Harvesting Fuel: Cutting Costs and Reducing Forest Fire Hazards Through Biomass Harvest

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The Institute for Agriculture and Trade Policy works locally and globally at the intersection of policy and practice to ensure fair and sustainable food, farm and trade systems.

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By Don Arnosti, Institute for Agriculture and Trade Policy

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EXECUTIVE SUMMARY

Project Background

The Institute for Agriculture and Trade Policy (IATP) received a Healthy Forest Restoration Biomass Utilization Grant (BUG) to conduct test biomass harvests to understand barriers to harvesting and utilizing biomass from the Superior National Forest in northeastern Minnesota. Partners in the project included the Laurentian Energy Authority (LEA), a logger's cooperative–Forest Management Systems (FMS)–and the Superior National Forest (SNF). Biological and physical research and analysis was led by a team from the University of Wisconsin–Stevens Point, while economic analysis was handled by researchers from the University of Minnesota.

Biomass is material in the forest not traditionally utilized in pulpwood or sawtimber markets, such as shrubs, small-diameter trees, tree branches and coarse woody debris. There is interest from the local to the national level in sustainable harvest of biomass. Sustainable harvest of biomass can provide renewable energy, create economic opportunities, slow the pace of climate change and improve forest health.

This study was designed to provide information on two sets of challenges to the development of biomass markets in and around the Superior National Forest: 1) economic and operational issues faced by loggers; and 2) environmental constraints of concern to land managers, scientists and policymakers involved in developing and refining biomass harvest practices. In the course of our study, we determined that administrative systems and constraints formed a third and important set of challenges to the development of biomass markets.

The Superior National Forest (SNF) is a three million acre National Forest in northeastern Minnesota managed for multiple uses including water, wildlife, timber and recreation. In some areas of the Forest, fuel loads (dense understory vegetation, and standing and down dead material) in excess of historical norms have accumulated. These excessive fuel load areas in the SNF have created high fire hazards and risks on significant acreage. Many of these acres are within the growing "urban interface" areas of the forest, where a high-intensity wildfire could threaten homes and people. Reduction of fuel load in these areas in a timely manner under current budgetary and market conditions presents a challenge in forest management.

The SNF approached this project with the hope of encouraging the development of local markets for biomass and providing harvesters with experience in removing biomass. In addition, the SNF was interested in testing new and different prescriptions for harvesting biomass. It was anticipated that biomass harvest could be a viable treatment method and in some instances even generate positive revenue, while also increasing the opportunity to reduce fuels in these high-risk, fire-prone areas.

Test Harvest Sites and Prescriptions

Nine test harvests were conducted in the summer and fall of 2006. Environmental data were gathered on pre-harvest and post-harvest biomass quantities for each harvest site. Economic data were gathered on the various harvest, forwarding and processing systems used.

- The Caribou Trail tests had six sites. These stands had experienced heavy spruce budworm kill of understory balsam fir ten or more years previously. Most of the dead balsam had blown over, creating mats of fuel under young regenerating balsam fir and hazel. A broken canopy of old-age aspen was present over most test plots, along with standing dead snags and dead and down aspen trees ten inches and more in diameter.

Prescriptions varied on the six sites, but usually called for harvest of aspen species less than 6 inches in diameter four feet off the ground, or "diameter at breast height" (dbh), balsam fir less than 5 inches dbh and spruce less than 2 inches dbh. Prescriptions also included crushing or removing 80 percent of the dead and downed and standing dead material. Merchantable balsam fir, other submerchantable species and brush was included for treatment on specific sites. Breaking up the continuity of excessive fuel on sites near the urban interface was intended to reduce the risk of fires and lessen the intensity of fires if they occurred.

- The Pitcha Lake location had three sites. This stand had a 60- to 80-year-old red and white pine overstory managed on a long rotation with a heavy understory growth of healthy balsam fir. The balsam provided continuous ladder fuels into the canopy, posing a high risk of a stand-replacing crown fire.

The prescription was to remove all balsam fir and spruce less than 5 inches dbh outside the marked leave areas. Small hardwoods that occurred together with the balsam fir could also be removed. The goal was to maintain and manage the stands for longer rotations, and manage ladder fuels to reduce crown fire risk.

Equipment Selection

The choice of harvest, forwarding and transportation systems was determined with a combination of research, creativity, availability and adaptive learning by the project participants. Loggers from Forest Management Systems led the effort, with significant research and coordination by the Institute for Agriculture and Trade Policy and recommendations from all Biomass Utilization Grant team members.

In some instances, commonly available logging equipment was used to harvest or handle biomass. In other instances, unique combinations of equipment or systems not often found in the region were tested. Team members traveled to Montana to observe the Ponsse EH-25 biomass harvest head in a Lodgepole pine thinning demonstration. Loggers met with TimberPro in Shawano, Wis., to discuss the development of a forwarder prototype. Many manufacturers were contacted to loan or provide access to equipment not commonly available in the region.

Biophysical Site Assessment

A variety of sampling techniques were used to measure the total biomass on site. These measurements were repeated post-harvest (on harvested sites) and the resulting differences were analyzed to compare with gross biomass yield measurements taken by weighing material removed from the site on trucks. Sample techniques were based on or adapted from standard methods in common use by the United States Forest Service (USFS) whenever possible to facilitate comparisons with other sites and other research.[1] Measurements were made of the materials that made up the overstory, midstory and understory, as well as snags, coarse and fine woody debris, duff and litter. Limited soil analysis was conducted in each area. Each site was tested for the presence of non-native earthworms and the species found on site were identified.

Biophysical Results

A great deal of concern has been expressed about the environmental impacts of biomass harvest. Much of this concern is based on the expectation of total removal of coarse woody debris and associated potential soil nutrient loss. Even on sites with a specific goal of removal of coarse woody debris, there were only low or moderate decreases of coarse woody debris after harvest, and in one case, an increase. The highest rate of coarse woody debris harvest only amounted to 39 percent removal.

Generally, efficiencies at removal of the specified biomass materials varied greatly. Many of the sites had areas that were not suitable to harvest (topography was rough or steep, overstory crop trees that were too dense for efficient biomass harvest or patchy distribution of the understory, which meant that some areas had little biomass material to harvest). The highest efficiency of harvest was 75 percent of the stems less than 1 inch dbh and 94 percent of stems greater than 1 inch dbh. Most sites fell well under this level of harvest.

The overstory had by far the largest volume of biomass on the sites. When any significant quantity of material greater than 5 inches in dbh will be removed, the bulk of the removals will be concentrated in this material. Some large stems may have more volume than entire acres of biomass 0-5 inches dbh. Materials from 1-5 inches in dbh generally held far more volume than smaller materials and were a significant source of biomass for these harvest operations.

Snags were far less impacted by the harvesting activity than expected. Generally, few snags were removed, even on sites where this was a goal.

Harvesting Economics

Analyses were conducted to determine the cost effectiveness of combining fuel load reduction with biomass harvesting for energy. All nine harvested sites were analyzed. Estimated costs of conventional mechanical fuel treatments (crush and/or pile and burn) were compared with the biomass treatment option. We analyzed the difference between biomass harvesting and delivery costs, and income from selling biomass. A number of harvesting and delivery systems, and transportation scenarios were examined to identify different opportunities for reducing mechanical treatment costs. Initially, only one test unit showed a reduction in fuel treatment costs using biomass harvest.

However, models were developed that optimized equipment mobilization and biomass transport, and projected economic costs of transporting biomass and machinery 25, 50, 75, 85, 100, 125 and 150 miles. Controlling for these factors, the models showed cost reductions for six of the nine test harvests for at least some of the modeled haul distances. These results showed that per acre, biomass treatment options can reduce costs in comparison with conventional fuel treatment costs. The amount of cost reduction varied with treatment equipment used and hauling distance to end users.

Harvesting Economics Observations

Certain factors appear to have a significant influence on whether a biomass harvest will reduce fuel management costs versus conventional treatments. These factors might be grouped in three categories: markets, management and operations. See the Recommendations section of the "Executive Summary" for a summary of these factors.

The Logger's Voice

There is a large body of literature which has focused on biomass harvest for energy production, and on biomass removal as a hazardous fuel reduction method. However, the literature that assesses the lessons of these trials, based on the perspective of the operators who put these trials into practice, is not common.

To this end, project researchers interviewed the operators of the harvest, forwarding and transport equipment to obtain their observations and recommendations. The information in this chapter flows from primary research, collected using field-based, in-depth, semi-structured interviews and follow-up phone discussions with forest and road equipment operators who participated in these trials. Logistical concerns identified are based on the operators' responses and input, and are intended to offer insights for future biomass harvesting research and operations. Data analysis identified two main logistics-related components in the operators' responses: one related to harvesting and delivery challenges; and another related to planning and coordination challenges. See the Recommendations section of the "Executive Summary" for a summary of Loggers' recommendations.

Administrative Systems

Timber harvest activities on National Forests are subject to a variety of federal laws, including the National Environmental Policy Act (NEPA). Before harvesting can commence, public involvement and other requirements of NEPA must be fulfilled. The NEPA process culminates in a decision document (a Record of Decision, Decision Notice or Decision Memo) that identifies the treatment objectives of the timber harvest and related activities. There is flexibility in adjusting site prescriptions after the decision document is issued, but only to the point that they still meet the treatment objectives identified and the scope and intensity of actions considered in the project analysis. Revision of site prescriptions to the point of meeting different treatment objectives generally requires additional public involvement and environmental effects analysis that consumes time and finances. See the "Recommendations" section of the "Executive Summary" for adjustments to site prescriptions and site layout features to consider during the planning phase (before the decision document is issued) that can help set up biomass harvest operations for success.

Discussion, Recommendations and Conclusions

Discussion

This study was designed to provide information to address two sets of challenges to the development of biomass markets in and around the Superior National Forest in northeastern Minnesota: 1) economic and operational issues faced by loggers, and 2) environmental constraints of concern to land managers, scientists and policy-makers involved in developing and refining biomass harvest practices. In the course of our study, we determined that administrative systems and constraints formed a third and important set of challenges to the development of biomass markets. While no definitive "right way" to harvest biomass for energy use can be identified as a result of these trials, important information has been uncovered which should be of value to land managers as they consider the use of biomass harvest as a tool to achieve their desired land management goals.

Recommendations

Figure E-1

Administrative Issues

Planning and Strategy	Biomass management activities must be considered and incorporated at early phases of the planning process in order to incorporate many of these recommendations, and to successfully utilize biomass harvest as a management tool on National Forest, state, county or private lands.
Site Prescription	Site prescriptions tailored to the practical and operational needs of biomass harvest are critical. These should, whenever possible, be flexible prescriptions that allow operator-determined options to lay out skid trails, reserve areas and permit a minimal removal of residual trees to facilitate harvest and forwarding.
	Larger management units are preferred, as they will reduce administrative and harvest costs per unit area (e.g. equipment mobilization costs).
	Combining roundwood and biomass harvest is one strategy to improve on-site maneuverability and harvest efficiency.
	Focus biomass removals on larger materials and higher density areas (intensive or thorough removal across a variably-stocked site is impractical and expensive).
Site Layout	Skid trails arranged in an efficient layout are necessary to make harvesting operations efficient.
	Clear site demarcation, using customary logging flags or painting, can speed up operations.
	Demarcation signs (flags, paint) from previous management operations should be removed to avoid possible confusion with biomass energy harvesting demarcation.
	Minimize forwarding distance to biomass yarding areas.
Communication	Emphasize communication and coordination between forest managers, purchasers and operators as early as possible in the project planning stages to ensure a more efficient and effective implementation of biomass harvesting operations.
	It is vital for forest managers to communicate harvest requirements to purchasers (and where feasible operators) before work begins. Purchasers should do the same with their operators.
	Communicating to purchasers and operators why certain prescriptions requiring specific exclusions or restrictions promotes a more informed understanding of the goals of the harvest by operators, and facilitates good communication.

Figure E-2

Operations

Equipment	Select equipment suitable to the terrain and forest conditions, carefully considering visibility from the cab, maneuverability and flexibility of use such as a dual harvester/forwarder. Lower cost equipment (such as biomass processing heads in place of timber processing heads) can improve harvest economics for this low value material.
	No adaptations to standard forwarding equipment are necessary for biomass. However, operators need to learn new techniques of loading and maneuvering to be successful.
	Self-loading grinders should be employed to eliminate the need for a separate loader.
	Material haul efficiency should be maximized with full chip van loads or by transporting both roundwood and biomass bundles on a load when practical.
Techniques	Learning the techniques necessary to search for, harvest and recover smaller biomass material is a new practice for loggers in Minnesota. Operator proficiency is expected to improve over time, leading to increased efficiencies and reductions in the cost of operations.
	Machine operators should visit a site prior to operations to properly understand the site conditions, expectations and challenges of the project.
	Forwarding and bundling hours can be reduced if material is sized and arranged in organized piles for faster collection.
	Delays in grinding can be avoided if root stumps and stones are removed from biomass before the grinder arrives on site.
Season of Operation	Summer forwarding improves visibility of smaller biomass piles resulting in more efficient and complete recovery of harvested biomass.
	Forwarding of materials should take place right after material is cut to improve speed and total recovery of material forwarding; snow or vegetative regrowth can obscure smaller biomass piles.

Figure E-3

Environmental Considerations

Biomass Harvest Guidelines	In Minnesota, where guidelines were recently developed, following the Biomass Harvesting on *Forest Management Sites*[2] should mitigate concerns about soil nutrients, structure and wildlife habitat.

Figure E-4

Market Considerations

Transport Distance	Distance to biomass markets should be no greater than 100 miles; preferably considerably less.
Moisture	Payment should be per ton and should be adjusted for moisture content to reward on-site drying, and fairly compensated for transport of drier, more favorable materials.
Storage	If bundles are desired for biomass storage reasons, payments must reflect this value.

Conclusion

Harvesting biomass to accomplish the goals of fuel reduction, improved forest health and supplying material for energy production is a new practice in Minnesota. Fuel reduction prescriptions need to be adjusted to address operational challenges, and planning and coordination concerns. Once biomass harvest is identified as a management option, incorporating an early understanding of production logistics into harvest plans and prescriptions can reduce fuels management and biomass production costs. Site prescriptions, distance to market, size and efficiency of operations and equipment all influence the economic viability of biomass harvests as a tool to manage forests. Environmental effects of biomass removal on soils, wildlife habitats and other natural features can be mitigated in Minnesota by following the Minnesota Forest Resource Council's *Biomass Harvesting on Forest Management Sites.*[3] Under the right combination of these circumstances, biomass harvest can reduce forest management costs.

CHAPTER 1: INTRODUCTION

By Don Arnosti and Katie Marshall

Background

The Institute for Agriculture and Trade Policy (IATP) along with three partners–the Superior National Forest (SNF), the Laurentian Energy Authority (LEA) and a logger's cooperative–Forest Management Systems (FMS)–received a Healthy Forest Restoration Grant to conduct test harvests and study the results to understand issues involved in harvesting biomass from a National Forest.

Biomass is material in the forest not traditionally utilized in pulpwood or sawtimber markets such as small-diameter trees and tree branches. There is interest from the local to the national level in sustainable harvest of biomass. Sustainable harvest of biomass can provide renewable energy, create economic opportunities, slow the pace of climate change and improve forest health.

Bundled biomass in SNF

This study was designed to provide information to address two sets of challenges to the development of biomass markets in and around the Superior National Forest in northeastern Minnesota: 1) economic and operational issues faced by loggers, and 2) environmental constraints of concern to land managers, scientists and policy-makers involved in developing and refining biomass harvest practices. In the course of our study, we determined that administrative systems and constraints formed a third and important set of challenges to the development of biomass markets.

Goals and Objectives

Fuel Reduction

The SNF in northeastern Minnesota is a 3 million acre National Forest managed for multiple uses including water, wildlife, timber and recreation. In some areas of the forest, fuel loads in excess of historical norms have accumulated. The SNF has conditions with high fire hazards and risks due to excessive fuel loads on significant acreage (dense understory vegetation and standing and down dead material). Many of these acres are within the growing urban interface areas of the forest where a high-intensity wildfire could threaten homes and people. Treatment of these areas in a timely manner under current budgetary and market conditions presents a challenge in forest management.

The SNF approached this project with the hope of encouraging the development of local markets for, and experienced harvesters of, biomass. In addition, the SNF was interested in testing new and different prescriptions for harvesting biomass. It was anticipated that biomass harvest could be a viable treatment method and in some instances even generate positive revenue while also increasing the opportunity to reduce fuels in these high-risk, fire-prone areas.

Economics of Biomass Harvest

This project was designed to gather economic information about a variety of harvest techniques and equipment operating under a range of field conditions in northern Minnesota. This information can then reduce the uncertainty that local contractors face as they contemplate investments in specialized equipment and training to harvest biomass under SNF fuel reduction and forest management contracts or under contract on other state, county or private forests in the region.

Viability of Biomass Harvesting Systems

There is a lack of knowledge and familiarity with biomass harvesting equipment by potential operators. Loggers and forest management contractors in northern Minnesota have little experience in harvesting and gathering biomass from the forest outside of a traditional timber harvest site. Available harvest equipment is sized to safely and efficiently handle fully grown trees on a mass scale. A paucity of information about cost, productivity and efficiency of biomass harvest equipment and techniques to harvest biomass on non-commercial timber sites causes most contractors to avoid the financial risk posed by pursuing such management contracts. This study presents information about biomass harvesting systems to help reduce that risk.

MFRC Best Management Practices and Environmental Concerns

Project partner Laurentian Energy Authority (LEA) represents the Public Utilities of Virginia and Hibbing, Minn. Hibbing and Virginia rebuilt their existing power facilities to burn woody biomass from the surrounding region starting in 2007. The LEA committed to purchasing biomass harvested under Best Management Practices (BMPs) that were under development by the Minnesota Department of Natural Resources and the Minnesota Forest Resources Council (MFRC) in order to address concerns of citizens worried about long-term ecosystem sustainability, and to ensure the continuing viability of their own fuel supplies.

Specific state legislation already required the preparation of ecologically based BMPs to guide biomass harvesting in Minnesota. However, cooperating scientists in that effort identified a critical shortcoming in available research: local field data that could be used to "calibrate" soils and habitat models to actual harvest conditions in Minnesota. This project, in part, helps to address that issue by providing field data on sites treated for biomass harvest.

Research was needed to quantify residues remaining after biomass harvesting by size class under a variety of harvest scenarios. The Minnesota Department of Natural Resources (DNR) used a Department of Energy grant to obtain this information on commercial harvest sites where biomass (slash) was gathered.[4] This project complements that research with "non-commercial materials" data from forest management sites. The information assisted scientists, and those in the future who will revise and update the BMPs, to accurately predict actual nutrient removals and remaining coarse and fine woody debris on harvested sites. This information is necessary to protect soils, forest productivity and wildlife habitat after biomass harvests. In Minnesota, BMPs are published by the Minnesota Forest Resources Council as "Site Level Forest Management Voluntary Guidelines."

Project Design

The Biomass Utilization Grant project tested a variety of biomass harvest systems and techniques on lands that are being highlighted in the Community Wildfire Protection Plans of local counties. Sites were identified where no commercial timber sales were planned, due to low timber volumes, young stand ages or desired future conditions. This project focused specifically on biomass harvest as a distinct forest management activity instead of biomass collection from commercial timber sales. Most forest biomass presently harvested in Minnesota is obtained from either commercial timber harvest sites, land clearance for development or road right-of-way maintenance. Existing biomass markets in Minnesota include Laurentian Energy Authority, Hibbing and Virginia; Central Minnesota Ethanol Co-op, Little Falls; Minnesota Power's Rapids Energy Center, Grand Rapids; District Energy, St. Paul; Minnesota Power's M.L. Hibbard facility, Duluth; and MinnTac, Mt. Iron.

The project planned to conduct 12 test biomass harvests, comprising approximately 180 acres on SNF sites. Because of seasonal operational limitations and a shortage of equipment and operators, test harvests planned for winter 2007 had to be cancelled. The cancellation resulted in nine completed harvests, with planning and pre-harvest data collection on two more. See Chapter Two for a description of harvest sites.

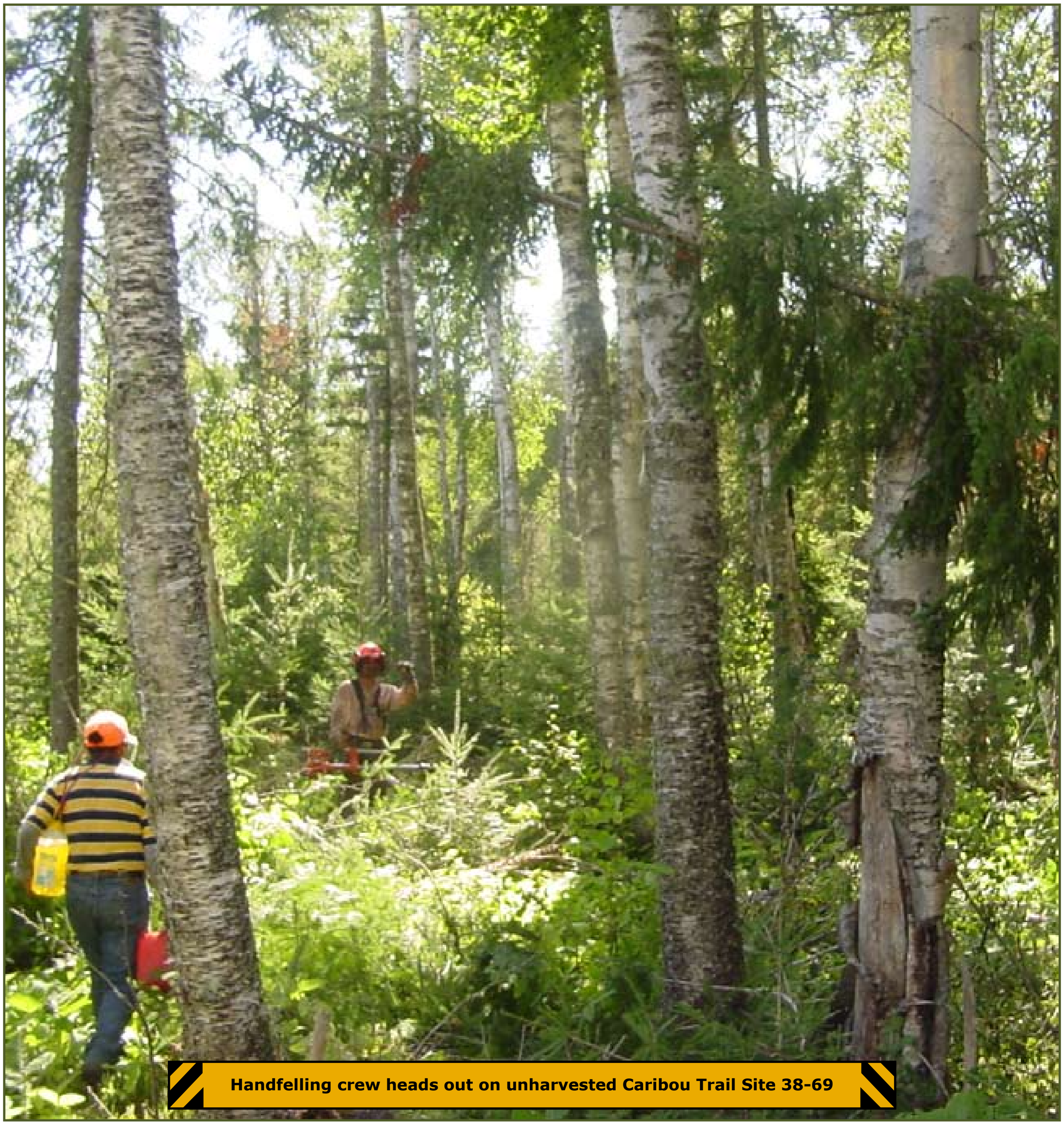
Test harvests were conducted utilizing several different combinations of equipment and techniques by FMS members and other area loggers. Chapter Three describes the harvesting systems used.

Environmental effects of biomass harvest are described in Chapter Four. Transects, variable and fixed radius plots, and other sampling techniques were used to gather data on pre-harvest and post-harvest biomass quantities from the same harvest sites. Variable factors, such as standing and down wood, green and dead snags, and size class and species were gathered. These data were complied, analyzed and cross-referenced with harvest systems and techniques as part of this study.

Data was gathered, compiled and analyzed for economic costs and productivity in each of the test areas. Chapter Five details the methods, results and analysis of the economics of biomass harvesting in this study.

A crucial aspect of understanding biomass harvest is the perspective of the loggers and their viewpoint on what is required for a viable biomass operation. Chapter Six, "The Logger's Voice," presents this perspective.

Finally, it became evident over the course of the study that Forest Service administrative processes affect the outcome of biomass harvest. Timber harvest activities on National Forests are generally subject to a variety of federal laws, including the National Environmental Policy Act (NEPA). Before harvesting can commence, public involvement and other requirements of NEPA must be fulfilled. Recommendations on how to facilitate a sustainable and efficient biomass harvest operation in compliance with NEPA and other relevant laws are also presented.



Handfelling crew heads out on unharvested Caribou Trail Site 38-69

CHAPTER 2: HARVEST SITES

By Don Arnosti, Dalia Abbas and Katie Marshall

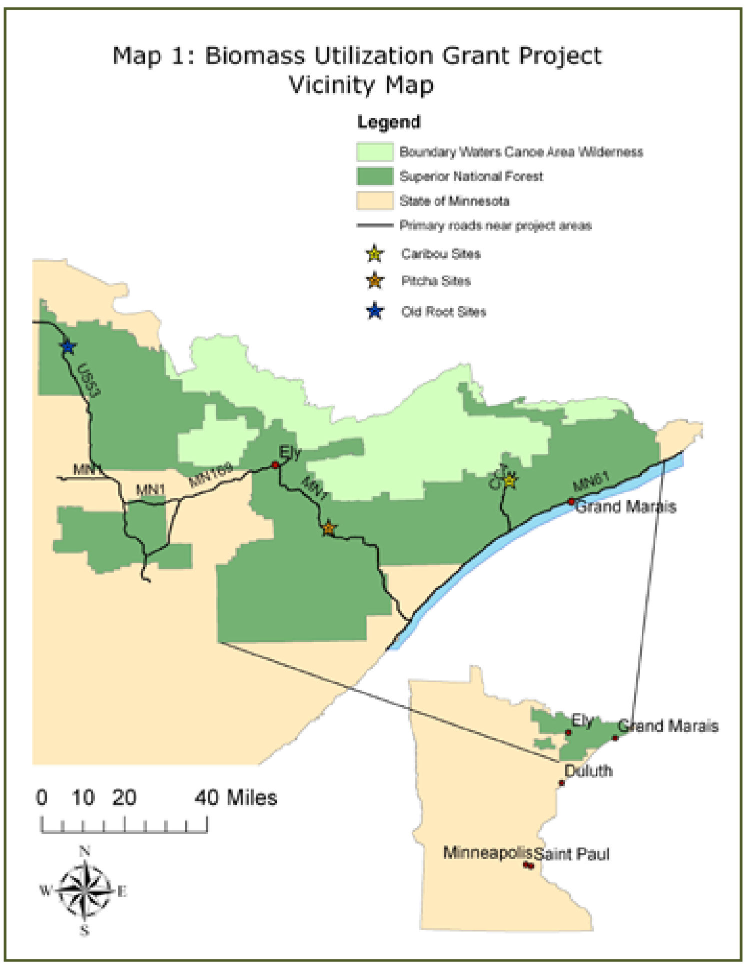
Site Selection

Sites were selected through a process of discussion and site visits by project team members. Three forest locations and 11 test plots were selected, representing three distinct forest management situations for the project.

Project Planning Team considering sites for biomass test harvest

The three locations included:

- Caribou Trail, which is composed of six test sites totaling 74 acres. These stands had experienced heavy spruce budworm kill of understory balsam fir 10 or more years previously. Most of the dead balsam had blown over, creating mats of fuel under young regenerating balsam fir and hazel. A broken canopy of old-age aspen was present over most test plots, along with standing dead snags and dead and down aspen trees 10 inches and more in diameter.



- Pitcha Lake, which is composed of three test sites totaling 32.5 acres. This stand had a 60- to 80-year-old red and white pine overstory managed on a long rotation with a heavy understory growth of healthy balsam fir. The balsam provided continuous ladder fuels into the canopy, posing a high risk of a stand-replacing crown fire.

- Old Root, which is composed of two test sites totaling 60 acres, that ultimately were not harvested. Old Root had experienced "straight-line" winds about five years previously that bent, tipped and broke nearly all stems in a 25-year-old aspen stand. Blackberry, raspberry and some young aspen were growing in the scattered and broken forest, presenting a nearly impenetrable tangle for people on foot.

For a table detailing each site and the number of acres, see Chapter Four, page 24.

Most of the material slated for removal from these trial locations was suitable only for biomass markets, due to the small diameter and/or deteriorated condition of the stems.

Each of these forest conditions was determined to be recurring, widespread and difficult to manage. Preliminary evaluation for the project indicated an estimated 39,000 acres of the SNF have forest health conditions similar to Caribou Trail, resulting from past outbreaks of spruce budworm in balsam fir. An estimated 20,000 acres of the SNF have ladder fuel situations similar to Pitcha Lake. Episodic and recurring storm downbursts and straight-line winds create blow-down such as at Old Root. The massive and historically unprecedented July 4, 1999 event blew down trees on approximately 477,000 acres of forest land in northeastern Minnesota.

Pitcha Lake and Caribou Trail were determined suitable for summer harvest under ordinary dry moisture conditions.

Due to heavier soils and a higher water table, the Old Root sites were designated for winter harvest in early 2007. However, a combination of factors, including unavailability of specialized loading equipment scheduled for testing on the site, difficulty in securing replacement equipment and operators during the peak of the commercial logging season (frozen ground conditions in winter) and warming weather conditions, limited the amount of time available to complete the harvest. The project team ultimately decided not to begin harvesting due to the possibility that the harvest and material transport would not be completed before the spring thaw.

Site Prescriptions

Timber harvest activities in National Forests are subject to a variety of federal laws, including the National Environmental Policy Act (NEPA). Before harvesting can commence, public involvement and other requirements of NEPA must be fulfilled. The NEPA process culminates in a decision document (a Record of Decision, Decision Notice or Decision Memo) that identifies the treatment objectives of the timber harvest and related activities. There is flexibility in adjusting site prescriptions after the decision document is issued, but only to the point that they still meet the treatment objectives identified and the scope and intensity of actions considered in the project analysis. Revision of site prescriptions to the point of meeting different treatment objectives generally requires additional public involvement and environmental effects analysis that consumes time and finances.

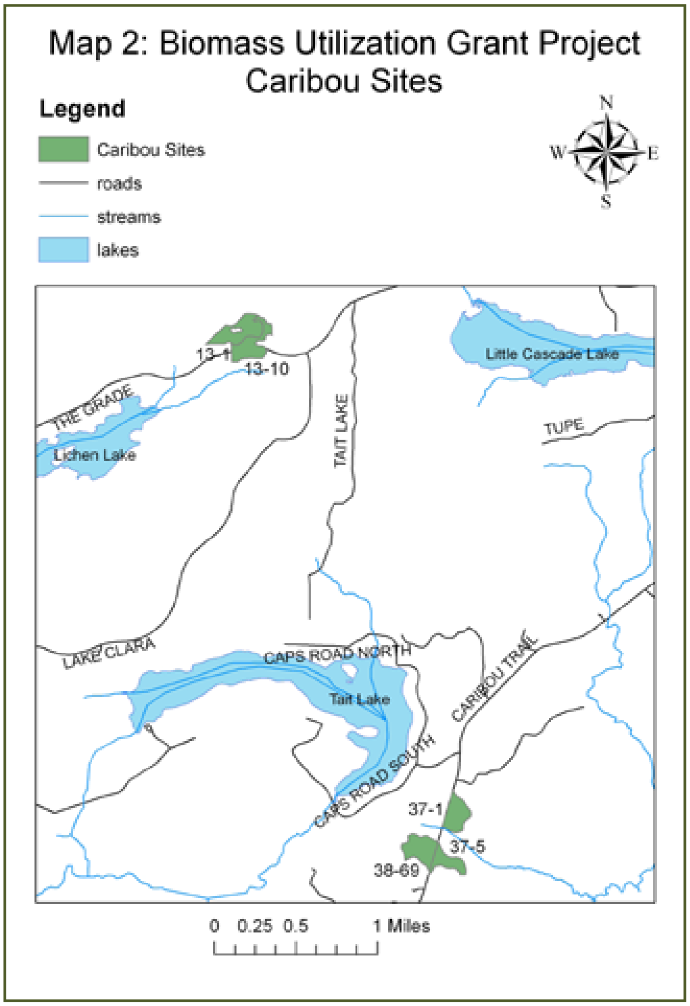
The project team discussed prescriptions with the Forest Service in an effort to introduce options specific to biomass into some of the test harvests. This was not always possible (without additional public comment and analysis to comply with NEPA) depending on the specific Decision Memo relevant to each site. Consideration of treatment objectives and prescription options that facilitate biomass harvest before the decision document is finalized can help achieve successful biomass harvest operations in the future.

For financial and operational reasons, the loggers participating in the project were generally interested in options that included biomass and roundwood (pulpwood) harvest combined, even if the total roundwood available for harvest fell below the quantities necessary to support a profitable commercial harvest. A suggestion was made to combine both fuel reduction and timber stand improvement goals on the Pitcha site, which would have combined balsam fir and cull-tree removal, but this was not authorized in the treatment objectives selected in the respective Decision Memo for each site.[5]

The following are the descriptions, forest management objectives and final project prescriptions for each site. A discussion follows each prescription describing options and trade-offs that were considered by the project team. Many discussions involved integrating resource purposes with wildlife, soil nutrient retention, wildfire hazard reduction and aesthetic directives often needing to be reconciled with each other.

Caribou Trail Sites

Site Description[6]



Six study sites totaling 74 acres were selected for inclusion in the Caribou Trail area. Study areas were selected where urban interface development is prevalent (i.e., adjacent to or upwind of lakeshore homes).[7]

The Landscape Ecosystem at these sites is mostly Mesic-Birch-Aspen-Spruce-Fir. Fire has not played a role within these sites for approximately 100 years, although the estimated fire return interval for this area is 85 years. The lack of fire has allowed understory vegetation to mature and accumulate excessive fuels. Of the conifer species, balsam fir is of a particular concern because of its high flammability and its ladder-fuel position in the understory. In addition, the result of fire exclusion in the area has increased insect infestation predominately in the balsam fir. Spruce Budworm, a defoliating insect, infested this area about 13 years ago, killing most of the understory balsam fir. These balsam firs have slowly been accumulating on the forest floor, increasing the potential for a high-severity wildfire. Historically, fire would have removed the balsam fir understory before disease occurred, decreasing fire risk. Furthermore, older stands have a hardwood overstory that is exhibiting signs of advanced age with broken tops and dying trees. This contributes more fuel to the forest floor and creates a continuous fuel path for fire to spread from the ground to the canopy.[8] The area is presently in Fire Regime III and Condition Class 2.

See the General Site Characteristics section of this report on page 24 for a description of soils at the Caribou Site.

Site Objectives

Break up the continuity of excessive fuel on sites near the urban interface to reduce the risk of fires and lessen the intensity of fires if they occur.[9]

Site Prescriptions

Generally, prescriptions targeted aspen species less than 6 inches in diameter 4 feet off the ground, or "breast height" (dbh), balsam fir less than 5 inches dbh and spruce less than 2 inches dbh. Stems were to be cut at no higher than 12 inches off the ground, while crushing or removing 80 percent of the dead and downed and standing dead material.[10]

Site 13-10 (15.4 acres):

The prescription called for removal of 50 percent of sub-merchantable trees and brush in 0.5 to 3 acre groups, with a focus on balsam fir understory pockets. In addition, all standing dead material and downed trees in harvest treatment areas were to be removed. A decision was made to allow the harvest operator to select areas to reserve from harvest to achieve the site goals of: 1) leaving 50 percent of the site unharvested; and 2) to minimize harvest immediately adjacent to the road which bisects the site, for visual quality reasons.

Options discussed for this site included: 1) how to determine which areas were reserved from harvest—either machine operator choice or forester designation; 2) amount of reserved area that should border the road for aesthetic reasons; 3) amount of stand area to reserve from harvest for wildlife habitat purposes; and 4) whether to permit removal of coarse woody debris and snags in the harvest areas.

Sites 13-1 E &W (12.4 and 10.2 acres, respectively):

The prescription called for removal of sub-merchantable balsam fir (<5 inches dbh), spruce (<2 inches dbh) and aspen (<6 inches dbh); leaving one sub-merchantable tree every 15 feet; crushing standing dead and downed material less than 6 inches dbh and leaving standing dead snags greater than 6 inches dbh.

Options discussed for these sites included: 1) removal of some of the larger dead and down material; and 2) clumping the leave trees, rather than spacing them every 15 feet.

Site 37-1 (10.0 acres):

The prescription called for removal of sub-merchantable balsam fir (<5 inches dbh) and aspen (<6 inches dbh) and as much brush as possible; removal of no more than 80 percent of dead and downed material; and removal of standing dead trees less than 6 inches dbh.

Options discussed for this site included: 1) some overstory removal (mature aspen); and 2) limiting brush removal to areas of high density.

Site 37-5 (10.3 acres):

The prescription called for removal of all balsam fir, both merchantable and non-merchantable, and the knocking over and crushing of standing dead and downed material less than 6 inches dbh.

Options discussed for this site included: 1) need for skid trails; and 2) removal of hardwood overstory trees obstructing skid trails for access to pockets of balsam fir.

Site 38-69 (15.5 acres):

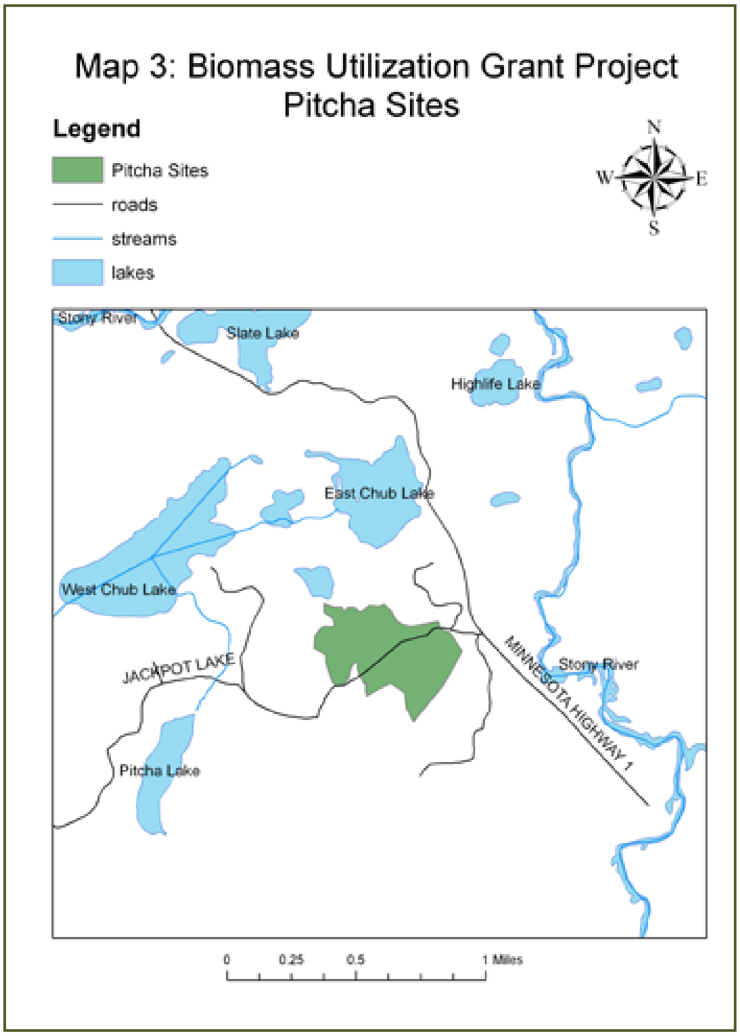
The prescription called for removal of brush greater than or equal to 1/2 inch dbh, removal of all sub-merchantable balsam fir (<5 inches dbh) and aspen (<6 inches dbh), and removal of no more than 80 percent of dead and downed trees and all standing dead snags less than 6 inches dbh.

Options discussed for this site included: 1) need for skid trails to facilitate biomass bundling and forwarding after hand harvest; 2) amount of dead and downed material available for removal; and 3) siting of a landing in a pocket of young aspen regenerating after a previous harvest.

Pitcha Lake Sites

Site Description[11]

The three Pitcha Lake test sites cover 32.5 acres. These sites are predominantly in the Dry Mesic Red Pine-White Pine Landscape Ecosystem.[12] These mature stands make up a pine complex; canopies are predominately pine (red and white), mixed with spruce, balsam fir, aspen and paper birch. Operability is good throughout, although some rolling topography exists in the northern-most areas. The mortality within the stands is minimal, <5 percent. The canopy trees range in size from 5 inches to 28 inches dbh, averaging around 12 inches dbh. Regeneration of the canopy pines is present in less than 5 percent of the area. Much balsam fir and hazel brush exists. The densest understory of balsam fir exists on the northern areas of the site where no thinning of the forest has occurred since stand establishment 60-80 years ago.



Historically, low-intensity surface fires removed dead and down fuels, kept balsam fir and spruce regeneration to a minimum, and helped minimize insect and disease outbreaks in older red and white pine stands. These fires burned under the canopy of red and white pine forests without killing the older trees. Eighty years of wildfire control has resulted in the establishment of balsam fir and spruce regeneration in the existing pine stands, and an accumulation of potential fuel for wildfires. The high fuel loading has put many pine stands at risk for intense crown fires that could devastate the stands. Private landowners adjacent to these stands would be threatened by large wildfires.

The area is in Fire Regime III and the stands are presently in Condition Class 2 or 3. Fire Regime is a classification of the natural role fire would play across a landscape without human intervention.[13] Fire Regime III is classified as fires that are surface/intermittent crown fires with a mixed severity occurring in 35 to 200 plus year intervals. Vegetation within Condition Class Two is described as being moderately altered from its historic conditions. Condition Class Three is described as being significantly altered from its historic conditions.

See the General Site Characteristics section of this report on page 24 for a description of soils at the Pitcha Site.

Site Objectives

Maintain and manage stands for longer rotations, and manage ladder fuels to reduce crown fire risk with mechanical methods and prescribed burning.

Site Prescription

The prescriptions for all three sites at Pitcha Lake were the same. The prescription was to remove all unmerchantable (less than or equal to 4.9 inches dbh) balsam fir and spruce outside the marked leave areas. Small hardwoods that occurred together with the balsam fir biomass could also be removed.

- Some unmerchantable white pine could be harvested if these trees were located within thick patches of balsam fir. Whenever possible, young, healthy scattered white pine and white spruce trees were to be left.
- Some balsam fir could be left if they were in small, relatively isolated pockets, or surrounded by white pine, white spruce and/or hardwoods regeneration.
- To maintain this valuable ecosystem legacy on site, no dead and down woody debris of any species that did not result from biomass harvest operations could be removed from site. Following biomass harvest, prescribed burns are to be conducted across all sites.

Retention/Residual tree guidelines

- Pre-identified leave areas are to help maintain a portion of the thick understory within the complex.
- These leave areas are easily located on the ground.
- No standing snags or defective and cull (dying) trees were to be removed from site. (A consideration on these sites was the percent canopy cover, which was toward the bottom end of guidance for managing forests for the Canada Lynx, which is present in the area.)

Biomass harvesting equipment was allowed to remove understory biomass where deemed necessary. The cutting of any trees greater than 5 inches dbh only occurred for skid trail/temporary road construction after approval from a Forest Service employee. This was to be a very rare occurrence.


Pitcha North site prior to biomass harvest

Options discussed for these sites included: 1) combining a timber stand improvement thinning with biomass removal; 2) harvesting all balsam fir, not just those of less than 5 inches dbh; and 3) harvesting only the densest pockets of brush and young balsam fir, not trying to harvest across the entire site.

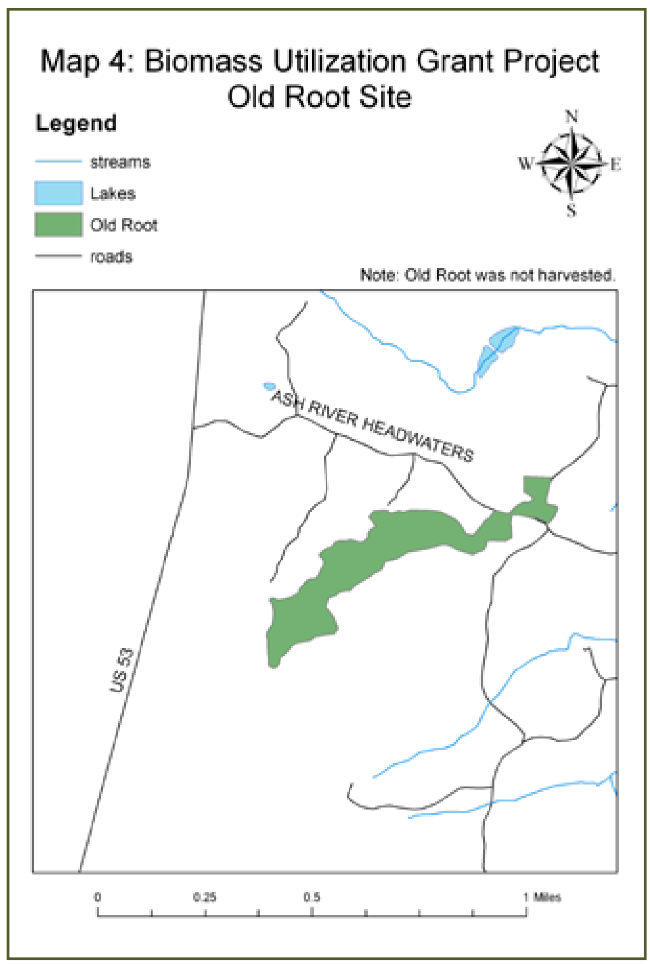
Old Root Sites

The Old Root test sites cover 60 acres. The Landscape Ecosystem at these sites is mostly Mesic-Birch-Aspen-Spruce-Fir.

See the General Site Characteristics section of this report on p. 24 for a description of soils at the Old Root Site.

Site Description[14]

Currently, the area identified in the Old Root Biomass Project Area consists of 25-year-old small diameter (4- to 8-inch) aspen blow-down that is the result of straight-line winds in 2002. As a result of the blow-down, the trees on the ground are jack-strawed and the fuel loading is consistent with a Fire Behavior Prediction System fuel model 13.[15] With the high fuel loading and difficulty of control of a fire in this type of fuel, there is a good possibility that a surface fire starting in the project area would be intense enough to transition to a high-severity crown fire in the adjacent pine plantations. This type of wildfire is difficult to manage and potentially devastating to the stand.



The area is in Fire Regime III and the stands are presently in Condition Class 2 or 3.

Site Objectives[16]

The purpose of this project is to break up the continuity of the fuel hazard within the project area by using mechanical treatments to reduce and remove the biomass. In the event of a wildfire, the treated areas would burn with less intensity than non-treated areas and result in safer conditions for fire personnel to manage and suppress it.

Site Prescription

Harvest 4 to 8 inch standing and down aspen on site. Twigs and branches in contact with the ground should be retained for nutrients and in order to avoid dulling chipping or cutting equipment. Reserve trees are designated by species; do not cut any upright paper birch, maple, oak, black ash or conifer species. In addition, retain up to six upright snags per acre.

Options discussed for these sites included: 1) summer harvest; and 2) retention of leave areas within the harvest units where regeneration and surviving trees were most dense.

Straight-line winds knocked down much of the young aspen stand leaving small pockets of standing trees on the Old Root site

CHAPTER 3: HARVEST SYSTEM SELECTION

By Don Arnosti and Katie Marshall

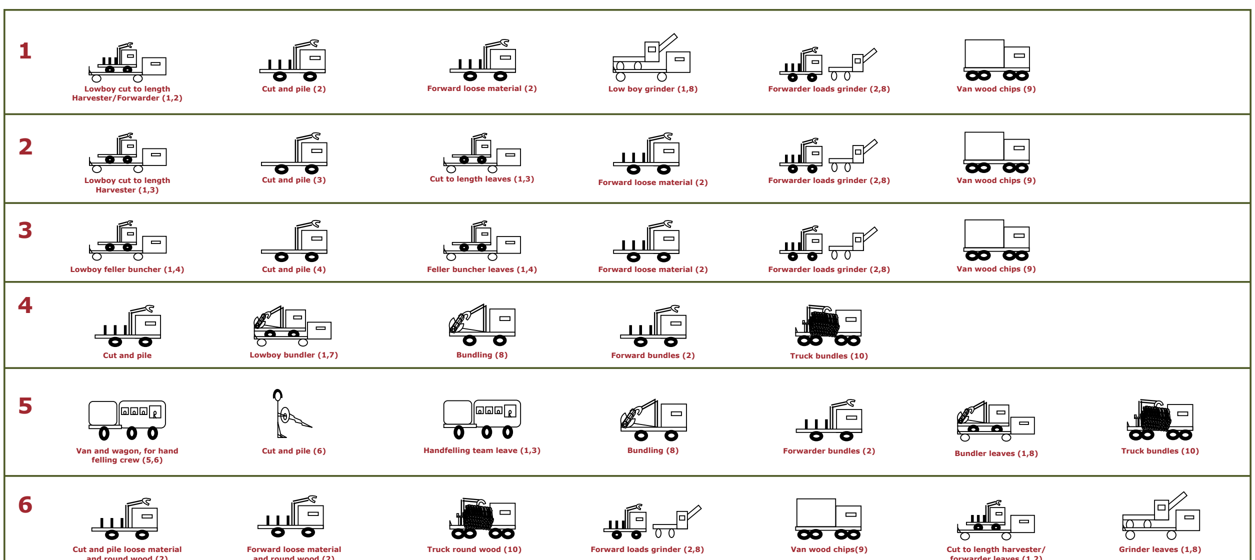
The choice of harvest, forwarding and transportation systems was determined with a combination of research, creativity, availability and adaptive learning by the project participants. Loggers from Forest Management Systems led the effort, with significant research and coordination by IATP, and recommendations from all Biomass Utilization Grant team members. In some instances, commonly available logging equipment was used to harvest or handle biomass such as the Ponsse Buffalo Dual, Timbco 425 D feller-buncher and the Fabtek 153 with cut-to-length processing head.


Ponsse Buffalo Dual harvester

In other instances, unique combinations of equipment or systems not often found in the region were tested. This equipment included a Ponsse EH-25 biomass harvest head, a Valmet 603 three-wheel feller buncher and a John Deere 1490D biomass bundler. Team members traveled to Montana to observe the Ponsse EH-25 biomass harvest head in a Lodgepole pine-thinning demonstration. Loggers met with TimberPro in Shawano, Wis., to discuss the development of a forwarder prototype with a saw on the loader arm for use on the Old Root sites, which ultimately was not built in time for the tests. Many manufacturers were contacted to loan or provide access to equipment not commonly available in the region.

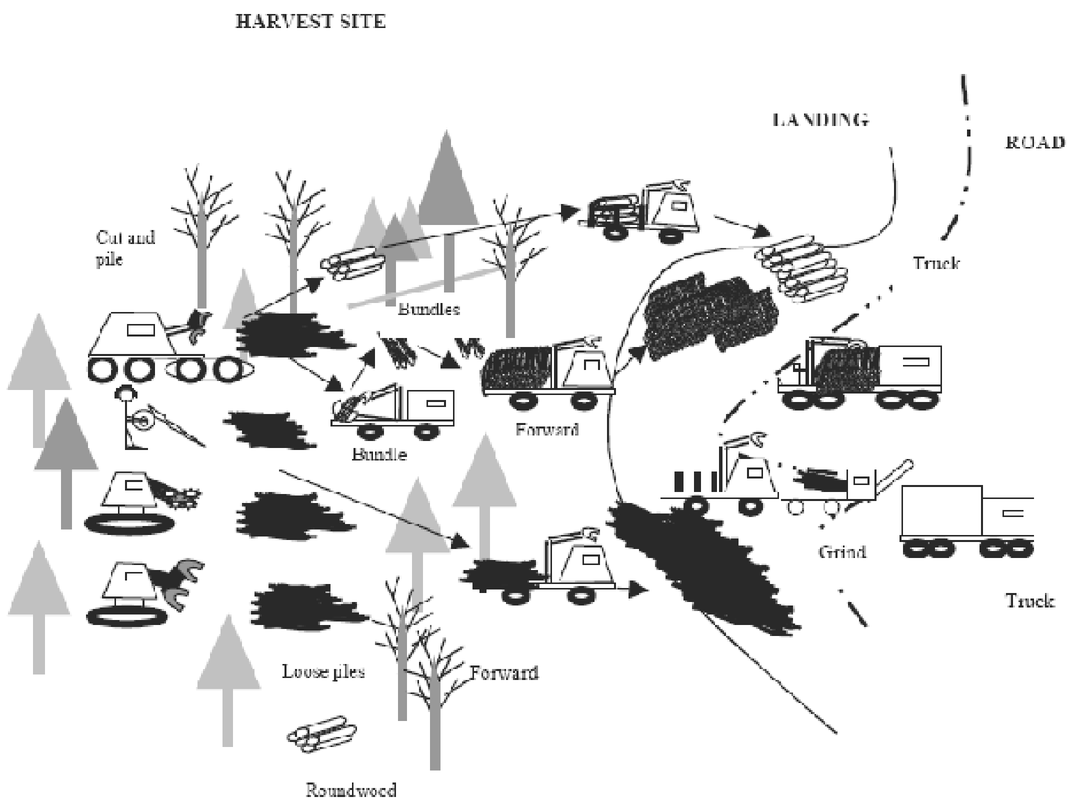
It was originally anticipated that pulpwood forwarders with their open bunks would need plates, meshes or other adaptations to handle the small diameter biomass to be harvested. Racks and plates were on order at a local welding shop when Lonnie Popejoy, the expert machine operator on the Ponsse Buffalo Dual, discovered loading techniques that allowed him to efficiently and rapidly load and forward small diameter, loose biomass without loss or any equipment modifications. Lonnie found that packing a layer of longer, stronger biomass stems around the bottom and sides of the bunks allowed for smaller biomass stems to be carried in this "basket." Voluminous loads were forwarded by maintaining a grip on the top of the pile with the loading grapple when traveling. The bunk add-ons were cancelled.

Harvest System at Each Site



Description of systems, treatments and products: 1. Lowboy 2. Ponsse Buffalo Dual harvester/forwarder 3. Fabtek 153 cut-to-length harvester 4. Timbco 425D feller buncher 5. Van Truck and 48-ft chip van (30-ton load) 10. Truck and picket trailer.

created by Dr. Dalia Abbas



Description of the different harvesting and delivery systems involved in these trials.

created by Dr. Dalia Abbas

Caribou 13-1E

A Ponsse Buffalo Dual with the EH-25 biomass harvest head was used to harvest the material. The material was bundled by the John Deere 1490D and then forwarded to the landing. The bundles were transported in four trucks to the Laurentian Energy Authority (LEA) woodyard.

Caribou 13-1W

A tracked feller-buncher was used to complete the harvest. The material was then forwarded loose to the landing using the Ponsse Buffalo Dual. The loose material was processed in the Rotochopper MC 266 grinder and transported in five vans to the LEA woodyard.

Caribou 13-10

A Ponsse Buffalo Dual with the EH-25 harvest head was used to harvest the material, which was then forwarded using the same machine to the landing. The loose material was processed in the Rotochopper MC 266 grinder and transported in five vans to the LEA woodyard.

Caribou 37-1

A tracked feller-buncher was used to harvest the material, which was forwarded loose to the landing. The loose material was processed in the Rotochopper MC 266 grinder and transported in three vans to the LEA woodyard.

Caribou 37-5

A Ponsse Buffalo Dual harvester with a standard cut-to-length processing system was used to harvest the material. The same machine was used to forward both pulpwood and biomass in separate loads to the landing. The loose biomass material was processed in the Rotochopper MC 266 grinder and transported in two vans to the LEA woodyard. The roundwood was transported in two trucks to the International Paper mill.

Caribou 38-69

The site was harvested by hand-felling crews, who cut the material with chainsaws and brushsaws and piled it loosely. The John Deere 1490D biomass bundler was used to bundle the material on the eastern part of the site, which was then forwarded to the landing by the Ponsse Buffalo Dual. However, due to operator time constraints, the bundler did not operate on the western part of the site. That material was forwarded loose to the landing (by the same Buffalo Dual). The loose material was processed in the Rotochopper MC 266 grinder and transported in one van to the LEA woodyard. The bundles were transported in three trucks to the LEA woodyard.

Pitcha North

A Valmet 603 three-wheel feller-buncher was used to harvest the material, which was then bundled by the John Deere 1490D biomass bundler and forwarded to the landing using a Ponsse Buffalo Dual. The bundles were transported in four trucks to the LEA woodyard.

Pitcha South

A small tracked feller-buncher was used to harvest the material, which was then forwarded loose to the landing using a Ponsse Buffalo Dual. The loose material was processed in a Rotochopper MC 266 grinder and transported in two vans to the LEA woodyard.

Pitcha C

A tracked feller-buncher harvested the material, which was then bundled by the John Deere 1490D biomass bundler and forwarded to the landing using the Ponsse Buffalo Dual. The bundles were transported in one truck to the LEA woodyard.

Old Root

Old Root was not harvested. See Chapter Two, page 15 for details.

CHAPTER 4: BIOMASS RESOURCE ASSESSMENT

By Dr. Michael Demchik

Introduction

Three regions on the Superior National Forest were selected for the study (see vicinity map in Chapter One, page 14). Six harvest areas were delineated in the Caribou Trail Area (denoted Caribou), three harvest areas were delineated in the Pitcha Lake Area (denoted Pitcha) and two harvest areas in the Old Root Area (denoted Root). The areas varied in size due to the landscape characteristics of the area. Table 4-1 details the size of each harvest area.

A variety of sampling techniques were used to measure the total biomass on site. These measurements were repeated post-harvest (on harvested sites), and the resulting differences were analyzed to compare with gross biomass yield measurements taken by weighing material removed from the site on trucks. Sample techniques were based on or adapted from standard methods (for example: methods from *Common Stand Exam Users Guide, Version 1.7*[17]) in common use by the United States Forest Service (USFS) whenever possible to facilitate comparisons with other sites and other research.

Limited soil analysis was conducted in each area. Each site was tested for the presence of non-native earthworms, and the species found on site were identified.

Figure 4-1

Size of harvest areas used in analysis of biomass

Region	Harvest Area	Acreage
Caribou Trail Area	13-10 38-69 37-5 13-1W 13-1E 37-1	15.4 15.5 10.3 10.2 (1 acre exclusion) 12.4 10.0
Pitcha Lake Area	North South C	22.5 6 4
Old Root	Not harvested	
	Total	106.3 acres

General Site Characteristics

Soil Pit

A representative area was selected from each of the three main harvest areas. A soil pit was dug to a minimum of 40 inches. Samples were taken from each main soil horizon and analyzed at the University of Wisconsin soil analysis lab.

Soil profiles for soil pits dug at each of the three regions for the BUG biomass project

Figure 4-2

Old Root

	Depth (in)	Color moist	Mot-tles	Texture	Coarse Frag-ments	pH	OM%	P ppm	K ppm	Ca ppm	Mg ppm	Total N percent
A	0-1.5	10YR3/2	No	sandy loam	0	5.9	9.2	16	218	1798	276	0.32
Eg	1.5-7	10YR6/1	Yes	silt loam	0	5.4	1.7	9	89	639	183	0.05
Btg	7.0-20	10YR5/4	Yes	silty clay	0	6.6	2.0	13	257	2573	1055	0.05
Cg	20+	10YR 6/3	Yes	clay	0	7.9	1.4	122	162	2322	790	0.05

Figure 4-3

Pitcha Lake

	Depth (in)	Color moist	Mot-tles	Texture	Coarse Frag-ments	pH	OM%	P ppm	K ppm	Ca ppm	Mg ppm	Total N percent
A	0-2	5YR 3/2	No	sandy loam	15 per-cent	5.0	7.0	4	74	810	98	0.17
B	2.0-10	5YR 4/4	No	(gravely) loamy sand	15 per-cent	5.5	2.5	3	29	235	34	0.07
2C	10+	5YR 4/4	No	(gravely) sand	60 per-cent	5.7	1.9	6	37	308	53	0.05

Figure 4-4

Caribou Trail

	Depth (in)	Color moist	Mot-tles	Texture	Coarse Frag-ments	pH	OM%	P ppm	K ppm	Ca ppm	Mg ppm	Total N percent
A	0-1.5	7.5YR3/3	No	loam	5	5.0	13.3	8	125	1627	181	0.33
Bw1	1.5-8	7.5YR 4/4	No	sandy loam	5	4.9	3.7	8	48	599	91	0.11
Bw2	8.0-15.0	7.5YR 4/6	No	sandy loam	20	5.2	4.1	5	29	634	74	0.10
2Cd1	15.0-21.0	10YR 3/6	No	(gravely) loamy sand	20	5.5	1.8	13	38	521	58	0.04
2Cd2	21+	10 YR 4/6	No	(gravely) loamy sand	20	5.6	1.6	18	45	638	72	0.04

The pits were evaluated taxonomically. The pit was located on one of the southern Caribou sites and in the Honeymoon Mountain Ground Moraine (212Lb08). Taxonomically, the soil is an Oxyaquic Dystrudepts. The soil pit site is mapped as an Ecological Land Type[18] (ELT) 14 with mineral soil material that has developed in a moderately well-drained sandy loam and tills with a subsurface texture ranging from sandy loam to silt. These sites are associated with ground moraines. This soil has variable potential for roads due to drainage, texture and shallow depth in parts of the area. At the site of the soil pit, these would not have been a restriction. However, further down the drainage catena, poor drainage would have required operations to occur during dry summer conditions or during frozen winter conditions. Rutting can be heavy on this soil during spring break up and during rainy periods. This soil is of medium to high fertility although in areas of shallow depth to bedrock, the total available rooting depth could limit total available nutrients. Bedrock outcrops presented a problem in some places.

The northern Caribou sites would likely be Lithic Typic Dystrudepts, as it is shallow to bedrock and mapped as an ELT 16 on the Superior NF, which are thin glacial tills consisting of sandy loam or loam underlain by bedrock.

The pit in the Pitcha site is in the Isabella McDougal End Moraine (212Le01). Taxonomically, the soil is a Typic Udorthents. It is mapped on the SNF as an ELT 11, which is a deep, well-drained sandy loam and loamy sands underlain by gravelly loamy sand or gravelly sandy loam and is associated with outwash plains and ground moraines. This soil has good potential for roads in areas not limited by steep slopes. This soil is droughty and of low fertility. The major operability limitations on these sites are only due to slopes. The majority of the site is of low to moderate slopes.

The pit on the Old Root site is in the Ash Lake Ground Moraine (212La17). Taxonomically, the soil is a Typic Endoaqualf and is mapped on the SNF as an ELT 3, which occurs on slightly concave and uniform slopes and are associated with somewhat poorly drained lacustrine plains and ground moraines. They have developed in deep somewhat poorly drained silty clays to clay lake sediments. This soil has poor potential for roads due to high clay content and poor drainage. This soil is of high fertility, but due to poor drainage, windthrow can be a problem. Rutting can be severe and can negatively affect regeneration. This site would, of necessity, be limited to winter harvest under frozen conditions.

Worms

Soil samples of one cubic foot were taken on each of the harvest units. These samples began at the ground surface and were extracted in a block. These were gently broken apart. All worms were transferred to a bottle of isopropyl alcohol and keyed using the University of Minnesota's Key to Reproductively Mature Earthworms.[19]

Worms were generally present on all sites; however, due to time of sampling (drier conditions), the worms at Pitcha were less apparent during the main sampling period. We revisited the sites and found worms to be distributed across the majority of the sites. Worms keyed out to the following main types:

- Old Root
    - Dendrobaena octaedra and Lumbricus rubellus
- Caribou
    - Dendrobaena octaedra and Aporrectodea turgida
- Pitcha
    - Lumbricus rubellus

The presence of different types of worms was recorded to document whether there were any impacts from exotic earthworm invasion. Invasive species such as Lumbricus rubellus rapidly remove the duff layer, which may affect the vegetation component, whereas Dendrobaena octedra has much less effect on the duff layer. The presence of the exotic worms in these areas is "patchy," as the duff layer is currently largely "intact" at this time. The range in depth of the duff layer is 1-2 inches (not including the "litter" layer) and along a measured pre- and post-treatment monitoring transect there were areas of duff and the presence of worms.[20]

Litter

Litter samples (one square foot) were taken on 12 plots. These samples were oven dried at 160 degrees Fahrenheit until a consistent weight was reached. This mass was regressed against litter depth. The following regression was developed to predict litter mass by depth (r2=0.95).

Mass (ounces) = (ounces) = 0.6+ (6.4 X depth)

Table 4-3 details the leaf litter calculated to be present on each site. Mass varied from a low of 7806 lbs/acre to a high of 30,242 lbs/acre.

Figure 4-5

Estimated pounds per acre of leaf litter on all biomass harvest sites in the Superior National Forest prior site harvest

Region	Site	Lbs/acre estimates
Caribou Trail Area	13-10	10734±3108
	13-1E	30242±6688
	13-1W	19794±2411
	37-1	8710±1611
	37-5	10073±3831
	38-69	7806±1206
Pitcha Lake Area	PC	7947±2179
	PN	17821±3257
	PS	14706±1486

Methods

Biomass Inventory Methods

Before and after harvest, the overstory trees and snags, mid/understory vegetation and woody debris (coarse and fine) were assessed for volume using the following methods. The assessment of these parameters will be discussed individually.

Overstory and Snags

Ten (or more) fixed radius plots were positioned on transects that cover the unit uniformly. The location of these transects varied based on the shape of each harvest unit. Each fixed radius plot was a circular 0.1 or 0.04 acre plot. Variation in plot size occurred between harvest areas only (all plots in a harvest unit were of the same size). This variation was used to be sure to measure a minimum of 10 trees per plot. The coordinates of each plot were recorded with a Garmin 76 GPS unit to aid in future sampling.

The breakpoint between a tree and a sapling was arbitrarily set as 5 inches. Each tree was tagged with a numbered aluminum tag affixed with an aluminum nail at the ground line. For each tree, the following data was collected:

- Species
- dbh (to nearest 0.1 inch with a D-tape following guidelines in *USFS Common Stand Exam Users Guide*[21])
- Height (total within 5 foot margin of error)

- Percent live crown (ocular estimate)
- Apparent vigor (ocular estimate in 4 categories)
  - 1 (great)
  - 2 (acceptable)
  - 3 (poor)
  - 4 (dead)
- Damage category and severity (*USFS Common Stand Exam Users Guide* [22])

Snags were also measured. For each snag, the following data was recorded:

- Species
- dbh
- Height (if possible) or height to snap off
- If height to snap off, estimated diameter at snap off
- Decay class following procedure of *USFS Common Stand Exam Users Guide*[23]

Mid/Understory

Using the plot center for the overstory as a starting point, two plots were located: one 30 feet directly to the north and one 30 feet directly to the south of each plot center. Two plot sizes were used: 0.005 acre and 0.0033 acre. The larger plot size was used in a similar manner to the overstory plots. If mid/understory conditions were very dense, the smaller plot size was used. All plots within a harvest unit were of the same size. All woody vegetation taller than 1 foot and less than 5 inches dbh was measured.

For each plant, the following data was recorded:

- Species
- Height
- Feet of spread (the average of the widest and the narrowest)
- dbh, if appropriate
- Ground diameter

Fine and Coarse Woody Debris

One Brown's Planal Transect was completed for each overstory plot. In order to randomize the location of the transect, a random number generator was used to choose: 1) which tree to use as a starting point; 2) how far from that tree to run the transect and 3) which cardinal direction (north, south, east, west) to run the transect. For each transect, the following information was recorded:

- For the first 0-6 feet of the plane, all 0.0-0.25 inch and 0.25-1 inch fuel were recorded by species.
- For the first 0-12 feet, all 1-3 inch fuel was recorded by species.
- For the whole 50 feet of the plane, all greater than 3 inch coarse fuels were recorded by diameter at large and small end (to a 0.1 inch increment), by species and decomposition class (log decay classes from *USFS Common Stand Exam Users Guide* were used).
- A measurement of duff depth was recorded at each plot. Duff is the soil layer consisting of partly and well-decomposed plant organic matter. It includes the humus layer. Most often duff is a surface layer and is sometimes called the forest floor layer.

Analytical Methods Determining Biomass Estimates from Field Data

Overstory
Published biomass regression equations of Jenkins et al. (2003) were used to assess the biomass in overstory trees.

Snags
USFS snag decay classes were converted to comparable decay classes from Duvall and Grigal (1999).[24] Specific gravity estimates of snags by decomposition class were used from Duvall and Grigal (1999).[25]

Three separate regressions from the literature were used to predict mass of the snags.

For Duvall and Grigal (1999) decay class 1, the regressions from Jenkins et al. (2003)[26] were used to predict the mass of a tree while still alive. Loss of foliage as 10 percent for conifers and 4 percent for hardwoods was assumed. Specific gravity for each species by each decay class from Duvall and Grigal (1999) were used to correct the calculation of a loss of mass due to decay.

For Duvall and Grigal (1999) decay class 2, fine branches and much of the bark are gone. Using equations of Jenkins et al. (2003), the biomass of these components were determined. Using a compilation of the work of Freedman et al. (1982),[27] Ker (1980)[28] and the summarization of Jenkins et al. (2003),[29] the following correction factors were developed:

- We assumed a 10 percent loss of biomass as foliage for conifers and 4 percent for hardwoods.
- We assumed that 30 percent of the branch biomass was in fine branches that have fallen and 70 percent of the bark had fallen.
- This estimation was then corrected for decomposition using the specific gravity for decay class of Duvall and Grigal (1999).

For Duvall and Grigal (1999) decay class 3, the shape of the snag was considered to be frustum of a cone. The volume was determined using Smallian's formula. The mass was corrected using specific gravities from Duvall and Grigal (1999).

Mid/Understory
For plants that exceeded 1 inch in dbh, biomass equations from Jenkins et al. (2003) were used to predict biomass. For plants less than 1 inch in dbh, a regression was developed. The four most common understory species (mountain maple, balsam fir, hazelnut and raspberry) were selected. Twenty specimens that cover the range of the sizes available up to 1 inch dbh were cut at ground level using saws and pruners. These samples were oven dried at 160 degrees F until a consistent weight was reached. All measured factors (basal diameter, height and spread) as well as basal diameter squared were regressed against dry weight. In all cases, the model that yielded the most conservative biomass estimate was simply basal diameter squared. The following models were developed using linear regression, and r^2 values are noted with each. (Note: the units used are inches and ounces.)

Formula 1
(Derived from mountain maple and used for similar species that include: black cherry, balm of gilead, aspen and mountain ash)
Weight=21.3*(basal diameter^2)
r^2=0.99

Formula 2
(Derived from hazelnut and used for alder and hazelnut)
Weight=29*(basal diameter^2)
r^2=0.86

Formula 3
(Derived from red raspberry and used for all Rubus spp.)
Weight=5.2*(basal diameter^2)
r^2=0.93

Formula 4
(Derived from balsam and used for all conifers)
Weight=20.3*(basal diameter^2)
r^2=0.99

Brown's Transects
Protocol from Brown (1974)[30] was used for estimating biomass. However, a few refinements were included. Coarse woody debris was classified in decomposition classes following the methodology in USFS Common Stand Exam Users Guide. Specific gravities of Duvall and Grigal (1999) were used with these decomposition classes to allow a greater level of accuracy in final biomass estimates. Similarly, specific gravities for coarse woody debris were used from Duvall and Grigal (1999). Specific gravity for fine debris was taken from Panshin and Zeeuw (1970),[31] Adams and Owens (2001),[32] and Cook (personal communications).[33]

Results

Caribou Trail Sites
Caribou 13-1 E
The prescription for stand 13-1E was to thin all submerchantable (≤4.9 inches) balsam fir, spruce and aspen to a spacing of 15 feet. All dead material less than 6 inches dbh was to be crushed.

Only 40 percent of this unit was harvested. On the portion that was harvested, 58 percent of the biomass <1 inch dbh and 88 percent of the biomass of 1-5 inch dbh was removed. On the portion that was harvested, the removal was quite complete. Additionally, some of the overstory (mostly within access areas) and some snags were removed. There was a significant increase in fine and coarse woody debris.

Figure 4-6

Change in site parameters after harvest across 13-1E

Trees and shrubs	13-1E
0-1 inch DBH 1-5 inch DBH >5 inch DBH	1683±450 lbs/acre 17004±7000 lbs/acre 9427±1500 lbs/acre
Snags	305±100 lbs/acre
Woody debris (0-3 inch) CWD (>3 inch)	-4361±750 lbs/acre -3105±500 lbs/acre
Total on harvested area Percent of whole parcel harvested **Rate across whole parcel** As delivered to the mill (green) **Estimated dry weight (25%)**	20953 lbs/acre 40% **8381 lbs/acre** 11200 lbs/acre **8960 lbs/acre**

Figure 4-7

Conditions before and after fuel reduction activities in Unit 13-1E

	13-1E		
Parameter	**Before (total parcel)**	**Before (harvested portions)**	**After (harvested portions)**
Trees and shrubs			
0-1 inch DBH 1-5 inch DBH >5 inch DBH	4450±900 13414±3350 103100±9450 (Basal Area 86)	2901±800 19322±4000	1218±450 2319±600
Snags	12393±2050		
Woody debris (0-3 inch) CWD (>3 inch) Class 1 Class 2 Class 3 Class 4 Class 5	8570±650 2760 8822 4700 2332 3734	5581±700 0 7250 5460 2575 1155	9942±750 995 9145 3075 2600 3730

Overall, the harvest met prescriptions very well in the portion harvested.

Caribou 13-1 W

The prescription for stand 13-1W was to thin all submerchantable (≤4.9 inches) balsam fir, spruce and aspen to a spacing of 15 feet. All dead material less than 6 inches dbh was to be crushed. For this harvest unit, our estimation of total biomass harvest was very poor when compared to the volume of material delivered to the mill. (Much more material was actually removed from the site than we calculated was harvested.) We cannot account for this problem through revisiting of the data. We will present the data as we have it with this issue taken into consideration.

Only 50 percent of this unit was harvested; however, because retention was patchy, we are presenting these results across the whole unit. Across the whole unit 45 percent of the biomass <1 inch dbh and 58 percent of the biomass of 1-5 inch dbh was removed. A small portion of the overstory was removed (3 percent) and no snags were removed. There was a small reduction in both fine and coarse woody debris.

Figure 4-8

Change in site parameters after harvest across 13-1W.

Trees and shrubs	**Results**
0-1 inch DBH 1-5 inch DBH >5 inch DBH	1636±500 lbs/acre 7960±4400 lbs/acre 2318±1500 lbs/acre
Snags	0 lbs/acre
Woody debris (0-3 inch) CWD (>3 inch)	-1468±1000 lbs/acre -1528±500 lbs/acre
Total on harvested area Percent of whole parcel harvested Rate across whole parcel As delivered to the mill (green) Estimated dry weight (25%)	8918 lbs/acre 100% (50% harvested but dispersed retention) 8918 lbs/acre* 27400 lbs/acre 21920 lbs/acre

***Note: For 13-1W, the large difference between estimated biomass yield and actual yield is difficult to determine. A portion of this variation is because only one plot fell in the trail system (with much higher rates of biomass removal).**

Figure 4-9

Conditions before and after fuel reduction activities in the Superior National Forest for Unit 13-1W

Parameter	Before (total parcel)	After (total parcel)
Trees and Shrubs		
0-1 inch DBH *1-5 inch DBH* *>5 inch DBH*	*3653±450* *13751±4400* *85041±13000 (BA 75)*	*2017±300* *5851±2500* *82723±13000 (BA 72)*
Snags	*4822±1400*	*4822±1400*
Woody debris (0-3 inch) *CWD (>3 inch)* *Class 1* *Class 2* *Class 3* *Class 4* *Class 5*	*10642±700* *501* *3381* *3974* *1407* *2172*	*9188±2000* *2232* *1828* *5224* *1306* *2373*

Overall, the harvest generally met prescriptions.

Caribou 13-10

The prescription for stand 13-10 was to remove 50 percent of submerchantable trees and shrubs in 0.5-3 acre patches. All dead and down material was to be harvested.

Seventy percent of this unit was harvested. However, because retention was patchy, we are presenting these results across the whole unit. Across the whole unit, 26 percent of the biomass <1 inch dbh and 57 percent of the biomass of 1-5 inch dbh was removed. A small portion of the overstory (2 percent) and snags (<1 percent) were removed. There was a moderate reduction in fine and a small reduction in coarse woody debris.

Figure 4-10

Change in site parameters after harvest across 13-10

Trees and shrubs	Results
0-1 inch DBH 1-5 inch DBH >5 inch DBH	859±115 lbs/acre 13668±1500 lbs/acre 2438±1000 lbs/acre
Snags	52±20 lbs/acre
Woody debris (0-3 inch) CWD (>3 inch)	4377±1250 lbs/acre* -702±500 lbs/acre
Total on harvested area Percent of whole parcel harvested Rate across whole parcel As delivered to the mill (green) Estimated dry weight (25%)	20692 lbs/acre 100% (70% HARVESTED but dispersed) **18336 lbs/acre** 16223 lbs/acre **12978 lbs/acre**
*** Note: 13-10 major change in fine woody debris appears to be due to soil disturbance by logging equipment.**	

Figure 4-11

Conditions before and after fuel reduction activities in Unit 13-10

Parameter	Before (total parcel)	After (total parcel)
Trees and shrubs		
0-1 inch DBH 1-5 inch DBH >5 inch DBH	3353±200 24170±1400 93692±5700 (BA 82)	2493±200 10502±1500 91254±5700 (BA 78)
Snags	7604±1100	7552±1150
Woody debris (0-3 inch) CWD (>3 inch) Class 1 Class 2 Class 3 Class 4 Class 5	12,724±1250 1298 3271 2693 3531 4802	8347±700 1567 1809 2500 3678 6742

The harvest generally met prescriptions; however, a greater portion of the area was harvested than prescribed (this is possibly due to more plots falling in the harvested areas than would be expected) and little of the dead and down material was removed.

Caribou 37-1

The prescription for stand 37-1 was to remove as much submerchantable (≤4.9 inches) balsam fir, aspen and shrubs as possible. No more than 80 percent of the dead and down material was to be removed.

Only 60 percent of this unit was harvested. Because retention was patchy, we are presenting these results across the whole unit. The harvest removed 37 percent of the biomass <1 inch dbh and 94 percent of the biomass of 1-5 inch dbh. A small portion of the overstory was removed (5 percent) and no snags were removed. There was a small increase in fine woody debris and a small decrease (13 percent) in coarse woody debris. While the total harvest of 94 percent of biomass from 1-5 inches dbh seems too large (after all, only 60 percent of the total parcel was harvested), it is actually not. The portion of the plot that was not harvested for biomass had much lower levels of biomass in this size range (five of the plots contained no stems in this size range at all).

Figure 4-12

Change in site parameters after harvest across 37-1

Trees and Shrubs	Results
0-1 inch DBH 1-5 inch DBH >5 inch DBH	1032±300 lbs/acre 983±250 lbs/acre 6635±2000 lbs/acre
Snags	0 lbs/acre
Total on harvested area Percent of whole parcel harvested Rate across whole parcel As delivered to the mill (green) Estimated dry weight (25%)	7807 lbs/acre 100% (60% harvested but dispersed retention) 7807 lbs/acre 13892 lbs/acre 11114 lbs/acre

Figure 4-13

Conditions before and after fuel reduction activities in 37-1

Parameter	Before (total parcel)	After (total parcel)
Trees and shrubs		
0-1 inch DBH 1-5 inch DBH >5 inch DBH	2775±300 1047±250 124727±13000 (BA 115)	1743±300 63±50 118092±13000 (BA 110)
Snags	11514±6850	11514±6850
Woody debris (0-3 inch) CWD (>3 inch) Class 1 Class 2 Class 3 Class 4 Class 5	13061±700 3465 135 2754 1332 1957	15206±4000 2625 2701 979 1244 792

Overall, the harvest generally met prescriptions for submerchantable material removal very well (concentrating most of the harvest effort on larger submerchantable materials); however, only a small amount of the coarse woody debris was harvested.

Both pulpwood and biomass were harvested from the Caribou Trail site 37-5

Caribou 37-5

The prescription for stand 37-5 was to remove all balsam (submerchantable and merchantable). All dead material less than 6 inches dbh was to be crushed.

Only 80 percent of this unit was harvested; however, because retention was in one solid unit (a portion of the unit was wetland and was excluded), we are presenting these results across only the part that was harvested. Across the harvested portion, 61 percent of the biomass <1 inch dbh and 79 percent of the biomass of 1-5 inch dbh was removed. A significant portion of the overstory (18 percent) and snags (16 percent) were removed. There was a moderate increase in fine woody debris and a small decrease in coarse woody debris.

Figure 4-14

Change in site parameters after harvest across 37-5

Trees and shrubs	Results
0-1 inch DBH 1-5 inch DBH >5 inch DBH	1321±150 6587±1000 27373±2700
Snags	1318±1450
Woody debris (0-3 inch) CWD (>3 inch)	-3406±850 1115±500
Total on harvested area Percent of whole parcel harvested Rate across whole parcel As delivered to the mill (green) Estimated dry weight (25%)	32078 80% 25662 lbs/acre* 25570 lbs/acre **20457 lbs/acre**
***Note: Skid trails ran across the majority of the plots by random chance.**	

Figure 4-15

Conditions before and after fuel reduction activities in Unit 37-5

Parameter	Before (total parcel)	After (total parcel)
Trees and shrubs		
0-1 inch DBH 1-5 inch DBH >5 inch DBH	2175±100 8287±950 153352±6650 (BA 148)	524±100 1700±350 125979±5950 (BA 120)
Snags	8458±1450	7139±1300
Woody debris (0-3 inch) CWD (>3 inch) Class 1 Class 2 Class 3 Class 4 Class 5	7065±650 1893 650 4803 290 1965	10471±850 4758 2030 1180 518 0

Overall, the harvest generally met prescriptions for balsam removal very well.

Caribou 38-69

The prescription for stand 38-69 was to remove as much submerchantable (≤4.9 inches) balsam fir, aspen and shrubs as possible. Remove no more than 80 percent of the dead and down material.

Across the whole unit, 40 percent of the biomass <1 inch dbh and 55 percent of the biomass of 1-5 inch dbh was removed. A small portion of the overstory was removed (<1 percent) and no snags were removed. There was a small increase in both fine and coarse woody debris.

Figure 4-16

Change in site parameters after harvest across 38-69

Trees and shrubs	Results
0-1 inch DBH 1-5 inch DBH >5 inch DBH	1030±400 lbs/acre 3245±1900 lbs/acre 690±1000 lbs/acre
Snags	0 lbs/acre
Woody debris (0-3 inch) CWD (>3 inch)	-1454±1000 lbs/acre -100±500 lbs/acre
Total on harvested area Percent of whole parcel harvested Rate across whole parcel As delivered to the mill (green) Estimated dry weight (25%)	3411 lbs/acre 100% (80% but dispersed retention) 3411 lbs/acre 8509 lbs/acre 6807 lbs/acre

Figure 4-17

Conditions before and after fuel reduction activities in Unit 38-69

Parameter	Before (total parcel)	After (total parcel)
Trees and shrubs		
0-1 inch DBH 1-5 inch DBH >5 inch DBH	2605±500 5899±2500 181343±23000 (BA 150)	1520±400 2654±2000 180653±13000 (BA 148)
Snags	21863±8300	21863±8300
Woody debris (0-3 inch) CWD (>3 inch) Class 1 Class 2 Class 3 Class 4 Class 5	9891±500 5571 7032 5360 2336 2410	11358±1500 7011 3363 5976 4076 2383

Overall, the harvest generally met prescriptions for submerchantable material removal; however, both coarse and fine woody debris increased.

Pitcha Lake Sites

The prescription for all the Pitcha units was to remove all submerchantable (≤4.9 inches) balsam fir and spruce outside of reserve areas. No dead or down material was to be removed.

Pitcha C

Fifty-five percent of the biomass sized from <1 inch dbh and 1-5 inch dbh was removed. Only a minor reduction occurred in the fine woody debris and only a minor increase occurred in the total quantity of coarse woody debris (CWD). Fine woody debris is dead and downed woody material three inches in diameter or less. Coarse woody debris is dead and downed woody material greater than three inches in diameter. Changes in snags are unknown due to alteration of the harvesting procedure (see methods section). No overstory was harvested.

Figure 4-18

Change in site parameters after harvest across Pitcha C

Trees and shrubs	Results
0-1 inch DBH 1-5 inch DBH >5 inch DBH	1512 lbs/acre 10479 lbs/acre 0 lbs/acre
Snags	unknown
Woody debris (0-3 inch) CWD (>3 inch)	418 lbs/acre -311 lbs/acre
Total on harvested area Percent of whole parcel harvested Rate across whole parcel As delivered to the mill (green) **Estimated dry weight (25%)**	12098 lbs/acre (based on 10 samples of portion harvested for post-harvest and pre-harvest on whole area due to small size of total area harvested) 14395 lbs/acre **11516 lbs/acre**

***Note: This table represents conditions prior to harvest across the whole parcel and then after harvest just on the harvest part for Pitcha C. This is due to incomplete harvest of the sites.**

Figure 4-19

Conditions before and after fuel reduction activities in Unit Pitch C

Parameter	Before (total parcel)	After (total parcel)
Trees and shrubs		
0-1 inch DBH 1-5 inch DBH >5 inch DBH	2717±400 18939±4050 116129±12000 (BA 120±10)	1205±400 8460±4650 Same
Snags	146±36	unknown
Woody debris (0-3 inch) CWD (>3 inch) Class 1 Class 2 Class 3 Class 4 Class 5	7615±500 0 2033 430 1487 2492	7197±2000 1118 1335 2146 524 1630

***Note: The harvest area measured is different than the pre-harvest area. There is no way to correct this as the post-harvest areas are too small to include. See note in Figure 4-18.**

Overall, the harvest of this site met the prescription restriction of leaving coarse woody debris and the overstory. The harvest only removed 55 percent of the targeted ladder fuels in the harvested areas.

Pitcha South

Seventy-five percent of the biomass <1 inch dbh and 55 percent of the biomass of 1-5 inch dbh was removed. Only a minor increase occurred in the fine woody debris and only a minor decrease occurred in the total quantity of coarse woody debris. Changes in snags are unknown due to alteration of the harvesting procedure (see methods section). No overstory was harvested.

Figure 4-20

Change in site parameters after harvest across Pitcha South

Trees and shrubs	Results
0-1 inch DBH 1-5 inch DBH >5 inch DBH	1825 lbs/acre 3457 lbs/acre 0 lbs/acre
Snags	???
Total on harvested area Percent of whole parcel harvested Rate across whole parcel As delivered to the mill (green) Estimated dry weight (25%)	4742 lbs/acre (based on 10 samples of portion harvested for post-harvest and pre-harvest on whole area due to small size of total area harvested) 10997 lbs/acre **8798 lbs/acre***

***Note: This table represents conditions prior to harvest across the whole parcel and then after harvest just on the harvest part for Pitcha South. This is due to incomplete harvest of the sites.**

Figure 4-21

Conditions before and after fuel reduction activities in Unit Pitch South

Parameter	Before (total parcel)	After (total parcel)
Trees and shrubs		
0-1 inch DBH 1-5 inch DBH >5 inch DBH	2438±400 6292±2500 164872±14500 (BA 171±16)	613±350 2835±1700 Same
Snags	169±62	???
Woody debris (0-3 inch) CWD (>3 inch) Class 1 Class 2 Class 3 Class 4 Class 5	7615±500 1286 1222 1180 860 902	8591±3000 1314 487 1218 578 1417

***Note: The harvested area measured is different than the pre-harvest area. There is no way to correct this as the post-harvest areas are too small to include. See note in Figure 4-20.**

Overall, the harvest of this site met the prescription restriction of leaving CWD and the overstory. The harvest only removed 75 percent of the biomass <1 inch dbh and 55 percent of the biomass of 1-5 inch dbh in the harvested areas.

Pitcha North

Thirty-seven percent of the biomass <1 inch dbh and 34 percent of the biomass of 1-5 inch dbh was removed. Only a minor increase occurred in the fine woody debris but a fairly sizable increase occurred in the total quantity of coarse woody debris. No changes in snag biomass were seen, and no overstory was harvested.

Figure 4-22

Conditions before and after fuel reduction activities in Unit Pitcha North

Trees and shrubs	Results
0-1 inch DBH 1-5 inch DBH >5 inch DBH	528±300 lbs/acre 1546±2000 lbs/acre 0 lbs/acre
Snags	0 lbs/acre
Woody debris (0-3 inch) CWD (>3 inch)	112±1300 lbs/acre 2227±500 lbs/acre
Total on harvested area Percent of whole parcel harvested Rate across whole parcel As delivered to the mill (green) Estimated dry weight (25%)	4413 lbs/acre 6400 lbs/acre 5120 lbs/acre

Figure 4-23

Change in site parameters after harvest across Pitcha North

Parameter	Before (total parcel)	After (total parcel)
Trees and shrubs		
0-1 inch DBH 1-5 inch DBH >5 inch DBH	1412±300 6277±2500 142740±8000 (BA 145)	884±300 4154±2000 Same
Snags	275±150	Same
Woody debris (0-3 inch) CWD (>3 inch) Class 1 Class 2 Class 3 Class 4 Class 5	4109±1300 1879 1374 965 533 1029	3997±1300 0 361 2254 760 178

Overall, the harvest of this site met the prescription restriction of leaving CWD and the overstory. The harvest only removed 37 percent of the biomass <1 inch dbh and 34 percent of the biomass of 1-5 inch dbh in the harvested areas. This relatively low overall harvest can be attributed in part to limited harvest in the northern portion of the unit and concentration of harvest near to existing skid trails. Two sample plots were not harvested at all and several had only part of the plot harvested.

Conclusion

Biomass harvest completed on Caribou Trail site 37-5

A great deal of concern has been expressed about the environmental impacts of biomass harvest. Much of this concern is based on the expectation of total removal of coarse woody debris and associated soil impoverishment. While we did not directly measure soil impoverishment (and we will leave this up to other researchers), the impact of the removal of coarse woody debris (even on sites where their removal was a portion of the prescription) was low at best. The highest level of CWD harvest was at Pitcha North and amounted to only 39 percent removal. Even on sites with a specific goal of removal of CWD, there were only low or moderate decreases and in one case an increase (Stand 38-69).

Generally, efficiencies of removal of the submerchantable materials varied greatly. Many of the sites had areas that were not appropriate to harvest (topography was rough or steep, too dense an overstory of crop trees restricted harvest activity or patchy distribution in the understory meant that some areas had little biomass material to harvest). The highest efficiency of harvest was 75 percent of the stems less than 1 inch dbh and 94 percent of stems greater than 1 inch dbh. Most sites fell well under this level of harvest.

Surprisingly, snags were far less impacted by the harvesting activity than expected. Generally, few snags were removed, even on sites where this was a goal. Overall, most of the harvests met the prescriptions quite well (although many of the areas could not be as fully harvested as was hoped due to site conditions mentioned above).

Most coarse woody debris remained on harvest sites, even where this material was targeted for removal

Observations of Use for Future Biomass Resource Assessments

- Under these site conditions, materials less than 1 inch in dbh generally contribute little to the total volume of biomass on the sites. They are probably not a good target for harvest and are also probably not worth assessing for volumes except in the most extreme cases.
- Under these site conditions, materials from 1-5 inches in dbh generally hold far more volume than smaller materials and could be a significant source of biomass from these harvest operations.
- Harvests that include removal of coarse woody debris as a goal may not have a high level of success (removal rate was not particularly high even on sites where this was a goal).
- The overstory has by far the largest volume of material on these sites. On sites where any significant quantity of material greater than 5 inches in dbh will be removed, the bulk of the appraisal prior to harvest should address this component. Some large stems may have more volume than entire acres of biomass 0-5 inches dbh.

Recommendation

- In Minnesota, guidelines were recently developed, following the guidelines for *Biomass Harvesting on Forest Management Sites*[34] should mitigate concerns about soil nutrients, structure and wildlife habitat.

CHAPTER 5: HARVESTING ECONOMICS

By Dr. Dalia Abbas, Dr. Dean Current, Mark Ryans, Dr. Steven Taff, Dr. Howard Hoganson, Dr. Kenneth Brooks

Introduction

The purpose of this chapter is to determine the cost effectiveness of combining fuel load reduction with biomass harvesting for energy. All nine harvested sites were analyzed. Estimated costs of conventional (CC) mechanical fuel treatments (crush and/or pile and burn) are compared with the biomass treatment option (BTO). We analyzed the difference between biomass harvesting and delivery costs (HDC) and income (I) from selling biomass, in United States Dollars (USD). A number of harvesting and delivery systems, income potentials, and transportation actual and hypothetical scenarios are examined to identify different opportunities for reducing mechanical treatment costs.

Methods

Equipment rates for biomass harvesting were calculated with the standard machine costing method used by the Forest Engineering Research Institute of Canada.[35] Inputs were based on estimates for new machines, as of 2007, received from machine owners, manufacturers and dealers. Productive machine hours were collected from machine operators during and after harvest. Areas harvested were measured using handheld GPS units. Biomass tonnage recovered per unit of harvest was determined from weight of biomass measured at the end users, and converted to U.S. short tons (1 lb. is 0.0005 tons). Biomass energy recovery costs are calculated on a per-ton and per-acre basis for each treatment unit, and for the developed scenarios. Per-acre harvesting and delivery costs (HDC) less income (I) from the sale of biomass was compared with conventional treatment costs (CC). The equation used was (HDC – I) less CC in six hypothetical scenarios in addition to study trials. If (HDC – I) was larger than CC, then a biomass option was considered more costly than CC. If (HDC – I) was less than CC, then a biomass option can be considered to reduce conventional treatment costs.

Production Systems, Estimated Costs and Income

Production Systems

Three different summer biomass harvesting and delivery systems were implemented, using different machines on the Caribou Trail and Pitcha Lake sites. See figures 5-1 and 5-2 for a map of both sites. See Chapter Three for further explanation of the production systems used.

- Treatment units #13-10, 13-1W, 37-1, 37-5 and Pitcha South combined harvesting loose biomass for energy using Cut and pile » forward » load grinder » grind » truck-van systems.
- Treatment units # 38-69 and 13-1E and Pitcha North and Pitcha "C" sites combined bundling loose biomass for energy using Cut and pile » bundle » forward » truck-trailer systems.
- Treatment unit # 37-5 in the Caribou Trail site combined a roundwood option with system # 1, the option involved roundwood harvest using Cut and pile » forward » truck-trailer systems.

Estimated costs and income

Harvesting

Machine rates were calculated using FERIC's costing method. Input data were collected and verified with machine owners, dealers and manufacturers.[36-41] Machine expected lifetime was estimated at five years, except the Husqvarna chainsaw and brushsaws, estimated at two years. Salvage value was estimated per individual machine to range from 10 percent to 35 percent of the purchase price. Lifetime repair and maintenance costs were estimated based on actual and potential costs records. Productive Machine Hours (PMH) is estimated at 1,500 hours/year. This was equivalent to a 75 percent utilization rate of 2,000 scheduled machine hours per year (250 days * 8 hours per day).[42] Interest rate of machine financing cost was 8.25 percent. Fuel cost was estimated at $2.50/gallon. However, handfelling gas was at $3.32/gallon. Fuel consumption varied. For example, the highest fuel consumption rate per hour was equivalent to 18 gallons per hour for the grinder, and almost 0.25 gallons per hour were spent for each Husqvarna machine. This meant that all eight machines used two gallons per hour in these trials.[43]

Operators' wages plus benefits were calculated at $31.05/hr gross.[44] Hand-felling operators' wages and benefits were $115.00/hr for a total of eight operators ($14.37/hr per operator).[45] No operator wages and benefits were included in the grinder hourly costs, since this cost item has already been included in the loader feeding the grinder (Ponsse Buffalo Dual harvester). Estimates of transportation costs for the lowboy, wood-chip trailer-van, and roundwood and bundles picket trailer-truck were based on actual market rates in the Superior National Forest area. Van and equipment trailer for hand-felling crew was estimated at $0.60/mile.[46]

Figures 5-1 and 5-2 show the calculated machines cost rates per unit for the Caribou Trail and Pitcha Lake sites.

Figure 5-1

Caribou Trail: Calculated machine rates per unit cost

No.	Machine	Cost/unit
1.	Lowboy	$115.00/PMH
2.	Ponsse Buffalo Dual, 2007	$133.80/PMH
3.	Fabtek 153, 2007, with a cut-to-length processing head	$133.40/PMH
4.	Timbco 425D feller buncher, 2007	$131.00/PMH
5.	Van and equipment trailer for hand-felling crew	$0.60/mile, ($60.00/day)
6.	Husqvarna, chainsaw and brushsaw, 8 operators, 2007	$161.45/PMH
7.	JD1490D Bundler 2007	$159.70/PMH
8.	Rotochopper MC266, 2007 (with no operator wages and benefits, since this is included in the loader costs).	$122.32/PMH
9.	Trailer and chip van for wood chips, 48 ft, 30-tons load.	$1.50/mile
10.	Truck and picket trailer	$1.50/mile

Figure 5-2

Pitcha Lake: Calculated machine rates per unit cost

No.	Machine	Cost/unit
1.	Lowboy	$115.00/PMH
2.	RC 100 Posi Track and feller buncher	$75/PMH
3.	Valmet 603 three wheel feller buncher 2007[47]	$85/PMH
4.	JD653 tracked feller buncher with hot saw	$129/PMH
5.	Ponsse Buffalo King forwarder 2007	$116/PMH
6.	JD1490D Bundler 2007	$160/PMH
7.	Rotochopper MC 266, 2007	$164/PMH
8.	Trailer and chip van for wood chips, 48 ft, 30-tons load.	$1.50/mile
9.	Truck and picket trailer for bundles	$1.50/mile

Conventional treatments

Mechanical treatment costs per acre are determined according to site density and machines used. Estimated fuel reduction costs in the Superior National Forest area range from $300.00/acre to $500.00/acre for conventional pile and burn mechanical treatments. It costs an additional $50.00/acre to $75.00/acre to burn these piles. This amounts to $575.00/acre for dense sites, which are similar to the conditions of the Caribou Trail study sites.[48] Pitcha Lake sites were classified as high-, medium- and low-density biomass sites. Conventional treatment costs were estimated at $575.00/acre for high-density sites, $462.50/acre for medium-density sites and $350.00/acre for low-density sites.

If a mechanical fuel treatment of the small biomass material is combined with a timber sale, buyers are given an allowance to do so, reducing the timber sale price. In a timber sale, the Forest Service is responsible for the $50.00/acre to $75.00/acre to burn piles, in addition to this allowance. Since estimating biomass per ton on a site is not a conventionally followed practice, errors in primary site classification can occur. At Pitcha Lake, more tonnage per acre was removed from the "medium" density biomass site than was removed from the identified "high" density site. The former came out to be approximately 10 tons/acre and the latter came out to be approximately 7 tons/acre. The harvester on the Pitcha C site inadvertently damaged two larger trees, which then had to be harvested for safety reasons. This resulted in a citation from the supervising forest personnel. Due to these circumstances, the operator decided not to complete operations. This is why this harvested site was only four acres. The actual tonnage per acre on the entire site may indeed have been more than 10 tons/acre. This was not determined.

This estimated $575.00/acre treatment cost is a relatively modest number in comparison with other mechanical treatment estimates. For example, initial estimates for the costs of mechanically treating sites in the Superior National Forest exceeded $1000.00/acre.[49] Estimates in more difficult sites with steeper slopes, as in Western United States regions, exceeded $3,535.00 per acre.[50]

Conditions for a timber sale would have been separate from those of mechanical treatments only, considered in these study trials. The size of a timber sale is a function of volume. Commercial timber sales on the SNF averaged 1869 MBF in fiscal year 2007. With the average volume per acres of a timber sale being 7 MBF/acre, sales would be an average of 267 acres in size.[51]

Income

In study trials, income is generated from biomass energy sales and roundwood sales, if any, for pulp and energy uses.

- Payments for biomass used in energy generation: The purchase price for biomass delivered at the wood yard was $21.00/ ton.[52] However, bundles were sold for $14.00/ton since the power plant deducted $7.00/ ton for grinding bundles.[53]
- Payments for roundwood used in pulp and paper and energy generation: At treatment unit 37-5, roundwood was harvested as well as biomass. Twenty tons of miscellaneous roundwood species and quantities were sold for energy.[54] Sixty-six tons of roundwood were sold for $60.30/ton to a pulp and paper company.[55] This total of 86 tons of roundwood is approximately 65 percent of the entire biomass recovered in this treatment unit.

Results

All harvesting trials were set up with an assessment research study in mind. The Laurentian Energy Authority (LEA) that purchased the biomass is located 150 miles from the Caribou Trail treatment units, and 85 miles from the Pitcha Lake units.[56] Loads from each unit were separated to determine tons removed per treatment unit. In an actual operation, truckloads would have been maximized to legal road weights, and probably would have been trucked to markets much closer than either 85 or 150 miles. Tonnage of biomass recovered in each treatment unit varied (Figure 5-3). On average, tests removed 8.4 green tons/acre of biomass from small-diameter trees and roundwood on the Caribou Trail units, and 5.0 green tons/acre on the Pitcha Lake units.

Caribou Trail Sites

Piled biomass awaiting grinding on Caribou Trail site 13-10

In the Caribou Trail study trials, per acre conventional treatment costs were less than the biomass energy option costs, as indicated in Figure 5-3. The highest cost differences between conventional treatment costs and the biomass treatment options were attached to units 13-1E and 13-1W because of two factors. First, forwarding distance and time to landing was longer and therefore costs were more than at other units. This distance was estimated at 0.28 miles one way from the furthest point of treatment in unit 13-1W and about 0.23 miles one way from the furthest point of unit 13-1E to the landing area. Second, the topography of the unit played an important role in cost difference. Both sites were relatively steep and had rough ground, which slowed the machines as they maneuvered.

Figure 5-3

Caribou Trail: Per acre conventional and biomass energy treatments summary of costs and income (USD)

Treatment units	Tons/ acre	CC/acre	HDC/ acre	I/acre	BTO/acre	Difference between CC and BTO (costs changes for the FS)
Unit 13-10 (Chips)	8.11	$575.00	$813.32	$170.35	$642.98	$-67.98
Unit 13-1W (Chips)	13.70	$575.00	$1708.81	$287.62	$1421.19	$-846.19
Unit 37-1 (Chips)	6.95	$575.00	$912.29	$145.87	$766.43	$-191.43
Unit 13-1E (Bundles)	5.60	$575.00	$1068.03	$78.47	$989.56	$-414.56
Unit 38-69 (Bundles)	4.24	$575.00	$839.00	$59.34	$750.00	$-205.00
Unit 37-5 (Chips and Roundwood)	12.79	$575.00	$1217.05	$537.23	$679.82	$-104.82

Acres: harvest area unit, CC: Conventional costs, HDC: Harvest and delivery costs, I: income from sale of extracted biomass material, BTO: Biomass treatment option (HDC-I)

Unit 13-1W had the highest cost differences between CC and BTO, even though the highest biomass tonnage per acre was generated on this site (more so than unit 37-5 which combined biomass and roundwood harvest). This especially high difference is likely a result of: (1) having been the only unit forwarded in snowy conditions, which made it more difficult for the forwarder machine to locate and collect smaller material, and move on the slippery forest ground. The operator, who had forwarded all other units, indicated that forwarding time would have been at least 10 hours less, had it not been in snowy conditions; (2) the perimeter points of this unit having been the furthest from the landing; (3) the harvester was only hauled to cut this unit and leave, which increased per-acre machine hauling costs; and (4) the harvester operator harvested more of the smaller material than the other sites. All of these factors increased harvesting costs in this site (Figure 5-4).

The smallest cost differences between CC and BTO were in units 37-5 and 13-10, respectively (Figure 5-3-Caribou Trail). Treatment units 37-5 and 13-10 were harvested and forwarded by the same operator and using the same harvester-forwarder combination. Both units generated a considerably higher portion of biomass per acre than other units (Table 5-3); therefore, the income per acre was more than other sites. Further, unit 37-5 combined residue and roundwood removals simultaneously. Roundwood is sold at a higher price than small-diameter trees for energy. This resulted in the average income per ton removed from this site being the highest ($42/ton versus the $21/ton for biomass energy alone and $14/ton bundled material).

The lowest per acre harvesting to forwarding costs are linked to treatment unit 37-1, without machine trucking costs to the harvest site considered (Figure 5-4). In this unit the harvest operator, unlike the operators at other units, designed his own skid trail and cut down four merchantable trees outside of prescription, to avoid getting into long maneuvering circles that could have made it more difficult both for him and the forwarder that followed. This situation was approved by the Forest Service Timber Sale Administrator, who cooperated with the project by providing the maximum amount of leeway provided for under Forest Service regulations. This serves to illustrate that there are opportunities to lower costs and improve cost effectiveness if prescriptions and harvest restrictions are flexible.

On the other hand, unit 38-69 had the highest harvesting and delivery costs per ton recovered (Figure 5–5). This unit combined three relatively expensive harvesting systems: hand felling, a Buffalo Dual forwarder, and a JD1490D Slash Bundler in a low biomass stocked treatment unit. Only 4.24 tons of bundles per acre were recovered from this unit.

Figure 5-4

Caribou Trail: Per acre production and sale of biomass compared with conventional treatments costs

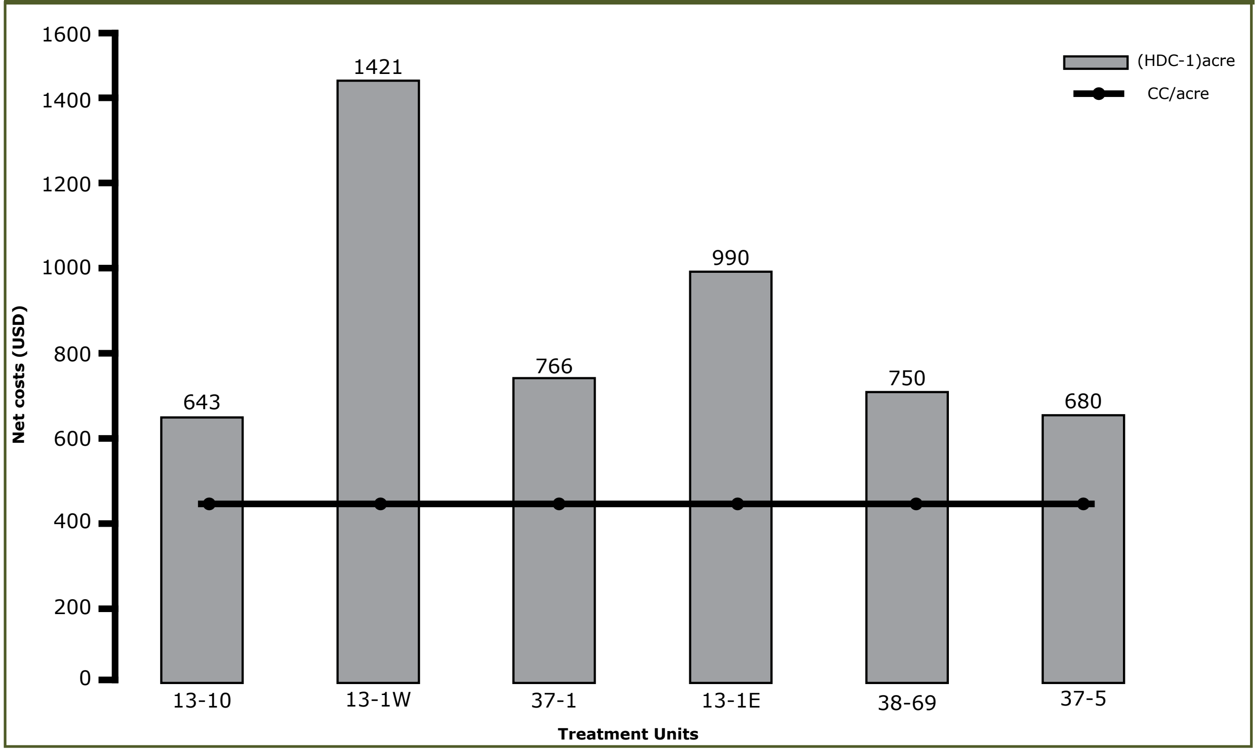


Figure 5-5

Caribou Trail: Per acre production costs, delivery at gate

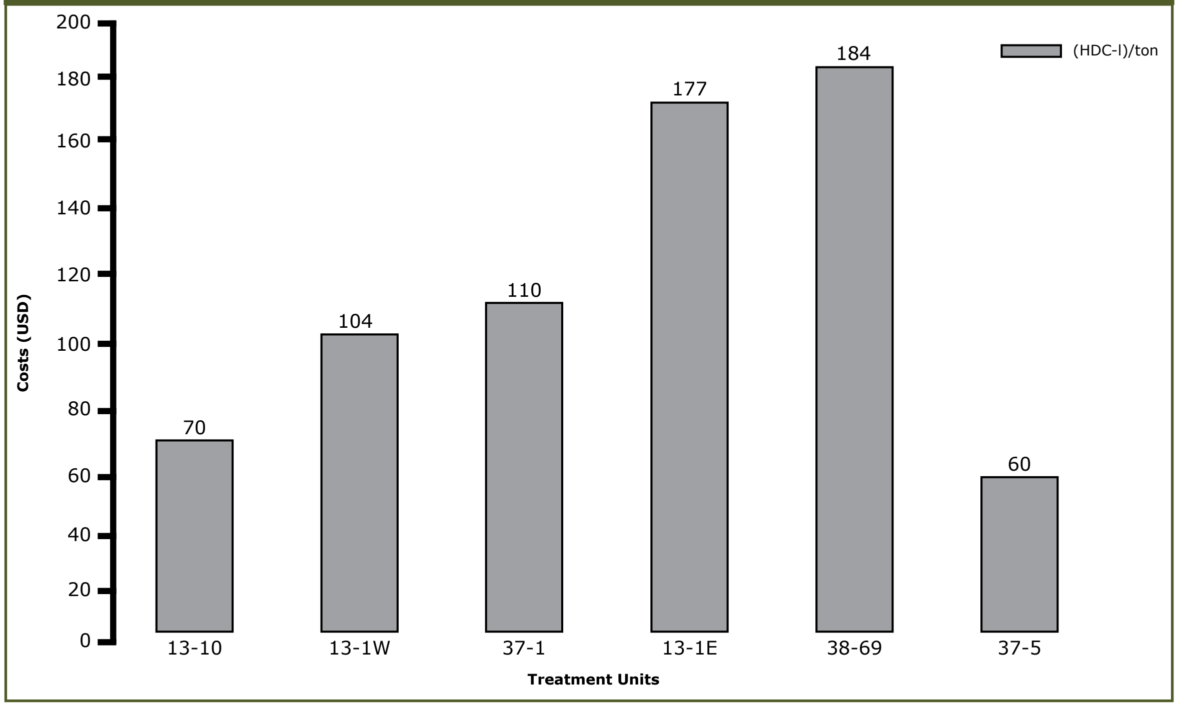
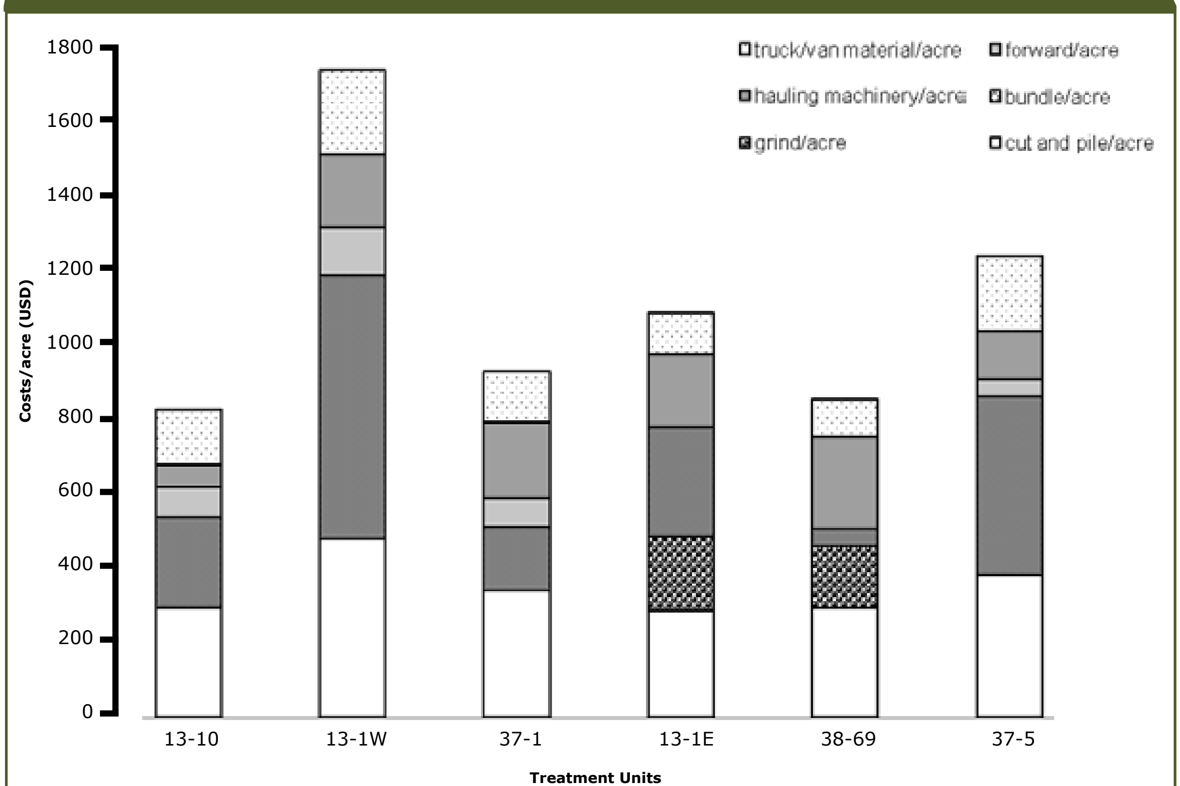


Figure 5-6

Caribou Trail: Per ton harvesting and delivery costs less income from biomass sale



Pitcha Lake Sites

The highest cost differences between conventional treatment costs and the biomass treatment options are attached to Pitcha C and Pitcha South sites because of the significant costs of trucking expensive machinery to operate on small areas (four and six acres respectively). Biomass treatment options in the Pitcha Lake North site slightly reduced conventional costs within 85 miles from the end user. This is primarily due to the large area treated with one system. Furthermore, all harvesting costs were divided by significantly larger site acreage (22.5 acres). In addition, the site had low biomass stocking, which allowed machinery to enter and leave this site in a faster and more convenient manner than the other sites. Visibility and accessibility of available material was also better due to low biomass stocking on the site.

Figure 5-7

Pitcha Lake: Per acre conventional and biomass energy treatments summary of costs, and income (USD)

Treatment Units	Tons/acre	CC/acre	HDC/acre	I/acre	BTO/acre	Difference between CC and BTO (costs changes for the FS)
PITCHA NORTH (low density) bundles	3.20	350.00	371.00	44.79	326.20	23.80
PITCHA C (high density) bundles	7.20	575.00	1236.45	100.77	1135.68	-560.68
PITCHA SOUTH (medium density) loose material	10.04	462.50	1091.83	210.81	881.03	-418.53

Acres: harvest area unit, CC: Conventional costs, HDC: Harvest and delivery costs, I: Income from sale of extracted biomass material, BTO: Biomass treatment option (HDC-I)

Per-acre conventional treatment costs were less than the biomass energy option costs for two sites (Pitcha C and Pitcha South). Only Pitcha North demonstrated cost reduction in the study trials, as indicated in Figure 5-7.

For both Pitcha North and South sites, however, the machine operator indicated that the short reach of the Posi Track and Valmet machines, and the short height of the Posi Track in the Pitcha South site resulted in visibility concerns. Operators were expected to cut smaller-diameter trees without scarring any larger trees not scheduled for cutting. When smaller-diameter trees were close to these larger trees, it was challenging for the operator to cut the smaller trees while avoiding the larger ones. Indeed, that became an operational problem at the Pitcha Lake sites, resulting in fines, down time and operator frustration on those units. Careful consideration should be given to visibility and operability when shorter machines and those with a lesser reach are used for operations in brushy sites with tight harvest size restrictions.

Figures (5-8 and 5-9) show that harvesting and delivering biomass from harvest sites is not profitable on its own. Even though material was stored on the site for almost seven months, resulting in dryer and higher-quality fuel for LEA, payments remained at a fixed rate per ton, hurting operational economics. (N.B: moisture content readings were taken in July.)

Figure 5-8

Pitcha Lake: Per acre production costs, delivery at gate

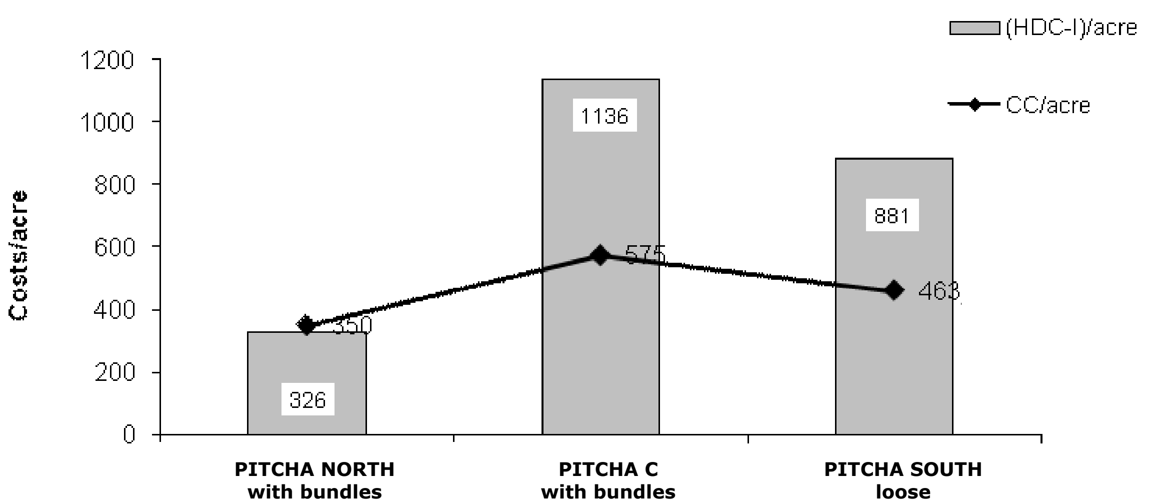


Figure 5-9

Pitcha Lake: Per acre production costs, delivery at gate

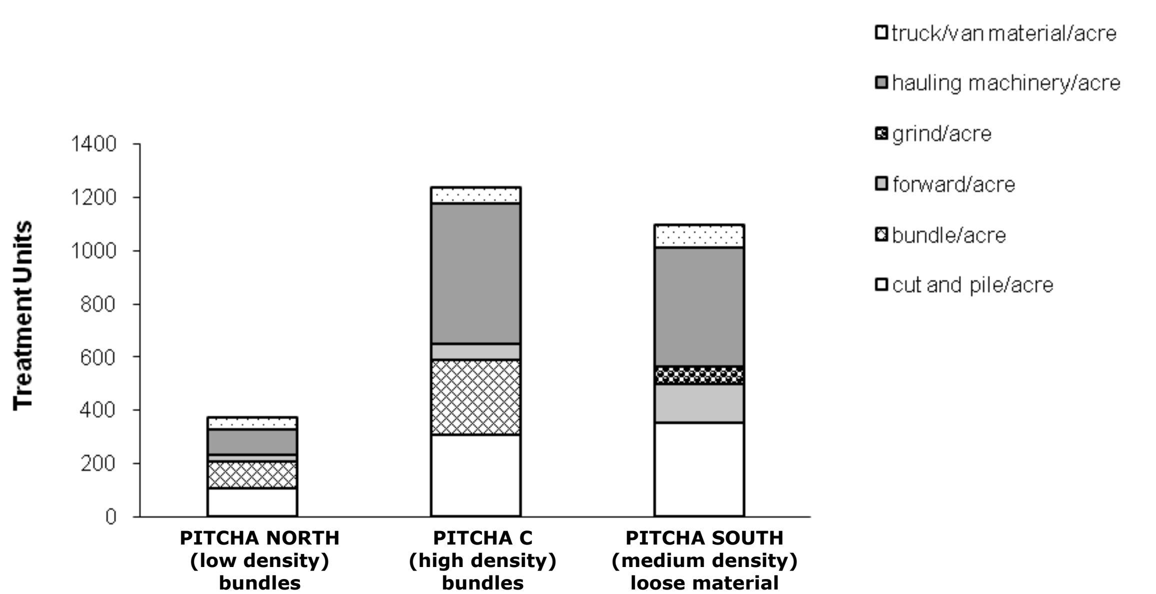
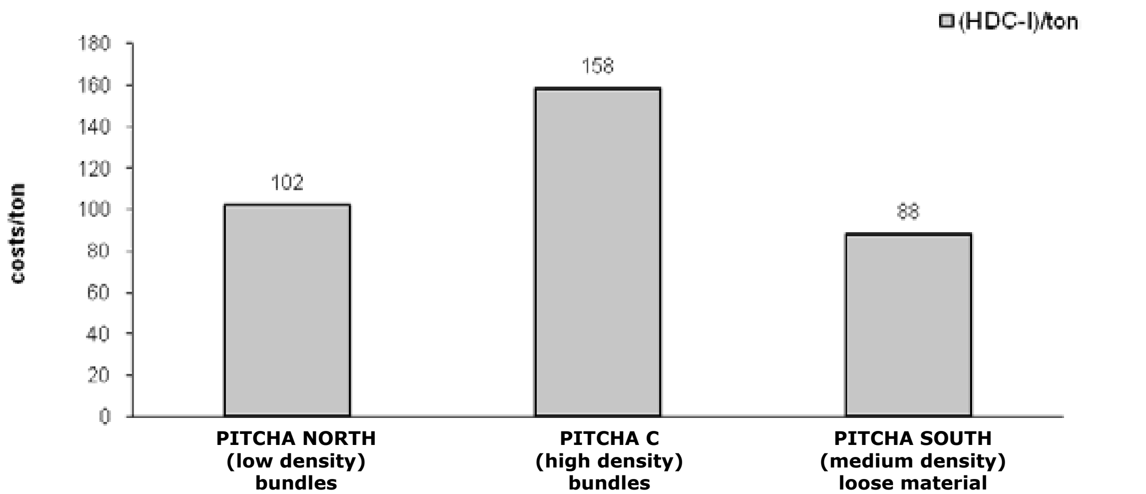


Figure 5-10

Pitcha Lake: Per ton harvesting and delivery costs less income from biomass sale



Discussion

Specific constraints to study trials

We assumed that the costs for mechanically treating a site, returns from selling biomass and on-site harvesting costs were fixed. It is recognized that these assumptions may not hold depending on changes in market conditions for biomass, fuel costs, site prescriptions and other variables. For example, emergence of a market for carbon in North America could have significant effects on both costs and benefits of biomass harvesting. Therefore, the only variables that could change under these conditions are the transportation distances and costs associated with the delivery of biomass materials to the market, and the "mobilization" expenses (hauling equipment to and from the harvest site). Based on these assumptions, different distance scenarios for biomass trucking and machine hauling were developed to identify if cost reductions were possible for the Superior National Forest. In order to compare different harvesting conditions, in different transportation scenarios, two study-specific constraints were adjusted.

First, full van loads of wood chips were modeled. Due to the study requirements to determine specific tons recovered per unit, vans only carried material removed from a single unit and left even if only partially loaded.

According to Minnesota Statutes 169.8261 (2006), forest products and six-axle wood chip trucks' gross weight loads may reach a maximum of 90,000 lbs, with a maximum of 98,000 lbs allowed in frozen conditions. There is an additional 5 percent allowance in weight all year round before a truck is fined for load violations.[57] According to numerous studies, an empty truck weighs approximately 38,160 lbs (19 tons). Also, study hauling took place in frozen conditions, where a payload of 32 tons of woodchips is possible. In this study, however, payloads are estimated at 30 tons, as an average between winter and non-winter conditions (Figure 5-11). Study trials resulted in 15 partially loaded trucks. Calculating full loads of 48 foot trailer vans, with a 30 ton load capacity, resulted in two fewer trucks in the alternate scenarios.

Figure 5-11

Potential truck payload year round.

	Winter loads	Non-winter loads
Tare (tons)	19.08	19.08
Gross wt. (tons)	51.45	47.25
Payload (tons)	32.37	28.17
Ave payload (tons)	30.27	

Figure 5-12 shows the cost estimates for trucking wood chips in full loads. In study trials, bundles and roundwood were combined in full truckloads. A truck and trailer load of bundles only was found to be about 23 tons per payload. Thus, less weight of biomass in bundles could be trucked per load versus wood chips. However, the benefits of bundles (longer storage life, low dry matter loss over time, low microbial activity and less risk of spontaneous combustion than chipped material[58]) need also to be considered when evaluating the bundling system.

Figure 5-12

Trucking costs estimates for wood chips payload.

Trucked distance	$/ton
150 miles each way	$15.00
125 miles each way	$12.50
100 miles each way	$10.00
75 miles each way	$7.50
50 miles each way	$5.00
25 miles each way	$2.50

Second, we modeled that the machines were hauled only once to treatment units. In study trials, the Ponsse Buffalo Dual and the JD 1490D Slash Bundler were hauled twice to the treatment units. The Buffalo Dual returned to the site twice to forward other sites harvested with other systems. The Bundler required off-site repairs and had to be transported to and from the site several times. Re-hauling either the bundler or the dual is an additional $2,000.00 each time, based on the estimated lowboy rate of $115.00/hr.[59] Since re-hauling can happen with any machine, and discussions with machine operators indicated it is fair to assume that operations may be completed without the need for being hauled twice to a site,[60] it is assumed that no machine has this bias.

Transportation Scenarios

Caribou Trail

Scenarios were developed to compare the study results with six hypothetical scenarios.

1. Study trials: trucks drove 150 miles to deliver biomass to an energy market and 135 miles to a pulp market.
2. Six hypothetical scenarios: Under similar study conditions, six scenarios were developed in relation to the base study trials scenario. However, the scenarios were modeled without re-hauling of machines to a site, with full loads of wood chip vans (30 tons/load), and assumed equidistance for machine hauling and the delivery of biomass and roundwood to markets.

Scenarios developed span 25, 50, 75, 100, 125 and 150 miles from whence machines were trucked to the harvest site to biomass delivery points. The aim was to determine whether the per-acre difference between conventional treatment costs and biomass treatment options could be positive numbers if markets were closer, and machine hauling costs (mobilization) were controlled. In such a situation, the biomass treatment option could reduce conventional treatment costs. In each scenario, machine and material trucking distances were adjusted in the calculation spread sheet. The truck speed was assumed to average 50 miles/hr, at a cost of $1.50/mile, and the lowboy speed was assumed to average 33 miles/hr, at a cost of $115.00/hr.

Pitcha Lake

The study results were compared with four hypothetical scenarios.

1. Study trials: trucks drove 85 miles for a biomass energy facility.
2. Four hypothetical scenarios: Under similar study conditions, four scenarios are developed in relation to the base study trials scenario. However, scenarios are without re-hauling machines to a site, and assume equidistance for machine hauling and the delivery of biomass and roundwood. Loads were already optimized at the Pitcha Site to 30 tons/truckload, since a clean 60 tons were removed from the chipped material on Pitcha South site. Therefore, no truckload alterations were made, as in the case of the Caribou Trail treatment units.

Scenarios developed span 25, 50, 75 and 85 miles from the harvest site to trucking and biomass delivery points. The aim is to determine whether the per-acre difference between conventional treatment costs and biomass treatment options can be positive numbers. In such a case, a biomass treatment option can reduce conventional treatment costs. In each scenario, machine and material trucking distances were adjusted in the spread sheet. The average truck speed was assumed to be 50 miles/hr, at a cost of $1.50/mile, and the average lowboy speed was assumed to be 33 miles/hr, at a cost of $115.00/hr.

Sensitivity Analysis

Caribou Trail

Figure 5-13 and Figure 5-15 estimate conventional treatment costs less the biomass energy option (harvesting and delivery costs less income from the sale of biomass), per acre and per scenario. Based on the scenarios sensitivity analysis, harvesting and delivery costs varied significantly because of changes in trucking costs, travel distances, the number of times machines are hauled to a site and truck payloads.

The results showed that per-acre biomass treatment options can reduce the costs in comparison with conventional treatment costs. The cost reduction varied according to treatment prescribed, equipment used, and machines and material hauling distance.

Biomass treatment options in units 37-5 and 13-10 reduced conventional costs at distances 100 miles and less. In the 75-mile scenario, the hand-felling 38-69 treatment unit costs start to show a potential for breaking even with the conventional fuel reduction treatment costs per acre; however, there is a $2.00/acre difference between the costs of the biomass option and the conventional treatment costs. In the 50-mile scenario, four out of the six units show potential reductions in treatment costs if the biomass option is considered. Units 13-1W (chips) and 13-1E (bundles) did not exhibit any costs reduction potentials.

Because of scenario adjustments to study trials, units 13-1W and 37-1 demonstrated higher costs in the 150-mile scenario since in the actual study trials both harvesting machines (Fabtek 153 and Timbco 425D) were hauled from a distance shorter than 150 miles.

Figures 5-13 and 5-14 show that harvesting and delivering biomass from harvest sites is not cost-effective taken alone, since costs exceed revenue. However, these biomass harvest options can be lower than mechanical treatment costs, when forest management objectives warrant the investment.

Figure 5-13

Caribou Trail: Per acre difference between conventional treatment costs (USD) and the biomass energy treatment option costs [(CC- (HDC-I))/acre]

	25 miles	50 miles	75 miles	100 miles	125 miles	150 miles	Study trials
Unit 13-10 (Chips)	$108.00	$80.00	$52.00	$24.00	-$4.00	-$32.00	-$68.00
Unit 13-1W (Chips)	-$514.00	-$597.00	-$680.00	-$764.00	-$847.00	-$930.00	-$846.00
Unit 37-1 (Chips)	$75.00	$8.00	-$60.00	-$127.00	-$194.00	-$262.00	-$191.00
Unit 13-1E (Bundles)	-147.00	-182.00	-217.00	-252.00	-286.00	-321.00	-415.00
Unit 38-69 (Bundles)	92.00	45.00	-2.00	-48.00	-95.00	-142.00	-205.00
Unit 37-5 (Chips and Roundwood)	$172.00	$126.00	$80.00	$34.00	-$13.00	-$59.00	-$105.00
Note: Positive numbers indicate where the biomass treatment option is less costly that the conventional treatment option.							

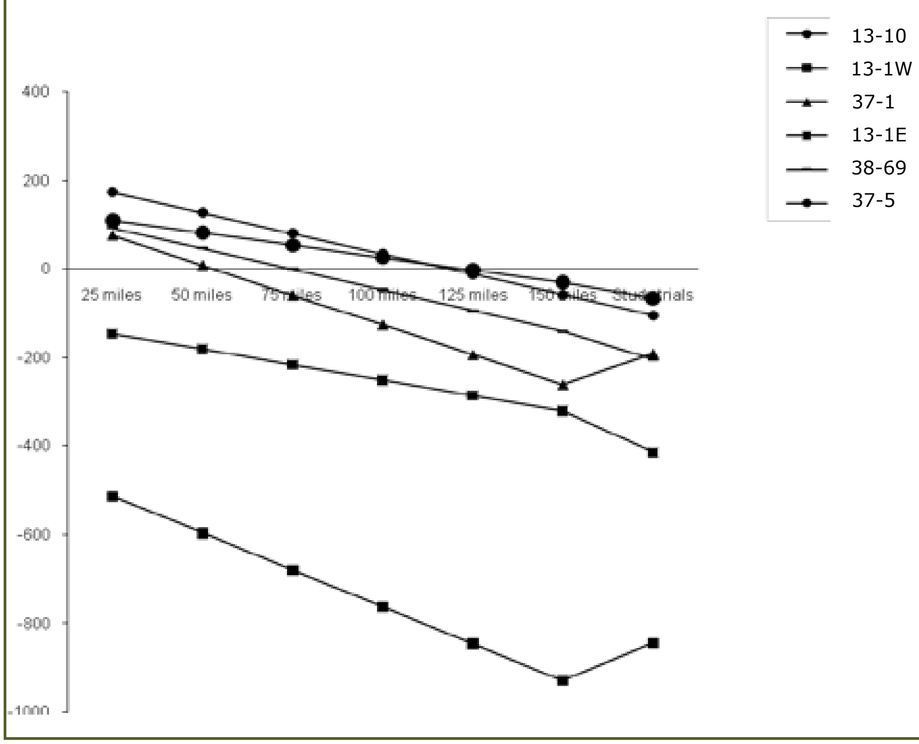
Figure 5-14

Caribou Trail: Per ton income less harvesting and delivery costs (USD)

	25 miles	50 miles	75 miles	100 miles	125 miles	150 miles	Study trials
Unit 13-10 (Chips)	-$58.00	-$61.00	-$64.00	-$68.00	-$71.00	-$75.00	-$79.00
Unit 13-1W (Chips)	-$79.00	-$86.00	-$92.00	-$98.00	-$104.00	-$110.00	-$104.00
Unit 37-1 (Chips)	-$72.00	-$82.00	-$91.00	-$101.00	-$111.00	-$120.00	-$110.00
Unit 13-1E (Bundles)	-$128.00	-$135.00	-$141.00	-$147.00	-$154.00	-$160.00	-$177.00
Unit 38-69 (Bundles)	-$114.00	-$125.00	-$136.00	-$147.00	-$158.00	-$169.00	-$184.00
Unit 37-5 (Chips and Roundwood)	-$39.00	-$42.00	-$46.00	-$49.00	-$53.00	-$57.00	-$60.00

Figure 5-15

Caribou Trail - Sensitivity Analysis - Per acre costs reductions for the Forest Service



Pitcha Lake Sensitivity Analysis

Figures 5-16 and 5-17 estimate conventional treatment costs less the biomass energy option (harvesting and delivery costs less income from the sale of biomass, per acre and per scenario). Based on scenario sensitivity analysis, changes in trucking costs, trucking distances and truck payloads demonstrate changes in biomass harvesting and delivery costs. Biomass treatment options in the Pitcha Lake South site slightly reduced conventional costs within the 85-mile trucking distance. Cost reductions were also calculated as machinery and biomass material trucking distances were reduced in the Pitcha North treatment unit. Cost reductions in other treatment units were not apparent even within the 25-mile distance. Figure 5-17 shows that harvesting and delivering of biomass from harvest sites such as these were not cost effective taken alone, even at a 25-mile distance from markets.

Figure 5-16

Pitcha Lake: Per acre difference between conventional treatment costs (USD) and the biomass energy treatment option costs [(CC- (HDC-I))/acre]

Treatment Units	25 miles	50 miles	75 miles	Study trials
PITCHA NORTH (low density) bundles	$121.39	$79.94	$38.50	$23.80
PITCHA C (high density) bundles	-$146.73	-$323.60	-$500.48	-$560.68
PITCHA SOUTH (medium density) loose material	-$45.47	-$204.64	-$363.80	-$418.53

Note: Positive numbers indicate where the biomass treatment option is less costly that the conventional treatment option.

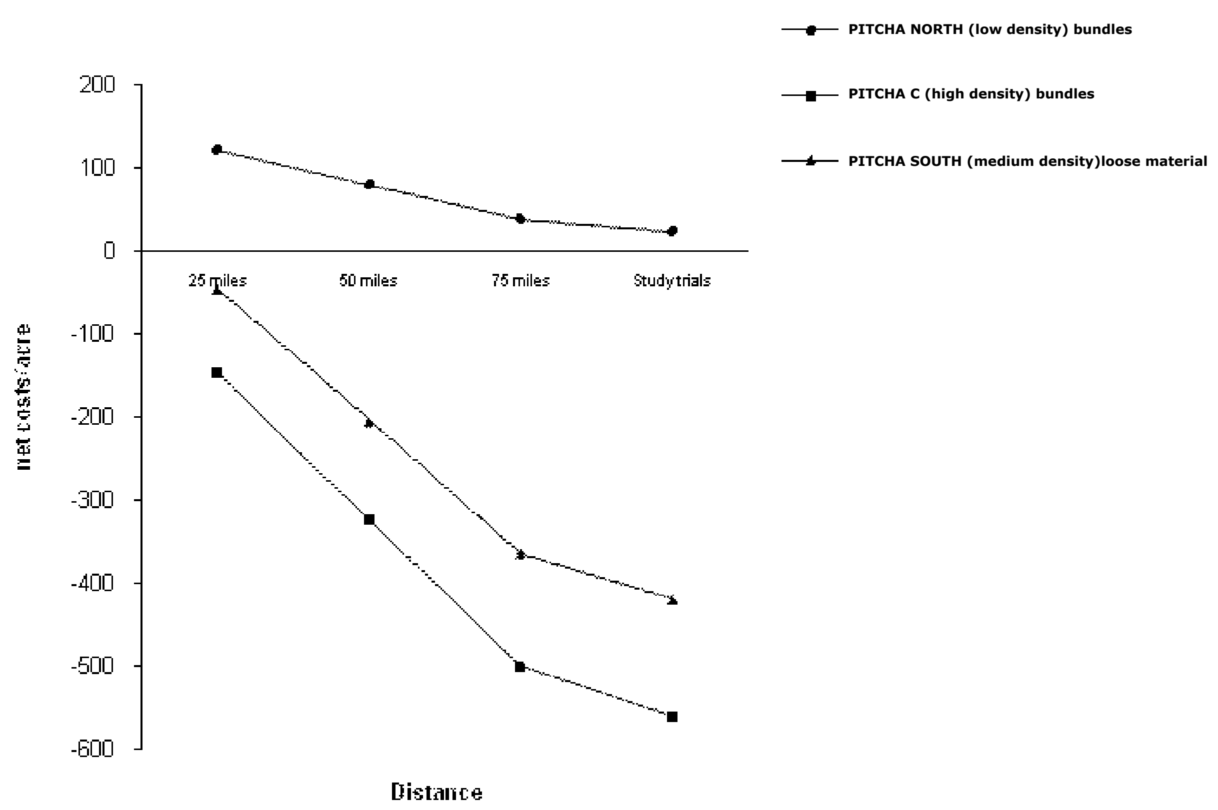
Figure 5-17

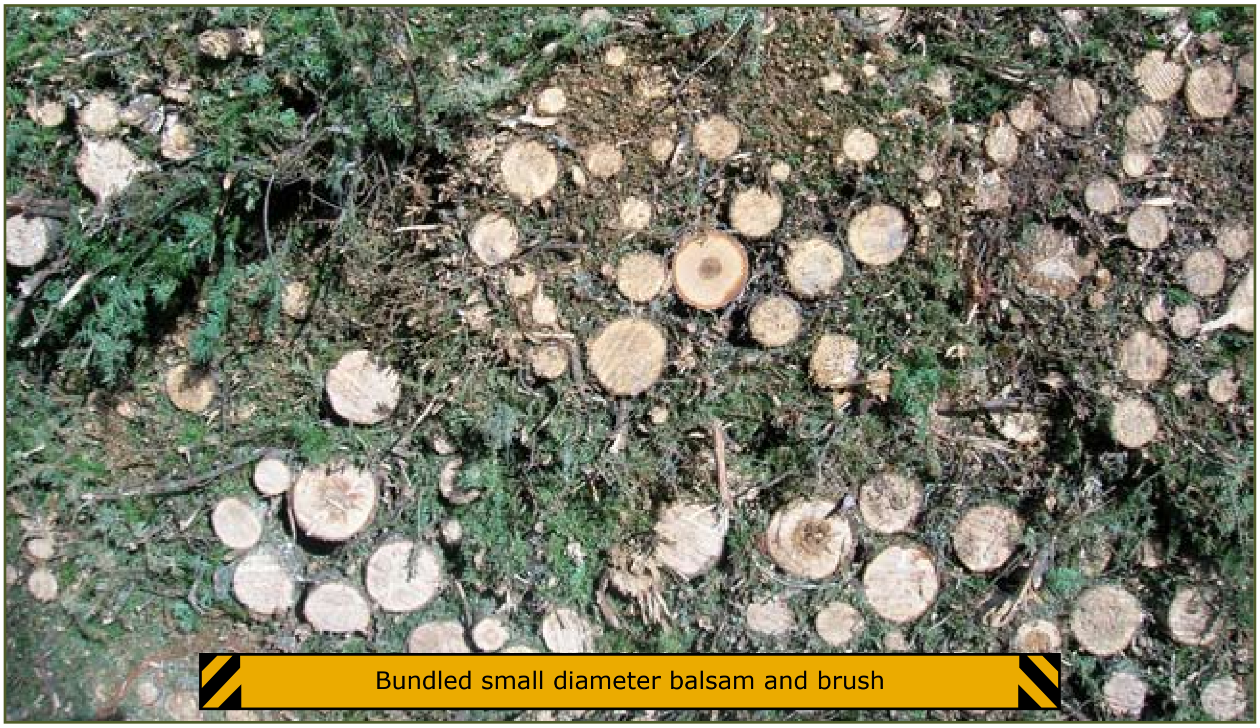
Pitcha Lake: Per ton income less harvesting and delivery costs (USD)

Treatment Units	25 miles	50 miles	75 miles	Study trials
PITCHA NORTH (low density) bundles	-$57.45	-$70.40	-$83.36	-$87.95
PITCHA C (high density) bundles	-$86.27	-$110.85	-$135.42	-$143.79
PITCHA SOUTH (medium density) loose material	-$29.60	-$45.46	-$61.31	-$66.77

Figure 5-18

Pitcha Lake - Sensitivity Analysis - Per acre costs reductions for the Forest Service





Bundled small diameter balsam and brush

Rotochopper loading chip van on 38-69

Comparisons between Caribou Trail and Pitcha Lake treatment units

Area harvested

- Both the Caribou Trail and Pitcha Lake sites varied in the size of the area harvested. However, the difference between areas harvested in the Pitcha Lake site was more significant.
- Both Caribou and Pitcha sites have shown that it is not cost-effective to treat sites of smaller acreage, regardless of tonnage of biomass removed. In this study, mobilization costs alone preclude harvest of areas smaller than 20 acres.
- In the Pitcha Lake North site it proved cost-effective (less than conventional treatment costs alone) to harvest biomass across a larger area, with the tested system, even though the site had a low biomass density of 3.2 tons/acre.

Costs

- Conventional treatment costs for Caribou Trail sites were assumed to be $575/acre, as all six test sites were identified by the Forest Service as high-density biomass sites. At Pitcha Lake, sites were pre-selected to be high-, medium- and low-density biomass sites. However, findings showed that the high-density site had less biomass recovered per acre than the identified medium site. (Evaluations and cost comparisons were made using pre-harvest rankings and assumed conventional treatment costs.) The dense site was compared with a conventional treatment cost of $575/acre; the medium site was compared with a conventional treatment cost of $462.50/acre, despite the fact that it generated more biomass per acre. It is important to reiterate that this dense site may have been denser to start with. However, because the operator did not complete his operations, harvesting only a small portion, the actual recoverable tonnage from this total site was not measured. Therefore, the analysis is based on the classification of each site as high-, medium- and low-density biomass and is not based on the measured recoverable weight. We made this choice because, in the future, cost analysis will be made at the start of each operation before harvest yield can be measured.
- Overall, except for Pitcha Lake North, biomass harvests as a fuel treatment method cost more in the study trials than conventional pile and burn fuel treatment methods. This is mostly due to the harvest site operations, which involved using expensive machinery on relatively small sites with low stocking, and partly due to the machinery hauling distance and biomass freight distance from these sites to the biomass market. This finding in the Pitcha Lake sites is not surprising, since distances covered from Pitcha Lake to the biomass market were almost half those of the Caribou Trails site. According to sensitivity analysis, Caribou Trail could demonstrate cost reductions within 100 miles of the market.

Machinery

- Distance machinery and biomass were trucked: Pitcha Lake was closer to the biomass market, 85 miles vs. 150 miles in the case of Caribou treatment units. However, this trucking distance advantage was not sufficient to make the overall total treatment costs favorable, as identified in the analysis.
- Break down of machinery: no machines were considered to be broken down in the trial sites at Pitcha Lake even though harvest at Pitcha North was halted for many days for prescription violations. Including machinery rental costs for this period would have skewed analysis to a large degree.

Grinding

- At the Pitcha Lake sites, total grinder costs are much lower because a bucket loader was attached to the grinder. Therefore, the cost of operating the grinder was lower than the Caribou trail sites, where a loader was necessary, adding to grinding costs.

Truckload

- A truckload of bundles weighed 23 tons for the Caribou Trail sites. However, for the Pitcha Lake sites, weight slips reached as high as 29 tons for one truckload. This resulted in fewer truckloads for the same amount of biomass. One possible cause for this could be that the materials bundled at the Pitcha Lake sites were denser. Consideration, therefore, should be given to the weight of material bundled to reduce trucking and bundling costs.

Moisture content

- Samples taken from material removed from Pitcha Lake were sent to a lab for moisture content measurements. These readings yielded an average moisture content of 23.85 percent approximately six months after harvest. No moisture content measurements were made at the time of harvest; however it was assumed that the initial moisture content was about 50 percent at the time of harvest as nearly all of the harvested material at the Pitcha Lake site was live. Substantially lower moisture content was achieved and therefore fewer truckloads were required to haul the biomass as a result of leaving material to dry on-site for this period of time.
- Despite superior fuel characteristics of drier fuel, and decreased trucking costs from a reduction in total loads required to haul a given volume of biomass, payment on a per-ton basis only, as during this test, discriminates against this practice. It is recommended that operators should be paid both on a per-ton and an average moisture content basis to reward the delivery of drier fuel to biomass markets.

Observations

Based on this analysis, the potential cost reductions between conventional treatment costs and the biomass treatment costs are affected by factors that might be grouped in four categories: biophysical, markets, management and operations.

Biophysical Factors

- Site conditions
- Weather conditions
- Biomass stock per acre
- Size of the area harvested

Market Factors

- Distance to market (no greater than 100 miles)
- Payment (per ton payments should be adjusted for moisture content)
- If bundles are favored for biomass storage reasons, payments must reflect this value

Management Factors

- Larger management units (reduced equipment mobilization costs)
- Flexible prescriptions (allowing operator-determined options for skid trails, reserve areas, and a minimal removal of residual trees reduces harvest and forwarding time)
- Combining roundwood and biomass harvest
- Forwarding distance to biomass yarding areas (may be determined by terrain or pure distance)
- Landings of sufficient size to accommodate all harvested biomass (improves grinding efficiency to have all materials at-hand)
- Focus biomass removals on larger materials and higher density areas (intensive or thorough removal is impractical and expensive)
- Summer forwarding improved visibility of smaller biomass piles (more efficient recovery)

Operation Factors

- Number of machines hauled to a site
- Number of units harvested with one machine that is hauled only once to the harvest site
- Harvest equipment selection (suitability to terrain and forest condition, visibility, maneuverability, flexible uses such as harvester/forwarder)
- Self-loading grinder (eliminates the need for another machine)
- Efficient layout of harvest access trails (improved harvest and forwarding efficiency)
- Maximize haul efficiency with full chip van loads, or mixing/matching roundwood and biomass bundles on a load when practical
- Efficient mobilization of equipment
- Operator's skill in reducing time for her/his operations

Conclusion

In most cases, conventional treatment costs are lower than the net costs of harvesting, delivering and selling biomass. Cost reductions were found at distances up to 100 miles from the biomass market under certain conditions, despite often modest per-acre biomass removals. We therefore conclude that harvesting and delivering forest energy biomass under certain conditions can reduce the costs of conventional mechanical treatments.

Biomass landing containing material from site 13-10 (left) and bundled biomass from site 13-1E (right)

taken by Dr. Dalia Abbas

CHAPTER 6: THE LOGGER'S VOICE

By Dr. Dalia Abbas, Dr. Dean Current, Dr. Kenneth Brooks, Don Arnosti

Introduction

There is a large body of literature that has focused on biomass for energy potentials and trials[61] and on biomass removal as a hazardous fuel reduction method.[62] However, literature that assesses the lessons from these trials, based on the perspective of the operators who put these trials into practice, is uncommon. This is especially important since "logistics costs and the integrated management of logistics activities can be vital to the success or failure of a product or industry, especially in the case of a fledgling industry."[63]

To this end, this chapter assesses the logistics of harvesting biomass for energy from the point of view of the operators. Logistical concerns identified are based on the operators' responses and input, and are intended to offer insights for future biomass harvesting research and operations.

As a disclaimer, this study does not endorse any machine brand or contractor over any other.

Description of Operations

Three biomass harvesting and delivery systems were implemented, using 13 different machine combinations. See Chapter Three for further description of these systems.

1. Treatment units #13-10, 13-1W, 37-1, 37-5 and Pitcha South combined harvesting loose biomass for energy using Cut and pile » forward » load grinder » grind » truck-van systems.
2. Treatment units # 38-69 and 13-1E and Pitcha North and Pitcha "C" sites combined bundling loose biomass for energy using Cut and pile » bundle » forward » truck-trailer systems.
3. Treatment unit # 37-5 combined a roundwood option with system # 1. The roundwood option was implemented using Cut and pile » forward » truck-trailer systems.

Methods

It was the first time the experienced forest harvesters involved in these trials encountered forest management operations targeting small-diameter trees and brush. Data collection, therefore, sought to identify the harvesting logistics of these operations. The main questions the interviews and this analysis answer include:

- What were the differences between these operations and the operators' regular harvesting operations?
- What adjustments were necessary to conduct these harvests?
- What lessons can be passed on to future biomass energy harvesting operations to improve efficiency and lower costs?

Data analysis is based on primary research collected from field-based, in-depth, semi-structured interviews, observations of operations, and follow-up phone discussions with forest and road machine operators involved in these trials. A handheld digital recorder was used. Interviews and discussions were transcribed for analysis. Operators were contacted by phone, prior to and during the operations, for an initial face-to-face interview. Follow-up phone discussions sought to capture post-operation perspectives and clarifications for field-collected information.

Since such operations were new to operators, semi-structured interviews were carried out as the most appropriate method. Semi-structured interviews are recommended to obtain new information.[64] Interviews were conducted with an open framework, which allowed for more focused, conversational and two-way communications.[65] A more structured interview would have limited the depth of open discussions allowed in semi-structured methods. To increase the validity of responses, triangulation of source methods were used, combining information from USDA Forest Service officers and project managers on-site, and literary sources of fuel reduction biomass trials and case studies.[66]

Respondents in these operations comprised nine forest machine operators representing all the harvesting and delivery systems used in these trials. One of the nine operators ran both the Ponsse Buffalo Dual (combines a harvester and forwarder) and the Rotochopper MC 266 grinder.

Results

Even though all cut, pile and forward machine operators were experienced loggers, this was the first time they had entered a site for the purposes of cutting, piling and forwarding biomass from small-diameter trees (less than 6 inches dbh), with no commercial roundwood harvest in eight out of the nine sites harvested. The only exceptions to this new experience with biomass-specific operations were the bundler machine operators.

Data analysis identified two main logistics-related components in the operators' responses. One was related to harvesting and delivery challenges, and another was related to planning and coordination challenges. The following sections detail these two challenges separately.

Discussion

Harvesting and Delivery: Challenges and Recommendations

On-site physical and technical challenges that impede practical harvesting operations are detailed here. Responses are based on the operators' experiences and their perspectives regarding the practicality of this biomass-harvesting project. Criteria in this section are concerned with material finding, cutting, piling, bundling, forwarding, grinding and trucking of the biomass material to the market. Logistical challenges in this section offer insights into the technical viability of using a conventional logging system to harvest small-diameter trees under conventional fuel reduction prescriptions. Recommendations for modifying prescriptions to improve the efficiency of biomass harvest are also offered.

Material Size and Visibility

Recommendation

Ensure that harvested biomass is piled in a manner that is visible.

Challenge

"A lot of time is wasted looking for the harvested biomass."

Loggers are more familiar with cutting large trees than small trees (1-6 inches diameter). Most operators expressed concerns about the size of the biomass material, and the difficulty in viewing this material from the machine cabin. One operator indicated that in many cases, smaller-diameter trees are only pushed over by the machine and "[you] can not see it till you get there."

The relatively small piles that the hand-felling operations built became a visibility issue for the larger machines that collected this material. For example, some piles were too small for the bundler operator to notice. "Searching for loose material is like a scavenger hunt" was an expression by one forwarder operator. Forwarding bundles, on the other hand, was easier, he said. Bundles are easier to forward since they are piled with two to three bundles in one location. The main concern, however, was finding these bundles in between the larger trees.

Locating material to cut for the hand-felling team was not a concern. Their concerns related to having an accessible path to these smaller trees, rather than seeing them in the first place.

Site Conditions

Recommendation

Avoid rocky ground or use caution when harvesting on rocky ground covered by brush to minimize machine damage.

Challenge

Harvesting smaller trees does not require as much machine power as harvesting larger trees. However, rough soils and rocks on the ground can ruin a machine cutting chain. When brushier material covered the ground, visibility of rocks below became a challenge. For example, one feller buncher machine in these trials ruined the saw chain when it hit a rock.

Winter Conditions

Recommendations

Collect smaller biomass piles immediately following harvest if they might be obscured by snow later on. Conduct harvest and forwarding operations in the summer when possible to shorten forwarding time.

Challenge

All sites were harvested in summer conditions. However, one site was cut and piled in summer, and then forwarded in winter. Winter conditions lengthened the forwarding time. Forwarding material in winter was more challenging since material had been covered in snow, and the forwarder operator was moving on slippery ground. He indicated his opinion that a summer forward would have taken 10 hours less time on that site. Summer conditions are more favorable, with more daylight hours and better visibility. This operator recommended forwarding material immediately after it is cut and piled.

Material Sizing and Arrangement

Recommendation

Hand-cut stems should be severed parallel to the ground to reduce damage to equipment tires. Cut stems should be piled in a parallel orientation to facilitate efficient pickup and reduce damage to remaining vegetation.

Challenge

Shortening long stems and arranging material in a pile with stems pointing toward the skid trail is important for the bundling and forwarding operations to run effectively. A bundler operator indicated that if material size is too long, or is "pointing in every direction," it becomes more difficult for the machine to pick and rotate this material into the bundler chute without hitting, or even scarring, standing trees in the process.

The forwarder operator added that some hand-felled stumps were spearhead-like and cut at an angle. This, he felt, caused a hazard to the forwarder's tires. He recommended that hand-felling crews should cut trees straight and parallel to the ground (Figure 6-1).

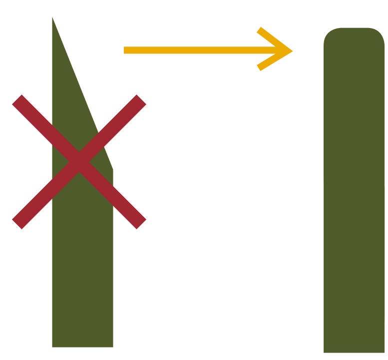


Figure 6-1 - spearhead-like stems will damage tires

Site Demarcation

Recommendation

It is recommended to have clearly demarcated, on-the-ground paint or flagging in order to speed up the harvest, which will reduce costs.

Challenge

Most operators expressed concerns with identifying the harvesting area perimeters. One operator indicated that forest managers should have used timber-harvesting conventional colors to mark the boundaries. He indicated that inconsistent ribbon colors overwhelmed him. At one time he spent about 15-20 minutes trying to locate the correct boundary ribbons, while the machine was still running.

Lack of clear and sufficient flagging on the harvest site can be confusing and can cause costly delays.

An additional concern was expressed because ribbons from previous harvesting operations were not removed. This operator indicated a preference for painting trees instead of flags, which are less clear.

Machine Size

Recommendation

Use smaller machines with a smaller, lower head or hand-felling on brushy sites with tight harvest size restrictions.

Challenge

"Machines are not set up to do the small stuff" (general remark from all large machine operators).

For both Pitcha North and South sites, the machine operator indicated that the short reach of the Posi Track and Valmet machines and the short height of the Posi Track in Pitcha South resulted in visibility concerns. Operators were expected to cut smaller-diameter trees without scarring any other tree out of prescription. When smaller-diameter trees were close to these larger trees, it was challenging for the operator to cut the smaller trees while avoiding the larger ones. Indeed, that became an operational problem on all Pitcha sites, resulting in fines, down time and operator frustration on those units. Careful consideration should be given to visibility and operability when shorter machines and those with a lesser reach are used for operations in brushy sites with tight harvest size restrictions.

All cut and pile operators indicated preferences for a smaller machine with a smaller and lower head, and with a long reach. This could allow operators to see and maneuver more easily. Machines of this sort have been developed and have been in use in Finland and Sweden since the mid-1970s.[67]

Skid Trails

Recommendation

Organized harvest and skid trails facilitate harvest and forwarding, and therefore reduce costs. These should be provided even if it requires a modest adjustment to the prescription to allow some residuals to be removed for this purpose.

Challenge

"Got to have rows" (operator). Most cut and pile and forward and bundler operators, except one cut and pile operator, expressed concerns because there were no planned skid trails to cut and then forward material. Operators created their own maneuvering trails as they searched for material to extract, since conventional mechanical fuel reduction prescriptions, which were followed, were not designed with skid trails in mind. This is because conventional treatments only target cutting and then roughly piling material. This approach did not anticipate the biomass-specific operations that required larger and more evenly sized piles that could be forwarded to the landing in an efficient and practical manner. For the operators, a lack of skid trails meant entering a location from one trail and leaving from another. At times this meant that standing snags fell on "operator cabins" as they searched for an exit trail, causing safety concerns.

The one cut and pile operator who did not express concerns designed his own skid trail from the start. Since he was limited to only four days to enter and leave the site, he "square[d] off" the site, while other sites were reportedly "randomly weaved around." This operator intersected rows, and backed up from the same trails. By doing this, he cut and piled a larger site that was forwarded over a relatively shorter time than the other sites with loose material. The forwarder operator indicated approvingly "he cut it so the forwarder can skid it."

However, this cut and pile operator had to cut down four pulpwood-sized trees that were not allowed by the prescription to make this system work for him and the forwarder. The Forest Service timber sale administrator approved this cutting, since this was a pilot study that offered learning opportunities to improve future operations. This operation may offer a lesson, suggesting that allowing a minimum number of larger trees to be cut could make the entire operation more efficient and therefore economically feasible.

In talks after the operations with U.S. Forest Service officers, they indicated that this approach could potentially be allowed in the future.[68] However, the decision to remove larger trees needs to be considered among other factors such as: the size of area harvested, stocking, visual considerations of the forest, habitat needs and the public input which is required to move ahead with these operations.[69]

Lack of skid trails in most sites created difficulties for the bundler and forwarder, because they both followed the trails of the earlier cut and pile systems to forward and/or bundle this material. Since there was no planned grid system, one bundler operator indicated he had to "pick and choose" skid trails, not knowing where these paths would lead him. This meant that significant time, and therefore resources, were wasted in the search for biomass material. This also meant that perhaps not all of the material intended for removal was actually recovered. The lack of skid trails was especially problematic when the bundler had to locate material previously hand-felled. The hand-felling crew made no large machine trails that could be tracked by the bundler. This bundler operator, therefore, had to search for routes, and at the same time try to identify piles of loose material in between trees, with no distinguishable trail.

Forwarding loose material with no identifiable skid trails also meant entering a spot from one trail and backing up from another one in search of biomass material. Lack of clear skid trails lengthened forwarding time. This operator said he spent most of the time traveling between the material piles and the landing and not picking up material. He described this as a "slow journey on a rough site with rocks."

In addition to the lack of skid trails from earlier machines, the forwarder and bundler targeted naturally downed material within the prescription, in addition to the biomass piles. Both machines, therefore, had to search for additional material, with no trail or clear route to follow. This situation might in part explain the rather low rates of removal of dead and downed material noted on sites 13-10 and 37-1 in Chapter Four.

Workspace

Recommendation

The site as well as materials felled by hand crews should be accessible by machines as necessary.

Challenge

The workspace was "…tight with little maneuvering space. There is also a potential for damaging the trees, for machine hoses to burst, and for a post [stem] to land in a cab" (operator).

The forwarder operator indicated that the mere existence of material on a site does not mean that it is accessible. For example, a hand-felling team may pile material where the crew is working, and only the crew can access this material. This workspace may not be accessible to a machine, unless piles are in a wide enough space for a forwarder or bundler to move around.

Grinding

Recommendation

Be sure material is prepared in a manner that can allow efficient utilization of the grinder's time during its operations on the harvest site.

Challenge

Operators involved with these trials were experienced loggers and truck drivers. The grinder was the only system which was relatively new to the operator.

Grinders can break down if the biomass material contains stones, rocks or stumps. The forwarder operator who fed the grinder said he had to cut off stumps in some piles before he ground them. The grinder was left idle while he was sorting material, creating additional costs.

Test operations utilized a horizontal grinder, which had an 18 inch diameter capacity. This meant that some bundles more than 20 inches were not ground. The power plant which purchased this material indicated a possibility of cutting open bundles before grinding to overcome this concern.[70] However, this limitation reduces some of the space and compression benefits of the bundling system.

Landing

Recommendation

Landings should be large enough to ensure that all biomass that is harvested from a site can be placed there so that grinding can proceed efficiently. However, landing size should stay within the recommendations of the Forest Biomass Harvesting Guidelines, published by the Minnesota Forest Resource Council, which indicate that "roads, landings and stockpile areas combined occupy no more than 1-3 percent of the site."[71]

Challenge

Material is forwarded to the landing area either in loose, bundled or roundwood forms. The landing is where material is either ground and blown into a wood chip van or piled (roundwood or bundles of biomass) for a trailer truck to load. Most sites in these trials had spacious landing areas that held all biomass and provided room for grinding and loading. However, one site had too small a landing area to accommodate all biomass removed from this site. The forwarder operator had to forward material, grind it, and then forward more material to grind. This meant that while the forwarder was traveling in the harvest site the grinder was idle on the landing, adding costs to the trial.

Trucking

Recommendations

When both bundles and roundwood are being trucked from a site to the same destination, combining them on one truck can maximize truckloads.

Challenge

Wood chips were trucked in chip vans and bundles were trucked on regular roundwood picket trailer trucks. Bundles are compressed residue with a ratio of 3:1 (operator # 6). A full truckload of bundles carried 23 tons of material from the Caribour Trail sites. The 48-ft wood chip vans used in the trials carry approximately 30 tons. Therefore, if operators are paid on a per-ton basis, trucking bundles reduces their income per truckload compared to wood chips. Operators in these trials combined bundles with roundwood harvested from one site to maximize payloads.

Winter conditions are favorable for wood chip van drivers, because they can purchase a permit to haul 10 percent more than summer loads. However, because trailer truck drivers are limited by the volume and height of the material, the maximum limitations were reached in summer conditions for the bundles. As the truck and trailer operator mentioned, "Bundles don't weigh nothing. It is like hauling popcorn" (operator # 8).

In the case of wood chips, this is not a concern. Because grinding frozen material can make finer sized chips, a truck can indeed increase its total load in winter. However, a trucking operator indicated that the power plant may not favor this finer material if it is less than 0.5 inches in diameter (operator # 9, and others).[72]

Planning and Coordination: Challenges and Recommendations

This section details planning and management concerns identified in these trials.

Visiting and Selecting Sites Prior to Harvesting

Recommendation

A site visit prior to bidding or harvesting biomass provides important information to the logger.

Challenge

Inspecting a harvest site prior to operations is a customary practice for loggers prior to timber sales.[73] However, visiting a site is not always customary in mechanical treatment operations.[74] Traditionally, in mechanical fuel treatments a contract and bid are organized. The lowest cost, or best value based on the entire operation's cost and the history of the bidder, determines who would complete the treatment operations. Most machine operators in this study did not visit the sites prior to harvesting. Most were paid an agreed-upon daily payment amount from the start, in return for completing these trials.

Remarks by operators indicated that in the future they would attempt to visit a site prior to bidding on a similar operation. Inspecting a site prior to operations can give operators an estimate of the length of time and amount of material they can expect to remove from a site, and therefore the potential profit the site might generate for them.

For example, as mentioned earlier, the bundling system did not fare well after a hand-felling system. One bundler operator voiced his concern by saying, "If I would have come here, I could have saved money and planned it. I would have planned it in relation to the parameters of the machine and identified possible problems."

The hand-felling crew leader indicated that because some areas were more difficult to access than expected, the crew spent more hours on site than anticipated. Since he had agreed to get paid on a per-acre basis, he felt in retrospect that he should have visited this site prior to bidding on it.

One other operator pointed out that if operators were going to be paid by volume, then they would definitely visit a site to agree on what, and how much, material can be removed.

Not only do some operators favor visiting a site prior to operations, but they have also indicated a preference to select a site to harvest, if this is an option. For example, the hand-felling team expressed preference for a site with smaller-diameter trees. A larger machine operator expressed an interest in the hand fell site, because material seemed larger there.

Harvesting Prescriptions

Recommendation

Prescriptions should allow biomass extraction in a flexible and efficient manner by operators. Consider prescribing one diameter for all species and marking stems to be protected. In addition, consider the other recommendations in this chapter that are influenced by prescriptions.

Challenge

Prescriptions need to be flexible. Visibility of smaller diameter material from a machine cabin was often a challenge. This challenge was further increased as some of the prescriptions targeted different sizes of small-diameter trees, varying by species. For example, Caribou Trail prescriptions called for removal of aspen species (*Populus tremuloides* and *P. grandidentata*) less than 6 inches dbh, balsam fir (*Abies balsamea*) less than 5 inches dbh, and spruce (*Picea glauca*) less than 2 inches dbh. One cut and pile operator expressed that this slight diameter difference between two species was confusing. He not only had to adjust to cutting non-customary smaller material, but he also had to distinguish them from each other. This operator indicated preference for guidelines which prescribe one diameter for all species.

One cut and pile operator felt that guidelines were not fully clarified with him at the start of operations, but rather with the forester in charge. This left him open to the possibility of an incomplete understanding of what was expected. He indicated his preference to discuss harvest guidelines at the beginning of operations directly with the forest managers, since he was going to be responsible for the implementation of the guidelines. Operators are subject to paying fines if prescription violations happen – as occurred on two of the Pitcha Lake sites.

Following precise harvest prescriptions proved problematic during the Pitcha tests. Due to restrictions on canopy closure in the area designed to safeguard habitat for the Canada Lynx, no overstory trees could be harvested. The Pitcha Lake decision memo further limited removals to balsam fir of less than 5” dbh (diameter at breast height) which are considered non-merchantable material, while retaining those of a larger diameter (which are merchantable material). It was difficult for the logger to differentiate from the seat of a harvester the difference between a 4.9” fir to be harvested, from 5.5 to 6.8” fir which were to be left, particularly when they were growing together in a clump.

The harvest operator on Pitcha North, working on a three-wheeled rubber tired buncher moved quickly through the stand harvesting trees “by eye.” He did not pay close enough attention to the harvest diameter restrictions, and was cited for harvesting a dozen or more over-size (between 5.5” and 6.8”dbh) trees midway through the project. His harvesting was shut down for a week waiting for the US Forest Service enforcement investigation and determination (resulting in lost use of a loaned harvester) leading to a cash fine for the out-of-prescription trees. He agreed that with more attention to the prescription, he could avoid harvesting over-sized trees. The harvest resumed on site with no further violations; however, due to lost shut-down time, the loaned harvester had to be returned to the manufacturer before the site was completely harvested.

A different harvester and operator were used on Pitcha C. This logger was extremely conscientious, following the prescription to the letter, even as the dense understory made maneuvering of his hot saw harvester very difficult. After a day of work, a single (oversized) tree of approximately 6” diameter that he had harvested was noted by the supervising forester. This resulted in a discussion between the forester and the operator, and a report to the Forest Service Law Enforcement office. The forester determined that no penalty was owed. The Law Enforcement office recorded the situation for their records without need of a site visit. The next work day, the operator inadvertently nicked a larger overstory tree with his spinning hot saw while maneuvering in heavy timber. For safety reasons he felled the tree. The logger self-reported this incident, and discussed the situation with the forester on site. Again, after a short discussion, there was a no penalty determination. However, after this incident, the logger determined that he could not access any more areas of the site to continue the harvest without a repeat of these situations and concluded his work.

The logger later said, “If they expect my work to be perfect, I can’t perform to expectations. The federal investigation of each small error made me feel like a criminal.” The supervising Forester, in contrast felt that this was one of the most conscientious loggers he had ever worked with, and was very pleased with his work. He felt that there was no formal enforcement nor investigation on the site as Forest Service Law Enforcement did not do an investigation. Further, there were no fines, as the forester was able to determine that there were not wrong doings. The net result of this incident was a truncated test harvest, a logger who left the site feeling he had “black marks” against him lodged in federal records, and a US Forest Service employee pleased with the work done up to the point the logger left.

These incidents illustrate that in order to have a successful biomass harvest there is a need for:

- More careful work on the part of loggers to fulfill unfamiliar cutting prescriptions.
- Better communication and explanation of the legal requirements related to timber harvest on National Forest land during the pre-operations meetings between the forester and the operator. The point that it is not legally possible for the Forest Service to overlook any situation when it comes to an illegal harvest of trees from public land needs to be stressed. While Forest Service Law Enforcement may not be called to the scene, the Forest Service Forester responsible for the site needs to be informed of any violation to the contract. This holds true even when a conscientious logger makes an honest mistake and is not intended as a slight to the conscientious logger's performance.
- Forest managers should utilize prescriptions that minimize the chance of inadvertent mistakes by operators. For example, hand-cutting could be prescribed in areas where a machine would have a hard time staying in prescription. Or in tight areas, such as described in the above story, the prescription could identify removal of trees less than 5 inches dbh and allow a few additional trees between 5 and 7 inch dbh to be removed as well. This could build in some wiggle room for accidents, while still meeting other resource objectives.

It is important to note that most operators did not mention this potential for violating prescriptions as a problem, especially since these were study trials for both the operations and Forest Service officers. Forest Service timber sale administrators were monitoring sites frequently during operations, assessing the implementation of guidelines. They regularly clarified guidelines with operators where necessary.

Another concern was related to guidelines that required operators to protect certain species. As visibility is a concern for large machines, one operator requested that if something was to be protected, it should be marked out for him.

Communications between Operators

Recommendation

Be sure that operators of harvesters are conducting their felling and piling activities to increase forwarder/bundler efficiencies by communicating any operational requirements.

Challenge

Some operators did not get a chance to know what type of machine was going to follow them on the site, or to discuss with the preceding system operator their experience with the site they had cut and piled. The bundler and some forwarder operators expressed concerns that machines earlier in the system that cut and piled material were not operating with the thought that another machine was going to follow. The forwarder operator described this as "two paddling in opposite directions."

This was especially noted when some material was arranged in different directions, and not in a uniform and organized manner that can allow the bundling and forwarding operations to be more efficient. Both operators expressed concerns about long material arranged in piles, which ought to have been cut shorter to be handled more efficiently. The forwarding operator commented, "Maybe they thought this material was going to be skidded" using a tree-length skidder. Lack of communication between machine operators can lead to frustrations and a waste of valuable time. (Because these trials mixed operators and machines that often had never worked together, this sort of communication issue was more likely to arise than on a typical integrated logging operation.)

Payment Preferences

Recommendation

Biomass harvesters should be compensated on a per-acre or per-hour basis, not on the tonnage of biomass removed. For example, a Stewardship Contract could be a mechanism for per-acre payments. Biomass purchasers should adjust payment based on moisture content of the biomass, thereby supporting the delivery of dryer biomass, which provides them a better fuel. Truckers and grinder operators suggested a variety of payment options: per ton, per hour, per mile.

Challenge

Because expensive machines are used to collect low-value material, most operators could not imagine the possibility that collecting this material could fully cover their costs, especially at the current local market rate of $21.00/ ton, delivered. Operators agree that compensation ought to be based on the effort put into the extraction of biomass material, and not the quantity of product removed.

Mechanical treatment costs per acre are determined according to site density and the machines used. Estimated fuel reduction costs in the Superior National Forest area range from $300.00/acre to $500.00/acre for conventional mechanical treatments, which involves cutting and piling excess fuel only. An additional $50.00-$75.00/acre is paid to burn these piles. This amounts to $575.00/acre for high density sites, similar to the sites in this study.[75] If fuel treatment combines a timber sale, buyers are responsible for slash treatment, and are given an allowance, reducing the timber sale price to do so. In a timber sale, the Forest Service is still responsible for this $50.00-$75.00/ acre to burn piles, in addition to this allowance.[76]

Operators have a number of suggestions on how best to be paid for harvesting, forwarding, processing and delivering biomass material, which is time-consuming to gather, small in diameter, and low in weight and value.

- If operators are paid to harvest a site over a limited time, for example: 10 acres in four days, operators would "square off" and concentrate the work in the easiest and fastest areas.
- If harvesters are paid on a per-hour basis, they would collect more of the smaller material.
- If harvesters are paid on a per-ton basis, smaller material in the 2-3 inches range is going to be left.
- If harvesters are paid to reduce fuels on a site on a per-acre basis, then this smaller material ought to be given to them as a "bonus" for doing the job.
- When loggers are harvesting biomass, the flexibility to remove a limited number of larger trees will allow more efficient onsite operations.
- If operators are paid on a per-ton basis, and there is enough material removed from a site to cover harvesting costs, the market purchasing this material should pay on a per-dry ton basis. This is fairer, and rewards "on-site drying" since by the time material is trucked to the market it is lighter than the freshly harvested material.

The biomass trucking and grinding operators' payment preferences varied. One woodchips van driver said he would prefer to be paid on a per-ton basis, because it is easier for him to identify a price per ton rather than on a per-hour basis. A trailer-truck operator indicated he would rather be paid on a per-hour or per-mile basis for trucking bundles, as it was not possible to maximize tonnage hauled with a bundles-only load. The grinder operator indicated if he is paid on a per-ton basis, then rocks and stumps in forwarded material, which require hand removal, would negatively impact his earnings.

Summary of Recommendations

Operations related

- Machine operators should visit a site prior to operations.
- Forwarding of materials should take place right after material is cut, to improve efficiency of material forwarding, as site conditions are constantly changing.
- Forwarding and bundling hours can be reduced if material is sized and arranged in organized piles.
- Costly idle grinding time can be avoided if stumps and stones are removed from biomass before the grinder arrives on site.

Management related

- Site prescriptions tailored to the practical and operational needs of biomass harvest should be developed.
- Skid trails are necessary to make harvesting operations more efficient and less costly.
- Clear site demarcation, using customary logging flags or painting, can speed up operations.
- Demarcations signs from previous management operations should be removed to avoid possible confusion with biomass energy harvesting demarcation.

Coordination and communication

- Greater communication and coordination among operators, and with the forest managers and operators in early planning stages ensures a more efficient and effective implementation of biomass harvesting operations.
- Communicating harvest requirements directly to machine operators before an operation begins is vital, since operators are held responsible for any violations.
- Communicating to operators why certain prescriptions required specific exclusions or restrictions promotes a more informed understanding of the goals of the harvest.

Trials and errors

- Learning the techniques necessary to search for, harvest and recover smaller biomass material is a new practice for loggers in Minnesota. We can expect technique improvements over time leading to improved efficiencies and reductions in the cost of operations.
- Further research and monitoring of ongoing operations can help speed up this learning process and lead to more viable harvesting systems in the future.

Conclusion

Harvesting biomass as a fuel reduction tool to supply material for energy production is a new practice in Minnesota. Semi-structured interviews with forest machine operators in nine biomass harvesting trials indicate that existing fuel reduction prescriptions need to be modified to address operational barriers and planning and coordination concerns. Once biomass harvest for energy production is prescribed, incorporating an early understanding of production logistics into harvest plans, prescriptions and onsite operations can reduce biomass production costs.

CHAPTER 7: DISCUSSION, RECOMMENDATIONS AND CONCLUSIONS

Discussion

This study was designed to provide information to address two sets of challenges to the development of biomass markets in and around the Superior National Forest in northeastern Minnesota: 1) economic and operational issues faced by loggers, and 2) environmental constraints of concern to land managers, scientists and policy-makers involved in developing and refining biomass harvest practices. In the course of our study, we determined that administrative systems and constraints formed a third, important set of challenges to the development of biomass markets.

A great deal of concern has been expressed about the environmental impacts of biomass harvest. Much of this concern is based on the expectation of total removal of coarse woody debris and associated potential soil nutrient loss. These trials resulted in lower-than-expected removals in most instances due to a variety of reasons. Often, substantial amounts of biomass materials targeted for harvest remained on site.

While no definitive "right way" to harvest biomass for energy use can be identified as a result of these trials, this study documented numerous factors and considerations which affect the cost and operational feasibility of biomass harvest. Taken in the right combination, we found instances where biomass harvest and sale reduced the cost of fuels reduction treatments on the lands studied in northeastern Minnesota. Application of relevant recommendations in this study can serve as a guide to loggers, land managers, policy-makers, and those involved in the biomass energy industry as they seek to work together to achieve their numerous and complementary objectives.

Recommendations

Figure 7-1

Administrative Issues

	corporated at early phases of the planning process in order to incorporate many of these recommendations, to successfully utilize biomass harvest as a management tool on National Forest, state, county and private lands.
Site Prescription	Site prescriptions tailored to the practical and operational needs of biomass harvest are critical. These should, whenever possible, be flexible prescriptions that allow operator-determined options to lay out skid trails, reserve areas, and permit a minimal removal of residual trees to facilitate harvest and forwarding.
	Larger management units are preferred, as they will reduce administrative and harvest costs per unit area (e.g., equipment mobilization costs).
	Combining roundwood and biomass harvest is one strategy to improve on-site maneuverability and harvest efficiency.
	Focus biomass removals on larger materials and higher density areas (intensive or thorough removal across a variably stocked site is impractical and expensive).

Site Layout	Skid trails arranged in an efficient layout are necessary to make harvesting operations efficient.
	Clear site demarcation, using customary logging flags or painting, can speed up operations.
	Demarcations signs from previous management operations should be removed to avoid possible confusion with biomass energy harvesting demarcation.
	Minimize forwarding distance to biomass yarding areas.
Communication	Emphasize communication and coordination between forest managers, purchasers and operators as early as possible in the project planning stages to ensure a more efficient and effective implementation of biomass harvesting operations.
	It is vital for forest managers to communicate harvest requirements to purchasers (and where feasible operators) before work begins. Purchasers should do the same with their operators.
	Communicating to purchasers and operators why certain prescriptions requiring specific exclusions or restrictions promotes a more informed understanding of the goals of the harvest by operators and facilitates good communication.

Figure7-2

Operations

Equipment	Select equipment suitable to the terrain and forest conditions, carefully considering visibility from the cab, maneuverability and flexibility of use such as a dual harvester/forwarder. Lower cost equipment (such as biomass processing heads in place of timber processing heads) can improve harvest economics for this low-value material.
	No adaptations to standard forwarding equipment are necessary for biomass. However, operators need to learn new techniques of loading and maneuvering to be successful.
	Self-loading grinders should be employed to eliminate the need for a separate loader.
	Material haul efficiency should be maximized with full chip van loads or by transporting both roundwood and biomass bundles on a load when practical.
Techniques	Learning the techniques necessary to search for, harvest and recover smaller biomass material is a new practice for loggers in Minnesota. Operator proficiency is expected to improve over time, leading to increased efficiencies and reductions in the cost of operations.
	Machine operators should visit a site prior to operations to properly understand the site conditions, expectations and challenges of the project.
	Forwarding and bundling hours can be reduced if material is sized and arranged in organized piles for faster collection.
	Delays in grinding can be avoided if root stumps and stones are removed from biomass before the grinder arrives on site.
Season of Operation	Summer forwarding improves visibility of smaller biomass piles resulting in more efficient and complete recovery of harvested biomass.
	Forwarding of materials should take place right after material is cut, to improve speed and total recovery of material forwarding; snow or vegetative regrowth can obscure smaller biomass piles.

Figure 7-3

Environmental Considerations

Biomass Harvest Guidelines	In Minnesota, where guidelines were recently developed, following the *Biomass Harvesting on Forest Management Sites*[77] should mitigate concerns about soil nutrients, structure and wildlife habitat.

Table 7-4

Market Considerations

Transport Distance	Distance to biomass markets should be no greater than 100 miles; preferably considerably less.
Moisture	Payment should be per ton and should be adjusted for moisture content to reward on-site drying, and fairly compensated for transport of drier using more favorable materials.
Storage	If bundles are desired for biomass storage reasons, payments must reflect this value.

Conclusion

Harvesting biomass to accomplish the goals of fuel reduction, improved forest health and supplying material for energy production is a new practice in Minnesota. Fuel reduction prescriptions need to be adjusted to address operational challenges and planning and coordination concerns. Once biomass harvest is identified as a management option, incorporating an early understanding of production logistics into harvest plans and prescriptions can reduce fuel management and biomass production costs. Site prescriptions, distance to market, size and efficiency of operations, and equipment all influence the economic viability of biomass harvests as a tool to manage forests. Environmental effects of biomass removal on soils, wildlife habitats, and other natural features can be mitigated in Minnesota by following the Minnesota Forest Resource Council's *Biomass Harvesting on Forest Management Sites*.[78] Under the right combination of these circumstances, biomass harvest can reduce forest management costs.

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Photo Appendix

1

PosiTrack in operation on Pitcha South site

2

PosiTrack machine used on Pitcha South test site

3

Brush saw used on site 38-69

4

FabTek Processor

5

Truck and trailer used for hauling ground biomass from many sites

6

Horizontal Grinder at work on Caribou Trail landing

7

Ponsse Buffalo Dual in forwarding configuration hauling biomass bundles on Pitcha North site

8

Timbco harvester with harvest head

9

Valmet three-wheeled harvester used on Pitcha North site

10

Ponsse Buffalo Dual harvester and forwarder used on many test harvests

11

Valmet three-wheeled harvester at work on Pitcha North site

12

Timbco harvester with harvest head

13

John Deere Bundler operating on Caribou Trail site 38-69 landing

14

Ponsse Buffalo Dual loading the Rotochopper with loose biomass

15

EH 25 Harvester Head

16

Brush saw operator at work on Caribou Trail site 38-69

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