Sustainability in Forest Operations: Harvesting on Fragile Ground, Best Management Practices Assessment, Perspectives on Forest Certification, and Life Cycle Assessment of Forest Products

Alex Kunnathu George
University of Maine, alex.george@maine.edu

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SUSTAINABILITY IN FOREST OPERATIONS: HARVESTING ON FRAGILE GROUND, BEST MANAGEMENT PRACTICES ASSESSMENT, PERSPECTIVES ON FOREST CERTIFICATION, AND LIFE CYCLE ASSESSMENT OF FOREST PRODUCTS

By

Alex Kunnathu George

M.Sc. (Forestry) Kerala Agricultural University, 2017
B.Sc. (Forestry) Tamil Nadu Agricultural University, 2014

A DISSERTATION

Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy (in Forest Resources)

The Graduate School
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August 2022

Advisory Committee:
Anil Raj Kizha, Ph.D., Associate Professor of Forest Operations, School of Forest Resources, University of Maine (Advisor).
Adam Daigneault, Ph.D., School of Forest Resources, University of Maine.
Laura Kenefic, Ph.D., Northern Research Station, U.S. Forest Service.
Ling Li, Ph.D., School of Forest Resources, University of Maine.
John-Pascal Berrill, Ph.D., Department of Forestry and Wildland Resources, California Polytechnic State University Humboldt.
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SUSTAINABILITY IN FOREST OPERATIONS: HARVESTING ON FRAGILE GROUND, BEST MANAGEMENT PRACTICES ASSESSMENT, PERSPECTIVES ON FOREST CERTIFICATION, AND LIFE CYCLE ASSESSMENT OF FOREST PRODUCTS

By Alex Kunnathu George

Dissertation Advisor: Dr. Anil Raj Kizha

An Abstract of the Dissertation Presented in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy (in Forest Resources) August 2022

Sustainably managed forest and forest products are at the center as the world move toward a green economy. Sustainable forest management (SFM) cannot be possible without sustainability in forest operations, which includes quality optimization and ergonomics along with environment, economics, and people. To excel in the above-mentioned performance areas, all tools need to be employed to generate knowledge that enables forest managers and policymakers to preserve forests as a renewable resource. Machine cost and productivity estimation, forest growth modeling (Forest Vegetation Simulator), soil erosion modeling (Universal Soil Loss Equation), forestry best management practices (BMP) assessment, questionnaire survey, and life cycle assessment (LCA) techniques were used in this thesis to study sustainable forest operations in the northeast U.S. The first chapter introduces the importance of forest operations in SFM. The second chapter shows how the cost of harvesting on fragile soil was higher than on sturdy soil. Number of logs per cycle was a common factor in determining the productivity of all equipment in a cut-to-length (CTL)
harvesting method. Dependence of harvesting cost on fuel and labor cost was recognized. Predicted time required to regrow harvested merchantable volume was comparable to similar silvicultural treatments in the region. The third chapter evaluates harvested stands and showed a negative correlation between predicted soil erosion rate and BMP implementation score among harvesting methods. Even though there was no significant difference between predicted soil erosion rate between harvesting methods, whole-tree method had the highest. The fourth chapter assesses the perception of forest managers on forest certification. For forest managers, social license to operate was the most important reason for being certified. Many responders embraced adopting region- and stakeholder-specific certification standards. The survey identified several strategies to improve certification programs. The last chapter (fifth) shows LCA of a chip mill, an in-woods chipping operation, a hardwood sawmill, and a softwood sawmill. LCA identified transportation and wood consumed as the most contributing input parameters to environmental impacts. Softwood sawn timber boards (plank) had the highest global warming potential (GWP), and the lowest was for chip mill bark. The influence of transportation on GWP was also explored.
DEDICATION

Dedicated to the loving memory of my mummy

Kunjumol George
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1 INTRODUCTION

The U.S. Forest products industry contributes $169 billion (5% of the manufacturing gross domestic product) to the state exchequer annually (Russell, 2020). The forest industry is gaining more traction as there is a push toward green economy (low carbon, resource efficient, and socially inclusive (UNEP, 2018)) to mitigate global climate change. A projection (2006-2030) on the forest industry by the United Nations (UN, n.d.) has shown a positive trend in forest resource consumption. The increased dependence on forests will raise sustainability related issues (FAO, 2018; Marchi et al., 2018; Thompson et al., 2013). Forest can only be a solution for climate change mitigation if they are sustainably managed (Schulze et al., 2022) and depends largely on executing forest operations in a sustainable way (Marchi et al., 2018). For that, there should be efficient deployment of forest management and decision-making tools to empower forest managers to identify and face current challenges. This thesis demonstrates how some of the available tools can be used to support sustainable forest operations in Northeastern U.S.

The northeastern U.S. has a 400-year history of active forest management (Thompson et al., 2013). Forest product industry is an integral part of the economy in the region. The industry faces many challenges, such as aging workforce and lack of skilled machine operators (Koirala, Kizha, & Roth, 2017), higher cost of entry into logging business (Leefers et al., 2020), climate change exposing more sensitive ground to forest operations (George et al., 2021; Soman et al., 2020), small diameter trees, unsatisfied land managers on receiving the monetary benefits of forest certification programs (George et al., 2022), lack of information on carbon budgeting of forest products (Nunery & Keeton, 2010; Pokhrel et al., 2022), impact of timber harvesting on environment (Akay et al., 2006; Kizha et al., 2021), etc.
Understanding the machine cost and productivity is essential to determine the feasibility of forest operations because of various stand, site, operational, and silvicultural factors involved (Han et al., 2004; Kizha & Han, 2015a; Louis et al., 2022). This enables the logging contractor and forest manager to negotiate and fix logging costs to run a profitable business. Cost and productivity method developed by Miyata et al., (1980) is the most widely used in the region, which uses machine cost, time operated, and log volume to estimate the cost and productivity of logging equipment (Adebayo et al., 2007; Miyata, 1980; Sahoo, Bilek, et al., 2019). There are several other methods to determine the amount of time a machine operates (Ackerman et al., 2014). However, most research used the cycle time method for estimating machine cost and productivity, as it enables understanding the factors affecting operational cost and effective comparison with other operations (Kizha & Han, 2015a; Louis et al., 2022).

Forest vegetation simulator (FVS) is a growth and yield model used to predict the growth rate of forests based on stand and site information and inventory data (Canavan & Ramm, 2000; Crookston & Dixon, 2005). Understanding volume available and time for the next entry will help to allocate resources in appropriate stands so that pillars of sustainability are achieved. The simulations and predictions from FVS have been widely used by forest managers to make operational, strategic, and tactical decisions.

The concern of environmental damage due to forest operations can be addressed by properly implemented BMP during the entire course of forest management (Aust & Blinn, 2004; Barrett et al., 2016). Continuous evaluation of implementation and loggers training is warranted for the effectiveness of BMP (Aust & Blinn, 2004; Carlson et al., n.d.). Predicted soil erosion rate using USLE can be used as a proxy to estimate the damage to water quality and residual stand.
This tool will facilitate selecting equipment mix and silvicultural treatments with minimum environmental disturbance.

To address the social part of sustainable management, there should be adequate understanding on stakeholders’ attitudes, beliefs, and perceptions because they strongly influence decision making (NOAA, 2015). A well-structured and executed survey can be used to collect information from a sample population in a systematic way which will identify problems and solutions that can inform policymakers for taking necessary corrective actions. Online surveys are faster with wider reach, and have reasonable response rate (Amany & Krishna, 2017; NOAA, 2015).

To minimize the issues with comprehension of carbon budgeting and carbon market, there is a necessity to assess carbon footprint of entire supply chain. LCA can profile carbon footprint of materials, production processes, etc. (Alzamora et al., 2022; Baumann & Tillman, 2004; Han et al., 2015). Along with estimating carbon footprint, life cycle impact assessment can help to choose products or processes with minimal environmental damage.

This dissertation comprises an introduction (Chapter 1) and four other chapters (Chapter 2-5) written and formatted as full-length manuscripts. These chapters explore various pillars of sustainable forest operations. The results of chapters 2, 3, and 4 were presented as oral presentations at various regional, national, and international conferences. The dissertation is organized as follows:

Chapter 1 introduces the dissertation by providing insights into forest operations and sustainability concepts in timber harvesting. The chapter also provides rationale for the upcoming chapters.
Chapter 2 is published in the International Journal of Forests Engineering (George et al., 2021). This chapter explores the cost and productivity of timber harvesting on fragile ground, emphasizing northern white-cedar. The chapter investigates the factors contributing to the cost of harvesting using cut-to-length method. The impact of fuel price and labor cost on timber harvesting is also explored. The chapter also stimulates harvest sustainability. The results of this study will be helpful to forest managers in choosing the right equipment mix for harvesting in sensitive soils.

Chapter 3 reveals the soil erosion potential of different timber harvesting methods using the USLE. In this chapter, forestry best management practices were assessed to understand the implementation percentage and correlated to modeled soil erosion estimates. Information on ground cover percentage for predominant harvesting methods are presented here. The results will be an added information to forest managers in selecting the harvesting methods with minimal environmental damage.

Chapter 4 is the results of a survey conducted among forest managers to understand their perspective on forest certification programs. This chapter discusses strategies to retain forest certification and proposes a reduced number of surveillance audits for continuously certified landowners. This chapter is published in the journal Trees, Forest, and People (George et al., 2022). This chapter will be useful to forest certification standards to make improvements based on the feedback from people on the ground (forest managers).

Chapter 5 studies the concept of carbon footprint and global warming potential through life cycle assessment (LCA). The environmental impact of four different wood-based production facilities is assessed using LCA. Along with identifying the input with higher environmental impact, comparisons of different production facilities are made here.
2 TIMBER HARVESTING ON FRAGILE GROUND AND IMPACTS OF
UNCERTAINTIES IN THE OPERATIONAL COSTS

2.1 Abstract

Forested wetlands with high water tables are sensitive to disruption from harvesting yet support commercially desired tree species like northern white-cedar. Winter harvest was conducted in Maine, U.S. to compare operational costs and productivity of cut-to-length harvesting in cedar (fragile soil) and non-cedar stands (mixedwood, sturdy soil), evaluate uncertainties in harvesting costs and influential factors, and forecast time for post-harvest recovery to pre-harvest volumes. Operational costs were calculated using detailed time and motion studies. Operational costs for the cedar stands were higher than non-cedar. Regression models were developed for harvester, forwarder, and self-loading truck; number of logs per cycle was a common factor. Sensitivity analysis showed the dependence of operational costs on labor and fuel costs. Forest Vegetation Simulator projections were used to assess harvest sustainability and suggested the time required to regrow harvested merchantable volume is comparable to cutting cycles recommended for similar treatments in the region. Predicted growth rates exceed those reported regionally on similar sites, suggesting additional study of post-harvest response is warranted. Results highlight site constraints on both operational and stand productivity in lowlands and will be useful for timber harvesting decision-making and forest management planning if combined with assessment of residual stand growth response.

2.2 Introduction

Forested wetlands, characterized by woody vegetation six meters or taller, provide a wide variety of ecosystem services to humankind (Jiang, 2016). In the state of Maine, U.S. forested wetlands account for 56% of total wetlands (Tiner, 2007). The major forested wetlands of Maine
are cedar swamps, spruce bogs, red maple fens, and silver maple floodplain forests (PIN, nd). Northern white-cedar (*Thuja occidentalis* L.) is one of the most important tree species in forested wetlands of the northeastern U.S. and southeastern Canada in terms of conservation and timber values (Boulfroy et al., 2012; Wesely et al., 2018).

Approximately 75% of cedar forests are found in habitats broadly described as lowlands in the northeastern U.S. (Boulfroy et al., 2012). Of these, 54% and 21% are located in flatwoods (relatively flat areas outside of floodplains; Ainslie 2002) and swamps (forested wetlands), respectively (Boulfroy et al., 2012). Cedar occurs in both mixed and pure stands where sites are characterized by deep, organic, and poorly drained soil conditions (Boulfroy et al., 2012; Frohn, 2017). These stands are relatively under-managed because of the fragile ecosystem where the species grows (Kenefic, 2013). In terms of timber harvesting, accessibility to the stand, absence of sturdy soil, and a high water table can pose hazards to both timber harvesting equipment and the ecosystem (Boulfroy et al. 2012).

Reduced volume of cedar growing stock in recent years in some parts of its range is attributed to a wide variety of stand conditions that create challenges for sustainable management (Boulfroy et al., 2012; Huff & McWilliams, 2016). Yet active management is necessary to ensure the economic (specialty products, shingles, essential oils), social (traditional uses by Native Americans), and ecosystem (biodiversity maintenance and wildlife habitat) benefits provided by cedar stands (Botti, 1991; Boulfroy et al., 2012; Heitzman et al., 1997; Verme & Johnston, 1986). Understanding the cost and productivity of harvesting lowland cedar is critical to sustainable management of these stands and their ecosystem services.

Timber harvesting involving heavy machines, such as harvesters, can cause soil disturbances in the form of compaction and rutting (Addison et al., 2019; Soman et al., 2019,
Furthermore, lowland sites such as forested wetlands that are water-logged for a portion of the year tend to have smaller trees compared to uplands (Hofmeyer et al., 2009). Because the cost of timber harvesting per unit volume is a function of the average tree size harvested, this can lead to reduced productivity in such stands (Kizha & Han, 2016; Soman et al., 2019). Additionally, shorter timber harvesting seasons, an impact of climate change, may have contributed to the observed 47% decline in cedar harvest in Maine since 2000 (Berry et al., 2019; Woodall et al., 2019). Changing winter temperatures can result in fewer days with frozen ground and snow cover, both of which are necessary for harvesting operations in lowlands. In Maine, winter warming has resulted in a lower number (decreased from 26 to 16 days) of nights less than -17°C over the last two decades (1995-2014) (Runkel et al., 2017). This has resulted in the shifting of timber harvesting operations from some lowlands to more upland sites (Keenan, 2015).

Silvics of cedar suggest the use of selection or irregular shelterwood systems for retention and release of well-established cedar trees and to begin regeneration (Boulfroy et al., 2012; Kenefic, 2013). Moreover, partial harvest prescriptions have fewer detrimental effects on fragile sites than clearcutting (Jiang, 2016), and thus are preferable on lowlands. This is relevant in the northeastern U.S. and in Maine specifically, due to the prevalence of harvests such as overstory removals (removing all trees to release established regeneration) and commercial clearcuts (removing all merchantable trees) (Belair and Ducey 201; Maine Forest Service 2021). Further, to sustainably manage lowland cedar, operations need to be limited to frozen ground conditions for reducing the impacts of soil compaction, rutting, root damage, risk of windthrow, and the probability of machines sinking (Boulfroy et al., 2012; George et al., 2019; Rossman et al., 2016; Russell et al., 2018).
Within mechanized ground-based harvesting systems available in the study region, cut-to-length (CTL) harvesting method, where the entire tree is processed at the stump, is ideal for fragile sites as compared to conventional whole-tree harvesting methods (Han et al. 2009; Jiang 2016; Kizha et al. 2021). Harvest residue (slash) is left on site to armor the trails and provide support when frozen, reducing potential soil disturbances and enhancing safety and efficiency of the operation (Cudzik et al., 2017). Additionally, logs are carried (forwarded) during primary transportation, thereby reducing soil disturbances and damage to advanced regeneration relative to whole-tree skidding; for this reason, this method is compatible with cedar management on sites with established regeneration (Waters et al., 2004). CTL equipment is also relatively compact, resulting in narrower trails; the equipment has tracks that disperse weight; and the number of machine passes are fewer as compared to whole tree-method (Louis & Kizha, 2021b; Rossman et al., 2016). The above-mentioned factors make CTL harvesting method the preferred option for lowland cedar harvesting.

Predicting the volume of timber available at the next entry is crucial information to determine sustainable harvest over the management period. The Forest Vegetation Simulator (FVS) and its regional variants are commonly used growth and yield models in the U.S., where growth rates can be predicted based on stand and site information and inventory data (Canavan & Ramm, 2000). FVS is an individual-tree model that supports the specification of management prescriptions by providing information on maximum allowable height and diameter, Stand Density Index (SDI), species, and silviculture (i.e., trees of specified sizes and species are removed prior to projection to simulate silvicultural treatment) (Crookston & Dixon, 2005; Dixon & Keyser, 2008).
Estimating the cost of harvesting and assessing the amount of available timber in the future will help determine the feasibility of harvesting lowland cedar growing in fragile ecosystems. The specific objectives of this study were to: a) Compare the cost and productivity of cut-to-length operations between lowland cedar on fragile soil and non-cedar mixedwood stand on sturdy soil; b) evaluate uncertainties in the harvesting costs with respect to influential factors using sensitivity analysis; and c) forecast time to recover to pre-harvest volume using FVS, for the purpose of scheduling subsequent harvest operations.

2.3 Materials and methods

2.3.1 Study area

The study was conducted in the Penobscot Experimental Forest (PEF) in Eddington (44°49’56” N, 68°36’ 26” W; Site 1) and Danforth (45°37’56” N, 67°48’ 14” W; Site 2), Maine, U.S. (Figure 2.1). In site 1 (S1), two treatments with different ground conditions were studied: S1 Treatment 1 (S1T1), a 4.4-ha cedar-dominated stand in a lowland characterized by wet, marshy land with organic soil and high-water table throughout the growing season, and Treatment 2 (S1T2), a 12.5-ha mixedwood stand on sturdy soil. In S1T1, average depth to the water table was 0.20 and 0.34 m for spring and summer, respectively. For S1T2, average depth to the water table was 1.08 m in spring and 3.20 m in summer (Murphy et al. 2011; UNB Forest Watershed Research Center 2014). During the operations, the average temperature and snow depth were 7.4°C and 16 cm, respectively. Soil types present in S1T1 were Bucksport and Wonsqueak muck (83%) and Peru-Colonel-Turnbridge association (17%); the slope was 0–3%. In S1T2, soil types Becket-Skerry complex (46%), Peru-Colonel-Tunbridge association (29%), and Monarda-Telos complex (21%) dominated, and the slope ranged from 2–15% (Soil Survey Staff, n.d.).
Figure 2.1 S1T1 (lowland cedar), S1T2 (non-cedar stand) and S2T1 (lowland cedar) in the study site along with the actual landing and hypothetical landing.

In site 2 (S2) treatment 1 (S2T1), a 3.3-ha cedar-dominated stand similar to S1T1 was studied. The Monarda-Burnham complex soil type dominated the site, and the slope ranged from 0–3%. The average temperature was -9.8°C. Snow depth and water table information were unavailable.

2.3.2 Stand inventory

S1T1 was inventoried using nested circular plots (Kenefic et al., 2018). Nine fixed-radius plots of 0.08 ha (16.1 m radius) were used to measure the diameter at breast height (dbh, at 1.37 m), tree height, and species of trees ≥ 11.4 cm dbh. The stand density of S1T1 was 1320 trees ha⁻¹.
with a basal area of 51 m$^2$ ha$^{-1}$, and quadratic mean diameter (QMD) of the stand was 22.1 cm. Cedar (81%) was the dominant species (Table 2.1). Other species included red maple (*Acer rubrum* L.; 8%), American larch (*Larix laricina* (Du Roi) K. Koch.; 7%), and red spruce (*Picea rubens* Sarg.; 1%) (Table 2.1).

Table 2.1 Stand inventory descriptions for S1T1, S1T2, and S2T1. S1T1 and S2T1 were cedar dominated stands on fragile ground, whereas S1T2 was a non-cedar stand on more sturdy soil profile.

<table>
<thead>
<tr>
<th>Stand Attributes</th>
<th>S1T1</th>
<th>S1T2</th>
<th>S2T1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (ha)</td>
<td>4.4</td>
<td>12.5</td>
<td>3.3</td>
</tr>
<tr>
<td>Basal Area (m$^2$ ha$^{-1}$)</td>
<td>51 ± 2</td>
<td>40 ± 3</td>
<td>46 ± 5</td>
</tr>
<tr>
<td>Trees per ha</td>
<td>1320 ± 31</td>
<td>739 ± 59</td>
<td>1085 ± 174</td>
</tr>
<tr>
<td>QMD$^a$ (cm)</td>
<td>22.1</td>
<td>26.2</td>
<td>23.4</td>
</tr>
<tr>
<td>Volume (m$^3$ ha$^{-1}$)</td>
<td>315</td>
<td>305</td>
<td>296</td>
</tr>
<tr>
<td>Timber harvested (m$^3$ ha$^{-1}$)</td>
<td>120</td>
<td>127</td>
<td>108</td>
</tr>
<tr>
<td>Removal percentage</td>
<td>38.1</td>
<td>41.6</td>
<td>36.5</td>
</tr>
</tbody>
</table>

$^a$ QMD - Quadratic Mean Diameter

S1T2 had 24 variable-radius plots inventoried utilizing a 20 Basal Area Factor prism. The parameters recorded were similar to those of the fixed-area plots described above. The dominant species was eastern hemlock (*Tsuga canadensis* (L.) Carr.; 54%). Other species were eastern white pine (*Pinus strobus* L.; 23%), cedar (8%), red maple (6%), black ash (*Fraxinus nigra* Marsh.; 3%), yellow birch (*Betula alleghaniensis* Britt.; 1%), quaking aspen (*Populus tremuloides* Michx.; 1%),
and paper birch (*Betula papyrifera* Marsh.; 1%). The treatment had a basal area of 40 m$^2$ ha$^{-1}$ with 739 trees ha$^{-1}$ (Table 2.1), and the QMD was 26.2 cm.

S2T1 was inventoried (4 plots) with the method used in S1T1. Stand density was 1085 trees ha$^{-1}$ with a basal area of 46 m$^2$ ha$^{-1}$, and the QMD was 23.4 cm. Cedar (81%) was the dominant species; other species were red maple (8%), red spruce (7%), balsam fir (*Abies balsamea* (L.) Mill; 2%), and paper birch (1%) (Table 2.1). The stand inventory was performed by U.S. Forest Service and the University Forest, which resulted in the difference in inventory techniques adopted.

### 2.3.3 Silvicultural prescription

Variants of the irregular shelterwood system were prescribed in all the treatments to improve growth of desired residual trees and establish regeneration. Silvicultural prescriptions for the treatments are detailed in George et al. (2019). After the harvest, basal area (BA) of S1T1, S1T2, and S2T1 was reduced to 31, 22, and 29 m$^2$ ha$^{-1}$, respectively.

### 2.3.4 Harvesting operation

A cut-to-length (CTL) harvesting method was employed for both treatments. The operation was conducted during the winter, February 2019 in S1 and February 2020 in S2, during which the ground was frozen, ensuring stability for the machines to maneuver the fragile soil conditions. The operation lasted four days each in S1T1 and S2T1, and eight days in S1T2. Machines and operators were different for S1 and S2. The operators had more than six years of experience.

### 2.3.5 Operational phases

Operational phases were felling and processing (harvester), extraction (forwarder), and loading (self-loading trucks). The components of Delay Free Cycle time (DFC; Table 2.2) used for a detailed time-motion study are detailed in George et al. (2019). Information on the machines used is provided in Table 2.3.
Table 2.2 Cycle elements and independent variables recorded during the detailed time and motion study (George et al., 2019).

<table>
<thead>
<tr>
<th>Operational phases</th>
<th>Cycle elements</th>
<th>Recorded predictor variable(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Felling and processing</strong> (Harvester)</td>
<td>Travel to trees</td>
<td>Butt-end diameters (cm)</td>
</tr>
<tr>
<td></td>
<td>Cutting</td>
<td>Decking distance (m)</td>
</tr>
<tr>
<td></td>
<td>Processing</td>
<td>Distance between trees (m)</td>
</tr>
<tr>
<td></td>
<td>Decking</td>
<td>Number of cuts per cycle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of logs per cycle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Species</td>
</tr>
<tr>
<td><strong>Extraction</strong></td>
<td>Travel empty</td>
<td>Butt-end diameters (cm)</td>
</tr>
<tr>
<td>(Forwarder)</td>
<td>Travel loaded</td>
<td>Loaded distance (m)</td>
</tr>
<tr>
<td></td>
<td>Loading</td>
<td>Number of pieces</td>
</tr>
<tr>
<td></td>
<td>Unloading</td>
<td>Species</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Travel empty distance (m)</td>
</tr>
<tr>
<td><strong>Loading</strong></td>
<td>Swing empty</td>
<td>Butt-end diameters (cm)</td>
</tr>
<tr>
<td>(Self-loading truck)</td>
<td>Grappling</td>
<td>Length of log (m)</td>
</tr>
<tr>
<td></td>
<td>Swing loaded</td>
<td>Number of pieces</td>
</tr>
<tr>
<td></td>
<td>Sorting</td>
<td>Species</td>
</tr>
</tbody>
</table>
Table 2.3 Machine rate and cost of the equipment used in the harvesting. All the information was provided by the forest management company which owned and operated the equipment.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Site 1 (S1)</th>
<th>Site 2 (S2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Harvester</td>
<td>Forwarder</td>
</tr>
<tr>
<td>Make and Model</td>
<td>Ponsse</td>
<td>Ponsse</td>
</tr>
<tr>
<td></td>
<td>Scorpion</td>
<td>Buffalo</td>
</tr>
<tr>
<td></td>
<td>King 2018</td>
<td>2016</td>
</tr>
<tr>
<td>Purchase price (US$)(^a)</td>
<td>650,000</td>
<td>400,000</td>
</tr>
<tr>
<td>Salvage Value (US$)</td>
<td>200,000</td>
<td>75,000</td>
</tr>
<tr>
<td>Variable or operating cost</td>
<td>69.32</td>
<td>37.89</td>
</tr>
<tr>
<td>(US$ PMH(^{-1}))(^b)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Economic life (yrs.)</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Labor cost (US$ PMH(^{-1}))</td>
<td>40.00</td>
<td>34.67</td>
</tr>
<tr>
<td>Fuel consumption (L PMH(^{-1}))(^c)</td>
<td>20.57</td>
<td>14.96</td>
</tr>
<tr>
<td>Scheduled machine hours (SMH yrs(^{-1}))</td>
<td>2000</td>
<td>2200</td>
</tr>
<tr>
<td>Utilization (%)</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>Machine rate (US$ PMH(^{-1}))</td>
<td>205.91</td>
<td>120.43</td>
</tr>
<tr>
<td>Operator experience (yrs)</td>
<td>8</td>
<td>6</td>
</tr>
</tbody>
</table>

\(^a\) All prices are expressed in US Dollars

\(^b\) PMH = Productive Machine Hour

\(^c\) L PMH\(^{-1}\) = Liter per Productive Machine Hour
S1 had a higher average forwarding distance than S2. For a realistic comparison of forwarding cost irrespective of the distance due to stand conditions, a hypothetical (imaginary) landing was presumed adjacent to the stand boundaries of S1T1 and S1T2. Difference in distances between the actual and hypothetical landings were 911 and 837 m for S1T1 and S1T2, respectively. The actual landing was at the stand boundary in S2T1. This has helped in effective comparison of extraction costs between the sites. Time and distance to reach the hypothetical and actual landing were separately measured for each forwarding cycle. For each DFC, travel time from hypothetical to actual landing was deducted, and variation in cost of extraction due to difference in forwarding distance was evaluated for S1T1 and S1T2.

2.3.6 Harvesting cost calculations

Harvesting cost was determined for the stump-to-truck phase of the operation. By assimilating machine rate (productivity and operating cost of the machine, US$ PMH$^{-1}$), average DFC time, and volume produced (log scaling, Huber’s formula) per DFC, the cost of operation was evaluated per unit volume (US$ m^3$) of wood generated from the treatments (George et al., 2019; Miyata, 1980; Soman et al., 2019). The cost of felling and processing per unit area (US$ ha^{-1}$) was estimated by multiplying wood harvested per unit area (m$^3$ ha$^{-1}$) and operating cost per unit volume (US$ m^3$).

2.3.7 Cost allocation

To evaluate the individual cost of felling and processing for the different assortments, an exclusive product allocation was carried out, in which DFC times from the whole operation were separated to calculate the cost and productivity for the three assortments (cedar, other softwoods, and hardwoods) (Louis & Kizha, 2019).
2.3.8 Sensitivity analysis

A local sensitivity analysis was conducted to understand the effect of fluctuation in fuel prices and labor wages on the cost of operations, keeping all other elements constant (Kizha & Han, 2016). For comparison, the minimum wage was kept as US$ 12.00 per scheduled machine hour (SMH), as per legal regulation for the state of Maine at the time of this study. The maximum wage used was US$ 30.00 per scheduled machine hour (SMH). Fuel price altered between US$ 0.50 and 1.5 per liter.

2.3.9 Stand projection

Treatments were projected using the FVS Northeast Variant’s Acadian growth and yield model for merchantable volume of timber, which has been developed for the Acadian region, where the study sites are located. Treatments were projected until the stands reached pre-harvest merchantable volume. Based on tree age and height data collected on-site, site indices of 12 m for cedar and 21 m for white pine at an index age of 50 years were used for the projections.

2.3.10 Statistical analysis

R software (version 4.0.3) was used to perform statistical analysis. Datasets were checked for the assumptions of linear regression. Linear regression was performed, keeping DFC time as the dependent variable (Table 2.2). Models were selected based on the lowest AIC values using the MASS package (Venables & Ripley, 2002). ANOVA followed by Tukey HSD post hoc was conducted to determine significant difference (p < 0.05) between the observed variables. Standard errors were estimated and denoted after parameter values.
2.4 Results

2.4.1 Harvesting operation

A total of 528, 1588, and 356 m$^3$ of wood was harvested from S1T1, S1T2, and S2T1, respectively (Table 2.1). In S1T1, most logs were cedar (72%), followed by hardwood (13%), larch (10%), and spruce (2%). In S1T2, hardwoods (48%) constituted the most, followed by hemlock (26%), cedar (14%), pine (6%), fir (4%), and spruce (2%). In S2T1, a similar trend to S1T1 was observed, i.e., cedar (52%), hardwood (31%), and spruce (17%). ANOVA revealed a significant difference in dbh (p < 0.01) between S1T1 (21.27 ± 0.20 cm) and S1T2 (35.36 ± 2.43 cm), and S1T2 and S2T1 (22.15 ± 0.38 cm). However, no difference was found between S1T1 and S2T1.

Total cost of operating in S1T1 (US$ 16.64 m$^3$) was higher compared to S1T2 (US$ 9.56 m$^3$) and S2T1 (US$ 13.17 m$^3$) (Table 2.4). Cost of harvesting cedar-dominated stands was higher than a non-cedar stand. Equipment and operators were the same for S1T1 and S1T2, the difference in cost can be attributed to stand conditions, number of logs handled, average log size, and extraction distance (Table 2.5) (Baek, 2018; Kizha & Han, 2016; Proto et al., 2018; Soman et al., 2019).
Table 2.4 Cost (US$ m\(^3\)) and productivity (m\(^3\) PMH\(^{-1}\), Productive Machine hours) of each operational phase.

<table>
<thead>
<tr>
<th>Operational phase</th>
<th>Cost</th>
<th>Productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S1T1</td>
<td>S1T2</td>
</tr>
<tr>
<td>Felling and Processing (Harvester)</td>
<td>6.45</td>
<td>3.80</td>
</tr>
<tr>
<td>Extraction (Forwarder)</td>
<td>8.85(^b)</td>
<td>4.42(^b)</td>
</tr>
<tr>
<td>Loading(^a) (Self-loading truck)</td>
<td>1.34</td>
<td>1.34</td>
</tr>
<tr>
<td>Total</td>
<td>16.64</td>
<td>9.56</td>
</tr>
</tbody>
</table>

\(^a\) All Products were merged at the landing

\(^b\) Hypothetical landing

Table 2.5 Factors influencing the total operational costs for the treatments.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Harvester</th>
<th>Forwarder</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S1T1</td>
<td>S1T2</td>
</tr>
<tr>
<td>Average DFC(^a) time (min)</td>
<td>0.53 ± 0.66</td>
<td>± 0.42 ±</td>
</tr>
<tr>
<td>Volume per log (m(^3))</td>
<td>0.20 ± 0.35</td>
<td>± 0.22 ±</td>
</tr>
<tr>
<td>Number of logs per cycle</td>
<td>1.88 ± 2.26</td>
<td>1.46 ±</td>
</tr>
</tbody>
</table>

\(^a\) DFC – Delay free cycle time
2.4.1.1 Felling and processing

From all the treatments, a total of 542 DFCs were recorded. ANOVA followed by Tukey HSD post-hoc test showed a significant difference in average DFC time between S1T1 (31.7 ± 1.63 sec) and S1T2 (39.42 ± 2.93 sec) (p = 0.03), and between S1T2 and S2T1 (24.91 ± 1.14 sec) (p < 0.01). No significant difference was observed between S1T1 and S2T1 (p = 0.19). The processing time contributed most to the DFC time (48% (15.51 ± 1.30) in S1T1, 61% (24.07 ± 2.41) in S1T2, and 69% (17.24 ± 0.64) in S2T1), followed by travel time between trees, decking time, and felling time. Processing time differed significantly between S1T1 and S1T2 only (p < 0.01) and the harvester produced a significantly lower number of logs per cycle in S1T1 (1.88 ± 0.05; 0.36 m$^3$ DFC$^{-1}$) and S2T1 (1.46 ± 0.05; 0.32 m$^3$ DFC$^{-1}$) than S1T2 (2.26 ± 0.11; 0.79 m$^3$ DFC$^{-1}$; p < 0.01). Similarly, for the number of cuts per cycle, significant difference was observed only between S1T1 (2.14 ± 0.07) and S1T2 (2.56 ± 0.13; p < 0.01).

Cost of the felling and processing and machine productivity rates for the treatments are reported in Table 2.4. The costs for felling and processing were US$ 774.00, 482.60, and 624.24 ha$^{-1}$ for S1T1, S1T2, and S2T1, respectively, i.e., lower cost for the non-cedar stand.

2.4.1.2 Extraction

Extraction accounted for 48% of the total in-woods (stump to landing) operational costs (Table 2.4). Hypothetical landings were assigned in S1 to understand the variation in the cost of forwarding due to changes in forwarding distances. The extraction cost was increased to US$ 13.33 and 7.46 m$^3$ (34 and 41%) for S1T1 and S1T2, respectively, when the logs were brought to the actual landing. This was due to the increase in forwarding distance by 911 m (S1T1) and 837 m (S1T2), which in turn increased the DFC time by 25 minutes (S1T1) and 22 minutes (S1T2). Standardizing the increased cost showed that an increase in forwarding distance by 100 m can
increase the forwarding cost by an average of US$ 0.43 m$^{-3}$ (US$ 0.49 m$^{-3}$ for S1T1 and US$ 0.36 m$^{-3}$ for S1T2). This can be affected by the terrain, slope, and other site conditions.

Loading logs (within the unit) from S1T1 (35 ± 3 minutes) took more time than S1T2 (19 ± 3 minutes) because of the higher number of logs handled per DFC (74.6 ± 3.84 for S1T1 and 55.38 ± 6.48 for S1T2) and difference in distances between the loading points. Relative to S1T2, S2T1 took more time (22.43 ± 2 minutes) to load logs, and more number logs were loaded (83.43 ± 3.60). At the landing, unloading time was higher for S1T1 (11.60 ± 1.96 minutes) compared to S1T2 (9.75 ± 0.67 minutes) because of a larger percentage of smaller trees in the former, which resulted in the operator grappling more logs per unloading cycle element (6.28 ± 0.55 for S1T1 and 3.95 ± 0.51 for S1T2). In S2T1, unloading time was 10.00 ± 0.81 minutes, and unloaded 7.29 ± 0.59 logs per cycle; this is similar to S1T1. There was no significant difference (p = 0.61) in unloading time between treatments.

2.4.1.3 Loading

It took an average of 49 minutes to load a truck. The average DFC time was estimated at 33.31 ± 5.81 sec and 34.64 ± 2.94 sec for S1 and S2, respectively. The loading cost for cedar pulpwood (US$ 1.93 m$^{-3}$) was higher compared to hardwood pulpwood (US$ 1.39 m$^{-3}$) (Table 2.6).
Table 2.6 Operational cost (US$ m⁻³) and productivity (m³ PMH⁻¹) of loading various products (George et al. 2019).

<table>
<thead>
<tr>
<th>Product</th>
<th>Delay free cycle time (sec)</th>
<th>Average volume per log (m³)</th>
<th>Cost</th>
<th>Productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cedar pulp</td>
<td>25.88 ± 1.34</td>
<td>0.13</td>
<td>1.93</td>
<td>44.96</td>
</tr>
<tr>
<td>Hardwood pulp</td>
<td>44.83 ± 2.68</td>
<td>0.18</td>
<td>1.39</td>
<td>62.40</td>
</tr>
<tr>
<td>Pine sawlog</td>
<td>28.88 ± 2.21</td>
<td>0.48</td>
<td>1.13</td>
<td>76.28</td>
</tr>
</tbody>
</table>

2.4.2 Sensitivity analysis on the cost of operation

The analysis showed that a 50% increase in fuel price would increase the cost of felling and processing by 5% and the extraction cost by 6%. On the other hand, a 50% increase in the wage of machine operators would increase the felling and processing cost by 7% and the extraction cost by 9%.

2.4.3 Stand projection

S1T1 had a post-harvest volume of 195 m³ ha⁻¹ and was projected to grow back to the pre-harvest level (315 m³ ha⁻¹) in 20 years. S1T2 had a post-harvest volume of 178 m³ ha⁻¹ and was projected to take 22 years to recover to the pre-harvest level (305 m³ ha⁻¹). S2T1 was projected to take 21 years to grow back from post-harvest level (188.01 m³ ha⁻¹) to the pre-harvest level (295 m³ ha⁻¹). This reflects not only differences in harvest volume but predicted net growth. S1T1, S1T2, and S2T1 were projected to grow at a rate of 6.01, 5.91, and 5.07 m³ ha⁻¹ yr⁻¹. In addition, though the cedar and non-cedar stands are predicted to reach their previous pre-harvest merchantable volumes in about 20 to 22 years, projected stand densities decrease over time from 778 to 709, 314 to 287 and 682 to 618 trees ha⁻¹ in S1T1, S1T2, and S2T1, respectively. This
indicates a predicted mortality rate of 4, 2, and 3 trees ha\(^{-1}\) yr\(^{-1}\) in S1T1, S1T2, and S2T1, respectively.

2.5 Discussion

For the regression models developed for operational phases, R\(^2\) were 0.57, 0.66, and 0.33 for felling and processing, forwarding, and loading (Table 2.7). Similar R\(^2\) and significant predictor variables were observed by Hiesl and Benjamin (2015) and Proto et al. (2018). Butt-end diameter, distance traveled, and logs per cycle were found to be the significant variables for predicting DFC time (Ioan Apăfăian et al., 2017; Nurminen et al., 2006; Proto et al., 2018), thereby establishing a direct relationship between the cost of the operation, average piece volume, and distance travelled by harvester and forwarder.

Table 2.7 Regression models selected based on the lowest AIC values for predicting the delay-free cycle (DFC) time for the operational phases (p < 0.05). Data from S1T1, S1T2, and S2T1 were combined.

<table>
<thead>
<tr>
<th>Machine</th>
<th>(R^2)</th>
<th>Standardized models predicting DFC time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Felling and</td>
<td>0.57</td>
<td>Log DFC = 0.91** + 0.03 (number of logs per cycle)* + 0.11 (hardwood)** + 0.11 (softwood)** - 0.12 (S1T2)<strong>&lt;br&gt; + 0.06 (S2T1)* + 0.05 (distance to deck)* + 0.02 (distance between trees)</strong> + 0.11 (butt-end diameter)**</td>
</tr>
<tr>
<td>Processing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Harvester)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extraction</td>
<td>0.66</td>
<td>DFC = 3203.44** - 14.19 (in-woods travel distance) - 568.00 (number of logs per loading cycle) - 171.94 (number of logs per unloading cycle)* + 32.59 (number of logs per cycle)*</td>
</tr>
<tr>
<td>(Forwarder)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
23

2.5.1 Operational phases

Processing time was the major contributor to the DFC time of the harvester (Nurminen et al. 2006, Ioan Apăfăian et al. 2017, Pajkoš et al. 2018). The higher processing time for S1T2 might be due to larger trees and higher percentage of hardwood extracted (48%), which was only 13% in S1T1. Due to the presence of large branches and the forked nature of hardwoods, the operator spent more time processing hardwoods (33.37 ± 4.26 sec) than cedar or other softwoods (15.20 ± 0.82 sec) (Kizha & Han, 2016). Further assortment of DFC supports this interpretation (Table 2.8).

Table 2.8 Cost (US$ m$^{-3}$) and productivity (m$^3$ PMH$^{-1}$, Productive machine hour) of felling and processing different assortments harvested from the treatments (George et al. 2019).

<table>
<thead>
<tr>
<th>Assortments</th>
<th>Delay free cycle time (sec)</th>
<th>Cost</th>
<th>Productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cedar</td>
<td>27.23 ±0.87</td>
<td>6.35</td>
<td>32.45</td>
</tr>
<tr>
<td>Hardwood</td>
<td>56.35 ± 6.75</td>
<td>6.09</td>
<td>33.83</td>
</tr>
<tr>
<td>Softwood</td>
<td>40.06 ± 3.78</td>
<td>5.66</td>
<td>36.40</td>
</tr>
</tbody>
</table>

The difference in felling and processing costs between the treatments could be partially due to the difference in average stem size between the treatments and equipment used (LeDoux & Huyluer, 2001; Puttock et al., 2005). There was a significant difference in dbh between the
treatments in S1, however, S1T1 and S2T1 had trees with similar dbh. Even with a higher DFC time, the increased machine productivity when handling larger and higher numbers of logs per DFC subsequently decreased the cost of this operational phase in S1T2 (Baek, 2018; Nurminen et al., 2006; Pajkoš et al., 2018). These arguments are validated by the regression models, in which butt-end diameter (p < 0.01) and number of logs (p < 0.05) have a significant effect on DFC time (Table 2.7) (George et al., 2019).

The study could not directly attribute the increased cost of felling in S1T1 to the fragile forest floor. However, in S1T1, the average distance traveled was 1.42 ± 0.09 m in an average time of 9.77 ± 0.49 sec (0.14 m sec\(^{-1}\)) between successive cuts. While in S1T2, the machine traveled an average distance of 2.68 ± 0.50 m in an average time of 8.41 ± 0.92 sec (0.31 m sec\(^{-1}\)), i.e., a greater distance in a shorter time (p < 0.01). This might be due to the microtopography of the terrain or limited ground stability, as lowland cedar stands are characterized by numerous pits and mounds resulting from tree roots and buried deadwood (Chimner and Hart 1996; Slaughter and Skean 2003; Wesely et al. 2018). The presence of understory vegetation and regeneration might have also contributed to the increased travel time. Finally, stand density being two times greater in S1T1 than S1T2 (Table 2.1) may have impeded visibility and maneuverability in the former, thereby increasing travel time. Additional investigation is required to substantiate this observation. Ultimately, this harvest would not have been possible during summer due to fragile ground conditions. In S2T1, rate of travel was 0.34 m sec\(^{-1}\) (i.e., 1.56 ± 0.48 m in 4.24 ± 0.87 sec). This suggests an average rate of travel faster than that observed in S1T1; different operators in S1 and S2 may have influenced this outcome.

Productivity of the forwarders was in accordance with studies by Ioan Apăfăian et al. (2017), Proto et al. (2018), and Pajkoš et al. (2018) (Table 2.4 and 2.5). Significant difference was
observed between S1T1 and S1T2 (p = 0.03), and S1T2 and S2T1 (p < 0.01) for number of logs loaded per cycle. Ioan Apăfăian et al. (2017) and Nurminen et al. (2006) made similar observations and attributed the change in loading time to differences in stand characteristics. At the landing, unloading time was higher for S1T1 and S2T1 compared to S1T2, probably due to higher number and smaller size of logs within the load resulting in tangling of the logs during unloading (Table 2.5).

The loading phase was the most productive for both study sites (Table 2.4) (Kizha et al., 2020). The productivity of a self-loading truck has previously been found to be lower than a loader (110 m³ PMH⁻¹). But self-loading trucks are preferred when there is a constraint of landing space and for smaller-sized logs (Kizha & Han, 2016; Soman et al., 2019).

2.5.2 Effects of fluctuating labor and fuel cost

Local sensitivity analysis was conducted to understand the fluctuation in cost of harvesting due to varying fuel price and labor cost, keeping all other factors constant. Even though the increase in the operational prices ranged between 7–9% due to a 50% increment in labor cost, such an increase would have a considerable impact on attracting new workforce to the trade. The shortage of machine operators is one of the major challenges faced by the industry (Koirala, Kizha, & Roth, 2017). Experienced operators also have an instrumental role on general timber harvesting (Kizha et al., 2020). These results can help in evaluating the optimal wage that could attract and retain skilled labor while being economically feasible for timber harvesting contractors. Even though the effects of variation in fuel price was only 5-6% variation in the in-woods operational cost, this would have a profound impact on the secondary transportation cost, which was not considered in this analysis (Kizha et al., 2015; Paulson et al., 2019).
2.5.3 Cost allocation based on DFC time for felling and processing

Cost allocation showed that cost of felling and processing cedar was higher than other softwoods and hardwoods (Table 2.8; George et al. 2019), which can be due to the smaller size of cedar in the present study. The smaller size of the cedar trees may be the result of the lowland site conditions (muck soil); Parker et al. (1983) showed that trees growing in peat and bogs were slow-growing, stunted, and smaller in size in comparison to those growing on well-drained soil. The percentage of wood recovery was also lower for cedar (2.2% lost) when compared to other species (0.97% lost) harvested from the treatments (obtained from measurement certificates generated by the harvester’s measuring device). This might be attributed to the occurrence of heart rot disease, typical to cedar in these sites (Hofmeyer et al., 2009; Johnston, 1990; Kenefic et al., 2019), leading to a greater number of cuts and fewer logs per DFC.

2.5.4 Stand projection

The stands were projected using FVS to determine the time required to regrow harvested merchantable volume. The relative differences in growth rate may, to some extent, be a factor of stocking, as stocking of S1T1 was somewhat higher than S1T2 and S2T1 after the harvest. However, growth rates for cedar stands of similar age (about 100 years old) on comparable sites (site index at 50 years = 12 m) can be inferred from yield tables (Boulfroy et al., 2012) and approximate 2.0 m³ ha⁻¹ yr⁻¹ across a range of stand densities. While it is reasonable to assume that growth rates in silviculturally managed stands will exceed those of cedar forests more generally, confirmation of projected growth in the present study through future remeasurement is warranted.

For the cedar stand, results obtained from FVS are comparable to the average annual mortality rate of < 0.2% observed regionally for cedar on average sites (Boulfroy et al., 2012). Whether the predicted reduction in tree numbers is accurate in these partially harvested stands is
unknown until future remeasurements are made. While reductions in canopy closure should increase available light and thus improve growth and vigor of residual trees (Ruel et al., 2014), partial harvesting may increase windthrow of this shallow-rooted species in low-density areas or gap edges on lowland sites (Boulfroy et al., 2012). Factors such as these are not explicitly incorporated into the distance independent FVS model and warrant future assessment. Nevertheless, if model outputs are accepted as reasonable, predicted time to regrow harvested volume (20 to 22 years) for both treatment areas is comparable to a 20-year cutting cycle, which has been suggested for selection systems on poor sites (Frank & Bjorkbom, 1973) and small-gap irregular shelterwood systems (Saunders et al., 2014) in the Acadian region. Remeasurements of the harvested stands will inform the accuracy of the model results.

2.5.5 Limitation of the study

This study was conducted in collaboration with managers within the constraints of commercial forestland management, using stands selected for a larger study of silvicultural treatments. As such, there were some differences between stands in terms of soils and tree species composition, and between S1 and S2 in machinery and operators. Even though the treatment in the cedar stands was replicated at two sites, caution should be taken when applying findings more broadly until results are confirmed at other locations. Nevertheless, the field-collected data analyzed in the present study provide useful insights into timber harvesting and operational costs on commonly harvested but rarely studied stand and site types in the region, with relevance to similar sites and species elsewhere.

2.6 Conclusion

This study examined the economic viability of timber harvesting operations on fragile soil and compared it with an operation conducted on sturdy soil. The fragile soils were replicated in
another stand. The harvesting cost was higher for the cedar stands compared to the stand on sturdy soil, accounting for 54% increment, and can be attributed to smaller piece size and higher in-woods movement and loading times. Overall, the extraction cost accounted for 48% of the total in-woods operational costs. The extraction cost dropped by 34–41% when forwarding distance was changed. There was no considerable difference in the cost of operations between the fragile soil stand replicates ($16.64 and 13.17 m$^3$). Local sensitivity analysis revealed the variations in the cost of harvesting due to fuel price and operator wage.

Evidence from this study suggests that treatments as applied are operationally feasible. If model projections are accurate, outcomes are consistent with regional silvicultural guidance regarding future re-entry in softwood-dominated stands. Projections of residual stand volume using FVS suggest the harvested areas will be operable again for the same volume at a cutting cycle length of about 20 years, though effects of spatially variable harvesting on residual stand growth and mortality are not well understood. This lack of information is not surprising, as cedar is one of the least-studied commercially valuable tree species in its range (Hofmeyer et al., 2007). Nevertheless, long-term sustainability will depend upon constraining future harvests to periodic growth, which – depending on cutting cycle – may or may not provide sufficient volume for an operable harvest. A quantitative understanding of stand and operational factors, including post-harvest growth and mortality, can help in efficient planning of economically feasible and sustainable harvest operations on similar lowland sites.
3 SOIL EROSION POTENTIAL OF MAJOR TIMBER HARVESTING METHODS

3.1 Abstract

Mechanized timber harvesting operations can increase soil erosion, altering sedimentation rates in nearby waterbodies and reducing the stand's productivity. However, an appropriate harvesting method assisted by well-executed BMP can considerably reduce soil erosion. Hence, the study objectives were to estimate the soil erosion rate using Universal Soil Loss Equation (USLE) for cut-to-length (CTL), whole tree (WT), and tree length (TL) harvesting methods; to evaluate the percentage area of disturbance categories with post-harvest ground cover; and to estimate the BMP implementation score. The data were collected from fifteen timber harvesting sites selected across the state of Maine, U.S. The erosion rate was 0.11, 0.12, and 0.14-tonnes ha\(^{-1}\) year\(^{-1}\) for CTL, TL, and WT harvest methods, respectively. The higher erosion rate in WT could be associated with timber dragging and less evenly distributed slash on the harvest area and skid trails. The post-harvest ground cover and BMP implementation score were the highest for CTL. No significant difference was observed between harvest methods for erosion rate and BMP implementation audit. A negative correlation was observed between erosion rate and BMP implementation score (-0.52). The study will help the forest managers make more informed decisions while selecting appropriate harvesting methods and BMP according to the stand conditions.

3.2 Introduction

Soil erosion in forestry typically occurs when the rainfall exceeds infiltration rate, combined with excessive soil saturation that results in loosening soil particles via surface flow which get transported to streams as sediments (Hawks et al., 2021; Pimentel, 2006; Vinson et al., 2017). Erosion rates on forestland are generally lower than the geologic average of less than 0.22
tonnes ha\(^{-1}\) yr\(^{-1}\) (Dissmeyer & Stump, 1978; Patric, 1976), but erosion rates in timber harvested areas can increase drastically due to the disturbances to soil (Yoho, 1980). Timber harvesting operations cause disruptions to the soil in the form of compaction, rutting, and displacement, which increase sedimentation and negatively affect the water quality (Aust et al., 2012; Brown et al., 2015). Most soil compaction occurs during the first few machines passes (Han et al., 2006). Soil disturbance caused by logging can reduce site productivity and alter site regeneration patterns (Kranabetter et al., 2006). Mechanized timber harvesting has consistently raised concerns over residual stand conditions reducing soil productivity due to soil erosion and sedimentation (S.-K. Han et al., 2009; Naghdí et al., 2020; Stuart & Edwards, 2006; Tavankar et al., 2021). The extent of erosion and related disturbances may vary depending on factors such as stand characteristics, harvesting methods, silviculture prescriptions, and season of harvest (Kizha et al., 2021; Soman et al., 2019). Clearcutting can increase the rate of watershed discharge by approximately 200% compared with preharvest conditions, thus increasing runoff and sediment delivery potential (Boggs et al., 2016).

Choosing a harvest method for forest operations depends on site and stand conditions, machine availability, and economic feasibility. (George et al., 2021; Kizha & Han, 2016; Louis et al., 2022). The most common harvesting methods used in the region are whole tree (WT; felled trees are dragged to the landing, processed, and merchandized at the landing), cut-to-length (CTL; trees are merchandized in-woods and carried to the landing), and tree length (TL; trees are delimbed in-woods, dragged to the landing and then merchandized) (Louis et al., 2022; MFS, 2020; Soman et al., 2020). Harvest method alternatives directly relate to the number of machine passages, the area under trail, ground cover, and landing size, which could impact the soil exposure (Cudzik et al., 2017; Han et al., 2006; Naghdí et al., 2020). Cut-to-length (CTL) harvesting method
is preferred on fragile sites over conventional whole-tree harvesting methods (Puttock et al. 2005; Jiang, 2016). In CTL, harvesting, delimbing, and bucking occur within the stand, whereas in WT, this happens in landing. Harvest residue (slash) is left on the site to armor the trails and provide support when frozen, reducing potential soil disturbances and enhancing the safety and efficiency of the operation (Cudzik et al., 2017; Puttock et al., 2005). In addition, logs are carried (forwarded) rather than dragged during primary transportation, reducing soil disturbances. CTL operations with forwarding decrease damage to advance regeneration relative to WT skidding (George et al., 2021; Waters et al., 2004). Finally, narrower machines result in narrower trails, tracks, or tires help disperse weight, and the number of machine passes is fewer for this harvesting method (Dahlman & Rossman, 2010). However, in terms of productivity and cost, WT method has an upper edge over CTL (George et al., 2019; Louis & Kizha, 2019, 2021b).

Forestry BMP typically include measures to protect and stabilize exposed soil (Aust & Blinn, 2004; Stuart & Edwards, 2006). These practices were formulated from the passage of the Federal Water Pollution Control Act (FWPCA) of 1972 to control and reduce non-point source pollutants (NPSP) effectively and water quality (Brown et al., 2015; Cristan et al., 2016; Hawks et al., 2022). NPSP are pollutants in which the emission zones cannot be easily identified and usually arise from agricultural and forestry activities. The pollutant cannot be attributed to a particular site or activity and often is caused by natural erosive processes, such as surface runoff from rainfall or snowmelt (US EPA, 2005). Sediments are the main NPSP that forestry BMP address, with skid trails, haul roads, and stream crossings typically being major contributors (US EPA, 2005). Sediment delivery in forestry occurs when eroded material from a watershed is transported to a stream channel (Cristan et al., 2016; Hawks et al., 2022). Several strategies have been adopted to minimize the negative impacts, including covering trails with slash mats, operating
at specific times according to season, using designated skid trails, and minimizing the number of machines passes. Harvesting operations often use logging residues to cover bare soil areas because they are readily available and are effective (Sawyers et al., 2012; Wear et al., 2013).

The U.S. has widely adopted the BMP approach toward sustainable forestry (Hawks et al., 2022). BMP programs can be implemented as non-regulatory, quasi-regulatory, and regulatory (Cristan et al., 2018). In non-regulatory programs, implementing BMP is voluntary, and the BMP application is not mandated by the state government (Kilgore & Blinn, 2004). However, forest operations must meet the requirements of the Clean Water Act, and third-party forest certification requires the proper implementation of BMP (George et al., 2022; Tumpach et al., 2018). Quasi-regulatory programs have some required practices (Cubbage, 2004), often regarding sediment (Aust & Blinn, 2004), which is mandated by state law on water quality standards (NASF, 2019). The regulatory BMP program enforces BMP implementation (Kelly et al., 2017) through a state Forest Practices Act (FPA) (G. Ice, 2004). State forestry agencies utilize BMP evaluations to conduct training workshops with landowners and loggers, improve BMP guidelines, and evaluate state programs (Kilgore et al., 2004).

Implementation of BMP is used to better understand the effects of NPSP on water quality and to evaluate the effectiveness of state programs (G. G. Ice et al., 2010). Forestry BMP implementation rates have increased over time due to environmental policy, third-party certification programs, and educational efforts (Hawks et al., 2022; G. G. Ice et al., 2010), resulting in an overall performance rate of 92.4% on recent state reports (Cristan et al., 2016; Hawks et al., 2022; MFS, 2020). Standard BMP guidelines designed to minimize erosion and sedimentation include leaving riparian buffers, minimizing stream crossings, directing runoff from road systems away from streams, and revegetating disturbed areas such as decks and skid trails (Hawks et al.,
The erosion rate can be used as a proxy to determine the effectiveness of BMP implementation (Barrett et al., 2016; Cristan et al., 2016).

Erosion from operation-specific features is often quantified using erosion models (Cristan et al., 2016; Hawks et al., 2021, 2022). The Universal Soil Loss Equation for Forestland (USLE-Forest) is an empirical model developed to estimate erosion in forested landscapes (Dissmeyer & Foster, 1984). Several studies have used the USLE-Forest and other modified versions of the USLE to predict erosion from different forest operations. Dangle et al. (2019) used the USLE-Forest to estimate soil erosion on skidder stream crossing approaches and found that the predicted erosion ranged from 0.2 to 117.7 tonnes ha\(^{-1}\) yr\(^{-1}\). Vinson et al. (2017) estimated skid trail erosion using USLE-Forest and found that skid trails with waterbars only had an estimated erosion rate of 24.1 tonnes ha\(^{-1}\) yr\(^{-1}\), which was substantially higher than the estimated erosion for skid trails covered in slash (2.3 tonnes ha\(^{-1}\) yr\(^{-1}\)). Using the USLE-forest model, Christopher and Visser (2007) reported that the average predicted erosion ranged from 0.6 tonnes ha\(^{-1}\) yr\(^{-1}\) for harvest areas to 21.1 tonnes ha\(^{-1}\) yr\(^{-1}\) for forest roads across multiple sites in Virginia. Studies have been conducted in Virginia to compare soil erosion from conventional and biomass harvest, and different geographic regions (Barrett et al., 2016; Hawks et al., 2022). Previous studies have further used USLE-Forest, to analyze the forest operation features and reported that particular skid trails and forest roads have high potential to erode (Cristan et al., 2016; Hawks et al., 2021, 2022).

An appropriate harvesting method assisted by well-executed BMP can reduce the soil erosion rate (Cristan et al., 2016). The effectiveness of forestry BMP for protecting water quality has been well-documented (Aust & Blinn, 2004; Lakel et al., 2010). There is limited understanding of the influence of harvest methods on erosion and BMP implementation. This study evaluates post-harvest site conditions on different harvest methods to understand the variation and
characterize factors contributing to soil erosion. The objectives of the study were to estimate erosion rates for different harvesting methods practiced in Maine, U.S., CTL, WT, and TL; evaluate and compare the disturbance classes (harvest operational areas as a percentage of total harvest area) for the selected harvesting methods; evaluate post-harvest ground cover (litter, light slash, heavy slash, piles, bare soil, and rock) for the chosen harvesting methods; and correlate the BMP implementation score for each site with estimated erosion rates. This will enable the forest managers to select the most environmentally friendly harvesting methods.

3.3 Materials and methods

3.3.1 Site selection

The study was conducted on 15 sites that were partial harvest operations spread across the state of Maine. Due attention was given to including harvest sites from different counties of the state, and field data were collected within eight months after the harvest. Five sites were selected for each of the three harvesting methods (treatments), totaling the number of sites to 15. Each harvesting site was further classified into six disturbance categories: access roads, landings, skid trails, stream crossings, harvest areas, and streamside management zones (SMZ) (Barrett et al., 2016). Access roads were the forest roads utilized for transporting timber and equipment in-and-out of the respective site. Decks or landings were a location where timber was extracted for processing and loading. Skid trails were the primary transportation trails where skidding or forwarding was concentrated. Harvest area consisted of the harvested area within the stand, excluding areas subjected to other disturbance categories. The SMZs were areas adjacent to streams where harvest activities were minimized. Classification into disturbance classes facilitated the evaluation of the rate of erosion, area of extent, and disturbances independently. The area under
each disturbance category was estimated using a combination of GPS and GIS tools. It was later converted as a percentage of the total area of the site.

### 3.3.2 Erosion rate

The erosion rate was modeled using the Universal Soil Loss Equation (USLE) modified for forest land (Dissmeyer & Foster, 1984) (Equation 1). This method provides an overall weighted average erosion rate for a harvested site (Barrett et al., 2016; Christopher & Visser, 2007):

\[ A = R \times K \times LS \times CP \]  

(Equation 1)

where \( A \) is estimated erosion per unit area per year (ton ha\(^{-1}\) yr\(^{-1}\)); \( R \) is the rainfall or runoff factor determined using an index map provided in the USLE handbook (75 (North) or 100 (South) for Maine); \( K \) is the soil erodibility factor, determined using the USDA Web Soil Survey; \( LS \) is the slope length and slope steepness factor determined using a clinometer and measuring tape; and \( CP \) is the cover and management practices determined using ten sampling points (quadrants extending 10 m) distributed across the harvested site.

### 3.3.3 Ground cover evaluation

Ground cover was evaluated using quadrants (10*10 m) which were visually estimated for the percentage of area occupied by bare soil, litter (grass and leaves), light slash, heavy slash, piles of woody debris, and rocks. The study did not distinguish between debris broken off or knocked down due to the harvesting operation and those already on the floor before harvesting. Representative data using quadrats were collected from the above-mentioned disturbance categories and were averaged for the larger area, i.e., the logging site. A minimum of three samples were collected from access roads, skid trails, and SMZs; two from decks or landings and stream crossings; and five from the harvested area.
3.3.4 BMP implementation audit scores

The selected sites were audited for BMP compliance using the State of Maine Forest auditing system. The audit form categorized the logging site into roads, decks, stream crossings, stream management zones, wetlands, skidding, harvest planning, and chemical application. The audit form contains 64 indicators that the researcher evaluated for each site. Audits scores were reported as the percentage of applicable audit questions that received a “Yes” for the respective question. This percentage represents the proportion of applicable BMP appropriately implemented by the operator (Barrett et al., 2016). An overall BMP score was calculated for each site and compared with audit scores for the selected treatments in the study.

3.3.5 Statistical analysis

Erosion rate for each disturbance class was modeled, and descriptive statistics were calculated for each harvest method. A weighted average erosion rate for each site was calculated based on each site's estimated erosion divided by the total site area. ANOVA was performed to test the difference in erosion rate of different harvest methods. Pearson correlation was performed between erosion rate and BMP implementation audit score. Polynomial regression was used to predict weighted average erosion rates based on BMP audit score, harvest season, and harvest methods.

3.4 Results and discussion

The average harvest size was 13.5 ha for the 15 sites studied. The average harvest size for TL, WT, and CTL was 4.3, 18.3, and 18.6 ha, respectively. There were multiple silvicultural prescriptions (1.3) for each harvest site. BMP were applied to various disturbance categories in all the selected harvest sites. A statewide BMP effectiveness report by MFS (2020) has observed that 76% of the sites had appropriately implemented BMP in the 142 sites evaluated.
3.4.1 Erosion rate in forest soils

The average erosion rate for the entire harvest sites analyzed was 0.12 ± 0.04 tonnes ha⁻¹ year⁻¹. Compared with other land uses, forestry typically has relatively low erosion rates. Erosion rates for US croplands average about 11.3 tonnes ha⁻¹ year⁻¹, and pastureland has an average erosion rate of approximately 6.8 tonnes ha⁻¹ year⁻¹ (Pimentel, 2006). In the northeast U.S., where the study is, soil erosion was estimated at 0.03, 0.3, and 43.0 tonnes ha⁻¹ year⁻¹ for woods, pasture, and cultivated land, respectively (Patric & Helvey, 1986).

Erosion estimate from the study (0.12 tonnes ha⁻¹ year⁻¹) was higher than the regional estimate (0.03 tonnes ha⁻¹ year⁻¹). Harvest sites in this study were evaluated within eight months of harvesting. Therefore, the soil erosion estimations performed in this study occurred during the most highly erodible period. Erosion would decrease substantially in the years following the harvest as the site begins to revegetate and stabilize (Hawks et al., 2022; Hood et al., 2002). Aust and Blinn (2004) reviewed forestry best management practices in the eastern United States, and the review showed that mature forests commonly had erosion rates ranging between 0.13 and 0.55 tonnes ha⁻¹ year⁻¹. After harvests, erosion rates typically ranged between 2.25 and 12.25 tonnes ha⁻¹ year⁻¹ and generally returned to undisturbed levels within 2–5 years.

3.4.2 Impacts of harvesting methods on erosion

The erosion rate ranged from 0.03 to 0.28 tonnes ha⁻¹ year⁻¹ and was found to be the highest for the WT harvest method, followed by TL and CTL (Table 3.1). A similar study in Virginia observed average erosion estimates of 0.2 to 9.0 tonnes ha⁻¹ year⁻¹ (Barrett et al., 2016) and 0.2 to 50 tonnes ha⁻¹ year⁻¹ (Hawks et al., 2022). Christopher and Visser (2007) found an overall weighted average erosion estimate of 3.2 tonnes ha⁻¹ year⁻¹ for a mixture of clear-cut and partially harvested sites in Virginia. This study's results showed that CTL method has a lesser rate of erosion than
other harvesting methods, which could be due to a fewer number of machine passes, carrying mode of primary transportation, and the opportunity to scatter slash uniformly in the harvest site (Han et al., 2006; Naghdi et al., 2020; Tavankar et al., 2021). No significant difference was observed in erosion rate between the treatments ($p = 0.865$). A study comparing erosion rates between conventional logging and biomass harvesting showed no significant difference (Barrett et al., 2016).

The erosion rates were highest on forest roads ($0.26 \pm 0.01$ tonnes ha$^{-1}$year$^{-1}$) in all three harvest methods, followed by landings and skid trails. Similar results have been reported by Barrett et al. (2016) and Hawks et al. (2021). Compaction and high percentages of bare soil contributed to reduced infiltration can increase runoff and erosion of these features (Han et al., 2006; S.-K. Han et al., 2009; Hawks et al., 2022). In addition to potential negative impacts on water quality, elevated erosion rates can decrease soil water holding capacity and organic matter, resulting in reduced nutrient availability and productivity of the soil (Cristan et al., 2016; Hawks et al., 2022). Furthermore, the effects of harvesting extend past soil erosion and sediment delivery and can impact soil physical properties, future species composition, and site productivity (Stone, 2002). These negative impacts are especially concerning for the highly erodible skid trails, landing, and haul roads (Hawks et al., 2022).
Table 3.1 Erosion rate (tonnes ha⁻¹ year⁻¹) of different harvest methods from the sampled sites within eight months of harvest.

<table>
<thead>
<tr>
<th>Harvesting Method</th>
<th>Disturbance Area</th>
<th>Erosion Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-woods</td>
<td>0.03 ± 0.00</td>
<td></td>
</tr>
<tr>
<td>Skid trail</td>
<td>0.05 ± 0.02</td>
<td></td>
</tr>
<tr>
<td>Landing</td>
<td>0.10 ± 0.08</td>
<td></td>
</tr>
<tr>
<td>Road</td>
<td>0.25 ± 0.02</td>
<td></td>
</tr>
<tr>
<td>Stream crossing</td>
<td>0.01 ± 0.00</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>0.11 ± 0.05</td>
<td></td>
</tr>
<tr>
<td>TL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-woods</td>
<td>0.03 ± 0.00</td>
<td></td>
</tr>
<tr>
<td>Skid trail</td>
<td>0.08 ± 0.02</td>
<td></td>
</tr>
<tr>
<td>Landing</td>
<td>0.12 ± 0.08</td>
<td></td>
</tr>
<tr>
<td>Road</td>
<td>0.26 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>Stream crossing</td>
<td>0.01 ± 0.00</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>0.12 ± 0.05</td>
<td></td>
</tr>
<tr>
<td>WT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-woods</td>
<td>0.08 ± 0.001</td>
<td></td>
</tr>
<tr>
<td>Skid trail</td>
<td>0.10 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>Landing</td>
<td>0.08 ± 0.02</td>
<td></td>
</tr>
<tr>
<td>Road</td>
<td>0.28 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>Stream crossing</td>
<td>0.00 ± 0.00</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>0.14 ± 0.01</td>
<td></td>
</tr>
</tbody>
</table>
3.4.3 BMP Implementation audit score

As opposed to erosion estimates, the BMP implementation audit score was higher in sites harvested using CTL (91.0 ± 5.3), followed by TL and WT. Among the audit categories, skid trails got the lowest score (70.0 ± 5.1), and it was in WT method. Similar observations were made by Barrett et al. (2016) and Hawks et al. (2021). In contrast, VanBrakle et al. (2013) reported higher implementation scores for skid trails and forest roads. Harvest planning, SMZ, and wetlands received full audit scores in all the harvest methods (Table 3.2). Studies have shown that most erosion from haul road and skid trails is trapped on-site in the harvest area and SMZ (Cristan et al., 2018; Hawks et al., 2021). No significant difference was observed between different treatments (p = 0.932). Schuler and Briggs (2000) reported that BMP application was 78% for roads, 87% for landings, 59% for skid trails, 88% for equipment, and 73% for buffer strips from a study in New York. Wisconsin DNR (2006) BMP compliance was 83%, and BMP effectiveness was 99% when adequate BMP were applied. They also reported that when BMP were not followed, water quality was impacted 71% of the time. McCoy and Sobecki (2011) observed the least BMP implementation effectiveness for stream crossing.

Logging decks and harvest areas generally had the highest BMP implementation rates and lowest erosion rates, sediment delivery ratios, and sediment masses delivered to streams compared with the other three more severely disturbed features (stream crossings, haul roads, and skid trails) (Hawks et al., 2021; Schuler & Briggs, 2000). This study contradicts stream crossings had the highest BMP implementation score, followed by roads, landings, and skid trails (Table 2). Due to a higher implementation score (>90) (Hawks et al., 2021), erosion from stream crossings is the least (Table 3.1 and 3.2). From the sites, it has been observed that forest managers took extra
precautions while dealing with stream crossings. They have tried to avoid stream crossing to the maximum and heavily armored both banks with a surplus slash.

Table 3.2 BMP implementation audit score for different harvest methods from the sampled sites within eight months of harvest.

<table>
<thead>
<tr>
<th>Harvest Method</th>
<th>CTL</th>
<th>TL</th>
<th>WT</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BMP categories</strong></td>
<td>Avg. Percent Approval</td>
<td>Avg. Percent Approval</td>
<td>Avg. Percent Approval</td>
<td>Avg. Percent Approval</td>
</tr>
<tr>
<td>Roads</td>
<td>81.4 ± 2.5</td>
<td>83.3 ± 0</td>
<td>82.3 ± 2.3</td>
<td>82.3 ± 1.6</td>
</tr>
<tr>
<td>Landings</td>
<td>81.7 ± 16.9</td>
<td>78.3 ± 2.9</td>
<td>80.3 ± 2.0</td>
<td>80.1 ± 7.3</td>
</tr>
<tr>
<td>Skid trail</td>
<td>78.8 ± 5.2</td>
<td>75.7 ± 10.9</td>
<td>70.0 ± 5.1</td>
<td>74.8 ± 7.1</td>
</tr>
<tr>
<td>Stream or wetland crossings</td>
<td>95.1 ± 4.2</td>
<td>91.9 ± 5.6</td>
<td>90.4 ± 3.1</td>
<td>92.5 ± 4.3</td>
</tr>
<tr>
<td>Streamside Management Zones</td>
<td>100.0 ± 0</td>
<td>100.0 ± 0</td>
<td>100.0 ± 0</td>
<td>100.0 ± 0</td>
</tr>
<tr>
<td>Wetlands</td>
<td>100.0 ± 0</td>
<td>100.0 ± 0</td>
<td>100.0 ± 0</td>
<td>100.0 ± 0</td>
</tr>
<tr>
<td>Harvest planning</td>
<td>100.0 ± 0</td>
<td>100.0 ± 0</td>
<td>100.0 ± 0</td>
<td>100.0 ± 0</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>91.0 ± 5.3</td>
<td>89.9 ± 1.2</td>
<td>89.0 ± 3.1</td>
<td>89.7 ± 3.2</td>
</tr>
</tbody>
</table>

3.4.4 Relation between BMP audit score and erosion

Correlation coefficients indicate varying levels of strength, including non-existent or negligible (0.01–0.19), weak-moderate (0.20–0.39), strong (0.40–0.69), and very strong (≥0.70). A strong negative correlation was observed between the BMP implementation audit score and the
average erosion rate (-0.52) (Table 3.3). This indicated that the erosion rate would decrease as the BMP implementation score increases. All the treatments showed a weak-modernated inverse relation between BMP implementation score and erosion. A correlation coefficient of -0.59 to 0.01 was observed by Hawks et al. (2022), and -0.48 to -0.37 by Hawks et al. (2021). A high BMP implementation (>90%) in CTL appears to minimize erosion (Table 3.1 and 3.2) (Hawks et al., 2021) and showed stronger correlation coefficient (Table 3.3). This emphasized that high BMP implementation is pivotal in minimizing erosion rate (Christopher & Visser, 2007; Cristan et al., 2018; Hawks et al., 2021).

Table 3.3 Pearson correlation between harvest methods’ erosion rate and BMP audit score.

<table>
<thead>
<tr>
<th>Harvest Method</th>
<th>Correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTL</td>
<td>-0.36</td>
</tr>
<tr>
<td>TL</td>
<td>-0.28</td>
</tr>
<tr>
<td>WT</td>
<td>-0.25</td>
</tr>
<tr>
<td>Overall erosion</td>
<td>-0.52</td>
</tr>
</tbody>
</table>

3.4.5 Ground cover

In the harvest area, the maximum area was covered by litter (66.5 ± 7.3%), followed by slash and bare soil (Table 3.4). As expected, WT method had the highest percentage of bare soil (14.0 ± 1.1) and the lowest slash (15.2 ± 3.0) compared to CTL and TL treatments. A significant difference was observed between the treatments for bare soil and heavy slash. This might be due to the difference in point of processing between the treatments; in WT, logs are delimbed and bucked at the landing compared to harvest area delimbing in TL, and harvest area delimbing and bucking in CTL (George et al., 2021; Han et al., 2006; Louis & Kizha, 2019). Kizha and Han (2015) reported that downed woody debris could considerably vary based
on the silvicultural prescriptions, terrain conditions, and machines used. There was more heavy slash in the harvest area in TL compared to other treatments.

Table 3.4 Percentage of harvest area occupied by each category of ground cover for different harvest methods.

<table>
<thead>
<tr>
<th>Ground cover</th>
<th>CTL</th>
<th>TL</th>
<th>WT</th>
<th>Average</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare soil</td>
<td>7.1 ± 0.6</td>
<td>8.2 ± 0.9</td>
<td>14.0 ± 1.1</td>
<td>9.8 ± 0.9</td>
<td>&lt;0.050</td>
</tr>
<tr>
<td>Litter</td>
<td>66.1 ± 5.1</td>
<td>62.5 ± 8.2</td>
<td>70.8 ± 8.5</td>
<td>66.5 ± 7.3</td>
<td>0.687</td>
</tr>
<tr>
<td>Light slash</td>
<td>13.0 ± 2.1</td>
<td>13.8 ± 1.8</td>
<td>8.1 ± 1.9</td>
<td>12.2 ± 1.9</td>
<td>0.062</td>
</tr>
<tr>
<td>Heavy slash</td>
<td>13.6 ± 1.0</td>
<td>15.0 ± 0.8</td>
<td>7.2 ± 1.1</td>
<td>12.0 ± 1.0</td>
<td>0.024</td>
</tr>
<tr>
<td>Rock</td>
<td>0.2 ± 0.0</td>
<td>0.5 ± 0.0</td>
<td>0.4 ± 0.0</td>
<td>0.3 ± 0.0</td>
<td>0.893</td>
</tr>
</tbody>
</table>

A similar trend was observed in skid trails ground cover, where WT (44.1 ± 4.3) had the highest percentage of bare soil, and CTL had the lowest (3.0 ± 0.4). CTL (71.5 ± 12.3) had the maximum slash, while WT had the lowest (Table 3.5). There was a significant difference in bare soil and light slash percent (Table 3.5). In WT, higher percent of heavy slash could be observed, as part of BMP and making room in the landing; skidders brought backslash to the harvest area without an even distribution (Barrett et al., 2016; Soman et al., 2019). Similar trends were observed by (Barrett et al., 2016; Groover, 2011), and they also noted significantly less light slash on integrated biomass harvests than on conventional harvest sites for a clearcut prescription using WT method.
Table 3.5 Percentage of skid trail area occupied by each category of ground cover for different harvest methods.

<table>
<thead>
<tr>
<th>Ground cover</th>
<th>CTL</th>
<th>TL</th>
<th>WT</th>
<th>Average</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare soil</td>
<td>3.0 ± 0.4</td>
<td>24.7 ± 3.0</td>
<td>44.1 ± 4.3</td>
<td>23.9 ± 2.6</td>
<td>&lt;0.050</td>
</tr>
<tr>
<td>Litter</td>
<td>25.5 ± 2.2</td>
<td>20.2 ± 1.8</td>
<td>18.5 ± 2.6</td>
<td>21.4 ± 2.2</td>
<td>0.354</td>
</tr>
<tr>
<td>Light slash</td>
<td>61.0 ± 8.1</td>
<td>45.1 ± 10.2</td>
<td>26.0 ± 2.8</td>
<td>44.0 ± 7.0</td>
<td>0.012</td>
</tr>
<tr>
<td>Heavy slash</td>
<td>10.5 ± 4.2</td>
<td>9.5 ± 1.6</td>
<td>11.0 ± 1.1</td>
<td>10.4 ± 2.3</td>
<td>0.074</td>
</tr>
<tr>
<td>Rock</td>
<td>0.2 ± 0.0</td>
<td>0.5 ± 0.0</td>
<td>0.4 ± 0.0</td>
<td>0.3 ± 0.0</td>
<td>0.452</td>
</tr>
</tbody>
</table>

3.5 Conclusion

This study predicted erosion and BMP implementation effectiveness by harvesting methods in a partial harvest prescription. The predicted rate of erosion was found to be in accordance with other studies conducted in the region. Even though there was no significant difference between the harvest methods, the erosion rate was highest, and BMP implementation was least for WT compared to CTL and TL. This might be due to the difference in operating techniques for each harvest method. In general, harvest areas with the least erodible features had the highest rates of BMP implementation. At the same time, skid trails and haul roads were more erodible with lower rates of BMP implementation. Based on the data, skid trails, landings, and haul roads have the potential to be the highest erodible features on-site. These results show that opportunities exist for better research on improving BMP implementation at haul roads and skid trails to mitigate erosion. Erosion estimates and BMP implementation score had an inverse relationship for all the harvest methods, verifying that erosion typically decreases as BMP implementation increases. Overall, there was a high BMP implementation score, which can mitigate soil erosion and minimize impacts on water quality and site productivity. Along with best
implementing BMP, minimizing the area occupied by landings, skid trails, stream crossings, and haul roads are the BMP recommendations for all harvest methods.

The sample size in this study was small, especially when different harvest methods were considered individually. This is because of the difficulty associated with contacting landowners and obtaining permission. This aspect should be considered when designing region-wide studies that require permissions across diverse sites and locations. Even with the relatively low sample size, this is one of the few studies comparing different harvest methods for soil erosion and BMP implementation. Although there are certain limitations, this is one among the few studies where the relationship between forestry BMP implementation rates and erosion estimates was examined from the same harvest sites so that the association among these variables and their impact on water quality could be better understood. Future research could expand the scope of these findings by including more sample sites, landowner types, experienced/certified loggers, and harvest intensity.
4 IS FOREST CERTIFICATION WORKING ON THE GROUND? FOREST MANAGERS PERSPECTIVES FROM THE NORTHEAST U.S.

4.1 Abstract

Forest certification programs (FCP) are intended to preserve the environmental, social, and economic values of forests to ensure sustainable management and assured incentives for forest managers in the form of price premiums and market access. In contrast, FCP have not delivered price premiums while also increasing financial and bureaucratic burdens on forest managers. This study used a survey-based approach to obtain the perspectives of forest managers from the northeast U.S. on third-party FCP and possible solutions for their improvement. Among the 157 completed surveys, 85 respondents were involved with FCP, and 38 of those had more than 15 years of experience with certification. There was a significant difference between the responses from consulting foresters and land management companies, respondents from Maine and other states, and respondents with more and less than 15 years of experience with certification programs. Social license (reputation) was the most important reason for getting certified, while market price premium was ranked the least important. Respondents largely agreed on the need to reduce the frequency of surveillance audits for continuously certified management units. They were also generally satisfied with the work quality of the certification auditors and believed logger certification made auditing more convenient. Many embraced adopting region- and stakeholder-specific certification standards. Other reported challenges of FCP included the lack of price premiums and increased cost and complexity of certification. Survey findings helped identify several strategies to improve FCP within the study region and beyond.
4.2 Introduction

Forest certification has emerged as a key tool for setting regional and international standards for sustainable forest management (SFM), which is one of the means to mitigate the impact of climate change on forests without compromising the productive, protective, and ameliorative functions (FAO, 2018). Forest certification programs (FCP) are voluntary third-party verification systems that ensure that wood products are accurately traced back through the manufacturing system, enabling conscious consumers to choose responsibly sourced wood-based products (Perera & Vlosky, 2006; SAPPI, 2019a; Smith et al., 2019). Certification ensures that the product has been grown and harvested sustainably under predetermined standards which address environmental, social, and economic values (Maesano et al., 2018; Marchi et al., 2018). Certification is also considered a market-based forest policy option (Søreide & Williams, 2013), as it is perceived that forest managers and firms enrolled in FCP will accrue net economic benefits relative to the status quo. A study by Basso et al. (2018) showed that South American countries with largest export to European Union (market with demand for certified products) have a greater number of certified forests.

Forest certification got traction in the early to mid-1990s with the support of the forest products industry and environmental community with an intent of establishing a common “language” globally to measure forest management sustainability by creating a standard (Barnard, 2019; Sarkar & Hegde, 2019; Vlosky et al., 2009). Establishing a global standard has been an immense challenge than initially expected due to different forest types worldwide requiring a unique management style depending on varying regional conditions (Perera & Vlosky, 2006). About 400 million hectares (11% of the world’s forest area) are certified globally, of which more than 90% are in the northern hemisphere. The U.S. reports 9% of the certified forest, after Canada
(40%) and Russia (11%) (Alvarez, 2018). Governmental influences, society’s pressures, characteristics of adopting entities, and international and domestic market demand are the major factors influencing the diffusion of FCP (Basso et al., 2018; Tröster & Hiete, 2018). A study done in Europe by Maesano et al. (2018) has concluded that economic, environmental, and social benefits of being certified could be a motivation for European forest landowners to become certified.

Forest certification is a “neutral third-party” level of verification with three separate entities involved in the process: 1. Forest certification system or standard; 2. Certification agency (auditing firm endorsed to audit and issue certificates); 3. Certification seeker (land managing company, paper mill, etc.) (Barnard, 2019; FAO, 2018; Perera & Vlosky, 2006). FCP provide a set of standards and structure for SFM, which includes Forest Management Certification (FM), Chain-of-Custody standards (CoC), and wood fiber sourcing (AF&PA, 2014; Ehrenberg-Azcárate & Peña-Claros, 2020; FAO, 2018). Forest Management certification verifies that forests are managed and harvested responsibly according to sustainability criteria and indicators defined by the certification system (Marchi et al., 2018; Paluš et al., 2018). They are primarily concentrated on state and county public lands, university forests, industrial/corporate lands, and private lands managed by consulting foresters or fiber sourcing companies (AF&PA, 2014; Barnard, 2019; Maesano et al., 2018).

In the U.S., there are four reliable, internationally recognized certification systems that forest managers, mills, and customers can choose from: Forest Stewardship Council® (FSC), Sustainable Forestry Initiative® (SFI), Programme for the Endorsement of Forest Certification Schemes™ (PEFC), and the American Tree Farm System™ (ATFS) (AF&PA, 2014; ATFS, n.d.; FSC-U.S., n.d.; PEFC, n.d.-a; Perera & Vlosky, 2006; SFI, n.d.). SFI and ATFS were endorsed by
PEFC in 2005 and 2008, respectively (Fernholz et al., 2021), but they differ in terms of standards, performance measures, or specific practices evaluated (AF&PA, 2014; Esler, 2017; Ford & Jenkins, 2011; Gutierrez Garzon et al., 2020; PEFC, n.d.-b; Waardenburg, 2012). Even though endorsement by PEFC gave international recognition, the scope of SFI is limited to North America and ATFS to the U.S. (Gutierrez Garzon et al., 2020). There are 14 and 34 million hectares of FSC and PEFC certified forests in the U.S., respectively (Alvarez, 2018). Perera et al. (2008) reported FSC certification as the most accepted and preferred, followed by SFI in a study analyzing retailers’ attitude toward forest certification in the U.S. Small woodland owners were mainly certified by ATFS (Perera & Vlosky, 2006).

4.2.1 Current status

Although not always critical to ensuring a sustainable wood fiber supply, FCP have played a significant role in fostering and establishing sustainable forestry (AF&PA, 2014). Forestry certification was initiated to prevent the degradation of tropical rainforests (Ehrenberg-Azcárate & Peña-Claros, 2020; Sarkar & Hegde, 2019). However, even after 30 years of establishment, the majority of certified lands are located in developed countries (i.e., North America and Europe), which are regarded as low-risk to SFM infractions due to the existing framework of well-enforced forest laws, regulations, policies, Best Management Practices (BMP), education and training programs, etc. (Barnard, 2019; Ehrenberg-Azcárate & Peña-Claros, 2020; Perera & Vlosky, 2006).

Since the inception of FCP, forest management practices have improved with more authority for field foresters to manage for ecological values and safer logging practices (Balch, 2021). Most certified areas are managed by large land management corporations that were already being managed sustainably prior to the introduction of FCP (Søreide & Williams, 2013). On the contrary, forests in Asia, Africa, and Latin America – which are at higher risk for unsustainable forest
management – mostly remain uncertified (Barnard, 2019; Perera & Vlosky, 2006). Furthermore, poor governance and corruption, coupled with wide variability across the standards and auditing protocols, have caused some organizations to reconsider and withdraw their support for certification programs across the globe (Barnard, 2019; Conniff, 2018; Søreide & Williams, 2013).

The continued value and credibility of FCP are uncertain in the future due to potential changes in forestland managers’ willingness and ability to participate in certification. FCP has benefited and succeeded to date based on their support from environmental organizations and forest industries, and the pressure these organizations have placed on entities such as manufacturers, brands, and retailers (Barnard, 2019; Brack, 2018; Perera & Vlosky, 2006). Globally, the growth of certified forests has mostly plateaued and even diminished in some regions over the last ten years (Barnard, 2019; Ehrenberg-Azcárate & Peña-Claros, 2020). This change in trend can be attributed to several reasons, including increased costs and complexity, lack of price premiums for the certified products, the perception that certification is not practical for small landowners, workforce capacity challenges, a dearth of incentivizing changes on the ground, the rise of risk assessment surveys, and the recent emergence of other means of providing customer assurances of sustainability, including advancement in tracing fiber to the point of origin (Barnard, 2019; Sarkar & Hegde, 2019; Smith et al., 2019). Within the U.S., the reasons for decreasing forest certification were the inability of certification systems (and partners) to develop cost-effective, efficient, and appropriate standards for family forest lands. Additionally, “Federal Lands Policy” prohibits the U.S. Forest Service and U.S. Fish and Wildlife Service lands from adopting FSC certifications (Barnard, 2019; Fernholz et al., 2021).

FCP in North America were originally devised to ensure SFM. In return, the forest managers were assured financial and reputational incentives as premium prices and increased
market access (FAO, 2018; Perera & Vlosky, 2006). In reality, FCP could not guarantee these assurances despite increasing the financial costs (5-25%) and bureaucratic burden on the forest managers (Perera & Vlosky, 2006). These factors resulted in several landowners withdrawing from certification programs in recent years. This is evident in the growth of FSC in North America; during 2014-20 certified area has increased slightly from 66 to 68 million ha compared to 49 to 66 million ha during 2010-14 (Fernholz et al., 2021). Even after almost 30 years, less than 12% of the world’s forests are certified conform to any of the aforementioned standards (SAPPI, 2019b), and about 40% of the certificates issued have been invalidated in the 30-year history of certification programs (Ehrenberg-Azcárate & Peña-Claros, 2020). Presently, forest certification has become a usual business practice and expense for market access (Balch, 2021; Paluš et al., 2018). Some studies have indicated that certified products are sold at a higher price, and the additional revenue generated may exceed the certification cost, especially for larger landholdings (Søreide & Williams, 2013) and wood product manufacturing (Vlosky et al., 2009). However, this is not the case for all, as others have noted that the anticipated prospect of price premiums (i.e., an increased price in the market for certified products compared to non-certified) has not been realized yet (Balch, 2021; Paluš et al., 2018).

The northeastern U.S. states include Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont (Karnatz et al., 2021). Forestry is an important contributor to the gross domestic product of the region, especially Maine, Vermont, Pennsylvania, and New Hampshire (Pelkki & Sherman, 2020). The economic contribution of the logging and trucking industry was estimated at USD 619 million in output and 9000 jobs for the state of Maine (Bailey et al., 2020), while the northeast’s forestry-related businesses annually contribute more than 6% of the region’s manufacturing GDP (NAFO, 2018). Forests of the region
face several challenges, such as limited markets (Koirala, Kizha, & De Urioste-Stone, 2017); extensive areas with fragile soil conditions (George et al., 2019; Soman et al., 2020); small-diameter trees prevailing in the majority of stands (Louis & Kizha, 2021b); emerging pest and diseases (Cortés & Moltzan, 2020; Louis & Kizha, 2021b); leading to higher management cost (Soman et al., 2019). Most forest managers working in these conditions are voluntarily implementing FCP. Similar circumstances exist in other regions of the U.S. (A. Kizha & Han, 2016).

Forest managers provide critical information and resources to the landowners to make informed decisions on managing their forests (AFF, 2019). For the study, forest managers are defined as personnel accountable for and contributing to planning, directing, and executing activities related to managing public or private forested lands. This includes consulting foresters, forest management companies, state or federal forest agencies, forest industry consultants, and logging contractors. Understanding the viewpoint of forest managers toward FCP is crucial, as they are the people on the ground who implement forest managerial activities and the connection between certification systems and landowners. This will help to identify weaknesses of the certification process and understand approaches required to improve FCP. With a global outlook on FCP, this study was conducted in the northeast region of the U.S., with a historically strong forest industry and large FCP participation: 1) to assess the perspective of forest managers toward FCP, specifically on forest management certification and 2) to suggest possible solutions for the improvement of third-party FCP. The results from the study can be applied to other regions of the U.S. and possibly abroad to strengthen and best implement FCP.
4.3 Materials and methods

This study used a mix of literature analysis, personal communication, and previous surveys of forest managers as the foundation for drafting a questionnaire to solicit forester and forestland manager perceptions of FCP in the northeast U.S. (Cooper et al., 2009). The survey was initially reviewed by ten experts in the field, including practicing foresters, academics from forestry and social sciences, and forest certification auditors. The final questionnaire (George et al., 2022) of 37 questions was prepared with a mix of close-ended (28) and open-ended (9) questions. Most close-ended questions were formulated using a Likert scale of five points: maximum= 5 (strongly agree), somewhat agree (4), neither agree nor disagree (3), somewhat disagree (2), and minimum= 1 (strongly disagree). This approach was used to gauge the relative strength in belief or, conversely, the level of uncertainty associated with forest managers' views about FCP (Koirala, Kizha, & Roth, 2017). The questionnaire was limited to a certain number of questions and a targeted completion time of fewer than ten minutes to minimize the risk of respondents skipping questions, providing identical answers to a set of responses, or completing questionnaires quickly (i.e., “straight-lining”) (Revilla et al., 2017). A revised survey draft was also pre-tested in the online survey platform Qualtrics by four individuals who had not previously viewed the survey.

The cross-sectional questionnaire (see Supplementary Material) was disseminated via email to 616 forest managers in the northeast U.S. The licensed foresters’ directory for Maine, New Hampshire, and Vermont, the Society of American Foresters’ directory, and the New England Region Council of Forest Engineering mailing lists were used to obtain emails of the survey population operating in the tri-state study area. The survey was administered using the Qualtrics survey platform with a window period of two months in July and August 2020. After dispatching the first batch of surveys, two reminders were sent to non-respondents at 20 days intervals. All
available responses, irrespective of completion, were included in the results and for further analysis. For questions that allowed multiple responses, replies were counted individually.

The study was approved by the University of Maine institutional review board for research on human subjects. An informed consent form was the opening page of the survey to ensure confidentiality and transparency. Participation in the survey was entirely voluntary. No incentives were provided to the respondents for their participation. Information that revealed the personal identities of the respondents was not used in any form of publications and presentations.

The main body of the questionnaire was divided into two sections. The first part solicited demographic information of the respondents and their affiliations, while the second part focused on obtaining a general understanding and perspectives on FCP. These questions focused primarily on a) the reasons for getting certified; b) the reasons for discontinuity in certification (if applicable); c) whether FCP is assisting in SFM; d) whether the forest needs to be continuously certified; and e) whether any concession should be given for continuously certified management units. Following Question 5, only participants who have or had certified forests were asked to respond. The last two questions regarding certification for sustainability and challenges faced by FCP were open to all respondents.

Open-ended questions and remarks were further analyzed to rank the importance of FCP. All expressed opinions from the survey were consolidated and broadly divided into four themes – certification process, standards, audit process, and markets – which helped develop recommendations for improving the FCP from a forest managers’ perspective. These common thoughts and criticism have been further utilized to substantiate the results obtained from the survey.
4.3.1 Statistical analysis

Median and mode were used as the measures of central tendency, and non-parametric tests were performed in R (1.3.1073). For questions with multiple levels, the mean was used to rank their order of importance. Chi-square tests of independence were performed to quantify the difference in opinion between respondents who have/had certified management units: a) from Maine (the largest and most forested state in our study) vs. other states (respondents working in both Maine and other states were excluded from the analysis); b) land management companies vs. consulting foresters (respondents working as both land management company and consulting forester were excluded from the analysis); and c) more vs. less than 15 years of experience with FCP. All comparisons described later in the results section refer to the difference between groups mentioned above.

The Chi-square tests of independence were performed because the state of Maine has more forestland under certification, and land holdings are more extensive than other states in the region (Fernholz et al., 2010). Land management companies are firms managing forests for large corporate woodland owners, and consulting foresters are independent professionals working with multiple landowners (especially private non-industrial woodland owners) during a particular period (Martin, 1994; Sass et al., 2021). Respondents' experience with FCP was considered to determine any difference in perception between more and less experienced forest managers (Labriole & Luzadis, 2011).

The significance level was set at a $p$-value of 0.05. The ‘N’ values mentioned are the total number of respondents for a particular question and do not pertain to the overall percentage of respondents. The ‘n’ values account for the percentage of respondents for a particular attribute.
4.4 Results

The survey was returned by 184 participants who manage forests in at least one of the northern New England states of Maine, New Hampshire, and Vermont. Twenty-seven of these respondents did not fully complete the questionnaire. With 157 completed surveys, the full completed response rate was 25%, calculated from a total of 616 email survey invitations. One hundred and seventy-two respondents (28% of those contacted) provided sufficient details, which was included in the analysis.

4.4.1 Demographics

Majority of respondents (75%) had more than 20 years of experience working in the forest industry, and 83 (48%) of the total had more than 30 years of experience (Figure 4.1). Consulting foresters (41%) were the largest group, followed by land management companies (18%), landowners (16%), others (14%; forest industry consultants, instructors, non-profits, and retired professionals), state or federal agency (6%), independent contractor (4%) and land trust (2%); noting that one respondent could list multiple positions. Among 172 respondents, 151 (88%) were identified as foresters, and 42 (24%) were found to have multiple roles in the forest industry.
Figure 4.1 Experience of respondents within the forest industry (N=172).

Most respondents worked in Maine (44%; Table 4.1). Other states included California, Connecticut, Hawaii, Massachusetts, Michigan, New York, Oklahoma, Oregon, Pennsylvania, Quebec (Canada), Rhode Island, Texas, Washington, West Virginia, and Wyoming. Around 40% of the respondents worked in more than one state.

Table 4.1 States where respondents frequently worked (N= 172).

<table>
<thead>
<tr>
<th>States</th>
<th>Number of responses (n)*</th>
<th>Percent of responses (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maine</td>
<td>121</td>
<td>44</td>
</tr>
<tr>
<td>New Hampshire</td>
<td>64</td>
<td>24</td>
</tr>
<tr>
<td>Vermont</td>
<td>50</td>
<td>18</td>
</tr>
<tr>
<td>Others</td>
<td>37</td>
<td>14</td>
</tr>
<tr>
<td>Total</td>
<td>272</td>
<td>100</td>
</tr>
</tbody>
</table>

* Respondents were asked to select multiple states, if applicable
4.4.2 Participation in forest certification programs

Among the respondents, 58% (N= 172) have or had certified their forest management unit. Most of the respondents’ organization or land management units were affiliated with FSC (35%), followed by SFI (33%), ATFS (23%), and PEFC (5%) certification programs. Among the respondents, 62% (N= 92) were found to have more than one FCP. Most of the respondents conformed to forest management certification (51%), followed by chain-of-custody certification (32%). Other certificates included fiber sourcing and controlled wood. Total years of association with FCP varied between 1-5 years to more than 20 years, with 48% being certified for at least 15 years (Table 4.2).

Table 4.2 Certification length of the organization/management unit (N= 87).

<table>
<thead>
<tr>
<th>Years with certification</th>
<th>Number of respondents (n)</th>
<th>Percent of respondents (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1 year</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1-5 years</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>5-10 years</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>10-15 years</td>
<td>24</td>
<td>28</td>
</tr>
<tr>
<td>15-20 years</td>
<td>17</td>
<td>20</td>
</tr>
<tr>
<td>&gt;20 years</td>
<td>24</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>87</td>
<td>100</td>
</tr>
<tr>
<td>Not answered the question</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Have or had certified forest management unit</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Never been certified</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>172</td>
<td></td>
</tr>
</tbody>
</table>
4.4.3 Reasons for getting certified

Respondents who noted that they were certified were asked to indicate their level of agreement for ten potential reasons for getting certified, which were identified through literature analysis. Ninety-two respondents answered the question on reasons for getting certified. The reason with the strongest agreement was social license (reputation) (median= 4, mode= 4), while receiving a market price premium was the reason for the strongest disagreement (median= 1.5, mode= 1) (Figure 4.2). Overall, respondents agreed with most of the hypothesized reasons for enrolling in FCP, including the cost of doing business, a requirement for market access, branding and consumer demand, and achieving organization’s sustainability goals. Additional reasons for getting certified mentioned by the respondents (as open-ended comments) included: meeting landowner objectives, setting an example of forest management standards, gaining recognition outside of their organization, participating in carbon offset programs, and consistent long-term management.
A statistically significant difference in levels of agreement with reasons for certification was observed between respondents primarily working in the state of Maine (median= 3, mode= 4, and N= 50) and other states (median= 3, mode=1, and N= 21; chi-square= 15.4, $p < 0.01$); between land management company (median= 3, mode= 4, and N= 31) and consulting foresters (median= 3, mode= 1, and N= 34; chi-square= 34.4, $p < 0.01$) across all statements on reasons for enrolling in certification programs. There was no significant difference between less than 15 years and more than 15 years of experience groups (chi-square= 7.2, $p= 0.12$)
4.4.4 Discontinuation of certification

Respondents were asked about the continuity of FCP. Among 92 respondents (8 qualified respondents did not answer the question), 84% have been continuously certified over the years. However, 15 respondents discontinued at least one certification program, led by FSC (65%), followed by ATFS (18%), SFI (6%), and PEFC (6%), which was most often discontinued between 2006–17. Among these respondents, one resumed certification (ATFS), and only two were willing to recertify in the future. Among the seven reasons for discontinuation, the most agreed reason was no particular benefit for being certified (median= 5, mode= 5, and N= 13), while most disagreed that it was due to minor nonconformities (median= 1, mode= 1, and N= 13; Figure 4.3a). Other reasons for discontinuing FCP mentioned by respondents (as open-ended statements) were insufficient and inexperienced auditors, difficulty in finding forest certification consultants, need for diverting funding from other management activities due to prohibitive cost, and no demand for products at a price premium.

4.4.5 Supplementary benefits of certification toward forest management

Respondents were asked to what extent they agree on FCP being essential to their organization in verifying and implementing the existing forest management plans, laws and regulations, best management practices, and education and training programs. Most respondents agreed on education and training programs (median= 3, mode= 4) but disagreed on laws and regulations (median= 3, mode= 1; Figure 4.3b). Additionally, respondents mentioned as open-ended statements that FCP were essential for monitoring non-fiber resources and management consistency. There was a significant difference in the responses across all four statements between land management company (median= 3, mode= 4) and consulting foresters (median= 2.5, mode=
1, chi-square = 12.7, p = 0.01); respondents with more than 15 years (median= 3, mode= 3) and less than 15 years (median= 3, mode= 4) of experience with FCP (chi-square = 13.7, p < 0.01).

4.4.6 Geographic scope of forest certification standards, involvement with auditors, and certified loggers

Respondents preferred forest certification standards to have a regional (median= 5, mode= 5) scope followed by national (median= 4, mode= 4, and N= 76) and global (median= 2, mode= 2; Figure 4.3c). Most of the respondents were found to be satisfied with the forest certification auditors. More than 72% agreed that the auditors are sufficiently qualified, experienced, and respectful (median= 4, mode= 4). Another 32% agreed that forest certification auditors exceeded the scope of certification standards by challenging management plans (Figure 4.3d). A concern regarding certification auditors was the inexperience with regional forest management practices. Also, 66% of the respondents agreed that employing certified loggers made the forest management audit process easier, while 25% neither agreed nor disagreed (median= 4, mode= 4). A significant difference was observed between respondents with more than 15 years (median= 3, mode= 3, and N= 38) and less than 15 years (median= 4, mode= 4, and N= 42) of experience with forest certification (chi-square = 13.9, p < 0.01). No significant difference was observed between the other groups (p > 0.05).
Figure 4.3a-d Respondents’ opinion regarding various aspects of forest certification programs.
4.4.7 Level of satisfaction with forest certification process

Satisfaction levels varied among the 91 respondents to this section of the survey. That is, 40% of respondents were satisfied with the certification process, 36% were unsatisfied, and 24% were neither satisfied nor unsatisfied (median= 3, mode= 4). In this section, no attempts were made to distinguish between different phases of the certification process like pre-audit, on-site audit, or post-audit process. When asked whether further changes are needed in the certification process, 67% agreed, 28% neither agreed nor disagreed, and only 5% disagreed (median= 4, mode= 5). The changes addressed here did not investigate any specifics of the forest certification process. It was an attempt to understand the percentage of respondents who wished to see improvements in certification programs. No significant difference was observed between any groups of respondents (p > 0.05).

4.4.8 Surveillance audits and desired changes

Surveillance audits are the intermittent annual appraisals conducted by the certification agency to verify the forest management units’ compliance with the certification standards. As audits are typically the highest cost element in the certification process (Maryudi et al., 2017), there is a reluctance toward yearly surveillance audits among forest managers. From a forest manager’s perspective, considerable time and resources were being devoted to auditing. About 57% of the respondents agreed, 31% disagreed, and 22% neither agreed nor disagreed (median= 4, mode= 4, and N= 89) that surveillance audits are necessary for maintaining certification status. Respondents who agreed said surveillance audits gave validity to FCP, and those who disagreed emphasized on high cost, frequency, and tedious paperwork, especially for small woodland owners. No significant difference was observed between any groups of respondents (p > 0.05).
When asked to specify an appropriate interval between audits, only 12% suggested an annual audit, while a majority (60%) opted for biannual or triennial intervals (mode = every 2 years). Other responses insisted on making it arbitrary, based on the period being certified and past audit findings (Table 4.3). A significant difference (chi-square = 11.2, p = 0.02) was observed between respondents from Maine (mode = every 3 years, N = 47) and other states (mode = every 2 years, N = 21).

Table 4.3 Respondent perceptions of forest certification surveillance audits (N=88).

<table>
<thead>
<tr>
<th>Time interval</th>
<th>Number of respondents (n)</th>
<th>Percentage of respondents (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appropriate interval between consecutive forest certification surveillance audits</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Every year</td>
<td>11</td>
<td>13</td>
</tr>
<tr>
<td>Every 2 years</td>
<td>28</td>
<td>31</td>
</tr>
<tr>
<td>Every 3 years</td>
<td>25</td>
<td>28</td>
</tr>
<tr>
<td>Every 4 years</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Every 5 years</td>
<td>17</td>
<td>19</td>
</tr>
<tr>
<td>Other</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>88</td>
<td>100</td>
</tr>
<tr>
<td>Minimum number of years a management unit should be continuously certified for reducing the frequency of surveillance audits</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-5 years</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td>5-10 years</td>
<td>25</td>
<td>43</td>
</tr>
<tr>
<td>10-15 years</td>
<td>17</td>
<td>29</td>
</tr>
<tr>
<td>15-20 years</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
Sixty-seven percent (N= 89) of the respondents agreed on reducing the frequency of surveillance audits for continuously certified management units, whereas 21% neither agreed nor disagreed and 11% disagreed (median= 4, mode= 4). Respondents suggested that the frequency of surveillance audits may be determined based on the size of landholding and compliance in the previous audits. Some respondents were willing to accept annual audits; however, the audit cost was still mentioned as a barrier. No significant difference was observed between any groups (p > 0.05).

Among the 67% who agreed to reduced surveillance audits, a majority (43%) suggested that a management unit should be continuously certified for 5-10 years to qualify for a reduction in surveillance audit frequency (mode= 5-10 years; Table 4.3). Other responses insisted on making it arbitrary, based on the findings from the past audits. A significant difference (chi-square= 13.5, p < 0.01) was observed between land management companies (mode= 10-15 years) and consulting foresters (mode= 5-10 years).

### 4.4.9 Market preferences for being certified

About 45% of respondents (N= 89) agreed that they received a preference in the market for being certified, 40% disagreed, and 15% neither agreed nor disagreed (median= 3, mode= 4). Respondents indicated that most of the preferences were in the form of market access, especially for pulpwood in tight market conditions. Only one respondent stated that they received a small price premium of about 3% for certified pulpwood. Another noted benefit included obtaining...
sustainable green certification for government contracts. No significant difference was observed between any groups of respondents (p > 0.05).

4.4.10 Necessity of forest management certification and difficulties in being certified

All respondents were asked the question, “How strongly do you agree that third-party FCP are necessary for SFM,” irrespective of their experience with FCP. About 50% disagreed on the statement and 23% neither agreed nor disagreed (median= 3, mode= 1). No significant difference was observed between any groups of respondents (p > 0.05). Respondents agreed on lack of price premium (median= 5, mode= 5, and N= 152) as the greatest challenge of FCP followed by increased cost and complexity (median= 5, mode= 5; Figure 4.4). A significant difference was observed between respondents from Maine (median= 4, mode= 3) and other states (median= 4, mode= 5; chi-square= 13.9, p < 0.01), along with land management companies (median= 4, mode= 3) and consulting foresters (median= 4, mode= 5; chi-square= 13.2, p= 0.01).
4.4.11 Major concerns and opinions of respondents

Thirty-four percent of respondents provided insight on major concerns about FCP in the northeast U.S. The most frequently discussed topic (more than 10 frequency of occurrence) identified by analyzing open-ended comments was the certification process, followed by the cost of auditing, lack of benefits for being certified, and the auditing process (Table 4.4).
Table 4.4 Major concerns identified from responses to the open-ended questions (N= 228).

<table>
<thead>
<tr>
<th>Identified thoughts</th>
<th>Frequency of occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Certification process</td>
<td>44</td>
</tr>
<tr>
<td>Cost of auditing and resources</td>
<td>41</td>
</tr>
<tr>
<td>No benefits</td>
<td>35</td>
</tr>
<tr>
<td>Auditing process</td>
<td>31</td>
</tr>
<tr>
<td>Stakeholder specific standards</td>
<td>28</td>
</tr>
<tr>
<td>Market price premium</td>
<td>21</td>
</tr>
<tr>
<td>Sustainability</td>
<td>18</td>
</tr>
<tr>
<td>Deviation from original intention</td>
<td>16</td>
</tr>
<tr>
<td>Market access</td>
<td>16</td>
</tr>
<tr>
<td>Auditor</td>
<td>15</td>
</tr>
</tbody>
</table>

Changes that the respondents wish to see in FCP were classified into four categories: certification process, certification standards, auditing, and markets (Table 4.5). Respondents wish to receive preferential treatment in the marketplace for being certified. Some key desired changes were price premium, compatibility between certification standards, and less cumbersome certification processes.
Table 4.5 Key changes respondents wish to see in forest certification programs.

<table>
<thead>
<tr>
<th>Certification process</th>
<th>Market</th>
</tr>
</thead>
<tbody>
<tr>
<td>● Compensation for the non-market elements</td>
<td>● Provide market price premium</td>
</tr>
<tr>
<td>● Government funding for meeting social aspects of standards</td>
<td>● Market access</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Certification standards</th>
<th>Auditing</th>
</tr>
</thead>
<tbody>
<tr>
<td>● Compatibility between different certification standards</td>
<td>● Less cumbersome; especially in record keeping</td>
</tr>
<tr>
<td>● Region-specific and stakeholder specific certification standards</td>
<td>● Less expensive</td>
</tr>
<tr>
<td>● Less emphasis on the social aspects and more on silvicultural practices</td>
<td>● Recruit auditors with experience in forest management</td>
</tr>
<tr>
<td>● Extended standard revision period to accommodate forest management plans</td>
<td>● Conduct field auditing by different specialists</td>
</tr>
<tr>
<td>● Inclusion of climate adaptation strategies</td>
<td>● More flexibility by using non-check list auditing supported with professional give and take</td>
</tr>
</tbody>
</table>

4.5 Discussion

This survey provided a general outlook of the forest managers toward FCP in the northeast U.S., especially Maine, New Hampshire, and Vermont. The response rate (25%) was reasonable, and the rate is higher or on par with other surveys conducted among forest industry (Abbas et al., 2014; Koirala, Kizha, & Roth, 2017; Meo et al., 2018). The survey’s online platform method and
the overlapping work-from-home situation due to the global pandemic (Covid-19) might have contributed to the relatively high response rate as well.

Majority of the respondents (48%) had an experience of more than 30 years in the forest industry. There were fewer respondents (18%) from the less than 15 years of experience group. This may be due to aging workforce in the forest management sector of the northeastern U.S. A similar observation was made by (Koirala, Kizha, & De Urioste-Stone, 2017) in a forest trucking survey conducted in the same region. Another reason might be that younger forest managers did not respond to surveys compared to the experienced managers (Amany & Krishna, 2017; Gigliotti & Dietsch, 2014). Age or experience of the respondents were not considered during population sampling. Many respondents (43%) were found to work in multiple states, which might be due to the tradition of land-owning-managing companies and consulting foresters operating in various states across the northeast U.S.

The majority of respondents were accredited by FSC and SFI, which is the general case prevailing among forest landowners in the North America (Chizmar et al., 2020; Perera & Vlosky, 2006). Even though small woodland owners hold nearly 40% of forest land in the region (Butler et al., 2021; Doak, n.d.), less number of responses for ATFS might be an indication of reluctance toward FCP by small woodland owners due to the prohibitive cost of certification (AF&PA, 2014; Perera & Vlosky, 2006). About 62% of the respondents were certified by more than one program, significantly higher than the U.S. national average (23%) (Alvarez, 2018). This might be due to the high percentage of consulting foresters in the survey population (41%), as they work with multiple clients and can be licensed in more than one state. Double certified areas represent about 18% of the total certified forest area globally (Fernholz et al., 2021).
A significant difference between the respondent groups might be due to the varying landholding size, ownership, and years of experience. Forest management and governance are influenced by the number of forestry holdings, landholding size, and ownership types (Maesano et al., 2018). In this study, significant difference between land management company (somewhat agree) and consulting forester (strongly disagree) was observed for supplementary benefits of FCP (implementing BMP, laws and regulations, existing management plan, and education and training). Size of the forest landholding managed and the certification program implemented were the factors determining the level of understanding on forest certification; enterprises managing large forest tracts have seen certification as more important in securing the provisions ecosystem services (Paluš et al., 2021). A significant difference in response was observed between less and more experienced forest managers (foresters) by Labriole and Luzadis (2011) in a study looking into the perception of foresters towards climate change, as observed in this study also.

4.5.1 Discontinuation of forest certification programs

Sixteen percent of respondents discontinued their certification. The major reasons for discontinuation were due to no particular benefit for being certified and the high cost of audits (Barnard, 2019; Guan & Ip Ping Sheong, 2019; Maraseni et al., 2017; Wibowo & Giessen, 2018). The most discontinued program was FSC, which was typically dropped after 2010. This might be linked to the changes made in the FSC certification standards by removing regional standards and adopting FSC-US Board in 2010 (FSC, n.d.). The reason for discontinuing is supported by responses to the question regarding the geographic scope of FCP standards. Respondents prefer to have regional certification standards (94%). Any standard revisions toward a global certification standard might lead to more discontinuations; only 25% agreed to have certification standards on a global scale. Changes in certification standards were the fourth reason for discontinued
certifications, with 70% in agreement. Poor performance of FSC was also observed by Ehrenberg-Azcárate and Peña-Claros (2020) during 2007-08 due to the global financial crisis in tropical Americas.

Organizations are more likely to participate in FCP if they regard it as an option to enhance their environmental practices or to alleviate external pressure from NGOs or the general public (Basso et al., 2018; Cashore et al., 2005). This conforms to the results from the study, where the most agreed reason for enrolling in forest certification was social license (reputation).

4.5.2 Preferences received

According to FAO (n.d.), the primary reason for certification is an expectation of better prices for producers’ products was not supported in this study, with 75% of respondents disagreeing on market price premium as a reason for certification. Furthermore, for the question asking whether any preferences were received in the market, 45% of respondents agreed, but only one acknowledged receiving a price premium. Other studies also mentioned that no or minimum price premiums for certified products over non-certified as a key problem connected to certified supply chain (Ehrenberg-Azcárate & Peña-Claros, 2020; Paluš et al., 2018; Vlosky et al., 2015). All respondents that discontinued certification believed there were no specific benefits for being certified. Respondents repeatedly indicated it was costly with no tangible benefit to the landowners for the resources (capital and labor) spent on certification, especially for small woodlands. One respondent said, “... [certification standards] could not explain how sustainable forestry differs from the ‘old forestry’.”

4.5.3 Surveillance audits and possibility for reduced frequency

Respondents felt that reducing the frequency of surveillance audits could reduce the overall cost of certification and encourage better compliance with certification standards. A majority
(60%) of the respondents agreed to have the audit conducted every 2-3 years. However, some stated it would be “…an expense with no return,” with the entire auditing process becoming more tedious and time-consuming. Many also noted that the frequency should be reduced to biennial or triennial based on landholding size and performance over the certified period. For example, one respondent stated that one’s “…track record should matter. More compliance, less auditing, and low cost. Saving money is a powerful motivator.” Another respondent noted that annual audits were valuable for the first five years to set the certification process on track. Lengthening the time between audits would also help in alleviating the impression that the rules are constantly changing.

FCP were found to assist in the regular functioning of a forest management unit. However, 40% of the respondents said FCP were not essential for implementing existing management plans and legal regulations. AF&PA, (2014) has noted that certification is not necessarily essential to ensure a sustainable wood supply as the sustainability of forests in the U.S. is assured by a strong rule of law and successful implementation of best management practices (BMP). Forest owners/managers have benefited from improved internal documentation, policies, record keeping, and implementation consistency (Balch, 2021). But responses showed that forest managers were unhappy with the tedious documentation and time spent, especially on annual audits. One respondent stated, “…certification adds minimal additional burden to management actions on the ground and more often might affect the work done in the office and reporting more than anything else by the non-field foresters.”

4.5.4 Certified loggers and forest certification

Logger certification is voluntary third-party certification for timber harvesting companies or loggers. The program certifies employees’ protection, harvest planning, and the application of logging techniques intended to protect soil and water resources, cultural heritage, wildlife, and
Certified loggers could help ease the certification auditing process. Certified loggers are skilled to realize landowners’ objective of forest management and implement the harvest with minimal environmental disturbances. Additionally, they meet the environmental standards needed by forest certification programs (Mullaney, 2018; TCNEF, 2019). From a logger’s perspective, membership in such programs will reduce their insurance premiums and ensure regular training programs, thereby enhancing the safety of the operation. Additionally, certain land-owning and managing companies require that only certified loggers work on their properties. Respondents also felt that certified loggers doing a better job in silviculture, best management practices, and communicating with the auditor, could make the audit process easier to implement. On the contrary, some respondents did not find a difference between certified and non-certified loggers. Overall, the Certified Logging Professional Program (CLP) was generally favored by the respondents. In terms of FCP, SFI generally places the greatest emphasis on logger safety (Haworth et al., 2007), and a couple of respondents also noted the same.

4.5.5 Sustainable forest management through certification

Half of the respondents disagreed on FCP being necessary for SFM, contrary to one of its primary purposes (FAO, n.d.; Sarkar & Hegde, 2019). With people on the ground not believing FCP as a tool for SFM and climate mitigation, the area of certified forests (in the northeastern U.S.) may reduce further. This is aligned with the recent negative trend in certified forest area (Ehrenberg-Azcárate & Peña-Claros, 2020; Espinoza & Dockry, 2014; Shreya, 2017). Respondents generally viewed forest certification as a tool for documenting management but not enforcing sustainability; as one respondent stated, “... certification can improve the comprehensiveness of a management regime; however, the quality of management is not driven
by certification.” This contradicts the findings by Paluš et al. (2021), forest certification is perceived as a tool to showcase commitment to environment while promoting SFM. To promote sustainability, opinions were to make certification a more adaptive management approach rather than adhere to strict standards. Several respondents regarded FCP as politically driven due to public pressure, with negligible impact on SFM, also stating adequate forestry laws already existed in the region. This was also evident when asked whether FCP was essential to implement laws and regulations. Some respondents stated that FCP as the basis for the forest industry to obtain and maintain their social license to practice forestry. One opinion expressed, “...certification confirms that forest is managed sustainably.” Certification appeals to some landowners for its value alignment, educational, ecological, social, and indirect economic benefits, even if there is no evident commercial advantage (Boakye-Danquah & Reed, 2019).

4.5.6 Importance of certification and need for awareness among stakeholders

Certification programs have a greater role in mitigating climate change (Klenk et al., 2015). They are one of the first examples of the shift away from state-centric governance to non-state players participating in forestry governance (Hackett, 2013). However, some respondents had a negative attitude toward FCP. If FCP were eliminated based on the negative feedback, the role of FCP might be taken over by more rigid governmental policies, where stakeholders' involvement might be significantly reduced (Balch, 2021). Adhering to FCP could assure sustainability to the consumers with the active participation of all stakeholders. On the contrary, respondents were also worried that FCP could instigate new policies; as one respondent noted, “...I am concerned that certifications will open the door to eventual mandates and state/local/federal regulation that will overburden an already overburdened industry.”
Others noted issues about FCP were the awareness, benefits, and need for certification not being fully communicated to the general public, forest managers, and landowners (Butler, 2008; Tian & Pelkki, 2021). This lack of awareness was also observed from the survey, with only 58% of the respondents having any experience with FCP. In contradiction, a study in the European context inferred that forest managers and landowners have a strong awareness of SFM and the objectives of various FCP, especially for large forest owners (Paluš et al., 2021). Respondents stated, “...foresters need a comprehensive course on what sustainable forestry really is”; “...landowners do not understand the standards being applied.”; and “...a land management organization stands no chance of being certified without a workforce educated in the laws, regulations, BMP, and requirements of the certification system”. Decision to participate in forest certification by landowners can be positively influenced by providing professional advice from forest managers regarding their land and having a written management plan (Paluš et al., 2018; Tian & Pelkki, 2021).

FCP should do more outreach to the general public, thereby encouraging consumers to buy certified products. Vlosky et al. (2015) and Paluš et al. (2018) emphasized the need for increasing the level of understanding about FCP among consumers. The anticipated financial rewards or preferred market access have never really materialized, with the general buying public in North America seldom makes buying decisions based on certification (Balch, 2021; Basso et al., 2018; Espinoza et al., 2012). Success of FCP is dependent on stakeholder involvement and transparency (Tröster & Hiete, 2018). One respondent stated, “...there is a serious need for long-term research and demonstration with certification.”
4.5.7 Recommendations for improving FCP

In general, respondents believed that FCP worked for large landowners. There was also consensus to improve the status quo prevailing in FCP, with reducing the cost of auditing getting top priority. Several strategies to improve FCP came directly from the respondents through open-ended questions and comments. Along with strategies, support and encouragement from stakeholders are needed for the FCP to expand (Basso et al., 2018). The strategies were broadly divided into four topics, the key points of which are summarized below.

4.5.7.1 Certification process

- Uphold principles and performance of certifications and consistency in application. The concern of forest land certified following timber liquidation and diameter limit cut was raised by several respondents. Several other respondents also mentioned that sustainable management was not the primary motivation for certification “…we are certified because of how we manage and intend to keep it that way. We are not managing so that we maintain certification.”

- Compatibility between different certification programs was also a factor that deterred respondents from certification: “…the over-complication of the FSC program to differentiate from SFI is unaccommodating. There should be compatibility between the programs for the greater good.”; “…competing certification systems are not helpful, with arguments over minutia.” A similar inference was made by van der Ven and Cashore (2018), changes in standards and shifting objectives within and across FCP have led to elusive evidence on social, environmental, and economic impacts.

- Financial support from the state or federal government for meeting the expectations of society. Many respondents believed that too much effort was being given to social issues.
One respondent remarked on a particular incident, “...an auditor once asked my logging contractor, if I treat them nice... but they didn't ask me how I get treated...”. Respondents were also of the opinion that much of the certification had to do with non-market elements (social aspects) and were not compensated for.

- The lack of education on sustainability to stakeholders and consumers was also raised by several respondents: “…improve the brand in consumers’ eyes.”

- Reconstruct the certification process from a pass-fail system (for FCP that uses them currently) to a scoring structure (for example, 1-100). This can translate to a property scoring 70 being less sustainable than scoring a 95. Therefore, in a tight market, high-scored properties could receive an upper edge over the lower score. This would also create incentives for constant improvement or maintaining a high score.

### 4.5.7.2 Certification standards

- Have the certification process compliant with different landownership types and have more regional guidelines.

- Provide more emphasis on silvicultural practices for more sustainable forestry.

- The changing environment should be understood and incorporated into FCP: “… herbicide restriction (in FSC) is taking a toll on practitioners.” On the contrary, one respondent thought not to change standards periodically to meet worldwide issues, as they do not pertain to North America. Similarly, there were concerns over a five-year standard review, “…doing a review is OK, but there seems to be too much emphasis on finding something new to add when it will do little to change on-the-ground practices.”

- Extend the standards revision period in compliance with the forest management state regulation.
4.5.7.3 Auditing

- Reduce bureaucracy and paperwork (simplification, especially on record-keeping). Respondents believed that forest certification has boiled down to paperwork.

- The cost of auditing has been increasing over the years. Reasonable costs for audits and better cost-benefit analysis are needed to ensure that the programs remain effective and affordable, especially for small woodland owners: “...the cost to the land manager for an annual audit can be greater than the monetary return for the certification value in the current market!”

- Frequency of surveillance audits: Even though most of the respondents agreed to a 2–3-year gap between certification audits, a few indicated surveillance is the foundation of certification and should there be conducted annually. One respondent commented, “…interval of recurring audits could be based on acreage, supplemental certifications, and/or memberships.” Another opinion was “…certified properties (managed by the respondent) being geographically dispersed with only a sample of properties being visited each year. Increasing the interval between audits would require more properties to be visited at each audit, which may cause logistical and time commitment issues.”

- Respondents desired to see meaningful changes in the auditors with regard to training in regional forestry practices, attitude during the audits, and the general auditing process: “auditors need to be experienced in land management/ harvesting/ silviculture/ marketing forest products,” “more field verification by multiple different specialists”, “consistency among different auditors”, “…it seems auditors are less into forest management practices and more about making sure to "check all the boxes" so that the company can pass”, and “…we do not need big brother to tell us how to manage our clients’ properties best.” Factors
that determine the problem solving capacity of FCP are the quality of certification requirements and capacity building measures (Tröster & Hiete, 2018).

4.5.7.4 Market

- Provide tangible monetary value to the landowner: “...give landowners more reasons to become certified.”; “…demand for the products at a premium price to at least cover the extra costs.” On the contrary, “…certification is a necessary attribute for entry to many key product and commodity markets.”

- Respondents reduced the pool of certified lands to reduce the certification cost; they could still claim to be certified by doing this. “...Certification is currently a cost of doing business and has no price premium and only occasional access privilege.”

4.5.8 Study limitations

Most of the respondents were foresters and land managers, not landowners, therefore, the decision-making capacity of respondents for being certified might be limited. Forestland owners set management goals and policies that impact the use of SFM practices (Maesano et al., 2018). The small number of responses, especially when analyzing the questions which apply to respondents with experience in FCP might have reduced the strength of the survey, although we did find statistically significant differences across key groups for several responses. The results from the study are limited to the geographical scope of the northeast U.S., primarily Maine, New Hampshire, and Vermont. However, responses related to auditing cost and market access apply elsewhere (Paluš et al., 2021; Savilaakso & Guariguata, 2017). It is also worth noting that the online survey might have missed some of the population. Further study on consumer willingness to pay for certified products should be conducted, as this will help to establish a reasonable cost of certification which can reduce the burden (cost of certification) on forest managers.
4.6 Conclusion

FCP were developed to ensure SFM through the active participation of all stakeholders in the forest product supply chain. We analyze a survey of regional forest managers in the northeastern U.S. to understand better the perceptions, opportunities, and limitations of FCP. A higher percentage of forestland certified by two FCP were observed among respondents. Respondents indicated that forest certification in the region has become a cost of doing business for forest managers, enabling better market access without any cost benefits. Respondents mentioned that social license (reputation) as the main reason for being certified. The prohibitive cost of forest certification auditing and lack of price premium are the greatest challenges. As there is no market price premium for certified wood, forest managers wish to have a reduced frequency of surveillance audits based on continuous certification status and performance in the previous audits. Preferred interval between surveillance audits was every two years as the longevity of forest management activities. Forest managers also wish to have regional-specific and stakeholder-specific (small woodland, industrial woodland, state, or federal land) certification standards. Respondents were typically satisfied with certification auditors and preferred non-checklist auditing and auditors with regional forest management knowledge. Significant difference in response was observed between different groups of respondents, which can be attributed to the difference in landholding size and ownership. Respondents were of mixed opinion regarding the essentiality of FCP in implementing existing forest management practices and regulations. Awareness needs to be created among the stakeholders - including consumers - regarding the need for SFM and the role of certification programs. Respondents wish to see improvements in the areas of certification process, standards, market, and auditing. This study can be considered as feedback from the forest managers to the FCP regarding the certification process.
5 LIFE CYCLE ASSESSMENT OF FEEDSTOCKS FOR THE FOREST PRODUCTS INDUSTRY: FOUR CASE STUDIES ACCOUNTING FOR A CIRCULAR BIOECONOMY

5.1 Abstract

As the global climate change mitigation efforts urge the push toward green economy, information on the carbon footprint of forest industry supply chain is crucial to ensure the sustainable management of renewable resources. This research quantified the carbon footprint of four different forest product industries: a chip mill, in-woods chipping, a hardwood sawmill, and a softwood sawmill in the northeastern U.S. SimaPro software and allied databases (USLCI and US-EI) were used to perform the life cycle assessments (LCA) following ISO 14040 and 14044 protocols. The functional unit was 1 tonne for chip mill (wood chips) and 1 m$^3$ for sawmill (planks). The highest contributing input for chip mill, in-woods chipping, hardwood, and softwood sawmill were transportation, raw material (residual wood), raw material (round wood), and transportation, respectively. The study also enumerated the substances that contributed most to the environmental impacts. A comparison of environmental impacts was made for wood chips, a common product or co-product in all four selected production facilities. A similar comparison was made between sawmills and wood chipping facilities. The global warming potential (GWP) of chip mill, in-woods chipping, hardwood, and softwood sawmill were 49.5, 21.7, 72.9, 73.7 kg CO$_2$ eq per respective functional units, respectively. Percent change in GWP with change in transportation method and distance was investigated. The study anticipates supporting various stakeholders in the forest industry supply chain, from consumers to policymakers. The results could assist the forest industry in choosing wood feedstock with minimal carbon footprint and have educated engagement in the ever-evolving carbon market.
5.2 Introduction

The forest industry is under pressure from the market to reduce the carbon footprint and increase the social acceptability of timber harvesting operations (FPInnovations, 2021; George et al., 2022; Marchi et al., 2018) as forests are a strategic tool to mitigate climate change (Alzamora et al., 2022). Even though wood from sustainably managed forests has the potential to be carbon neutral (Schulze et al., 2022), wood products and energy generated can be considered carbon-neutral only if the forest sequester at least the same quantity of CO$_2$ released during their production (Marchi et al., 2018). Hence there is a need to understand fossil fuel consumption of wood products throughout the supply chain to determine the climate change mitigation potential of sustainably managed forests and wood products (Pokhrel et al., 2022; Schulze et al., 2022). Forest products cause greenhouse gas emissions (GHG) through the utilization of fossil fuels in the manufacturing processes (Alzamora et al., 2022; Marchi et al., 2018; Schulze et al., 2022). Along with the manufacturing process, timber harvesting and transportation significantly impacted GHG emissions (Alzamora et al., 2022; González-García et al., 2014), thereby greater global warming potential (GWP). A study comparing GWP of wood pellets by Pokhrel et al., (2022) showed that transportation had the highest contribution to different environmental impact categories.

Due to the climate mitigation potential of forest products and their applicability toward sustainable development, there is an increasing concern about the possible scarcity of forest products by 2030 (Mantanu et al., 2010; Sommerhuber et al., 2017). Hence there is a need to use underutilized co-products of forest products as feedstock for other manufacturing processes (or co-generation of energy utilizing the co-product at the primary production facility) to have a minimal carbon footprint and sustainability. In the context of climate change, the carbon footprint
is a measure used to quantify GWP or GHG emissions with the life cycle of a product, events, and activities expressed in kg of CO$_2$ equivalent from energy consumption (Galvín, 2020).

Life cycle assessment (LCA) is an internationally accepted methodology to identify, quantify, and analyze all inputs and output involved in production, use, and disposal of a product of interest (Baumann & Tillman, 2004). LCA has become a key procedure in the forest industry to understand the environmental impacts associated with wood extraction and the processing and transportation of wood products (Abbas & Handler, 2018; Pokhrel et al., 2022; Rydin & Svensson, 2022). There are four phases in an LCA study: i) definition of goal and scope (system boundary), ii) inventory analysis (input and output), iii) impact assessment (carbon emission in kg CO$_2$ equivalent), and iv) interpretation (International Standard Organization, 2006a, 2006b). Mainly, emission studies using LCA are of two types, cradle-to-grave or cradle-to-cradle (Baumann & Tillman, 2004; International Standard Organization, 2006a; Rydin & Svensson, 2022), where the impact of a product or process is analyzed from raw material acquisition, processing, consumption, and final disposal (Puettmann et al., 2013). A functional unit is applied to normalize all the system inputs and compare various impact categories between different forest products; volume (m$^3$) or mass (kg or tonne) are the frequently used functional units (Abbas & Handler, 2018; Proto et al., 2017; Zhang et al., 2016).

Understanding the carbon footprint using LCA will help to identify forest products with minimum emission and production phases in which improvements can be made to reduce GWP of the forest industry. Information from LCA studies can be used in forest certification processes and eco-inventory platforms that report industry performance in climate change mitigation (Alzamora et al., 2022). Reducing the GWP and carbon footprint labeling of the supply chain could help gain social acceptance for the forest industry and wood products. Studies have shown increased
purchase probability and willingness to pay a price premium for carbon footprint labeled products (Feucht & Zander, 2017; George et al., 2022; Thøgersen, 2021). Quantifying annual or periodic carbon emission rates from different forest products are crucial in carbon budgeting for the state, Forest Carbon Program of Maine, to be a carbon-neutral state by 2045 (Mills, 2021). This will help manufacturers identify critical negative points of GWP in their production system and adopt better technology with fewer emissions. LCA studies are used to estimate the net effects of product substitutions with respect to climate change, air & water quality, and other impact categories (Galvín, 2020; González-García et al., 2014; Rydin & Svensson, 2022).

Echoing the crucial role of forests in climate change mitigation and the importance of timber and forest-based industries in GHG reduction, the objective of this study was to estimate and compare the carbon footprint products from a chip mill, an in-woods chipping operation, a hardwood sawmill, and a softwood sawmill using the LCA technique, and also to better understand the effects of transportation on carbon footprints. Along with bridging the knowledge gap on the carbon footprint of wood products, this study will supplement the carbon budgeting of the forest industry in the northeastern U.S. as we proceed towards a circular bioeconomy. Circular bioeconomy emphasizes on the use of renewable resources in a way that prevents wastage of resources (Tan & Lamers, 2021).

5.3 Materials and methods

LCA was performed to quantify carbon footprint and other environmental impact assessment categories (EIAC), including ozone depletion (kg CFC-11 eq), global warming (kg CO₂ eq), smog (kg O₃ eq), acidification (kg SO₂ eq), eutrophication (kg N eq), carcinogenic (CTuh), non-carcinogenic (CTuh), respiratory effects (kg PM2.5 eq), ecotoxicity (CTUe), and fossil fuel depletion (MJ “surplus”) (Similar order is followed throughout the manuscript while mentioning
EIAC and substance contribution). The environmental impacts were normalized to find the EIAC of maximum concern (Pokhrel et al., 2022; Unnasch & Buchan, 2021). A case study approach was taken to perform LCA using protocols prescribed by ISO 14040 (2006) and ISO 14044 (2006b) standards. The study was conducted in Maine, U.S.

LCA was done using SimaPro 9.3.0.3 software. The databases of USLCI and US-EI 2.2 (DATASMART package) were used since they are based on the U.S. manufacturing and electricity data (Pokhrel et al., 2022). The mass and energy flow within the system boundary were calculated using the collected input-output data and databases, representing variation of production facilities. Carbon footprint and other impact assessments used the North American Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI) 2.1, a built-in tool for SimaPro.

5.3.1 System boundary and unit processes

The system boundary for the cradle-to-gate LCA of this study included all the activities from the production facilities' log yard to the first (retailer/wholesaler/exporter/consumer) (Figure 5.1). LCA of a chip mill, in-woods chipping (landing), a hardwood sawmill, and a softwood sawmill were performed. The production facilities were in the northeastern U.S.
5.3.1.1 Chip mill

The wood chip mill received mixed wood (i.e., hardwood and softwood) of inferior quality (tree length and cut-to-length) from the log yard. The logs were brought to the feeding system using front-end loaders and forklifts. The facility could consume logs of a maximum of 66 cm and a minimum of 10 cm in diameter. Wood for chipping were loaded to the conveyer belt of the facility using electrically operated cranes. Logs were debarked using a drum debarker (primarily) and a ring debarker. Removed bark was taken out to the bark pit via vibration conveyor belts. The debarked log was then fed to the chipper powered by two 800 hp motors using another electric crane. The wood chips were moved to a surge bin, then moved to screens (8 cm) and were segregated into three sizes. Larger chips were re-chipped and screened again. The chips of acceptable size were moved to storage bins through a conveyor. The permissible bark content in the final product was <1%. The entire production process used electric motors, which consume hydroelectricity from the grid. The wood chips were transported via chip trucks to consumption points, where they were used for electricity and pulp production (majority). The coproduct, bark,
was given to nearby farmers for use in land amelioration. The facility had 84.4% green wood chips and 15.6% bark production.

5.3.1.2 **In-woods chipping**

In the in-woods chipping system, wood chips of inferior quality were produced and were primarily used for biomass energy production. Logging residue (slash and low-quality wood after processing logs) was fed into a chipper (750 hp) using a loader (175-200 hp), and green wood chips were blown into a chip truck by the chipper itself. The wood chips were transported via chip trucks to consumption points for electricity production and heat. There was no co-product.

5.3.1.3 **Hardwood sawmill**

Hardwoods, primarily sugar maple and yellow birch, were processed into sawn lumber. Logs were loaded into the facility using an electric crane and were debarked using a drum debarker. The size of logs fed into the system ranged from 25 to 60 cm. Debarked logs were sawed and resawed using a double-cut saw, a head saw, a resaw, and a combination saw. Then the sawn boards were trimmed and squared using edgers to obtain maximum merchantable lumber. Squared boards were graded mechanically and were transferred to a kiln for drying with a 12-day seasoning schedule. Logs and lumber were transferred between each point via conveyor belts. A biomass boiler (600 hp) was used to power the kiln using sawdust produced from the facility and was also used for facility heating. During wood seasoning, the moisture content was brought down to 6% from 80-120%. Seasoned lumber was graded, packed, and shipped to the point of consumption. Around 35% of the sawn lumber was sold as green, without seasoning. The facility did not plane the lumber. The lumber was packed using wood dunnage and plastic strappings. The co-products from the facility were bark, wood chips, and sawdust. The facility consumes hydroelectricity from the grid.
5.3.1.4 Softwood sawmill

The facility processed white pine (softwood) into 25 cm (1 inch) thick planks. Logs were fed into the facility’s ring debarker using a diesel-powered crane. Debarked logs were converted into planks with the help of a head rig, resaw, trimmer, edger, etc. The planks were sorted and were transferred to a kiln for a 6-day seasoning schedule. The moisture content of the planks was brought down to 11%. Kilns were powered using a 600 hp boiler and cogenerated electricity. Along with co-products (except wood shavings) from the facility, mixed whole-tree wood chips from outside were also used to feed the boiler. Seasoned planks were planed and graded before packing for final shipment. The co-products from the facility were bark, wood chips, wood shavings, and sawdust. The product was transported using trucks to the point of consumption. The co-products were trucked in bulk, without packaging.

5.3.2 Life cycle inventory analysis

For inventory analysis, information on input and output for the above-mentioned production facilities were collected by visiting the facilities. The input parameters were selected based on the collected information from Life cycle inventory (LCI) database, DATASMART in Simapro are mentioned in Table 5.1. The functional unit was 1 tonne of wood chips for chip mill and in-woods chipping (wood chips are merchandized for unit mass), and 1 m³ planks for sawmills (planks are traded for unit volume). Functional units reflect the goal and scope, which is the reference connecting the inputs and outputs normalized for LCA (Pokhrel et al., 2022; Rydin & Svensson, 2022).
Table 5.1 Inputs of LCA modeling for different forest products along with their LCI dataset chosen from DATASMART in SimaPro.

<table>
<thead>
<tr>
<th>LCI Dataset</th>
<th>Chip mill</th>
<th>In-woods chipping</th>
<th>Hardwood sawmill</th>
<th>Softwood sawmill</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product and co-products</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood chips (tonne)</td>
<td>1</td>
<td>1</td>
<td>0.62</td>
<td>0.21</td>
</tr>
<tr>
<td>Plank (m³)</td>
<td>NA</td>
<td>NA</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Bark (tonne)</td>
<td>0.08</td>
<td>NA</td>
<td>0.30</td>
<td>0.09</td>
</tr>
<tr>
<td>Sawdust (tonne)</td>
<td>NA</td>
<td>NA</td>
<td>0.13</td>
<td>0.15</td>
</tr>
<tr>
<td>Shavings (tonne)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Input from nature</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water, well, US (l)</td>
<td>NA</td>
<td>NA</td>
<td>1.14</td>
<td>830.00</td>
</tr>
<tr>
<td><strong>Input from technosphere: materials/fuels</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roundwood, softwood, green, at mill, NE-NC/m³/RNA (m³)</td>
<td>0.54</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Roundwood, hardwood, green, at mill, NE-NC/m³/RNA (m³)</td>
<td>0.86</td>
<td>NA</td>
<td>2.36</td>
<td>1.60</td>
</tr>
<tr>
<td>Residual wood, hardwood, under bark, u=80%, at forest road/US-US-EI U (m³)</td>
<td>NA</td>
<td>0.69</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Residual wood, softwood, under bark, u=140%, at forest road/US-US-EI U (m³)</td>
<td>NA</td>
<td>0.69</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Description</td>
<td>Unit</td>
<td>Value 1</td>
<td>Value 2</td>
<td>Value 3</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------</td>
<td>------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>Forest residue, processed and loaded, at landing system/ton/RNA (tonne)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Shavings, softwood, kiln dried, NE-NC/kg/RNA (tonne)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Bark, softwood, green, at sawmill, NE-NC/kg/RNA (tonne)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Wood chips, softwood, green, at sawmill NE-NC/kg NREL/RNA U (tonne)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Sawdust, softwood, green, at sawmill NE-NC/kg/RNA (tonne)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Proxy_Oil and grease, at plant NREL/US U (kg)</td>
<td>0.009</td>
<td>0.005</td>
<td>0.22</td>
<td>0.22</td>
</tr>
<tr>
<td>Transport, combination truck, long-haul, diesel-powered, Northeast/tkm/RNA (&gt; 322 km) (tkm)</td>
<td>NA</td>
<td>NA</td>
<td>402.34</td>
<td>804.67</td>
</tr>
<tr>
<td>Transport, combination truck, short-haul, diesel powered, Northeast/tkm/RNA (&lt; 322 km) (tkm)</td>
<td>216.00</td>
<td>64.37</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Ethylene glycol, at plant/RNA (kg)</td>
<td>NA</td>
<td>0.001</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Diesel, at refinery/l/US (l)</td>
<td>0.50</td>
<td>1.83</td>
<td>1.21</td>
<td>1.85</td>
</tr>
<tr>
<td>Residual fuel oil, at refinery/l/US</td>
<td>0.17</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Pallet (22kg)/US- US-EI U (kg)</td>
<td>NA</td>
<td>NA</td>
<td>3.3</td>
<td>26.18</td>
</tr>
</tbody>
</table>
5.3.3 Sensitivity and what-if analysis

A local sensitivity analysis was performed to understand the effect of transportation distance toward environmental impacts. The analysis explored the variation in global warming potential of the products when there is a 50% or 100% increase and decrease in transportation distance, keeping all other inputs constant (George et al., 2021; Kizha & Han, 2016; Unnasch & Buchan, 2021). Also, it investigated the change in GWP if rail was used for transportation of products instead of combination trucks.

5.4 Results and discussion

5.4.1 Life cycle impact assessment

Life cycle impact assessment of primary product of all the four production facilities are described below.
5.4.1.1 Chip mill

The impacts from material and energy flows (wood, lubricants, electricity, diesel, heating, and transportation) in the production and shipping of 1 tonne of green wood chip from a chip mill consuming mixed roundwood is shown in Figure 5.2. Transportation contributed heavily (41%) to all EIAC except ozone depletion, followed by raw material (round wood, hardwood, 30%). Similar trend was observed many LCA studies (Abbas & Handler, 2018; Oneil & Puettmann, 2017; Puettmann et al., 2013; Sahoo, Bergman, et al., 2019). About 76% of ozone depletion was contributed by lubricants followed by transportation. Lubricants have ozone-depleting compounds like methyl alcohol, toluene, and other volatile organic compounds (Marbach et al., 2000; US EPA, 2015).

The contribution of hardwood (30%) to all EIAC was two times that of softwood (16%). One of the reason might be due to decreased productivity of harvesting equipment when working on hardwood compared to softwood (Abbas & Handler, 2018; George et al., 2021; Louis & Kizha, 2021a). The input with the least effect on all impact assessment categories was fuel oil used to heat the facility (Abbas & Handler, 2018). The substances contributing to the different EIAC were HCFC 140, carbon dioxide, nitrogen oxides, ammonia, ammonia, arsenic, arsenic, ammonia, antimony, and coal, respectively (Pokhrel et al., 2022; Unnasch & Buchan, 2021). Normalization of the EIAC showed that carcinogenic was the impact category of maximum concern. This finding indicates that the facility could focus first on mitigating the release of carcinogenic substances to make their products more environmentally friendly. The GWP of the facility was 49.5 kg CO$_2$ eq tonne$^{-1}$ of wood chips produced. This result compares favorably with data from Murphy et al., (2015), who reported GWP of wood chips from Europe ranging from 51.2 to 86.7 kg CO$_2$ eq oven dry tonne$^{-1}$. 

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5.4.1.2 In-woods chipping

LCA of 1 tonne of green wood chips produced at the forest operation landing and its transportation to the first point of consumption is shown in Figure 5.3. The GWP of in-woods chipping was 21.7 kg CO$_2$ eq tonne$^{-1}$ of wood chips produced. Some of the reported GWP of in-woods chipping ranged from 16.2 to 23.3 kg CO$_2$ eq tonne$^{-1}$ (Abbas & Handler, 2018) and 35.5 (Johnson et al., 2012). Antifreeze (ethylene glycol) used by the equipment and lubricants had the least impact on EIAC because of the small amount used. On average, for all EIAC, the contribution of raw material (residual softwood = 40%; hardwood = 28%) was the highest, followed by transportation (25%) (Sahoo, Bilek, et al., 2019; Zhang et al., 2016). This might be due to the energy spent and emission on harvesting and processing small diameter trees (Abbas & Handler, 2018; Johnson et al., 2012). More research is needed to understand the contribution of forest operations to EIAC in the region. Studies have shown that the productivity of logging equipment decreases as the size of wood handled decreases (George et al., 2021; Louis & Kizha, 2021a). The substances that contributed maximum to EIAC were the same as chip mill except for ozone.
depletion. CFC 114 contributed the maximum to ozone depletion. Carcinogenic was the EIAC of concern for in-woods chipping also.

Figure 5.3 Impact assessment graph showing relative contribution of the inputs for 1 tonne of wood chips at in-woods.

5.4.1.3 Hardwood sawmill

During the production of 1 m$^3$ of hardwood plank, similar to in-woods chipping, the contribution of raw material (round wood, hardwood = 30%) was highest, followed by transportation (24%) (Figure 5.4) (Murphy et al., 2015; Sahoo, Bergman, et al., 2019). Low density polyethylene for packing contributed the least to EIAC, which was directly related to the small quantity consumed (Pokhrel et al., 2022; Silvenius et al., 2011). EIAC of maximum concern and substances contributed maximum to EIAC were similar to in-woods chipping except for smog (isoprene) and noncarcinogenic (acrolein).

The GWP of the facility for the primary product was 72.9 kg CO$_2$ eq m$^3$ of lumber produced. Reported GWP for hardwood lumber ranged from 131-250 kg CO$_2$ eq m$^3$ (Hubbard et al., 2020; Sahoo, Bergman, et al., 2019). This might be because the facility assessed was not planing the lumber produced. The electricity used by the facility was 141 kWh m$^3$ of rough-sawn
plank produced, which was less than Hubbard et al. (2020) (97 kWh m⁻³, excluding planing). The facility was comparatively old, and the manager informed that they would be updating the facility. Since both facilities used electricity from the grid (not differentiated based on the generation method), the lesser efficiency of old production systems could explain this difference.

Figure 5.4 Impact assessment graph showing the relative contribution of inputs for 1 m³ of hardwood plank at sawmill.

5.4.1.4 Softwood sawmill

For the hardwood sawmill, during the production of 1 m³ of softwood plank, the highest environmental impact was by transportation (46%), followed by raw material (round wood, softwood = 16%) (Figure 5.5) (Pruettmann et al., 2013; Sahoo, Bergman, et al., 2019). Impact of electricity cogeneration with heat was meager. The EIAC of maximum concern and substances contributed maximum to EIAC were similar to the hardwood sawmill. GWP estimated for softwood lumber in the Northeast U.S. was 78.38 kg CO₂ eq m⁻³ (Pruettmann et al., 2013), which was comparable to the findings of this study, 73.7 kg CO₂ eq m⁻³. The facility studied was comparatively new; hence, even with an additional production stage (planning), there was not much difference in GWP when compared to the hardwood sawmill (72.9 kg CO₂ eq m⁻³).
5.4.2 Comparing the production facilities

5.4.2.1 Wood chips from all four processes

In all the four forest product processes studied, wood chips were common as primary products or co-product. Wood chips were the primary product in chip mill and in-woods chipping, whereas it was a co-product in sawmills (Figure 5.6). Among EIAC, chips from hardwood sawmill had the highest impact. The GWP of wood chips from chip mill, in-woods chipping, hardwood sawmill, and softwood sawmill were 49.5, 21.7, 64.6, and 28.6 kg CO$_2$ eq tonne$^{-1}$, respectively (Table 5.2). This shows that it is environmentally feasible and less damaging to produce chips in-woods. Using in-woods chips as feedstock will reduce the impact of products down the supply chain compared to chips from other production facilities. The softwood sawmill assessed used whole tree chips to co-generate heat and electricity (Table 5.1). The facility manager said it is more economically feasible for them to use whole tree chips from outside than chips (co-product) from their facility.
Chips from sawmills were well dried and devoid of bark. They can be used as feedstock for other wood products and can become part of circular bioeconomy. When co-products are used as feedstock for another production facility, the environmental impact of the new product will be lesser because the impacts have already been accounted in the original production process, when compared to using round wood. Figure 5.6 depict the same; even though more resources were used to produce 1 m$^3$ of softwood plank, the impact of co-product was lesser or on par with chip mill and in-woods chipping. EIAC for hardwood chips may be higher due to higher allocation for chips (35%) compared to softwood mill (19%).

![Comparative impact assessment graph showing the relative contribution of inputs for wood chips from all the selected four processes with relation to functional unit.](image)

**Figure 5.6** Comparative impact assessment graph showing the relative contribution of inputs for wood chips from all the selected four processes with relation to functional unit.

### 5.4.2.2 Chip mill vs. in-woods chipping

For wood chips (1 tonne) from chip mill and in-woods chipping, there was a difference of 55% in GWP (Figure 5.6); GWP was lowest for in-woods chipping. Even though both produced green chips, there was a great quality difference in the product, raw material used, and production facilities. This difference may also be attributed to the fact that the residue used for in-woods chipping was a co-product of timber harvesting (Sahoo, Bergman, et al., 2019). But, as mentioned
earlier, there may be chances for consuming more energy and resources while processing smaller trees.

5.4.2.3 Hardwood vs. softwood sawmill

The softwood sawmill had the highest impact on all EIAC for production of 1 m$^3$ of plank (Figure 5.7). Global warming potential was 72.9 and 73.7 kg CO2 eq m$^3$ for hardwood and softwood mills, respectively. This difference can be attributed to the varying production process mentioned in the Methodology section. Even though the softwood mill was relatively new and consumed less electricity per cubic meter of plank (61.38 kWh), the hardwood mill studied (140.58 kWh m$^3$) had a lower overall impact. Advanced technology is expected to have better efficiency and lesser emission (Cervantes et al., 2018; Shi et al., 2021). Factors contributing to higher impact for categories other than global warming would be due to transportation of products to farther distance (804.8 km) than for the hardwood sawmill (402.3 km) (Figure 5.5; Table 5.1).

![Impact analysis graph](image)

Figure 5.7 Impact assessment graph showing relative contribution of inputs for 1 m$^3$ of hardwood and softwood plank at sawmill.
5.4.3 Global warming potential

Among EIAC described in the manuscript, there is a major focus on global warming potential (GWP) as it determines the basis of carbon trading and future climatic conditions. Softwood planks had the highest GWP among primary products, and in-woods chips had the least. Hardwood chips got the highest GWP among co-products, and the lowest was for chip mill bark (Table 5.2). GWP or other EIAC of co-products depends on percentage allocation during the life cycle inventory. For chip mill bark, the percentage allocation was 16%, and for hardwood chips, the percentage allocation was 34%. As mentioned earlier, using co-products as feedstock (or cogeneration energy) for a production process will reduce the impact of products down the supply chain.

Table 5.2 Global warming potential (GWP) of all products and co-products for one functional unit.

<table>
<thead>
<tr>
<th>Product</th>
<th>GWP</th>
<th>Product type</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chip mill</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood chips</td>
<td>49.51 kg CO$_2$  eq tonne$^{-1}$</td>
<td>Primary product</td>
</tr>
<tr>
<td>Bark</td>
<td>9.43 kg CO$_2$  eq tonne$^{-1}$</td>
<td>Co-product</td>
</tr>
<tr>
<td><strong>In-woods chipping</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chips</td>
<td>21.70 kg CO$_2$  eq tonne$^{-1}$</td>
<td>Primary product</td>
</tr>
<tr>
<td><strong>Hardwood sawmill</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planks</td>
<td>72.94 kg CO$_2$  eq m$^{-3}$</td>
<td>Primary product</td>
</tr>
<tr>
<td>Chips</td>
<td>64.56 kg CO$_2$  eq tonne$^{-1}$</td>
<td>Co-product</td>
</tr>
<tr>
<td>Bark</td>
<td>12.04 kg CO$_2$  eq tonne$^{-1}$</td>
<td>Co-product</td>
</tr>
<tr>
<td>Sawdust</td>
<td>13.48 kg CO$_2$  eq tonne$^{-1}$</td>
<td>Co-product</td>
</tr>
</tbody>
</table>
Table 5.2 continued

<table>
<thead>
<tr>
<th>Product</th>
<th>CO$_2$ eq m$^{-3}$</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plank</td>
<td>73.73</td>
<td>Primary product</td>
</tr>
<tr>
<td>Chip</td>
<td>28.59</td>
<td>Co-product</td>
</tr>
<tr>
<td>Bark</td>
<td>12.04</td>
<td>Co-product</td>
</tr>
<tr>
<td>Sawdust</td>
<td>19.56</td>
<td>Co-product</td>
</tr>
<tr>
<td>Shavings</td>
<td>16.55</td>
<td>Co-product</td>
</tr>
</tbody>
</table>

5.4.4 Effect of transportation on global warming potential

For all the production processes assessed, transportation distance was the input, contributing the maximum or the second maximum (Figure 5.2, 5.3, 5.4, 5.5). The role of transportation toward GWP is acknowledged by researchers (Pokhrel et al., 2022; Puettmann et al., 2013; Sahoo, Bilek, et al., 2019, 2019), and it contributes the largest portion (30%) to U.S. GHG. The sensitivity analysis showed that a 50% increase or decrease in transportation distance could change GWP of a product by 17% in either positive or negative direction. Similarly, for 100%, there could be 35% change in GWP (Table 5.3).
Table 5.3 Global warming potential (GWP) of production facilities with 50% (1.5) or 100% (2.0) increase or decrease in transportation distance. Value in parentheses is the percent change.

<table>
<thead>
<tr>
<th>Production facility</th>
<th>Change in transportation distance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-2.0</td>
</tr>
<tr>
<td>Chip mill</td>
<td>29.30</td>
</tr>
<tr>
<td>(kg CO₂ eq tonne⁻¹)</td>
<td>(-41)</td>
</tr>
<tr>
<td>In-woods chipping</td>
<td>14.50</td>
</tr>
<tr>
<td>(kg CO₂ eq tonne⁻¹)</td>
<td>(-33)</td>
</tr>
<tr>
<td>Hardwood sawmill</td>
<td>57.60</td>
</tr>
<tr>
<td>(kg CO₂ eq m⁻³)</td>
<td>(-21)</td>
</tr>
<tr>
<td>Softwood sawmill</td>
<td>36.20</td>
</tr>
<tr>
<td>(kg CO₂ eq m⁻³)</td>
<td>(-51)</td>
</tr>
</tbody>
</table>

Substituting rail transportation for the combination truck gave an average GWP reduction of 30% (Table 5.4). Rail has less GWP because it transports more quantity per trip, and is more fuel efficient (Kalluri, 2016). A ‘what-if analysis’ for in-woods chipping was not performed because it may not be practical to build rail to connect forest parcels. Percentage change of GWP in response to change in transportation mode was least for the hardwood sawmill because transportation was not the most contributing input (Figure 5.4).
The study performed LCA case studies of four wood production facilities from the mill log yard to the first point of delivery. Impact assessment showed that transportation was the highest contributing input parameter to EIAC for the chip mill and softwood sawmill. Raw materials (wood) contributed the maximum (average of all EIAC) for in-woods chipping and the hardwood sawmill.

Major substances contributing to each EIAC were CFC, carbon dioxide, ammonia, arsenic, antimony, nitrogen dioxide, isoprene, acrolein, and coal.

Comparing different products showed the importance of percentage allocation during life cycle inventory, especially for co-products.
- Softwood planks had the highest GWP, and chip mill bark had the lowest GWP among all the products and co-products assessed.
- On average, there was a 17% and 35% change in GWP when transportation distance increased or decreased by 50% or 100%, respectively. A GWP decrease of 30% was observed if rail was used instead of combination trucks.
- One of the limitations of the study was that there was only one sample for each production facility, which limits the generalization and applicability of the results. Since LCA follows ISO standards, it will be possible to compare these results with similar production facilities. The human resources used for the production processes were not considered.


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APPENDIX: QUESTIONNAIRE USED TO UNDERSTAND THE PERSPECTIVE OF
FOREST MANAGERS TOWARDS FOREST CERTIFICATION PROGRAMS

Q1 How many years have you been working in/with the forest industry?
   ○ Less than 5 years
   ○ 5-10 years
   ○ 10-15 years
   ○ 15-20 years
   ○ 20-25 years
   ○ 25-30 years
   ○ More than 30 years

Q2 Please describe your current role in forestry:
   □ Independent contractor
   □ Land management company
   □ State or Federal agency
   □ Consulting forester
   □ Landowner
   □ Land trust
   □ Nonprofit landowner
   □ Others (Please specify) ____________________

Q3 Please give your current job title: _________________________

Q4 Please mention the States where you most frequently work (select all applicable):
   □ Maine
   □ New Hampshire
☐ Vermont
☐ Massachusetts
☐ Rhode Island
☐ Connecticut
☐ Others (Please specify) ______________________________

Q5 Is your organization/management unit presently, or in the past, been certified by any third-party forest certification program?
  ○ Yes
  ○ No

Skip To: Q34 If Is your organization/management unit presently, or in the past, been certified by any third-party forest certification program = No

Q6 Please check the forest certification programs your organization/management unit is affiliated to (select all applicable).
  ☐ Forest Stewardship Council (FSC)
  ☐ Sustainable Forestry Initiative (SFI)
  ☐ Program for the Endorsement of Forest Certification Systems (PEFC)
  ☐ American Tree Farm Systems (ATFS)
  ☐ Others (Please specify) ______________________________

Q7 What type of certificate is your organization/management unit affiliated to (select all applicable)?
  ☐ Forest Management
  ☐ Chain-of-custody
  ☐ Fiber sourcing
☐ Controlled wood

☐ Others (Please specify) _________________________

Q8 How long has or was the organization/management unit been certified?

- ☐ <1 year
- ☐ 1-5 years
- ☐ 5-10 years
- ☐ 10-15 years
- ☐ 15-20 years
- ☐ >20 years

Q9 How strongly do you agree with the following reasons for certification?

<table>
<thead>
<tr>
<th>Reason</th>
<th>Strongly agree</th>
<th>Somewhat agree</th>
<th>Neither agree nor disagree</th>
<th>Somewhat disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>A requirement for market entry/access</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Achieve your organization's sustainability goals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer demand</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost of doing business</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Market price premium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deed restrictions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Social license (reputation)

Branding of products

Staff morale gets improved

Validation of forest management plan or practices

Others (Please write in)

Q10 Has your organization/management unit been continuously certified since you first received your certification?

☐ Yes

☐ No

Skip To: Q17 If Has your organization/management unit been continuously certified since you first received your certificate = Yes.

Q11 Which certification programs were discontinued and when (select all applicable)?

☐ Forest Stewardship Council (FSC)

☐ Sustainable Forestry Initiative (SFI)

☐ Program for the Endorsement of Forest Certification Systems (PEFC)

☐ American Tree Farm Systems (ATFS)

☐ Others (Please specify) _______________________

Q12 How strongly do you agree with the reasons for discontinuing certification?

<table>
<thead>
<tr>
<th>Strongly agree</th>
<th>Somewhat agree</th>
<th>Neither agree nor disagree</th>
<th>Somewhat disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
</table>

130
<table>
<thead>
<tr>
<th>Minor Nonconformities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landowner is not interested</td>
</tr>
<tr>
<td>Change in ownership of the land</td>
</tr>
<tr>
<td>No particular benefit for being certified</td>
</tr>
<tr>
<td>Cost of annual audits</td>
</tr>
<tr>
<td>Change in certification standards</td>
</tr>
<tr>
<td>Others (Please write in)</td>
</tr>
</tbody>
</table>

Q13 Have you resumed any of the discontinued certification?

- O Yes
- O No

Display This Question: If Have you resumed any of the discontinued certification? = Yes. Carry Forward Selected Choices from "Which certification programs were discontinued and when (select all applicable)?"

Q14 Which certification programs were resumed (select all applicable)?

- □ Forest Stewardship Council (FSC)
- □ Sustainable Forestry Initiative (SFI)
- □ Program for the Endorsement of Forest Certification Systems (PEFC)
American Tree Farm Systems (ATFS)

Others (Please specify) ______________________

Display This Question: If Have you resumed any of the discontinued certification? = No

Q15 Are you willing to recertify your organization/management unit?
   - Yes
   - No

Display This Question: If Are you willing to recertify your organization/management unit? = Yes or No

Q16 [Optional] Please provide explanation(s) for your responses to the previous question: _____

Q17 How satisfied are you with the certification process?
   - Very satisfied
   - Somewhat satisfied
   - Neither Satisfied nor unsatisfied
   - Somewhat unsatisfied
   - Very unsatisfied

Q18 To what extent do you agree that further changes are needed in the certification process?
   - Strongly agree
   - Somewhat agree
   - Neither agree nor disagree
   - Somewhat disagree
   - Strongly disagree

Display This Question: If To what extent do you agree that further changes are needed in the certification process? = Strongly agree or Somewhat agree
Q19 [Optional] Please provide the change(s) that you wish to see in the certification process: ___

Q20 To what extent do you agree that forest certification programs are essential to you/your organization in verifying and implementing the existing forest management plans, laws, regulations, policies, Best Management Practices (BMP), education & training programs, etc.?

<table>
<thead>
<tr>
<th></th>
<th>Strongly agree</th>
<th>Somewhat agree</th>
<th>Neither agree nor disagree</th>
<th>Somewhat disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing management plan</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laws and regulations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Best Management Practices</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education and Training programs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Others (Please write in)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Q21 To what extent do you agree that your organization/management unit received any preference in the market for being certified during your period of certification?

- [ ] Strongly agree
- [ ] Somewhat agree
- [ ] Neither agree nor disagree
- [ ] Somewhat disagree
- [ ] Strongly disagree
Display This Question: If To what extent do you agree that your organization/management unit received any preference in the market for being certified during your period of certification? = Strongly agree or Somewhat agree

Q22 [Optional] Please list the preference(s) received: ____________________________

Q23 To what extent do you agree that annual certification audits (surveillance audits) are necessary for maintaining certification status?

- Strongly agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Strongly disagree

Q24 [Optional] Please provide explanation(s) for your responses to the previous question: _____

Q25 What is an appropriate interval between certification surveillance audits?

- Every year
- Every 2 years
- Every 3 years
- Every 4 years
- Every 5 years
- Other length of time (Please write in) _______________

Q26 [Optional] Please provide explanation(s) for your response to the previous question: _____

Q27 To what extent do you agree that there should be any reduction in the frequency of surveillance audits for continuously certified organizations/management units?

- Strongly agree
○ Somewhat agree
○ Neither agree nor disagree
○ Somewhat disagree
○ Strongly disagree

Q28 [Optional] Please provide explanation(s) for your response to the previous question: ______

Display This Question: If To what extent do you agree that there should be any reduction in the frequency of surveillance audits for continuously certified organizations/management units? = Strongly agree or Somewhat agree

Q29 As you responded strongly agree/ somewhat agree to the previous question, what is the minimum number of years an organization/management unit should be continuously certified to qualify for less frequent surveillance audits?

○ 1-5 years
○ 5-10 years
○ 10-15 years
○ 15-20 years
○ More than 20 years
○ Other (Please write in) ______________

Q30 To what degree do you think the geographic scope of forest certification standards should be?

<table>
<thead>
<tr>
<th></th>
<th>Strongly agree</th>
<th>Somewhat agree</th>
<th>Neither agree</th>
<th>Somewhat disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>National</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Q31 How strongly do you agree with the following statements on forest certification auditors?

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly agree</th>
<th>Somewhat agree</th>
<th>Neither agree</th>
<th>Somewhat disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sufficiency qualified</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experienced</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respectful</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exceeding the scope of certification standards by challenging management plans</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Others (Please write in)</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Q32 To what extent do you agree that employing certified loggers make the forest management audit process easier?

- Strongly agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Strongly disagree

Q33 [Optional] Please provide explanation(s) for your response to the previous question: ______
Q34 How strongly do you agree that third-party forest certification programs are necessary for sustainable forest management?

- Strongly agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Strongly disagree

Q35 [Optional] Please provide explanation(s) for your response to the previous question: 

Q36 What of the following factors are deterrents to your organization/management unit seeking certification or you see as challenges/weaknesses of certification programs?

<table>
<thead>
<tr>
<th>Factor</th>
<th>Strongly agree</th>
<th>Somewhat agree</th>
<th>Neither agree nor disagree</th>
<th>Somewhat disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased cost and complexity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Additional burden re: rules and regulations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack of price premiums</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size of ownership</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Workforce capacity challenges</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No meaningful changes on the ground</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Advent of other means of providing customer assurance for sustainability

Others (Please write in)

Q37 Do you have any additional concerns, challenges, or comments related to your participation in forest certification programs that were not addressed in this survey? If so, please list below. ___

______________________________________________________________________________
BIOGRAPHY OF THE AUTHOR

Alex Kunnathu George was born in Kolenchery, Kerala, India, on June 5, 1991. He was raised in Muvattupuzha, Kerala, and graduated from high school in 2009. He attended Tamil Nadu Agricultural University with National Talent Scholarship and graduated in 2014 with a bachelor’s degree in Forestry. In 2014, he joined Kerala Agricultural University and secured a master’s degree in Forestry with a specialization in Wood Science in 2018. After graduation, he worked as Teaching Assistant for a year at Kerala Agricultural University and Program Officer at GICIA India Pvt. Ltd. He joined the University of Maine, Orono, in the spring of 2019 and successfully completed his comprehensive exam in May 2021 and advanced to a doctoral candidate in Forest Resources. After receiving his doctoral degree, Alex will be pursuing his vision of research and transferring the experience gained to future foresters. Alex is a candidate for the Doctor of Philosophy degree in Forest Resources from the University of Maine in August 2022.