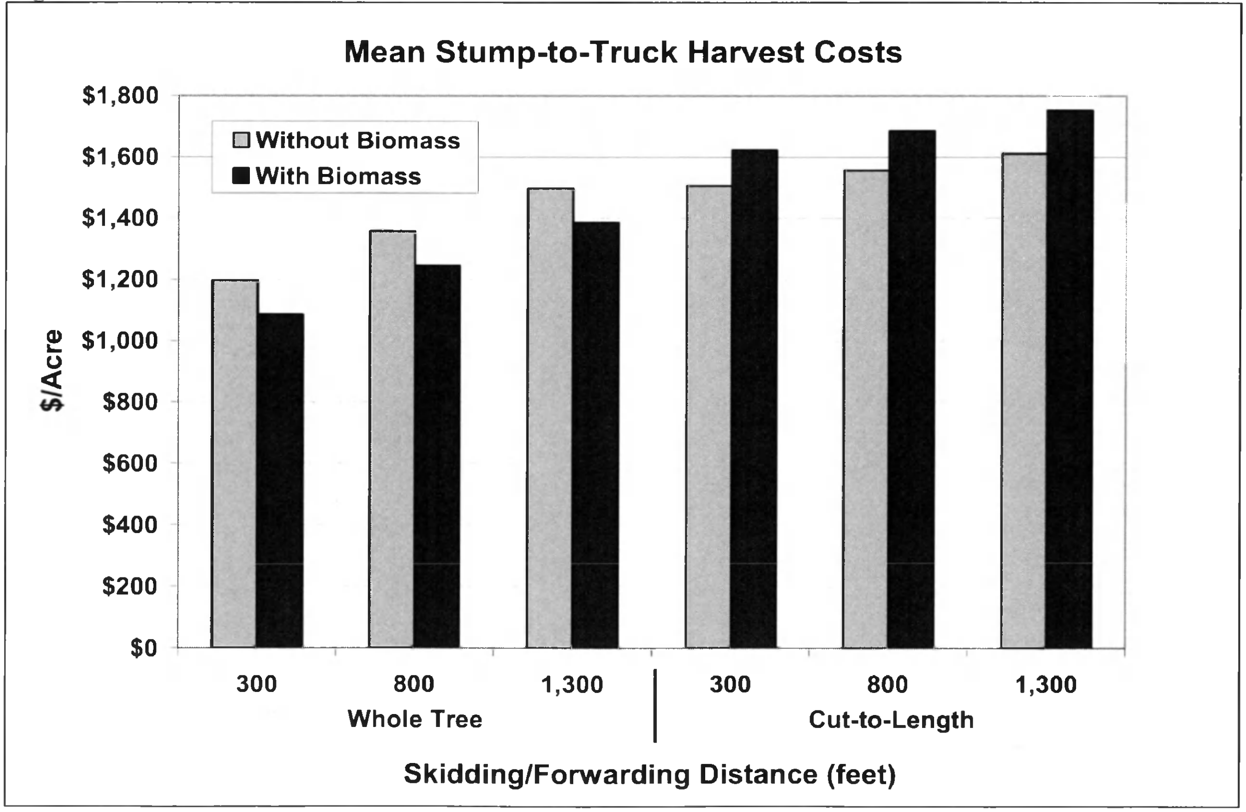
[14] Defined by Gregory (1972) as "the cost of transforming standing timber into logs on the mill deck" [or, stump to mill].

which is the alternative biomass disposal method to collection and delivery. As seen, using a whole tree system mean harvest costs without biomass collection range between $1,198 and $1,498. Likewise, mean harvest costs with biomass collection range between $1,086 and $1,386 per acre depending on skidding distance. Similarly, using a cut-to-length system, mean harvest costs range between $1,506 and $1,611 per acre without biomass collection and $1,623 and $1,752 per acre with biomass collection. Figure 5.1 displays these results.

The marginal harvest cost of biomass using a whole tree system was estimated as the difference between the cost of harvest with biomass and the cost of harvest without biomass. The marginal per ton harvest cost of biomass is the quotient of this cost

Figure 5.1 – Mean harvest costs with and without biomass collection.



difference divided by the average number of biomass tons available per acre. Using a whole tree system, the marginal harvest cost of biomass is approximately \$-112 per acre for any skidding distance, or \$-8 per ton. <u>This means that it costs \$8 per ton more to pile and burn the biomass than it costs to chip it at the landing.</u> Using the same method, the marginal harvest cost of biomass using a cut-to-length system ranges from \$117 to \$141 per acre depending on forwarding distance, or approximately \$9.75 to \$11.75 per ton.

Before delivery, biomass harvest costs using a cut-to-length system are up to 141% higher per ton than the cost of using a whole tree system. These cost differences between harvest systems are attributable to the location of the biomass at the time of collection. Whole tree systems remove the material to the landing as part of the prescription where it is piled during the processing of merchantable material and essentially ready for chipping. The low and consistent costs of biomass collection are the cost of chipping only, and the biomass collection is essentially free. Conversely, cut-to-length systems process the merchantable material in the woods and require a slash-bundler to gather, bundle, and load the biomass on a forwarder, which then transports the biomass to the landing where it is either chipped or loaded onto a truck for delivery. Slash bundling technology is relatively new and expensive, and this clearly explains the sizable difference in the costs of biomass availability between the two harvest systems.

When delivery costs are included, the mean biomass cost of availability for a whole tree system increases 14%, and the cost of availability with a cut-to-length system increases 62% to 66%. Table 5.1 shows the mean per acre biomass costs of availability with and without biomass collection and delivery, as well as the difference between the two costs. As seen, collecting and delivering biomass using a whole tree system costs

$44 per acre less than if the biomass is piled and burned. Using a cut-to-length system results in costs ranging from $174 to $198 per acre more if biomass is collected and delivered.

Table 5.1 – Mean per acre biomass costs of availability, by harvest system.

	WT 300	WT 800	WT 1300	CTL 300	CTL 800	CTL 1300
Without Biomass (Includes pile and burn costs)	$1,494	$1,654	$1,795	$1,803	$1,852	$1,908
With Biomass	$1,450	$1,610	$1,751	$1,977	$2,039	$2,106
Difference	-$44	-$44	-$44	$174	$187	$198

Table 5.2 shows the mean per ton biomass costs of availability if mean per acre harvest costs are divided by mean tons per acre. As seen, the data show that the mean delivered marginal cost of biomass is $3 per ton less than piling and burning using a whole tree system and between $15 and $17 per ton using a cut-to-length system. Also evident is that the cost of collecting biomass using a cut-to-length system from harvest units very close to the landing versus those that are the maximum distance from the landing are slight, at approximately $1 per ton for forwarding distance increases of 500 feet.

Table 5.2 – Mean per ton biomass costs of availability, by harvest system.

	$/Ton Delivered Cost - WT	$/Ton Delivered Cost – CTL 300	$/Ton Delivered Cost – CTL 800	$/Ton Delivered Cost – CTL 1300
Mean	$-3	$15	$16	$17

5.3 Economic Impact of Biomass Collection and Delivery on Net Revenue Generated by the Comprehensive Prescription

Using product values outlined in Table 4.12, harvest costs outlined in Tables 4.6 and 4.7, pile and burn costs of $175 per acre, and GIS data used to derive Table 4.10, net revenues or costs associated with and without biomass collection were ascertained. Table 5.3 shows mean net revenue generated from each acre without biomass collection and delivery. A clear relationship is seen between decreasing revenue and increasing skidding distance for both harvest systems. On average, $253 to $553 in net revenue is expected if biomass is not collected and sold using a whole tree system. Using a cut-to-length system, $140 to $245 in net revenue is expected if biomass is not collected and sold. Table 5.4 shows the mean net revenue generated with biomass collection and delivery from each acre in the Ravalli County study area. Again there is a clear relationship between decreasing revenue and increasing average skidding distances. On average, using a whole tree system with biomass collection results in $707 to $1,007 in net revenue per acre depending on skidding distance. With this harvest system, biomass collection and delivery results in 45% to 64% more revenue.

Table 5.3 – Mean total net revenue per acre associated with all harvest systems and skidding/forwarding distances <u>without</u> biomass collection.

	Net Revenue ($/Acre) Without Biomass - WT 300	Net Revenue ($/Acre) Without Biomass - WT 800	Net Revenue ($/Acre) Without Biomass - WT 1300	Net Revenue ($/Acre) Without Biomass - CTL 300	Net Revenue ($/Acre) Without Biomass - CTL 800	Net Revenue ($/Acre) Without Biomass - CTL 1300
Mean	$553	$393	$253	$245	$195	$140

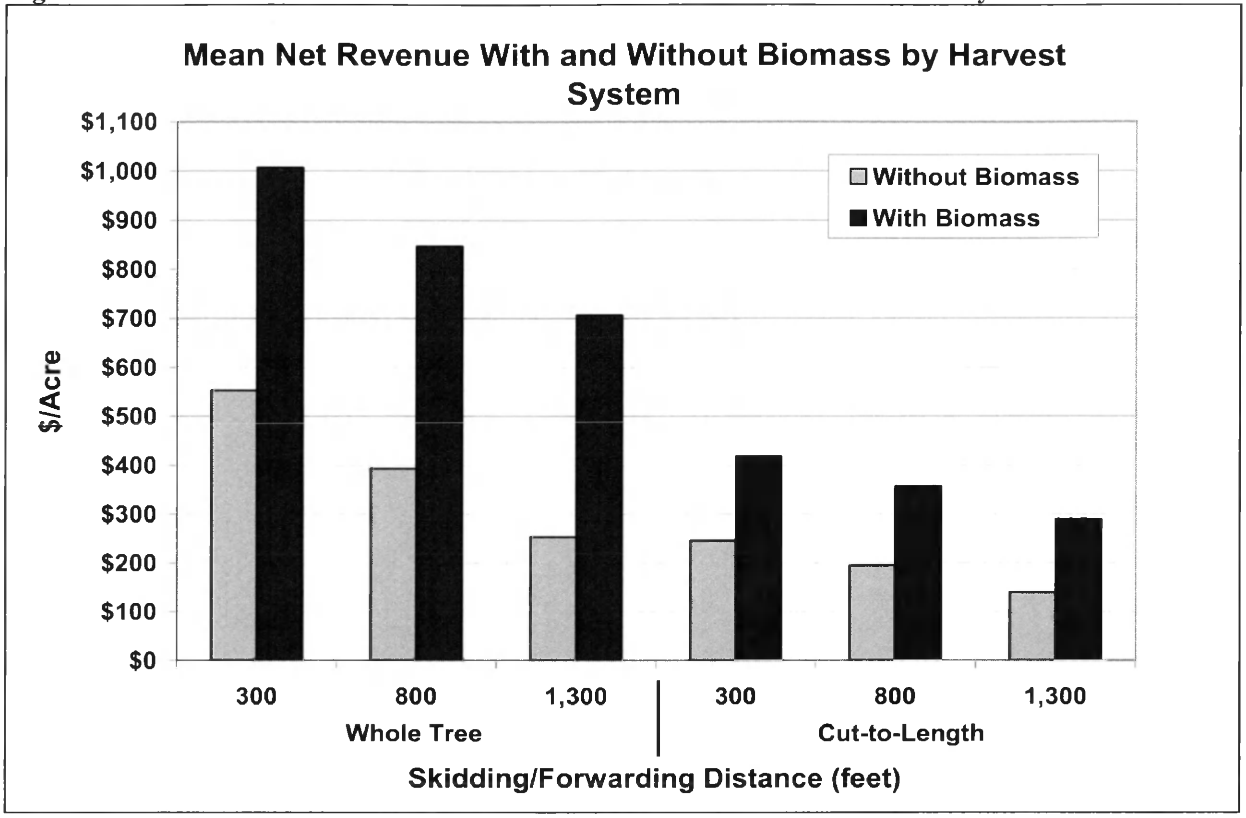
Table 5.4 – Mean total net revenue per acre associated with all harvest systems and skidding/forwarding distances with biomass collection.

	Net Revenue ($/Acre) With Biomass - WT 300	Net Revenue ($/Acre) With Biomass - WT 800	Net Revenue ($/Acre) With Biomass - WT 1300	Net Revenue ($/Acre) With Biomass - CTL 300	Net Revenue ($/Acre) With Biomass - CTL 800	Net Revenue ($/Acre) With Biomass - CTL 1300
Mean	$1,007	$847	$707	$418	$357	$289

per acre, with the increase in revenue attributable to the very low cost of biomass collection via the location of the biomass at the time of collection. Using a cut-to-length system however, $289 to $418 in net revenue is expected per acre with biomass collection depending on forwarding distance. Collecting biomass with this system results in up to 52% more net revenue than if the biomass is left in the woods and piled and burned.

If the net results of biomass collection and delivery using a cut-to-length system are broken down a little further, we see that on average net revenue is approximately 41% higher if biomass is collected and the average forwarding distance is 300 feet. At an average forwarding distance of 800 feet, average net revenue increases by 45% and with an average forwarding distance of 1,300 feet average net revenue increases by 52%. Therefore, collecting and delivering biomass using this type of harvest system at any average forwarding distance is largely attractive. Although the cut-to-length operation would generate revenue at any forwarding distance with or without biomass collection, revenues are higher with biomass collection at all average forwarding distances. Figure 5.2 displays these results.

Figure 5.2 – Mean net revenues with and without biomass collection and delivery.



5.4 Biomass Availability

In addition to estimating the impact that collection and delivery of biomass has on the comprehensive prescription, countywide estimates of current biomass stock were estimated. Table 4.9 shows that just less than 69,000 acres of low elevation fire-adapted forests of Douglas fir, ponderosa pine, or dry lower mixed conifer are included in the study area. With an average of 14 green tons per acre, the data show that there is an approximate stock of 971,833 green tons (at 50% moisture content) of biomass currently available from the implementation of the comprehensive prescription utilizing a whole tree system. Likewise, using a cut-to-length system approximately 824,648 green tons of biomass stock are presently available. If reduced to bone-dry weights, the stock estimates are approximately half these values, or 485,917 tons and 412,324 tons respectively.

Additionally, if one considers that not all one-acre sample plots initially queried from the FIA data were suitable for the comprehensive prescription[15], it then follows that not all lands in Ravalli County selected using GIS would meet the minimum prescription requirements. Therefore, adjusting the study area lands by some means seemed plausible. Assuming that the percentage of FIA sample plots not eligible for treatment (as described in the 'Data and Methods' chapter) is proportional to lands in the selected study area not eligible for treatment, 31% of the total study area would not qualify for treatment. Therefore 47,456 acres in Ravalli County could reasonably be considered eligible for the comprehensive prescription. It further follows that 670,553 tons of biomass stock are currently available from the reduced study area utilizing a whole tree system, and 568,997 tons of biomass stock are currently available utilizing a cut-to-length system at, 50% moisture content; again, bone-dry estimates are approximately half of these. Table 5.5 displays these results.

Table 5.5 – Number of study area acres and reduced study area acres, by harvest system.

	Harvest System				
	Whole Tree	Cut-to-Length		Whole Tree	Cut-to-Length
Study Area Acres	68,778	68,778	Reduced Study Area Acres	47,456	47,456
50% Moisture Content Biomass (Tons)	971,833	824,648	50% Moisture Content Biomass (Tons)	670,553	568,997
Bone-Dry Biomass (Tons)	485,917	412,324	Bone-Dry Biomass (Tons)	335,277	284,499

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[15] Of 161 FIA sample plots received from Dr. Fiedler's modeling process, 50 did not meet the minimum basal area requirement for treatment.

CHAPTER VI

Discussion

This analysis has shown the economic effects that collection and delivery of small diameter forest biomass has upon the comprehensive prescription if implemented in the low elevation forests of Ravalli County, Montana for two harvest systems. Lands suitable for the prescription have been identified via GIS, and distances and delivery costs to the markets calculated. The approximate volume of biomass available as a by-product of this fuel reduction treatment has additionally been determined, per acre and countywide. It has been reasonably demonstrated using forest inventory data and generally accepted methodology that the application of the comprehensive prescription on selected lands of Ravalli County generates, on average, positive net revenue. It has additionally been demonstrated that collecting and delivering the small diameter forest biomass available as a result of the prescription to Darby also results in average revenues in excess of average costs. On average, total net revenues may be increased when biomass is collected and delivered if using either a whole tree or cut-to-length system.

True to previous economics analyses of the comprehensive prescription (Fiedler et al. 1999, 2001; Keegan et al. 2003), the value of selectively harvested fir and pine has not only offset the cost of the prescription, but also generated positive returns. Fiedler et al. (1999) found that using a whole tree system, the prescription can result in up to $950 in revenue per acre in dense stands (650 tress per acre) without biomass collection or product delivery. They have also found that applying the prescription in moderately open stands (225 trees per acre) results in costs of up to $75 per acre without biomass collection and delivery. Due to the average number of trees per acre cut in this analysis (308 trees per acre), it logically follows that the results determined here would likely fall somewhere between those results determined by Fiedler et al. (1999). The results of this thesis have shown this to be true with respect to the average with and without biomass collection. However, the FIA data analyzed for this thesis show more variability in net revenues (Appendix IV).

In contrast to the Fried et al. (2003) Biosum analysis that showed "biomass never pays its own way out of the woods," this thesis has demonstrated that under the tenants of the comprehensive prescription, biomass alone will on average pay its way out of the woods in Ravalli County if using either system analyzed. Under the most expensive circumstances, biomass does not pay for itself but the total revenue generated from the sale of harvested merchantable material exceeds harvest costs. Due to the prescription, which removes trees in most size classes, volumes of merchantable timber can generally be expected, resulting in revenues of several hundred dollars per acre, thus eliminating some of the uncertainty that accompanies the Biosum estimates of "razor thin margin[s]" of revenue. Also contrary to the Biosum analysis, biomass costs of availability averaged under $20 per green ton using a cut-to-length system. This is due to low delivery costs and higher delivered value of biomass in Ravalli County.

As demonstrated in this analysis, a whole tree system generates significant quantities of biomass that are placed at the roadside landing during the operation, and the marginal cost of the biomass is that of chipping and delivery. It is well known that delivery costs are typically high and often offset the total delivered value of harvested material (Han et al. 2002). Estimates of delivery in the Biosum analysis of western Oregon averaged $293 per acre, which explains the exceptionally high delivery cost of $17.50 per ton of biomass. Han et al. (2002) found that biomass delivery costs alone were approximately $12 per ton at a distance of 53.5 miles. However, due to the proximity of the market to the harvest areas, average delivery cost to the Darby School District in this analysis is $72 per acre, hauling 12 to 14 green tons of chipped biomass at an average distance of 26 miles. This translates to a $5 to $6 per green ton delivery cost. The maximum haul cost found in this analysis is $183, or $13 to $15 per green ton.

Additionally, Keegan et al. (2003) found that biomass collected via slash bundling methods in western Montana cost in excess of $30 per green ton delivered to a user, and it has been determined in this analysis that the delivered cost of biomass to Darby ranges $15 to $17 per green ton using the same system. Under the most expensive biomass collection scenario (cut-to-length at 1300 feet), delivered biomass costs approximately $41 per green ton. Also, Keegan et al. (2003) estimated average statewide net revenue at over $3,000 per acre where more than 25 oven-dry tons of sawtimber were removed. This analysis showed that average net revenue is far less in Ravalli County at $289 to $1,007 per acre, with much less sawtimber removed, at just over 30 green tons per acre (or just over 15 oven-dry tons per acre. However, some of the acres analyzed in this thesis were capable of generating up to $4,000 per acre in net revenue without biomass collection and delivery, and others capable of generating well over $4,000 per acre with biomass collection and delivery (Appendix IV).

Similar to the Keegan et al. (2003) analysis that determined lands west of the continental divide were capable of providing 9.0 bone-dry tons of biomass per acre, this study found that the selected lands in Ravalli County currently contain 6.0 to 7.0 bone-dry tons per acre of biomass stock, as a result of the comprehensive prescription. The noticeable difference in biomass estimates is likely due to the necessary modeling assumptions made during the course of this analysis. For example, assigning all cut trees on a one-acre plot a consistent cubic foot weight. Additionally, differing data selection criteria outlined in Chapter 3 as well as the differing size of FIA data sets likely explain differing estimates.

In this thesis, estimates of biomass available from the prescription are somewhat different than those supplied to Emergent Solutions (2003) by Dr. Carl Fiedler, author of the comprehensive prescription. Fiedler's correspondence with this group indicated that western Montana lands would produce roughly 14.0 to 15.0 bone dry tons of small diameter biomass via the prescription while Emergent Solution's FIA data analysis showed biomass estimates ranging from 2.0 to 15.0 bone-dry tons per acre, which is rather variable. In this regard, it is difficult to relate the biomass estimates put forth in this thesis with those of Emergent Solutions, which did not cite a specific biomass volume generated from evaluated lands, but rather the spectrum of possible volumes.

While this analysis has identified the lands in Ravalli County and the Bitterroot National Forest that are of the correct forest type suitable for the prescription, it is at this time impossible to identify via GIS technology those lands in the county that do not have the minimum basal area to merit harvest activity. Due to this, the distribution and location of those areas suitable for the prescription are unknown, and this would surely affect the estimates of delivered per ton costs and overall net revenues produced in this thesis in an also unknown manner. Fortunately, there are currently efforts underway by

USDA Forest Service Region 1 personnel that will eventually result in GIS data sets derived from VMAP (successor to SILC) that will allow for identification of trees per polygon and corresponding diameter distributions. At that time more accurate cost and revenue estimates may be produced.

The use of GIS also introduces an often times immeasurable degree of error that cannot reasonably be controlled for in most applications, including that of this thesis. The use of GIS in this thesis has introduced an additional layer of error that is disconnected with the error introduced via the use of FIA data and prescription and harvest cost modeling. For example, a road or polygon, while known to exist at a specific location on the landscape, may in fact be identified via GIS as located 10 meters, for example, from its actual landscape location. The question of GIS error in a context such as this is whether or not the degree of imprecision is acceptable for the question at hand, and whether or not the data is accurate[16]. It is reasonable to assume that the results derived in this thesis are accurate, but likely contain an unknown degree of imprecision that is acceptable for the questions put forth in this thesis.

It is also necessary to note that the revenue calculations in this analysis did not include sale preparation or related project costs, nor do they include move-in costs. Move-in costs would reflect planning, administration, and set up costs that are likely to vary from one contractor to the next resulting in cost estimates that may be understated depending on the location of the individual contractor in relation to the harvest site. However, there is evidence that suggests many logging crews report to work at the logging site, and commuting costs are not borne by the logging company (Thomas 2003).

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[16] In econometric terms, accuracy is best related to an unbiased estimator while precision can be related to estimator efficiency.

It is also believed that the operating cost and depreciation schedule imbedded within the FRCS harvest cost program may be a little accelerated for the Ravalli County area. If this is so, harvest costs may be overstated and revenue understated. It was further believed that adjusting the cost and depreciation schedule to those of a local contractor would introduce new assumptions and modeling errors that were deemed altogether unnecessary. But if the overstated harvest costs that are a result of the operating cost and depreciation schedule are allowed to substitute for move-in costs, then one may well 'cancel' the other out.

There is additionally a tremendous amount of uncertainty that accompanies any suggestion of timber harvests on public lands. The controversial nature of extractive industries and the cautious relationships local communities have with the Forest Service and the timber industry suggests large-scale mechanical thinning operations will be for the time being unrealized. And while the Healthy Forests Restoration Act, which protects 'categorical exclusions' adopted in the National Environmental Policy Act of 1969 (42 USC 4321), may currently expedite thinning activities, the debate surrounding the Healthy Forests Act is far from over. The result of all this political uncertainty is that <u>actual</u> biomass availability in Ravalli County is unpredictable. Regardless, the estimates produced in this thesis are based upon proven data and methodology and provide stump to mill harvest and transportation cost estimates for lands throughout Ravalli County.

WORKS CITED

Aden, Andy, and Kelly Ibsen. 2004. Useful Information About Conventional and Alternative Fuels and Their Feedstocks. National Renewable Energy Laboratory. Available at: http://www.eere.energy.gov/biomass/

ACINET: America's Career Infonet. 2003. Available at: http://www.acinet.org/acinet/default.asp

Bitterroot Resource Conservation and Development. Available at: http://www.bitterrootrcd.org.

BNF GIS Metadata. 21 March 2003. USDA Forest Service, Bitterroot National Forest, Hamilton, Montana.

Brown, James K. 1978. Weight and Density of Crowns of Rocky Mountain Conifers. USDA Forest Service Research Paper INT-197. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Brown, James K, J.A. Kendall Snell, and David L. Bunnell. 1977. Handbook for Predicting Slash Weight of Western Conifers. USDA Forest Service Gen. Tech. Rept. INT-37. Intermountain Forest and Range Experiment Station, Ogden, Utah.

BBER: Bureau of Business and Economic Research. 2004. University of Montana, Missoula, Montana. Available at: http://www.bber.umt.edu/forestproducts/index.htm.

Chung, Woodam. 2003. Interview by Dan Loeffler. Personal. Missoula, Montana, October.

Cleaves, David, Jorge Martinez, and Terry Haines. 2000. Influences on Prescribed Burning Activity and Costs in the National Forest System. USDA Forest Service Gen. Tech. Rept. SRS-37. Southern Research Station, Asheville, N.C.

Coston, Tom. 2003. Interview by Dan Loeffler. Telephone. Missoula, Montana, 11 November.

Downing, Mark, and Robin L. Graham. 1996. The Potential Supply and Cost of Biomass from Energy Crops in the Tennessee Valley Authority Region. Biomass and Bioenergy, 11 (4), 283-303.

Emergent Solutions, Christopher Allen and Associates. 2003. Pre-feasibility Assessment: Small Diameter Under (SDU) Wood Feedstock for a 10 MW Co-generation Facility at the Milltown Dam Site. Submitted to U.S. Forest Service – State and

Private Forestry, Montana Community Development Corporation, Bonner Development Group. Available at: http://www.mtcdc.org/downloads/fin.PDF

Federal Register. 2001. Volume 66, No. 3, 751-777.

Fiedler, Carl E., Charles E. Keegan III, Daniel P. Wichman, and Stephen F. Arno. 1999. Product and Economic Implications of Ecological Restoration. Forest Products Journal, 42 (2), 19-23.

Fiedler, Carl E., Charles E. Keegan III, Chris W. Woodall, Todd A. Morgan, Steve H. Robertson, and John T. Chmelik. 2001a. A Strategic Assessment of Fire Hazard in Montana. Report submitted to the Joint Fire Sciences Program, September 29, 2001.

Fiedler, Carl E., Stephen F. Arno, Charles E. Keegan, and Keith A. Blatner. 2001b. Overcoming America's Wood Deficit: An Overlooked Option. Bioscience, 51 (1), 53-58.

Fiedler, Carl E., Charles E. Keegan, Todd A. Morgan, and Christopher W. Woodall. 2003. Fire Hazard and Potential Treatment Effectiveness: A Statewide Assessment in Montana. Journal of Forestry, 101 (2), 7.

Fight, Roger, Xiaoshan Zhang, and Bruce Hartsough. 2003. Users Guide to STHARVEST: Software to Estimate the Cost of Harvesting Small Timber. Gen. Tech. Rep. PNW-GTR-582. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 12 p.

Franke, Rick. 2004. Interview by Dan Loeffler. Telephone. Missoula, Montana, 17 February.

Franklin, Jerry. 1989. Toward New Forestry. American Forests. November/December 1989, 37-44.

Fried, Jeremy S., Glenn Christensen, Dale Weyermann, R. Jamie Barbour, Roger Fight, Bruce Hiserote, and Guy Pinjuv. 2003. Modeling Opportunities and Feasibility of Siting Wood-fired Electrical Generating Facilities to Facilitate Landscape-Scale Fuel Treatments with FIA BioSum. Submitted to the Proceeding of the 2003 Systems Analysis in Forest Resources Symposium. Available at: http://www.fs.fed.us/pnw/fia/ear/jfried/projects/fia_biosum.

GAO. 2003. Wildland Fire Management: Additional Actions Required to Better Identify and Prioritize Lands Needing Fuels Reduction. U.S. General Accounting Office, Washington D.C., GAO-03-805.

Gregory, G. Robinson. 1972. Forest Resource Economics. New York: Ronald Press.

Han, Han-Sup, Harry W. Lee, Leonard R. Johnson, Richard L. Folk, and Thomas M. Gorman. 2002. Economic feasibility of Small Wood Harvesting and Utilization on the Boise National Forest – Cascade, Idaho City, Emmett Ranger Districts. University of Idaho, College of Natural Resources, Department of Forest Products, Moscow, Idaho, 61 pp.

Han, Han-Sup, Harry W. Lee, Leonard Johnson. 2004. Economic Feasibility of an Integrated Harvesting System for Small-Diameter Trees in Southwest Idaho. Forest Products Journal, 54 (2), 21-27.

Hartsough, Bruce R. 2004. Interview by Dan Loeffler. Telephone. Missoula, Montana, 6 January.

Hartsough, Bruce R., Erik S. Drews, Joseph F. McNell, Thomas A. Durston, Bryce J. Stokes. 1997. Comparison of Mechanized Systems for Thinning Ponderosa Pine Stands and Mixed Conifer Stands. Forest Products Journal, 47 (11/12), 59-68.

Hartsough, Bruce R., and Roger D. Fight. 2003. Fuel Reduction Cost Simulator (Beta version). Unpublished.

Hartsough, Bruce R., Xiaoshan Zhang, and Roger D. Fight. 2001. Harvesting Cost Model for Small Trees in Natural Stands in the Interior Northwest. Forest Products Journal, 51 (4), 54-70.

Keegan, Charles E. III, Michael J. Niccolucci, carl E. Fiedler, J. Greg Jones, and Roy W. Regel. 2002. Harvest Cost Collection Approaches and Associated Equations for Restoration Treatments on National Forests. Forest Products Journal, July/August, 96-99.

Keegan, C.E. III, Todd A. Morgan, Carl E. Fiedler, Steve H. Robertson, and A. Lorin Hearst. 2003. Wood for Energy in Montana: Sources and Costs. Submitted to Howard Haines, Montana Department of Environmental Quality.

Keegan, Charles III, Carl E. Fiedler, Fred J. Stewart. 1995. Cost of Timber Harvest Under Traditional and "New Forestry" Silvicultural Prescriptions. Western Journal of Applied Forestry, 10 (1): 36-42.

Kellogg, L.D., and P. Bettinger. 1994. Thinning Productivity and Cost for a Mechanized Cut-to-Length System in the Northwest Pacific Coast Region of the USA. Journal of Forest Engineering, 5(2): 43-54.

Krogstad, Don. 2004. Interview by Dan Loeffler. Telephone. Missoula, Montana, 15 January.

Leenhouts, Bill. 1998. Assessment of Biomass Burning in the Conterminous United States. Conservation Ecology [online] 2 (1). Available at: http://www.consecol.org/vol2/iss1/art1.

Long, James, Scott D. Roberts. 1992. Growth and Yield Implications of a "New Forestry" Silvicultural System. Western Journal of Applied Forestry, 7 (1), 6-9.

Lunnan, Anders. 1997. Agriculture-Based Biomass Energy Supply – A Survey of Economic Issues. Energy Policy, 25 (6), Elsevier: Great Britain, 573-582.

Manfredo, Michael J., Martin Fishbein, Glenn E. Hass, and Alan E. Watson. 1990. Attitudes Toward Prescribed Fire Policies. Journal of Forestry 88 (7), 19-23.

McKinnon, Don. 2003. Interview by Dan Loeffler. Telephone. Missoula, Montana, September.

Moore, Paul. 2004. Interview by Dan Loeffler. Telephone. Missoula, Montana, January.

Morris, G. 1999. The Value of the Benefits of U.S. Biomass Power. NREL/SR-570 27541. National Renewable Energy Laboratory, Golden, Colorado, 24 p.

NREL. 1998. International and Domestic Market Opportunities for Biomass Power Volumes I and II. National Renewable Energy Laboratory, Golden, Colorado, NREL/SR-570-25492.

NRIS 2004. Natural Resource Information System, GIS, Montana State Library. Available at: http://nris.state.mt.us/nsdi/nris/road2000/road2000.html

O'Laughlin, Jay. 2002. Reducing Hazardous Fuels: Comprehensive Silviculture and Sustainable Forestry. Presented to the Western Governors Association, Secretaries of Interior and Agriculture, Chair of the Council on Environmental Quality, and the Chief of the USDA Forest Service at the signing of the 10-Year Implementation Agreement for the National Fire Plan, May 23, 2002, Idaho City, ID. Contribution no. 957, Idaho Forest, Wildlife and Range Experiment Station, University of Idaho, Moscow.

OR DOE. 2004. Oregon Department of Energy. Available at: http://www.energy.state.or.us/biomass/BiomassHome.htm.

PNW, 2004. USDA Forest Service Pacific Northwest Research Station. Available at: http://www.fs.fed.us/r6/nr/fp/FPWebPage/ForestProducts/ForestProducts.htm

Randhawa, S.U., T.M. Scott, and E.D. Olsen. 1990. LOGSIM: A Tool for Mechanized Harvesting System Design and Analysis. Applied Engineering in Agriculture, 6(2): 231-237.

Roos, Anders, Robin L. Graham, Bo Hektor, and Christian Rakos. 1999. Critical Factors to Bioenergy Implementation. Biomass and Bioenergy, 17, 113-126.

Sampson, R. Neil, Lance R. Clark, and Lynette Z. Morelan. 1995. Forest Ecosystem Health in the Inland West. Gen Tech. Rept. RM-267. USDA Forest Service Rocky Mountain Forest and Range Experiment Station.

Samson, R. Neil, Megan S. Smith, Sara B. Gann. 2001. Western Forest Health and Biomass Energy Potential. Submitted to the Oregon Office of Energy. The Samson Group, Inc., Alexandria, Virginia.

Scheele, Rick. 2003. Interview by Dan Loeffler. Telephone. Missoula, Montana, 30 October.

Sedjo, Roger A. 1997. The economics of forest-based biomass supply. Energy Policy, 25 (6), Elsevier: Great Britain, 559-566.

Snell, J.A. Kendall, James K. Brown. 1980. Handbook for Predicting Residue Weights of Pacific Northwest Conifers. Gen. Tech. Rept. PNW-103. USDA Forest Service Pacific Northwest Forest and Range Experiment Station.

Sorenson, Jerry. 2004. Interview by Dan Loeffler. Telephone. Missoula, Montana, January.

Thomas, Craig. 2003. Interview by Dan Loeffler. Personal. Missoula, Montana, 24 December.

U.S. Congress. House of Representatives. Committee on Small Business. 2000. *Hearing on the Effects of the Roadless Policy on Rural Small Business and Rural Communities.* 11 January.

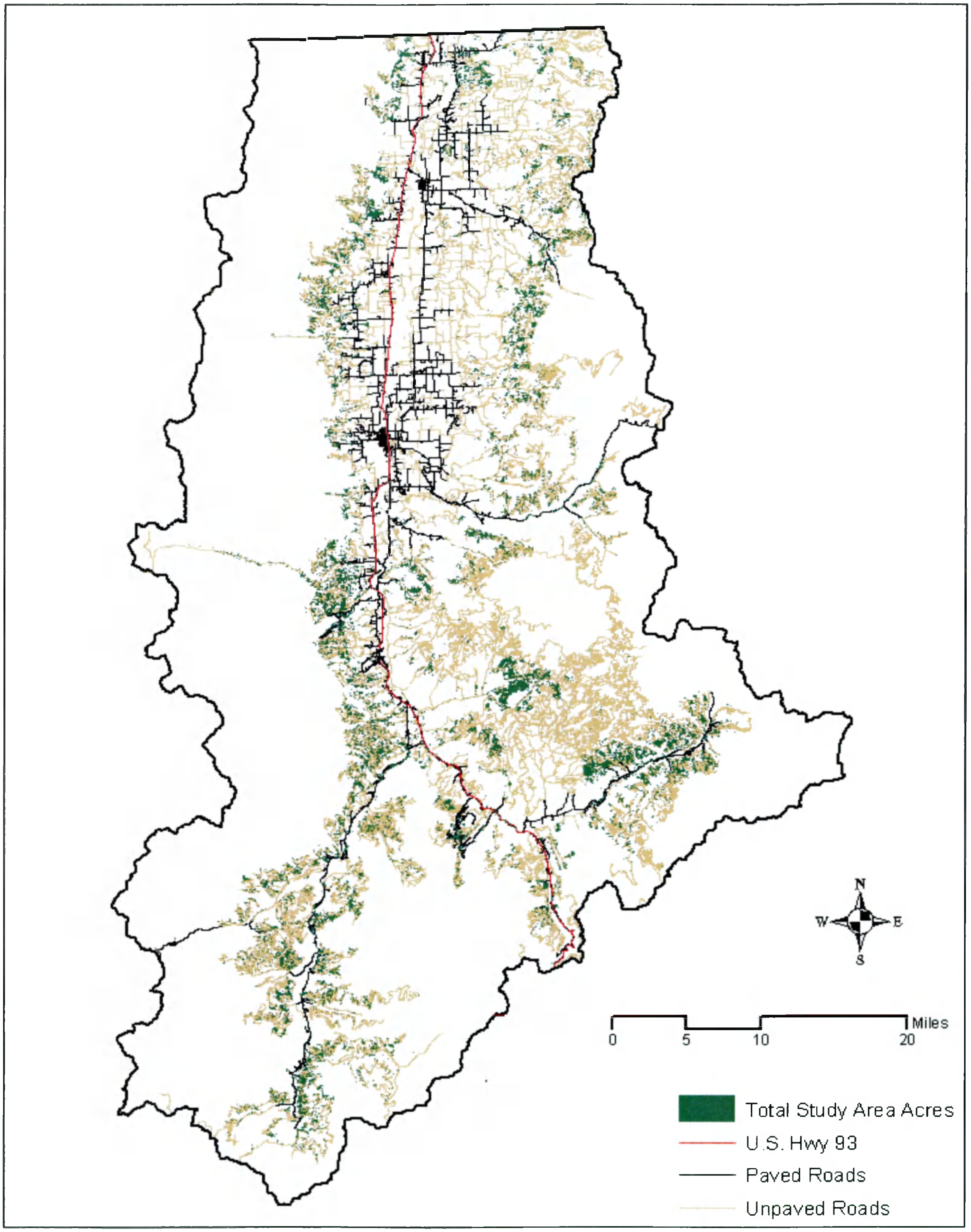
U.S. Congress. House of Representatives. Committee on Resources. 2004. *Oversight Hearing on Developing Biomass Potential: Turning Hazardous Fuels into Valuable Products.* 108th Congress, 2nd Session, 23 June.

USFS. 2003a. A Strategic Assessment of Forest Biomass and Fuel Reduction Treatments in Western States. Available at: http://www.fs.fed.us/research/infocenter.html.

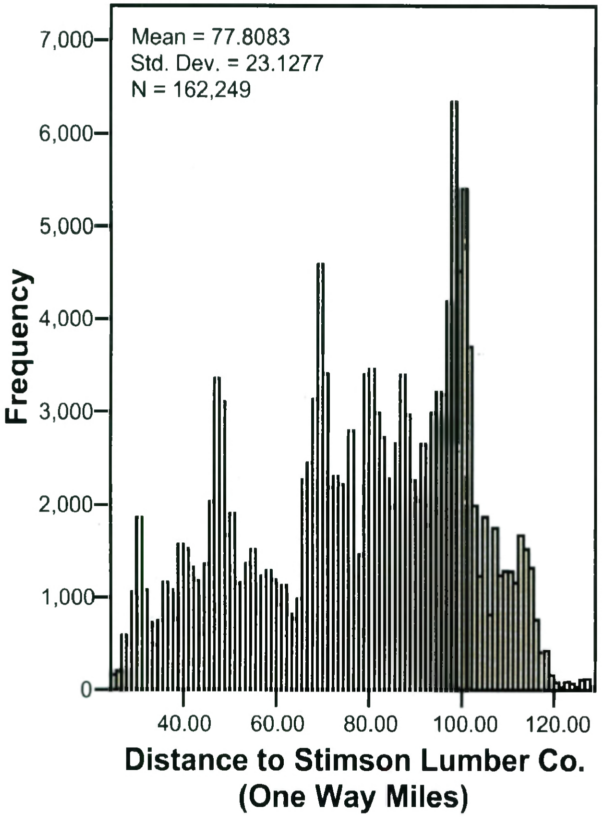
USFS. 2003b. Northern Region National Fire Plan Cohesive Strategy Geospatial Dataset. Available at: http://www.fs.fed.us/r1/cohesive_strategy/datafr.htm.

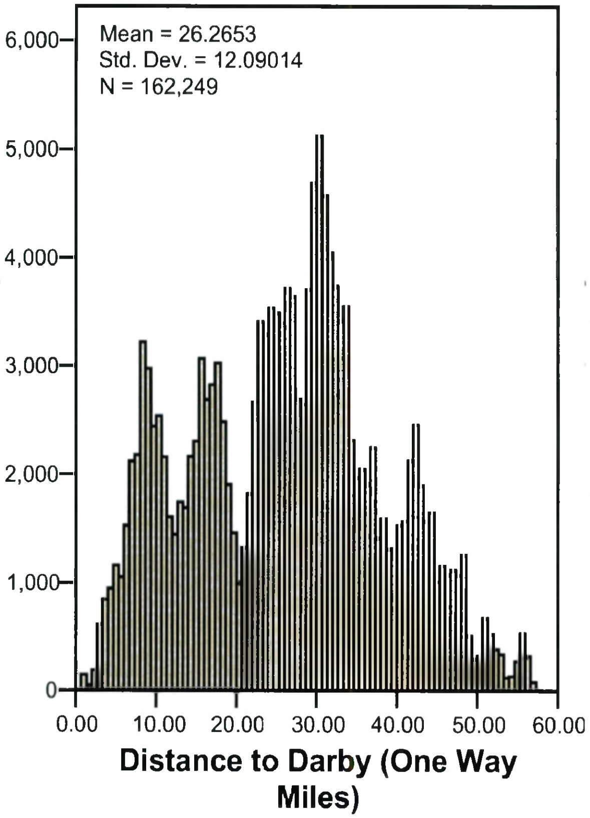
USFS FIADB. 2003. Forest Inventory and Analysis National Program Office. Available at: http://fia.fs.fed.us.

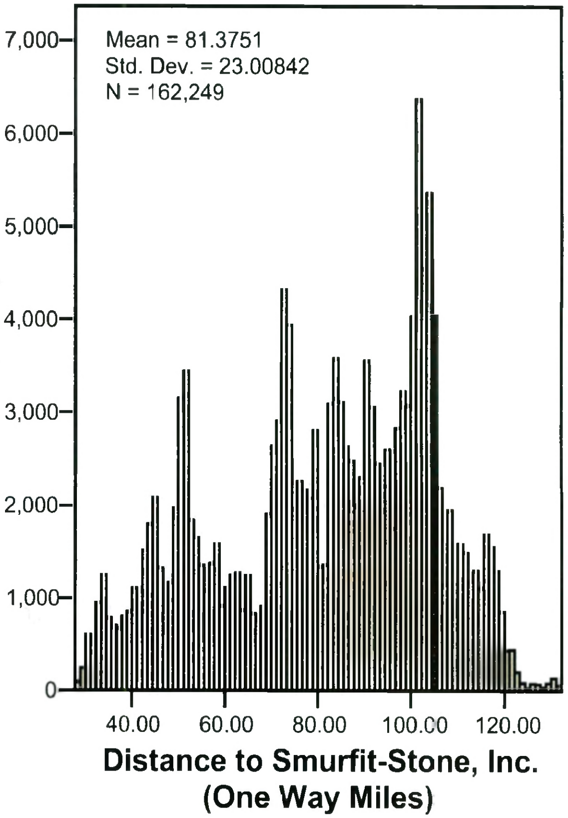
APPENDIX I


N
W
E
S
0
5
10
20
Miles
Total Study Area Acres
U.S. Hwy 93
Paved Roads
Unpaved Roads

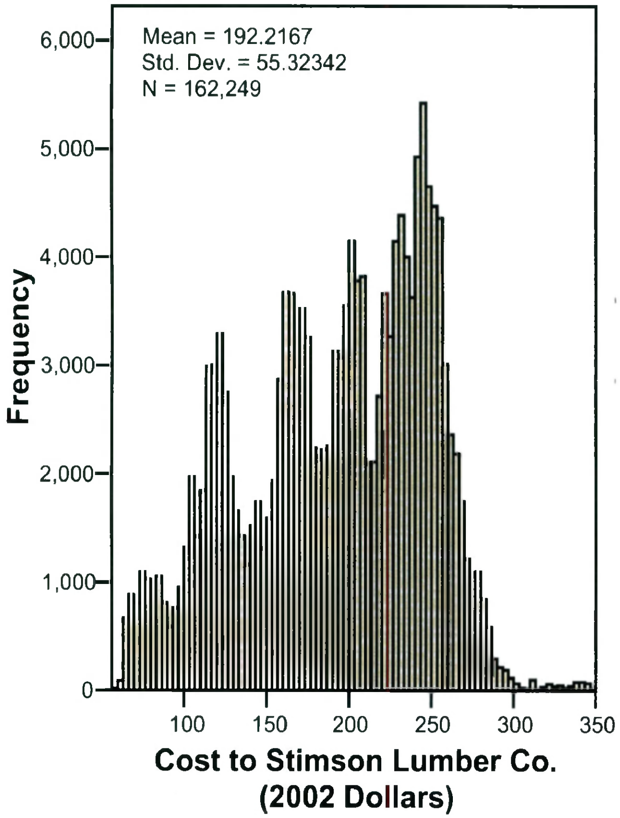
APPENDIX II







Note: Distances and costs in this appendix are from each polygon in the study area (where n > 160,000).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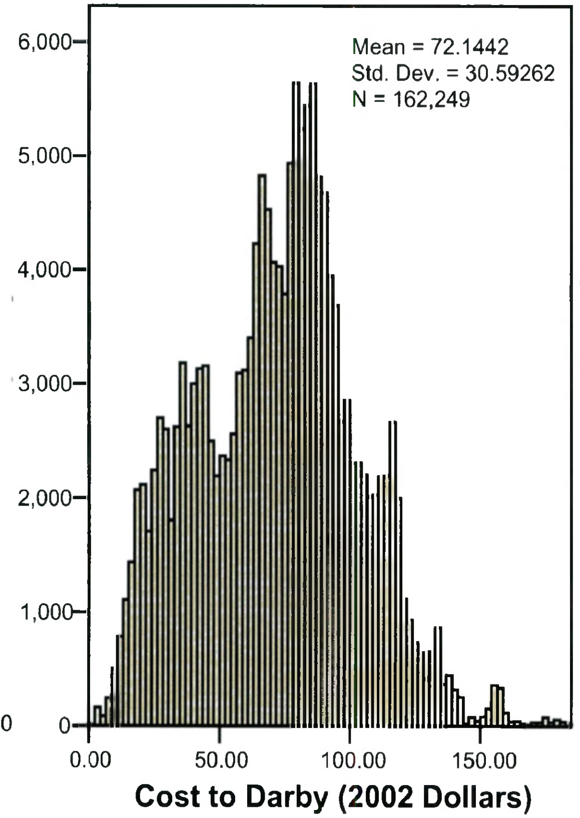
Std. Dev. = 55.32342
N = 162,249
Frequency
6,000
5,000
4,000
3,000
2,000
1,000
0
100
150
200
250
300
350
Cost to Stimson Lumber Co. (2002 Dollars)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Std. Dev. = 30.59262
N = 162,249
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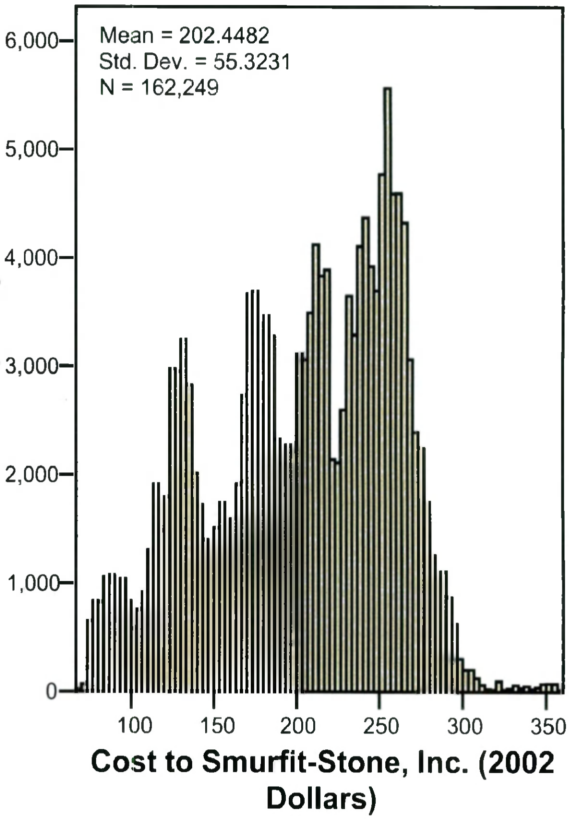
5,000
4,000
3,000
2,000
1,000
0
0.00
50.00
100.00
150.00
Cost to Darby (2002 Dollars)


Mean = 202.4482
Std. Dev. = 55.3231
N = 162,249
6,000
5,000
4,000
3,000
2,000
1,000
0
100
150
200
250
300
350
Cost to Smurfit-Stone, Inc. (2002 Dollars)

APPENDIX III

Number of study area acres within specified distances to the three market centers.

	Number of Acres within Specified Distance to Market Center		
Distance to Market (Miles)	Darby School District (Biomass)	Stimson Lumber Company (Saw)	Smurfit-Stone, Inc. (Pulp)
Less than or equal to 10	9,011	0	0
Less than or equal to 20	23,145	0	0
Less than or equal to 30	41,144	1,602	185
Less than or equal to 40	57,919	6,578	4,373
Less than or equal to 50	67,109	13,707	10,000
Less than or equal to 60	68,779	19,313	17,639
Less than or equal to 70	-	27,112	22,285
Less than or equal to 80	-	35,981	33,318
Less than or equal to 90	-	45,872	42,861
Less than or equal to 100	-	58,325	52,414
Less than or equal to 110	-	65,410	63,826
Less than or equal to 120	-	68,539	68,161
Less than or equal to 130	-	68,779	68,698
Less than or equal to 140	-	-	68,779

GIS identified acres available for harvest activity within incremental transportation costs of the three market centers.

	Number of Acres Within Specified Transportation Cost to Market Center		
Delivery Cost per Truck (2002 Dollars)	Darby School District (Biomass)	Stimson Lumber Company (Saw)	Smurfit-Stone, Inc. (Pulp)
Less than or equal to $10	402	0	0
Less than or equal to $20	3,526	0	0
Less than or equal to $30	8,351	0	0
Less than or equal to $40	13,095	0	0
Less than or equal to $50	18,102	0	0
Less than or equal to $60	23,206	16	0
Less than or equal to $70	30,935	1,063	16
Less than or equal to $80	39,454	2,912	1,022
Less than or equal to $90	49,367	4,308	2,882
Less than or equal to $100	55,909	5,550	4,285
Less than or equal to $110	60,814	7,708	5,506
Less than or equal to $120	65,339	11,393	7,675
Less than or equal to $130	66,874	14,650	11,313
Less than or equal to $140	67,983	16,872	14,575
Less than or equal to $150	68,279	19,235	16,827
Less than or equal to $160	68,591	22,196	19,194
Less than or equal to $170	68,647	26,731	22,079
Less than or equal to $180	68,754	30,594	26,650
Less than or equal to $190	68,779	33,255	30,527
Less than or equal to $200	-	37,006	33,191
Less than or equal to $210	-	41,178	36,901
Less than or equal to $220	-	43,898	41,110
Less than or equal to $230	-	48,517	43,761
Less than or equal to $240	-	53,222	48,423
Less than or equal to $250	-	59,416	53,088
Less than or equal to $260	-	63,869	59,272
Less than or equal to $270	-	66,453	63,757
Less than or equal to $280	-	67,779	66,413
Less than or equal to $290	-	68,311	67,743
Less than or equal to $300	-	68,507	68,307
Less than or equal to $310	-	68,534	68,505
Less than or equal to $320	-	68,587	68,534
Less than or equal to $330	-	68,641	68,586
Less than or equal to $340	-	68,709	68,641
Less than or equal to $350	-	68,779	68,708
Less than or equal to $360	-	-	68,779

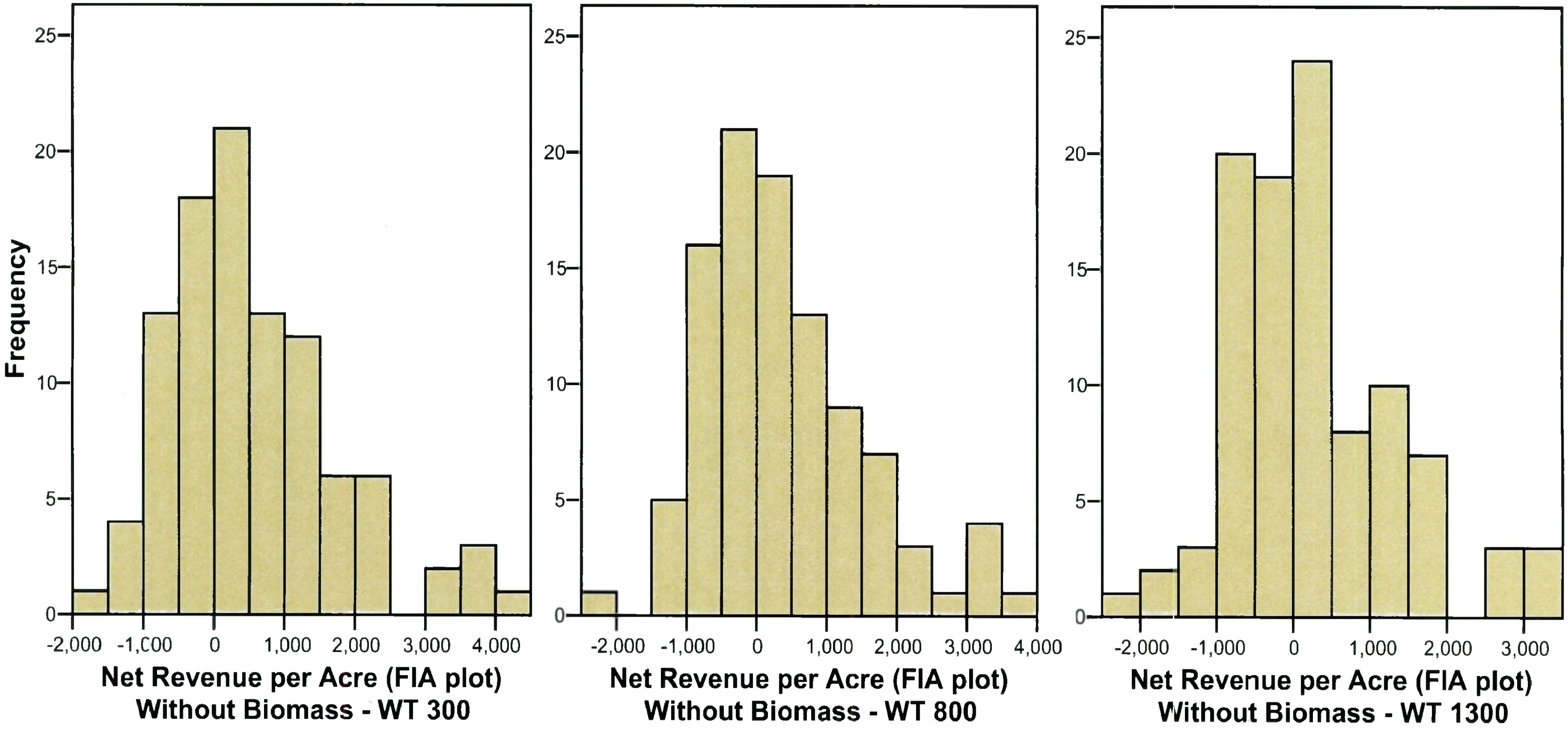
Tons of available products in the study area, by transportation cost for a whole tree system.

	Number of Biomass, Pulplog, and Sawlog Tons (50% Moisture Content) Within Specified Delivery Costs to Market Center for a Whole Tree System		
Delivery Cost per Truck (2002 Dollars)	Darby School District (Biomass)	Stimson Lumber Company (Saw)	Smurfit-Stone, Inc. (Pulp)
Less than or equal to $10	5,678	0	0
Less than or equal to $20	49,819	0	0
Less than or equal to $30	117,999	0	0
Less than or equal to $40	185,037	0	0
Less than or equal to $50	255,788	0	0
Less than or equal to $60	327,906	547	0
Less than or equal to $70	437,115	35,336	148
Less than or equal to $80	557,480	96,781	9,312
Less than or equal to $90	697,551	143,213	26,255
Less than or equal to $100	789,993	184,477	39,037
Less than or equal to $110	859,307	256,221	50,160
Less than or equal to $120	923,244	378,713	69,920
Less than or equal to $130	944,929	486,950	103,063
Less than or equal to $140	960,594	560,831	132,779
Less than or equal to $150	964,776	639,361	153,292
Less than or equal to $160	969,191	737,805	174,859
Less than or equal to $170	969,986	888,529	201,141
Less than or equal to $180	971,494	1,016,952	242,779
Less than or equal to $190	971,846	1,105,409	278,101
Less than or equal to $200	-	1,230,087	302,367
Less than or equal to $210	-	1,368,763	336,165
Less than or equal to $220	-	1,459,170	374,516
Less than or equal to $230	-	1,612,692	398,665
Less than or equal to $240	-	1,769,101	441,130
Less than or equal to $250	-	1,974,980	483,635
Less than or equal to $260	-	2,123,006	539,967
Less than or equal to $270	-	2,208,881	580,822
Less than or equal to $280	-	2,252,968	605,024
Less than or equal to $290	-	2,270,656	617,139
Less than or equal to $300	-	2,277,166	622,280
Less than or equal to $310	-	2,278,073	624,085
Less than or equal to $320	-	2,279,817	624,343
Less than or equal to $330	-	2,281,621	624,818
Less than or equal to $340	-	2,283,891	625,318
Less than or equal to $350	-	2,286,212	625,930
Less than or equal to $360	-	-	626,576

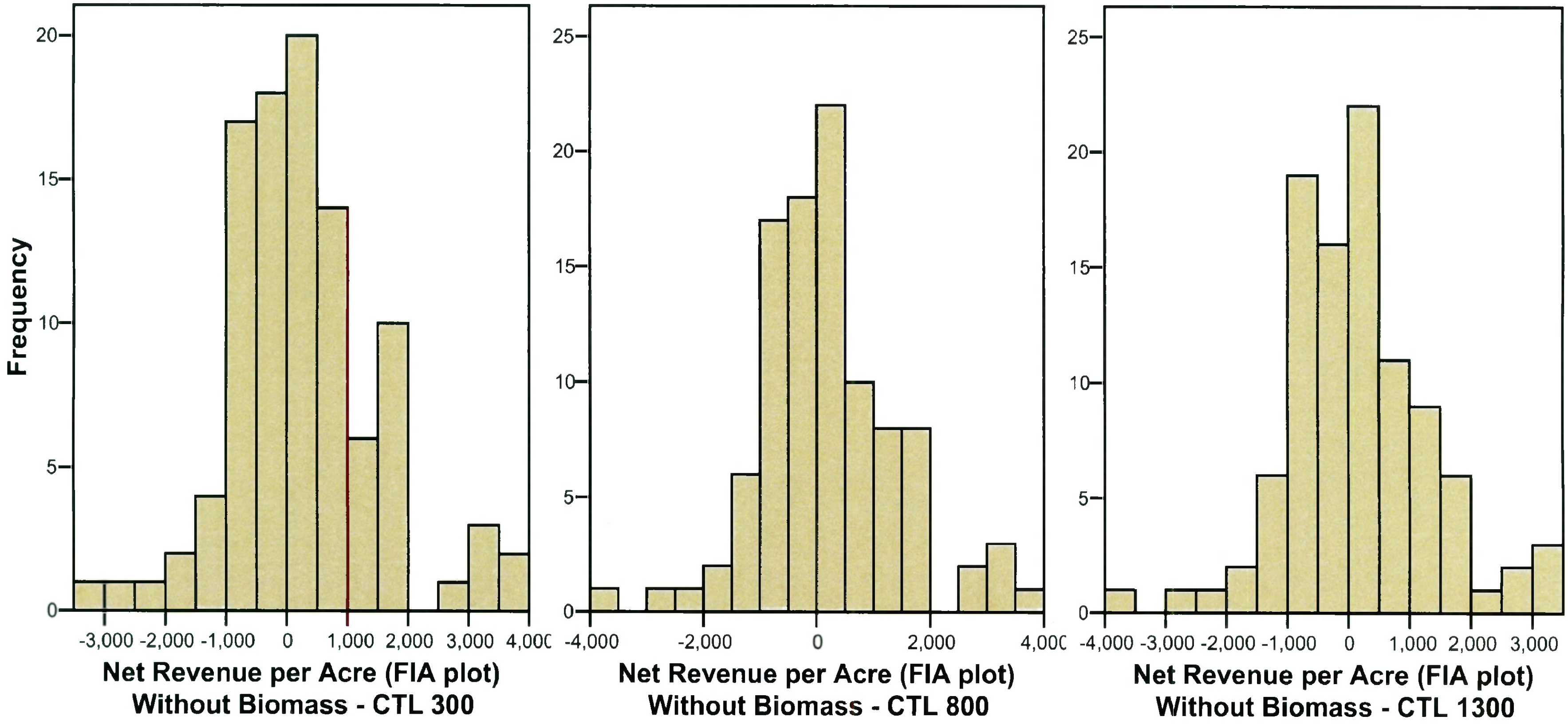
Tons of available products in the study area, by transportation cost for a cut-to-length system.

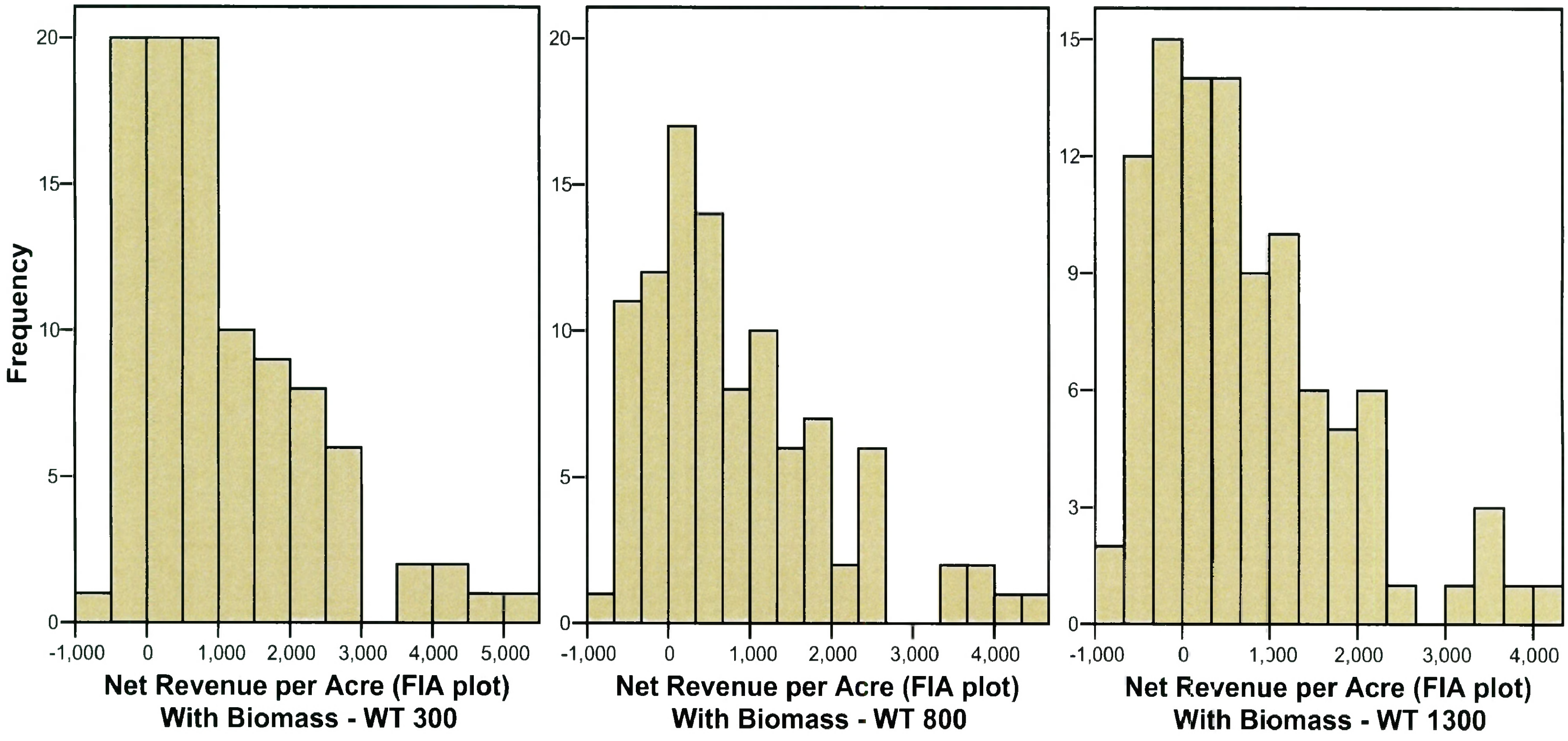
	Number of Biomass Tons (50% Moisture Content) Within Specified Delivery Cost to Market Center for a Cut-to-Length System		
Delivery Cost per Truck (2002 Dollars)	Darby School District (Biomass)	Stimson Lumber Company (Saw)	Smurfit-Stone, Inc. (Pulp)
Less than or equal to $10	4,818	0	0
Less than or equal to $20	42,274	0	0
Less than or equal to $30	100,128	0	0
Less than or equal to $40	157,013	0	0
Less than or equal to $50	217,049	0	0
Less than or equal to $60	278,245	547	0
Less than or equal to $70	370,913	35,336	148
Less than or equal to $80	473,049	96,781	9,312
Less than or equal to $90	591,907	143,213	26,255
Less than or equal to $100	670,348	184,477	39,037
Less than or equal to $110	729,164	256,221	50,160
Less than or equal to $120	783,418	378,713	69,920
Less than or equal to $130	801,819	486,950	103,063
Less than or equal to $140	815,112	560,831	132,779
Less than or equal to $150	818,660	639,361	153,292
Less than or equal to $160	822,406	737,805	174,859
Less than or equal to $170	823,081	888,529	201,141
Less than or equal to $180	824,361	1,016,952	242,779
Less than or equal to $190	824,659	1,105,409	278,101
Less than or equal to $200	-	1,230,087	302,367
Less than or equal to $210	-	1,368,763	336,165
Less than or equal to $220	-	1,459,170	374,516
Less than or equal to $230	-	1,612,692	398,665
Less than or equal to $240	-	1,769,101	441,130
Less than or equal to $250	-	1,974,980	483,635
Less than or equal to $260	-	2,123,006	539,967
Less than or equal to $270	-	2,208,881	580,822
Less than or equal to $280	-	2,252,968	605,024
Less than or equal to $290	-	2,270,656	617,139
Less than or equal to $300	-	2,277,166	622,280
Less than or equal to $310	-	2,278,073	624,085
Less than or equal to $320	-	2,279,817	624,343
Less than or equal to $330	-	2,281,621	624,818
Less than or equal to $340	-	2,283,891	625,318
Less than or equal to $350	-	2,286,212	625,930
Less than or equal to $360	-	-	626,576

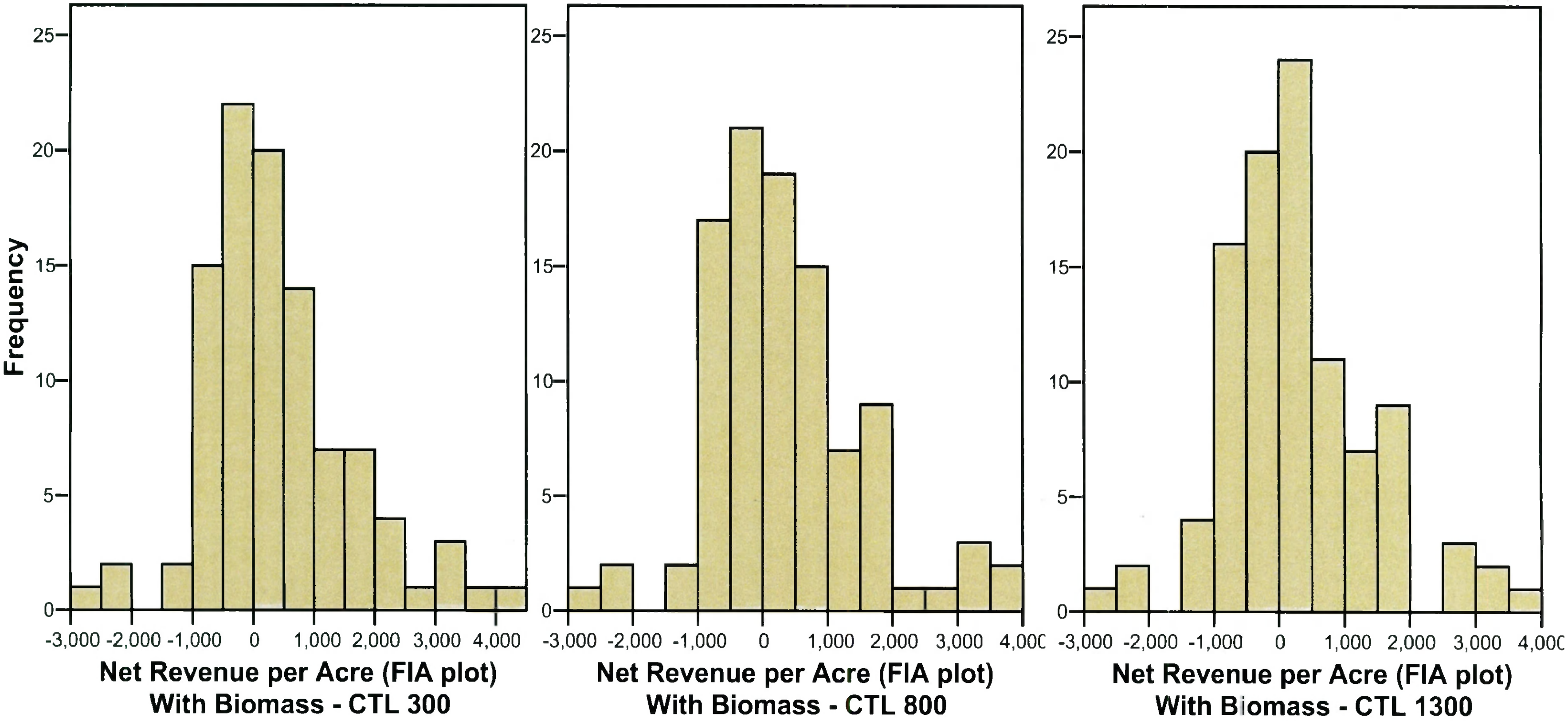
APPENDIX IV



Note: Net revenue calculations ($/acre) are for FIA data plots only and include mean delivery costs to the markets, as shown in Table 4.10.


Frequency
20
15
10
5
0
-3,000 -2,000 -1,000 0 1,000 2,000 3,000 4,000
Net Revenue per Acre (FIA plot) Without Biomass - CTL 300
25
20
15
10
5
0
-4,000 -2,000 0 2,000 4,000
Net Revenue per Acre (FIA plot) Without Biomass - CTL 800
25
20
15
10
5
0
-4,000 -3,000 -2,000 -1,000 0 1,000 2,000 3,000
Net Revenue per Acre (FIA plot) Without Biomass - CTL 1300


Frequency
20
15
10
5
0
-1,000
0
1,000
2,000
3,000
4,000
5,000
Net Revenue per Acre (FIA plot)
With Biomass - WT 300
20
15
10
5
0
-1,000
0
1,000
2,000
3,000
4,000
Net Revenue per Acre (FIA plot)
With Biomass - WT 800
15
12
9
6
3
0
-1,000
0
1,000
2,000
3,000
4,000
Net Revenue per Acre (FIA plot)
With Biomass - WT 1300


Frequency
25
20
15
10
5
0
-3,000
-2,000
-1,000
0
1,000
2,000
3,000
4,000
Net Revenue per Acre (FIA plot)
With Biomass - CTL 300
Net Revenue per Acre (FIA plot)
With Biomass - CTL 800
Net Revenue per Acre (FIA plot)
With Biomass - CTL 1300