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Title: Measuring Costs of Carbon Sequestration in Northwest Russia.

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Global warming that may cause environmental catastrophes, dramatic economic losses and, in extreme case, may lead to an extinction of human race, is driven by anthropogenic emissions of greenhouse gases (carbon dioxide, methane, nitrous oxide and others) into atmosphere. It has been shown that forests can efficiently absorb carbon from the atmosphere and reduce the concentration of greenhouse gases mitigating climatic change.

In this study we explore environmentally oriented forest management options for carbon mitigation. We concentrate on Northwest Russia, St. Petersburg region in particular. This research is a part of larger project comparing carbon dynamics in two ecosystems: U.S. Pacific Northwest and Northwest Russia. We use

STANDCARB model to simulate the growth of forest and account for sequestered carbon that allow exploring the effect of different management regimes on carbon storage and economic value. We evaluate 140 regimes with different combinations of rotation length, regeneration type, intensity and frequency of thinnings. We employ Data Envelopment Analysis to identify the set of carbon and profit efficient management regimes. The set of efficient points comprises production possibility frontier that shows a tradeoff between stored carbon and monetary value. Then, we measure the marginal costs of carbon sequestration along the production possibility frontier.

The results suggested that the marginal costs of carbon sequestration exhibit diminishing returns and are negatively correlated with the discount rate. At 4% discount rate the marginal costs vary from 0.08 to 4.71 USD.

Measuring Costs of Carbon Sequestration in Northwest Russia

by

Valentyn Panchenko

A THESIS

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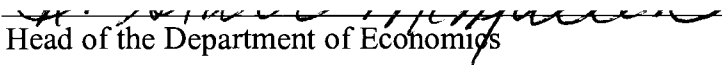Presentation June 11, 2002
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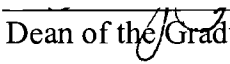
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LIST OF ABREVIATIONS

C – carbon

DEA – Data Envelopment Analysis

DMU – Decision making unit

IPCC – Intergovernmental Panel on Climate Change

OECD – Organization for Economic Cooperation and Development

PPF – Production Possibility Frontier

UNCED – United Nations Conference on Environment and Development

US EPA – U.S. Environmental Protection Agency

USD – U.S. Dollar

MEASURING COSTS OF CARBON SEQUESTRATION IN NORTHWEST RUSSIA

1   INTRODUCTION

The earth's climate is predicted to change because human activities are altering the chemical composition of the atmosphere through the buildup of greenhouse gases – primarily carbon dioxide, methane, and nitrous oxide (US EPA, 2002a). These gases contribute to the warming of the planet's surface by the atmosphere. Although uncertainty exists about exactly how earth's climate responds to these gases, global temperatures are rising.

Rising global temperatures are expected to raise sea level and change precipitation and other local climate conditions. Changing regional climate could alter forests, crop yields, and water supplies. It could also affect human health, animals, and many types of ecosystems.

From historical perspective, climatic changes have been the most important factor leading to drastic changes in the evolution of life on the Earth. Thus, global warming may disturb global equilibrium of biological species and communities, and lead to a different stationary equilibrium of biological configuration. As a result some species may become extinct, while others may evolve. In extreme case,

this could imply replacing the human race with another adapted mutant race or new form of life (Rao, 2000).

Transferring carbon dioxide from the atmosphere into carbon (C) in biomass is the only known practical way to remove large volumes of a greenhouse gas from the atmosphere (Brown et al., 1997). This removal is known as C sequestration or C storage. Many C sequestration researches focused on forests because of relatively high storage capacities of trees.

There are two kinds of forest-based C sequestrations: afforestation and reforestation, the establishment of forest on land previously used for some purpose other than growing trees, and forest management directed towards sequestering C in existing forests, choosing management regimes resulting in higher C storage. Most of previous researches concentrated on the afforestation approach (Sedjo et al., 1997).

In this study we explore forest management options. We focus on Northwest Russia (see map in Appendix A). This research is a part of larger project comparing C dynamics in two ecosystems: U.S. Pacific Northwest and Northwest Russia. Using STANDCARB model to simulate the forest growth and account for sequestered C, we explore the effect of different management regimes on C storage and economic value. We evaluate 140 regimes with different combinations in rotation length, regeneration type (natural vs. artificial), intensity and frequency of

thinnings. Then we employ Data Envelopment Analysis (DEA) to identify the set of efficient management regimes, where efficient means that C sequestration cannot be increased without sacrificing some monetary value gained from forestry. The set of efficient points comprises Production Possibility Frontier (PPF) that shows tradeoff between stored C and monetary value. Then, we are able to measure the marginal costs of C sequestration as the negative of the PPF slope.

2   LITERATURE REVIEW

2.1   The Greenhouse effect

Energy from the sun determines the earth's weather and climate and heats the earth's surface; in turn, the earth emits energy back into space. Atmospheric greenhouse gases (water vapor, C dioxide, and other gases) block some of the outgoing energy, retaining heat somewhat like the glass panels of a greenhouse.

Without this natural "greenhouse effect," temperatures would be much lower than they are now, and life as known today would not be possible. Instead, thanks to greenhouse gases, the earth's average temperature is a more hospitable 60°F. However, problems may arise when the atmospheric concentration of greenhouse gases increases. Since the beginning of the industrial revolution, atmospheric concentrations of $CO2$ have increased nearly 30%, methane concentrations have more than doubled, and nitrous oxide concentrations have risen by about 15% (US EPA, 2002a). These increases have enhanced the heat-trapping capability of the earth's atmosphere. Sulfate aerosols, a common air pollutant cool the atmosphere by reflecting light back into space; however, sulfates are short-lived in the atmosphere and vary regionally.

Scientists generally believe that the burning of fossil fuels and other human activities are the primary reason for the increased concentration of C dioxide. Plant respiration and the decomposition of organic matter release more than 10 times the C dioxide released by human activities; but these releases have generally been in balance with absorption by terrestrial vegetation and the oceans during the centuries before to the industrial revolution. What has changed in the last few hundred years is the additional release of C dioxide by human activities. Fossil fuels burned to run cars and trucks, heat homes and businesses, and power factories are responsible for about 98% of anthropogenic C dioxide emissions, 24% of methane emissions, and 18% of nitrous oxide emissions (US EPA, 2002b). Increased agriculture, deforestation, landfills, industrial production, and mining also contribute to some emissions. Estimating future emissions is difficult, because it depends on demographic, economic, technological, policy, and institutional developments. Several emissions scenarios have been developed based on differing projections of these underlying factors. For example, by 2100, in the absence of emissions control policies, C dioxide concentrations are projected to be 30-150% higher than 2002 levels (US EPA, 2002a).

2.2 Climatic changes

Atmospheric CO_2 levels are rising rapidly - currently, they are 25 percent above where they stood before the industrial revolution - and Earth's atmosphere now contains about 200 gigatons more C than two centuries ago. Increasing concentrations of greenhouse gases are likely to accelerate the rate of climate change (US EPA, 2002a). According to the report of National Climatic Data Center (NCDC, 2001) global mean surface temperatures have increased 0.5-1.0°F since the late 19th century. The 20th century's 10 warmest years all occurred in the last 15 years of the century. Global temperatures in 2001 were 0.51°C (0.92°F) above the long-term (1880-2000) average, which places 2001 as the second warmest year on record, exceed only by 1998. Snow cover in the Northern Hemisphere and floating ice in the Arctic Ocean has decreased. Globally, sea level has risen 4-8 inches over the past century. Worldwide precipitation over land has increased by about one percent. Annual anomalies in excess of 1.0°C (1.8°F) were widespread across North America and much of Europe and the Middle East.

Scientists expect that the average global surface temperature could rise 0.6-2.5°C (1-4.5°F) in the next fifty years, and 1.4-5.8°C (2.2-10°F) in the next century, with significant regional variation (NCDC, 2001). Evaporation will increase as the climate warms, which will increase average global precipitation. Soil moisture is

likely to decline in many regions, and intense rainstorms are likely to become more frequent.

2.3 Assessing Economic Impacts of Global Warming

Attempts to understand the complex scientific and economic issues of global warming have increasingly involved the use of models to help analysts and decision makers understand likely future outcomes as well as the implications of alternative policies.

The Intergovernmental Panel on Climate Change survey (IPCC, 2001) summarized studies on the economic impact of global warming: For some areas, damages are estimated to be significantly greater and could negatively affect economic development. For others, climate change may increase economic production and present opportunities for economic development. For countries having a diversified, industrial economy and an educated and flexible labor force, the limited set of published estimates of damages are of the order one to a few per cent of GDP. In contrast, for countries generally having a specialized and natural resource-based economy, heavily emphasizing agriculture or forestry, and a poorly developed and land-tied labor force, estimates of damages from the few studies available are several times larger. Small islands and low-lying coastal areas are particularly vulnerable. Published estimates range between $5 and $125 per Mg of additional C. This range of estimates does not represent the full range of

uncertainty. The studies do not include analysis of catastrophic risks, which probability increase significantly with global warming.

Substantial work in modeling the global warming impacts was done by William D. Nordhaus and collaborators, who recently developed integrated-assessment models of the economics of climate change, called RICE-99 for the Regional Dynamic Integrated model of Climate and the Economy and DICE-99 for the Dynamic Integrated model of Climate and the Economy (Nordhaus, Boyer, 2000). These newer models can help policymakers design better economic and environmental policies.

The DICE-RICE models are an extension of the Ramsey model and include climate investment in the environment. Concentrations of greenhouse gases in the atmosphere are regarded as "negative capital" and emissions reductions as lowering the quantity of negative capital. Sacrifices of consumption that lower emissions prevent economically harmful climate change and, thereby, increase consumption possibilities in the future.

The DICE model predicted that short-term impact of global warming on the world's economy would be modest at most. According to Nordhaus the major concerns raised by global warming are non-economic. The possible long-run ecological consequences include the rise of sea level damage to immobile ecological systems such as parks, danger to public health from vector-borne

disease, jeopardy to water systems, and the risk of catastrophic change. All of these subjects, but especially the risk of catastrophe, may have dramatic economic consequences and require intensive research. Nordhaus acknowledges that there is still a great scientific uncertainty surrounding global warming, but argues that the models can illuminate the policy choices that society has to make today based on present knowledge.

2.4 Political Response to Climatic Change

During the last decade attention has started to be paid to retarding the greenhouse effect by means of, among other things, international protocols. At the 1992 UNCED convention in Rio a framework protocol on climate change was signed. This international agreement was set out in more precise terms at Kyoto in December 1997. The Kyoto Protocol forms the first concrete step towards a global reduction in greenhouse gas emissions. Specific commitments concerning efforts to limit greenhouse gas emissions and enhance natural sinks apply to the 24 developed countries belonging to the Organization for Economic Cooperation and Development (OECD) as well as to 12 "economies in transition" (Central and Eastern Europe and the former Soviet Union). The minimum goal of the Kyoto protocol is to return to the greenhouse gas emissions to 1990 levels. The Protocol determines quotas for the emissions of each country. Countries wishing to emit

more than their allotted pollution are allowed to purchase "pollution permits" from other nations that pollute less.

The Kyoto Protocol has so far been ratified almost only by small island nations (by the end of 2001). Those nations' contributions to global greenhouse emissions are negligible, but they will suffer severe damages from rising sea level, which may be one of the major effects of global warming. With the exception of Romania, no industrialized country has so far ratified the Protocol. In July 2001 US president Bush declared that the United States would no longer recognize its commitments under the treaty. Most European countries still remain committed to the Protocol.

Nordhaus (RFF seminar, 1998) brought to light two major arguments against the Kyoto. First, the Protocol imposes no constraints on the rapidly growing emissions of greenhouse gases from the developing countries. It would only limit emissions of industrialized countries. Second, Nordhaus argues against its reliance on emissions trading. An agreement like the Kyoto Protocol that tries to limit quantities of emissions can result in great uncertainty about the prices of emissions permits and, probably, volatility in those prices. It would be better to reduce emissions with a system of harmonized taxes on them. Nordhaus reported on recent economic modeling that he and his colleagues have carried out. Their calculations show that the Protocol would bring only modest benefits to the United States over

the coming century, but at substantial costs. That, he observed, is not a formula for consensus.

2.5 C sequestration

The report of the Office of Fossil Energy, U.S. Department of Energy (OFE, 1999) suggests that fossil fuels will remain the mainstay of energy production well into the 21st century. To stabilize and ultimately reduce concentrations of released greenhouse gases, it will be necessary to employ C sequestration - C captures, separation and storage or reuse. C sequestration, along with reduced C content of fuels and improved efficiency of energy production and use, must play major roles if the nations are to enjoy the benefits of fossil fuels use and still reduce CO_2 emissions.

For better understanding of C sequestration let us review the global C cycle.

2.5.1 Global C cycle

The global C cycle is made up of C flows and stocks. Hundreds of billions of Mgs of C as CO_2 is absorbed from or emitted to the atmosphere annually through natural processes. These flows include plant photosynthesis, respiration, and decay, as well as the oceanic absorption and release of CO_2. The atmosphere contains about 750 billion Mgs of C. An additional 800 billion Mgs are dissolved in the surface layers of the world's oceans. Terrestrial C stocks are much more

difficult to measure empirically. Some 1,300 billion Mgs of C are believed to have accumulated in ground litter and soils. Terrestrial organisms, primarily plants, account for an estimated 550 billion Mgs of C. By far the largest C reservoirs are the deep oceans and fossil fuel deposits, which account for some 34,000 and 10,000 billion Mgs of C respectively (WRE, 2002).

Figure. 2.1. Greenhouse gases emissions by different sectors
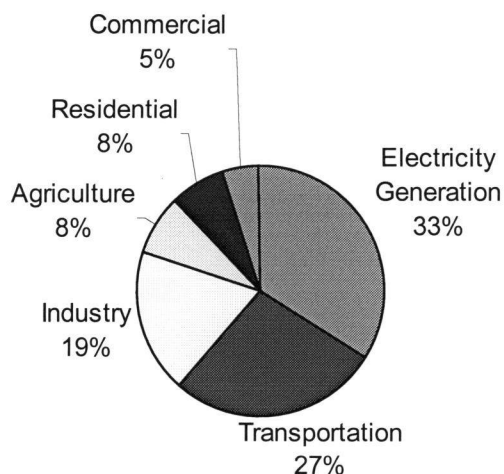
CO_2 forms when the C in biomass burns or decays. Many biological processes set in motion by people release CO_2. These include slash-and-burn agriculture; clearing land for permanent pasture, cropland, or human settlements; the development of infrastructure, such as roads and dams; accidental and

intentional forest burning; and intensive logging and fuelwood collection. Clearing

forest vegetation cover releases much of the C in the vegetation to the atmosphere,

as well as some of the C lodged in the soil. However, as emphasized before, the

major reason for C emissions from anthropological activity is burning of fossil

fuels as a result of electrical energy production, transportation and other industrial

activities (Figure 2.1).

2.5.2 Role of forest in C sequestration

C that could be released through human activity or forest degradation can

be kept out of the atmosphere through the following land-use-based approaches

(Brown, 1998):

- slowing or stopping the loss of existing forests, thus preserving current C reservoirs;

- adding to the planet's vegetative cover through reforestation or other means, thus enlarging living terrestrial C reservoirs;

- increasing the C stored in non-living C reservoirs such as agricultural soils;

- increasing the C stored in artificial reservoirs, including timber products;

- substituting alternative energy sources for fossil fuel consumption, thus reducing energy-related C emissions.

These approaches are all based on the same basic principle: adding to the planet's net C stores in vegetative cover or soil, or preventing any net loss, will help moderate global warming by reducing atmospheric CO2.

Recent US data (Figure 2.2) suggests that forests play the crucial role in C sequestration.

Figure 2.2. C reservoirs (U.S. data)

Forests   Agricultural Soils   Urban Trees   Landfilled Yard Trimmings
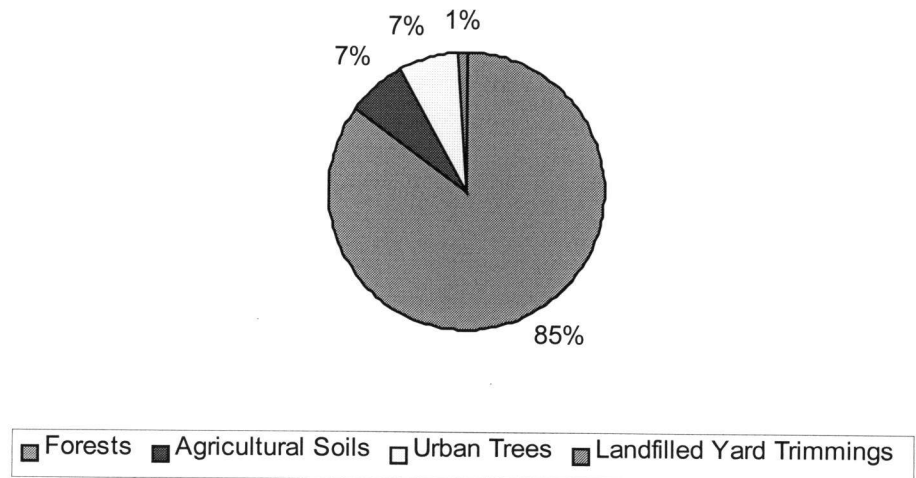
Source: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2000, EPA

It makes no difference to atmospheric CO2 concentrations whether a Mg of C is added to the forest of a temperate or tropical country. However, the application

of the different approaches is likely to vary from country to country. The variation is caused by different climatic as well as economic conditions. Slowing deforestation, for example, would be more beneficial in environmental terms in tropical countries where significant deforestation is taking place. The best way to expand vegetative C reservoirs might be new plantations in one country and better management of existing forests in another. C can also be sequestered by establishing forest reserves and parks, managing natural forests in sustainable matter, making exploitative activities such as logging more efficient, and improving the productivity of agricultural land.

2.5.3 Marginal costs of C storage in forests

Considering forests' substantial potential for climatic change mitigation many interdisciplinary researchers have been involved in cost-benefit analysis of additional C storage to help foresters and decision makers assess current practices and adopt environmentally oriented policies.

The first studies of the C sequestration costs appeared in the second half of the 1980's and were related to the cost of establishing of forest plantations (Sedjo et al., 1997). Nearly all of these studies concentrated on technical side of the issue and did not utilize any optimization. Based on physical models they looked at how much C can be stored within certain amount of biomass. Then, they used simple accounting methods to find the cost of growing this amount of biomass. These

studies failed to consider the costs and revenues of land management, the time profile of C sequestration, cash flow discounting, the opportunity costs of the forestland.

More advanced studies utilize behavioral land use models that relies on afforestation/reforestation approaches. Plantinga et al. (1999) looks at different allocations of land between forest, agricultural and urban uses. They take into consideration variations in time frame for returns from different types of land and consider an optimal dynamic allocation rule based on economic profit. Then, researchers are able to assess how changes in allocation will affect profitability. After applying estimates for average amount of C sequestered per area of land they derive marginal costs of C sequestration for forests in the USA (see Table 2.1).

According to Solberg et al. (1998) one of the first published studies that took into account the time profile and costs of C sequestration looking into various forest management options appeared to be from Norway in 1990 by Lunnan et al. Hoen and Solberg (1994) continued work in that direction and applied frontier analysis to estimate marginal costs of C sequestration. They applied linear programming to find an optimal set of forest management regimes in terms of C sequestered and profitability among the full set of feasible treatment schedules. Then, on the basis of optimal regimes, they built an efficient frontier reflecting tradeoff between stored C and profitability. The slope of the frontier gives the marginal costs of C sequestration. Diminishing marginal returns result in the

marginal costs increasing with the amount of C sequestered. The major weakness of the method is lack of accurate accounting for C storage while applying different management procedures.

In her thesis Olga Zyrina (2000) tried to fill this gap. She applied similar approach to forest stands in Western Oregon. To improve the accuracy of forest C flows accounting she used advanced STANDCARB model (Harmon, Domingo, 2001). She examined different forest management regimes and utilized DEA that used linear programming to find marginal costs of C sequestration.

After review of several papers on C sequestration, we summarize various approaches, models and cost estimates of C sequestration in Table 2.1. We observe significant variation in marginal costs of C storage depending on geographical location and approach. Marginal costs vary from as small amount as $1.5 per Mg of C in the case of conservation project in tropical Mexico (Masera et al. 1997) to as large as $500 per Mg in the case of global assessment of 400 Mt C sequestration in the USA (McCarl, Schneider 2001). This variation can be explained by diverse natural conditions, different methods for C sequestration and different scientific approaches to marginal cost calculations. Even in case of similar approaches results can deviate because of different assumptions regarding the discount rate and cost accounting.

Table 2.1 Overview of studies on C sequstration

Paper	Approach	Model	Location	Marginal costs of C $/Mg
McCarl, Schneider 2001	Aggregate study: agriculture and forestry	C emission coefficients and Global equilibrium model	USA	$10-$500
Zyrina, 2000	Silvicultural Management	Frontier analysis	Pacific Northwest	$2-$32
Platinga et al. 1999	Afforestation	Land Use Model	Maine	$95-$120
Platinga et al. 1999	Afforestation	Land Use Model	Wisconsin	$75-$95
Platinga et al. 1999	Afforestation	Land Use Model	South Carolina	$45-$90
Platinga 1999	Afforestation	Land Use Model	Maine	$6-$38
Marland, Schlamadinger 1998	Comparison of approaches	Tree growth model	USA	n/a
Alig et al. 1997	Afforestation	Land Use Model	USA	n/a
Hoen 1997	Silvicultural Management	Carbon fixation	Norway	$14-$214
Swisher 1997	Afforestation, Conservation	Land Use Model	USA	n/a
Masera et al. 1997	Afforestation, Conservation	Benefit-cost analysis	Tropical forest, Mexico	$1.50
Masera et al. 1997	Afforestation, Conservation	Benefit-cost analysis	Temperate forest	$15
Masera et al. 1997	Afforestation, Conservation	Benefit-cost analysis	Pulp Wood forest	$20
Hoen, Solberg 1997	Silvicultural Management	Frontier analysis	Norway	$20-$100
Ravindranath, Somashekhar 1995	Afforestation, Conservation	Demand-driven scenario	India	$2.5-$7.3
Wangwacharakul, Bowonwiwat 1995	Afforestation	Opportunity cost analysis	Thailand	$3-$12
Hoen, Solberg 1994	Silvicultural Management	Frontier analysis	Norway	$21-$79
Harmon et al. 1990	Silvicultural Management	Old vs young forests	Oregon	n/a

In this paper we follow the silvicultural management approach applied by Hoen and Solberg (1994). Following Olga Zyrina (2000) and using STANDCARB model we expand their approach in terms of C flows accounting. We explore how sustainable forests management can increase C storage mitigating climate change. To assess as many regimes as possible we more than double the number of forest management options in comparison to Zyrina (2000). Besides, we develop special Matlab codes that allow creating flexible input parameters for STANDCARB model as well as instruments for more efficient output data analyses. This study concentrates on Northwest Russia forest ecosystem.We characterize some typical features of the region below.

2.6 Northwest Russian forests

Russia's vast forests are a natural resource of global importance, both ecologically and economically. The forests serve Russia and the rest of the world as a source of timber and as a critical stabilizer of the global climate. Sprawling from the Baltic Sea to the Pacific Ocean, Russian forests cover the area of 851,392,300 hectares, 22% of the world's forests area. About 26% of the world's last frontier forests (large virgin forests) are in Russia (UN-ECE, 2000).

The majority of the old-growth forests remaining in Europe are located in Northwest Russia. These forests are often considered as a source of cheap raw material for West-European forest industry. As a result the Northwest Russian

forest have received much emphasis in the debate on conservation and sustainable development.

2.6.1 Federal regulation of forest

All forests in Russia belong to federal government according to the Forest Law of the Russian Federation. The government is responsible for sustainable forest use and estimation of costs for the forest harvesting permits. For management purposes, Russian forests are classified into three categories (Ovaskainen et al., 1999):

The first category (20% of the total forest area) includes riparian areas, protective forests along roads, and other protective areas. Clear-cutting is prohibited in these forests. However, these territories are not strictly protected and according to Greenpeace Russia, intensive intermediate fellings are practiced in 95% of these forests, even clear-cutting (restricted to 10 ha) are practiced in 50% of the area.

The second category (5.5%) includes forests around populated areas, cities and rural areas. Harvesting is allowed in these forests with artificial regeneration required.

The vast majority of forests is included into third category (74.5%). These are forests for industrial timber production with all harvesting methods allowed and clear-cutting as the main forest practice.

Taking into consideration restrictions regarding forest management practices this research will concentrate on the second (methods including artificial regeneration) and the third group of forests.

2.6.2 The Finnish forest industry in Russia

Finland is the main wood importer from Northwest Russia region. The wood trade from Russia to Finland has a long history. Already in the beginning of the 1970's, Finland imported some 5 million m3 of Russian wood. Imports remained at approximately the same level until the early 1990's, when they rose rapidly to the present level of about 10 million m3. (FAO, 2000). Most Finnish wood imports come from Northwest Russia.

The main reasons for the increased imports are the poor condition of Russia's domestic forest industry and the increased demand in Finland. Low wood prices and possibly a corrupt timber trade system have also attracted some companies looking for opportunities to make a quick profit (Ovaskainen et al., 1999).

Finnish companies and their contractors harvest 5% of the timber exported

to Finland from Russia themselves, while 47% is harvested by Russian companies

and 48% is purchased from trading companies and agents.

In addition to the large companies of the Finnish forest industry, there are

many small Finnish timber-harvesting contractors working in Russia with their own

machinery (in 1996 more than 100). Most of them operate in the Republic of

Karelia (about 100) and in the St. Petersburg oblast (about 20). These contractors

mostly provide services either for foreign companies and agents who buy timber

from Russia. The substantial presence of Finnish involvement in the Northwest

Russian timber industry is a source of controversy because if its social and

ecological impact on the region.

2.6.3   Social aspects of forestry in Northwest Russia

The Russian forest sector is a significant employer that directly accounted

for more than two million employees in Russia in 1990. Between 1990 and the

mid-1990s the number of people directly employed by the forest sector fell from

2.0 to 1.8 million people. Employment in the forest sector has not fallen as steeply

as the physical output. (Ovaskainen et al., 1999)

Forestry in Northwest Russia is characterized by a relatively low proportion

of forestry workers to the total number of staff, while the proportion of manual

workers in the forest industries, as well as on the subsidiary agricultural farms and

in the exploitation of non-timber forest products, is about 45% of all employees (the proportion of persons in charge and specialists being 25%). The proportion of forestry workers is only 5-6%, while 15-16% are persons in charge and specialists, and 20-25% are forest-guard personnel. (Ovaskainen et al., 1999)

State forest enterprises had a wide social importance in Soviet times; they provided employment, produced goods and services, and offered a large variety of social facilities for employees and the local population. The transition period has forced firms to be much more efficient economically. With lack of state regulations and enforcement mechanisms, firms substantially downsized social and environmental objectives in the forest industry.

2.6.4 Environmental issues in Northwest Russia

Current forestry practices have generated public opposition. According to an attitude survey carried out by Greenpeace Russia in 1998, the main problems in Northwest Russian forestry are the large-scale clear-cutting and poor results in reforestation of cut areas. Even forest fires, which are the major problem according to the Federal Forest Service, are considered to be a minor problem compared to bad forestry practices (Ovaskainen et al., 1999).

Russia has made a number of international environmental commitments with respect to forestry. The major step was joining Kyoto Protocol in 1997 (it is still not ratified). However, due to a weak national forest management policy,

Russia has difficulties fulfilling these commitments. The inefficiency of environmental control results from a lack of resources and inefficient organizations (Ovaskainen et al., 1999).

It is difficult for Russian authorities to ensure compliance with environmental legislation, and adequate mechanisms and institutions for effective implementation are simply absent. Violations of environmental regulations are commonplace.

Expectations that a drastic drop in industrial production in Russia would bring about corresponding reductions in pollution and contamination have not been realized. In reality, these problems are as acute now as before the transition. This can be explained by obsolete industrial technology and lack of investment in environmental protection.

This research is one of the first attempts to assess forest management regimes in St. Petersburg oblast forests from one environmental perspective, C sequestration.

2.6.5 Characteristics of St. Petersburg region forests

The forest fund of the St. Petersburg region covers 6.1 million hectares, including 4.7 million hectares of forest-covered lands (01.01.1999). About 42% of the forest fund lands in the St. Petersburg region are forest with special

management regime (category one and two). The rest of the lands are forests with multiple use regimes (category three).

The estimated standing total timber volume is 582×10^6 m3 (01.01.1999). The annual allowable timber harvest of mature timber (final harvest) totals to 9.8×10^6 m3 including 4.2×10^6 m3 of the most valuable coniferous species (43%). Timber harvest in 1998 comprised 3.8×10^6 m3 of merchantable wood that is 39% of the annual allowable timber harvest.[1]

The annual allowable timber harvest for thinning and sanitation cuts is 2.5×10^6 m3 of timber. The 1998 harvested volume from thinning was 1.6×10^6 m3, 64% of the allowable volume.

Coniferous species dominate forests of the St. Petersburg region. They cover about 63% of the total forest area with standing volume of 403×10^6 m3. Pine comprises 38%, spruce – 31%, birch – 24%, aspen – 6%, and other species – 1% (Figure 2.3).

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[1]Statistical information used in this chapter was kindly provided by S. Griaznov, St. Petersburg Forest Academy. It reflects recent data on Saint Petersburg oblast statistics.

Figure 2.3 Major forest species in St. Petersburg region
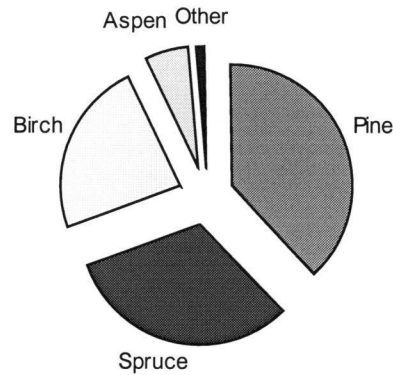
In this research we concentrate on predominately spruce forests because this specie covers a large share of forest area in St. Petersburg oblast and because spruce stands are located on more manageable territory in contrast to pine growing on the wetlands. Additionally, from financial prospective spruce is a relatively profitable specie.

2.7   Forest management practices

Forest management practices vary with site characteristics such as soils, species, and climate and are influenced by economic considerations, including input costs, the prices of harvested products and discount rate. In this research we will concentrate on the following aspects of silvicultural management: planting, precommercial thinning, commercial thinning and rotation period.

Planting can substantially increase the volume of harvest for a given rotation length by reducing the time between harvest and reestablishment of tree cover. In mixed species forests, planting provides greater control of species composition. Weeding usually follows planting to support young tree and suppress other species.

Precommercial thinning promotes growth by opening overly dense canopies and contributes to larger and higher quality harvest. Usually, thinning is undertaken at early stages, 20-30 years from the establishment of new tree cover.

Commercial thinning is usually driven by economic motives, but it is not the only factor in decision-making. This method is used when species of shade tolerance or intermediate tolerance are considered desirable. Rate of growth, potential for further growth, health, quality, spacing, and species composition are ultimate factors that also must enter each determination.

Rotation is one of the crucial components of forest management. Rotation length can affect quality and volumes of timber harvest as well as C storage. Optimal rotation length can be determined using Faustmann's equation that is derived from maximizing SEV formula(Pearse, 1990). Optimal rotation depends on economic variables, costs and revenues as well as discount rate. Additionally, it depends on species composition and climatic parameters. Recent research on forests in U.S. Pacific Northwest revealed that longer rotation periods contribute to

higher level of C sequestered (Zyrina, 2000). In this research we investigate whether it is the case for Northwest Russian forests.

To focus this research we identified the forest management practices that seem feasible for Northwest Russia. After consultations with forestry specialists (Krankina, Department of Forestry, OSU; Griaznov, St. Petersburg's Forest Academy) we determined that dominate practices included varying combinations of rotations, type of regeneration, precommercial and commercial thinning, and eventual clear-cut.

Rotation lengths for coniferous species in Northwest Russia vary in the range from 80 to 200 years. Pre-commercial thinning is applied about 20 years after stand establishment. Commercial thinning starts after 40 years of growth and is usually applied several times, but not often in intervals of less than 10 years. The last thinning is performed at least 20 year before the final clear-cut. The thinning intensities are usually in the range of 25-35% of the total stand. Both artificial and natural regeneration are applicable to St. Petersburg region.

3 METHODOLOGY

This research follow techniques developed in the study of the marginal cost of C sequestration in Oregon Cascade forests (Zyrina, 2000). Data on outputs in the form of harvested forest products and various C pools are generated from a forest stand simulation model for 140 feasible forest management regimes. For each regime harvests are converted to soil expectation values (SEV) based discounted profits, which in turn depend on estimated revenues and harvesting costs. Then, we determine the set of efficient regimes in terms of C and SEV. Using the set of efficient regimes we find a tradeoff between C and monetary values that gives the marginal cost of C sequestration.

3.1 STANDCARB model

The forest stand simulation model we use is STANDCARB version 2.0, developed by Mark Harmon et al. in 2001. It is designed to simulate the dynamics of living and dead pools of C in a forest stand. STANDCARB can be used to examine the effects of climate, tree species, succession, wildfire, frequency of timber harvest, site preparation, regeneration and other silvicultural methods have on C dynamics and forest product output at the stand level.

3.1.1 General description of the model

STANDCARB operates on an annual time step for all variables, except those used to estimate the effects of climate on tree establishment, growth, and decomposition. These climate-related variables are calculated on a monthly time step. In addition, while disturbances are simulated annually, there are arbitrary semiannual time steps that occur once the normal growth and decomposition related processes are addressed.

In STANDCARB a stand is represented by replicate cells that are then averaged to predict stand level value. Each cell represents a 64 m2 area, assumed to be the area occupied by a single. In this project, we represent a stand as composed of 100 cells (10x10) or 0.64 ha.

The model simulates four layers of vegetation (upper trees, lower trees, shrubs, and herbs) potentially occurring in each cell and interacting with one other. The model simulates C store in seven live pools, six corresponding detrital (dead) pools, and three stable pools (see Figure 3.1).

Figure 3.1 Composition of C pools.

Life pool	Dead pool	Stable pool
foliage	dead foliage	stable foliage
branches	dead branches	stable wood
sapwood	dead sapwood	
heartwood	dead heartwood	
heart-rot		
coarse roots	dead coarse roots	stable soil
fine roots	dead fine roots	
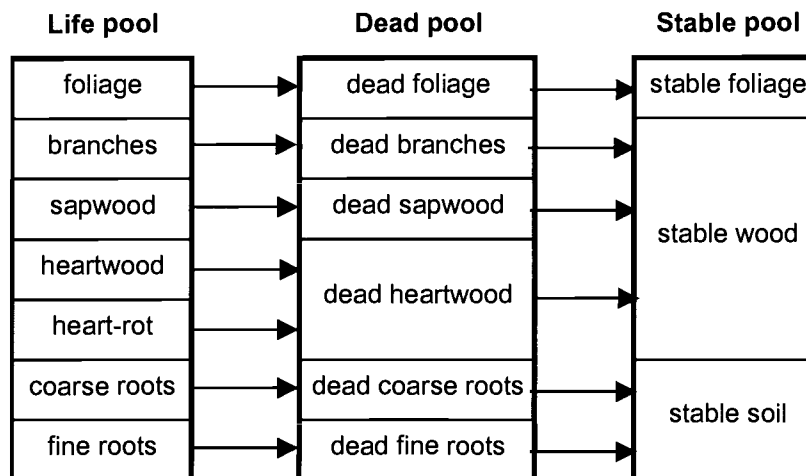
Harmon et al. (2001) suggest that the results of STANDCARB simulations must be interpreted with caution. There are many factors that may cause the projected results to deviate from what actually occurs. Each simulation has a number of tacit assumptions, and when these are not met the projected results may be misleading. Further the authors advise the use of relative differences rather than absolute differences between management regimes. Following this advice, in the current analysis we compare the results for different treatments on relative basis and tend not to concentrate on absolute values.

3.1.2 Input and output specification of the model

In our simulation, the major specie of the stand is spruce. Additionally, the model allows for the occasional growth of pine, birch and aspen as minor species. Artificial suppression, e.g. thinning, is assumed to prevent dominance of minor species. This stand composition is typical for the manageable forest area in Northwest Russia (see section 2.6.5 for discussion). The STANDCARB initial specification requires the input of the stands' species, percentage of timber removed from the forest, type of regeneration and thinning, and rotation age. It is possible to determine other conditions for the selected area such as climate, species, growth, decomposition and mortality rates. An example of input files with parameters used in our simulation can be found in Appendix C.

STANDCARB produces output in terms of C and live and harvested volumes. C storage is divided for tree pools: live, dead and stable C. An output includes the mean value and the standard error over 100 cells of modeled area. The measurement unit for C output is Mg/ha, live biomass is measured in m3/ha, and stand density is measured in stems/ha. Each of these outputs is reported as yearly averages every five years.

STANDCARB also produces actual amount of wood harvested each year, along with information on the harvest's species composition, height and age, based on the harvested upper tree layer. This information is used to allocate harvests into

product classes for which we have corresponding prices. Examples of the output files can be found in Appendix D.

3.1.3 Calibration of the model

Originally parameterized for stands in the U.S. Pacific Northwest, STANDCARB was recalibrated for forests in the St. Petersburg region. This work was accomplished by Harmon, Krankina, Zyrina of the OSU College of Forestry. Recalibration was accomplished by modifying the growth parameters of four added species, spruce, pine, birch and aspen including the sprouting feature of aspen. The modified STANDCARB tree growth curves were calibrated to mimic actual growth curves from the region (Lesotaksatsionnyj spravochnik, 1980). A close correspondence was achieved by changing light, tree density and other growth parameters. Interactions between different species were also reevaluated. Spruce was modeled as a dominant species by changes in the light parameter. Additionally, soil, solar radiation and precipitation parameter values were changed to represent the region.

The modified STANDCARB is not appropriate for simulating wet site stands, so stands dominated by pine are excluded from our analysis.

3.1.4 Realization of the simulation

To examine an extensive set of feasible and potentially efficient regimes we mixed the following types of silvicultural practices:

- rotation time – from 80 to 200 years with 20 year steps

- regeneration type – natural regeneration (no planting) vs. artificial regeneration (planting)

- precommercial thinning – 35% of lower tree layer trees 20 years after new stand establishment vs. no precommercial thinning

- commercial thinning – one commercial thinning of 25% of trees; one commercial thinning of 35% of trees; two commercial thinnings: first 25%, second 25% or first 35%, second 25%; no commercial thinning; time of thinning differs with the period of rotation and occurs in the middle of stand's life for one thinning and is equally distributed in time in case of two commercial thinnings

The above variations gave 140 different management regimes (see full description in Appendix B), for which we needed to create 140 groups of input files. These included CutPatt.dvr (see Appendix C), specifying treatment's time and pattern, i.e. cells (trees) that are removed from 10x10 matrix (stand), and HarvInt.dvr (see Appendix C), describing times and types of treatments

(precommercial thinning, commercial thinning and clear-cut) were formed for each regime. In order to specify these files we used Matlab code (see Appendix E). Patterns of treatments for CutPatt.dvr were determined stochastically using the Matlab random number generator. In case of two commercial thinnings, the same cell (tree) is not thinned twice.

The file Simul.drv contains parameter for some site characteristics, and some growth characteristics of trees. (see Appendix C). The parameter SiteIndex was set to 2, as this matches most of commercial and treatable sites in Northwest Russian. MaxDensity parameter was set to 28,885 according to the growth curves described previously in the section 3.1.3. In file Simul.drv we defined type of regeneration, artificial versus natural. Besides, for each rotation period we need to change the number of years in one simulation. The Simul.drv parameter that sets periodicity of the output characteristics was set to every 5 years. All the other input parameters for soil, climate, species, and other site characteristics are common for all 140 silvicultural regimes.

For the purpose of these research we used two types of files Total.out (see Appendix D) and Volume.out (see Appendix D). Total.out contains information regarding average C amount in Mg/ha for live, dead and stable pools on 5-year period basis. Volume.out includes data on harvested volume in m3 per ha as well as density, height and age of the harvest for each treatment. We use Matlab code to collect and process this large amount of data (see Appendix E).

In the STANDCARB model trees start to grow on bare ground. To simulate primary forest and initialize C at different pools, for each management regime we grow the forest without any treatment for 300 years. After that period we start with a clear-cut and proceed with treatments specific for each regime. We noticed that 300-year free growth of the forest influences the results of subsequent rotations. It can be explained by the following fact. Some of the dead pools decay, but do not get replenished with periodic rotations. Thus, to get steady output parameters we start accounting from 6th rotation period after free growth. In order to eliminate stochastic deviations we used 5 steady periods (from 6th to 10th) to calculate the average C summing up amounts in 3 pools from the file Total.out. Harvested volume, height and age from Volume.out were also averaged for steady 5 years.

Figure 3.2. Steady state rotations
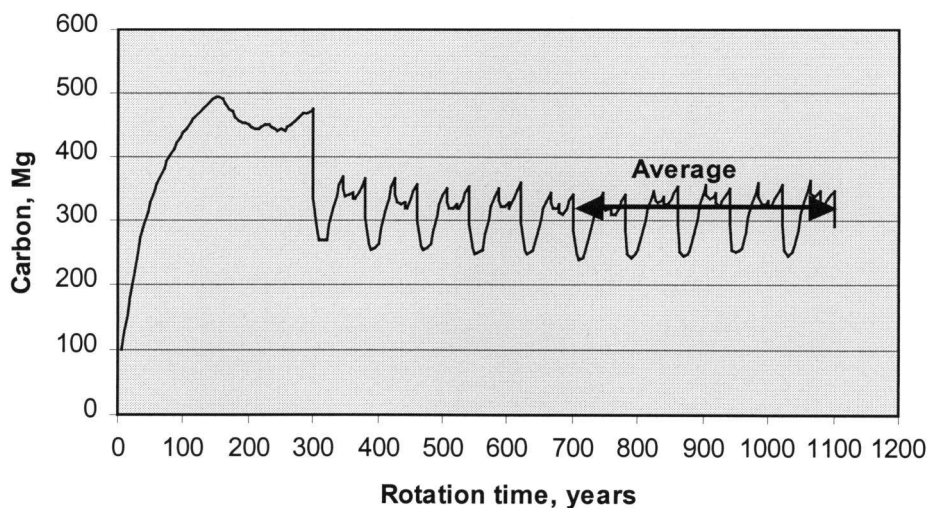
To illustrate consider the example depicted in Figure 3.2. It represents yearly total mean C stored using the management regime with 80-year rotations, natural regeneration, precommercial thinning and two commercial thinnings of 35% and 25%. We take an average level of C for 5 steady rotations starting with 6th rotation after 300-year free growth.

3.2 Measuring soil expectation value

In order to measure the marginal costs of C sequestration, we following Zyrina (2000) we calculate soil expectation value (SEV) as the measure of the forest stands' economic value for each management regime. By comparing the total C storage and SEV resulting from different regimes, we examine the tradeoffs between SEV and additional C storage. The following discussion introduces the applied methodology.

3.2.1 Concept of SEV

SEV reflects the present value of a perpetual series of even-aged rotations (Pearce, 1990). This is, in theory, the value of the bare earth's capability of producing such a series.

Pearse (1990) shows detailed derivation of the formula for SEV:

$$SEV = \frac{\sum\limits_{j=0}^{t}(Rj - Cj)(1+i)^{t-j}}{(1+i)^t - 1},$$

where t is rotation length in years;

i – discount rate in percentage;

j – years between rotation period j=1..t;

R_j – revenues in year j;

Cj – costs in year j.

The numerator of the SEV formula represents future profit value under particular management regime. The denominator is derived using infinite series discounting formulae and transforms the future value in the nominator to the present value. SEV calculations require revenue and cost estimates that are discussed in the next two sections.

3.2.2 Revenue analysis

Revenue calculations require prices for various harvest outputs and the allocation of harvests to various forest product categories. According to commercial quality we can divide the harvest into three categories:

- high and medium grade wood that constitutes commercial roundwood including logs, bolts, posts, and pilings

- low grade wood, chips used in pressed board production and pulpwood used in the manufacture of paper

- heating wood used for burning

We use commercial wood quality Tables (Lesotaksatsionnyj spravochnik, 1980) to obtain the distribution for every particular harvest. The quality distribution depends on the type of silvicultural treatment (clear-cut vs. commercial thinning), site-index (2nd in our case), age, diameter and height of the trees. The type of treatment influences quality through technological procedure of the treatment, we usually expect more tree damages resulting in lower wood quality during thinning in comparison to clear-cut. The age of trees signals about decay processes in the wood reducing its quality. In this analysis we differentiate by the type of treatment, diameter, and age of the trees (Table 3.1).

Table 3.1. Harvest quality distribution

Diameter	Commercial quality in %			
cm	large	medium	small	heat wood
Clear-cut				
Age <150				
<20	10.00%	42.00%	37.00%	3.00%
<30	29.00%	44.00%	16.00%	2.00%
<40	50.00%	31.00%	12.00%	2.00%
Age >150				
<20	10.00%	35.00%	40.00%	10.00%
<30	25.00%	35.00%	24.00%	11.00%
<40	35.00%	27.00%	22.00%	12.00%
Commercial thinning				
<10	-	5.00%	80.00%	7.00%
<15	-	35.00%	55.00%	4.00%
<20	10.00%	40.00%	40.00%	3.00%
>20	20.00%	50.00%	20.00%	2.00%

Note: waste is not included and comprises 4-8% of total harvest

It is difficult to obtain actual domestic timber prices for Northwest Russian forests products. However, 1999 export prices for forest products from Russia are available from FAO (2002). The prices for roundwood are given in US dollars per m3 and include the costs of delivery to the border. The export information is structured by importer countries. We notice that roundwood prices of export to different countries seriously deviate from average price of 30 US dollars. Export prices to Finland appeared to be at much lower level than export prices to other countries. Partial explanation for that phenomenon is provided below.

The export to Finland as a percentage of total harvest in St. Petersburg oblast was about 30% in 1994 (computed on the basis of data from Ovaskainen et al., 1999). The transportation costs from St. Petersburg oblast to Finnish border are relatively low. Besides, a large proportion of timber products are harvested by Finnish companies (see section 2.6.2) and exported to Finland using low Russian domestic prices. Assuming that the export price of wood to Finland represents the opportunity cost of wood in NW Russia these prices can be used to compute revenues from harvests in St. Petersburg oblast (Table 3.2).

Additionally, the FAO (2002) database contained prices for pulpwood. We were not able to use these prices because they were expressed in USD/ton and there was no description regarding quality of pulpwood and the level of technological processing that can have high influence on the price. Our analysis does not include costs of any technological processing in the price of chips.

More extended timber price information for the year 2000 was obtained from Sergey Griaznov, St. Petersburg's Forest Academy (see Table 3.2).

Table 3.2. Prices for timber products in Northwest Russia

Product	Price in USD/m3	Taxes in USD/m3	Net price in USD/m3
Roundwood	$25.00	$2.00	$23.00
Source: FAO			
Roundwood	$20.00	$2.00	$18.00
Woodchips	$5.00	$0.80	$4.20
Heat wood	$2.00	$0.09	$1.91
Source: Grjaznov			

Griaznov's prices do not include transportation cost. Comparing them to the prices from FAO, we notice that export price of roundwood is slightly higher because it includes transportation to the Russian-Finnish border. Due to the lack of other sources and considering price information from St. Petersburg's Forest Academy reliable we proceed with these prices in our research.

All timber products in Russia are subject to federal tax that is based on physical units – m3. In the analysis we use the price net of the tax.

The revenues were calculated in dollars per standard site of 25 hectares, though STANDCARB gives output per ha. Scaling of up to 25 ha rests on the assumption of no edge effect that is modeled in STANDCARB.

3.2.3 Cost analysis

Detailed cost description regarding forest practice in Northwest Russian was provided by Sergey Griaznov, St. Petersburg's Forest Academy. All financial

data was transformed in the US dollars of the year 2000. We reviewed and adjusted the information to apply it for the purpose of our research. The cost calculations we used are explained below and summarized in Table 2.3.

The costs calculation is based on accounting method. Every treatment is divided into particular jobs. For each job we have a certain time norm, the estimated amount of time needed to perform the activity. Time norms were developed on the basis of historical information. In the analysis, all the time norms are expressed in man-hours per cubic meter, per hectare, or per kilometer depending on the type of activity that is described. Next, time norms are transferred to a daily scale assuming 7-hour working day excluding 1 hour for administrative and other needs. Besides, for each job we have information on amount of people in the crew that is transformed into wages, calculations on equipment amortization, usage of materials (gas, oil, etc) and corresponding prices that are converted into costs of materials and labor. Summing up all the cost information we obtain daily costs for particular job. Multiplication of the daily costs by time norms for corresponding job provides us with costs for the particular job expressed in US dollars per physical unit of the job, i.e. cubic meter, hectare or kilometer depending on the nature of performed activity.

We use a one US dollar per hour wage rate plus 40% of social security and taxes. We multiply the base wage by the number of workers in the crew and by 8 hours of working day that gives us daily wages for particular job.

Amortization of equipment per day was calculated in the following matter: price of equipment was divided by duration of usage in days (transformed from yearly basis assuming 200 working days per year).

Gasoline usage was estimated on daily basis and transformed into monetary costs assuming price of gasoline at the level of 0.33 US dollars per liter. From historical observations oil costs were taken as 0.1% of gasoline costs.

Depending on the nature of performed activity we divide the costs into a fixed or variable component. While variable costs are associated with the amount of timber harvested, fixed costs do not vary with the volume of the harvest and relate to preparation and other jobs. Fixed costs are calculated assuming standard 25-hectare site.

In our simulation we use 4 different types of forest treatment: clear-cut, commercial thinning, precommercial thinning, planting. We discuss the costs associated with each type of treatment.

Clear-cut costs are divided into 2 broad components: preparation and assisting costs and logging costs. Preparation and assisting costs are associated with the whole site, do not depend on harvest volume, and thus, are treated as fixed. They include logging site layout, inventory, layout of skidding roads, removal of dangerous trees, logging crew and equipment transportation (assume distance of 60 kilometers from the processing base), and forest care and fire protection. In reality

the latter costs occur continuously between clear-cuts. For simplicity in our model we include them as a part of assisting jobs and account for them at the time of clear-cut.

Logging costs are variable costs, which depend on the harvest volume. Costs of logging that is based on logging crew method break down into costs of debuncher, yarder and feller. The costs for each job are calculated using norms, as was previously discussed, and include wages, equipment amortization and costs of materials.

Commercial thinning costs are similar to the costs of clear-cut and consist of preparation and assisting jobs and logging. Preparation and assisting costs include site layout, accounting of tree inventory, removal of dangerous trees, logging crew and equipment transportation. Practical experience shows that costs of logging in case of commercial thinning are about 50% per m3 higher than in case of clear-cut.

Precommercial thinning does not include variable component and is calculated on site basis using work norms. It is relatively inexpensive as tree are still small and it is easy to cut unwanted species.

Obviously, *planting costs* are also calculated on site basis. They are based on the estimates of number of plants per site, costs of plants, transportation and

labor costs. Weeding occurring several months after planting is also included into this category of cost.

As any type of organization forestry business requires certain amount of time and resources spent for administrational and organizational activities that includes planning, human recourse management, paperwork etc. Administrational costs are estimated at the level of 20% of silvicultural management costs discussed earlier.

Besides, operational and managerial costs forest companies have to pay taxes that are defined in per physical unit (cubic meter) terms and vary with the quality of timber. In our analyses taxes will be automatically deducted from the price of wood and could be found in previously discussed revenue analysis (see Table 3.2).

Summarizing our discussion we obtain the following costs for each treatment (Table 3.3). For detailed calculations of costs refer to appendix F.

Table 3.3. Costs of forestry

Silvicultural practices	Cost in $		Cost in $ (including administation costs)	
	Per site (25 ha)	Per m3	Per site (25 ha)	Per m3
Clearcut				
Preparation and assisting jobs	$4,507.61		$5,409.13	
Logging		$2.92		$3.50
Commercial thinning				
Preparation and assisting jobs	$3,286.17		$3,943.40	
Logging		$4.37		$5.25
Planting and weeding	$5,930.71		$7,116.86	
Precommercial thinning	$813.50		$976.20	

3.2.4 Discount rate choice

As often happens in empirical research there is no consensus in the literature regarding what discount rate to use. Nilsson (1995) provides an overview of discussion regarding discount rates. A debate during the 1970s concluded that a discount rate of 10% would be appropriate (Sjaastad and Wisecarver, 1977). Foresters have always argued for lover interest rates due to long-term frames in forestry. D'Arte (1993) suggests that distant futures rate should be exceedingly low, close to zero. A zero rate is also supported by Mischan and Page (1982). A low rate is suggested for sustainable projects. Specific analyses of C storage have used various interest rates. Dixon et. al (1991) used 5%; Nordhaus (1991) used 8%;

Pearce (1992) employed rate of return of 6% dealing with afforestation and C fixation in the United Kingdom.

The current refinancing rate (as of 04/02/2002) set by Central Bank of Russia comprises 25% (CBR, 2002). It is a nominal interest rate that is driven by high inflation and Russian ruble devaluation. We convert Russian input and output prices into USD. Besides most of timber contacts as well as input prices and salaries in Russia are anchored to the USD. Thus, following principle of interest rate parity it is appropriate to use US discount rate for the project. Taking into consideration current low US interest rates, long-term horizon and sustainability of the project we propose apply 4% discount rate to current analysis. In addition, we conduct sensitivity analysis to determine impacts of various discount rates from 2% to 4% on the SEV.

3.3 Data envelopment analysis

We obtained physical outputs for each of 140 management regimes from the STANDCARB model and calculated SEV based on these outputs and price and cost information. Since STANDCARB model does not employ any optimization, we want to select those regimes that are efficient in terms of SEV and C storage. By the efficient regime we mean a regime for which it is impossible to increase C sequestration without sacrificing SEV. After constructing a production possibility

frontier using efficient regimes (SEV vs. stored C) we will be able to find tradeoffs between SEV and C sequestration.

We employ data envelopment analysis (DEA) to assess relative efficiency of various forest management regimes and determine the best practice treatments.

DEA is a performance measurement technique, which can be used for evaluating the relative efficiency of decision-making units (DMU's) in organization. It was first put forward by Charnes, Cooper and Rhodes in 1978 based on pioneering ideas of Farrell (1957). Later the method was extended by Färe, Grosskopf and Lovell (1994). Further theoretical development of the method led to widespread applications to various empirical research questions. Due to its flexibility, the DEA method has become popular in environmental economics research, where the usual economic indicators like prices or profit are not available. For example, Grosskopf et al. (2002) developed DEA-based methodology to estimate shadow price of bad output (pollution). Färe and Zaim (2002) applied DEA to measure environmental performance.

The DMU, in our case management regime, is said to be output efficient if given fixed inputs we cannot increase one output without sacrificing another output. Figure 3.3 illustrates the main idea of the DEA.

Figure 3.3 Radial output efficiency measure
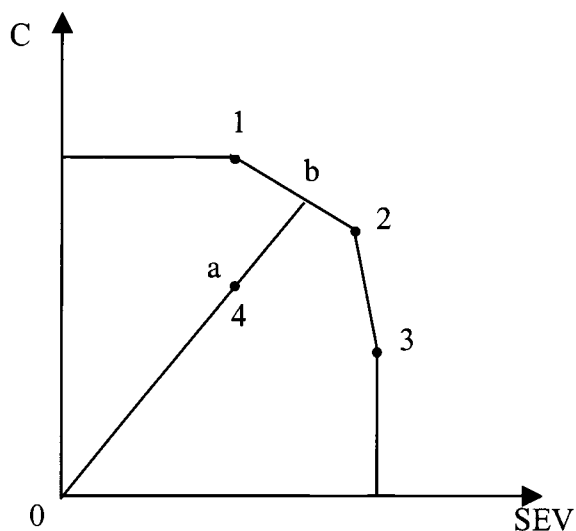
Regimes 1,2,3 are relatively efficient and form the best practice frontier, or

PPF. Here we rely on the assumption that the technology is linear between efficient

points. Regime 4 produces less amount of output given a fixed level of input and

lies in the interior of the production possibility set. Thus, regime 4 is not efficient.

The efficiency score F_o is measured in radial way and for this regime is equal to the

ratio 0b/0a. Its shows by what proportion we need to expand current output in order

to bring it on the efficiency frontier.

DEA uses linear programming to determine which management regimes are

efficient. Primarily, DEA is used to measure technical efficiency that does not

contain any price information. In this study we deviate from traditional DEA approach; we will look at a tradeoff between SEV and C sequestered. We calculated monetary value of SEV. At the same time the STANDCARB model gives the level of stored C expressed in physical units (Mg) and does not reflect any economics information by itself. Following DEA approach we apply output efficiency measure. In order to find efficiency score F_o of the particular forest management regime k' we specify the following linear programming problem:

Goal Function: $\qquad F_o = \text{Max } \lambda,$

under given constraints: $\qquad \sum_{k=1}^{K} z_k \cdot SEV_k \geq \lambda \cdot SEV_{k'}$

$$\sum_{k=1}^{K} z_k \cdot C_k \geq \lambda \cdot C_{k'}$$

$$\sum_{k=1}^{K} z_k = 1,$$

where k is an index of each management regime, k=1..K;

k' is an index of the current regime for which relative efficiency is found;

SEV_k is soil expectation value of kth regime;

C_k is C level of kth regime;

z_k are so called intensity variables.

The inequality constrains show that we can always perform worse or at the same level as the reference technology (left hand side of the inequalities). F_o

represents radial distance from the given management regime to the best practice frontier. If the observation is efficient, i.e. belong to the best practice frontier, F_o will be equal to unity, otherwise in case of inefficiency F_o will be greater than one suggesting by what amount we can scale both outputs to reach the best practice frontier. OnFront software (Färe and Grosskopf, 2000) is employed to perform empirical DEA.

3.4 Measuring marginal costs

After construction of PPF we are able to estimate marginal costs (MC) of C sequestration. The latter represents opportunity costs of storing additional unit of C sacrificing some dollar amount of SEV and can be found along the PPF curve for each level of C.

Mathematically marginal costs of C sequestration can be expressed as reciprocals of PPF slopes, i.e.

$$MC = \left| \frac{\Delta SEV}{\Delta C} \right|$$

where ΔSEV - difference in SEV between adjacent efficient regimes

ΔC - difference in C level between adjacent efficient regimes.

Absolute value of the above expression is negative representing tradeoff between C and SEV. Following economic theory, we expect that MC will increase with amount of C stored.

4 RESULTS

After running the STANDCARB simulation for 140 different forest management regimes, we obtained the results. Before discussing these, it is important to note that the data used in this research was simulated and will, at best, be representative of an average manageable spruce-dominant stand in Northwest Russia. Therefore the result do not reflect any particular forest stand, but provide guidance regarding overall forest behavior in the region and may be used to develop general guidelines for environmentally oriented forest management.

We first examine the results in terms of C sequestration, timber production, wood and wood production and SEV. We conduct sensitivity analysis to determine the influence of different discount rates on SEV. Then we consider the production possibility frontier and the marginal costs of C sequestration.

4.1 C sequestration

For each management regime an average C level in Mg is calculated over 5 stable rotations (see section 3.1.4) from the STANDCARB model output. The results support our expectations that C storage is increasing in length of rotation period (see Figure 4.1). However, the increase is progressing in decreasing rate and

is close to its maximum capacity with rotation period of 200 years. For natural regeneration, C storage declines slightly for rotations longer than 180.

Figure 4.1. Average C for 80–200-year rotations with no thinning treatment
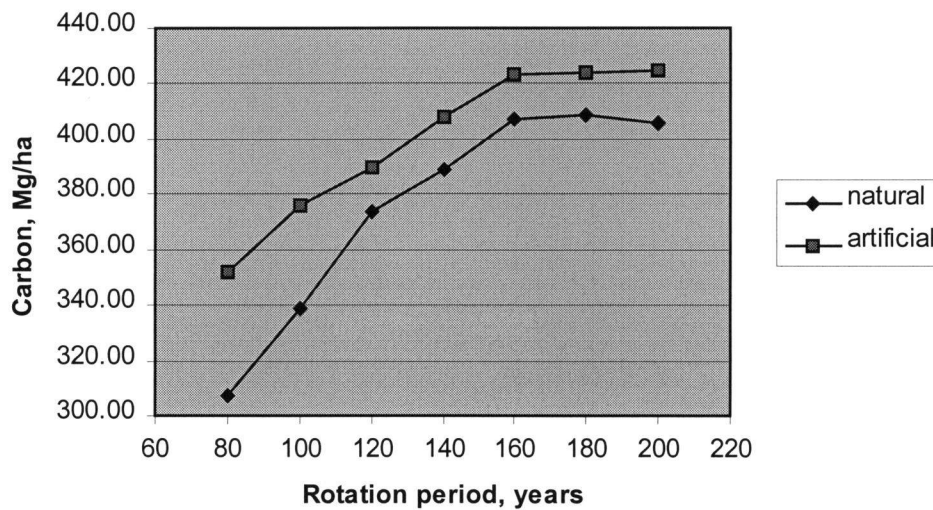
The maximum C sequestration was reached at the level of 428.43 Mg/ha for a regime with 200-year rotation period, artificial regeneration, precommercial thinning and no commercial thinning. The minimum C occurs at the level of 276.62 Mg/ha for a regime with 80-year rotation period, natural regeneration, precommercial thinning, a first commercial thinning of 35% of the stand and a second commercial thinning of 25% of the stand.

C storage is sensitive to other silvicultural practices. From Figure 4.1 we observe that artificial regeneration compared to identical regimes with natural regeneration provides additional C storage ranging from 50 Mg/ha for the regime with 80-year rotations to 15-17 Mg/ha for the regimes with 160-200-year rotations. The difference in C storage resulting from artificial regeneration is greater for the regimes with shorter rotations.

We illustrate the effect of thinning by examining regimes with median rotation period of 140 years and artificial regeneration (see Figure 4.2).

Precommercial thinning performed 20 years after new stands establishment appears to yield higher level of C only when no further thinning is applied. In other case precommercial thinning decreases C storage by 0.5 % to 3% percent. We also observe that higher intensity and frequency of commercial thinning contribute to decreases in average C storage.

Figure 4.2. Average C for regimes with 140-year rotation, artificial regeneration
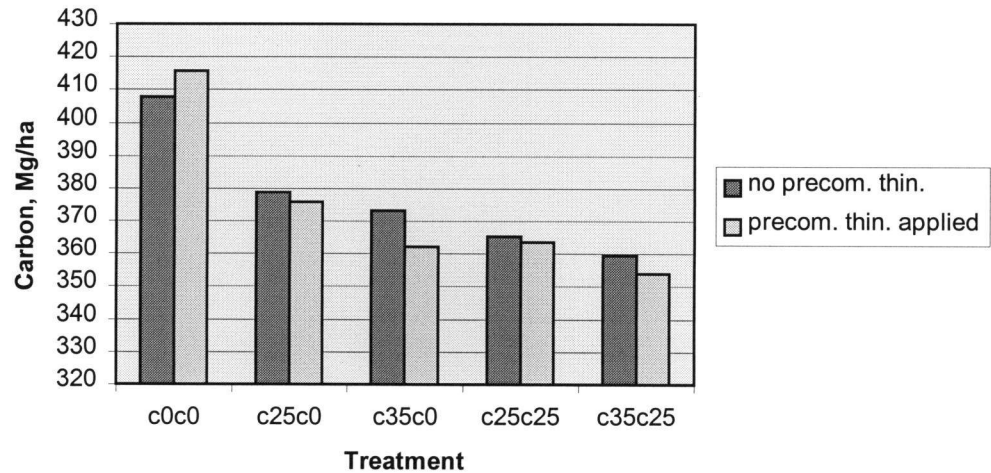
Treatment abbreviation:
   c0c0 – no further commercial thinning
   c25c0 – one commercial thinning, 25 % of stand
   c35c0 – one commercial thinning, 35 % of stand
   c25c25 – two commercial thinning, first - 25 %, second - 25 % of stand
   c35c25 – two commercial thinning, first - 35 %, second - 25 % of stand

4.2   Timber harvest

Now we are going to look at the effect of management practices on timber harvest. Timber harvest was calculated as an average over five stable rotation periods and is measured in m3/ha/year. The main species considered in the analysis was spruce. Other species such as birch, aspen and pine comprised to less then 2% of total harvest and therefore were excluded from the harvest analysis and further calculations.

Over 140 management regimes maximum total volume (including thinnings) is observed at the level of 355.66 m3 /ha for the regime with 200-year rotation, artificial regeneration, precommercial thinning, 35% first commercial thinning and 25% second commercial thinning. The minimum occurred at the level of 185.34 for the regime with 80-year rotation, natural regeneration, precommercial thinning, 35% first commercial thinning and 25% second commercial thinning.

Figure 4.3. Timber production for regimes with 80–200-year rotations and with no thinning
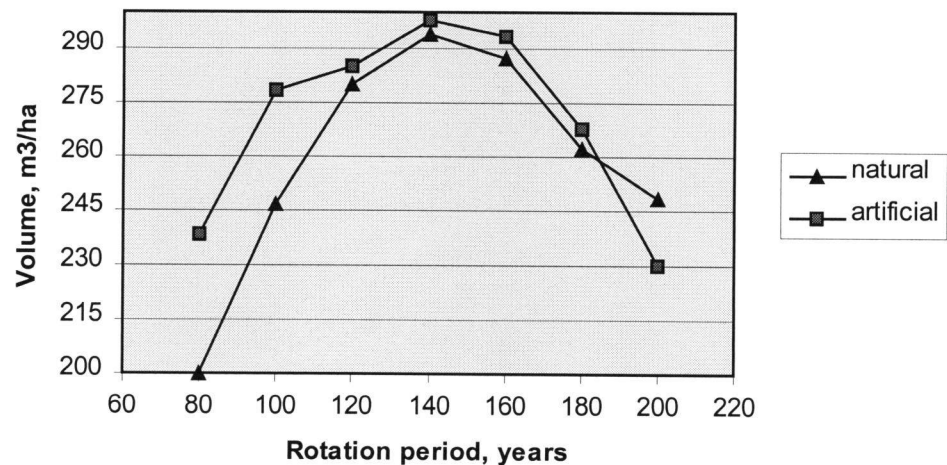
Among the regimes with no thinning (Figure 4.3) maximum harvest volume is observed for the regimes with 140-year rotations. For the regimes with longer rotations volumes fall. This decline can be explained by excessive tree density and age when trees start degrading.

Additionally, graphical analysis (Figure 4.3) suggests that artificial regeneration increases overall volume of timber production. Timber volume gains range from 5 to 40 m3 /ha. Artificial regeneration appears to provide more benefits for shorter periods of rotation. However, for 200-year rotation artificial regeneration has negative effect on volume. This only happens in regimes with no thinning. If the stand is thinned, artificial regeneration yields more volume.

Figure 4.4. Total harvest volume for the regime with 140-year rotations, artificial regeneration
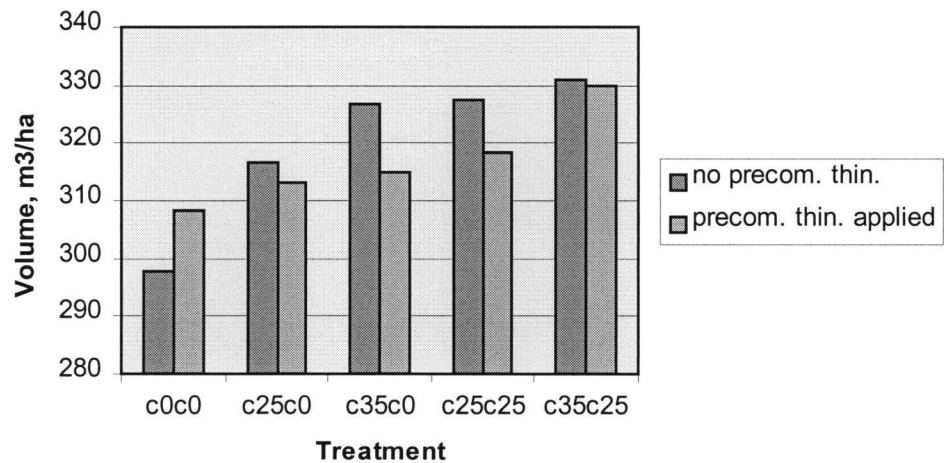
Treatment abbreviation:
    c0c0 – no further commercial thinning
    c25c0 – one commercial thinning, 25 % of stand
    c35c0 – one commercial thinning, 35 % of stand
    c25c25 – two commercial thinning, first - 25 %, second - 25 % of stand
    c35c25 – two commercial thinning, first - 35 %, second - 25 % of stand

To analyze impact of other silvicultural practices on harvested volume we select regimes with median rotation period of 140 years and with artificial regeneration (Figure 4.4). Precommercial thinning appears to be highly effective in case when no other thinning is applied. If we conduct further commercial thinnings, precommercial thinning gives lower volumes of timber. Nevertheless, the regime that yields the highest volume with 200-year rotation applied precommercial thinning as well. Thus, we cannot be certain about the effect of precommercial thinning on the volume when other thinnings are used. More intensive and frequent commercial thinnings give higher total volume of timber. However, the quality of timber is generally lower during commercial thinnings, as is the final clear-cut harvest volume.

Due to difference in time frame, costs and quality of timber it is difficult to assess effects of thinnings on the base of physical volume. SEV analysis that reflect cost-benefits of each treatment in monetary values as well as accounts time for time value will help to get better understanding of different treatments.

4.3 Soil Expectation Value

We now examine how different silvicultural practices influence SEV and conduct a sensitivity analysis of SEV using different discount rates.

Because of discounting we expect SEV to decline with increases in rotation length (Figure 4.5). Over 140 regimes for 4% discount rate maximum SEV is reached at 105.93 $/ha for the regime applying 80-year rotation period, artificial regeneration, no precommercial thinning and one commercial thinning of 35%. Minimum SEV is negative -$16.98 corresponding to the regime with 200-year rotation, natural regeneration and precommercial thinning.

Figure 4.5. SEV of 4% discount rate for regimes with 80–200-year rotations, with no thinning
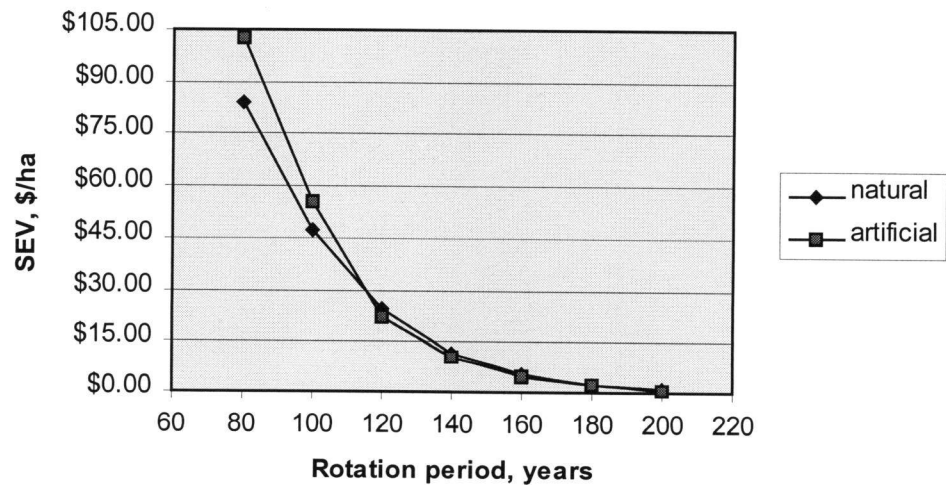
Discussing effects of regeneration methods on SEV, we observe that artificial regeneration increases SEV (max 25$/ha increase) for relatively short rotations. With increases in rotation length the difference between regimes with

artificial and natural regeneration gradually shrinks to zero. This is because the additional discounted revenues associated with higher volumes in case of artificial regeneration are reduced by the costs of planting.

Now we look at the effect of discount rate on SEV. Taking into consideration long rotation periods used in our research we expect SEV will be very sensitive to discount rate. To examine this hypothesis, we compare the results for different discount rates using regimes with artificial regeneration and no other treatment (Figure 4.6)

Figure 4.6. SEV of regimes with 80–200-year rotations with artificial regeneration and no thinnings
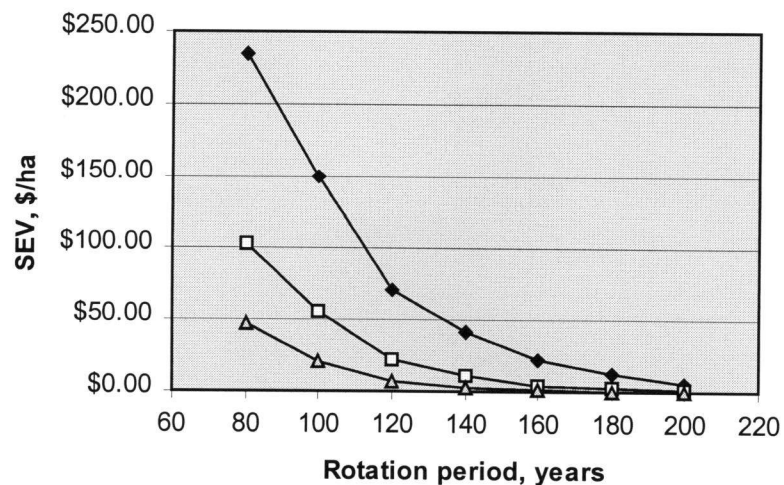
For all regimes higher SEVs correspond to lower discount rates. The absolute effect of discount rate is larger for shorter period rotations and almost disappear with 200-year rotations.

To examine the effect of silvicultural methods on SEV we select the regime with 140-year rotations and artificial regeneration and apply 4% discount rate (Figure 4.7).

Figure 4.7. SEV for regimes with 140-year rotation, artificial regeneration, 4% discount rate
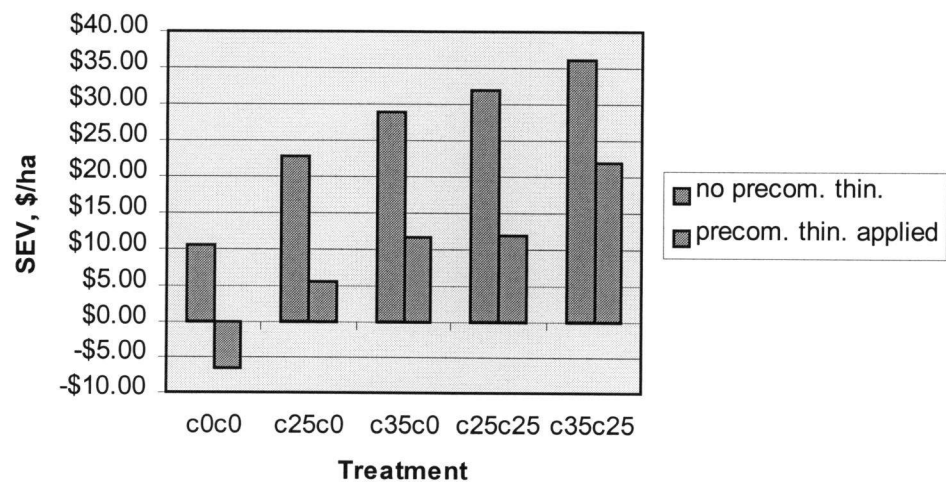
Treatment abbreviation:
    c0c0 – no further commercial thinning
    c25c0 – one commercial thinning, 25 % of stand
    c35c0 – one commercial thinning, 35 % of stand
    c25c25 – two commercial thinning, first - 25 %, second - 25 % of stand
    c35c25 – two commercial thinning, first - 35 %, second - 25 % of stand

It appears that at 4% discount rate precommercial thinning reduces SEV in all cases. It contributes to larger losses for regimes with longer rotations. In addition, more intensive and frequent commercial thinnings correspond to higher SEV. Though absolute differences depend on rotation length and discount rate applied, we observe the same pattern for most of regimes.

4.4 DEA and Production Possibility Frontiers

Now we going to determine C and SEV efficient regimes and construct PPF. Using OnFront software with SEV and C as parameters we are able to compute the efficiency score of each management regime (efficiency scores for each management regime may be found in Appendix H). The set of regimes with the efficiency score equal to 1 comprise the PPF, as shown in Figure 4.8.

Of 140 feasible management regimes only 5 efficient regimes emerged. We notice that that all efficient regimes use artificial regeneration and the most of them do not use any type of thinning; the only efficient regime that use commercial thinning of 35% yields minimal C (and maximal SEV) within the efficient set. The reason for exclusion of regimes with precommercial thinning from efficient set is that additional C benefits associated with precommercial thinning do pay off costs of the treatment. At the same time monetary benefits of commercial thinning do not exceed C losses associated with the treatment.

Comparing the efficiency scores of all regimes we find that the regimes using artificial regeneration in comparison with the regimes with natural regeneration ceteris paresis tend to be more efficient (closer to the efficiency frontier). As we could expect from earlier results, any kind of thinning does not improve efficiency and, most of the time, the regimes using this type of treatment are less efficient than those that do not use thinning.

Figure 4.8. PPF at 4% discount rate
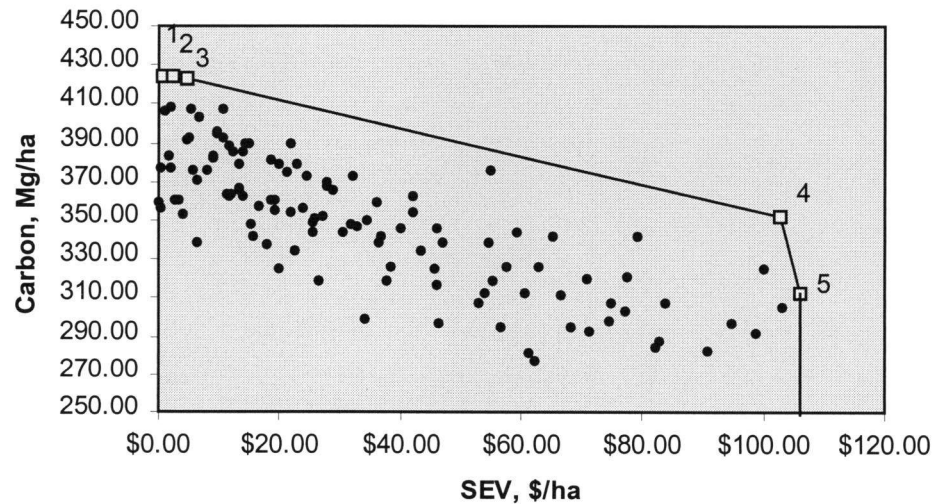
Efficient regimes:
1 – 200-year rotation, artificial regeneration, no thinnings
2 – 180-year rotation, artificial regeneration, no thinnings
3 – 160-year rotation, artificial regeneration, no thinnings
4 – 80-year rotation, artificial regeneration, no thinnings
5 – 80-year rotation, artificial regeneration, one 35% commercial thinning

As we have already noticed in the previous section, the discount rate has a strong nonlinear effect on SEV analysis and therefore affects not only absolute values on the PPF, but also the set of efficient regimes (Figure 4.9). On C side all PPFs originate from almost the same point because C level is not discounted. But on SEV side, the PPF shifts out as the discount rate decreases Most of the efficient regimes remain the same for different discount rate. However there are some notable changes. As illustrated in Figure 4.9, at the discount rate of 2% precommercial thinning becomes relatively inexpensive and the regime with 200-year rotation that applies precommercial thinning substitutes for the regime with the same rotation length but no thinning treatment.

With the decrease in discount rate the regime with 80-year rotations and with 35% commercial thinning disappears from the efficient set because present value increase associated with commercial thinning declines and does not offset C losses.

Figure 4.9. PPF with different discount rates (r).
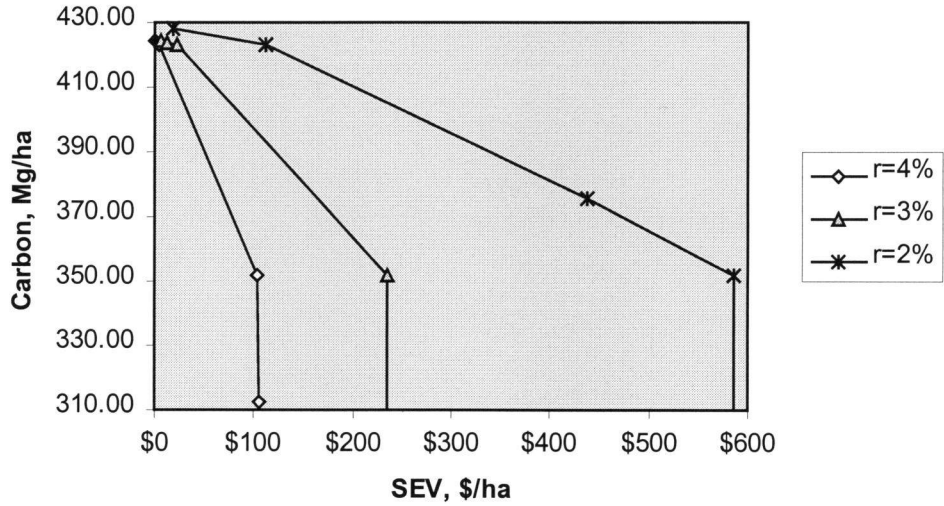
Efficient regimes*:

r=4%	r=3%	r=2%
200-year rotation, no thinning	200-year rotation, no thinning	200-year rotation, precommercial thinning
180-year rotation, no thinning	180-year rotation, no thinning	
160-year rotation, no thinning	160-year rotation, no thinning	160-year rotation, no thinning
		100-year rotation, no thinning
80-year rotation, no thinning	80-year rotation, no thinning	80-year rotation, no thinning
80-year rotation, one 35% commercial thinning		

* All efficient regimes use artificial regeneration

4.5 Marginal costs

After establishing the set of efficient regimes and constricting PPF, we will now proceed with the marginal costs analysis. The slope of the PPF is $\Delta C/\Delta SEV$, thus, the marginal costs of storing additional amount of C in forest are the reciprocals of the slopes of PPF.

Examining PPFs with different discount rates (Figure 4.8), we notice that the slopes of the PPF and, consequently, the marginal costs are very sensitive to the discount rate.

As shown in Figure 4.10, the marginal costs C storage increases in C following economic law. We can clearly see that the marginal costs are rising in increasing rate and when C storage reaches the level close to its maximum capacity that is around 425 MgC/ha, marginal costs increase dramatically and asymptotically approach infinity.

Figure 4.10. Marginal costs of C sequestration
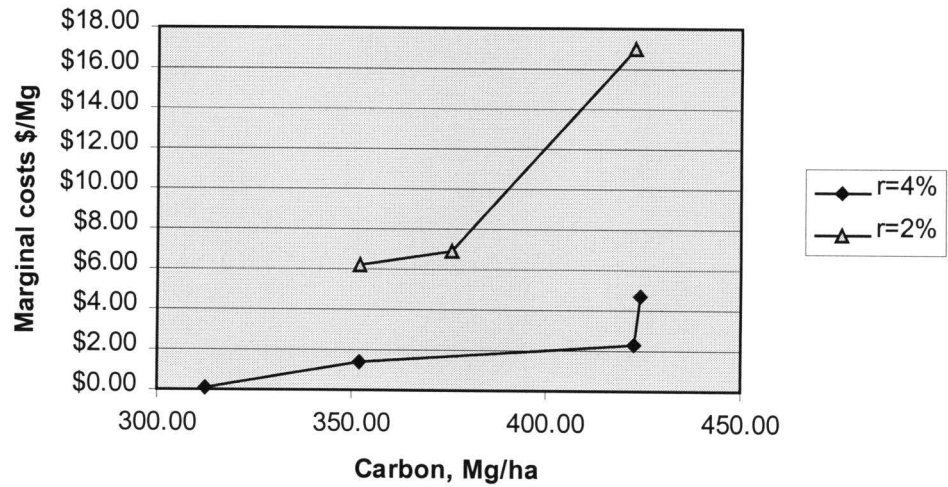
Analyzing differences in interest rates (Figure 4.10), we support our early hypothesis regarding reciprocal relationships between discount rate and marginal costs. Numerical values for marginal costs of C sequestration are shown in the Table 4.1.

Table 4.1. Marginal costs of C sequestration

Discount rate, r=4%

Efficient regimes*	SEV, $/ha	C, Mg/ha	MC, $/MgC
200-year rotation, no thinning	$0.74	424.36	
180-year rotation, no thinning	$2.24	424.04	$4.71
160-year rotation, no thinning	$4.78	422.93	$2.29
80-year rotation, no thinning	$102.84	352.09	$1.38
80-year rotation, one 35% thinning	$105.93	312.45	$0.08

Discount rate, r=2%

Efficient regimes*	SEV, $/ha	C, Mg/ha	MC, $/MgC
200-year rotation, precommercial thinning	$17.65	428.43	
160-year rotation, no thinning	$111.38	422.93	$17.04
100-year rotation, no thinning	$437.10	375.93	$6.93
80-year rotation, no thinning	$585.12	352.09	$6.21

All efficient regimes use artificial regeneration

Looking at the Table 4.1, we notice that initially additional C storage can be achieved for as low as $0.08/Mg (4% discount rate applied). As we increase C storage the marginal costs rise to the level of $4.71/Mg (4% discount rate). Ironically, a decrease in the discount rate results in increasing marginal costs. This result can be explained from the prospective of the opportunity costs. Lower discount rate yields higher present value of profits (SEV) and therefore, higher opportunity costs of sacrificing these profits for C sequestration.

Now we compare the marginal costs of C storage derived in our results with the results of other research. Before proceeding we acknowledge that comparison is

made for different climatic conditions, sites and methods and therefore cannot

pretend for any robust findings.

Table 4.2. Comparison of the marginal costs of C storage at 4% discount rate

Site - Northwest Russia, dominant specie - Spuce (our analysis)				
Efficient regimes*	SEV, $/ha	C, Mg/ha	% increase in C***	MC, $/MgC
200-year rotation, no thinning	$0.74	424.36		
180-year rotation, no thinning	$2.24	424.04	35.82%	$4.71
160-year rotation, no thinning	$4.78	422.93	35.71%	$2.29
80-year rotation, no thinning	$102.84	352.09	35.36%	$1.38
80-year rotation, one 35% thinning	$105.93	312.45	12.69%	$0.08
Site - Pacific Northwest USA, dominant specie - Douglas fir (Zyrina, 2000)				
Efficient regimes**	SEV, $/ha	C, Mg/ha	% increase in C***	MC, $/MgC
150-year rotation with natural regeneration and no thinning	$208.52	802.73		
150-year rotation with artificial regeneration and thinning	$3,086.29	682.96	156.91%	$24.03
150-year rotation with natural regeneration and thinning	$3,390.83	667.48	118.58%	$19.67
50-year rotation with artificial regeneration and thinning	$5,857.36	428.29	113.63%	$10.31
50-year rotation with natural regenerationand thinning	$5,927.73	393.58	37.07%	$2.03
Site - Norway, dominant specie - Spuce (Hoen, Solberg, 1994)				
Data for these sections is not comparable			% increase in C***	MC, $/MgC
			80.00%	$21.06
			60.00%	$11.30
			40.00%	$7.78
			20.00%	$3.22

* All efficient regimes use artificial regeneration

** All efficient regimes use growth enchancement or fertilization (Zyrina, 2000)

*** % increase in C storage with respect to efficient regime with minimal C storage

Examining Table 4.2, we notice that the marginal costs found in our analysis are relatively low comparing to other two researches. At the same time, C storage capacities in Northwest Russia appeared to be much lower than in Pacific Northwest USA and Norway. The differences in storage capacities depend on specie composition, types of treatment, soil and climatic parameters. Zyrina (2000) applied growth enhancement as a treatment. It appeared to increase the efficiency and is used in all regimes from the efficient set. In Northwest Russia this treatment was not feasible (based on consultation with Krankina).

5   CONCLUSIONS

After review of current issues of global warming, methods for C sequestration and major silvicultural practices we applied STANDCARB model to simulate performance of managed forest stand in Northwest Russia region. We modeled 140 different silvicultural regimes that included variation in rotation length, method of regeneration (natural vs. artificial), precommercial thinning usage, intensity and frequency of commercial thinnings.

STANDCARB output gave us physical information on amount of average C stored and timber production for every management regime. Analysis revealed that longer rotations contributed to higher level of C and higher timber production. However, diminishing returns and limiting capacities were observed for both parameters. It is important to highlight that in all cases artificial regeneration contributed to better results in the amount of C sequestered as well as in harvested volumes. Besides, precommercial thinning appeared to be C and volume effective when no further thinning was applied. More intensive and frequent commercial thinnings leaded to lower average C storage, but yielded higher total timber production.

Then we applied SEV analysis to evaluate perpetual profitability of the land for each management regime. As we accounted for time value of money longer

rotations generated lower SEVs. Naturally, lower discount rates contributed to higher SEVs. In monetary terms precommercial thinning appeared to be ineffective almost all regimes. The only case when precommercial thinning became efficient was 200-year rotation regime with no other thinnings applied when C and timber production approach to limiting capacities. More intensive and frequent commercial thinnings returned higher SEV.

We applied OnFront software to construct efficient frontier on the set of 140 management regimes. Depending on discount rate applied only 4-5 regimes appeared to be efficient in terms of C and SEV. Common feature of all efficient regimes was artificial regeneration and no thinning applied. This relatively simple in terms of forest treatment combination yielded the most environmental and monetary benefits. Inverting the slopes of production possibility frontier we able to compute marginal opportunity costs of C sequestration. Following economic laws, they appeared to be increasing in C. The marginal costs for 4% discount rate ranged from .08$/MgC for relatively low C level to 4.5/MgC with median level 1.84$/MgC. The discount rate of 2% gave the marginal costs ranging from 6.21$/MgC for low C level to 17.04$/MgC for high C level with median cost of 6.93$/MgC. Thus, we conclude that choice of discount rate plays dramatic role in marginal costs values.

It is important to emphasize that the entire analysis was based on simulated data and the results may not fully reflect particular stands in Northwest Russia.

However, general findings of the analysis may be applied to develop guidelines for sustainable forest management. The marginal opportunity costs derived at the research provide some rough ideas regarding the amount of C compensation to forest owners.

It is essential to recognize that our research concentrated just on one method of C sequestration. On average it provides an opportunity to increase C sequestration by about 100 Mg/ha. To broad this research it would be interesting to explore different methods of C sequestration, e.g. afforestation, and compare costs associated with those methods.

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APPENDICES

Appendix A. Map of Northwest Russia

Source: www.forest.ru

Appendix B. Specification of forest management regimes

#	Regime name	Rotations, years	Regeneration type	Precommercial thinning, % of trees	1st commercial thinning, % of trees	2nd commercial thinning, % of trees
1	80np0c0c0	80	natural	no treatment	no treatment	no treatment
2	80np0c25c0	80	natural	no treatment	50th year - 25%	no treatment
3	80np0c35c0	80	natural	no treatment	50th year - 35%	no treatment
4	80np0c25c25	80	natural	no treatment	45th year - 25%	60th year - 25%
5	80np0c35c25	80	natural	no treatment	45th year - 35%	60th year - 25%
6	80np25c0c0	80	natural	20th year - 25%	no treatment	no treatment
7	80np25c25c0	80	natural	20th year - 25%	50th year - 25%	no treatment
8	80np25c35c0	80	natural	20th year - 25%	50th year - 35%	no treatment
9	80np25c25c25	80	natural	20th year - 25%	45th year - 25%	60th year - 25%
10	80np25c35c25	80	natural	20th year - 25%	45th year - 35%	60th year - 25%
11	80ap0c0c0	80	artificial	no treatment	no treatment	no treatment
12	80ap0c25c0	80	artificial	no treatment	50th year - 25%	no treatment
13	80ap0c35c0	80	artificial	no treatment	50th year - 35%	no treatment
14	80ap0c25c25	80	artificial	no treatment	45th year - 25%	60th year - 25%
15	80ap0c35c25	80	artificial	no treatment	45th year - 35%	60th year - 25%
16	80ap25c0c0	80	artificial	20th year - 25%	no treatment	no treatment
17	80ap25c25c0	80	artificial	20th year - 25%	50th year - 25%	no treatment
18	80ap25c35c0	80	artificial	20th year - 25%	50th year - 35%	no treatment
19	80ap25c25c25	80	artificial	20th year - 25%	45th year - 25%	60th year - 25%
20	80ap25c35c25	80	artificial	20th year - 25%	45th year - 35%	60th year - 25%
21	100np0c0c0	100	natural	no treatment	no treatment	no treatment
22	100np0c25c0	100	natural	no treatment	60th year - 25%	no treatment
23	100np0c35c0	100	natural	no treatment	60th year - 35%	no treatment
24	100np0c25c25	100	natural	no treatment	50th year - 25%	70th year - 25%
25	100np0c35c25	100	natural	no treatment	50th year - 35%	70th year - 25%
26	100np25c0c0	100	natural	20th year - 25%	no treatment	no treatment
27	100np25c25c0	100	natural	20th year - 25%	60th year - 25%	no treatment
28	100np25c35c0	100	natural	20th year - 25%	60th year - 35%	no treatment
29	100np25c25c25	100	natural	20th year - 25%	50th year - 25%	70th year - 25%
30	100np25c35c25	100	natural	20th year - 25%	50th year - 35%	70th year - 25%
31	100ap0c0c0	100	artificial	no treatment	no treatment	no treatment
32	100ap0c25c0	100	artificial	no treatment	60th year - 25%	no treatment
33	100ap0c35c0	100	artificial	no treatment	60th year - 35%	no treatment
34	100ap0c25c25	100	artificial	no treatment	50th year - 25%	70th year - 25%
35	100ap0c35c25	100	artificial	no treatment	50th year - 35%	70th year - 25%
36	100ap25c0c0	100	artificial	20th year - 25%	no treatment	no treatment

#	Regime name	Rotations, years	Regeneration type	Precommercial thinning, year, % of trees	1st commercial thinning, year, % of trees	2nd commercial thinning, year, % of trees
37	100ap25c25c0	100	artificial	20th year - 25%	60th year - 25%	no treatment
38	100ap25c35c0	100	artificial	20th year - 25%	60th year - 35%	no treatment
39	100ap25c25c25	100	artificial	20th year - 25%	50th year - 25%	70th year - 25%
40	100ap25c35c25	100	artificial	20th year - 25%	50th year - 35%	70th year - 25%
41	120np0c0c0	120	natural	no treatment	no treatment	no treatment
42	120np0c25c0	120	natural	no treatment	70th year - 25%	no treatment
43	120np0c35c0	120	natural	no treatment	70th year - 35%	no treatment
44	120np0c25c25	120	natural	no treatment	60th year - 25%	90th year - 25%
45	120np0c35c25	120	natural	no treatment	60th year - 35%	90th year - 25%
46	120np25c0c0	120	natural	20th year - 25%	no treatment	no treatment
47	120np25c25c0	120	natural	20th year - 25%	70th year - 25%	no treatment
48	120np25c35c0	120	natural	20th year - 25%	70th year - 35%	no treatment
49	120np25c25c25	120	natural	20th year - 25%	60th year - 25%	90th year - 25%
50	120np25c35c25	120	natural	20th year - 25%	60th year - 35%	90th year - 25%
51	120ap0c0c0	120	artificial	no treatment	no treatment	no treatment
52	120ap0c25c0	120	artificial	no treatment	70th year - 25%	no treatment
53	120ap0c35c0	120	artificial	no treatment	70th year - 35%	no treatment
54	120ap0c25c25	120	artificial	no treatment	60th year - 25%	90th year - 25%
55	120ap0c35c25	120	artificial	no treatment	60th year - 35%	90th year - 25%
56	120ap25c0c0	120	artificial	20th year - 25%	no treatment	no treatment
57	120ap25c25c0	120	artificial	20th year - 25%	70th year - 25%	no treatment
58	120ap25c35c0	120	artificial	20th year - 25%	70th year - 35%	no treatment
59	120ap25c25c25	120	artificial	20th year - 25%	60th year - 25%	90th year - 25%
60	120ap25c35c25	120	artificial	20th year - 25%	60th year - 35%	90th year - 25%
61	140np0c0c0	140	natural	no treatment	no treatment	no treatment
62	140np0c25c0	140	natural	no treatment	80th year - 25%	no treatment
63	140np0c35c0	140	natural	no treatment	80th year - 35%	no treatment
64	140np0c25c25	140	natural	no treatment	70th year - 25%	110th year - 25%
65	140np0c35c25	140	natural	no treatment	70th year - 35%	110th year - 25%
66	140np25c0c0	140	natural	20th year - 25%	no treatment	no treatment
67	140np25c25c0	140	natural	20th year - 25%	80th year - 25%	no treatment
68	140np25c35c0	140	natural	20th year - 25%	80th year - 35%	no treatment
69	140np25c25c25	140	natural	20th year - 25%	70th year - 25%	110th year - 25%
70	140np25c35c25	140	natural	20th year - 25%	70th year - 35%	110th year - 25%
71	140ap0c0c0	140	artificial	no treatment	no treatment	no treatment
72	140ap0c25c0	140	artificial	no treatment	80th year - 25%	no treatment
73	140ap0c35c0	140	artificial	no treatment	80th year - 35%	no treatment
74	140ap0c25c25	140	artificial	no treatment	70th year - 25%	110th year - 25%
75	140ap0c35c25	140	artificial	no treatment	70th year - 35%	110th year - 25%
76	140ap25c0c0	140	artificial	20th year - 25%	no treatment	no treatment

#	Regime name	Rotations, years	Regeneration type	Precommercial thinning, year, % of trees	1st commercial thinning, year, % of trees	2nd commercial thinning, year, % of trees
77	140ap25c25c0	140	artificial	20th year - 25%	80th year - 25%	no treatment
78	140ap25c35c0	140	artificial	20th year - 25%	80th year - 35%	no treatment
79	140ap25c25c25	140	artificial	20th year - 25%	70th year - 25%	110th year - 25%
80	140ap25c35c25	140	artificial	20th year - 25%	70th year - 35%	110th year - 25%
81	160np0c0c0	160	natural	no treatment	no treatment	no treatment
82	160np0c25c0	160	natural	no treatment	90th year - 25%	no treatment
83	160np0c35c0	160	natural	no treatment	90th year - 35%	no treatment
84	160np0c25c25	160	natural	no treatment	80th year - 25%	130th year - 25%
85	160np0c35c25	160	natural	no treatment	80th year - 35%	130th year - 25%
86	160np25c0c0	160	natural	20th year - 25%	no treatment	no treatment
87	160np25c25c0	160	natural	20th year - 25%	90th year - 25%	no treatment
88	160np25c35c0	160	natural	20th year - 25%	90th year - 35%	no treatment
89	160np25c25c25	160	natural	20th year - 25%	80th year - 25%	130th year - 25%
90	160np25c35c25	160	natural	20th year - 25%	80th year - 35%	130th year - 25%
91	160ap0c0c0	160	artificial	no treatment	no treatment	no treatment
92	160ap0c25c0	160	artificial	no treatment	90th year - 25%	no treatment
93	160ap0c35c0	160	artificial	no treatment	90th year - 35%	no treatment
94	160ap0c25c25	160	artificial	no treatment	80th year - 25%	130th year - 25%
95	160ap0c35c25	160	artificial	no treatment	80th year - 35%	130th year - 25%
96	160ap25c0c0	160	artificial	20th year - 25%	no treatment	no treatment
97	160ap25c25c0	160	artificial	20th year - 25%	90th year - 25%	no treatment
98	160ap25c35c0	160	artificial	20th year - 25%	90th year - 35%	no treatment
99	160ap25c25c25	160	artificial	20th year - 25%	80th year - 25%	130th year - 25%
100	160ap25c35c25	160	artificial	20th year - 25%	80th year - 35%	130th year - 25%
101	180np0c0c0	180	natural	no treatment	no treatment	no treatment
102	180np0c25c0	180	natural	no treatment	100th year - 25%	no treatment
103	180np0c35c0	180	natural	no treatment	100th year - 35%	no treatment
104	180np0c25c25	180	natural	no treatment	90th year - 25%	150th year - 25%
105	180np0c35c25	180	natural	no treatment	90th year - 35%	150th year - 25%
106	180np25c0c0	180	natural	20th year - 25%	no treatment	no treatment
107	180np25c25c0	180	natural	20th year - 25%	100th year - 25%	no treatment
108	180np25c35c0	180	natural	20th year - 25%	100th year - 35%	no treatment
109	180np25c25c25	180	natural	20th year - 25%	90th year - 25%	150th year - 25%
110	180np25c35c25	180	natural	20th year - 25%	90th year - 35%	150th year - 25%
111	180ap0c0c0	180	artificial	no treatment	no treatment	no treatment
112	180ap0c25c0	180	artificial	no treatment	100th year - 25%	no treatment
113	180ap0c35c0	180	artificial	no treatment	100th year - 35%	no treatment
114	180ap0c25c25	180	artificial	no treatment	90th year - 25%	150th year - 25%
115	180ap0c35c25	180	artificial	no treatment	90th year - 35%	150th year - 25%
116	180ap25c0c0	180	artificial	20th year - 25%	no treatment	no treatment

#	Regime name	Rotations, years	Regeneration type	Precommercial thinning, year, % of trees	1st commercial thinning, year, % of trees	2nd commercial thinning, year, % of trees
117	180ap25c25c0	180	artificial	20th year - 25%	100th year - 25%	no treatment
118	180ap25c35c0	180	artificial	20th year - 25%	100th year - 35%	no treatment
119	180ap25c25c25	180	artificial	20th year - 25%	90th year - 25%	150th year - 25%
120	180ap25c35c25	180	artificial	20th year - 25%	90th year - 35%	150th year - 25%
121	200np0c0c0	200	natural	no treatment	no treatment	no treatment
122	200np0c25c0	200	natural	no treatment	110th year - 25%	no treatment
123	200np0c35c0	200	natural	no treatment	110th year - 35%	no treatment
124	200np0c25c25	200	natural	no treatment	100th year - 25%	170th year - 25%
125	200np0c35c25	200	natural	no treatment	100th year - 35%	170th year - 25%
126	200np25c0c0	200	natural	20th year - 25%	no treatment	no treatment
127	200np25c25c0	200	natural	20th year - 25%	110th year - 25%	no treatment
128	200np25c35c0	200	natural	20th year - 25%	110th year - 35%	no treatment
129	200np25c25c25	200	natural	20th year - 25%	100th year - 25%	170th year - 25%
130	200np25c35c25	200	natural	20th year - 25%	100th year - 35%	170th year - 25%
131	200ap0c0c0	200	artificial	no treatment	no treatment	no treatment
132	200ap0c25c0	200	artificial	no treatment	110th year - 25%	no treatment
133	200ap0c35c0	200	artificial	no treatment	110th year - 35%	no treatment
134	200ap0c25c25	200	artificial	no treatment	100th year - 25%	170th year - 25%
135	200ap0c35c25	200	artificial	no treatment	100th year - 35%	170th year - 25%
136	200ap25c0c0	200	artificial	20th year - 25%	no treatment	no treatment
137	200ap25c25c0	200	artificial	20th year - 25%	110th year - 25%	no treatment
138	200ap25c35c0	200	artificial	20th year - 25%	110th year - 35%	no treatment
139	200ap25c25c25	200	artificial	20th year - 25%	100th year - 25%	170th year - 25%
140	200ap25c35c25	200	artificial	20th year - 25%	100th year - 35%	170th year - 25%

Appendix C. STANDCARB input files

Major STANDCARB input files used for the regime with 200-year rotations with artificial regeneration, precommercial thinning, two commercial thinnings: a first of 35% and a second of 25%

File Simul.drv

```
Program     StandCarb
Data_File   Simulation_Parms
Version     1


SpeciesUpper          Piab
SpeciesLower          Piab

SiteName              testsite1

GrowthMethod          Siteindex
SiteIndexSpecies      Piab
SiteIndex             Site2Medium

Regen                 af
MaxTreeDensity     323500
RegenTreeDensity   4000
MaxTreeCells       100

#ofRows            10
#ofCols            10

#ofReps            1
TimeEnd            2300
Interval           5

CellWidth             8

TimeHerb              1
TimeShrub             5
TimeUpper             5
TimeLower            15

Border             same

NeighborOnOff         1
Cohort                1
Restart               1
```

```
WaterPot_SaturationLimit    100
MaxMonths_WetSoil           12

PET_Reduction        10
InitialSoilCarbon    100
Units                OM

GPP_DecreaseMax       0
GPP_Shape             1

DiagnosticsMode       10
PlantDiag             0
DieOutDiag            0
ReplacementDiag       1
DensityDiag           1
InterceptionDiag      0
WaterBalanceDiag      0
TranspirationDiag     0
TempResponseDiag      0
DetritalMoistureDiag  0
AbioticResponseDiag   0
LightDiag             0
RespirationDiag       0
MortalityDiag         0
SubstrateQualityDiag  0
WaterPotRespDiag      0
SpeciesDiag           1
NeighborDiag          0
YearNeighbor          100

RandomNumSeed        -4987
```

File Locate.drv

Locate driver file for StandCarb

Model #	File #	Site Name	Soil Texture	Ecoregion	Long	Lat	Elev	Aspect	Slope Steep	Soil Depth	Drainage Factor
ML02	22	default	loam	OTHR	123	40	300	180	0	100	
ML02	22	testsite1	loam	Other	30	58	93	180	0	100	
ML02	22	testsite2	loam	ORCW	123	44	1000	180	0	100	

File Climate.drv

Climate driver file - StandCarb

Model #	File #	Month	Temp Min	Max	24-hr	Precip
ML02	23	Jan	-11.6	-5.5	-8.2	3.4
ML02	23	Feb	-11.9	-5.0	-8.0	3.0
ML02	23	Mar	-8.0	-0.4	-4.1	3.0
ML02	23	Apr	-0.8	7.7	3.4	3.2
ML02	23	May	4.8	15.4	10.4	4.7
ML02	23	Jun	9.1	19.5	14.6	6.8
ML02	23	Jul	11.9	22.1	17.1	7.5
ML02	23	Aug	10.6	19.9	15.2	8.1
ML02	23	Sep	6.2	14.4	10.1	6.5
ML02	23	Oct	1.4	7.4	4.2	5.1
ML02	23	Nov	-3.5	1.0	-1.0	4.4
ML02	23	Dec	-8.4	-3.4	-5.8	3.8

File Radiate.drv

Radiation driver file - StandCarb

Model #	File #	Month	Solar Radiation Diffuse	Direct	Total	Sunrise Azimuth Angle	Solar Alt-Angle South
ML02	24	Jan	19.40	6.5	26.7	52.29	11.08
ML02	24	Feb	53.60	25.0	73.3	68.40	19.04
ML02	24	Mar	112.90	90.3	210.0	86.13	29.58
ML02	24	Apr	153.30	160.0	313.3	105.40	41.42
ML02	24	May	183.90	225.8	423.3	123.00	50.79
ML02	24	Jun	213.30	270.0	483.3	133.02	55.09
ML02	24	Jul	232.30	219.4	466.7	128.34	53.18
ML02	24	Aug	180.60	161.3	353.3	112.52	45.46
ML02	24	Sep	106.70	96.7	203.3	93.56	34.22
ML02	24	Oct	58.10	29.0	90.0	74.30	22.40
ML02	24	Nov	23.30	6.7	30.0	56.75	13.09
ML02	24	Dec	16.10	3.2	20.0	47.08	8.95
ML02	24	Year	112.80	107.8	224.4	110.85	43.65

File HarvInt.drv (formed by the Matlab code)

Harvest Interval driver file - StandCarb

Model #	File #	Pre-Commercial Interval UTree	LTree	Util	Fire Type	Commercial Interval UTree	LTree	Util	Fire Type	Clear-Cut Interval UTree	LTree	Util	Fire Type	Herbicide Salvage Int	Util	UTree Int	Effect	LTree Int	Effect
ML02	26	0	0	3	0	0	0	3	0	300	300	3	0	0	2	0	1	0	3
ML02	26	0	320	3	0	0	0	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	400	400	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	470	470	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	0	0	3	0	500	500	3	0	0	2	0	1	0	3
ML02	26	0	520	3	0	0	0	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	600	600	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	670	670	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	0	0	3	0	700	700	3	0	0	2	0	1	0	3
ML02	26	0	720	3	0	0	0	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	800	800	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	870	870	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	0	0	3	0	900	900	3	0	0	2	0	1	0	3
ML02	26	0	920	3	0	0	0	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	1000	1000	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	1070	1070	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	0	0	3	0	1100	1100	3	0	0	2	0	1	0	3
ML02	26	0	1120	3	0	0	0	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	1200	1200	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	1270	1270	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	0	0	3	0	1300	1300	3	0	0	2	0	1	0	3
ML02	26	0	1320	3	0	0	0	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	1400	1400	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	1470	1470	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	0	0	3	0	1500	1500	3	0	0	2	0	1	0	3
ML02	26	0	1520	3	0	0	0	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	1600	1600	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	1670	1670	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	0	0	3	0	1700	1700	3	0	0	2	0	1	0	3
ML02	26	0	1720	3	0	0	0	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	1800	1800	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	1870	1870	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	0	0	3	0	1900	1900	3	0	0	2	0	1	0	3
ML02	26	0	1920	3	0	0	0	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	2000	2000	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	2070	2070	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	0	0	3	0	2100	2100	3	0	0	2	0	1	0	3
ML02	26	0	2120	3	0	0	0	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	2200	2200	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	2270	2270	3	0	0	0	3	0	0	2	0	1	0	3
ML02	26	0	0	3	0	0	0	3	0	2300	2300	3	0	0	2	0	1	0	3

File CutPatt.drv (formed by the Matlab Code)

Cut Pattern driver file for StandCarb

ML02   27

Year   320
Species all
```
0   0   0   1   0   1   1   0   1   0
0   0   0   0   1   1   0   0   0   0
1   1   0   0   1   0   0   0   0   0
0   0   1   0   0   1   0   0   1   0
0   1   1   0   0   1   0   1   1   1
0   0   0   0   0   0   0   0   1   0
1   0   0   0   1   0   0   0   0   0
0   0   0   0   1   1   0   0   0   0
0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   1   0
```

Year   400
Species all
```
0   0   0   0   1   1   0   1   0   1
0   0   0   0   1   0   1   0   1   0
0   0   0   1   0   1   1   0   1   0
0   0   0   0   0   0   0   0   0   0
0   1   0   0   0   0   0   0   1   0
0   1   1   0   1   0   0   0   0   0
0   1   0   0   0   0   0   0   1   0
1   0   1   0   0   1   0   0   0   0
0   0   0   0   1   0   1   0   0   1
0   1   0   1   0   0   0   1   0   0
```


....

Year   300,500,700,900,1100,1300,1500,1700,1900,2100,2300
Species all
```
1   1   1   1   1   1   1   1   1   1
1   1   1   1   1   1   1   1   1   1
1   1   1   1   1   1   1   1   1   1
1   1   1   1   1   1   1   1   1   1
1   1   1   1   1   1   1   1   1   1
1   1   1   1   1   1   1   1   1   1
1   1   1   1   1   1   1   1   1   1
1   1   1   1   1   1   1   1   1   1
1   1   1   1   1   1   1   1   1   1
1   1   1   1   1   1   1   1   1   1
```

File Estab.prm

Establishment probabilities for layers - StandCarb model

| Model | File | | Natural Fast | | Slow | | Artifical Fast | | Slow | |
#	#	Layer	Open	Closed	Open	Closed	Open	Closed	Open	Closed
ML02	1	Herb	0.500	0.250	0.600	0.300	0.100	0.100	0.300	0.300
ML02	1	Shrub	0.300	0.150	0.300	0.150	0.200	0.150	0.300	0.150
ML02	1	Tree	0.200	0.050	0.100	0.050	0.700	0.300	0.400	0.100

File TreeReg.prm

Program	StandCarb
Data_File	Tree_Regeneration_Parms
Version	1

| > | | Light | | DegreeDays | | WaterPot | | |
> Species		Max	Min	Max	Min	Max	Min	Sprout
Bepe		1.00	0.10	3100	1100	4.0	0.01	0
Piab		1.00	0.02	3100	1100	4.0	0.01	0
Pisy		1.00	0.10	3100	1100	4.0	0.01	0
Potr		1.00	0.10	3100	1100	4.0	0.01	5

File Growth.prm

Growth parameters for species - StandCarb model version 2

Model #	File #	Species	Light Comp Point	Ext Coeff	Foliage Prod Rate Max	Fine Root Foliage Ratio	Sap Live	Rate Heart Wood Form	Branch Bole Ratio	Coarse Root Bole Ratio	Temp Min	Temp Max	Wood Pcnt	Density	Height Max	Rate	Shape	Heart-Rot Lag	Rate Form
ML02	3	Herb	5	0.23	2.00	0.75	0.00	0.000	0.000	0.000	0	37	0.0	0.45	0	0.015	1.0	0	0.000
ML02	3	Shrub	30	0.40	1.20	0.50	0.00	0.000	1.500	1.500	0	37	0.0	0.45	0	0.015	1.0	0	0.000
ML02	3	Bepe	10	0.90	0.45	0.33	10.00	0.010	0.200	0.150	0	37	86.4	0.47	30	0.020	2.0	50	0.020
ML02	3	Piab	2	0.18	0.55	0.30	4.00	0.022	0.400	0.300	0	37	90.1	0.37	40	0.015	2.2	90	0.010
ML02	3	Pisy	10	0.17	0.47	0.25	5.00	0.024	0.280	0.140	0	37	89.5	0.39	40	0.011	1.8	75	0.002
ML02	3	Potr	10	0.90	0.37	0.33	9.00	0.010	0.180	0.150	0	37	86.1	0.36	30	0.025	1.7	30	0.050

File GrowLayer.prm

Growth parameters for plant layers
StandCarb model, version 2

Model Growth # Effic	File #	Layer	Foliage		FineRoot		Sapwood		Branch		CRoot		HeartRot		Initial Foliage Mass	Canopy Inter Min	Bole
			Q10	Resp10	Q10	Resp10	Q10	Resp10	Q10	Resp10	Q10	Resp10	Q10	Resp10			
ML02	4	Herb	2.000	0.500	2.000	0.500	2.000	0.000	2.000	0.000	2.000	0.000	2.000	0.000	0.01	0.006	0.00
ML02	4	Shrub	2.000	0.500	2.000	0.500	2.000	0.050	2.000	0.050	2.000	0.050	2.000	0.000	0.01	0.006	0.50
ML02	4	LTree	2.000	0.250	2.000	0.500	2.000	0.017	2.000	0.017	2.000	0.017	2.000	0.010	0.01	0.006	1.00
ML02	4	UTree	2.000	0.250	2.000	0.500	2.000	0.017	2.000	0.017	2.000	0.017	2.000	0.010	0.01	0.006	1.00

File Mort.prm

Mortality parameters - StandCarb model version 2

Model #	File #	Species	Mort Max	Branch Prune Max	Coarse Root Prune Max	Time Close	Age Max	Turnover-Rates Foliage	Fine Root
ML02	5	Herb	0.000	0.000	0.000	0	0	1.000	0.500
ML02	5	Shrub	0.010	0.020	0.010	0	0	0.500	0.500
ML02	5	Bepe	0.008	0.020	0.005	130	250	1.000	0.500
ML02	5	Piab	0.008	0.020	0.005	150	450	0.250	0.500
ML02	5	Pisy	0.020	0.020	0.005	120	500	0.333	0.500
ML02	5	Potr	0.010	0.020	0.005	100	150	1.000	0.500

File EcoRegion.prm

```
Program      StandCarb
Data_File    EcoRegions
Version      1
```

>	% Snags		
>	Open	Closed	Local
> EcoRegion	Canopy	Canopy	Abundances
NW_Russia	90	50	Other
Other	90	30	Other

Local_Abundances	NW_Russia	Wet_NwRus	Other
Bepe	–	10	10
Piab	20	50	99
Pisy	50	50	5
Potr	40	1	5

File Decomp.prm

Decomposition parameters - StandCarb model

Model #	File #	Species	Decay-Rates						Optimum-Lag		Stable-Pools		
			Foliage	Fine Root	Coarse Root	Sap Wood	Heart Wood	Branch	Snag Fall	Salv	Wood	Foliage	Soil
ML02	6	Herb	0.500	0.500	0.000	0.000	0.000	0.000	0	0	0	5	5
ML02	6	Shrub	0.250	0.250	0.100	0.050	0.000	0.100	0	0	10	5	5
ML02	6	Bepe	0.250	0.300	0.150	0.300	0.300	0.150	8	2	20	5	5
ML02	6	Piab	0.150	0.150	0.100	0.200	0.100	0.100	5	5	20	5	10
ML02	6	Pisy	0.150	0.150	0.100	0.210	0.110	0.100	10	10	20	5	5
ML02	6	Potr	0.400	0.300	0.150	0.300	0.300	0.150	8	2	20	5	5

File DecayPool.prm

Parameters for dead and stable pools
Standcarb model, version 2

Model # Constant	File #	Pool	Q10	Temp Opt	Moist Min	Moist Max	Transfer Rate	Decay Rate	Mass Ratio	Stable Store Max	Area Matric Shape	Area Matric Lag	Moist Diffuse Shape	Moist Diffuse Lag	Temp Shape	Temp Lag	Drying
ML02	7	DeadFoliage	2.000	45	30	350	0.300	0.0000	20.00	300	5.0	0	15	4	15	4	0.00150
ML02	7	DeadFineRoot	2.000	45	30	400	0.300	0.0000	0.00	300	5.0	0	15	4	15	4	0.00000
ML02	7	SalvSnagSapWood	2.000	45	30	300	0.150	0.0000	0.02	300	5.0	0	15	4	15	4	0.00075
ML02	7	SalvSnagHeartWood	2.000	45	30	200	0.150	0.0000	0.02	200	5.0	0	15	4	15	4	0.00025
ML02	7	SnagSapWood	2.000	45	30	300	0.150	0.0000	0.02	300	5.0	0	15	4	15	4	0.00075
ML02	7	SnagHeartWood	2.000	45	30	200	0.150	0.0000	0.02	200	5.0	0	15	4	15	4	0.00025
ML02	7	SalvLogSapWood	2.000	45	30	300	0.150	0.0000	0.10	300	5.0	0	15	4	15	4	0.00075
ML02	7	SalvLogHeartWood	2.000	45	30	200	0.150	0.0000	0.10	200	5.0	0	15	4	15	4	0.00025
ML02	7	LogSapWood	2.000	45	30	300	0.075	0.0000	0.10	300	5.0	0	15	4	15	4	0.00075
ML02	7	LogHeartWood	2.000	45	30	200	0.075	0.0000	0.10	200	5.0	0	15	4	15	4	0.00025
ML02	7	DeadBranch	2.000	45	30	200	0.150	0.0000	0.10	200	5.0	0	15	4	15	4	0.00150
ML02	7	DeadCRoot	2.000	45	30	200	0.150	0.0000	0.00	200	5.0	0	15	4	15	4	0.00000
ML02	7	StableFoliage	2.000	45	30	400	0.000	0.2000	20.00	400	5.0	0	15	4	15	4	0.00100
ML02	7	StableWood	2.000	45	30	600	0.000	0.2000	0.10	600	5.0	0	15	4	15	4	0.00100
ML02	7	StableSoil	2.000	45	15	100	0.000	0.0120	0.00	100	5.0	0	15	4	15	4	0.00000

File SitePrepp.prm

Site Prep parameters - StandCarb model

Model #	File #	Pool	Light Burn	Medium Burn	Hot Burn
ML02	9	DeadFoliage	75.0	50.0	0.0
ML02	9	DeadFineRoot	100.0	75.0	0.0
ML02	9	SnagSapWood	100.0	85.0	50.0
ML02	9	LogSapWood	95.0	75.0	10.0
ML02	9	SnagHeartWood	100.0	95.0	75.0
ML02	9	LogHeartWood	100.0	90.0	50.0
ML02	9	DeadBranch	75.0	50.0	0.0
ML02	9	DeadCRoot	100.0	100.0	50.0
ML02	9	StableSoil	100.0	100.0	100.0
ML02	9	Stablefoliage	100.0	50.0	5.0
ML02	9	Stablewood	100.0	50.0	5.0

File Harvest.prm

Harvest parameters - StandCarb model

Model #	File #	Treatment	Low Utilization %-Cut	Low Utilization %-Taken	Medium Utilization %-Cut	Medium Utilization %-Taken	High Utilization %-Cut	High Utilization %-Taken
ML02	10	PCom	5	0	10	0	100	0
ML02	10	Com	5	50	10	90	100	95
ML02	10	CCut	80	80	95	90	100	95

			Low Utilization %-Taken	Low Utilization MinVol	Medium Utilization %-Taken	Medium Utilization MinVol	High Utilization %-Taken	Utilization MinVol
ML02	10	Salv	50	100	75	50	100	25

File Soil.prm

Soil parameters for StandCarb model

Model #	File #	Soil Texture	Water PotAsym	Water Pot1	SoilWater MaxPer
ML02	11	sand	0.00	0.25	25.0
ML02	11	loamySand	0.01	0.25	35.0
ML02	11	sandyLoam	0.02	0.25	35.0
ML02	11	loam	0.03	0.25	45.0
ML02	11	siltLoam	0.04	0.25	50.0
ML02	11	silt	0.05	0.25	50.0
ML02	11	sandyClayLoam	0.06	0.25	50.0
ML02	11	clayLoam	0.07	0.25	50.0
ML02	11	siltyClayLoam	0.08	0.25	50.0
ML02	11	sandyClay	0.09	0.25	45.0
ML02	11	siltyClay	0.10	0.25	60.0
ML02	11	clay	0.11	0.25	60.0

File SiteIndex.prm

Bole growth efficiencies for Site Indexes - StandCarb model

Model #	File #	Site Index Species	Site-1 High	Med	Low	Site-2 High	Med	Low	Site-3 High	Med	Low	Site-4 High	Med	Low	Site-5 High	Med	Low
ML02	12	Bepe	1.50	1.45	1.40	1.35	1.30	1.19	1.07	0.95	0.85	0.75	0.65	0.57	0.49	0.41	0.33
ML02	12	Piab	0.18	0.16	0.15	0.14	0.12	0.11	0.10	0.08	0.07	0.06	0.05	0.04	0.03	0.035	0.01
ML02	12	Pisy	0.33	0.31	0.29	0.27	0.25	0.23	0.21	0.19	0.20	0.18	0.16	0.09	0.07	0.05	0.03
ML02	12	Potr	1.79	1.69	1.59	1.50	1.41	1.27	1.13	1.00	0.90	0.80	0.70	0.62	0.54	0.45	0.36

Appendix D. STANDCARB output files

Major STANDCARB output files for the regime with 200-year rotations with artificial regeneration, precommercial thinning, two commercial thinnings: a first of 35% and a second of 25%

File Total.out

Model	File		TotalLive		TotalDead		TotalStable				
#	#	Time	Mean	StdErr	Mean	StdErr	Mean	StdErr	Volume	Density	Harvest
ML02	31	5.0	1.41	0.16	0.22	0.03	97.06	96.57	0.07	6760.00	0.00
ML02	31	10.0	20.13	1.51	8.98	0.87	94.55	94.08	0.69	7800.00	0.00
ML02	31	15.0	34.60	1.61	27.40	1.28	92.04	91.58	5.66	7920.00	0.00
ML02	31	20.0	47.46	1.19	39.77	0.75	89.65	89.20	24.50	7611.42	0.00
ML02	31	25.0	67.83	1.37	57.45	1.16	87.74	87.30	50.91	7879.36	0.00
ML02	31	30.0	84.03	1.57	74.03	1.38	88.33	87.89	76.05	6645.73	0.00
ML02	31	35.0	99.26	1.73	83.89	1.44	90.15	89.70	99.63	5706.95	0.00
ML02	31	40.0	112.68	1.95	90.34	1.47	92.14	91.68	121.69	5214.08	0.00
ML02	31	45.0	124.94	2.08	94.34	1.53	94.23	93.75	142.29	4901.83	0.00
ML02	31	50.0	136.05	2.25	96.77	1.56	96.58	96.09	161.56	4631.74	0.00
ML02	31	55.0	146.22	2.41	98.43	1.57	99.16	98.67	179.72	4386.01	0.00
ML02	31	60.0	155.79	2.46	100.32	1.60	101.17	100.67	196.92	4161.04	0.00
ML02	31	65.0	164.42	2.62	101.58	1.54	103.48	102.96	213.27	3950.84	0.00
ML02	31	70.0	172.62	2.67	103.82	1.49	104.83	104.30	228.82	3755.60	0.00
ML02	31	75.0	180.23	2.74	105.22	1.45	106.74	106.20	243.59	3575.21	0.00
··········											
ML02	31	2225.0	168.20	9.34	92.28	3.46	151.67	150.91	218.50	4365.03	0.00
ML02	31	2230.0	173.79	9.11	94.10	3.32	151.32	150.56	225.50	4229.23	0.00
ML02	31	2235.0	178.90	8.90	95.68	3.26	150.74	149.98	231.87	3831.84	0.00
ML02	31	2240.0	183.67	8.67	96.76	3.20	150.23	149.47	237.83	3393.08	0.00
ML02	31	2245.0	187.65	8.42	98.24	3.21	149.78	149.03	242.80	2722.38	0.00
ML02	31	2250.0	191.39	8.22	99.36	3.12	149.63	148.88	247.68	2281.19	0.00
ML02	31	2255.0	189.62	9.16	101.97	4.31	149.47	148.72	246.21	3186.38	0.00
ML02	31	2260.0	196.27	9.52	97.36	3.14	149.40	148.65	255.50	3793.89	0.00
ML02	31	2265.0	193.28	10.39	102.96	5.43	149.15	148.40	252.58	3492.46	0.00
ML02	31	2270.1	190.84	10.96	104.77	5.59	149.01	148.26	248.97	3769.57	0.00
ML02	31	2270.2	148.51	11.92	120.66	6.75	149.01	148.26	193.36	3210.82	52.84
ML02	31	2275.0	146.34	12.04	111.26	5.36	148.40	147.65	188.01	4729.29	0.00
ML02	31	2280.0	149.74	12.02	101.70	4.07	148.90	148.16	190.49	5056.87	0.00
ML02	31	2285.0	152.70	11.92	97.88	4.25	148.53	147.78	193.65	5117.68	0.00
ML02	31	2290.0	159.62	11.77	94.39	3.78	149.15	148.40	202.72	5039.12	0.00
ML02	31	2295.0	158.92	11.56	100.42	5.55	149.53	148.78	201.56	5090.70	0.00
ML02	31	2300.1	168.01	11.51	96.19	3.31	149.55	148.80	213.34	4965.75	0.00
ML02	31	2300.2	0.08	0.06	167.21	5.00	149.55	148.80	0.00	0.00	202.67

File Volume.out

Volume.out

Model Fire # Type	File #	Time	Layer	Species	Volume	Density	Harvest Volume	Density	Height	Age	Treatment	% Cut	% Taken	% Cells Cut	Util
ML02	34	300.2	UT	Bepe	0.2	40.0	0.1	46.4	11.7	124.0	ccut	100.0	95.0	2.0	high
ML02	34	300.2	LT	Bepe	0.0	0.0	0.0	0.0	0.0	0.0	ccut	100.0	95.0	0.0	high
ML02	34	300.2	UT	Piab	278.6	532.4	264.6	532.4	27.0	143.2	ccut	100.0	95.0	97.0	high
ML02	34	300.2	LT	Piab	9.2	2703.6	8.8	2703.6	0.0	0.0	ccut	100.0	95.0	87.0	high
ML02	34	300.2	UT	Pisy	1.4	6.4	1.4	6.4	26.9	147.0	ccut	100.0	95.0	1.0	high
ML02	34	300.2	LT	Pisy	0.0	0.0	0.0	0.0	0.0	0.0	ccut	100.0	95.0	0.0	high
ML02	34	400.2	UT	Bepe	0.2	40.0	0.2	40.0	22.3	99.0	com	100.0	95.0	1.0	high
ML02	34	400.2	LT	Bepe	0.0	0.0	0.0	0.0	0.0	0.0	com	100.0	95.0	0.0	high
ML02	34	400.2	UT	Piab	65.3	49.7	62.0	49.7	22.7	98.7	com	100.0	95.0	22.0	high
ML02	34	400.2	LT	Piab	8.0	616.0	7.6	616.0	0.0	0.0	com	100.0	95.0	27.0	high
ML02	34	400.2	UT	Pisy	2.3	17.4	2.2	17.4	19.1	99.0	com	100.0	95.0	2.0	high
ML02	34	400.2	LT	Pisy	0.0	0.0	0.0	0.0	0.0	0.0	com	100.0	95.0	0.0	high
ML02	34	470.2	UT	Piab	65.9	274.8	62.6	276.4	22.5	121.4	com	100.0	95.0	25.0	high
ML02	34	470.2	LT	Piab	0.3	804.1	0.3	804.1	0.0	0.0	com	100.0	95.0	23.0	high
ML02	34	500.2	UT	Bepe	0.6	279.4	0.5	279.4	11.4	62.9	ccut	100.0	95.0	7.0	high
ML02	34	500.2	LT	Bepe	0.0	0.0	0.0	0.0	0.0	0.0	ccut	100.0	95.0	0.0	high
ML02	34	2000.2	LT	Bepe	0.0	0.0	0.0	0.0	0.0	0.0	com	100.0	95.0	0.0	high
ML02	34	2000.2	UT	Piab	106.7	81.6	101.4	81.6	22.6	98.5	com	100.0	95.0	36.0	high
ML02	34	2000.2	LT	Piab	10.3	961.0	9.8	961.0	0.0	0.0	com	100.0	95.0	42.0	high
ML02	34	2070.2	UT	Piab	48.4	152.1	46.0	152.1	23.5	121.2	com	100.0	95.0	17.0	high
ML02	34	2070.2	LT	Piab	1.5	605.2	1.4	605.2	0.0	0.0	com	100.0	95.0	17.0	high
ML02	34	2070.2	UT	Pisy	2.4	2.8	2.3	2.8	29.5	169.0	com	100.0	95.0	1.0	high
ML02	34	2070.2	LT	Pisy	0.0	0.0	0.0	0.0	0.0	0.0	com	100.0	95.0	0.0	high
ML02	34	2100.2	UT	Bepe	0.6	280.0	0.5	280.0	13.6	61.3	ccut	100.0	95.0	7.0	high
ML02	34	2100.2	LT	Bepe	0.0	0.0	0.0	0.0	0.0	0.0	ccut	100.0	95.0	0.0	high
ML02	34	2100.2	UT	Piab	173.3	1096.1	164.7	1096.1	18.3	89.5	ccut	100.0	95.0	86.0	high
ML02	34	2100.2	LT	Piab	18.0	3433.4	17.1	3433.4	0.0	0.0	ccut	100.0	95.0	100.0	high
ML02	34	2100.2	UT	Pisy	4.9	72.5	4.7	72.5	18.5	106.0	ccut	100.0	95.0	4.0	high
ML02	34	2100.2	LT	Pisy	0.0	0.0	0.0	0.0	0.0	0.0	ccut	100.0	95.0	0.0	high
ML02	34	2200.2	UT	Piab	94.9	72.5	90.1	72.5	22.7	98.7	com	100.0	95.0	32.0	high
ML02	34	2200.2	LT	Piab	2.6	821.7	2.5	821.7	0.0	0.0	com	100.0	95.0	32.0	high
ML02	34	2270.2	UT	Piab	55.5	67.9	52.7	72.6	27.2	147.4	com	100.0	95.0	17.0	high
ML02	34	2270.2	LT	Piab	0.1	490.8	0.1	490.8	0.0	0.0	com	100.0	95.0	14.0	high
ML02	34	2300.2	UT	Bepe	0.2	80.0	0.2	80.0	14.0	64.0	ccut	100.0	95.0	2.0	high
ML02	34	2300.2	LT	Bepe	0.0	0.0	0.0	0.0	0.0	0.0	ccut	100.0	95.0	0.0	high
ML02	34	2300.2	UT	Piab	198.1	1166.7	188.2	1166.7	19.5	99.2	ccut	100.0	95.0	91.0	high
ML02	34	2300.2	LT	Piab	12.7	3454.1	12.1	3454.1	0.0	0.0	ccut	100.0	95.0	98.0	high
ML02	34	2300.2	UT	Pisy	2.1	147.4	2.0	147.4	13.0	71.0	ccut	100.0	95.0	5.0	high
ML02	34	2300.2	LT	Pisy	0.0	0.0	0.0	0.0	0.0	0.0	ccut	100.0	95.0	0.0	high

Appendix E. Matlab codes

File Inpp.m

Purpose: create input files for STANDCARB

%Names of regimes = names of directories, where STANDCARB input files are saved

```
Regime={'80np0c0c0'    '80np0c25c0'   '80np0c35c0'    '80np0c25c25' '80np0c35c25'
        '80np25c0c0'   '80np25c25c0'  '80np25c35c0'   '80np25c25c25' '80np25c35c25'
        '80ap0c0c0'    '80ap0c25c0'   '80ap0c35c0'    '80ap0c25c25' '80ap0c35c25'
        '80ap25c0c0'   '80ap25c25c0'  '80ap25c35c0'   '80ap25c25c25' '80ap25c35c25'
        '100np0c0c0'   '100np0c25c0'  '100np0c35c0'   '100np0c25c25' '100np0c35c25'
        '100np25c0c0'  '100np25c25c0' '100np25c35c0'  '100np25c25c25'
        '100np25c35c25'        '100ap0c0c0'   '100ap0c25c0'  '100ap0c35c0'
        '100ap0c25c25' '100ap0c35c25' '100ap25c0c0'   '100ap25c25c0' '100ap25c35c0'
        '100ap25c25c25'        '100ap25c35c25'        '120np0c0c0'   '120np0c25c0'
        '120np0c35c0'  '120np0c25c25' '120np0c35c25'  '120np25c0c0'  '120np25c25c0'
        '120np25c35c0' '120np25c25c25'        '120np25c35c25'        '120ap0c0c0'
        '120ap0c25c0'  '120ap0c35c0'  '120ap0c25c25' '120ap0c35c25' '120ap25c0c0'
        '120ap25c25c0' '120ap25c35c0' '120ap25c25c25'        '120ap25c35c25'
        '140np0c0c0'   '140np0c25c0'  '140np0c35c0'   '140np0c25c25' '140np0c35c25'
        '140np25c0c0'  '140np25c25c0' '140np25c35c0'  '140np25c25c25'
        '140np25c35c25'        '140ap0c0c0'   '140ap0c25c0'  '140ap0c35c0'
        '140ap0c25c25' '140ap0c35c25' '140ap25c0c0'   '140ap25c25c0' '140ap25c35c0'
        '140ap25c25c25'        '140ap25c35c25'        '160np0c0c0'   '160np0c25c0'
        '160np0c35c0'  '160np0c25c25' '160np0c35c25'  '160np25c0c0'  '160np25c25c0'
        '160np25c35c0' '160np25c25c25'        '160np25c35c25'        '160ap0c0c0'
        '160ap0c25c0'  '160ap0c35c0'  '160ap0c25c25' '160ap0c35c25' '160ap25c0c0'
        '160ap25c25c0' '160ap25c35c0' '160ap25c25c25'        '160ap25c35c25'
        '180np0c0c0'   '180np0c25c0'  '180np0c35c0'   '180np0c25c25' '180np0c35c25'
        '180np25c0c0'  '180np25c25c0' '180np25c35c0'  '180np25c25c25'
        '180np25c35c25'        '180ap0c0c0'   '180ap0c25c0'  '180ap0c35c0'
        '180ap0c25c25' '180ap0c35c25' '180ap25c0c0'   '180ap25c25c0' '180ap25c35c0'
        '180ap25c25c25'        '180ap25c35c25'        '200np0c0c0'   '200np0c25c0'
        '200np0c35c0'  '200np0c25c25' '200np0c35c25'  '200np25c0c0'  '200np25c25c0'
        '200np25c35c0' '200np25c25c25'        '200np25c35c25'        '200ap0c0c0'
        '200ap0c25c0'  '200ap0c35c0'  '200ap0c25c25' '200ap0c35c25' '200ap25c0c0'
        '200ap25c25c0' '200ap25c35c0' '200ap25c25c25'        '200ap25c35c25'};
```

```
% Rotation periods
Rotper=[    80    80    80    80    80    80    80    80    80
            80    80    80    80    80    80    80    80    80
            80    100   100   100   100   100   100   100   100   100
            100   100   100   100   100   100   100   100   100
            100   120   120   120   120   120   120   120   120   120
            120   120   120   120   120   120   120   120   120
            120   140   140   140   140   140   140   140   140   140
```

```
140    140    140    140    140    140    140    140    140    140
140    160    160    160    160    160    160    160    160    160
160    160    160    160    160    160    160    160    160    160
160    180    180    180    180    180    180    180    180    180
180    180    180    180    180    180    180    180    180    180
180    200    200    200    200    200    200    200    200    200
200    200    200    200    200    200    200    200    200    200
200];
```

% Regeneration type 0-natural, 1-artificial
```
Regen=[    0    0    0    0    0    0    0    0    0    0
           1    1    1    1    1    1    1    1    1    1    0
           0    0    0    0    0    0    0    0    0    1    1
           1    1    1    1    1    1    1    1    0    0    0
           0    0    0    0    0    0    0    1    1    1    1
           1    1    1    1    1    1    0    0    0    0    0
           0    0    0    0    0    1    1    1    1    1    1
           1    1    1    1    0    0    0    0    0    0    0
           0    0    0    1    1    1    1    1    1    1    1
           1    1    0    0    0    0    0    0    0    0    0
           0    1    1    1    1    1    1    1    1    1    1
           0    0    0    0    0    0    0    0    0    0    1
           1    1    1    1    1    1    1    1    1];
```

%Percentage of trees cut during precommercial thinning, 0 – no thinning, 25% - standard
for all precommercial thinnings
```
Preper=[0    0    0    0    0    25    25    25    25    25    0
        0    0    0    0    25    25    25    25    25    0    0
        0    0    0    25    25    25    25    25    0    0    0
        0    0    25    25    25    25    25    0    0    0    0
        0    25    25    25    25    25    0    0    0    0    0
        25    25    25    25    25    0    0    0    0    0
        25    25    25    25    25    0    0    0    0    0
        25    25    25    25    25    0    0    0    0    0
        25    25    25    25    25    0    0    0    0    0
        25    25    25    25    25    0    0    0    0    0
        25    25    25    25    25    0    0    0    0    0
        25    25    25    25    25    0    0    0    0    0
        25    25    25    25    25];
```

%Year when precommercial thinning is performed, 0 – no thinning
```
Preyear=[0    0    0    0    0    20    20    20    20    20    0
         0    0    0    0    20    20    20    20    20    0    0
         0    0    0    20    20    20    20    20    0    0    0
         0    0    20    20    20    20    20    0    0    0    0
         0    20    20    20    20    20    0    0    0    0    0
         20    20    20    20    20    0    0    0    0    0
         20    20    20    20    20    0    0    0    0    0
         20    20    20    20    20    0    0    0    0    0
         20    20    20    20    20    0    0    0    0    0
```

```
20     20     20     20     20     0      0      0      0      0
20     20     20     20     20     0      0      0      0      0
20     20     20     20     20     0      0      0      0      0
20     20     20     20     20     0      0      0      0      0
20     20     20     20     20];
```

%Percentage of trees cut during 1st commercial thinning, 0 – no thinning, 25% or 35%

```
Com1per=[0   25     35     25     35     0      25     35     25     35     0
         25     35     25     35     0      25     35     25     35     0
         25     35     25     35     0      25     35     25     35     0
         25     35     25     35     0      25     35     25     35     0
         25     35     25     35     0      25     35     25     35     0
         25     35     25     35     0      25     35     25     35     0
         25     35     25     35     0      25     35     25     35     0
         25     35     25     35     0      25     35     25     35     0
         25     35     25     35     0      25     35     25     35     0
         25     35     25     35     0      25     35     25     35     0
         25     35     25     35     0      25     35     25     35     0
         25     35     25     35     0      25     35     25     35];
```

%Year when 1 commercial thinning is performed, 0 – no thinning

```
Com1year=[0   50     50     45     45     0      50     50     45     45     0
          50     50     45     45     0      50     50     45     45     0
          60     60     50     50     0      60     60     50     50     0
          60     60     50     50     0      60     60     50     50     0
          70     70     60     60     0      70     70     60     60     0
          70     70     60     60     0      70     70     60     60     0
          80     80     70     70     0      80     80     70     70     0
          80     80     70     70     0      80     80     70     70     0
          90     90     80     80     0      90     90     80     80     0
          90     90     80     80     0      90     90     80     80     0
          100    100    90     90     0      100    100    90     90     0
          100    100    90     90     0      100    100    90     90     0
          110    110    100    100    0      110    110    100    100    0
          110    110    100    100    0      110    110    100    100];
```

%Percentage of trees cut during 2nd commercial thinning, 0 – no thinning, 25%

```
Com2per=[0   0      0      25     25     0      0      0      25     25     0
         0      0      25     25     0      0      0      25     25     0      0
         0      25     25     0      0      0      25     25     0      0      0
         25     25     0      0      0      25     25     0      0      0
         25     25     0      0      0      25     25     0      0      0
         25     25     0      0      0      25     25     0      0      0
         25     25     0      0      0      25     25     0      0      0
         25     25     0      0      0      25     25     0      0      0
         25     25     0      0      0      25     25     0      0      0
         25     25     0      0      0      25     25     0      0      0
         25     25     0      0      0      25     25     0      0      0
```

```
     25      25      0       0       0       25      25      0       0       0
     25      25      0       0       0       25      25];
```

%Year when 1 commercial thinning is performed, 0 – no thinning

```
Com2year=[0  0       0       60      60      0       0       0       60      60      0
           0  0       60      60      0       0       0       60      60      0       0
           0  70      70      0       0       0       70      70      0       0       0
           70 70      0       0       0       70      70      0       0       0
           90 90      0       0       0       90      90      0       0       0
           90 90      0       0       0       90      90      0       0       0
           11 11      0       0       0       11      11      0       0       0
           11 11      0       0       0       11      11      0       0       0
           13 13      0       0       0       13      13      0       0       0
           13 13      0       0       0       13      13      0       0       0
           15 15      0       0       0       15      15      0       0       0
           15 15      0       0       0       15      15      0       0       0
           17 17      0       0       0       17      17      0       0       0
           17 17      0       0       0       17      17];
```

% Create separated directories for regimes with artificial and natural regeneration
mkdir('z:\2\','a');
mkdir('z:\2\','n');

for i=1:140 % 140 regimes, i – regime index

  if Regen(i) % artificial regeneration
    mkdir('z:\2\a',char(Regime(i))); %create directory with the name of regime
    FIDh=fopen(strcat('z:\2\a\',char(Regime(i)),'\HarvInt.dvr'),'w');
    FIDc=fopen(strcat('z:\2\a\',char(Regime(i)),'\CutPatt.dvr'),'w');

  else % natural regeneration
    mkdir('z:\2\n',char(Regime(i))) %create directory with the name of regime
    FIDh=fopen(strcat('z:\2\n\',char(Regime(i)),'\HarvInt.dvr'),'w');
    FIDc=fopen(strcat('z:\2\n\',char(Regime(i)),'\CutPatt.dvr'),'w');
  end

%header for the file CutPatt.dvr
fprintf(FIDc,'Cut Pattern driver file for StandCarb\r\n\r\n');
fprintf(FIDc,'ML02 27\r\n\r\n');

%header and common lines for the file HarvInt.dvr
fprintf(FIDh,'Harvest Interval driver file - StandCarb\r\n\r\n');
fprintf(FIDh,'Pre-Commercial_____ Commercial_____ Clear-
Cut_____   Herbicide_____\r\n');
fprintf(FIDh,'Model File Interval___   Fire Interval___   Fire Interval___   Fire
Salvage_ UTree_____ LTree_____\r\n');
fprintf(FIDh,'#   #   UTree LTree Util Type UTree LTree Util Type UTree LTree Util
Type Int Util Int Effect Int Effect\r\n');
fprintf(FIDh,'ML02 26   0   0   3   0   0   0   3   0   300 300   3   0   0 2
0   1   0 3\r\n');
```

```
clearcurr=300; % first clear-cut
clearstr=sprintf('\r\nYear %4.0f',clearcurr);

for j=1:10 % 10 rotations after free growth for each regime


if Preyear(i) %if precommercial thinning is used
precurr=clearcurr+Preyear(i);   %current year of precommercial thinning

% print line to file HarvInv indicating precommercial thinning and its year
fprintf(FIDh,'ML02 26    0 %4.0f 3  0    0  0 3  0  0  0    3  0  0 2
0  1   0  3\r\n',precurr);

C=rand(10,10)>(1-Preper(i)/100); % randomly select Preper(i)% of cells that should be
thinned

% print line to file CutPatt.drv indicating year of thinning
fprintf(FIDc,'\r\nYear %4.0f\r\n',precurr);
fprintf(FIDc,'Species all\r\n');

% print matrix to file CutPatt.drv indicating pattern of thinning
for k=1:10
  for l=1:10
    fprintf(FIDc,'%1.0f  ',C(k,l));
  end %of l
  fprintf(FIDc,'\r\n');
end %of k

end %of if precomm

if Com1year(i) %if  1-commercial thinning is used

com1curr=clearcurr+Com1year(i);   % current year of 1-commercial thinning

% print line to file HarvInv indicating 1-commercial thinning and its year
fprintf(FIDh,'ML02 26    0  0  3  0   %4.0f %4.0f 3  0   0  0    3  0  0
2   0  1    0  3\r\n',com1curr,com1curr);

C=rand(10,10)>(1-Com1per(i)/100); randomly select Com1per(i) % of cells that should be
thinned

% print line to file CutPatt.drv indicating year of thinning
fprintf(FIDc,'\r\nYear %4.0f\r\n',com1curr);
fprintf(FIDc,'Species all\r\n');

% print matrix to file CutPatt.drv indicating pattern of thinning
for k=1:10
  for l=1:10
    fprintf(FIDc,'%1.0f  ',C(k,l));
  end %of l
  fprintf(FIDc,'\r\n');
```

```
end %of k

end %of if com1

if Com2year(i) %if 2-commercial thinning is used

com2curr=clearcurr+Com2year(i);   % current year of 1-commercial thinning

% print line to file HarvInv indicating 2-commercial thinning and its year
fprintf(FIDh,'ML02 26   0   0   3   0    %4.0f %4.0f 3   0   0   0   3   0   0
2   0 1   0 3\r\n',com2curr,com2curr);

ex=1; %not to cut at the same cell during 2-thinning
while ex
   B=rand(10,10)>(1-Com2per(i)/100);
   for k=1:100;
     if B(k)==1 & C(k)==1
       ex=1;
       break;
     else ex=0;
     end %of if
   end %of for k
end %of while

% print line to file CutPatt.drv indicating year of thinning
fprintf(FIDc,'\r\nYear %4.0f\r\n',com2curr);
fprintf(FIDc,'Species all\r\n');
% print matrix to file CutPatt.drv indicating pattern of thinning

for k=1:10
   for l=1:10
     fprintf(FIDc,'%1.0f  ',B(k,l));
   end %of l
   fprintf(FIDc,'\r\n');
end %of k

end %of if com2

clearcurr=clearcurr+Rotper(i); %current year of clear-cut

% print line to file HarvInv indicating clear-cut and its year
fprintf(FIDh,'ML02 26   0   0   3   0    0   0 3   0    %4.0f %4.0f 3   0   0
2   0 1   0 3\r\n',clearcurr,clearcurr);


clearstr=strcat(clearstr,',',num2str(clearcurr)); %form the string clearstr with years of clear-
cut
end %of j

% print line to file CutPatt.drv indicating years of clear-cut
fprintf(FIDc,'%c',clearstr);
```

```
fprintf(FIDc,'\r\nSpecies all\r\n');

% print matrix of 1s to file CutPatt.drv indicating clear-cut

for k=1:10
    fprintf(FIDc,'1   1   1   1   1   1   1   1   1   1\r\n');
end %of k

fclose all;
end %of i
```

File Outpp.m

Purpose: Collect information from STANDCARB output files

clear all;
%Names of regimes = names of directories, where STANDCARB input files are saved

```
Regime={'80np0c0c0'   '80np0c25c0'   '80np0c35c0'   '80np0c25c25' '80np0c35c25'
        '80np25c0c0'   '80np25c25c0'  '80np25c35c0'  '80np25c25c25' '80np25c35c25'
        '80ap0c0c0'    '80ap0c25c0'   '80ap0c35c0'   '80ap0c25c25' '80ap0c35c25'
        '80ap25c0c0'   '80ap25c25c0'  '80ap25c35c0'  '80ap25c25c25' '80ap25c35c25'
        '100np0c0c0'   '100np0c25c0'  '100np0c35c0'  '100np0c25c25' '100np0c35c25'
        '100np25c0c0'  '100np25c25c0' '100np25c35c0' '100np25c25c25'
        '100np25c35c25'     '100ap0c0c0'   '100ap0c25c0'  '100ap0c35c0'
        '100ap0c25c25' '100ap0c35c25' '100ap25c0c0'  '100ap25c25c0' '100ap25c35c0'
        '100ap25c25c25'     '100ap25c35c25'     '120np0c0c0'   '120np0c25c0'
        '120np0c35c0'  '120np0c25c25' '120np0c35c25' '120np25c0c0'  '120np25c25c0'
        '120np25c35c0' '120np25c25c25'     '120np25c35c25'     '120ap0c0c0'
        '120ap0c25c0'  '120ap0c35c0'  '120ap0c25c25' '120ap0c35c25' '120ap25c0c0'
        '120ap25c25c0' '120ap25c35c0' '120ap25c25c25'     '120ap25c35c25'
        '140np0c0c0'   '140np0c25c0'  '140np0c35c0'  '140np0c25c25' '140np0c35c25'
        '140np25c0c0'  '140np25c25c0' '140np25c35c0' '140np25c25c25'
        '140np25c35c25'     '140ap0c0c0'   '140ap0c25c0'  '140ap0c35c0'
        '140ap0c25c25' '140ap0c35c25' '140ap25c0c0'  '140ap25c25c0' '140ap25c35c0'
        '140ap25c25c25'     '140ap25c35c25'     '160np0c0c0'   '160np0c25c0'
        '160np0c35c0'  '160np0c25c25' '160np0c35c25' '160np25c0c0'  '160np25c25c0'
        '160np25c35c0' '160np25c25c25'     '160np25c35c25'     '160ap0c0c0'
        '160ap0c25c0'  '160ap0c35c0'  '160ap0c25c25' '160ap0c35c25' '160ap25c0c0'
        '160ap25c25c0' '160ap25c35c0' '160ap25c25c25'     '160ap25c35c25'
        '180np0c0c0'   '180np0c25c0'  '180np0c35c0'  '180np0c25c25' '180np0c35c25'
        '180np25c0c0'  '180np25c25c0' '180np25c35c0' '180np25c25c25'
        '180np25c35c25'     '180ap0c0c0'   '180ap0c25c0'  '180ap0c35c0'
        '180ap0c25c25' '180ap0c35c25' '180ap25c0c0'  '180ap25c25c0' '180ap25c35c0'
        '180ap25c25c25'     '180ap25c35c25'     '200np0c0c0'   '200np0c25c0'
        '200np0c35c0'  '200np0c25c25' '200np0c35c25' '200np25c0c0'  '200np25c25c0'
        '200np25c35c0' '200np25c25c25'     '200np25c35c25'     '200ap0c0c0'
        '200ap0c25c0'  '200ap0c35c0'  '200ap0c25c25' '200ap0c35c25' '200ap25c0c0'
        '200ap25c25c0' '200ap25c35c0' '200ap25c25c25'     '200ap25c35c25'};
```

% Rotation periods
```
Rotper=[    80    80    80    80    80    80    80    80    80
            80    80    80    80    80    80    80    80    80
            80    100   100   100   100   100   100   100   100   100
            100   100   100   100   100   100   100   100   100   100
            100   120   120   120   120   120   120   120   120   120
            120   120   120   120   120   120   120   120   120   120
            120   140   140   140   140   140   140   140   140   140
            140   140   140   140   140   140   140   140   140   140
            140   160   160   160   160   160   160   160   160   160
            160   160   160   160   160   160   160   160   160   160
            160   180   180   180   180   180   180   180   180   180
```

```
180     180     180     180     180     180     180     180     180     180
180     200     200     200     200     200     200     200     200     200
200     200     200     200     200     200     200     200     200     200
200];
```

% Regeneration type 0-natural, 1-artificial

```
Regen=[  0     0     0     0     0     0     0     0     0     0
         1     1     1     1     1     1     1     1     1     1     0
         0     0     0     0     0     0     0     0     0     1     1
         1     1     1     1     1     1     1     1     0     0     0
         0     0     0     0     0     0     0     1     1     1     1
         1     1     1     1     1     1     0     0     0     0     0
         0     0     0     0     0     1     1     1     1     1     1
         1     1     1     1     0     0     0     0     0     0     0
         0     0     0     1     1     1     1     1     1     1     1
         1     1     0     0     0     0     0     0     0     0     0
         0     1     1     1     1     1     1     1     1     1     1
         0     0     0     0     0     0     0     0     0     0     1
         1     1     1     1     1     1     1     1];
```

%Percentage of trees cut during precommercial thinning, 0 – no thinning, 25% - standard
for all precommercial thinnings

```
Preper=[0    0     0     0     0     25    25    25    25    25    0
        0     0     0     0     25    25    25    25    25    0     0
        0     0     0     25    25    25    25    25    0     0     0
        0     0     25    25    25    25    25    0     0     0     0
        0     25    25    25    25    25    0     0     0     0     0
        25    25    25    25    25    0     0     0     0     0
        25    25    25    25    25    0     0     0     0     0
        25    25    25    25    25    0     0     0     0     0
        25    25    25    25    25    0     0     0     0     0
        25    25    25    25    25    0     0     0     0     0
        25    25    25    25    25    0     0     0     0     0
        25    25    25    25    25    0     0     0     0     0
        25    25    25    25    25];
```

%Year when precommercial thinning is performed, 0 – no thinning

```
Preyear=[0   0     0     0     0     20    20    20    20    20    0
         0     0     0     0     20    20    20    20    20    0     0
         0     0     0     20    20    20    20    20    0     0     0
         0     0     20    20    20    20    20    0     0     0     0
         0     20    20    20    20    20    0     0     0     0     0
         20    20    20    20    20    0     0     0     0     0
         20    20    20    20    20    0     0     0     0     0
         20    20    20    20    20    0     0     0     0     0
         20    20    20    20    20    0     0     0     0     0
         20    20    20    20    20    0     0     0     0     0
         20    20    20    20    20    0     0     0     0     0
         20    20    20    20    20    0     0     0     0     0
```

```
20      20      20      20      20      0       0       0       0       0
20      20      20      20      20];
```

%Percentage of trees cut during 1st commercial thinning, 0 – no thinning, 25% or 35%

```
Com1per=[0   25      35      25      35      0       25      35      25      35      0
         25  35      25      35      0       25      35      25      35      0
         25  35      25      35      0       25      35      25      35      0
         25  35      25      35      0       25      35      25      35      0
         25  35      25      35      0       25      35      25      35      0
         25  35      25      35      0       25      35      25      35      0
         25  35      25      35      0       25      35      25      35      0
         25  35      25      35      0       25      35      25      35      0
         25  35      25      35      0       25      35      25      35      0
         25  35      25      35      0       25      35      25      35      0
         25  35      25      35      0       25      35      25      35      0
         25  35      25      35      0       25      35      25      35      0
         25  35      25      35      0       25      35      25      35];
```

%Year when 1 commercial thinning is performed, 0 – no thinning

```
Com1year=[0   50      50      45      45      0       50      50      45      45      0
          50  50      45      45      0       50      50      45      45      0
          60  60      50      50      0       60      60      50      50      0
          60  60      50      50      0       60      60      50      50      0
          70  70      60      60      0       70      70      60      60      0
          70  70      60      60      0       70      70      60      60      0
          80  80      70      70      0       80      80      70      70      0
          80  80      70      70      0       80      80      70      70      0
          90  90      80      80      0       90      90      80      80      0
          90  90      80      80      0       90      90      80      80      0
          100 100     90      90      0       100     100     90      90      0
          100 100     90      90      0       100     100     90      90      0
          110 110     100     100     0       110     110     100     100     0
          110 110     100     100     0       110     110     100     100];
```

%Percentage of trees cut during 2nd commercial thinning, 0 – no thinning, 25%

```
Com2per=[0   0       0       25      25      0       0       0       25      25      0
         0   0       25      25      0       0       0       25      25      0       0
         0   25      25      0       0       0       25      25      0       0       0
         25  25      0       0       0       25      25      0       0       0
         25  25      0       0       0       25      25      0       0       0
         25  25      0       0       0       25      25      0       0       0
         25  25      0       0       0       25      25      0       0       0
         25  25      0       0       0       25      25      0       0       0
         25  25      0       0       0       25      25      0       0       0
         25  25      0       0       0       25      25      0       0       0
         25  25      0       0       0       25      25      0       0       0
         25  25      0       0       0       25      25      0       0       0
         25  25      0       0       0       25      25];
```

```
%Year when 1 commercial thinning is performed, 0 – no thinning
Com2year=[0   0    0    60   60   0    0    0    60   60   0
          0   0    60   60   0    0    0    60   60   0    0
          0   70   70   0    0    0    70   70   0    0    0
          70  70   0    0    0    70   70   0    0    0
          90  90   0    0    0    90   90   0    0    0
          90  90   0    0    0    90   90   0    0    0
          11  11   0    0    0    11   11   0    0    0
          11  11   0    0    0    11   11   0    0    0
          13  13   0    0    0    13   13   0    0    0
          13  13   0    0    0    13   13   0    0    0
          15  15   0    0    0    15   15   0    0    0
          15  15   0    0    0    15   15   0    0    0
          17  17   0    0    0    17   17   0    0    0
          17  17   0    0    0    17   17];


FreeGR=300; %specify "free" growth period, no clear-cut
RotBEG=5; %rotation period when we start accounting
RotEND=10; %rotation period when we finish accounting

for i=1:140 %140 regimes
clear s;

%read the whole file volume.out into string set s, elements of string – ordered records from
file
s=textread(strcat('z:\2\',char(Regime(i)),'\volume.out'),'%s');
fprintf ('%s\n', char(Regime(i)));

Tind=29;% record index in set s

% initialize vectors
ccT=[];ccSpecU=[];ccSpecU=[]; ccSpecL=[]; ccVolU=[]; ccVolL=[]; ccDenU=[]; ccDenL=[];
ccHVolU=[]; ccHVolL=[]; ccHDenU=[]; ccHDenL=[]; ccHeightU=[]; ccHeightL=[]; ccAgeU=[];
ccAgeL=[];
com1T=[];com1SpecU=[];com1SpecU=[]; com1SpecL=[]; com1VolU=[]; com1VolL=[];
com1DenU=[]; com1DenL=[]; com1HVolU=[]; com1HVolL=[]; com1HDenU=[];
com1HDenL=[]; com1HeightU=[]; com1HeightL=[]; com1AgeU=[]; com1AgeL=[];
com2T=[];com2SpecU=[];com2SpecU=[]; com2SpecL=[]; com2VolU=[]; com2VolL=[];
com2DenU=[]; com2DenL=[]; com2HVolU=[]; com2HVolL=[]; com2HDenU=[];
com2HDenL=[]; com2HeightU=[]; com2HeightL=[]; com2AgeU=[]; com2AgeL=[];

Tcurr=0; %Current time
%skip FreeGR and first RotBeg rotation !!!!!!
while Tcurr<(FreeGR+Rotper(i)*RotBEG+.2);
   Tind=Tind+17;
   Tcurr=str2num(char(s(Tind)));
end;

Tind=Tind+17*2; %set the index in set s to the first line, where we start accounting
```

```
com1=0;

while Tcurr<(FreeGR+Rotper(i)*RotEND+.2);%until RotEND rotation !!!!!!!!

  Tcurr=str2num(char(s(Tind)));% current time

 ccSpecU=(char(s(Tind+2))); %current specie name

if strcmp(ccSpecU,'Piab') %if spruce


  Treat=char(s(Tind+9)); %current type of treatment


 if strcmp(Treat,'ccut') %if clear cut

 ccT=[ccT Tcurr]; %vector of times of clear cut (cc)
 ccVolU=[ccVolU str2num(char(s(Tind+3)))]; %vector of volumes of upper layer trees
during cc
 ccVolL=[ccVolL str2num(char(s(Tind+3+17)))]; %vector of volumes of lower layer trees
during cc
 ccDenU=[ccDenU str2num(char(s(Tind+4)))]; %vector of densities of upper layer trees
during cc
 ccDenL=[ccDenL str2num(char(s(Tind+4+17)))]; %vector of densities of upper layer trees
during cc
 ccHVolU=[ccVolU str2num(char(s(Tind+5)))]; %vector of harvested volumes of upper
layer trees during cc
 ccHVolL=[ccVolL str2num(char(s(Tind+5+17)))]; %vector of harvested volumes of lower
layer trees during cc
 ccHDenU=[ccDenU str2num(char(s(Tind+6)))]; %vector of harvested densities of upper
layer trees during cc

 ccHDenL=[ccDenL str2num(char(s(Tind+6+17)))]; %vector of harvested densities of
lower layer trees during cc

 ccHeightU=[ccHeightU str2num(char(s(Tind+7)))]; %vector of heights of upper layer trees
during cc
 ccHeightL=[ccHeightL str2num(char(s(Tind+7+17)))]; %vector of heights of lower layer
trees during cc
 ccAgeU=[ccAgeU str2num(char(s(Tind+8)))]; %vector of ages of upper layer trees during
cc
 ccAgeL=[ccAgeL str2num(char(s(Tind+8+17)))]; %vector of heights of lower layer trees
during cc

 else

 if Com2year(i) & com1   %current commercial thinning is second

 com1=0;
```

```
%same harvest parameter vectors for second commercial thinning as for clear-cut
com2T=[com2T Tcurr];
com2SpecU=[com2SpecU (char(s(Tind+2)))];
com2SpecL=[com2SpecL (char(s(Tind+2+17)))];
com2VolU=[com2VolU str2num(char(s(Tind+3)))];
com2VolL=[com2VolL str2num(char(s(Tind+3+17)))];
com2DenU=[com2DenU str2num(char(s(Tind+4)))];
com2DenL=[com2DenL str2num(char(s(Tind+4+17)))];
com2HVolU=[com2VolU str2num(char(s(Tind+5)))];
com2HVolL=[com2VolL str2num(char(s(Tind+5+17)))];
com2HDenU=[com2DenU str2num(char(s(Tind+6)))];
com2HDenL=[com2DenL str2num(char(s(Tind+6+17)))];
com2HeightU=[com2HeightU str2num(char(s(Tind+7)))];
com2HeightL=[com2HeightL str2num(char(s(Tind+7+17)))];
com2AgeU=[com2AgeU str2num(char(s(Tind+8)))];
com2AgeL=[com2AgeL str2num(char(s(Tind+8+17)))];

else   %current commercial thinning is first

com1=1;

%same harvest parameter vectors for first commercial thinning as for clear-cut
com1T=[com1T Tcurr];
com1SpecU=[com1SpecU (char(s(Tind+2)))];
com1SpecL=[com1SpecL (char(s(Tind+2+17)))];
com1VolU=[com1VolU str2num(char(s(Tind+3)))];
com1VolL=[com1VolL str2num(char(s(Tind+3+17)))];
com1DenU=[com1DenU str2num(char(s(Tind+4)))];
com1DenL=[com1DenL str2num(char(s(Tind+4+17)))];
com1HVolU=[com1VolU str2num(char(s(Tind+5)))];
com1HVolL=[com1VolL str2num(char(s(Tind+5+17)))];
com1HDenU=[com1DenU str2num(char(s(Tind+6)))];
com1HDenL=[com1DenL str2num(char(s(Tind+6+17)))];
com1HeightU=[com1HeightU str2num(char(s(Tind+7)))];
com1HeightL=[com1HeightL str2num(char(s(Tind+7+17)))];
com1AgeU=[com1AgeU str2num(char(s(Tind+8)))];
com1AgeL=[com1AgeL str2num(char(s(Tind+8+17)))];


    end %of if Com2year

    end %of if ccut
end %of if spec
  Tind=Tind+17*2;


end;

AveccHVolU(i)=mean(ccVolU); %average volume over 5 rotations for upper layer trees
during cc
```

AveccHVolL(i)=mean(ccVolL); %average volume over 5 rotations for lower layer trees during cc
AveccHeightU(i)=mean(ccHeightU); %average height over 5 rotations for upper layer trees
AveccAgeU(i)=mean(ccAgeU); %average age over 5 rotations for upper layer trees

if Com1year(i) %1-st commercial thinning is used

%find averages
  Avecom1HVolU(i)=mean(com1VolU);
  Avecom1HVolL(i)=mean(com1VolL);
  Avecom1HeightU(i)=mean(com1HeightU);
  Avecom1AgeU(i)=mean(com1AgeU);

end

if Com2year(i) %2-nd commercial thinning is used

%find averages
  Avecom2HVolU(i)=mean(com2VolU);
  Avecom2HVolL(i)=mean(com2VolL);
  Avecom2HeightU(i)=mean(com2HeightU);
  Avecom2AgeU(i)=mean(com2AgeU);

end

%reading file total.out for C accounting
clear s;
s=textread(strcat('z:\2\',char(Regime(i)),'\total.out'),'%s');

%skip FreeGR and first RotBEG rotations !!!!!!
Tind=21;
Tcurr=0; while Tcurr<(FreeGR+Rotper(i)*RotBEG+.2);
 Tind=Tind+12;
 Tcurr=str2num(char(s(Tind)));
end;

T=[];CL=[];CD=[];CS=[];V=[];D=[];H=[];Tcurr=0;

while Tcurr<(FreeGR+Rotper(i)*RotEND+.2); %until last rotation

 Tind=Tind+12;

 Tcurr=str2num(char(s(Tind))); %current time
 T=[T Tcurr]; %vector of current time

 CL=[CL str2num(char(s(Tind+1)))]; %vector of live carbon (in 5 year increments)

```
CD=[CD str2num(char(s(Tind+3)))]; % vector of dead carbon (in 5 year increments)

CS=[CS str2num(char(s(Tind+5)))]; % vector of stable carbon (in 5 year increments)

V=[V str2num(char(s(Tind+7)))]; % vector of tree volume (in 5 year increments)

D=[D str2num(char(s(Tind+8)))]; % vector of tree density (in 5 year increments)

H=[H str2num(char(s(Tind+9)))]; % vector of tree heights (in 5 year increments)


end;

% for years with treatments take an average level of before treatment and after treatment
values
% and form new vectors including corrected values for years with treatment
Ta=[];CLa=[];CDa=[];CSa=[];
[z,max]=size(T);
k=1;
while k<=max
    if (floor(T(k))-T(k))
       Ta=[Ta floor(T(k))];
       CLa=[CLa (CL(k)+CL(k+1))/2];
       CDa=[CDa (CD(k)+CD(k+1))/2];
       CSa=[CSa (CS(k)+CS(k+1))/2];
       k=k+1;
     else
       Ta=[Ta T(k)];
       CLa=[CLa CL(k)];
       CDa=[CDa CD(k)];
       CSa=[CSa CS(k)];
     end
   k=k+1;
end

% take an average over 5 stable periods
ACL(i)=mean(CLa);
ACD(i)=mean(CDa);
ACS(i)=mean(CSa);

ATC(i)=ACL(i)+ACD(i)+ACS(i); %sum over C pools to get total C stored


end %of for i
```

File Outc.m

Purpose: SEV calculations

%This code use variables from the code outp, that should be downloaded in workspace before
%Names of regimes = names of directories, where STANDCARB input files are saved

Regime={'80np0c0c0'   '80np0c25c0'   '80np0c35c0'   '80np0c25c25' '80np0c35c25'
        '80np25c0c0'   '80np25c25c0' '80np25c35c0' '80np25c25c25' '80np25c35c25'
        '80ap0c0c0'   '80ap0c25c0'   '80ap0c35c0'   '80ap0c25c25' '80ap0c35c25'
        '80ap25c0c0'   '80ap25c25c0' '80ap25c35c0' '80ap25c25c25' '80ap25c35c25'
        '100np0c0c0'   '100np0c25c0' '100np0c35c0' '100np0c25c25' '100np0c35c25'
        '100np25c0c0' '100np25c25c0' '100np25c35c0' '100np25c25c25'
        '100np25c35c25'   '100ap0c0c0'   '100ap0c25c0' '100ap0c35c0'
        '100ap0c25c25' '100ap0c35c25' '100ap25c0c0' '100ap25c25c0' '100ap25c35c0'
        '100ap25c25c25'   '100ap25c35c25'   '120np0c0c0'   '120np0c25c0'
        '120np0c35c0' '120np0c25c25' '120np0c35c25' '120np25c0c0' '120np25c25c0'
        '120np25c35c0' '120np25c25c25'   '120np25c35c25'   '120ap0c0c0'
        '120ap0c25c0' '120ap0c35c0' '120ap0c25c25' '120ap0c35c25' '120ap25c0c0'
        '120ap25c25c0' '120ap25c35c0' '120ap25c25c25'   '120ap25c35c25'
        '140np0c0c0'   '140np0c25c0' '140np0c35c0' '140np0c25c25' '140np0c35c25'
        '140np25c0c0' '140np25c25c0' '140np25c35c0' '140np25c25c25'
        '140np25c35c25'   '140ap0c0c0'   '140ap0c25c0' '140ap0c35c0'
        '140ap0c25c25' '140ap0c35c25' '140ap25c0c0' '140ap25c25c0' '140ap25c35c0'
        '140ap25c25c25'   '140ap25c35c25'   '160np0c0c0'   '160np0c25c0'
        '160np0c35c0' '160np0c25c25' '160np0c35c25' '160np25c0c0' '160np25c25c0'
        '160np25c35c0' '160np25c25c25'   '160np25c35c25'   '160ap0c0c0'
        '160ap0c25c0' '160ap0c35c0' '160ap0c25c25' '160ap0c35c25' '160ap25c0c0'
        '160ap25c25c0' '160ap25c35c0' '160ap25c25c25'   '160ap25c35c25'
        '180np0c0c0'   '180np0c25c0' '180np0c35c0' '180np0c25c25' '180np0c35c25'
        '180np25c0c0' '180np25c25c0' '180np25c35c0' '180np25c25c25'
        '180np25c35c25'   '180ap0c0c0'   '180ap0c25c0' '180ap0c35c0'
        '180ap0c25c25' '180ap0c35c25' '180ap25c0c0' '180ap25c25c0' '180ap25c35c0'
        '180ap25c25c25'   '180ap25c35c25'   '200np0c0c0'   '200np0c25c0'
        '200np0c35c0' '200np0c25c25' '200np0c35c25' '200np25c0c0' '200np25c25c0'
        '200np25c35c0' '200np25c25c25'   '200np25c35c25'   '200ap0c0c0'
        '200ap0c25c0' '200ap0c35c0' '200ap0c25c25' '200ap0c35c25' '200ap25c0c0'
        '200ap25c25c0' '200ap25c35c0' '200ap25c25c25'   '200ap25c35c25'};

% Rotation periods

Rotper=[	80	80	80	80	80	80	80	80	80
80	80	80	80	80	80	80	80	80	80
80	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
100	120	120	120	120	120	120	120	120	120
120	120	120	120	120	120	120	120	120	120
120	140	140	140	140	140	140	140	140	140
140	140	140	140	140	140	140	140	140	140
140	160	160	160	160	160	160	160	160	160
160	160	160	160	160	160	160	160	160	160

```
160   180   180   180   180   180   180   180   180   180
180   180   180   180   180   180   180   180   180   180
180   200   200   200   200   200   200   200   200   200
200   200   200   200   200   200   200   200   200   200
200];
```

% Regeneration type 0-natural, 1-artificial

```
Regen=[   0   0   0   0   0   0   0   0   0   0
          1   1   1   1   1   1   1   1   1   1   0
          0   0   0   0   0   0   0   0   0   1   1
          1   1   1   1   1   1   1   1   0   0   0
          0   0   0   0   0   0   0   1   1   1   1
          1   1   1   1   1   1   0   0   0   0   0
          0   0   0   0   0   1   1   1   1   1   1
          1   1   1   1   0   0   0   0   0   0   0
          0   0   0   1   1   1   1   1   1   1   1
          1   1   0   0   0   0   0   0   0   0   0
          0   1   1   1   1   1   1   1   1   1   1
          0   0   0   0   0   0   0   0   0   0   1
          1   1   1   1   1   1   1   1   1];
```

%Percentage of trees cut during precommercial thinning, 0 – no thinning, 25% - standard for all precommercial thinnings

```
Preper=[0   0   0   0   0   25   25   25   25   25   0
        0   0   0   0   25   25   25   25   25   0   0
        0   0   0   25   25   25   25   25   0   0   0
        0   0   25   25   25   25   25   0   0   0   0
        0   25   25   25   25   25   0   0   0   0   0
        25   25   25   25   25   0   0   0   0   0
        25   25   25   25   25   0   0   0   0   0
        25   25   25   25   25   0   0   0   0   0
        25   25   25   25   25   0   0   0   0   0
        25   25   25   25   25   0   0   0   0   0
        25   25   25   25   25   0   0   0   0   0
        25   25   25   25   25   0   0   0   0   0
        25   25   25   25   25   0   0   0   0   0
        25   25   25   25   25];
```

%Year when precommercial thinning is performed, 0 – no thinning

```
Preyear=[0   0   0   0   0   20   20   20   20   20   0
         0   0   0   0   20   20   20   20   20   0   0
         0   0   0   20   20   20   20   20   0   0   0
         0   0   20   20   20   20   20   0   0   0   0
         0   20   20   20   20   20   0   0   0   0   0
         20   20   20   20   20   0   0   0   0   0
         20   20   20   20   20   0   0   0   0   0
         20   20   20   20   20   0   0   0   0   0
         20   20   20   20   20   0   0   0   0   0
         20   20   20   20   20   0   0   0   0   0
         20   20   20   20   20   0   0   0   0   0
         20   20   20   20   20   0   0   0   0   0
```

```
20   20   20   20   20   0   0   0   0   0
20   20   20   20   20];
```

%Percentage of trees cut during 1st commercial thinning, 0 – no thinning, 25% or 35%
```
Com1per=[0   25   35   25   35   0   25   35   25   35   0
         25   35   25   35   0   25   35   25   35   0
         25   35   25   35   0   25   35   25   35   0
         25   35   25   35   0   25   35   25   35   0
         25   35   25   35   0   25   35   25   35   0
         25   35   25   35   0   25   35   25   35   0
         25   35   25   35   0   25   35   25   35   0
         25   35   25   35   0   25   35   25   35   0
         25   35   25   35   0   25   35   25   35   0
         25   35   25   35   0   25   35   25   35   0
         25   35   25   35   0   25   35   25   35   0
         25   35   25   35   0   25   35   25   35   0
         25   35   25   35   0   25   35   25   35   0
         25   35   25   35   0   25   35   25   35];
```

%Year when 1 commercial thinning is performed, 0 – no thinning
```
Com1year=[0    50    50    45    45    0    50    50    45    45    0
          50    50    45    45    0    50    50    45    45    0
          60    60    50    50    0    60    60    50    50    0
          60    60    50    50    0    60    60    50    50    0
          70    70    60    60    0    70    70    60    60    0
          70    70    60    60    0    70    70    60    60    0
          80    80    70    70    0    80    80    70    70    0
          80    80    70    70    0    80    80    70    70    0
          90    90    80    80    0    90    90    80    80    0
          90    90    80    80    0    90    90    80    80    0
         100   100    90    90    0   100   100    90    90    0
         100   100    90    90    0   100   100    90    90    0
         110   110   100   100    0   110   110   100   100    0
         110   110   100   100    0   110   110   100   100];
```

%Percentage of trees cut during 2nd commercial thinning, 0 – no thinning, 25%
```
Com2per=[0    0    25    25    0    0    0    25    25    0    0
         0    0    25    25    0    0    0    25    25    0    0
         0    25    25    0    0    0    25    25    0    0    0
         25    25    0    0    0    25    25    0    0    0
         25    25    0    0    0    25    25    0    0    0
         25    25    0    0    0    25    25    0    0    0
         25    25    0    0    0    25    25    0    0    0
         25    25    0    0    0    25    25    0    0    0
         25    25    0    0    0    25    25    0    0    0
         25    25    0    0    0    25    25    0    0    0
         25    25    0    0    0    25    25    0    0    0
         25    25    0    0    0    25    25    0    0    0
         25    25    0    0    0    25    25    0    0    0
         25    25    0    0    0    25    25];
```

%Year when 1 commercial thinning is performed, 0 – no thinning

```
Com2year=[0   0    0   60   60   0    0    0   60   60   0
          0   0   60   60    0   0    0   60   60    0   0
          0  70   70    0    0   0   70   70    0    0   0
         70  70    0    0    0  70   70    0    0    0
         90  90    0    0    0  90   90    0    0    0
         90  90    0    0    0  90   90    0    0    0
         11  11    0    0    0  11   11    0    0    0
         11  11    0    0    0  11   11    0    0    0
         13  13    0    0    0  13   13    0    0    0
         13  13    0    0    0  13   13    0    0    0
         15  15    0    0    0  15   15    0    0    0
         15  15    0    0    0  15   15    0    0    0
         17  17    0    0    0  17   17    0    0    0
         17  17    0    0    0  17   17];
```

FreeGR=300; %specify "free" growth period, no clear-cut
RotBEG=5; %rotation period when we start accounting
RotEND=10; %rotation period when we finish accounting

r=[.01 .02 .03 .04 .05 .06]; //discount rates

mf=1; //multiplicator of fixed costs for sensitivity analysis
mv=1; //multiplicator of variable costs for sensitivity analysis

%Costs

Plantcost=5930.71*1.2*mf; %planting per site 25 ha

CCcostF=4507.61*1.2*mf; %clear cut fixed per site 25 ha
CCcostV=2.92*1.2*mv; %clear cut variable per CUM

PTcost=813.5*1.2*mf; %precommercial thinning per site 25 ha

ComcostF=3286.17*1.2*mf; %commercial thinning fixed per site 25 ha
ComcostV=4.37*1.2*mv; %commercial thinning variable per CUM

%Commercial grade distribution according to the table in text

DIST=[.5 .8 .07; .35 .6 .04; .5 .4 .3; .7 .2 .02; .52 .37 .03; .73 .16 .02; .81 .12 .02; .45 .4 .1; .6 .24 .11; .63 .22 .12];

%Prices per cum

Pround=18; %roundwood
Pchips=4.2; %chips
Pheat=1.91; %heatwood

```
FID=fopen('z:\formout.txt','w'); %save output in file formout.txt


for i=1:140 %140 regimes


for j=1:length(r) %for discount rate sensitivity analysis

%initialize papameters

Cost=0; %future value of costs
Rev=0; %future value of revenues

if Preyear(i) %precommercial thinning is used
   Cost=Cost+PTcost*(1+r(j))^(Rotper(i)-Preyear(i));
end

if Com1year(i) %first commercial thinning is used


Cost=Cost+(ComcostF+ComcostV*25*(Avecom1HVolU(i)+Avecom1HVolL(i)))*((1+r(j))^(R
otper(i)-Com1year(i)));

   %calculate a-diameter of trees in cm
   a=sqrt(Avecom1HVolU(i)*.64/Avecom1HeightU(i)/Com1per(i)*4/3.14)*100;
   % g-rank(row) variable in distribution table
   if a<=10
     g=1;
   else if a<=15
       g=2;
     else if a<=20
        g=3;
       else g=4;
       end
     end
   end

% *25 indicates scaling to 25 ha
Rev=Rev+(Pround*DIST(g,1)*25*(Avecom1HVolU(i)+Avecom1HVolL(i))+Pchips*DIST(g,2)
*25*(Avecom1HVolU(i)+Avecom1HVolL(i))+Pheat*DIST(g,3)*25*(Avecom1HVolU(i)+Avec
om1HVolL(i)))*(1+r(j))^(Rotper(i)-Com1year(i));

end

if Com2year(i) %second commercial thinning is used


Cost=Cost+(ComcostF+ComcostV*25*(Avecom2HVolU(i)+Avecom2HVolL(i)))*(1+r(j))^(Ro
tper(i)-Com2year(i));
```

```
a=sqrt(Avecom2HVolU(i)*.64/Avecom2HeightU(i)/Com2per(i)*4/3.14)*100;
if a<=10
  g=1;
else if a<=15
    g=2;
  else if a<=20
      g=3;
    else g=4;
    end
  end
end


Rev=Rev+(Pround*DIST(g,1)*25*(Avecom2HVolU(i)+Avecom2HVolL(i))+Pchips*DIST(g,2)
*25*(Avecom2HVolU(i)+Avecom2HVolL(i))+Pheat*DIST(g,3)*25*(Avecom2HVolU(i)+Avec
om2HVolL(i)))*(1+r(j))^(Rotper(i)-Com2year(i));


end
%account for cost/revenues during ccut

  Cost=Cost+CCcostF+CCcostV*25*(AveccHVolU(i)+AveccHVolL(i));

  Cost=Cost+Regen(i)*Plantcost; %in case of planting

  a=sqrt(AveccHVolU(i)*.64/AveccHeightU(i)/100*4/3.14)*100;

  ga=0;
  if AveccAgeU(i)>150
    ga=3;
  end %of AveccAgeU

  if a<=20
    g=5+ga;
  else if a<=30
      g=6+ga;
    else g=7+ga;
    end
  end




Rev=Rev+(Pround*DIST(g,1)*25*(AveccHVolU(i)+AveccHVolL(i))+Pchips*DIST(g,2)*25*(A
veccHVolU(i)+AveccHVolL(i))+Pheat*DIST(g,3)*25*(AveccHVolU(i)+AveccHVolL(i)));


SEV(i,j)=(Rev-Cost)/(((1+r(j))^Rotper(i))-1);   //calculate SEV for each regime and discount
rate
```

```
end %of for j

% print results as coma separated to file formout.txt
fprintf (FID,'%s, %3.2f, %4.2f, %4.2f, %4.2f, %4.2f, %4.2f, %4.2, %4.2, %4.2, %4.2,
%4.2f\r\n', char(Regime(i)), ATC(i), AveccHVolU(i)+AveccHVolL(i),
Avecom1HVolU(i)+Avecom1HVolL(i), Avecom2HVolU(i)+Avecom2HVolL(i), SEV(i,1),
SEV(i,2), SEV(i,3), SEV(i,4), SEV(i,5), SEV(i,6));

end %of for i

fclose all;
```

Appendix F. Costs calculations

Cost summary

Method: Logging crew

Specie: Spruce

Silvicultural practices	Cost in $		Cost in $ (including administration costs)	
	Per site (25 ha)	Per m3	Per site (25 ha)	Per m3
Clear-cut				
Preparation and assisting jobs	$4,507.61		$5,409.13	
Logging		$2.92		$3.50
Commercial thinning				
Preparation and assisting jobs	$3,286.17		$3,943.40	
Logging		$4.37		$5.25
Planting and weeding	$5,930.71		$7,116.86	
Precommercial thinning	$813.50		$976.20	

Calculation of costs for preparation and assisting jobs

1. Logistics

1.1 Logging site layout

Time norm per km in man-hours	Volume of work in km	# of days	Daily costs	Daily wages	Social sec	Total costs
4.6	1.5	1	11.2	8	3.2	11.2

1.2 Inventory

Time norm per ha in man-hours	Volume of work in ha	# of days	Daily costs	Daily wages	Social sec	Total costs
2.6	25	9	11.2	8	3.2	104

1.3 Layout of skidding roads

Time norm per km in man-hours	Volume of work in km	# of days	Daily costs	Amortization	Price of equipment	# of working days in a year	Gas costs	Gas usage per day	Gas price	Oil costs	Daily wages	Social sec	Total costs
2.8	10	4	17.7	1	200	200	5	20	0.25	0.5	8	3.2	70.8

2. Removal of dangerous trees

Time norm per ha in man-hours	Volume of work in ha	# of days	Daily costs	Daily wages	Social sec	Gas and material costs per day	Total costs
2.8	25	10	17.7	8	3.2	6.5	177

3. Logging crew and equipment transportation   2994

3.1. Loading-unloading works

Time norm per operation in man-hours	# of operations	# of days	Daily costs	Daily wages	Social sec	Yarder costs per day	Total costs
7.2	4	4	153.2	8	3.2	142	630

3.2. Equipment transportation

Time norm per km in man-hours	Distance in km	# of operations	# of days	Daily costs	Daily wages	Social sec	Yarder costs per day	Total costs
0.45	60	4	15	153.2	8	3.2	142	2364

4. Forest care and protection   1141

Calculation of logging costs

Daily working norms in м3				Costs of		
debuncher	yarder	feller	debuncher	yarder	feller	total logging crew
180	72	144	1	2	0	3

Debuncher costs per day

Service costs	Amortization	Price	Duration of usage in years	# of working days in a year	Gas cost	Gas usage per day	Gas price	Oil cost	Daily wage expenses	Monthly wage of operator	# of operators	# working days in a year	Social sec	Total costs per day
30	30	15000	2.5	200	62	189	0.33	6	12	200	1	200	4.8	145

Yarder costs per day

Service costs	Amortization	Price of equipment	Duration of usage in years	# of working days in a year	Gas costs	Gas usage per day	Gas price	Oil cost	Daily wage expenses	Monthly wage of operator	# of operators	# working days in a year	Social sec	Total costs per day
20	20	10000	2.5	200	62	189	0.33	6	24	200	2	200	9.6	142

Feller costs per day

Daily wages	Monthly wages	# of working days in a year	Social sec	Amortization	Price of equipment	# of working days in a year	Gas costs	Gas usage per day	Gas price	Oil cost	Total costs per day
9	150	200	3.6	1	200	200	5	20	0.25	0.5	19.1

Planting costs 5931

Time norm per ha in man-hours	# of days	Daily yarder costs	Amortization	Transportation costs	Plants usage per ha	Prices of plants	Plants costs	Daily wages	# of operators	Wages costs per day	Social sec	Daily planting costs	Total costs
4.6	16	142	5	60	6000	0.01	1500	8	5	40	16	298	4895

Weeding costs

Time norm per ha in man-hours	# of days	Daily yarder costs	Daily equipment amortization	Total costs
2	7	142	3	1036

Precomercial thinning costs

# of days	Daily equipment amortization	Daily yarder costs	Daily wages	Social sec	Daily gas costs	Daily oil costs	Daily thinning costs	Total thinning costs
5	4	142	8	3.2	5	0.5	162.7	813.5

Appendix G. C, Volume and SEV values for each regime

Regime	Average C	Total Volume	SEV, $/ha			
	Mg/ha/year	m3	r=2%	r=3%	r=4%	r=5%
80np0c0c0	307.32	200	$478.11	$192.19	$84.03	$38.16
80np0c25c0	297.33	201.58	$501.71	$208.27	$94.88	$45.37
80np0c35c0	291.94	197.6	$497.30	$211.14	$98.83	$48.78
80np0c25c25	284.61	199.16	$433.76	$180.29	$82.21	$39.34
80np0c35c25	282.76	193.64	$432.68	$188.32	$90.88	$46.53
80np25c0c0	310.97	202.46	$451.62	$170.97	$66.56	$23.66
80np25c25c0	292.34	194.46	$445.97	$174.45	$71.42	$27.87
80np25c35c0	287.22	197.04	$466.09	$190.20	$82.74	$35.67
80np25c25c25	281.08	191.4	$379.77	$149.52	$61.45	$23.90
80np25c35c25	276.62	185.34	$368.74	$147.70	$62.41	$25.53
80ap0c0c0	352.09	238.3	$585.12	$235.20	$102.84	$46.70
80ap0c25c0	324.76	230.18	$517.62	$216.90	$99.95	$48.45
80ap0c35c0	312.45	222.14	$506.21	$220.16	$105.93	$53.89
80ap0c25c25	303.49	213.84	$365.98	$159.85	$77.25	$39.51
80ap0c35c25	305.41	222.72	$457.99	$205.94	$102.99	$54.74
80ap25c0c0	342.10	228.58	$522.92	$199.63	$79.09	$29.35
80ap25c25c0	320.34	222.52	$461.97	$184.19	$77.59	$31.82
80ap25c35c0	307.49	215.08	$399.38	$167.23	$74.92	$33.46
80ap25c25c25	306.79	211.94	$320.71	$127.75	$53.07	$20.77
80ap25c35c25	297.79	210.4	$385.08	$163.28	$74.60	$34.39
100np0c0c0	338.76	246.44	$373.66	$128.08	$47.13	$17.88
100np0c25c0	318.36	248.34	$370.09	$136.35	$55.29	$23.79
100np0c35c0	312.59	242.56	$374.69	$143.31	$60.74	$27.46
100np0c25c25	295.11	235.6	$331.98	$129.58	$56.57	$26.62
100np0c35c25	294.45	239.92	$359.98	$147.63	$68.27	$34.17
100np25c0c0	343.56	254.12	$355.89	$109.63	$30.56	$3.66
100np25c25c0	318.58	243.74	$335.32	$113.35	$37.71	$9.57
100np25c35c0	312.02	250.88	$407.28	$145.96	$53.98	$18.09
100np25c25c25	298.49	235.48	$293.55	$100.77	$33.99	$8.67
100np25c35c25	297.24	239.64	$321.25	$118.95	$46.26	$16.94
100ap0c0c0	375.93	278.06	$437.10	$149.82	$55.14	$20.92
100ap0c25c0	344.04	268.66	$370.19	$140.95	$59.43	$26.72
100ap0c35c0	341.58	267.9	$381.53	$149.62	$65.19	$30.32
100ap0c25c25	326.15	265.3	$346.63	$139.12	$62.85	$30.74
100ap0c35c25	319.63	264.52	$361.44	$150.70	$70.96	$36.15
100ap25c0c0	369.65	269.18	$335.26	$102.56	$27.95	$2.67

Regime	Average C	Total Volume	SEV, $/ha			
	Mg/ha/year	m3	r=2%	r=3%	r=4%	r=5%
100ap25c25c0	349.89	266.3	$322.37	$107.11	$34.45	$7.79
100ap25c35c0	346.22	267.78	$349.14	$125.51	$46.18	$14.98
100ap25c25c25	325.22	271.74	$326.81	$119.82	$45.63	$15.95
100ap25c35c25	325.79	273.02	$350.84	$137.08	$57.60	$24.04
120np0c0c0	373.35	280.52	$275.05	$79.68	$24.49	$7.72
120np0c25c0	347.02	276.36	$279.71	$91.05	$32.95	$12.89
120np0c35c0	334.09	282.12	$313.24	$110.13	$43.45	$18.54
120np0c25c25	326.41	279.62	$279.86	$97.73	$38.57	$16.66
120np0c35c25	316.92	275.98	$294.42	$109.01	$46.04	$21.31
120np25c0c0	370.74	277.46	$242.84	$56.48	$6.22	-$7.13
120np25c25c0	341.85	273.28	$250.21	$69.57	$15.67	-$1.41
120np25c35c0	334.19	276	$271.64	$82.11	$22.66	$2.37
120np25c25c25	324.56	276.64	$246.63	$73.85	$19.91	$1.60
120np25c35c25	318.56	278.3	$264.03	$84.84	$26.62	$5.61
120ap0c0c0	389.40	280.6	$245.99	$71.26	$21.90	$6.90
120ap0c25c0	362.62	301.36	$302.61	$106.42	$41.99	$17.92
120ap0c35c0	354.25	296.02	$298.55	$105.79	$42.07	$18.08
120ap0c25c25	345.50	295.7	$274.23	$98.50	$40.09	$17.85
120ap0c35c25	338.47	306.84	$319.58	$124.12	$54.73	$26.21
120ap25c0c0	391.15	289.06	$225.98	$51.59	$4.72	-$7.60
120ap25c25c0	360.40	297.1	$255.50	$74.25	$18.66	$0.31
120ap25c35c0	351.75	297.6	$279.60	$89.28	$27.26	$5.04
120ap25c25c25	348.48	301.14	$258.74	$82.93	$25.61	$4.96
120ap25c35c25	342.12	307	$289.91	$101.55	$36.78	$11.61
140np0c0c0	388.70	293.84	$188.30	$45.77	$11.69	$3.05
140np0c25c0	356.22	302.84	$225.62	$68.74	$23.86	$9.13
140np0c35c0	347.63	309.88	$257.54	$84.98	$31.85	$12.98
140np0c25c25	344.15	306.44	$219.92	$69.84	$25.59	$10.47
140np0c35c25	338.30	313.24	$256.21	$89.92	$36.50	$16.30
140np25c0c0	391.91	299.78	$164.36	$24.80	-$5.95	-$11.61
140np25c25c0	360.32	302.92	$188.11	$41.48	$3.26	-$6.94
140np25c35c0	347.49	315.24	$236.50	$65.74	$15.12	-$1.23
140np25c25c25	338.96	299.68	$184.11	$44.90	$6.40	-$4.88
140np25c35c25	337.10	312.28	$226.48	$67.04	$18.05	$1.23
140ap0c0c0	407.62	297.82	$172.06	$41.83	$10.69	$2.79
140ap0c25c0	378.85	316.54	$214.23	$65.39	$22.73	$8.71
140ap0c35c0	373.10	326.68	$252.52	$84.51	$32.06	$13.19
140ap0c25c25	365.49	327.3	$226.09	$75.15	$28.89	$12.33
140ap0c35c25	359.64	330.86	$250.49	$88.70	$36.16	$16.15
140ap25c0c0	415.76	308.22	$151.20	$21.60	-$6.76	-$11.83
140ap25c25c0	375.74	313.1	$186.98	$44.60	$5.59	-$5.62
140ap25c35c0	362.02	314.88	$208.88	$56.40	$11.54	-$2.71
140ap25c25c25	363.50	318.38	$195.78	$54.10	$12.04	-$1.70
140ap25c35c25	353.94	333.38	$234.98	$73.60	$21.97	$3.39

Regime	Average C	Total Volume	SEV, $/ha			
	Mg/ha/year	m3	r=2%	r=3%	r=4%	r=5%
160np0c0c0	407.48	287.42	$121.10	$24.57	$5.20	$1.12
160np0c25c0	379.12	309.5	$157.42	$42.08	$13.10	$4.59
160np0c35c0	355.60	320.1	$189.10	$56.30	$19.33	$7.28
160np0c25c25	357.69	317.52	$164.95	$48.13	$16.58	$6.45
160np0c35c25	350.82	343.4	$210.11	$68.25	$25.90	$10.82
160np25c0c0	405.30	282.26	$91.32	$2.28	-$12.76	-$13.62
160np25c25c0	366.88	319.08	$143.77	$25.80	-$2.46	-$9.17
160np25c35c0	360.37	323.52	$168.26	$37.28	$2.67	-$6.93
160np25c25c25	355.74	323.62	$147.05	$30.33	$0.47	-$7.49
160np25c35c25	352.96	322.22	$158.38	$36.80	$3.86	-$5.79
160ap0c0c0	422.93	293.56	$111.38	$22.60	$4.78	$1.03
160ap0c25c0	389.34	321.18	$160.09	$45.48	$15.00	$5.49
160ap0c35c0	378.80	332.22	$186.20	$56.89	$19.94	$7.62
160ap0c25c25	375.17	339.94	$181.05	$57.28	$21.17	$8.66
160ap0c35c25	367.97	346.38	$207.91	$70.67	$27.70	$11.80
160ap25c0c0	417.81	290.4	$82.52	$0.49	-$13.13	-$13.70
160ap25c25c0	390.40	315.12	$129.57	$22.94	-$3.05	-$9.29
160ap25c35c0	383.49	334.42	$157.74	$34.28	$1.68	-$7.29
160ap25c25c25	377.20	325.3	$136.20	$28.55	$0.34	-$7.39
160ap25c35c25	363.48	345.98	$185.53	$51.60	$11.21	-$2.26
180np0c0c0	408.33	262.32	$72.77	$12.27	$2.15	$0.38
180np0c25c0	383.33	293.08	$113.09	$28.96	$8.79	$2.99
180np0c35c0	362.97	314.68	$147.68	$42.34	$13.97	$5.00
180np0c25c25	366.89	309.36	$130.89	$38.19	$13.19	$5.05
180np0c35c25	360.51	343.78	$167.93	$52.66	$19.20	$7.59
180np25c0c0	415.56	266.2	$46.90	-$9.26	-$15.65	-$14.33
180np25c25c0	378.83	301.22	$92.21	$9.28	-$8.31	-$11.45
180np25c35c0	373.58	322.3	$123.42	$21.22	-$3.71	-$9.67
180np25c25c25	361.96	309.76	$100.06	$14.63	-$5.46	-$10.03
180np25c35c25	359.81	339.8	$134.39	$28.10	$0.11	-$7.68
180ap0c0c0	424.04	267.74	$76.04	$12.82	$2.24	$0.40
180ap0c25c0	395.21	299.39	$112.15	$30.27	$9.57	$3.34
180ap0c35c0	385.20	324.74	$142.42	$41.46	$13.82	$4.97
180ap0c25c25	384.96	319.08	$121.49	$35.30	$12.12	$4.61
180ap0c35c25	381.20	353.38	$160.56	$50.71	$18.53	$7.33
180ap25c0c0	420.90	264.96	$48.05	-$9.06	-$15.62	-$14.32
180ap25c25c0	393.49	297.16	$87.61	$9.82	-$7.72	-$11.16
180ap25c35c0	385.35	323.66	$116.82	$20.45	-$3.71	-$9.63
180ap25c25c25	380.97	342.34	$116.80	$22.02	-$2.28	-$8.67
180ap25c35c25	377.42	348.68	$137.51	$31.43	$1.90	-$6.84
200np0c0c0	405.82	248.1	$51.78	$7.24	$1.05	$0.15
200np0c25c0	392.72	291.78	$79.02	$18.13	$5.05	$1.59
200np0c35c0	382.35	322.22	$110.76	$28.96	$8.80	$2.90
200np0c25c25	376.38	316.5	$95.85	$25.39	$8.11	$2.88

Regime	Average C	Total Volume	SEV, $/ha			
	Mg/ha/year	m3	r=2%	r=3%	r=4%	r=5%
200np0c35c25	365.89	335.12	$130.61	$38.96	$13.37	$4.91
200np25c0c0	409.97	231.06	$15.44	-$15.78	-$16.98	-$14.59
200np25c25c0	382.09	314.17	$70.99	$2.63	-$10.67	-$12.40
200np25c35c0	376.75	315.24	$82.78	$7.16	-$9.03	-$11.81
200np25c25c25	379.48	326.44	$72.75	$4.57	-$9.49	-$11.77
200np25c35c25	369.36	341.7	$100.25	$15.37	-$5.27	-$10.13
200ap0c0c0	424.36	229.76	$36.44	$5.09	$0.74	$0.11
200ap0c25c0	402.88	313.72	$88.26	$22.01	$6.49	$2.11
200ap0c35c0	395.46	321.7	$110.73	$30.35	$9.48	$3.16
200ap0c25c25	393.08	333.86	$109.33	$31.64	$10.68	$3.89
200ap0c35c25	389.50	351.76	$132.67	$40.52	$14.10	$5.22
200ap25c0c0	428.43	240.04	$17.65	-$15.47	-$16.93	-$14.59
200ap25c25c0	399.00	293.48	$59.43	$0.55	-$11.13	-$12.52
200ap25c35c0	391.15	331.98	$89.26	$10.22	-$7.85	-$11.38
200ap25c25c25	391.38	322.38	$66.64	$3.92	-$9.47	-$11.72
200ap25c35c25	385.22	355.66	$109.76	$20.14	-$3.28	-$9.34

Appendix H. Efficiency scores for each regime

Data sorted by efficiency scores ascending – efficiency decreases

4% discount rate

Regime	SEV, $/ha	C, Mg/ha/year	Fo(x,y)	C,S)
200ap0c0c0	$0.74	424.36	1
180ap0c0c0	$2.24	424.04	1
160ap0c0c0	$4.78	422.93	1
80ap0c0c0	$102.84	352.09	1
80ap0c35c0	$105.93	312.45	1
100ap0c0c0	$55.14	375.93	1.026
140ap0c0c0	$10.69	407.62	1.027
80ap0c35c25	$102.99	305.41	1.028
160np0c0c0	$5.20	407.48	1.037
180np0c0c0	$2.15	408.33	1.038
80ap0c25c0	$99.95	324.76	1.04
200np0c0c0	$1.05	405.82	1.045
200ap0c25c0	$6.49	402.88	1.046
120ap0c0c0	$21.90	389.40	1.052
200ap0c35c0	$9.48	395.46	1.06
180ap0c25c0	$9.57	395.21	1.06
200ap0c25c25	$10.68	393.08	1.064
160ap0c25c0	$15.00	389.34	1.065
200ap0c35c25	$14.10	389.50	1.067
80ap25c0c0	$79.09	342.10	1.068
80np0c35c0	$98.83	291.94	1.072
140np0c0c0	$11.69	388.70	1.074
200np0c25c0	$5.05	392.72	1.076
140ap0c35c0	$32.06	373.10	1.076
180ap0c35c0	$13.82	385.20	1.079
140ap0c25c0	$22.73	378.85	1.079
120ap25c0c0	$4.72	391.15	1.081
180ap0c35c25	$18.53	381.20	1.081
180ap0c25c25	$12.12	384.96	1.083
160ap0c35c0	$19.94	378.80	1.084
120ap0c25c0	$41.99	362.62	1.085

Regime	SEV, $/ha	C, Mg/ha/year	Fo(x,y)	C,S)
120np0c0c0	$24.49	373.35	1.09
160ap0c25c25	$21.17	375.17	1.092
180np0c25c0	$8.79	383.33	1.094
100ap25c0c0	$27.95	369.65	1.094
200np0c35c0	$8.80	382.35	1.097
160np0c25c0	$13.10	379.12	1.097
100ap0c35c0	$65.19	341.58	1.097
160ap0c35c25	$27.70	367.97	1.099
100ap0c25c0	$59.43	344.04	1.102
140ap0c25c25	$28.89	365.49	1.104
80np0c25c0	$94.88	297.33	1.104
140ap0c35c25	$36.16	359.64	1.105
160ap25c35c0	$1.68	383.49	1.106
120ap0c35c0	$42.07	354.25	1.109
200np0c25c25	$8.11	376.38	1.115
140ap25c25c0	$5.59	375.74	1.123
100ap25c35c0	$46.18	346.22	1.123
180ap25c35c25	$1.90	377.42	1.124
160ap25c25c25	$0.34	377.20	1.125
120ap0c35c25	$54.73	338.47	1.128
180np0c25c25	$13.19	366.89	1.133
80ap25c25c0	$77.59	320.34	1.133
200np0c35c25	$13.37	365.89	1.135
120np25c0c0	$6.22	370.74	1.136
100ap25c25c0	$34.45	349.89	1.138
180np0c35c25	$19.20	360.51	1.139
120ap0c25c25	$40.09	345.50	1.139
120ap25c25c0	$18.66	360.40	1.14
140np0c25c0	$23.86	356.22	1.142
180np0c35c0	$13.97	362.97	1.143
100np0c0c0	$47.13	338.76	1.144
140ap25c25c25	$12.04	363.50	1.146
160ap25c35c25	$11.21	363.48	1.147
120ap25c35c0	$27.26	351.75	1.148
100ap0c25c25	$62.85	326.15	1.148
140np0c35c0	$31.85	347.63	1.15
120np0c25c0	$32.95	347.02	1.15
100ap0c35c25	$70.96	319.63	1.15
140ap25c35c0	$11.54	362.02	1.151
160np0c25c25	$16.58	357.69	1.153
140ap25c35c25	$21.97	353.94	1.153
160np0c35c0	$19.33	355.60	1.154
160np0c35c25	$25.90	350.82	1.154
80np0c35c25	$90.88	282.76	1.154
120ap25c35c25	$36.78	342.12	1.156

Regime	SEV, $/ha	C, Mg/ha/year	Fo(x,y) | C,S)
80np0c0c0	$84.03	307.32	1.159
100ap25c35c25	$57.60	325.79	1.161
120ap25c25c25	$25.61	348.48	1.162
100np25c0c0	$30.56	343.56	1.166
120np0c35c0	$43.45	334.09	1.167
140np0c35c25	$36.50	338.30	1.169
140np25c25c0	$3.26	360.32	1.175
160np25c35c0	$2.67	360.37	1.176
140np0c25c25	$25.59	344.15	1.176
180np25c35c25	$0.11	359.81	1.179
80ap25c35c0	$74.92	307.49	1.179
80ap0c25c25	$77.25	303.49	1.187
80np25c0c0	$66.56	310.97	1.188
140np25c35c0	$15.12	347.49	1.19
100ap25c25c25	$45.63	325.22	1.19
100np0c25c0	$55.29	318.36	1.19
160np25c25c25	$0.47	355.74	1.193
100np0c35c0	$60.74	312.59	1.196
160np25c35c25	$3.86	352.96	1.198
120np0c25c25	$38.57	326.41	1.204
120np25c25c0	$15.67	341.85	1.207
80ap25c35c25	$74.60	297.79	1.212
100np25c35c0	$53.98	312.02	1.215
120np25c35c0	$22.66	334.19	1.216
140np25c35c25	$18.05	337.10	1.218
120np0c35c25	$46.04	316.92	1.218
80np25c35c0	$82.74	287.22	1.229
100np25c25c0	$37.71	318.58	1.233
80ap25c25c25	$53.07	306.79	1.235
80np0c25c25	$82.21	284.61	1.239
100np0c35c25	$68.27	294.45	1.24
80np25c25c0	$71.42	292.34	1.24
140np25c25c25	$6.40	338.96	1.241
120np25c25c25	$19.91	324.56	1.258
120np25c35c25	$26.62	318.56	1.262
100np0c25c25	$56.57	295.11	1.269
100np25c35c25	$46.26	297.24	1.289
80np25c25c25	$61.45	281.08	1.31
100np25c25c25	$33.99	298.49	1.32
80np25c35c25	$62.41	276.62	1.325

2% discount rate

Regime	SEV, $/ha	C, Mg/ha/year	Fo(x,y) | C,S)
80ap0c0c0	$585.12	352.09	1
100ap0c0c0	$437.10	375.93	1
160ap0c0c0	$111.38	422.93	1
200ap25c0c0	$17.65	428.43	1
180ap0c0c0	$76.04	424.04	1.002
140ap25c0c0	$151.20	415.76	1.003
200ap0c0c0	$36.44	424.36	1.007
180ap25c0c0	$48.05	420.90	1.014
140ap0c0c0	$172.06	407.62	1.015
160ap25c0c0	$82.52	417.81	1.016
180np25c0c0	$46.90	415.56	1.027
120ap0c0c0	$245.99	389.40	1.033
160np0c0c0	$121.10	407.48	1.033
120ap25c0c0	$225.98	391.15	1.036
180np0c0c0	$72.77	408.33	1.041
200np25c0c0	$15.44	409.97	1.045
160np25c0c0	$91.32	405.30	1.046
80ap25c0c0	$522.92	342.10	1.047
100ap25c0c0	$335.26	369.65	1.05
200np0c0c0	$51.78	405.82	1.05
200ap0c25c0	$88.26	402.88	1.052
140np0c0c0	$188.30	388.70	1.056
140np25c0c0	$164.36	391.91	1.056
120np0c0c0	$275.05	373.35	1.063
160ap0c25c0	$160.09	389.34	1.064
180ap0c25c0	$112.15	395.21	1.067
200ap0c35c0	$110.73	395.46	1.067
200ap25c25c0	$59.43	399.00	1.067
140ap0c25c0	$214.23	378.85	1.071
140ap0c35c0	$252.52	373.10	1.072
160ap25c25c0	$129.57	390.40	1.073
200ap0c25c25	$109.33	393.08	1.074
200ap0c35c25	$132.67	389.50	1.074
180ap25c25c0	$87.61	393.49	1.077
120ap0c25c0	$302.61	362.62	1.081
160ap25c35c0	$157.74	383.49	1.081
200np0c25c0	$79.02	392.72	1.081
120np25c0c0	$242.84	370.74	1.082
160ap0c35c0	$186.20	378.80	1.082
180ap0c35c0	$142.42	385.20	1.082
200ap25c35c0	$89.26	391.15	1.083
180ap0c35c25	$160.56	381.20	1.086

Regime	SEV, $/ha	C, Mg/ha/year	Fo(x,y) | C,S)
200ap25c25c25	$66.64	391.38	1.086
140ap25c25c0	$186.98	375.74	1.09
180ap0c25c25	$121.49	384.96	1.091
180ap25c35c0	$116.82	385.35	1.091
160np0c25c0	$157.42	379.12	1.092
80ap0c25c0	$517.62	324.76	1.094
160ap0c25c25	$181.05	375.17	1.094
200ap25c35c25	$109.76	385.22	1.095
180np0c25c0	$113.09	383.33	1.098
200np0c35c0	$110.76	382.35	1.102
140ap0c25c25	$226.09	365.49	1.103
160ap0c35c25	$207.91	367.97	1.103
180ap25c25c25	$116.80	380.97	1.104
100ap0c25c0	$370.19	344.04	1.105
120ap0c35c0	$298.55	354.25	1.105
120ap25c25c0	$255.50	360.40	1.105
180ap25c35c25	$137.51	377.42	1.105
160ap25c25c25	$136.20	377.20	1.106
100ap0c35c0	$381.53	341.58	1.107
100ap25c25c0	$322.37	349.89	1.107
100ap25c35c0	$349.14	346.22	1.107
140ap0c35c25	$250.49	359.64	1.109
100np25c0c0	$355.89	343.56	1.112
200np25c25c0	$70.99	382.09	1.112
100np0c0c0	$373.66	338.76	1.118
180np25c25c0	$92.21	378.83	1.118
140ap25c35c0	$208.88	362.02	1.119
200np25c25c25	$72.75	379.48	1.119
120ap25c35c0	$279.60	351.75	1.12
140ap25c25c25	$195.78	363.50	1.121
180np25c35c0	$123.42	373.58	1.122
200np0c25c25	$95.85	376.38	1.124
160ap25c35c25	$185.53	363.48	1.125
200np25c35c0	$82.78	376.75	1.125
140np0c25c0	$225.62	356.22	1.129
80ap25c25c0	$461.97	320.34	1.131
140ap25c35c25	$234.98	353.94	1.132
80ap0c35c0	$506.21	312.45	1.133
120np0c25c0	$279.71	347.02	1.133
140np25c25c0	$188.11	360.32	1.133
160np25c25c0	$143.77	366.88	1.133
120ap25c25c25	$258.74	348.48	1.138
180np0c25c25	$130.89	366.89	1.138
120ap0c25c25	$274.23	345.50	1.14
120ap0c35c25	$319.58	338.47	1.141

Regime	SEV, $/ha	C, Mg/ha/year	Fo(x,y)	C,S)
140np0c35c0	$257.54	347.63	1.141
160np25c35c0	$168.26	360.37	1.141
180np0c35c25	$167.93	360.51	1.141
200np0c35c25	$130.61	365.89	1.141
180np0c35c0	$147.68	362.97	1.142
120ap25c35c25	$289.91	342.12	1.143
200np25c35c25	$100.25	369.36	1.144
160np0c35c0	$189.10	355.60	1.147
140np25c35c0	$236.50	347.49	1.15
160np0c25c25	$164.95	357.69	1.151
160np0c35c25	$210.11	350.82	1.152
120np0c35c0	$313.24	334.09	1.157
180np25c35c25	$134.39	359.81	1.158
80np0c0c0	$478.11	307.32	1.161
120np25c25c0	$250.21	341.85	1.162
80np25c0c0	$451.62	310.97	1.163
160np25c25c25	$147.05	355.74	1.165
80np0c25c0	$501.71	297.33	1.166
100ap25c35c25	$350.84	325.79	1.166
180np25c25c25	$100.06	361.96	1.166
100ap0c25c25	$346.63	326.15	1.167
140np0c25c25	$219.92	344.15	1.168
160np25c35c25	$158.38	352.96	1.168
140np0c35c25	$256.21	338.30	1.17
120np25c35c0	$271.64	334.19	1.176
80np0c35c0	$497.30	291.94	1.177
80ap0c35c25	$457.99	305.41	1.177
100ap25c25c25	$326.81	325.22	1.179
100np0c25c0	$370.09	318.36	1.181
100ap0c35c25	$361.44	319.63	1.181
100np25c35c0	$407.28	312.02	1.182
140np25c35c25	$226.48	337.10	1.187
100np25c25c0	$335.32	318.58	1.196
100np0c35c0	$374.69	312.59	1.197
120np0c25c25	$279.86	326.41	1.197
80ap25c35c0	$399.38	307.49	1.2
140np25c25c25	$184.11	338.96	1.201
120np25c25c25	$246.63	324.56	1.219
120np0c35c25	$294.42	316.92	1.221
80np25c25c0	$445.97	292.34	1.226
80ap0c25c25	$365.98	303.49	1.231
120np25c35c25	$264.03	318.56	1.231
80np25c35c0	$466.09	287.22	1.232
80ap25c35c25	$385.08	297.79	1.24
80ap25c25c25	$320.71	306.79	1.243

Regime	SEV, $/ha	C, Mg/ha/year	Fo(x,y) | C,S)
80np0c25c25	$433.76	284.61	1.259
80np0c35c25	$432.68	282.76	1.266
100np0c35c25	$359.98	294.45	1.266
100np25c35c25	$321.25	297.24	1.278
100np0c25c25	$331.98	295.11	1.28
100np25c25c25	$293.55	298.49	1.288
80np25c25c25	$379.77	281.08	1.304
80np25c35c25	$368.74	276.62	1.328