THE BOREAL FOREST OF THE RUSSIAN FEDERATION:

ECONOMIC AND ENVIRONMENTAL CONSIDERATIONS OF CARBON SEQUESTRATION

By

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To the Faculty of Washington State University:

The members of the Committee appointed to examine the dissertation of WILLIAM EARL SCHLOSSER find is satisfactory and recommend that it be accepted.

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(Chair)

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THE BOREAL FOREST OF THE RUSSIAN FEDERATION: ECONOMIC AND ENVIRONMENTAL CONSIDERATIONS OF CARBON SEQUESTRATION

Abstract

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This dissertation, presented in three sections, discusses the historical context and current state of forest management in the Russian Federation, and the establishment of forest management authority by the Ministry of Natural Resources, its duties, mandates, and organizational hierarchy as it applies to forest management. It will examine the implications to forest management in relation to Russia's role in global climate change issues, harvest rates in the boreal forest, and targets for reforestation, fire fighting, and infrastructure development. The evolution of a market economy in Russia is directly linked to the potential success of forest management goals.

A carbon balance assessment for containerized *Larix gmelinii* seedlings in the Russian Far East determined that the level of carbon emissions to the atmosphere originating as a result of inputs to the seedling growing process exceeded the volume of carbon sequestered by the seedlings at a ratio of approximately 1:40 (1 part sequestered carbon to 40 parts carbon emissions). Seedling production resulted in an initial carbon deficit, determined as the excess amount of carbon released to the atmosphere as carbon dioxide (CO_2). To offset this initial deficit, seedlings would need to grow to an estimated 74.68 cm in total tree height after outplanting.

The lumber manufacturing industry of the Russian Far East and Siberia was evaluated in order to determine potential improvements in lumber recovery and the corresponding enhancement of temporal carbon storage duration in lumber manufactured from trees harvested from the boreal forest (taiga) of the Russian Far East. Lumber recovery improvements were evaluated to ascertain long-term carbon storage impacts. Approximately 38.9% of the carbon stored in trees of the boreal forest is transferred into carbon stored in lumber manufactured at this mill complex in the Russian Far East. This carbon sequestration can be increased from 38.9% to 45.6%, or more, with milling improvements to increase lumber recovery.

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DEDICATION

This dissertation is dedicated to the men and women of all countries that work together in the Russian Federation for the purpose of managing boreal forests for long term sustainability of the resource and the benefit of the Russian people. It is dedicated to the people of Pacific Rim Taiga and the Russian Environmental Partnership Institute who exemplify this land use ethic.

I dedicate it finally, to my family. To my wife who has stood beside me and helped me in ways I can never express with mere words. To my son and daughters who encouraged me every step of the way, I say, thank you.

CHAPTER ONE

INTRODUCTION

This dissertation consists of three separate but related, research projects. The research results of each of the three endeavors have been written in the form of a peer reviewed journal articles. This dissertation will combine each of these three articles, in chapters two, three, and four. Each of these papers (chapters 2–4) will adhere to the style formats required by each journal. Each chapter will possess self-contained literature cited, tables, figures, and chart sections. Numbering from all tables, figures, and charts will restart within each chapter.

Chapter two is titled, "Russian Forest Management Under the Ministry of Natural Resources: A historical review of Russian forest management and a look to the future". It was co-authored with Russian forest management specialist, Victor K. Teplyakov, Ph.D., of Moscow, Russia, and Philip R. Wasnschneider, Ph.D. of Washington State University. This article provides a historical review of forest management policy in Russia and forest management at the turn of the 21st century. Soon following the election of Russian President Vladimir Putin in 2000, the Russian Federal Forest Service and other land management departments were abolished and all of their management authority was transferred to the Ministry of Natural Resources. This article explores the challenges facing the Ministry of Natural Resources and the larger issue of the establishment of a market economy in the Russian Federation which is stifled currently by a shadow economy.

Chapter three is titled "A Carbon Balance Assessment for Containerized *Larix gmelinii* Seedlings in the Russian Far East" and is co-authored with John H. Bassman, Ph.D., Philip R. Wandschneider, Ph.D., and Richard L. Everett, Ph.D. This article was submitted to, and accepted by, the Journal of Forest Ecology and Management. This article evaluates carbon emissions caused by raising containerized conifer seedlings in a greenhouse facility located in Khabarovskii krai, Russian Federation. This information is matched with carbon sequestration, as determined by mass spectrometry, of the seedlings raised at this complex. Results indicated a 1:40 ratio of carbon sequestration to emissions. It is the first article of its kind of to equate carbon dioxide emissions of raising containerized conifer seedlings to the amount of carbon the seedlings sequester during their tenure at the greenhouse complex.

Chapter four it titled "Increasing Long Term Storage of Carbon Sequestered in Russian Softwood Logs Through Enhanced Lumber Recovery" and is co-authored with John H. Bassman, Ph.D., Francis G. Wagner, Ph.D., and Philip R. Wandschneider Ph.D. This article was submitted to, and accepted by, the Forest Products Journal. This article evaluated the Russian wood processing industry and its role in converting wood sequestered carbon into carbon sequestered in lumber. The approach utilized in this research involved a lumber throughput survey that evaluated the recovery of solid wood delivered to the mill as logs and the amount of lumber derived from that raw material. Results indicated that a significant improvement to carbon recovery could be observed with changes to milling practices and equipment upgrades.

Within each chapter, the theme of carbon sequestration in the Russian boreal forest is repeated. This topic has received considerable international attention over the past two decades. Russia will fulfill a critical role in the global effort to reduce the negative effects of climate change. The vastness of the Russian taiga will insure this responsibility. The question remains of how Russia will face this responsibility.

The Russian Ministry of Natural Resources is faced with many challenges and little allocation of budgets to accomplish them. However, their role is central to the management of the Russian taiga, and therefore the country's response to carbon sequestration, reforestation, fire fighting, and harvesting practices. The subsequent chapters of this dissertation detail the critical components of these challenges and some opportunities that Russia may seize.

CHAPTER TWO

RUSSIAN FOREST MANAGEMENT UNDER THE MINISTRY OF NATURAL RESOURCES:

A historical review of Russian forest management and a look to the future

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Russian Forest Management Under the Ministry of Natural Resources:

A historical review of Russian forest management and a look to the future

Executive Summary

This manuscript discusses the historical context and current state of forest management in the Russian Federation, and the establishment of forest management authority by the Ministry of Natural Resources, its duties, mandates, and organizational hierarchy as it applies to forest management. It will examine the implications to forest management in relation to Russia's role in global climate change issues, harvest rates in the boreal forest, and targets for reforestation, fire fighting, and infrastructure development. The evolution of a market economy in Russia will be directly linked to the potential success of these forest management goals.

In brief, it is expected that forest management activities during the coming decades will show a greater emphasis on timber extraction and fire protection of highly valued timber stands. Forest regeneration efforts will most likely be scaled back considerably, while non-forest-regeneration silvicultural treatments will be used only to a limited extent. Forest complex infrastructure developments, such as roads, will be concentrated to those areas which are juxtaposed with significant deposits of oil, gas, or commercially valuable minerals.

The shadow economy of Russia, coupled with the top-down edicts from the President, will continue to hamper the realization of a Russian market economy which in turn will stifle the emergence of a commercial forest products sector that might have been a mechanism to assist in the development of a sustainable forest products sector.

Forest policy, dictated by decrees of the President of the Russian Federation, will continue to guide rules and conventions to a much greater extent than the guarantees of the constitution, promises by the Duma, or well thought-out guidelines written as part of policy regulations.

The Historical Context of Russian Forest Policy

The earliest nomadic settlers of European Russia were called "Dreavlyane"; the people of the forest. These early Slavs settled the forests and marshes while placing a spiritualist value on the great oaks of the woodlands (Krylov 1984). By the beginning of the 10th century, laws and regulations that governed various ownership rights for forestry were in place and even carried the penalty of death for illegal timber harvest on the Czar's forestlands. The Russian Law, Long Edition (circa 1209) contained 121 articles, and of those, 10 were devoted to forestry (Teplyakov *et al.* 1998). During the 15th through the 17th centuries, the main uses of the Russian forests included wood products, fishing, hunting, apiaries, and potash production. During the middle of the 16th century, under the leadership of Ivan the Great (A.K.A. Ivan the Terrible) the construction of shipbuilding yards and lumber mills in the northwestern territories of Russia was made a priority, placing greater utilization pressures on the forests of that region (Teplyakov 1992).

By 1649, Czar Aleksei Mikhailovich had adopted regulations which contained the previous body of laws into a legal document which confirmed six different and unique forms of forest ownership, differentiating between private, public, and Czar owned forestlands (Teplyakov 1992). Czar Aleksei Mikhailovich and later his son, Czar Peter the Great (A.K.A. Peter I) formalized the management of Russia's forestlands in the Code of Russia in the late 17th century (Krylov 1978). Interestingly, their justification for managing the forests was tied directly to the national defense, dictating the need for a stable supply of mast wood for military sailing ships, and to allow for the construction of abatis (trees felled chest high) to thwart the advancement of attacking cavalry (Arnold 1895, Krylov 1978, Redko 1981, Tikhonov 1984, Bobrov 1990, Teplyakov *et al.* 1998).

As early as 1702, Czar Peter the Great sent a manifesto throughout Europe inviting various specialists, including foresters, to come to Russia (Teplyakov *et al.* 1998); the great Czar made it no secret that he wished Russia to be a member of the European Community and this open invitation was one step toward that end. The defining moment in early Russian forest management occurred when Peter I wrote a decree (circa 1703) requiring an inventory of all forests at a distance of 50 verst (53.0 km, 32.9 mi.) from big rivers and 20 verst (21.2 km, 13.2 mi.) from small ones. Within these boundaries, it was illegal to cut species of oak (*Quercus* spp.), maple (*Acer* spp.), elm (*Ulmus* spp.), larch (*Larix* spp.), and pine (*Pinus* spp.) with the stem diameter of 12 vershkov (53.3 cm, 21 inches) or greater. Fines were levied for violations of the decree: (1) for cutting any tree but oak it equaled 10 rubles, and (2) for cutting an oak and a significant amount of other species capital punishment was an accepted penalty (Krylov 1978). Considering that forestlands outside this waterway buffer zone were economically infeasible, with this decree, Czar Peter I had nationalized practically all mature forestlands in Russian territory.

Over the next 2 years, the intended effect was seen across the countryside as timber harvests for personal uses were severely curtailed but the secondary effect was unintentional as production of horse carts, wagons, and mills nearly stopped. By 1705, the Czar lifted severe sentences for the construction of the listed items, but shipbuilding by the private sector was still forbidden (Krylov 1978, Redko and Shlapak 1993).

While the British flag still waved over the American Colonies and the Broad Arrow of the British Crown identified the King's Trees (national assets) in the New World of North America (Cameron 1928), Czar Peter the Great created the Forest Service of Russia (1719). Given the military significance of forests in the early 18th century, it is no surprise that this first forest service of Russia was formed as a division of the Russian Navy. The Admiralty Collegium was uniquely Russian in its organization, although Czar Peter I ordered the foresters in its ranks to bear German titles such as *forstmeister, waldmeister,* and *ober waldmeister* (Centennial of the Forest Department 1898, Krylov 1978, Teplyakov *et al.* 1998).

Within three years of creating a forest management division as part of the government, the Czar revisited the issue of commercial shipbuilding. He issued a new decree (February 7, 1722) stating:

"…since local people misunderstood the Czar's intentions who sent a message of the need to preserve forests, it was not intended to limit the people in their desire to build ships, it is allowed now for the people of Zaonezhye [Karelia–northwestern Russia] to cut trees for the needs of ship building, but not for fire wood or any other small needs" (Krylov 1978).

In contrast to the scientific efforts of the time, there was a national backlash in forest management following the death of Czar Peter I. Four Russian rulers would follow Peter the Great during 16 years (1725-1741). Empress Catherine I, issued a decree on December 30, 1726, stating that due to the negative impacts to peasants of limiting forest harvest activities, all *Waldmeister* (Forest Management) offices were to be abolished. The responsibility of forest supervision was assigned to land owners, village elders and stewards in each region. Forest management decisions and administrative functions were transferred to the authority of provincial governors and army commanders. That decree opened the door to increased utilization of mature forests and amplified revenues to the national treasury from stumpage fees (Arnold 1895, Krylov 1978).

The daughter of Czar Peter I, Empress Elizabeth Petrovna in 1741 began her twenty year rule of Russia by adopting all of the decrees of her father, including all of those related to forestry (Teplyakov *et al.* 1998). She reestablished all of the Forest Management offices in her realm and nationalized all forestlands. Her efforts placed more importance on implementing scientifically based forest management options as opposed to the mercantilist style of forest management which was observed during the rule of her four predecessors.

Two years following the death of Empress Elizabeth Petrovna, Empress Catherine II (A.K.A. Catherine the Great) took over rule of Russia[1]. In harmony with the continuous ebb and flow of forest guidelines in Russia, she greatly liberalized forest policy reversing her predecessor's nationalization of forest resources and declaring that the maximization of economic returns from forest ownership should be the guiding policy of forestry in Russia (Kopylova 1999a). She brought to an end regulations on forest protection and created the mechanisms for private ownership of forestlands. The reaction by the countryside was to increase timber harvest volumes. The government's

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[1] German born Peter III was Czar of Russia for one year (1761-1762) before he was dethroned and assassinated as a result of a coup d'état arranged by his wife, Catherine II. (Gorkin 1999).

response was a laissez faire attitude that lacked regulations and procedures to ensure forest sustainability (Kopylova 1999a).

Emperor Paul I (1796-1801), issued a decree on May 26, 1798, reinitiating the management of all public forests to be carried out by forest masters and rangers appointed by the Admiralty Board (Centennial of the Forest Department 1898). In so doing he fulfilled his role in maintaining the ebb and flow of forest management policy in Russia.

The basic structure of the Russian Forest Service would be modified significantly only four times during the 300 year Romanov Dynasty. By 1917, approximately 36% of all Russian forests were under state management, with the remaining 64% held in private ownership (Kopylova 1999a). After socialism became established in Russia, all of the land was transferred back to state ownership (Carlsson 2000). During the Bolshevik regime, authority for forest management would be reorganized twenty more times with three complete liquidations (1917-1992) (Teplyakov *et al.* 1998). In the absence of a market economy, the period of socialism in Russia would be recalled as a period of unsustainable harvesting of forest resources that reached even the most remote regions (Kopylova 1999a).

Following the collapse of the USSR and the reinstatement of authority of the Russian Federation on the land of Russia, the RFFS has been the primary and predominant forest fund management agency. Still retaining state ownership of all lands in the Russian Federation, the Russian government enacted numerous laws aimed at forest resource exploitation. The first significant regulation to be implemented was the 1993 adoption of the "Principles of Forest Legislation". The Russian economy and rule of law were still in a state of flux and it became clear to Moscow that the centralized style of forest management called for in the legislation was too restrictive (Kopylova 1999a).

By 1997, the Russian government passed the "Forest Code of Russian Federation". The most noteworthy component of the 1997 legislation was the transference of forest management authority from the centralized federal bureaucracy into the hands of a combined committee of the subjects of the federation and the RFFS (Kopylova 1999a) (Chart 1). The legislation allowed for property rights to be reallocated to private citizens and companies through leases (up to 49 years), concessions (up to 49 years), and short-term utilization (less than 1 year). Nevertheless, in reality, the federal government has retained practical ownership of all forestlands and agricultural lands of the federation leaving property rights a nebulous topic (Carlsson 2000).

It is important to recognize that in the historical context of the Russian forest policy, events are plagued with constant change. For over 300 years the rulers of Russia have oscillated between giving people private land ownership rights and then taking them completely away, it did not matter if the ruling party was a Czar, Empress, General Secretary of the Communist Party, or the duly elected President of the Federation. The trend has been to give a little and then take it back. More often than not, political changes in Russian history gravitate to a central theme of "taking one step forward, and two steps back" (from a political book by this name written by Vladimir Ilych Ulyanov A.K.A. Lenin). For the Russian people, decisions from the top of the political pyramid are unquestionably accepted as the ultimate argument in determining the economic environment.

The Russian Federation has been a tempest of change during its most recent decade, and even once-thought strongholds of stability have gone through significant transformations. It should be no surprise then, that less than six months after his election, President Vladimir Vladimirovich Putin, brought to an end the existence of the RFFS, the State Committee for Environmental Protection, and other federal departments and transferred their authority to the Ministry of Natural Resources (MNR) by Presidential Decree No. 867 on May 17, 2000 (Environmental News Service 2000). In this decree, the president also reaffirmed the absolute authority of forestland ownership rights by the state in the Russian Federation, reversing the previous policy of allowing decision-making influence by the subjects of the federation.

The MNR was a pre-existing organization of the Russian Federation that has historically been the lead management agency for the nation's oil, gas, and mineral deposits (Vasenda 2001). Although environmental management restructuring at this scale has caught the attention of many around the world, it is a significant concession that many of the people once employed in the RFFS are now receiving their salary (albeit sometimes delayed) from the MNR.

The Context of Forest Management Sciences in Russia

Historical

In 1724, during the reign of Peter the Great, Russia's first forest economist Ivan Pososhkov wrote a book titled “The Book on Scarcity and Wealth” where he pointed to the need for "rational forest use", protection of forests from wild fires, and described the need for revision of forest regeneration practices. His book was published only in 1842

(Arnold 1895). His works were unique for the time of popular ideas on forestry (globally) that accentuated the notion that forests, due to their vastness, failed to be valuable assets which anyone was free to exploit (Cameron 1928). However, these works were granted political grace in light of the tendency of the Czar to support the science and practices of forestry. The decade following publication of this book would be recognized as the time of awakening of professional forestry in Russia as the first forest plantations were established. Soon after the death of Peter the Great, one of Russia's first silviculturalists, Fokel, created the Lindulov forest plantation of Siberian larch (*Larix sibirica*) which has been preserved to this day in memory of the "Forestry Czar – Peter I" (Melekhov 1957, Tikhonov 1984, Redko 1993).

Bolotov was considered the father of Russian silviculture. He published an article entitled “Cutting, Improvement, and Regeneration of Forests” in 1766. By 1814, regeneration regulations would be entered into state-approved forest management practices for the first time by requiring that all advanced regeneration on the harvested site already at a height of 8.8 cm (3.5 in) be protected: "not to log and make every effort to preserve from damage" (Terinov 1969). Malgin (1841) pointed out the benefits of leaving pine (during thinning) in scattered leave-tree groups in forests dominated by spruce in order to increase overall wind resistance of the stand. Russian scientist and forestry leader, Alexander Teploukhov, in the mid-1800s published numerous articles concerning forest management and silviculture. He criticized German monocultures, pointed to the need for forest stand diversification to improve soil recruitment, and offered demonstrations of tree planting as being far superior to seeding cut or burnt sites (Melekhov 1957, Tikhonov 1984, Teplyakov *et al.* 1998). Teploukhov also advanced the concept of forest fire management to include the necessity of slash management on sites following logging (Teploukhov 1850).

The Society for the Advancement of Forest Management was created in 1832 as a means of disseminating knowledge concerning the advancement of forest management in Russia. This national publication, written in Russian, was the first and only publication of its time to advocate forestry sciences as it tackled national issues from Odessa to St. Petersburg, and from Crimea to Siberia (Beilin 1962, Tikhonov 1984). In one particular article by Kotta, very advanced ideas of agroforestry were developed and put into practice. In extension of the notion of improving Russian silviculture, the "All Russia Forestry Congress" was convened annually to discuss issues of silviculture and forest management.

By the end of the 19th century, the body of forest science in Russia had surpassed forestry in West European countries in terms of developing the soil sciences, implementing thinning as a silvicultural tool, and applying mixed forest regeneration to enhance forest resilience against pests and fire (Melekhov 1957, Tikhonov 1984). In 1904, the forestry textbook "Silviculture" was published as a culmination of the forestry sciences up to that time. It was one of the first textbooks on forestry that detailed the concept of shade tolerance (shadow tolerant species) and how all trees, even shadow tolerant trees are slowed in growth as a result of excess shade (Turskii 1904).

Professor Mikhail Mikhailovich Orlov analyzed international and Russian experiences at the beginning of the 20th century. He wrote that it seemed strange to him that the country of Russia, with about a half of its territory covered by forests, did not place forest management and forestry in an "appropriate place in the country’s overall management system". He observed that usually, forestry became a part of the most powerful and influential branch of the national economy, even when the respective countries did not care about their forests and forest management. With this in mind, Orlov wrote "… Forestry of Russia – USSR – Russian Federation – is unique… and management systems should be more specific." He recommended and scientifically justified that management and regulation systems should be modified by introducing market elements (khozraschet) into the Russian forest management system. The first step of the reform he recommended was to give freedom of forest management practices to managers. But, he warned, this freedom must be bestowed with responsibility for all activities (Orlov 1930).

Russia and western Europe mutually benefited from the exchange of ideas and forest practices for centuries. At the beginning of the 20th century, there were even accounts of students from England learning Russian in order to study soil sciences directly from Dokuchayev's original works on the formation of soils (Teplyakov *et al.* 1998). The events of the 20th century would artificially separate Russia from the rest of the developed world as the Lenin-Stalin led governments would introduce xenophobic practices eliminating all cross-cultural exchanges, even scientific ones. Research into Russian forestry did not stop during the period of socialism, it continued to be innovative and highly prioritized with noteworthy accomplishments (Teplyakov 1994, Kopylova 1999c). Broader exploitation and intensive management of forestlands would become the theme of forestry sciences in the USSR during the period 1917-1989 (Krankina & Dixon 1992). Russian forest management diverged from the forestry sciences of western Europe and the United States. Even 10 years after the collapse of the Soviet

Union, scientists are still reconciling the erudition of the two countries; each learning from the other side.

Current Conditions

Today, approximately half of the forests of the Russian Federation are outside of the areas of active management because of lacking infrastructure such as roads and rail linkages between regions. This factor is singularly responsible for the majority of forest management challenges such as fire fighting, managing insect and disease outbreaks, artificial reforestation practices, and realizing financial profits from forest management activities. Kopylova (1999b) reported that when averaged over the long-term, about 1.0 million ha. (2.5 million ac.) each year are destroyed by forest fires in the Russian Federation. During 2000, more than 18,000 forest fires were ignited in the Russian boreal forest covering an area of 1.8 million ha. (4.4 million ac.), an increase from the 1999 losses which totaled the annual average of 1.0 million ha. (2.5 million ac.) (MNR 2001). Pest infestations during 2000 in the Russian boreal forest impacted approximately 2.6 million ha. (6.4 million ac.), while forest pathogens were a problem on an additional 13.4 million ha. (33.1 million ac.) (MNR 2001).

Nilsson & Shvidenko (1998) reported that at the beginning of the 1990s, Russian forests generated approximately 1,880 million m^3 of gross growth per year. Roughly 966 million m^3 (51%) of this growth was converted to net growth, while the remaining 914 million m^3 (49%) was lost to mortality. Much of this mortality could have been converted to salable products or prevented completely with an improvement in basic infrastructure.

As the 21st century greeted Russia, the Russian economy was bound by a lingering recession, a currency crash (1998-99), and sluggish export possibilities; the downturn of the Asian economy was especially damaging to Russian forest products sector. Average daily productivity of the Russian forest sector worker (all sectors combined) dropped between 1990 and 1995 by 44%, while at the same time Russian laborers received only 10%, on average, of what their colleagues in the west received (Moiseyev *et al.* 1999). The Russian forest sector was still struggling with record low harvest rates, as of 1996, that were only 47% of what they had been only 10 years earlier (Päivinen *et al.* 2000). Average annual output of roundwood and processed wood from 1990–1997, as compared to average annual production during the period 1970–1990 indicated that production had fallen off a staggering 70% (Figure 2) (Moiseyev *et al.* 1999).

The territory of Russia encompasses approximately 1,709.4 million ha (4,223.9 million acres) (Nilsson *et al.* 2000) with 884 million ha (2,184 million acres) in the boreal forest zone representing over half of the world's boreal forest reserve (Krankina *et al.* 1997). Global climate change is considered a serious threat to these forests because of predictions indicating that productivity, and carbon sequestration abilities, of boreal forests will be diminished by as much as 50% due to global warming. Further, these models forecast increased carbon releases from the soil and detritus layers of boreal forests because of significantly increased decomposition in the changed climate (Manabe & Wetherald 1987). Nilsson *et al.* (2000) estimated that between 1961 and 1983, Russian soils sequestered, on average, 10.1 g C $m^{-2} \bullet yr^{-1}$. This trend reversed between 1984 and 1994 as these forest soils became a net source of carbon emissions into the atmosphere at the rate of 7.1 g C $m^{-2} \bullet yr^{-1}$ due to anthropogenic and natural disturbances.

As the Kyoto Protocol of the UN Framework Convention on Climate Change is debated globally and targets are discussed between countries, there is little disagreement that Russian boreal forests will be considered a critical carbon sink influenced by internal factors of Russia (e.g., forest management practices, forest policy, anthropogenic and natural disturbances) and external factors (e.g., global warming, world-wide wood demand). The elimination of the RFFS, the State Committee for Environmental Protection, and other federal departments and transference of their authority to the MNR in May 2000, while being significant, is only so in terms of how the land resources will be managed in the future. An examination of the organization and goals of the Ministry is necessary.

Structure of the Ministry of Natural Resources

The strengthening of authoritarian rule by the Russian government is evidenced in the new structure of Russian forest management. The structure of the RFFS, prior to the reorganization, was conceived in 1993 and formalized only in 1997 (Chart 1). This rapid evolution, and the establishment of 7 new federal districts (Chart 2, Figure 1), reminds the Russian people of the familiar aroma of soviet times. The seven federal districts report directly to the leadership of the ministry in Moscow. The districts are named as follows (Figure 1):

1) Tcentralny (Central District)
2) Privolzhsky (Volga River District)

3) Yuzhny (Southern District)

4) Uralsky (Ural Mountain District)

5) Sibirsky (Siberian District)

6) Dalnevostochny (Far Eastern District)

7) Severo-zapadny (Northwest District)

Federal District Forestry Departments are a new level of administration not observed in Russian forest management prior to Putin's Decree of May 2000. Organized much like the military of Soviet times, the MNR has a central leadership in Moscow with the listed Regional Districts, each covering a specific geographically continuous region made up of the subjects of the Russian Federation (republic, krai, oblast, autonomous bodies, and okrugs; similar to 'states' in the USA) (Figure 1). Within each 'state' there exists a director of the Forestry Department Administration who oversees all of the resource activities of his or her specialists on the forestland (Chart 2).

Professor Mikhail Mikhailovich Orlov (1930) argued that the establishment of the “leskhoz” (similar to a National Forest in the US Forest Service system) as an additional management structure between the “lesnichestvo” (similar to a Ranger District) and oblast/kray (states) would make management more complicated because any additional link in the chain of command and forest management would reduce power and decision making abilities by requiring more time. He argued that a three link structure (Ministry – oblast/kray – lesnichestvo) is better than a four link structure (Ministry – oblast/kray – leskhoz – lesnichestvo). Considering the changes involving the MNR of today, Russia has acquired an even longer chain of links (Ministry – Federal District – oblast/kray – leskhoz – lesnichestvo) resulting in even slower movement of information and decisions.

Shortly after administrative responsibility was transferred from Goskomekologiya (former Committee for Environmental Protection) and Rosleskhoz (former RFFS) to the MNR, the Ministry conducted an evaluation to verify the list of organizations it managed. At the time of the reorganization, the MNR took over supervision of 282 enterprises (e.g., commercial ventures, production facilities); 187 with a geological orientation, 81 from the RFFS, 6 from water services, and 8 from the former state Committee for Environmental Protection. The MNR also took over management of 2,216 organizations (e.g., managerial offices, institutions); 65 from geology, 1,924 from the former RFFS (including 1,767 leskhozes and 30 national parks), 57 from water services, 170 from environmental protection (including 100 nature preserves) (MNR 2001). In order to streamline the Ministry, the MNR created a transition team to make recommendations on reorganization. Their mandate was dictated in an internal document of the MNR;

> "…In order to increase effectiveness of the enterprises' functioning and to strengthen control over their activities, to improve management's quality control, and to increase revenues into the federal budget from the utilization of federal property, a verification of the number of managed enterprises and organizations is to be conducted." (MNR 2001)

The results of the efforts of the reorganization team were to preserve 143 of the commercial ventures in the form of state run industrial complexes. Fifty of the former commercial offices were transformed into joint-stock companies (which the MNR holds interest), 50 were reformed to become larger companies, while 39 more were liquidated completely. In terms of the administrative centers, out of the 2,216 original offices, 3 have been liquidated with a decision pending on another 113 (MNR 2001).

Also significant in this reorganization is the integration of the national Forestry Research Institutes, and the Aerial Forest Fire Fighting Network (AviaLesoOkhrana), into the ranks of the MNR (Chart 2). These organizations are subordinated at the Regional District level to the Regional Director of the MNR.

The human resources of the MNR are a cumbersome mixture of individuals from the former RFFS, the former State Committee for Environmental Protection, and the pre-existing MNR. There are additional managers that came to the reorganized division from outside the melting pot. For example, the Director of the Far East District of the MNR is a geologist (from the pre-existing structure of the MNR), with a forester as a Deputy Director (from the former RFFS). However, the new head of the MNR in Moscow, Minister Artyukhov, is a political appointee with no history of working in any of the related departments or even a related field of science; he built his career in the car transportation industry. Since the collapse of the Soviet Union, he has filled various government positions, including the post of first deputy finance minister. Artyukhov headed the State Tax Service in 1996 and 1997, and was then transferred to run the Federal Road Service. For the year preceding his most recent appointment Artyukhov held the post of first deputy transport minister (Korchagina 2001).

After over a year of reorganization, it has been a trend that the Regional Directorates in Siberia and the Russian Far East are being led by former executives from the pre-existing MNR. Their administrative focus before, and since, the reorganization has been on the exploitation of oil, gas, and precious minerals and now, an orientation to timber harvesting (Kolomytsev 2001). The Ministry reported that the annual allowable cut (timber) in the Russian Federation during the year 2000 was 549.8 million m^3. According to forestlands managed by leskhozes of the MNR, the volume of timber logged from major cutting operations increased from 1999 by 5.7 million m^3 for a year 2000 total timber harvest of 116.8 million m^3. An additional 19.4 million m^3 was harvested in intermediate thinnings with 11.2 million m^3 harvested during other types of stand treatments (MNR 2001). This amounts to approximately 23% of the annual allowable cut for Russia, a 1% increase over 1999.

There has been a general tendency since 1991 in Russia of increased annual harvest volumes. The former RFFS called on the timber industry to harvest more timber because the overall forest age class distribution was getting older, and the market value of timber harvest was declining. At the same time, the forest fire situation became worse because a significant amount of on-ground fuel-wood had accumulated. Also, the associated increase in timber sale and leasing revenues brought more money into forest management units for their everyday operations such as reforestation, fire fighting, and pest control.

Timber harvest leases managed by the MNR remained unchanged from 1999 to 2000 with approximately 51.2 million m^3 harvested by leaseholders. Timber sold during auctions conducted by the MNR increased 8% between 2000 and 2001 to 29.9 million m^3. However, the auction price increased dramatically (66%) over the same period to reach 1,789.5 million rubles (≈US$64.1 million) and was a result of higher valued timber being sold. Timber sale revenues generated an additional 793 billion rubles (≈US$28.4

billion), an increase of 77.5% from 1999, again largely a result of high valued wood being sold during the Ministry's first year of operating with forestry responsibilities (MNR 2001).

In terms of operating budgets, forest management was allocated only 2.9 billion rubles (approximately US$103.6 million) by the MNR for operations in the 2000 fiscal year; this amount is on par with the forest management budget received for the fiscal year 1999. Of the operating budget for 2000, 560.2 million rubles (≈US$20.0 million) was allocated to forest fire control, 134.3 million rubles (≈US$4.8 million) was allocated to make government investments in commercial ventures, 72.8 million rubles (≈US$2.6 million) for special educational purposes of personnel, and 19.7 million rubles (≈US$0.71 million) for scientific research and engineering into forest management (MNR 2001).

Forests are not the only resource managed by the MNR. Although all mining in Russia is privatized, the management and oversight of oil, gas, and mineral resource exploitation demand a significant amount of the Ministry's human resources. Pelkki *et al.* (2001) estimate that western Siberia possesses the largest oil and gas reserves in the world in terms of area and volume and are seconded in terms of value only to the Middle East. These fields account for 75% of Russia's oil and gas production but carry a severe environmental consequence. Since their first development in the 1970's repeated oil spills have occurred from pipeline failures. Estimates on the level of environmental contamination vary but indicate that as much as 200,000 tons of oil each year are spilled within an 800 km (500 mile) radius of Nizhnevartovsk, Russia (Whitney 1996). When considering the total area of Russia, the magnitude of oil spills into water and on land are estimated at 1 million tons annually, the rough annual equivalent of 25 Exxon Valdez size spills (Hertsgaard 2000).

The problem has been evident for many years and continues to be so today. In May and June 2001, flood-damaged eastern Siberian reservoirs spilled fuel into the swollen Lena River. News reports put the volume of the fuel spill into the Lena River at 13,000 to 18,000 tons (Associated Press 2001). These oil spills degrade forest soils, change rain- and snowfall infiltration, interrupt forest regeneration, fuel massive forest fires, and destroy aquatic ecosystems.

Barriers to Increased Management

Improved forest management of the Russian taiga brings with it many desirable social and ecosystem based outcomes while either a decrease in, or abuse of, forest management activities carries negative consequences. According to Shvidenko *et al.* (1998), the adaptation of reliable and operational systems for forest fire protection is the most important aspect of boreal forest sector management. The inability to access remote lands prevents harvest activities, reforestation, forest fire fighting, insect control, and forest disease control as well.

Current carbon storage measured in the Russian taiga is below its optimum (Shvidenko *et al.* 1998). Research conducted by various scientists at the International Institute for Applied Systems Analysis (IIASA) has concluded that Russian forests could sequester between 400 Tg $C \bullet yr^{-1}$ and 700 Pg $C \bullet yr^{-1}$ through improved management scenarios. In addition, analyses show that carbon emissions from forest disturbances (fire, biotic, abiotic) would be significantly reduced under improved management of the

Russian taiga (Shvidenko *et al.* 1998, Nilsson & Shvidenko 1998, Nilsson *et al.* 2000). The effect of greater sequestration by the forests of Russia coupled with a significant decrease in the amount of carbon emissions from the forest during disturbances falls in the range of values needed to offset the amount of carbon emissions from Russian industry to make Russia a net sink of carbon annually (Nilsson *et al.* 2000).

A constant deterioration of Russian boreal forests from 1975-2001 has demonstrated that small climatic changes have been a negative force, the situation being exacerbated by anthropogenic pressures (Nilsson & Shvidenko 2000). Limited access continues to be a significant obstacle to increased utilization; however, it is not the only factor precluding increased management activities. Russia must develop a stable market economy and a steady commercial forest sector that makes long-term investments in infrastructure, reforestation, fire control, and ecosystem health possible. The question remains as to the way the MNR will approach the issue of an eventual managerial compromise between the goals of resource extraction and the responsibility of forest management (fire control, reforestation, insect and disease control). At this point, it seems evident that the significant revenues being generated by timber harvesting are not being substantially reinvested in the management of the resource.

Development of a 21st Century Market Economy in Russia

The evolution of a market economy and overall market efficiency in the Russian Federation has received considerable and on-going debate (see Gaddy & Ickes 1999, Carlsson *et al.* 2000, Vasenda 2001, Nysten-Haarala 2001). Many of the discussions are directly applicable to the dialogue concerning the MNR. For the MNR to succeed in being a positive change agent for the Russian economy and Russia's environmental goals, we assert that the private forestry sector of the Russian Federation must also develop and mature to provide for some of the inputs to management that have been historically lacking in the Russian forest sector specifically, and the Russian economy in general.

An established private forest sector would solve some of these problems by providing the means of creating, within the bounds of sustainable development supported by the Ministry, an investment infrastructure and a cadre of resource professionals from outside of the bureaucratic agency. Carlsson *et al.* (2000) set forth eight criteria to evaluate the institutional framework necessary for a well-functioning market economy that adheres to the principles of sustainability of forest resources.

1. Constitutional rules are acknowledged and transparent;
2. The structure of property rights is settled and well defined, i.e. private actors can acquire property or get the right to utilize property for their own benefit;
3. Rules and regulations from official authorities are regarded as legitimate and apply equally to similar actors;
4. The market decides the price of property and goods;
5. Decision making regarding collective choice and operational rules is decentralized;
6. Private investors can realize the returns on their investments;
7. Rules are enacted aimed at preventing the devastation of natural resources; and
8. Legitimate authorities take measures against violations of rules.

So far, the Russian Federation has failed to achieve all of these factors simultaneously. Gaddy & Ickes (1999), as well as others, point to the existence of a Russian virtual economy, rooted in the times of the former Soviet Union, preventing many of these conditions from being met. The virtual economy of Russia has been jokingly defined as the situation of the government pretending to provide services to its citizens while taxpayers pretend to pay taxes, and companies pretending to pay their employees while the employees pretend to work. This situation prevents the further development of a still infantile market economy in Russia. The virtual economy is defined by the set of conditions where prices, wages, taxes, and production levels are not set freely in the marketplace, but instead are set through a complicated interplay between politicians who are also major shareholders in businesses, companies that pay their taxes by providing services to the local administrations, business directors that keep their companies operating at a loss because they are able to maintain their personal salaries and pilfer value from the meager earnings generated by the firm while paying their employees a small amount only after a 3 to 6 month delay. Such an economy is only able to maintain itself because it has been insulated from free market competition. This insulation has more often than not been provided by the politicians that are also the financial beneficiaries of the dysfunctional economic policy they implement.

The virtual economy is fed by corruption; from local administrations that require bribes to carry out basic functions or to provide special treatment, to scandals involving the highest levels of administration. For example, according to deputies in the State Duma and officials of the Central Bank, bank officials mishandled and possibly even embezzled portions of International Monetary Fund (IMF) and other loans to Russia in 1998 and 1999. Even former Russian Prime Minister Viktor Chernomyrdin admits that some World Bank credits, such as the coal industry credit, "just disappeared" (Cohen 1999). Such situations involving multimillion-dollar corruption at the highest levels of the Russian government involving IMF and World Bank funds undermine the ability of the economy to attract foreign investors while discouraging increased domestic investments. It is relevant to note that former Prime Minister Chernomyrdin (1992-1998) has a net worth (circa June 2001) estimated at $1.1 billion. He founded gas giant Gazprom. He is now the Russian ambassador to the Ukraine, a major client of Gazprom. He and his family still own significant Gazprom stakes and related properties in Russia (Forbes 2001).

Foreign assistance programs from a variety of donors have provided aid to Russia since the collapse of the Soviet Union. However, much of this aid addresses symbols instead of substance, failing to empower recipients, failing to coordinate efforts between other donors, failing to operate in the extended time horizons of forest management, and failing to provide sufficient funds to make substantial changes in the areas where they intervene (Laarman 2001).

We would point to examples of foreign assistance projects by the US and other countries that have attempted to transplant forest code derivatives from other countries into the Russian legal system. We feel that this transfer of legal infrastructure is bound to failure because laws and codes must reflect the legal, social, and commercial practices of the Russian Federation in order to receive the acceptance and respect of the players in the economy, legal system, and social structure. Russia must develop its own path to achieve its goals in natural resource policy.

The role of the MNR is crucial in developing the structure of a potentially well-functioning forest sector market economy that adheres to the principles of forest resource sustainability. We will consider each of the conditions proposed by Carlsson *et al.* (2000) to evaluate the probability of these conditions being met.

First, are "constitutional rules acknowledged and transparent"? The Russian Federation enacted a national constitution on December 12, 1993. This constitution, and its enforcement, on the surface, meet the conditions of transparency and equal enforcement, however, as demonstrated above, they are compromised by the entrenchment of the shadow economy of Russia and inconsistent enforcement of rules and regulations by administrations at all levels. This nontransparent veil must be lifted to achieve the proper enforcement of constitutional laws.

Next, is the "structure of property rights settled and well defined, i.e. private actors can acquire property or get the right to utilize property for their own benefit?". Ostensibly, property rights are one of the founding tenants of the Russian Constitution. Article 9 of the Constitution directly addresses Natural Resources as the title of the article:

Article 9 [Natural Resources]

(1) The land and other natural resources are used and protected in the Russian Federation as the basis of the life and activity of the peoples living on their respective territories.

(2) The land and other natural resources may be in private, state, municipal and other forms of ownership.

As we can see, in article 9, section 2, the constitution provides for private land ownership including land which is dedicated to natural resource uses. This would include forests, minerals, oil, farm land, business, and related uses. Article 35 addresses the issues of private property in even more detail.

Article 35 [Private Property]

(1) The right of private property is protected by law.

(2) Everyone has the right to have property in his or her ownership, to possess, use, and manage it either individually or jointly with other persons.

(3) No one may be arbitrarily deprived of his or her property unless on the basis of decision by a court of law. Property can be forcibly alienated for state needs only on condition of a preliminary and equal compensation.

(4) The right of inheritance is guaranteed.

In Article 36, land ownership rights are detailed:

Article 36 [Land Ownership]

(1) Citizens and their associations have the right to have land in their private ownership.

(2) The possession, use and management of the land and other natural resources are freely exercised by their owners provided this does not cause damage to the environment or infringe upon the rights and interests of other persons.

(3) The terms and procedures for the use of land are determined on the basis of federal laws.

Finally, in the shortest of the 137 articles contained in the Russian Federation Constitution, Article 58 details the responsibility of all citizens to protect the environment.

Article 58 [Duty to Protect the Environment]

"Everyone is obliged to preserve nature and the environment, and care for natural wealth."

The prominence of property right guarantees in the Russian Constitution would lead to the erroneous conclusion that private ownership of vast areas of forestlands and agricultural land in the Russian Federation is not only allowed but encouraged. On the other hand, it is important to recognize that property rights are not the same as property ownership (Carlsson *et al.* 2000). Property rights are derived from the utilization of scarce resources provided by the property owner to a land user. The historic instability of property ownership in Russia is therefore key to understanding why property rights in Russia are also insecure, even today.

The former RFFS issued 50-year leases of forest concessions to domestic and foreign investors between 1997-2000. A few of these leases were purchased by foreign investors, yet, the application of property rights has been unequal between foreign and domestic concerns. Property rights, as they are understood in the international community are not a fact of life in the Russian Federation.

It is Article 36, paragraph 3, of the constitution which casts a shadow over the ability of Russian citizens to own land and exercise personal property rights in the Russian Federation. It seems that there are no guiding federal laws to set the terms and procedures for land use in Russia. In order to cast light into these shadows, the Duma convened hearings during its June 2001, session to address property rights and ownership issues. There has been and continues to be a strong resistance on the part of the Communists and the Agrarian Party to allow the acquisition of land by private citizens (thereby granting property rights). In their slogans painted on banners during public demonstrations they state "*to sell the land, is to sell Mother Russia!*". There is still significant resistance to property right privatization as it applies to forests and agriculture land.

In an agreement between the Union of Right Forces, the Communist and Agrarian factions, and the president, all controversial parts of new legislation dealing with the turnover of agricultural land and forestland were taken out of the draft that was read on the Duma floor in June 2001. The Union of Right Forces plans on submitting amendments to allow land ownership by foreigners, especially in the case of agricultural land (Borisova 2001). As of the middle of 2001, there were no appreciable areas of forestlands or farmlands in the Russian Federation that are privately held. The lack of private land ownership and poorly defined land use rights will remain a significant barrier to the development of a private forestry sector in the Russian Federation into the near future.

However, simple privation of the land resource is not the solution to this situation. There has been a 200 year gap since Russian people were last allowed to own and manage private forestlands. A current day privatization of Russia's forestlands must be combined with some method of instilling a private forestland ownership culture in the people that will take over the stewardship of the forest resources. Without it, it is questionable if private forestland owners, with no experience or an applicable model to emulate would be successful.

Third, "rules and regulations from official authorities are regarded as legitimate and apply equally to similar actors". Although people are guaranteed equal treatment under the constitution, this particular condition has not been applied uniformly in Russia. A relevant example concerning the MNR during the first half of 2001, involves the competition for the right to develop the Gamburtseva oil deposit in the Nenets Autonomous Area. Although the competition was offered competitively, there were allegations of price fixing and unfair bidding practices surrounding the award to an "insider" familiar to the leadership of the MNR (Raff 2001). Oil companies displeased with results appealed the award. The Russian court declared the award illegal and ordered the MNR to conduct a new competition for the rights (Tutuschkin 2001). This case in point illustrates two sides of this condition to the development of a sustainable free market economy in Russia: on one hand, the system of rules and regulations from official authorities failed to treat all actors in the economy in the same way, while on the other hand, the players in the controversy were able to turn to the courts for a temporary remedy.

Fourth, does "the market decide the price of property and goods?" This condition is especially relevant to the forest sector of Russia, and is only partly operating efficiently at this time. Forest concession owners are allowed to market round log products offshore that were harvested from Russian forests, but prices are limited in that private companies cannot sell for a lower price than state held companies sell for. This condition insures that the state-run logging enterprises remain competitive while also insuring that private companies pay income taxes at higher revenue levels than might otherwise be observed. Even if the state-run organizations are not able to sell in a depressed market, floor prices are enforced making the more efficient private companies actually subsidize their client's purchases when they sell logs for low prices (and still pay income taxes based on an artificially high price). Private logging organizations operating on a state lease or concession are even required to sell logs to the state-owned logging organization at the request of the local administration, for prices set by the state, this condition being non-negotiable in order to keep their license to harvest timber. This inconceivable situation is replicated in other forest business situations around Russia.

Russian and foreign companies operating in Russia as a registered organization must report all hard currency exchanges to the Tax Police and hold that income in a Russian bank. Further, the law states that no less than 75% of all hard currency brought into the country must be converted to rubles through the state-run Central Bank, at the state's exchange rate. Proposals in the Duma during June 2001 offer to reduce this requirement to 50% of all hard currency revenues. The impact of this requirement is an artificial tax further influencing free pricing systems in Russia.

The Russian Tax Authority (Tax Police) has significant power in the Russian Federation. They are able to limit who companies sell to, the terms they negotiate, and they must approve all foreign contracts for the sale of items. Because of these interventions, Russia is still not allowing the market to set the price of all goods and services.

Fifth, is "decision making regarding collective choice and operational rules decentralized?" In the case of forest management by the MNR this condition has worsened in comparison to the management structure observed during the times of the former RFFS. The recent evolution from many departments into one Ministry added another level of vertical structure (e.g., compare the organizations presented in Charts 1 & 2).

During the era of the RFFS, decision making authority was in the hands of a manager located in each subject of the Russian Federation (krai, oblast, etc.). This director was in close contact with field managers and was responsible for forest management activities in his region (Haung 1997). Under the scheme of the MNR, authority for day-to-day management decisions no longer rests in the hands of the local authorities, but is now the purview of the head of the Regional District (Kolomytsev 2001). The MNR Director at the krai or oblast level of administration cannot even sign banking papers on behalf of the local MNR office. In this way, the decision making authority is not as decentralized as one would hope and reason as appropriate, but at least it does not rest solely in Moscow. We assert that the conversion of forest management authority from the RFFS to the MNR has moved forest management decisions in the direction of centralization.

Sixth, can "private investors realize the returns on their investments?" Although there are countless stories about unfair tax regulations, mysterious licensing rules, and a bureaucracy that confiscates profits, the structure of laws and regulations are in place to allow private investors to make and realize profits from investments in the Russian Federation. The establishment of stock market exchanges in Moscow, St. Petersburg, and Vladivostok, has moved Russia forward in this arena substantially. Foreign firms have at their access a mechanism to repatriate capital from investments in the Russian Federation, after taxes of course.

The last two conditions can be considered together; are "rules enacted aimed at preventing the devastation of natural resources?", and do "legitimate authorities take measures against violations of rules?' To these questions a number of conditions must be considered. Although the protection of natural resources was guaranteed in the constitution of the federation, its enforcement is more difficult to establish. Prior to the new authority granted to the MNR, the State Committee for Environmental Protection was responsible for ensuring that legislation concerning the protection of natural resources was enforced. Field based employees of this organization inspected forest management activities from the equipment used on a logging site to the slope of roads and skidding trails. They examined cutting plans and levied substantial fines for violations of the law. Since the summer of 2000, when their organization was abolished by the Kremlin, past Director Viktor Danilov-Danilyan has been "a captain without a ship" (Ognev 2000).

The reformed Ministry now has responsibility for environmental protection. During the second half of 2000 and the first half of 2001, the MNR inspected logging activities of concession holders and leskhozes. Their inspections for compliance with environmental laws resulted in 1.5 billion rubles (≈US$53.8 million) of fines levied against concession holders. An additional 156.7 million rubles (≈US$5.6 million) were filed as damages in court suits against timber sale operators for damage incurred to forest resources of the federation. In addition, during this period, the MNR fined approximately 1,500 government employees and private citizens 4.1 million rubles (≈US$147,000), and filed 126 criminal suits against individuals for violations of environmental laws (MNR 2001). Based on these events, it would seem that the MNR has taken the responsibility of environmental protection seriously. It will be prudent to watch the outcomes of these cases to see if the application of environmental laws was made fairly and uniformly.

The concern by concession holders and many in the international community is that by combining all of the listed agencies into one governmental organization, there is one centralized decision making authority responsible for combining environmental protection with economic gains from the extraction of natural resources. While it is a streamlined organization, the potential conflicts of interest are substantial in this scheme.

What is in Russia's Future Forest Management Challenges?

Russia is faced with the challenge of not only market risks but political risks as well. The Russian people would be well served from laws, no matter how poorly written, that are stable and enforced consistently as opposed to a continuous change in the underpinnings of regulations that have little or no basis in operational reality. On this matter, the responsibility rests squarely with the federal administration of Russia. Historical events dictate that Russia's policy will only be implemented from above.

In the forestry sector, we are witnessing an ebb of management control as decision making authority is being centralized after only 4 years of being slightly decentralized to the level of the subjects of the federation. This progression away from decentralized management authority is a hindrance to the development of a stable and progressive forest sector market economy. It is reasonable to assert that the MNR will be the key agency in interpreting the path of land use policy in Russia, as proclaimed by Presidential decree.

In terms of focal issues facing the boreal forest, the leading topic is Russia's role in abating the negative effects of global climate change during the coming decades. This concern encompasses matters of forest growth, fire, reforestation, logging, and land use changes. The Kyoto Protocol of the UN Framework Convention on Climate Change contains, for the first time, quantified, legally binding commitments, after countries have ratified the protocol, to limit or reduce greenhouse gas emissions (Nilsson *et al.* 2000). According to the Protocol, the industrialized countries must reduce their emissions by at least 5% below 1990 levels within the commitment period 2008–2012. Article 3.3 of the Protocol states that biological sources and sinks should be used for meeting commitments during the commitment period, but limits these sources and sinks to afforestation, reforestation and deforestation since 1990. Article 3.4 provides for the possibility of using additional land-use change and forestry activities to meet reduction commitments (Nilsson *et al.* 2000).

The MNR has operated for the past decade with an institutional mentality of resource extraction. This is the founding principle of oil, gas, mineral, and precious metal removal. Forestry is a very different resource; it requires management, long-term planning, and reinvestment of human resources and monetary capital. In the global picture of the 21st century, Russia's boreal forests play an important role in global climate change predictions.

We can speak in terms of a range of possible courses of action for the MNR to implement at this time. At one extreme, that of singular extraction, the MNR will treat forest resources as a mineral deposit to be "mined" and forgotten. The other extreme, that of long-term resource management, would have the MNR treat the forest as a renewable resource to be invested in and managed. The most realistic possibility will be found between these two extremes, a scheme which would harvest highly valuable stands of timber but reinvest only in those forest stands which meet some criteria of economic profitability.

Under forest management of the first extreme, the forest resources of Russia would continue to be a source of carbon emissions to the atmosphere. While there would be a peak in the amount of carbon stored in lumber and other wood products resulting from harvest and conversion to solid wood products (Schlosser *et al.* 2001), the conversion would be short lived as the cut-over lands would be left to naturally regenerate and all "economically infeasible" forestlands would be left with little or no forest fire protection. Under this scenario, Russia would continue to be a net source of carbon emissions to the atmosphere (barring a dramatic reduction of industrial carbon emissions) and the importance of the Russian boreal forest would be reduced in terms of mitigating the negative effects of global climate change.

Under the environmentally focused scenario, the MNR would continue and expand efforts started by the former RFFS and the Committee for Environmental Protection to manage the forestlands of the country to improve forest health, reduce forest fire size and limit the conditions leading to catastrophic forest fires. The MNR would invest in the long-term development of seed breeding centers and reforestation centers that develop the infrastructure of providing bare-root and greenhouse grown (containerized) seedlings for outplanting to the burnt and harvested forest sites, invest more in forest inventory and planning, pest monitoring and control. The Ministry would make substantial investments in developing a road network into the vast forested areas of Siberia and the Far East that currently have no access except by air. This scenario would be a departure from the traditional management style of the MNR. However, the MNR is now a different organization than it was prior to the reorganization of 2000. Today, the Ministry has foresters and resource managers in its ranks with a long history of boreal forest management. If these natural resource management professionals are able to shape the new MNR to adhere to the principles of long-term forest management, then it is possible that the boreal forest will begin to show increased growth, reduced forest fire losses, and improved forest regeneration benefits into the future. If the agency is allowed to reinvest in resource development this could be a real revolution for forest resources of Russia. Unfortunately, this option assumes a bottom-up system of policy change in the Russian government, a reality that we know is prone to failure in Russia.

The more likely outcome is a compromise between the two extremes. As organizations evolve they are influenced by the people making up the organization and by the leader of the organization, in this case, President Putin. In Russia, top-down management is the norm, and it is the most likely course of action that the MNR will be managed in union with his desires. It was no accident that the President made this change in the way he did. It was his desire to focus forest management activities on a more utilization oriented path than was observed under the 1997 forest code. In public interviews he asserted that Russia must strengthen its economy to catch up with the utilization standards of the west and this must be done before Russia considers further environmental protection (Klose 2000).

As evidenced during events of 2000–01, it is likely that the MNR will focus the majority of forest management activities on actions that are considered profitable in the short-term perspective. The President has made it clear that economic development of the motherland is the "new" guiding principle for forest management. This will likely result in increased harvest rates and a focus on infrastructure development to access forestlands which are also juxtaposed with areas of mineral, oil, or gas resources. By default, these roads and support facilities of the natural resource complex will be available for forest fire protection as well, provided that AvaiLesoOkhrana (Air Forest Fire Fighting Network) is fully funded and given the human resources needed to fight the fires. The critical link will be to see if reforestation of burnt and cut over sites will be made a priority or not; such an investment would require a financial commitment above what is needed for short-term returns. It is doubtful if the long-term investment in a tree seedlings will be considered favorably in an economy where the overriding discount rate (due to inflation and currency devaluation) is well in excess of 40% per annum.

Of course, environmental protection exceeds the considerations of reforestation alone and speaks to a greater philosophy of a land ethic; to protect soil, biologic systems, and ecosystems from damage, to protect rare and endangered species from extinction, and to insure the long-term productivity of the entire resource.

Conclusions

Economic events in Russia demand people's attention much like a flash light does when it is turned on in a dark room. The static of Russian mental habits combined with the dynamics of near instantaneous information exchange in our electronic age results in a colorful mosaic of economic events when viewed against the traditionally monochrome political canvas of Russian society. The constant change of political decorations and reshuffle of more or less socially colorful figures creates an illusion of a change in the eyes of a historically submissive audience. Political librettos written at the very top of power have inevitably controlled the pulse of economic transformations in Russia. In reality, these transformations have gravitated to a central theme of state control over prices, resources, and markets.

The economic structure of Russia at the beginning of the 21st century is a result of over 300 years worth of financial systems evolution. Shock therapy was imposed on the Russian economic system in 1917 and again in 1991. New external market conditions that strive to establish the rules and regulations for a market economy in Russia are destined for failure. North (1991) concluded that although economic systems may change overnight in Russia, "informal constraints embodied in customs, traditions, and codes of conduct are much more impervious to deliberate policies." A survey of the world's financial systems reveals that many forms of market economies have developed. The history of Russia teaches us that the evolution of the Russian market system will take on a somewhat different form from that which exists in the west. Its development is not yet complete, nor is it yet stable.

Patterns of politically acceptable behavior in Russia have sustained little change throughout the past three centuries. The dominant Russian ideology of total obedience to authority has been extrapolated from deep in the dark centuries of the Russian past, elevated to the rank of the socially recognized ethical norm of behavior. This ideology is rooted in a religion that has been the moral stronghold of the Russian people. This spiritual philosophy proclaimed total conformity with the idea of a supreme figure governing each person in the form of a "master." The master is evidenced as the head of a household, director of a workplace, or the leader of a governing political organization. The hierarchy passes through the chief of state before resting finally with God. This philosophy was woven into the basic fabric of the society's culture to sculpt a national character with a diminished primary sense of "self". Communist ideology vaporized the centuries-long power of the Russian Orthodox Church and replaced the void with patriotic hymns and a new God to praise and be submissive to. This turn of script proved to be a variation on the same theme of supremacy of the "people", but never the "individual". This uniquely Russian situation demonstrates why today, the decrees of the President of the Russian Federation will garner substantially more significance in society than rights proclaimed in the constitution, by the Duma, or verbose legal policies offered as part of aid packages from foreign donors.

The total reign of governmental supremacy over the individual appears to be the least conducive factor in the social fabric for an unrestrained release of entrepreneurial energy in any form of economic activity. A western style free market economy in Russia does not seem to be probable in the coming decades. On the brighter side, the ideology of "common sense", when introduced into the national temperament of Russia, will act as a fertilizer to feed the individual sprouts of an institutionalized mentality scattered throughout diversified, albeit bleak, economic landscapes of Russia.

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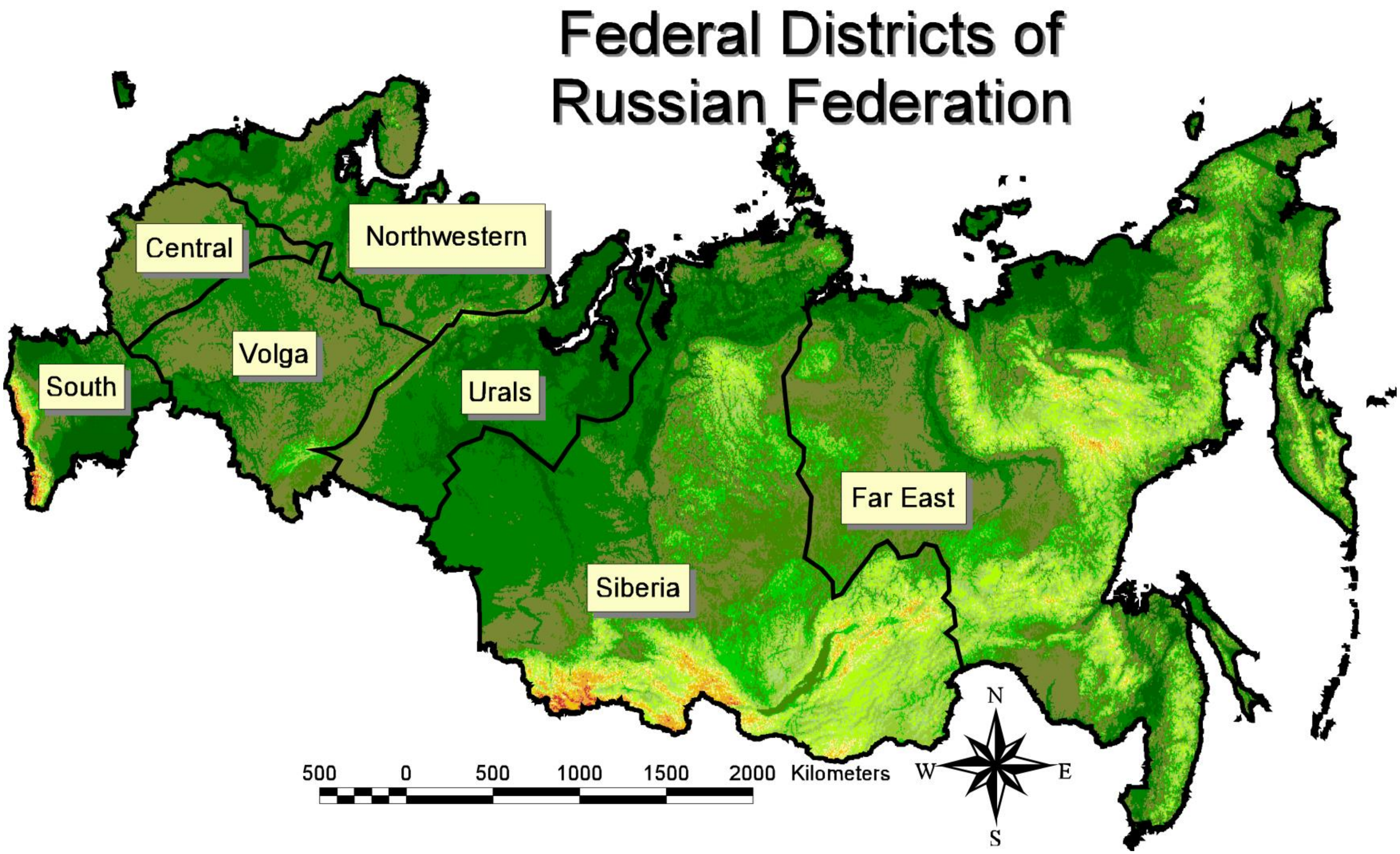
Figure 1. Map of the Russian Federation showing administrative regions (Directorates) of the Ministry of Natural Resources.



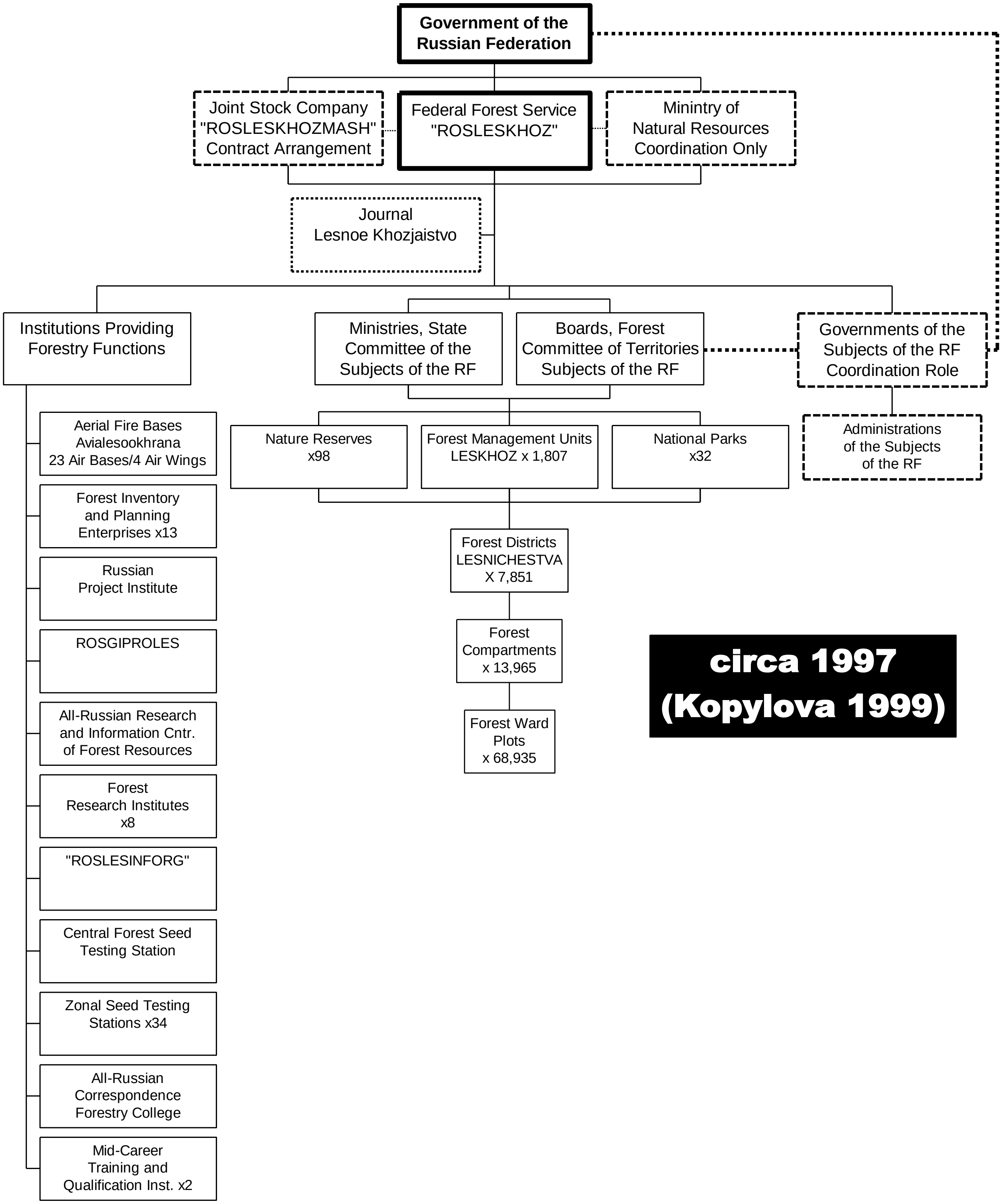
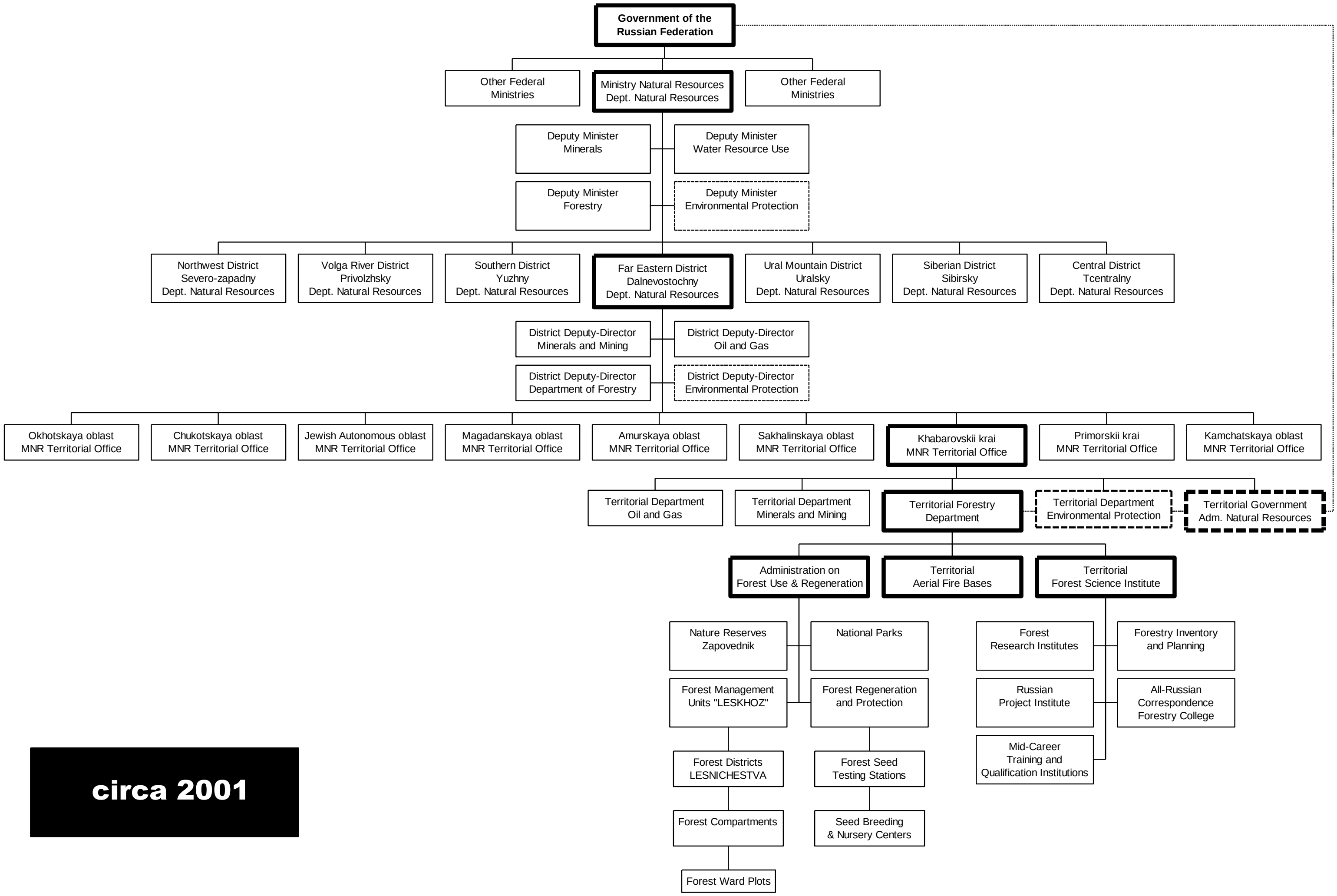


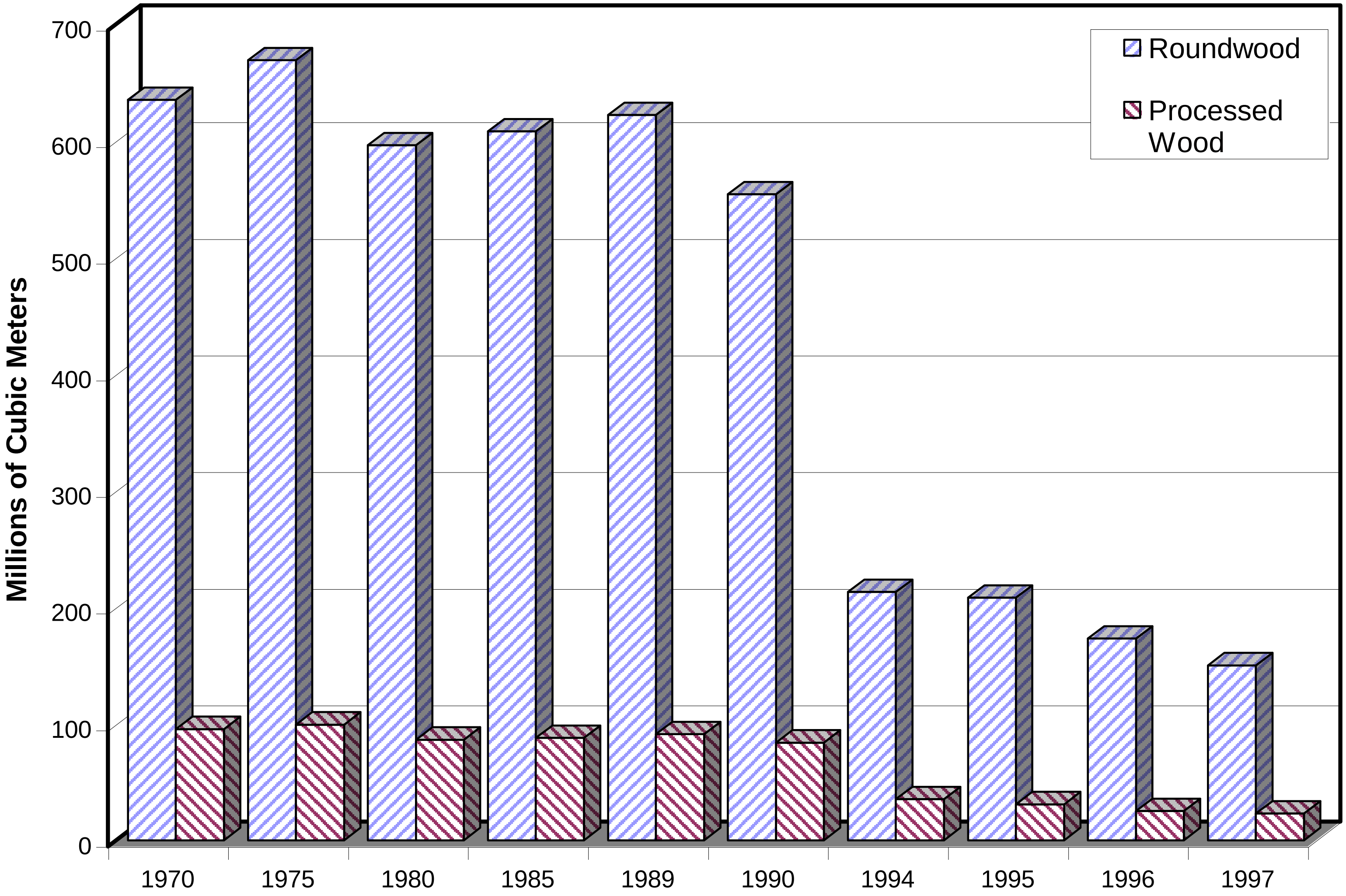
Chart 1. Previous organizational structure of the Russian Federal Forest Service, circa 1997.

Chart 2. Organizational structure of forest management in the Russian Ministry of Natural Resources; example shown for Khabarovskii krai, Far Eastern District. Other subjects of the federation and other districts not shown.



circa 2001

Figure 2. Timber harvest levels in the Russian Federation. Data 1970–1997 (Moiseyev *et al.* 1999).



CHAPTER THREE

A CARBON BALANCE ASSESSMENT FOR CONTAINERIZED *LARIX GMELINII* SEEDLINGS IN THE RUSSIAN FAR EAST

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Abstract

A carbon balance assessment for containerized *Larix gmelinii* seedlings in the Russian Far East determined that the level of carbon emitted to the atmosphere as a result of inputs used in the seedling growing process exceeded the volume of carbon sequestered by the seedlings at a ratio of approximately 1:40 (1 part sequestered carbon to 40 parts carbon emissions). Seedlings were raised at the Nekrasovka Greenhouse Complex, Khabarovskii krai, Russian Federation, during 1998, 1999, and 2000. The amount of carbon sequestered by the seedling growth prior to out-planting was determined by mass spectrometry. Seedling production resulted in an initial carbon deficit, defined as the net carbon released to the atmosphere in the form of carbon dioxide (CO_2). On average, each seedling raised at the greenhouse complex brought about the emission of 76.4 g of carbon dioxide from production inputs, the equivalent of 20.8 g of carbon per seedling. Averaged over three, one-year production cycles, the carbon content of the seedlings was approximately 0.516 ± 0.078 g per seedling, resulting in a 20.28 g carbon deficit per seedling (equivalent to a 74.36 g atmospheric carbon dioxide deficit). To offset this initial deficit, seedlings would need to grow to an estimated 74.68 cm in total tree height after out-planting. In boreal forests of the Russian Far East, this would require approximately 3 to 10 years with time varying depending on specific site conditions.

Keywords:

carbon sequestration, carbon balance, Russia, boreal forests, *Larix gmelinii*, Gmelina larch, reforestation

Introduction

Anthropogenic emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_20) have increased from the mid 19th century to the beginning of the 21st century by approximately 30%, 145%, and 15% respectively (IPCC 1995). Atmospheric levels of carbon dioxide have increased over the same period from an estimated 280 parts per million by volume (ppmv) (Bolin *et al.* 1977) to present day levels of approximately 360 ppmv (IPCC 1995; Nilsson *et al.* 2000). Higher concentrations of greenhouse gasses reduce the ability of the Earth to radiate planetary heat through the atmosphere. Most scientists agree that the increases in greenhouse gases are a major cause in the observed trend of global climate warming (IPCC 1995; IPCC 2001).

Plants in both terrestrial and aquatic ecosystems withdraw carbon dioxide from the atmosphere in the process of photosynthesis. Carbon sequestered from the atmosphere is stored in plant fiber (above and below ground) for extended periods of time, especially in perennial plants such as trees (see Bolin *et al.* 1977; IPCC 1995 for discussions). Higher atmospheric carbon dioxide levels, combined with increased atmospheric nitrous oxide, contribute to enhanced plant productivity generally and, consequently, the rate at which carbon dioxide is removed from the atmosphere (Hollinger *et al.* 1995; Schulze *et al.* 1995; Burton 1997). Therefore, there is some possible homeostatic feedback effect wherein more emissions induce a greater uptake of carbon. On the other hand, increased warming enhances decomposition of detritus on and in soils. The magnitude of these combined biological processes, as well as many other sources of carbon emissions and assimilation, remains largely undetermined. However, it is clear that terrestrial and aquatic ecosystems have been unable to offset increased emissions of carbon dioxide from the burning of fossil fuels, forest fires, and other sources as evidenced by rising atmospheric carbon dioxide levels.

Boreal forests are the most widespread vegetation type in the northern hemisphere (Schulze *et al.* 1999). The world's boreal forests are considered an important sink for atmospheric carbon; both above- and below-ground. The Russian taiga (boreal forest) encompasses some 1,709.4 million ha (4,223.9 million acres) (Nilsson *et al.* 2000) with 884 million ha (2,184 million acres) in the boreal forest zone –nearly half of the world's boreal forest reserve (Krankina *et al.* 1997). Species of *Larix* are an important component of the Russian boreal forest zone, occupying vast areas across its range (Kuvayev & Stetsura 1985; Abaimov 1997; Kajimoto 1999). The role of *Larix* species in the boreal forest ecosystem is noteworthy because of its ability to establish and grow on poor soils and on steep slopes prone to erosion and mass wasting, and its ability to withstand extremely cold winter-time temperatures while tolerating periodic summer-time forest fires common to the region (Kuvayev & Stetsura 1985).

Global warming is expected to reduce net carbon sequestration abilities of such forests by up to 50% due primarily to enhanced rates of soil and detritus decomposition (Manabe & Wetherald 1987). Nilsson *et al.* (2000) have estimated that from the period 1961-1983 Russia experienced a net sequestration of 10.1 g $C \bullet m^{-2} \bullet yr^{-1}$ (0.2979 oz. $C \bullet yd^{-2} \bullet yr^{-1}$) into the soil. This trend reversed between 1984-1994 and these forests became a net source of carbon emissions into the atmosphere at the rate of 7.1 g C $m^{-2} \bullet yr^{-1}$ (0.2094 oz. $C \bullet yd^{-2} \bullet yr^{-1}$) due to anthropogenic and natural disturbances.

Forest preservation, large-scale reforestation, and aforestation efforts have been proposed as actions that will help mitigate global climate change by increasing long-term carbon sequestration capacity. The American Forestry Association (2000) Internet web site even offers an interactive page for calculating how many trees a year a household must plant to offset their greenhouse-gas contributions to global warming (increased tree planting would also offer additional ecological and economic benefits).

The net amount of carbon sequestered as a result of reforestation or aforestation efforts must consider carbon costs (from carbon dioxide emissions) of seedling husbandry, planting, and managing the forests, as well as the changes caused to carbon pools as a result of the activity. Figure 1 presents a rough schematic of the carbon pools (sinks and sources) influenced by tree planting and forest management. Our study addresses only one aspect of this large and complex issue. Specifically, we focus on the "carbon cost" of raising containerized seedlings at a greenhouse facility, destined for forestry out-planting in the Russian boreal forest. We estimate a net carbon cost at the point of out-planting by also calculating the amount of carbon sequestered in the seedling.

We use a carbon balance approach related to the Life Cycle Assessment (LCA) method. Variations of the LCA approach have been used on many projects globally (see for examples; Aycaguer *et al.* 2001; Vehar 2001; Börjesson & Gustavsson 2000; McCann & Magee 1999; AFPA 1996; Atkinson *et al.* 1996; Komiyama *et al.* 1996; Nieuwlaar *et al.* 1996) to determine the environmental burden for a process or service during the life of a project, or a specific phase of an undertaking (Ayres 1995; Heijungs & Guinée 1992). In our study, we evaluate only carbon dioxide emissions to the environment caused by raising containerized conifer seedlings – beginning with the processing of collected cones and ending with the preparation of shipping the seedlings to forestry units in the region. We focus on a specific greenhouse complex in the Russian Far East. This "cone-to-seedling" (*to the farm gate*) approach allows the forest manager to receive seedlings with a "carbon cost" prior to planting in various forest conditions. The carbon dioxide cost of seedling transportation and planting in the boreal forest is highly variable and must be assigned by the forest manager where the seedlings will be raised; these post greenhouse activities were not considered in this research.

Many activities involved in growing containerized seedlings in greenhouses create a net release of carbon dioxide to the atmosphere that is not immediately sequestered by the seedlings the practice produces (Table 1). These carbon dioxide emissions must be offset against the sequestration of the tree seedlings in determining the net carbon balance. To date, there have been no comprehensive studies employing the LCA approach to determine the net carbon dioxide emissions cost of raising containerized seedlings in a commercial greenhouse setting.

This carbon balance assessment focuses on the activity of raising containerized seedlings at the Sosnovka Seed Breeding Center (48.43º N, 135.13º E) in the Russian Far East region of Khabarovskii krai (krai, republic, oblast, autonomous bodies, and okrugs are administratively similar to 'states' in the USA). The seedlings referenced in this study were raised at the Center's Nekrasovka Greenhouse Complex and were used to repopulate boreal forests in the Russian Far East that were harvested or burnt by forest fires. Gmelina larch (*Larix gmelinii* (Rupr.) Kuzeneva), Korean pine (*Pinus* *koraiensis* Siebold & Zucc.), and spruce (*Picea ajanensis* (Lindl. et Gord.) Fisch. ex Carr.) are all produced at this facility. Two greenhouses were operational in 1998 (500,000 seedlings) and a third greenhouse was added in 1999 . The annual total number of seedlings in 1999 and 2000 raised in the three-greenhouse complex was 700,000 and 755,700 respectively (Table 2). The primary species raised at this facility is Gmelina larch.

Seed is extracted from cones, then cleaned and stored in a dedicated freezer facility. Each spring seedlings are sown into containers, raised for one season (April-October) in a greenhouse, and then placed in a dedicated winter storage cooler prior to outplanting in the forest the following spring; each seedling spends only one growing season at the greenhouse facility. Our study was based on three growing seasons from 1998–2000; data represented for each year represent a new and unique batch of seedlings.

Only carbon dioxide emissions were evaluated. Other greenhouse gases were not assessed. Some of the seedling production activities caused carbon dioxide to be released into the atmosphere directly in the production of seedlings (e.g. petroleum combustion). In other cases, carbon dioxide is released into the atmosphere in the production of inputs used in seedling production (e.g. cement and fertilizer production). Although there are additional activities that cause carbon dioxide to be released to the atmosphere during nursery production (Table 1), generally these other sources are minor relative to those evaluated – some are discussed briefly in this manuscript. While not the focus of the paper, some other greenhouse gasses are mentioned in relation to their interaction with carbon dioxide.

The objectives of the study were to: (1) evaluate the amount of carbon released to the atmosphere as a direct result of raising containerized conifer seedlings in the Russian Far East; (2) calculate a seedling carbon "initial deficit"; and (3) provide tools for estimating the time required for seedlings to "pay back" their carbon deficit and represent a net carbon sequestration gain to the environment. These findings should prove useful in assessing the overall lifecycle carbon sequestration of Russian boreal forests. The methods developed here may also provide a useful framework for additional studies in other forest systems.

Methods and Data

Carbon Dioxide Emissions from Production

Table one lists the main carbon emitting activities at the seed breeding center which used electricity produced by regional coal burning facilities. Grass-peatmoss was the main potting media. Perlite was used as a seed covering at the time of seed sowing. Liquid fertilizers were applied to the seedlings recurrently during the growing season. Fuel-powered trucks, tractors, and automobiles were used in the management and operation of the seed breeding center. An electric water pump (with a gas-powered back-up) pulled water from a well and then pressurized water lines supplying an electric powered irrigation unit. Two gasoline powered electric generators provided back-up power supply for the greenhouse facility while one diesel-powered generator provided back-up electrical support at the freezer-and-cooler complex, when the regional power supply was off-line.

Carbon dioxide discharge from the listed activities was determined using results from a variety of studies conducted by the US Environmental Protection Agency (EPA), production information (inputs and outputs) included in the US Census of Manufacturers, independent research studies, and emission statistics published for various energy sectors in Russia. The Sosnovka Seed Breeding Center reported actual seedling production (Table 2) and the corresponding annual usage of listed inputs such as fuel, electricity, fertilizer, and perlite (Table 3). The volume of cement and the weight of steel used in construction were recorded directly from construction records.

Carbon Sequestration by Seedlings

Seedlings raised at the Sosnovka Seed Breeding Center's Nekrasovka Greenhouse Complex during the year 2000 were sampled to determine their oven-dry weight and carbon content. We estimated that the *L. gmelinii* seedlings from the year 2000 were representative of 1998 and 1999 production in terms of culture and management regime of that particular species, and therefore we estimated that their average weight and carbon content would be representative of the previous years.

Three seedling container sizes (distributed by Stuewe & Sons, Corvallis, Oregon, USA: Rigi-Pots 45-70, 45-95 and 45-110) were used at the greenhouse complex during the three years evaluated in this study: 70 ml (80 mm deep), 95 ml (100 mm deep), and 110 ml (120 mm deep). The latter two were primarily used in the culture of larch species, while the 70 ml container was used primarily for raising Korean pine seedlings, with a small number used to raise larch seedlings.

During the winter of 2000–01, twenty larch seedlings from each of the three container sizes were selected at random (60 total) from the seedling winter storage cooler, and oven-dry weight (ODW) of each seedling was determined. Since the seedlings were larch, needles were not present. Each seedling was cleaned of substrate matter (peat moss and perlite), numbered, and then placed in an oven at 70° C (158° F) and dried to constant mass.

A separate sample of 12 seedlings raised in greenhouses utilizing polyethelene covering on the frame of the greenhouse, and another sample of 10 seedlings from a greenhouse covered with nonpolyethelene resin plastic were taken. Both were random samples from the 95 ml and 110 ml containers. These seedlings were oven-dried, ground, placed in containers, and labeled. The percent composition of carbon was determined for each of the 22 seedling samples at the Idaho Stable Isotopes Laboratory, University of Idaho. Carbon composition was determined using a continuous-flow elemental analyzer coupled with an isotope ratio mass spectrometer (the elemental analyzer used was a CE Instrument's model NC2500 of Milan, Italy; the isotope ratio mass spectrometer used was a Finnigan MAT delta-plus manufactured in Bremen, Germany). The isotope ratio mass spectrometer was used as the detector to determine the precise isotope ratio compositions. Stable isotope composition was recorded per mil as $\delta^{13}C$. Information on the 1998, 1999, and 2000 growing seasons were utilized to link seedling carbon sequestration with seedling production related carbon dioxide emissions.

Results

Electricity Production and Consumption

Electricity production in the Russian Far East and Siberia derives from coal (75%), hydroelectric (24%), and nuclear (<1%) sources. Energy production in Khabarovskii krai and neighboring Primorskii krai, Sakhalinskaya oblast, and Kamchatskaya oblast is exclusively from power plants burning primarily bituminous coal (Kalashnikov 1997). This variety of coal supplies 20 to 29 megajoules (MJ) of energy per kilogram (8,616 to 11,202 $\text{BTU}\bullet\text{lb}^{-1}$) of coal burned and has a high sulfur content (up to 35%) (McConnell 1999). The Khabarovsk Economic Research Institute (Kalashnikov 1997) estimates that the average energy efficiency of these facilities for electricity production is only 31-34%.

One short ton of bituminous coal produces approximately 27,431 MJ ($26\text{x}10^6$ BTU) of energy (Grillot 2000) and one kilowatt hour (kW-h) of electricity requires 3.6 MJ (3,412.1412 BTU) (McConnell 1999). From 1998–2000, the Sosnovka Seed Breeding Center's seed freezer and seedling cooler facility used 10,200 kW-h of electricity per year (Table 3), consuming 4.1188 short tons of coal as calculated using equation (1):

$$\left(\frac{\text{10,200 kW-h}}{\text{Year 2000}}\right)\bullet\left(\frac{\text{3412.1412 BTU}}{\text{1 kW-h}}\right)\bullet\left(\frac{\text{1 short ton coal}}{26\text{x}10^{6}\text{ BTU}}\right)\div 0.325 = \text{4.1188 short tons coal} \qquad (1)$$

where .325 = average electrical energy conversion efficiency.

Burning of typical bituminous coal with an energy content of 20–29 $\text{MJ}\bullet\text{Kg}^{-1}$ (average 24 MJ) will release 94 g $\text{CO}_2\bullet\text{MJ}^{-1}$ ($3.5\text{x}10^{-3}$ oz $\text{CO}_2\bullet\text{BTU}^{-1}$), or 2.25 Kg $\text{CO}_2\bullet\text{Kg}^{-1}$ of burned coal (Statoil 2000). Therefore, the electricity produced in support of the freezer and cooler complex released 8,407.3 kg CO_2 (18,534.6 lb CO_2) into the atmosphere during each year of production (Equation 2):

$$\left(\frac{4.1188\text{ short tons coal}}{\text{Each Year}}\right)\bullet\left(\frac{907.2\text{ Kg coal}}{1\text{ short ton coal}}\right)\bullet\left(\frac{2.25\text{ Kg }CO_2}{1\text{ Kg coal}}\right)=8{,}407.3\text{ Kg }CO_2 \qquad (2)$$

Results of the calculations for each of the three years evaluated are presented in Table 3 for the freezer-and-cooler complex as well as the greenhouse facilities.

Petroleum Consumption

Gasoline and diesel fuel-powered generators, tractors, and automobiles (cars, trucks, and a bus) are used at the seed-breeding facility. Between 4,000 and 4,500 liters of gasoline and diesel fuel (between 1,057 and 1,189 gallons [US]) were consumed each year from 1998–2000 (Table 3).

Carbon dioxide emissions to the atmosphere resulting from the operation of fuel-powered vehicles and equipment were calculated using a 99% conversion factor of carbon in fuel to carbon dioxide and the relationship that diesel fuel is approximately 87% by weight composed of carbon, while gasoline is 86% by weight composed of carbon (EPA 2000). Considering the year 2000 fuel data, 4,300 liters (1,136 gal [US]) of fuel were consumed (gasoline and diesel combined). The approximate weight of petroleum (at 15° C) is 0.7393 $Kg\bullet L^{-1}$ (6.1568 $lb\bullet gal^{-1}$ at 59° F), and the average gasoline and diesel carbon content by weight is 86.5%. The conversion of fuel-bound carbon to atmospheric carbon dioxide from combustion in the year 2000 is 2,722.3 Kg CO_2 (Equation 3) (5,989.1 lb CO_2):

$$\left(\frac{4{,}300\ \text{L fuel}}{\text{Year 2000}}\right)\bullet\left(\frac{0.7393\ \text{Kg fuel}}{1\ \text{L fuel}}\right)\bullet\left(\frac{99\ \text{Kg Carbon}}{100\ \text{Kg fuel}}\right)\bullet\left(\frac{86.5\ \ \text{Kg CO}_2}{100\ \text{Kg Carbon}}\right)=2{,}722.3\ \text{Kg CO}_2 \quad (3)$$

Estimates of the carbon dioxide contribution to the atmosphere from fuel combustion at this facility are presented for each of the three years in Table 3.

Growth Stimulant Usage

The seed breeding center uses a variety of fertilizers and supplements to satisfy the nutrient needs of its seedlings. Included are a pre-emergent fertilizer (9-45-15 at $\approx 0.24 \text{g} \bullet \text{tree}^{-1} \text{year}^{-1}$), a growth fertilizer (20-10-20 at $\approx 1.70 \text{g} \bullet \text{tree}^{-1} \text{year}^{-1}$), a hardening off fertilizer (5-11-26 at $\approx 0.48 \text{g} \bullet \text{tree}^{-1} \text{year}^{-1}$), and an iron supplement (Sprint 330 at $\approx 0.02 \text{g} \bullet \text{tree}^{-1} \text{year}^{-1}$). The facility used 1,225 Kg (2,700 lbs) of fertilizers (all combined) in 1998, 1,715 kg (3,780 lbs) in 1999, and 1,850 kg (4,078 lbs) in 2000. All of the fertilizers were mixed on site and applied in liquid form through a fertilizer injector (Dosmatic Plus DP305, Model A30-2.5) into a hanging irrigation system (McConkey Co., ITS Basic Grower).

Both particulate matter and gaseous air emissions are generated from the application of nutrients as fertilizers. Researchers have observed only nitrogen-based molecule emissions as a result of applying fertilizers (EPA 2000; Johansson 1984). There is no evidence to conclude that carbon dioxide is emitted to the atmosphere as a result of fertilizer application *per se* although small quantities of nitrogen emissions may occur. Therefore, in this study, zero emissions were assumed to occur at the time of fertilizer application.

On the other hand, the fertilizer manufacturing process does release greenhouse gases into the atmosphere. The production of nitrogen fertilizers, including urea, produces small amounts of nitrogen oxides but no reported carbon dioxide is released (EPA 1993). Production of phosphate fertilizers does not directly contribute additional greenhouse gasses to the atmosphere (Pacific Environmental Services, Inc. 1996). However, the burning of natural gas during the manufacturing of fertilizers emits carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), methane (CH_4), nitrous oxide (N_2O), volatile organic compounds, trace amounts of sulfur dioxide (SO_2), and particulate matter (EPA 1995).

The exact quantities of greenhouse gasses emitted from the manufacture of fertilizers are still being determined (EPA 2000). Current available estimates on natural gas emissions were used to estimate carbon dioxide released into the atmosphere (Census 1999; EPA 2000). Specifically, the nitrogenous fertilizer manufacturing industry was used as a proxy for the entire fertilizer industry in estimating carbon dioxide release in this study.

The nitrogenous fertilizer manufacturing industry burned 11.13 billion cubic meters (393.2 billion standard cubic feet) of natural gas in 1997 in the production of approximately 2.86×10^9 kg (6.3 billion pounds) of fertilizer (Census 1999). Roughly 1.926 kg CO_2 is released into the atmosphere for every cubic meter (0.11998 lbs $CO_2 \bullet$ cubic foot^{-1}) of natural gas burned (EPA 2000). The Sosnovka Seed Breeding Center applied 1,850 kg (4,079 lbs) of fertilizers in 2000. Using industry production rates and published carbon dioxide emission rates, the emissions caused by the use of fertilizers at this greenhouse facility are estimated for the year 2000 to be 13,837.4 Kg (30,505.7 lbs) CO_2 (Equation 4):

$$\left(\frac{11.13\text{x}10^9\ \text{m}^3\ \text{natural gas}}{2.86\text{x}10^9\ \text{Kg fertilizer}}\right)\bullet\left(\frac{1.922\ \text{Kg CO}_2}{1\ \text{m}^3\ \text{natural gas}}\right)\bullet\left(\frac{1{,}850\ \text{Kg fertilizer}}{\text{Year 2000}}\right)=13{,}837.4\ \text{Kg CO}_2 \quad (4)$$

Results for calculations for the other two years are shown in table 3. It is important to note that these are rough estimates using indirect evidence of the emissions of carbon dioxide caused by fertilizer manufacture.

Perlite Consumption

Perlite is a pearl-colored product manufactured from glassy volcanic rock. It is used in the greenhouse industry as a covering over seedling containers immediately after substrate and seeds are placed in the seedling containers. It provides protection for seeds from direct sunlight, water splashing during irrigation, and alleviates the effects of extreme temperature variations during germination. The components of perlite include silicon dioxide (71-75%), alumina (12.5-18%), potassium oxide (4-5%), calcium oxides (1-4%), and trace amounts of metal oxides (EPA 1995).

The manufacturing process of perlite involves mining, crushing, drying in a rotary dryer, grinding, screening, and shipping to expansion plants where furnaces are operated at temperatures as high as 980° C (1,800° F). Production rates are normally less than 1,800 $\text{kg}\bullet\text{hr}^{-1}$ (3,960 $\text{lbs}\bullet\text{hr}^{-1}$) (EPA 1995).

Particulate matter is the primary pollutant generated from the manufacture process of perlite. Nitrogen oxides created during perlite expansion are generally negligible

(EPA 1995). Sulfur dioxide (SO_2) emissions may result when sulfur-containing fuels are used in the manufacture process through the mixing of particulate matter (from processing) and exhaust gasses (from machinery). Of most relevance to our analysis of carbon is the fact that the primary fuel source used in the industry is natural gas. Fuel consumption ranges from 2,800 to 8,960 kilojoules (KJ) per kilogram (2.4×10^6 to 7.7×10^6 $Btu \bullet ton^{-1}$) of finished product (EPA 1995).

Operation of expansion furnaces during perlite manufacture releases 420 kg $CO_2 \bullet Mg\ perlite^{-1}$ (840 lbs $CO_2 \bullet ton\ perlite^{-1}$) (W.R. Grace and Company 1984). Dryer operation releases an additional 16 kg $CO_2 \bullet Mg\ perlite^{-1}$ (32 lbs $CO_2 \bullet ton\ perlite^{-1}$) (Ecology Audits, Inc. 1979). Combined, these sources produce a total of 436 kg $CO_2 \bullet Mg\ perlite^{-1}$ (872 lbs $CO_2 \bullet ton\ perlite^{-1}$) produced.

The greenhouse complex used a total of just 45 kg (100 lbs) of perlite in 1998, and 68 kg (150 lbs) in each of 1999 and 2000. Converting the "carbon dioxide cost" of this input to production, we estimate that this caused a 19.6 kg (43.2 lbs) CO_2 discharge into the atmosphere in 1998 and a 29.6 kg (65.3 lbs) CO_2 discharge in each 1999 and 2000 production years (Table 3).

Seedling Container Trays and Greenhouse Coverings

The seedling container trays (Rigi-pots distributed by Stuewe & Sons, Corvallis, Oregon, USA) were manufactured from high-density polyethylene (HDPE) plastic resin. The greenhouse coverings (clear polyethylene plastic) material was manufactured from linear low-density polyethylene (LLDPE). In contrast to the other inputs to production at this greenhouse facility, both of these polyethylene products represent a dense carbon sink in their final product form. Both HDPE and LLDPE products are approximately 86% by weight composed of carbon atoms in the complex polyethylene molecule (EPA 2001).

Although various volatile organic compounds (VOC) are created in the manufacture of polyethylene resins (EPA 1997, Barlow *et al.* 1996, EPA 1983), there are no reported emissions of carbon dioxide from the manufacture process. Barlow *et al.* (1996), reported that the manufacture process created gaseous and volatile hydrocarbons including heavy hydrocarbons (HHC), primarily C_4–C_{16}, (HDPE: 38.5 g HHC/ Mg polyethylene resin; LLDPE: 21.3 g HHC/ Mg polyethylene resin) and light hydrocarbons (LHC) including ethane (HDPE: 0.02 g LHC/ Mg polyethylene resin; LLDPE: 0.04 g LHC/ Mg polyethylene resin), ethylene (HDPE: 0.01 g LHC/ Mg polyethylene resin; LLDPE: 0.02 g LHC/ Mg polyethylene resin), and propylene (HDPE: <0.01 g LHC/ Mg polyethylene resin; LLDPE: <0.01 g LHC/ Mg polyethylene resin).

Because HDPE and LLDPE are 86% by weight composed of carbon, polyethylene resin plastics are not considered a net source of carbon dioxide emissions in the manufacture process, even though some amount of carbon dioxide can be emitted to the atmosphere from combustion equipment used to heat reactors, dryers, and other process equipment used for the container tray and greenhouse covering manufacture process (EPA 1997). In summary, no carbon emissions to the atmosphere have been attributed to the seedling raising process as a result of the use of polyethylene products.

Cement Used in Construction

The Russian Federal Forest Service built two warehouses to accommodate equipment used in support of the greenhouse facilities. The first building is home to seed cleaning, seed sorting, and storage equipment. It is also home to a walk-in freezer (seed storage) and walk-in cooler (seedling winter storage). The second structure contains a seed sowing line, peat moss grinder, winter storage for seedling containers, and a small project office. Both of these buildings required substantial amounts of cement in construction (flooring and foundation).

Energy consumption is the largest single factor contributing to carbon dioxide emissions in the manufacture of cement (EPA 1995). The carbon dioxide emissions from cement manufacturing are generated by two mechanisms: (1) fuel combustion releases substantial quantities of carbon dioxide, and (2) substantial quantities of carbon dioxide are generated through calcining of limestone or other calcareous material. The calcining process thermally decomposes calcium carbonate ($CaCO_3$) to calcium oxide (CaO) and carbon dioxide (CO_2) (Buildinggreen 1996). Cement contains approximately 63.5 percent calcium oxide. About 1.135 units of calcium carbonate are required to produce 1 unit of cement, and the amount of carbon dioxide released in the calcining process is about 500 $\mathrm{Kg \bullet Mg^{-1}}$ (1,000 pounds per ton) of cement produced.

When combined, the carbon dioxide emissions total approximately 374 kg $CO_2 \bullet m^{-3}$ (629 lbs $CO_2 \bullet yd^{-3}$) of cement produced (Buildinggreen 1996). Each building at the Sosnovka Seed Breeding Center required approximately 144.0 cubic meters (188.3 cubic yards) of cement for flooring and foundations. Therefore, each building caused the release of approximately 53,856 kg (118,730 lbs) CO_2 when built. By placing a useful life of the buildings at 20 years we estimate the average annual carbon dioxide emission equivalent to be 2,692.8 kg (5,936.5 lbs) CO_2 per year per building due to cement usage.

In addition, approximately 11.0 cubic meters (14.4 cubic yards) of cement were used for footings in the greenhouse foundation representing an emission of 4,114.0 kg (9,069.7 lbs) CO_2 per greenhouse. We estimate the useful life of a greenhouse frame support to be 20 years.

Combining these sources, the 1998 carbon dioxide emission factor, when the center operated two greenhouses and two production buildings, is calculated as (2 • 205.7 kg CO_2) + (2 • 2,692.8 kg CO_2) for a total of 5,797.0 kg (12,780.0 lbs) CO_2. In 1999 and 2000, the center operated 3 greenhouses bringing the annual emission factor to 6,002.7 kg (13,233.5 lbs) CO_2 from cement usage (Table 3).

Steel and Iron Used in Construction

In addition to concrete, the two warehouses were built using steel frames and metal siding. Each building included 34 metric tons (74,956 lbs) of steel framing and 14 metric tons (30,864 lbs) of metal siding and roofing, for a total steel use of approximately 48.0 metric tons (105,820 lbs) each. In addition to being an energy intensive manufacturing process, the production of iron and steel causes the emission of carbon dioxide (EPA 2001). Iron is approximately 4.0% to 4.5% carbon by weight, and carbon dioxide is produced during the oxidation process. The steel that is created from this process is less than 1.7% carbon by weight (Worrell *et al.* 2001). Worell *et al.* (2001) further determined that the processes involved in manufacturing primary steel and secondary steel created the average emissions 1.38 kg CO_2/kg final product steel in the USA during 1994.

Unfortunately, there exists no similar assessment of the Russian steel manufacturing sector for any year. The US steel manufacturing industry of 1994 can be used as a proxy for the Russian steel manufacturing industry, recognizing that the actual probable emissions caused from steel manufacture in Russia will be larger due to a greater reliance on coal for electricity generation (Kalashnikov 1997) and fewer efficiencies in the manufacture process of iron products (Royal & Purdum 1998), due, in large part, to the historically monopolistic, state-enterprise structure of the industry (Kelly 2000).

Based on the 1994–US carbon dioxide emissions rate of 1.38 kg CO_2/kg steel, each building used at the Sosnovka Seed Breeding Center caused the emissions of approximately 66,240 kg CO_2 (1.38 kg CO_2 x 48,000 kg steel) (146,032 lbs CO_2) during their construction. Combined, this totals 132,480 kg CO_2 (292,064 lbs CO_2) for both buildings. By placing a useful life of the buildings at 20 years we estimate the average annual carbon dioxide emission factor to be 6,624.0 kg (14,603.2 lbs) CO_2 per year for both buildings due to processed steel usage (Table 3).

In the calculations concerning building construction (cement and steel) we are assuming that carbon should be counted at full value whenever it is emitted or stored. However, since the framework for the current study counts annual emissions, some way must be found for reconciling the once every 20 year carbon emissions for building construction with the annual emissions related to other inputs. Counting emissions at either the once-in-20-years construction related emissions or at zero for nonconstruction years would misrepresent these emissions. Instead, we prorated the emissions over the 20-year life of the project. One might think of it as if one were undertaking 20 identical projects, with each project starting one year apart. An alternative approach might involve discounting future carbon emissions to the atmosphere or placing a premium on current carbon sequestration (depending on timing). Whether time should matter and how time should be treated in these calculations is clearly an important issue, but it is beyond the scope of the present paper. In summary, for this study the carbon dioxide released to the atmosphere was allocated to the seedlings over the useful life of the structures, even though all of the carbon dioxide emissions were observed in the year of construction. Figure 3, presents the emission flow volumes graphically: 1) showing the emissions and sequestration as they occur (block charts); and 2) showing the allocation of emissions to seedlings, prorated over the useful life of the structures (line chart).

Total Carbon Dioxide Emissions from all Sources

Actual emissions of carbon dioxide during the initial construction phase of the center totaled 240,192 kg (529,524 lb) CO_2 from cement and steel manufacture (Figure 3). Additional carbon dioxide emissions from cement usage in construction occurred in 1998 (8,228 kg – 18,139 lb) and 1999 (4,114 kg – 9,070 lb). Annual emissions of carbon dioxide caused by facility operations equaled just 34,114.4 kg (75,208 lb) in 1998; 38,508.1 kg (84,894.4 lb) in 1999; and 39,061.6 kg (86,114.6 lb) in 2000 (Figure 3).

In order to allocate carbon dioxide emissions from construction to the outputs of the process (seedlings), we propose to distribute the carbon dioxide emissions that occurred during construction over the useful life of the structures as discussed above.

By apportioning one time emissions over the structure's useful life, and then to the volume of seedlings grown each year, we derive the "fixed carbon cost" attributable to the seedlings, expressed on a per-seedling-per-year basis. The annual "variable carbon cost" is added to this sum to create the actual carbon emissions cost of raising the seedlings.

Following this procedure, the total allocated emissions to the atmosphere equaled approximately 46,555.0 Kg (102,634.5 lbs) CO_2 in 1998; 51,164.4 Kg (112,796.3 lbs) CO_2 in 1999; and 51,717.9 Kg (114,016.5 lbs) CO_2 in 2000 (Figure 3). When considered in light of annual production, the "initial carbon outlay" was approximately 93.1 g (3.28 oz) per seedling in 1998; 73.1 g (2.58 oz) per seedling in 1999; and 68.4 g (2.41 oz) per seedling in 2000. The three year weighted average "initial carbon outlay" was approximately 76.4 g (2.69 oz) per seedling. This can be considered the average carbon dioxide emissions cost of raising conifer seedlings at this facility.

There would appear to be a decreasing trend of average annual carbon dioxide emissions in that the average annual carbon cost per tree decreased each year, over the 3 year period. This has occurred because of allocating fixed carbon costs over the total number of seedlings. Thus, energy costs, such as electricity required for the freezer-and-cooler operations, and the cement and steel used for the construction of the support buildings remained the same as operations expanded. Both the refrigeration complex and the support buildings operated with excess capacity in 1998, and to a lesser extent even in 1999 and 2000. Since seedling production increased each year, these fixed costs were allocated among an increasing number of seedlings and the average declined. In economic terms these declining average carbon emissions are “returns to size” of the operations. We would not expect to see this average annual carbon emission cost continue to decrease past 2000 unless additional greenhouses are built.

Carbon Sequestered by the Seedlings

There was no significant statistical difference (P=0.8973) between the ODW of the 95 ml and the 110 ml container-grown larch seedlings (Table 5). There was a significant difference between the ODW of the 70 ml container-grown seedlings and the ODW of the other two groups, individually at the 90% confidence interval. One greenhouse, occupied by 110 ml seedling containers, was covered with a low quality plastic (nonpolyethelene resin composite). The other greenhouses were covered with a 6 mil polyethelene greenhouse clear film (3 year), specially manufactured for greenhouse purposes (LLDPE). This factor probably contributed to the lower than expected ODW of the seedlings from the 110 ml containers.

While determining the percent composition of carbon in the seedlings, six of the twenty-two samples displayed peak voltages that were less than 0.5 v during mass spectrometry testing. The Idaho Stable Isotopes Laboratory requires a voltage peak of 1.0 v or more on each sample to insure accuracy of the results during an evaluation. Since that criteria was not met, these six sample results were discarded from the sample set leaving sixteen accurate samples.

The average carbon content of the seedlings was 43.4% ± 6.7%. There was no statistical difference between carbon content of the seedlings raised in the greenhouses covered with polyethelene plastic versus non-polyethelene plastic, nor was there any statistical difference in the carbon content between the seedlings raised in the three different container sizes (P=0.90).

By considering the three container sizes that were used for raising *L. gmelinii* at the Nekrasovka greenhouse in the year 2000, we can determine the quantity of carbon sequestered by the tree seedlings. First, the 70 ml seedling containers produced seedlings with an average ODW of 0.88 g ± 0.198 g. At 43.4% ± 6.7% carbon by weight, these seedlings possessed, on average, 0.3816 g ± 0.0337 g carbon each. The seedlings raised in the 95 ml containers possessed an average ODW of 1.21 g ± 0.381 g, for an average per seedling carbon content of 0.5247 g ± 0.0595 g. Finally, the seedlings raised in the 110 ml containers grew to an average ODW of 1.19 g ± 0.513 g, for an average carbon content per seedling of 0.5160 g ± 0.0780 g (Table 5).

Payback Period

During the three years covered in the evaluation at this greenhouse complex, a total of almost 2.0 million seedlings were raised (mostly larch) resulting in the release of approximately 149,437.3 Kg (329,447.3 lb) CO_2 attributable to those years of production. When averaged over the three years of seedling production (all species), each seedling represents an average release to the atmosphere of 76.4 g (2.69 oz) CO_2. Since the carbon dioxide molecule is made up of one carbon atom ($12\ g\bullet mole^{-1}$) and two oxygen atoms ($32\ g\bullet mole^{-1}$), the actual magnitude of carbon emissions to the atmosphere from 76.4 g CO_2 per seedling is, on average, approximately 20.8 g (0.73 oz) C per seedling. This is the amount of carbon that each larch seedling, must sequester from the atmosphere in order to "break even" on a carbon budget from greenhouse production (pre-planting).

On average, each larch seedling at this greenhouse complex raised in 95 ml and 110 ml seedling containers has sequestered 0.5210 g ± 0.0504 g of C. Considering the average per seedling carbon emission contribution of 20.8 g C, these seedlings represent a net carbon cost of approximately 20.3 g (0.72 oz) C per seedling. In other words, each seedling must sequester an additional 20.3 g C per tree in order to "pay back" the carbon costs attributable to raising the seedling in these greenhouses. Sequestration versus emission can be expressed as a ratio of 1:40. For each unit of carbon sequestered by seedlings during this three year sample period, this greenhouse complex typically caused 40 units of carbon emissions to the atmosphere.

Pellicer *et al.* (2000) determined that the total carbon concentration of *L. eurolepis* (European regions of the former Soviet Union) cuttings did not change with time, although nitrogen reserves did. Assuming the same is true for *L. gmelinii,* we conclude that the total oven-dry weight of each tree must reach 47.9 g ($20.8\ \text{g}\bullet\text{tree}^{-1} \div 43.4\%$) to equal the break-even point where carbon dioxide emissions at the greenhouse equal carbon sequestration by the individual seedlings (not adding the addition carbon emission producing management activities that will occur in the intervening years). Brown (1978) observed that converting green weight to oven-dry weight for various softwood species averaged approximately 50% moisture on small-diameter trees. This conversion was not in disagreement with conversions observed for the seedlings raised at this greenhouse complex. With this in mind, total live tree weight would have to exceed 95.8 g (3.38 oz) to sequester 20.8 g C.

Published data on the biomass accumulation of softwoods in the Russian Far East during the first 10 years after planting are not available. However, data are available for trees under 4.57 m (15.0 ft) indigenous to the Northern Rocky Mountains of the USA, including larch species (Brown 1978). Distinct genetic differences exist between these North American larch species and Russia's *L. gmelinii* based on variations at isozyme loci (Whitlock 1995; Semerikov & Lascoux 1999). However, despite the spatial and temporal separation, similar environmental conditions have led to low levels of genetic variation between certain species of *Larix*, such as that found between *L. occidentalis* (Nutt.) and *L. lyallii* (Parl.) (A. Henry) with *L. gmelinii* (Semerikov & Lascoux 1999). This notwithstanding, the whole tree weight predictions of Brown (1978) can be used with caution, recognizing the need for further research in this area (Equation 5):

$$w = e^{\left[-3.720+\left(2.411*\ln h\right)\right]} \tag{5}$$

Where: 'W' is whole tree weight (green) in pounds

'h' is tree height recorded in feet

'e' and 'ln' are natural log functions

and $R^2 = 0.87$ with the MSR = 3.109 for trees less than 4.57 m (15 feet) in height.

Rearranging to express as a function of tree height (h):

$$h = e^{\left[\frac{\ln w + 3.720}{2.411}\right]} \tag{6}$$

By inserting the targeted 'break-even' green-weight as 0.211 pounds (95.8 g) for 'w' in Equation 6 we can estimate the total tree height needed for our seedlings to sequester the ‘break-even’ 20.8 g C used to grow them as 74.68 cm (2.45 feet).

Although early tree biomass growth estimates for the Russian Far East are scarce, anecdotal evidence, observations, and discussions with working foresters in Khabarovskii krai indicate that moderate to highly productive forest sites in the region could supply this amount of tree growth after 3 growing seasons providing competition is eliminated prior to planting. However, on low-productivity sites, especially where persistent permafrost conditions exist, this amount of tree height growth may take as long as 10 years to attain, especially if competition from shrubs and grasses is present, or if animal damage is an issue.

Discussion

This study measures carbon emissions for one aspect of forest management in one location. However, its results should be useful as an indicator of the general magnitude of the seedling nursery phase of forest management in the Russian Boreal forest. Application of our research procedures to other geographical regions would need to account for differences in greenhouse-gas emissions from differing practices. For instance, approximately 45.4% of the total carbon dioxide emissions brought about by raising these tree seedlings were caused by the burning of coal to produce electricity. At first glance, it would seem that this factor would be less significant in regions that acquire electricity from hydroelectric power. However, Rudd *et al.* (1993) point out that bacterial decomposition of flooded forest biomass in hydroelectric reservoirs produce significant amounts of carbon dioxide and methane from both aerobic and anaerobic decomposition. These greenhouse-gas emissions may be comparable to emissions from fossil-fuel power plants. While other authors disagree with the magnitude of their findings and the pattern of greenhouse-gas emissions (especially from methane) (Gagnon & Chamberland 1993; Svensson & Ericson 1993; Rosa & Schaeffer 1994), there is agreement that greenhouse-gas emissions from hydroelectric reservoirs are far from negligible.

The second largest source of carbon dioxide emissions in raising greenhouse seedlings at this complex was from natural gas combustion in the process of manufacturing fertilizers and perlite. Approximately 24.0% of total carbon dioxide emissions were from fertilizer manufacture and only 0.1% from perlite manufacture. It is unlikely that this factor will be significantly different in other locations since this facility has procured its fertilizers and perlite from North America and Europe in the past.

Cement usage at this facility accounted for approximately 11.9% of total carbon dioxide emissions while steel used in building construction accounted for 13.3%, when allocated over the useful life of the structures. This allocation methodology is logical but it does not follow the actual pattern of greenhouse-gas emissions–at least for a one-time project. In our study we have apportioned total carbon dioxide emissions over the useful life of the structures by averaging the total carbon dioxide emissions over the life of the project. However, most of the carbon dioxide emissions were actually released over a much shorter time period; the period of initial construction (Figure 3).

Petroleum usage at this facility accounted for only 5.4% of total carbon dioxide emissions from production inputs. Energy efficiency of vehicles at this facility most likely contributed to a slightly higher usage than otherwise might be expected at a similar facility in North America or Europe because the age of the machines was considerable. Newer motors and more efficient designs would lead to higher fuel efficiency and therefore less carbon dioxide emissions during the production of seedlings.

Other potential sources of carbon dioxide emissions were not included in this study (Table 1). Further research into this area should quantify the magnitude and significance of these sources. These factors raise the issue of what indirect carbon emissions should be counted and which should not. We have used the guideline that carbon should be attributed to the project if its emission would not have occurred but for the existence of the project. By this reasoning, for example, we do not count the carbon used to support the laborers living, as these activities would have occurred regardless of whether or not the seedlings were raised in a greenhouse.

In terms of national policy and implications of tree-planting efforts in various countries, these results have far-reaching implications. Although many policy makers and policy specialists advocate tree planting as a net carbon sequestration event, we must consider the temporal impacts of a national reforestation program in the Russian Federation and other forestation programs elsewhere. In the short term, a containerized greenhouse-based reforestation program will cause a net carbon dioxide emission increase to the atmosphere that will not be offset immediately through increased carbon sequestration by the seedlings. In the longer term, a containerized greenhouse-based reforestation program for the Russian Federation should result in increased net carbon sequestration. If carbon sequestration in forests is to be an important tool in addressing world climate change concerns, more studies like this are needed to understand when and by how much net carbon sequestration occurs.

The general approach used in this paper must be broadened and widely replicated if we are to understand and quantify the net carbon balance for forestation activities. Other studies are needed to capture carbon emissions of, for example, management activities at other stages of the tree lifecycle. Still, carbon relevant management activities are likely to occur during the nursery and planting stages of forestation, in which case this study captures most of the relevant typical carbon emissions. However, the figures produced in this study are based on particular circumstances and assumptions. A number of factors will determine how representative these figures may be.

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Table 1. Inputs to raising containerized tree seedlings that are also potential sources of carbon emissions to the atmosphere.

Component	Magnitude of C emissions	Inclusion in this Research
Electricity:		
Used at greenhouse complexes:	Major	Yes
Used at seed storage freezers:	Major	Yes
Used at seedling storage coolers:	Major	Yes
Petroleum Products:		
Vehicles:	Potentially Major	Yes
Generators and other motors:	Potentially Major	Yes
Growth Stimulants and Media:		
Fertilizers:	Major	Yes
Perlite:	Insignificant	Yes
Peat Moss:	Insignificant	No
Building Supplies and Infrastructure:		
Cement:	Major	Yes
Metals (esp. steel):	Major	Yes
Polyethelene resin plastics:	Carbon Sink	Yes
Lumber (from manufacturing process):	Carbon Sink	No
Tree Planting Activities:		
Forest Site Preparation:	Potentially Major	No
Vehicle fuel for transporting people and seedlings to the forest site:	Minor	No
Forest Management Activities:	Minor	No

Table 2. Containerized seedling production at the Nekrasovka Greenhouse Facility in Khabarovskii krai, Russian Federation.

	Tree Species				
Year	*Larix gmelinii*	*Picea ajanensis*	*Pinus koraiensis*	Other	Total
1998	500,000	0	0	0	500,000
1999	700,000	0	0	0	700,000
2000	700,000	3,900	22,100	29,700	755,700

Table 3. Various input levels to raising containerized seedlings at the Sosnovka Seed Breeding Facility.

Year	**Component** (Average CO_2 emissions, expressed as a % of total over 3 year period)	**Component Usage**	**Annual CO_2 Cost**
1998	Electricity at greenhouses (28.5%)	17,000 KW-h	14,012.1 Kg
1999		17,500 KW-h	14,424.3 Kg
2000		17,100 KW-h	14,094.6 Kg
1998	Electricity at freezer and cooler facility (16.9%)	10,200 KW-h	8,407.3 Kg
1999		10,200 KW-h	8,407.3 Kg
2000		10,200 KW-h	8,407.3 Kg
1998	Petroleum used at all locations (5.4%)	4,000 L	2,532.4 Kg
1999		4,500 L	2,848.9 Kg
2000		4,300 L	2,722.3 Kg
1998	Fertilizer manufacture (*from burning natural gas*) (24.0%)	1,225 kg	9,162.6 Kg
1999		1,715 kg	12,827.6 Kg
2000		1,850 kg	13,837.4 Kg
1998	Perlite manufacture (0.1%)	45 kg	19.6 Kg
1999		68 kg	29.6 Kg
2000		68 kg	29.6 Kg
1998	Cement usage (11.9%)	*Averaged over 20 year life*	5,797.0 Kg
1999			6,002.7 Kg
2000			6,002.7 Kg
1998	Steel usage (13.3%)	*Averaged over 20 year life*	6,624.0 Kg
1999			6,624.0 Kg
2000			6,624.0 Kg
1998	Total of listed sources		46,555.0 Kg
1999			51,164.4 Kg
2000			51,717.9 Kg

Table 4. Annual seedling production and grams of carbon released to the atmosphere in support of the greenhouse facility.

Year	CO_2 Release	Number of Seedlings Raised	g CO_2 / seedling	Equivalent g C / seedling
1998	46,555.0 Kg	500,000	93.1 g	25.4 g
1999	51,164.4 Kg	700,000	73.1 g	19.9 g
2000	51,717.9 Kg	755,700	68.4 g	18.7 g
All Years	**149,437.3 Kg *Total***	**1,955,700 *Total***	**76.4 g *Weighted Average***	**20.8 g *Weighted Average***

Table 5. Seedling data from *Larix gmelinii* raised in 2000 at the Nekrasovka greenhouse facility.

Container Size (ml)	**Height above root (cm)**	**Root depth (cm)**	**Stem caliper (mm)**	**Winter storage weight (g)**	**ODW Total grams (Standard deviation)**	**Carbon in plant fiber at 43.4% Total grams (Standard deviation)**
70 ml	23.93	7.36	2.33	0.94	0.88 (0.198)	0.3816 (0.0337)
95 ml	37.16	9.22	2.60	1.30	1.21 (0.381)	0.5247 (0.0595)
110 ml	35.55	11.33	2.54	1.29	1.19 (0.513)	0.5160 (0.0780)

'+'.

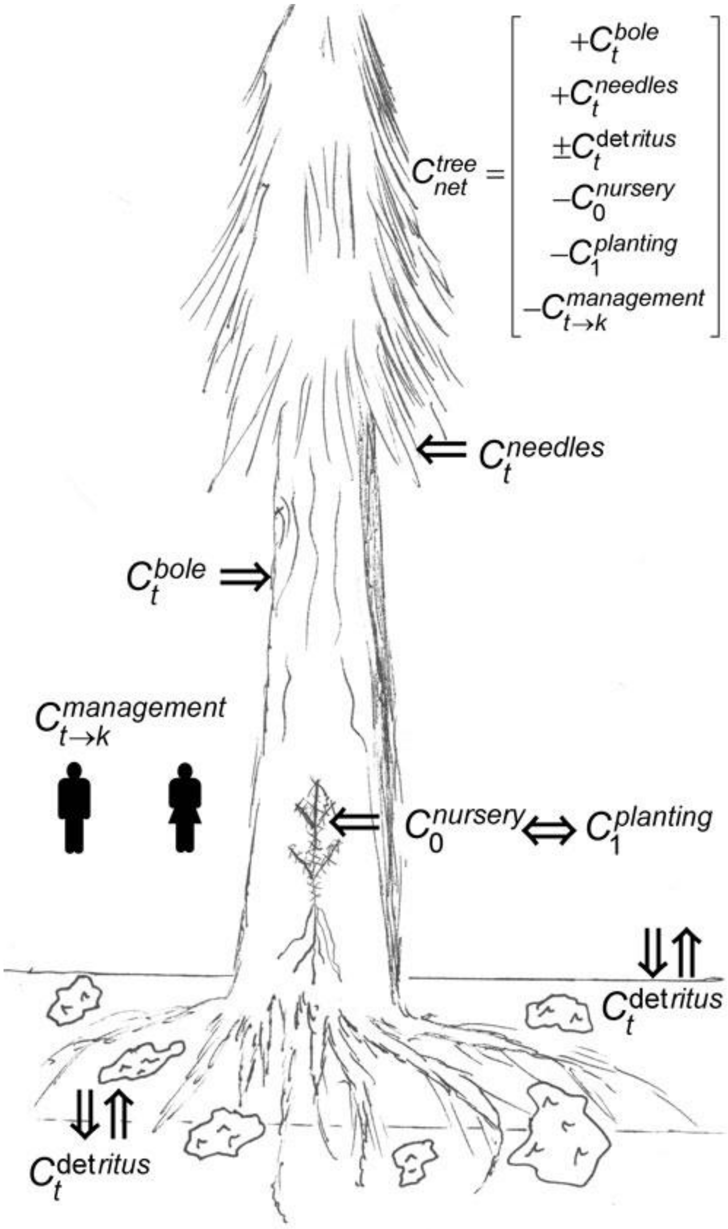

Figure 1. Potential carbon sinks and sources involved with raising a containerized seedling to a mature tree. C represents carbon, the subscripts denote a time index beginning at year zero (0) in the greenhouse and going to year 'k', which is any year being considered in the net sequestration determination. Superscripts indicate sources of carbon emissions when coupled with a '-' and sinks of carbon when coupled with a '+'.

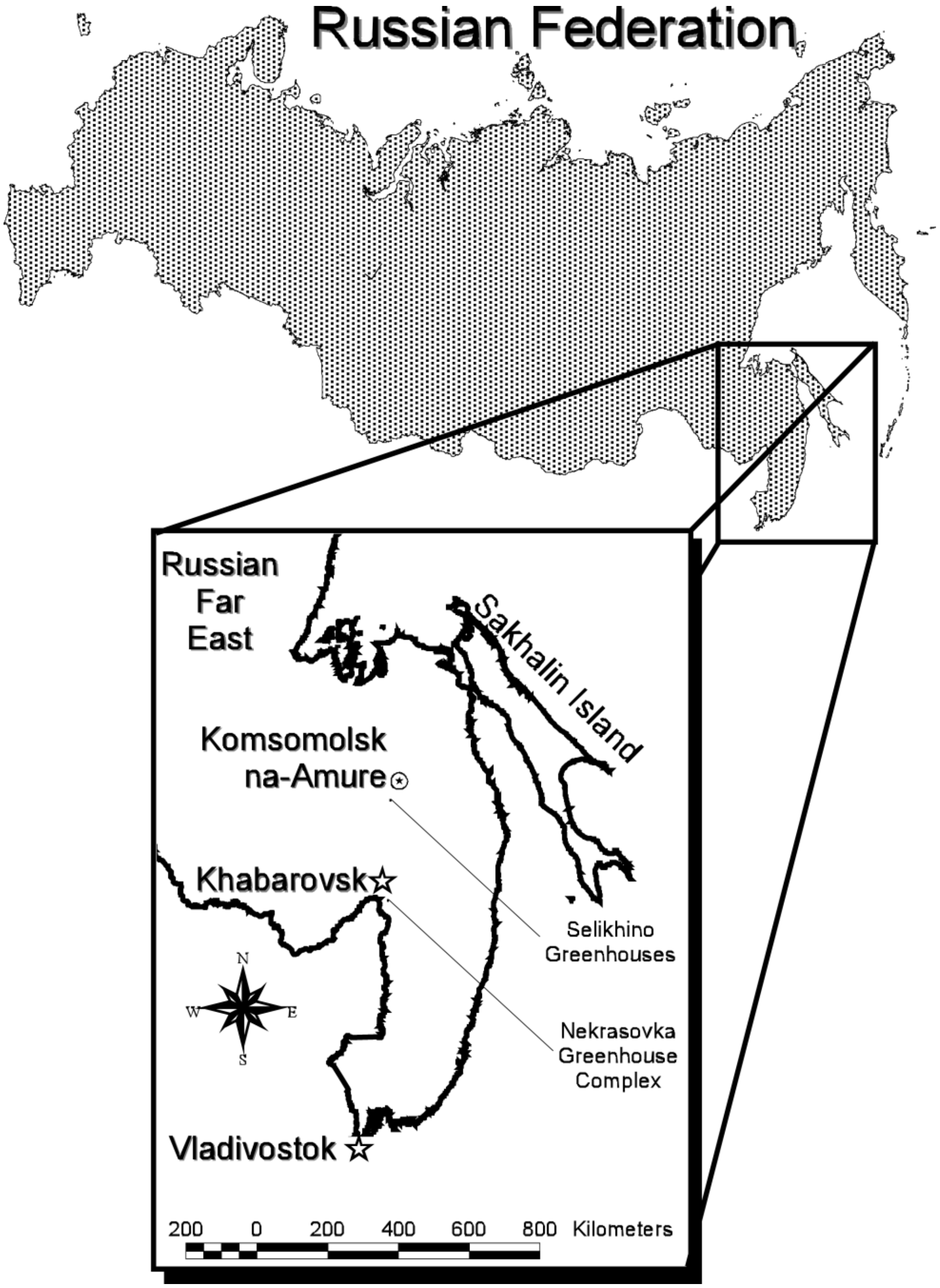

Figure 2. Russian Far East greenhouse locations of the Sosnovka Seed Breeding Center in the Russian Far East.

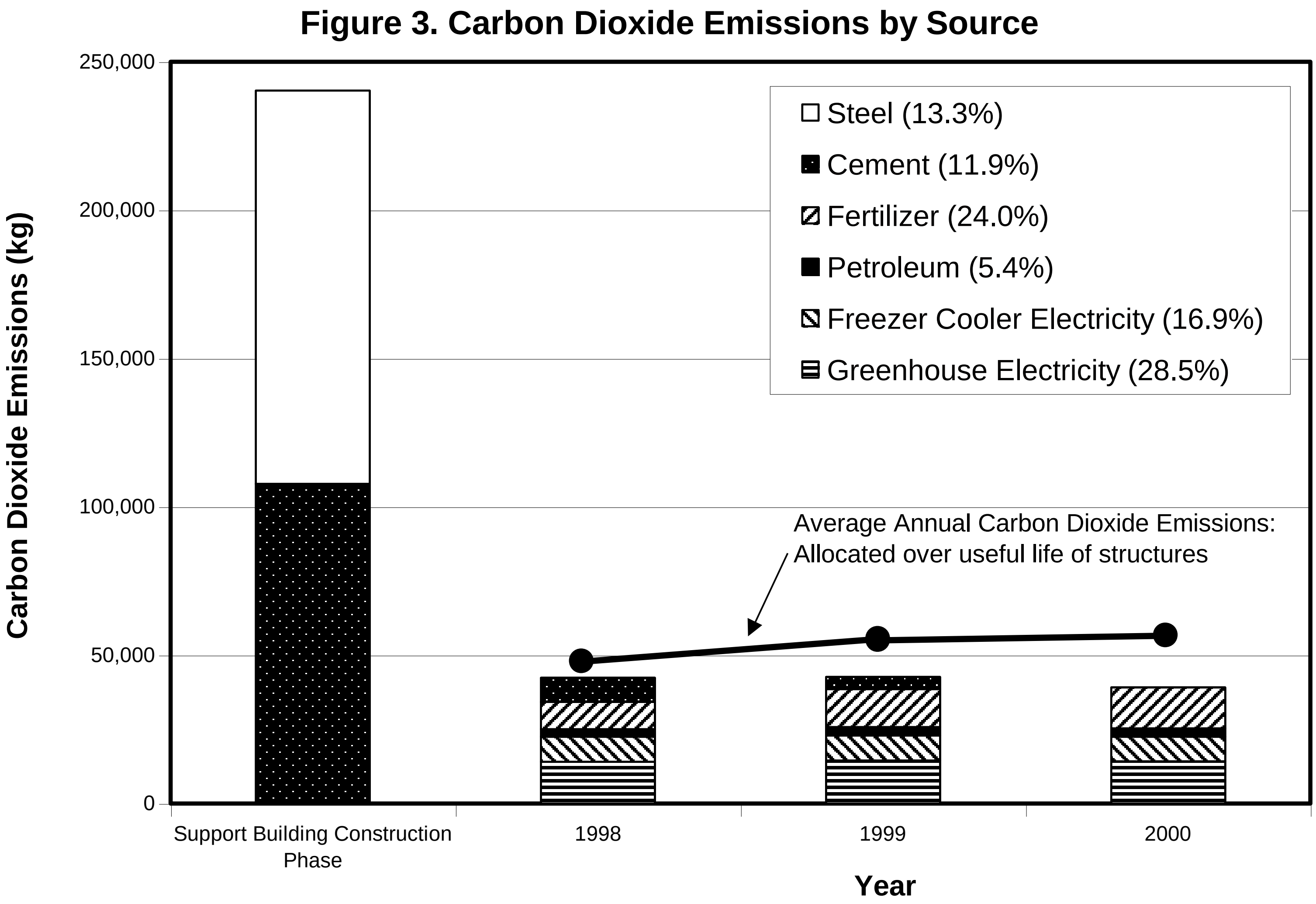

Figure 3. Carbon emissions by source.

CHAPTER FOUR

INCREASING LONG TERM STORAGE OF CARBON SEQUESTERED IN RUSSIAN SOFTWOOD LOGS THROUGH ENHANCED LUMBER RECOVERY

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Increasing Long Term Storage of Carbon Sequestered in Russian Softwood Logs Through Enhanced Lumber Recovery

Abstract

The lumber manufacturing industry of the Russian Far East and Siberia was evaluated in order to determine potential improvements in lumber recovery and the corresponding enhancement of temporal carbon storage duration in lumber manufactured from trees harvested from the boreal forest (taiga) of the Russian Far East. The Khorsky DOK lumber mill (in the Russian Far East) was observed to recover approximately 68% lumber from cubic meter round log volume of *Pinus koraiensis*, cut to 22 mm and 50 mm thick random width boards. However, lumber that failed to meet merchantability standards accounted for as much as 34% in their 50 mm thick lumber, and up to 71% in their 22 mm thick lumber. Research demonstrated that better operator training and technological improvements could improve overall lumber recovery. Lumber recovery improvements were evaluated to ascertain long-term carbon storage impacts. Approximately 38.9% of the carbon stored in trees of the boreal forest is transferred into carbon stored in lumber manufactured at this mill complex in the Russian Far East. This carbon sequestration can be increased from 38.9% to 45.6%, or more, with milling improvements to increase lumber recovery, thereby enhancing economic benefits to the manufacturer and simultaneously increasing long-term carbon storage in forest products destined for use in building construction.

Keywords:

carbon, lumber recovery, Russian Far East, boreal, taiga, *Pinus koraiensis*

Introduction

Global atmospheric levels of the greenhouse gases carbon dioxide (CO_2), methane (CH_4), and nitrus oxide (N_20) have increased from preindustrial concentrations by approximately 30%, 145%, and 15%, respectively (Climate Change 1995). Carbon dioxide concentrations have increased from an estimated 280 parts per million by volume (ppmv) (Bolin et al. 1979) to present day levels of approximately 360 ppmv (Climate Change 1995, Nilsson *et al.* 2000), the highest levels of CO_2 in the last 100,000 years (Climate Change 1995). Increasing concentrations of greenhouse gases are of concern because they can lead to an increase in global warming effects. Mean global surface temperatures have increased by 0.3ºC to 0.6ºC (0.54º-1.08ºF) since the late 1800's and by 0.2ºC to 0.3ºC (0.36º-0.54ºF) in the last 40 years (Climate Change 1995). The past decade has been the warmest in recorded history. It is estimated that average global temperatures could increase by as much as 3.5ºC (6.3ºF) in the next 100 years over those experienced in 1900 (Climate Change 1995). Such global warming could have serious biological, social, and economic consequences.

There are two broad approaches to reducing the increase of carbon dioxide in the atmosphere, and, presumably, mitigating global warming: (1) reducing emissions of greenhouse gases; and (2) removing CO_2 from the atmosphere and sequestering it in long-term storage pools. Both alternatives have received considerable attention in global climate conferences (UNFCCC 1999, Climate Change 1995). Forests are the largest of the long-term terrestrial carbon sinks. There are three general ways to increase the duration that carbon is sequestered by forest ecosystems: 1) increasing forest area through afforestation, 2) increasing the average amount of carbon held on site over multiple rotations using appropriate forest management practices, and 3) converting standing timber to solid wood products that remain in use for prolonged periods, followed by successful reforestation of the harvested forest site. This paper explores the last of these three methods through a case study involving the Russian boreal forest and a Russian sawmill.

Forests are significant global sinks for atmospheric carbon and have the potential to sequester large quantities over standard rotation lengths (Climate Change 1995, Nilsson *et al.* 2000). However, forest ecosystems are not static carbon sinks, but dynamic systems. The basic concept in sequestering carbon in forests is to increase the average carbon content of the forest system and forest products given that carbon is continuously being absorbed by new growth while a portion is released back to the atmosphere from fires, insects, diseases, respiration, and decomposition. The conversion of atmospheric CO_2 to biomass in the form of carbon held in wood fiber is considered by many policy-makers worldwide to be an extremely important mechanism to mitigate global warming. The sequestration of this carbon can be extended if these trees are converted into products with long useful lifetimes; the third option presented above. For example, it is estimated that the half-life of carbon held in structural lumber used in new home construction is 100 years (Skog & Nicholson 1998). Other wood products show promising residence times for prolonged carbon sequestration (Table 1).

A principal factor influencing how much of the carbon removed from forests by logging is transformed into long-term forest products is the efficiency achieved by wood-manufacturing industries in convertinglogs to products (Steele & Wagner 1990). Wood processing techniques that improve the recovery of lumber sawn from round logs increase long-term carbon sequestration because waste material is either burned or converted into short-term products (e.g. paper), thereby rapidly recycling carbon back into the atmosphere.

It should be noted that only a portion of the carbon held in forest ecosystems is held in the bole of a tree. Carbon in the boreal forest zone is also held in other tree parts, in the soil, and in other plants on the landscape. It is estimated that in the boreal forest zone of Southern Finland, carbon distribution in trees, averaged over the life of the rotation, is about 60% in stemwood, 24% in roots, 12% in branches, and 4% in needles (Mäkipää *et al.* 1999). During logging activities, only the carbon stored in the stemwood is removed and converted to wood products and mill waste. Carbon contained in the other parts of a tree remains on-site and may be released back to the atmosphere quickly (if burned) or slowly (through decomposition). While these other carbon release paths are important, we do not address issues related to any of them in this paper.

The Russian Federation encompasses some 1,709.4 million ha (4,223.9 million acres), including approximately 884 million ha (2,184 million acres) occupied by forest ecosystems (Krankina *et al.* 1997, Krankina & Ethington 1995). No other country's forest reserve is larger than the forests existing within the Russian Federation. Russia contains approximately 20% of the world's timber resources and over half of the world's reserve of boreal or taiga forests (Krankina *et al.* 1997). These forests represent an enormous asset to the Russian Federation and the world in reducing atmospheric carbon, especially since the overall carbon balance of the Russian Federation is not currently favorable.

The Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) called for the development of a full carbon account for each participating country for the year 1990 and projections of levels for 2010 (UNFCCC 1999). The first full carbon account for Russia was completed by the International Institute for Applied Systems Analysis (IIASA) in 2000. This study shows that the Russian Federation made a net contribution of 527 teragrams of carbon (Tg C) to the atmosphere in 1990, and projections for the year 2010 indicate a range of atmospheric contributions of 156-385 Tg C, including energy and industrial sectors (Nilsson *et al.* 2000).

Carbon sequestered in the wood fiber of Russian trees is either recovered through lumber manufacture, or released back to the atmosphere through burning (primary) or decomposition (secondary). Anecdotal evidence and observations suggest that a majority of the wood waste from Russian sawmills in Siberia and the Far East, in the form of mismanufactured lumber and log ends, is used for heating and cooking purposes by mill workers and the surrounding community. The remainder of this wood, along with a majority of other wood waste (saw dust, chips, and bark), is used as landfill or incinerated at the mill without energy recovery. Currently, the Siberian and Far Eastern regions of Russia do not support a pulp-and-paper industry capable of utilizing the waste products created by lumber mills in the region during manufacture. There are no wood-to-energy conversion facilities in the region. Sawmill waste products that, in another country, would be utilized for other products such as paper, fiberboard, or even wood-to-energy are not viable options for sawmills in these regions. Carbon contained in the wood not converted to wood products has a severely limited residence time before being returned to the atmosphere through burning or decomposition.

Furthermore, the domestic market for lumber products is very limited as concrete and brick are the primary building materials for Russian construction.

Therefore, the primary outlet for all finished and raw lumber products from the Russian Far East are export markets. The primary markets for RFE lumber includes Japan, Korea, and China. Although reliable numbers do not exist, it is an industry-wide understanding that Russian produced lumber must meet stringent export requirements in order to gain acceptance and have financial benefits. Dependence on this demanding market has two implications. One is that there is little export potential for waste products to offset the meager local markets. The second is that more wood ends up as waste because it does not meet the demanding standards.

Case Background

The goal of the Russian Environmental Partnership Project was to foster sustainable environmental projects that increased long-term carbon sequestration, reduced carbon emissions, and improved economic viability for sustainable business practices in Siberia and the Russian Far East. (The project was funded by the US Agency for International Development-Moscow, and implemented by Pacific Rim Taiga, Inc. of the USA.) From 1998 through 2000, one aspect of this project was to improve lumber recovery at selected lumber mills in these regions. Enhanced lumber recovery has the double effect of increasing carbon in long-term storage and reducing raw material demands needed to meet product orders. Therefore, increasing the recovery of lumber from round logs in Russia has positive and direct economic and carbon sequestration benefits.

Various components of the Russian lumber processing industry were evaluated from 1998 through 2000 as part of the Russian Environmental Partnership Project. Three sawmills were evaluated; one in Siberia and two in the Russian Far East. Mills were selected based on recommendations from the territorial administrations as being representative of those in the Asian portion of the Russian Federation. The mills processed a variety of softwood species. Included in these studies were Korean pine (*Pinus koraiensis* Siebold & Zucc.), Siberian pine (*Pinus sibirica* DuTour), Siberian larch (*Larix sibirica* Led.*)*, and Gmelina larch (*Larix gmelinii* (Rupr.) Kuzeneva).

This paper presents information and draws conclusions about one of these mills, Khorsky DOK, located in the Russian Far East, Khabarovsk Territory. This mill was regarded by the regional administration and the Forest Industry Technological Institute at Khabarovsk to be one of the largest, most integrated, and technologically advanced sawmills in the Russian Far East territory of Khabarovskii Krai. This research documents inefficiencies in current operations at this mill. It quantifies potential improvements in lumber recovery at this Russian sawmill and draws conclusions about increases of sequestered carbon in durable lumber products as a result of improved lumber recovery.

In the remainder of this paper we present an overview of an evaluation of the Russian mill made by U.S. mill specialists. The mill experts identified a number of sources of inefficiencies at the mill. We document some of the resulting inefficiencies by measuring the accuracy and precision of sawmill cuts for a sample of logs. The sample is compared to a control set to check for biases in sample selection. Measurements of sawmill accuracy are compared to standards as a basis for estimating the potential for improvements in efficiency. Other areas of sawmill operation are also evaluated for efficiency.

Methods

Mill specialists from the U.S. worked with Russian mill management and laborers to evaluate the lumber recovery at Khorsky DOK. That is, they evaluated how each log was sawn (quality and quantity of lumber from logs). The specialists evaluated potential adjustments to equipment and techniques, focusing on the modification of existing equipment. Since capital was a limiting factor, the replacement of saws and major equipment procurement was not considered a realistic option for these companies. All three of the mills were committed to optimizing existing technology. The mill specialists evaluated saw blade sharpening techniques, headrig adjustments, operator experience, and other factors in determining how current lumber recovery could be improved with existing equipment.

Field work at the Khorsky DOK sawmill was completed in January (lumber recovery / sawing accuracy) and February (saw blade sharpening technology), 1999. During the lumber recovery study, 50 Korean pine logs (Table 2) averaging 4.04 meters (13.25 feet) in length were evaluated. Both log end-diameters, inside bark, were measured to determine individual log cubic volume. Volume determinations used the G.O.S.T.[1] scaling rules of Russia. The grades and volume for all lumber produced from the 50 logs were recorded, providing a baseline recovery of lumber from each log. Boards cut from the logs had a rough-cut thickness of 22 mm (0.87 in) and 50 mm (1.97 in), were of

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[1] G.O.S.T. means государственный стандарт or the "State Approved Standard" used for all commercial weights, scales, and volumes in Russian commerce.

variable width, and variable lengths of up to 4 meters (13.1 ft). All of the sampled logs were milled into rough-cut lumber in one shift.

The mill operated three saws at the site evaluated. The headsaw was a Japanese Fuji band saw[2], the second was a twin band resaw, and the third was a single band resaw. The consultants determined that the study was run under normal operating conditions, and that the sawmilling procedures observed were representative of normal operating procedures by mill management. However, it is probable that the mill staff were paying special attention to lumber recovery since they were being evaluated by foreign specialists. Such bias would serve to establish the upper limit of lumber recovery obtained by mill personnel in the absence of adjustments recommended by the consultants.

Two 50 log sets were evaluated to verify how well the sample set represented the average logs processed by the mill. The sample set (Table 2) of Korean pine logs measured a total volume of 26.46 cubic meters (934.30 cubic feet) (G.O.S.T.). Average log volume was approximately 0.53 ± 0.2 cubic meters (18.71 cubic feet), corresponding to a small-end log diameter in the 38 cm (14.96 in) diameter class. The control set (Table 2) also contained 50 logs with a total volume of 23.94 cubic meters (845.32 cubic feet), and an average log volume before processing of 0.48 ± 0.27 cubic meters (16.95 cubic feet). The average log diameter of the control set was in the 36 cm (14.17 in) diameter class. There was no statistically significant difference between the two sets of logs (CI=95%), and the logs used for the lumber recovery study were determined to be representative (i.e. not selected with bias) for that mill.

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[2] Fuji Bandsaw, orgin Japan, model unknown.

A sample of 100 boards was cut to a target thickness of 24 mm (0.94 in), and a sample of 96 boards was cut to a target thickness of 53 mm (2.09 in). The product to be sold from these sizes included rough-cut, kiln-dried lumber at 22 mm (0.87 in) and 50 mm (1.97 in), respectively. Thickness was measured at 10 points on each board (Figure 1) using a dial caliper, recorded to an accuracy of 0.1 mm (1/254 in). These measurements were then entered into the USDA Forest Service Lumber Product Size Analysis Program (USDA Forest Service 1990). This computer program was used to assist in determining the degree of top-to-bottom, end-to-end, within-board sawing variation, between-board sawing variation, and total sawing variation. Total sawing variation is a gauge of the magnitude of deviation in lumber thickness produced during milling and is a function of within-board and between-board sawing variation (Steele & Wagner 1986).

Results and Discussion

Critical to the evaluation of the lumber recovery from this mill was the assessment of sawmilling practices in terms of accuracy and precision. These benchmarks of performance were compared with similar results from US sawmills to establish potential ranges of improvements possible.

From the sample of 50 Korean pine logs, the mill recovered (green) a total of 18.08 cubic meters (638.40 cubic feet) of rough-cut lumber, representing a 68.3% recovery from the cubic round log volume.

Data indicated that the between-board variation was beyond the range of measurements observed in other studies in the U.S. (Steele *et al.* 1986) for the boards cut to a target thickness of 24 mm (0.94 in). The within-board variation was 2.3 mm (0.091 in), and between-board variation was 0.65 mm (0.026 in). Total sawing variability was calculated using the sum of the squares of the within-board variation and the between-board variation:

$$TSV = \sqrt{WBV^2 + BBV^2}$$

Where:

TSV = Total Sawing Variation

WBV = Within-Board Variation

BBV = Between-Board Variation

Total sawing variation for the lumber cut to a target thickness of 24 mm (0.94 in) was 2.39 mm (.094 in). A sample of the data set is presented in Table 3.

Between-board variation in the lumber cut to a target of 53 mm (2.09 in) was determined to be less than optimal as well. The within-board variation was 2.8 mm (0.11 in) and the between-board variation was 1.65 mm (0.065 in). Total sawing variation was 3.25 mm (0.128 in).

When calculating how thick to initially cut lumber (operator's target thickness), the mill must employ a simple formula to achieve a target of 95% or more of the total production in the range of acceptable thickness for the product they are manufacturing (Brown 1986). The formula is:

$$\begin{bmatrix} Target \\ Thickness \end{bmatrix} = \begin{pmatrix} Final\ Product \\ Thickness \end{pmatrix} + \begin{pmatrix} Planer \\ Allowance \end{pmatrix} + (Shrinkage) + (1.65\, x TSV)$$

Where: 1.65 represents a one sided *student's-T* distribution at the 95% confidence interval.

Both lumber products evaluated in the lumber recovery study at Khorsky DOK were sold without being planed. "Planer Allowance" was therefore set to zero. Shrinkage was set at 2% of initial thickness by the mill management; all measurements were taken green, prior to kiln drying.

A closer examination of this formula reveals that the greater the total sawing variation, the greater the target thickness has to be to insure that an acceptable percent of lumber is within the range of thickness for the final product. The lower the value for the total sawing variation, the closer the target thickness is to the final product thickness, and therefore, less wood wasted during manufacture. The aim of the sawmill is to reduce sawing variation to its minimum maintainable amount and thereby increase lumber recovery on a sustainable basis.

Baseline Lumber Recovery

Considering the 50 mm (1.97 in) thickness product, the target being sought by the rough saw was 53 mm (2.09 in). The actual average thickness obtained from the 970 samples was 53.1 mm (2.09 in) with a standard deviation (across all points) of 1.8 mm (0.07 in). While the mill generally achieved their average target thickness, they were not especially precise in attaining their target. The data indicates that out of the 97 boards cut to a target thickness of 53 mm (2.09 in), 11 of the boards (11.3%) were below the final dry rough thickness of 50 mm (1.97 in) in at least one sample point, and an additional 22 boards (22.7%) were cut to within less than 1.06 mm (0.042 in) of the product specification of 50 mm (critical thickness = final product thickness + shrinkage). The boards cut to less than 50 mm failed to make export quality standards and were either resawn to 22 mm (0.087 in), sold in the domestic market, or wasted. The management of the mill confirmed that the majority of the solid waste was scraped and burned in homes or the mill, while the planer waste and sawdust was burned without energy recovery. The boards cut to within 1.06 mm (0.042 in) of the minimal thickness of 50 mm (1.97 in) were processed, but during kiln drying the shrinkage brought the boards to less than the product size of 50 mm (1.97 in). A total of 33 boards (34%) were mis-manufactured with most of them utilized for domestic products. Given the sawing variation, target thickness should have been 56.4 mm (2.22 in) for this product.

The boards sawn for the 22 mm (0.87 in) product thickness, had similar problems. The target thickness being sought by the rough saw was 24 mm (0.94 in). Considering the 1,000 sample points taken (10 points per board), the actual average thickness obtained was 23.2 mm (0.91 in) with a standard deviation (across all sample points) of 1.0 mm (0.004 in). In this case, the mill was not accurate in achieving their target thickness; they were 0.8 mm (0.031 in), on the average, less than their target. The data indicated that out of the 100 boards cut to an actual average thickness of 23.2 mm (0.913 in), 31 boards (31%) had at least one point on a surface below the finished size of 22 mm (0.087 in), and an additional 40 boards (40%) had a point cut to within less than 0.44 mm (0.017 in) of the critical size of 22 mm (0.087 in). Only one board in the entire sample had all sample points measured at or above 24 mm (0.094 in). The boards cut to less than 22 mm (0.087 in) failed to make product quality standards and were wasted. The boards cut to within 0.5 mm (0.020 in) of the minimal thickness of 22 mm (0.087 in) were processed but during kiln drying the boards shrank below the product specifications. A total of 71 boards (71%) were mis-manufactured and were wasted. The remainder of the boards, only 29%, were consistently thick enough to be kiln dried and remain above the target thickness of 22 mm (0.087 in). Given the sawing variation, target thickness should have been 26.9 mm (1.06 in) for this product.

This high degree of deviation, conceptually seen as thickness fluctuations of the board, and mathematically seen as the total sawing variation, results in reductions in lumber recovery. Consistency in the primary sawing of the boards means that greater accuracy can be exercised in the initial cutting of the logs into lumber. For instance, a high amount of variability, as seen in the 50 mm (1.97 in) thickness boards, means that the operator must cut the board initially to something thicker than the product specifications, for instance, 56.4 mm (2.22 in) when attempting to produce 50 mm (1.97 in) thickness boards. The irregularities and oversize can be surfaced out during planing. If the thickness is more uniform (i.e. lower total sawing variation) then the initial cut can be closer to the final dimensions with only a small amount in addition to be removed during planing. This increase in accuracy, or improvement in recovery, has significant financial benefits to the sawmill and amounts to important improvements in the amount of carbon held in long-term storage as lumber versus carbon held in wood fiber that is wasted as planer dust or mis-manufactured wood products and then released to the atmosphere through burning or decomposition.

Recommendations to Improve Lumber Recovery

After evaluating milling practices, operator know-how, and the technical characteristics of the milling equipment, recommendations were formulated and implemented in a program to improve lumber recovery utilizing existing technology. The subsequent section details the major factors addressed during the consultations with Khorski DOK.

In the process of debarking, the operator was removing not only bark, but a significant degree of wood fiber as well. The equipment, a Rosser head debarker, was being used too aggressively. The impact of this wood loss on the small end of the log resulted in a reduction of recovered lumber. Less aggressive debarking practices were recommended and exercised.

Some irregularities were introduced during sawing at the headrig. The sweeper keeps sawdust and foreign matter from building up on the headrig. On this particular machine, the sweeper malfunctioned and was not repaired. Lack of a track sweeper caused sawdust to accumulate on the carriage, reducing the precision of the cut made by the headrig.

The most significant factor affecting lumber recovery was the saw operator. Saw operation accounted for the vast majority of less than optimal recovery from the logs. To illustrate, log number 9 was a Korean pine log, with a small-end diameter of 38 cm (15 in), possessing 0.53 cubic meters (18.71 cubic feet) volume, grade 2 (G.O.S.T.). While implementing a grade sawing program, the log is opened on the poor face (the first cut). The log is then rotated 180º so that the cut face is against the knees of the carriage. The log is then sawn on the best face until grade diminishes. The log is then rotated 90º and sawing is completed. This particular log had a discernible good face and bad face. The specialists observed the saw operator placing the log on the carriage without adjusting the log position to open the log on its bad face. Instead, the sawyer opened the log on its best face, cutting a slab from clear wood, and leaving the bad face intact. This decision-making process is not consistent with optimizing lumber recovery. Unfortunately, this scenario was repeated on other logs. In some cases, the operator opened the log on a bad face and in other instances the operator opened it on a good face, when a bad one was available. The quality of the log, or the existence of a good or bad face, did not seem to influence the operator's decision on where to open the log for milling.

Within-board sawing variation is due to "wandering" of the saw in the cut. Between-board sawing variation is due to poor saw sets (carriage). On each of the resaw heads, there was no uniform feed rate. Because of the limited ability of the mill's equipment to properly feed the material through the saw, a great deal of variation both within-the-boards and between-the-boards was introduced by the resaws. Repair and maintenance of the resaws is necessary in order to increase lumber recovery at this facility.

It was determined that the headsaw operator and resaw operators should be better informed about lumber grade requirements for their markets and know procedures necessary to maximize the grade of lumber from each log. Thus, operator training would have a positive impact on lumber recovery at this mill. The equipment, although not state-of-the-art, is not inherently defective. A well-trained operator could increase lumber recovery using this equipment over what was observed at the mill complex during the study period.

Installing track cleaners on the headrig carriage would lessen within-board variation. Proper feed rates on all three band saw machines would lessen within-board variation as well. This would be most difficult to accomplish on the third machine as the feed device is inadequate to allow for proper feed, and during the study, cants were forced through the saw by manpower (Figure 2). Repair of the existing equipment would make a substantial improvement in lumber recovery volume and grade.

Saw blade sharpening is a critical factor in the recovery of lumber grade while processing. It also influences consistency of within-board variation (discussed above). The saw blades at Khorsky DOK (and most other Russian sawmills that were evaluated) were not being maintained or sharpened to their potential. An increase to mill production of 5-8% and improved sawing quality would result from implementing a proper bandsaw maintenance program at the facility.

A worker training program was implemented as part of this project that began with a seminar on swedging and shaping, alignment of teeth, leveling, and tensioning of the equipment. Discussions included grinding wheel speeds, and the proper grit and shape of grinding wheels to grind bandsaws. Other improvements included installation of pressure guides on the bandmills, scheduled corrections to blade alignment, and the installation of a laser light guide to assist the headrig operator in determining the best opening face of each log. Installation of a winter time "frost tooth" blade in all bandsaws was recommended for use during winter sawing (when logs are frozen). The outcome of the hands-on training with the mill personnel was an immediate increase in consistency and improved grade recovery from the logs processed.

Improvements in Lumber Recovery

An evaluation of over 400 sawmills in the USA in the early to mid 1980's by Steele et al. (1986) revealed a total sawing variation (converted to millimeters) from 0.508 mm to 0.934 mm (0.02-0.04 in). If we assume this sawing variation to be achievable in the

Russian Far East, then we must conclude that the total sawing variations realized by this mill (2.39 mm (.094 in) and 3.25 mm (0.128 in)) are well out of this range of variability. Improvements to the milling procedures in this mill are needed in order to reduce wood waste created from milling, or alternatively increase lumber and carbon recovery.

Using these standards in comparison to those achieved at the Khorsky DOK, permit estimates of lumber recovery through improvements to technical milling aspects (adjustments to equipment) and worker training programs (best-opening-face training, saw sharpening techniques). The most immediate improvement is by decreasing the inaccuracies in sawing that create the high degree of variation seen in the board thickness measurements and evidenced by the total sawing variation calculations.

50 mm Lumber

Approximately 11% of the boards sawn to a target 50 mm (1.97 in) thickness were lost because of inaccuracies in milling that created board thickness points below 50 mm. These errors can be almost entirely eliminated through improvements to equipment and personnel abilities outlined above.

The amount of wood volume lost due to a high degree of variation was calculated based on an average board length of 2 meters (6.56 ft) and width of 20 cm (7.87 in). Using the data collected for the 97 boards milled to a target product thickness of 50 mm (1.97 in), the total volume rough sawn was 2.11 cubic meters (74.50 cubic feet). Of that only 1.94 cubic meters (68.50 cubic feet) was actually contained in the final product (after planing). Thus, 0.17 cubic meters (6.00 cubic feet), or 8.7%, of the final product volume was lost during planing (as shavings). Subtracting the 11 boards that were milled to a thickness below 50 mm (1.97 in) and lost from the grade, the total amount lost to planing and mis-manufacture was 0.40 cubic meters (14.12 cubic feet), or 22.6% of the final product volume.

Adjustments outlined during the evaluation of the mill (equipment and training) would reduce the board thickness variability and, therefore, the total sawing variation. It is expected that the mill can maintain a thickness 95% of the time within a range of 2.0 mm (0.08 in) for all thicknesses, with existing equipment and personnel. For a product dimension of 50 mm (1.97 in) the mill could rough cut 95% of all pieces to a range of 51 mm (2.01 in) to 53 mm (2.09 in), averaging 52 mm (2.05 in), and the remaining 5% within 50-54 mm (1.97-2.13 in). In this improved scenario, the total milled product volume from our sample would be 2.02 cubic meters (71.33 cubic feet). Actual volume of the final product would be 1.94 cubic meters (68.50 cubic feet), resulting in only 4.1% loss to planing, and ostensibly, none to mis-manufacture.

Considering only the losses to planing, the difference between the current observed loss of 8.7% and the potential loss of 4.1%, results in a net improvement of 4.6%. In real terms, for every 100 cubic meters (3,531 cubic feet) of round logs the mill processes, 68.33 cubic meters (2,413 cubic feet) of lumber would be recovered. Through improvements to the manufacture process this could be increased to 71.47 cubic meters (2,524 cubic feet) (4.1% more). Considering the losses due to mis-manufacture and excess losses due to planing, a net improvement of 10.86 cubic meters (383 cubic feet) (10.86%) would result with the improved scenario (from 68.3% to 79.2% recovery).

22 mm Lumber

Using the same criteria as used with the 50 mm (1.97 in) boards, the total volume rough cut to lumber for this product was 0.973 cubic meters (34.36 cubic feet) (in 100 boards). The actual volume of the finished product (100 boards 22x200x2000mm) was 0.88 cubic meters (31.07 cubic feet). That is, 0.093 cubic meters (3.28 cubic feet) (10.6%) were lost to planing. The target loss due to planing, after improvements, is calculated to be only 9.3%, resulting in a 1.3% improvement in lumber recovery. However, with this sample set, an additional 31 boards were mis-manufactured, because the minimum thickness was breached, causing 0.297 cubic meters (10.49 cubic feet) to be discarded for undersize reasons. When combined, the losses to planing and mis-manufacture total 0.390 cubic meters (13.77 cubic feet), or 44.3% of the actual volume of the finished product. By increasing precision to a 2.0 mm (0.08 in) variation on each board the total volume in the rough-cut lumber would have been 0.962 mm (0.038 in) with a loss to planing of 0.082 cubic meters (2.90 cubic feet), or 9.3% of the finished product volume. The 2.0 mm (0.08 in) sawing variation precision would mean that the mill would rough cut 95% of the lumber within the range of 23-25 mm (0.91-0.98 in), averaging 24 mm (0.94 in), and the remaining 5% of the boards rough cut to within 22-26 mm (0.87-1.02 in). The recovery improvement would be a very significant 35.0%.

Additional improvements can be attained. Anecdotal evidence suggests that the mill can increase lumber recovery from the observed 68% of log volume to over 75% of log volume, through the optimal selection of the opening face and adjustments to the debarking process. When combined, the reduction of sawing variation, operator training, and saw blade maintenance could result in lumber recovery improvements from the observed 68% to above 80% at Khorsky DOK.

The specialists conducted lumber recovery studies at 3 mill locations in Siberia and the Far East. One of these performed slightly better than the Khorsky DOK sawmill; however, it was operating two wood-mizer portable sawmills and had a very low daily production. The other was operating a circular saw headrig and had total sawing variation not significantly different from the Khorsky DOK sawmill.

Implications for carbon sequestration

Mäkipää and others (1999) determined that approximately 60% of carbon held in boreal forests is contained in the boles of trees. When trees are harvested and converted to lumber, some portion of the round log is converted to boards. The remainder (wood waste), in Siberia and the Russian Far East, is generally burned. By increasing recovery of lumber from round logs, a direct increase of carbon sequestered in long-term storage can be obtained.

The improvements to lumber manufacturing that lead to improved lumber recovery include better personnel training in operating mill equipment, better maintenance of existing equipment, improved saw sharpening schedules and techniques, and an enhanced overall commitment by mill management to optimizing lumber recovery. Taken together, these efforts will increase the precision of milling and significantly reduce wood waste created during milling. We must consider the conversion of carbon stored in the bole of a tree in the boreal forest to lumber milled from a Russian sawmill. It has been established that approximately 60% of the above ground carbon in the boreal forest is contained in the bole of a tree (Mäkipää *et al.* 1999). We can estimate the logging recovery of stemwood from the forest to be approximately 95% (estimating 5% of stemwood is left in the forest as logging slash), yielding a net recovery of site carbon from trees at approximately 57%. This estimate concurs with research conducted by Shvidenko & Nilsson (reported in Schulze *et al.* 1999) where they determined that approximately 57% of Russian boreal forest carbon was taken from the forest for industrial products such as paper and other wood products. We have demonstrated that current lumber recovery, and therefore carbon recovery, from round logs in this Russian sawmill was 68.3%. These factors combined indicate that the recovery of solid wood and carbon concurrently is approximately 38.9% (0.600 x 0.683 x 0.950 = 0.389). Through milling improvements that increase the sawmill lumber recovery from 68.3% to 80.0%, the conversion of carbon from the tree to marketable lumber can increase from 38.9% to approximately 45.6% (0.600 x 0.800 x 0.950 = 0.456). In other words, improvements to milling practices to increase lumber recovery directly contribute to the amount of carbon transferred from standing trees to lumber (Figure 3). The magnitude of this change causes approximately 6.7% more lumber and carbon to be recovered through reductions to the total sawing variation (or increasing lumber recovery) at this sawmill. Obviously all of the figures used in the calculations of potential improvements in efficiency in this case study are estimates. However, these estimates are robustly representative of obtainable results.

In summary, there is a significant potential for increasing the temporal sequestration interval for atmospheric and terrestrial carbon converted by trees in solid wood and then by man to commercial solid wood products. The exact magnitude of the impact depends on the eventual destinies of the lumber and the waste wood. The longest temporal storage for wood-origin carbon is observed when it is converted from mature trees to lumber products. To understand fully how much additional carbon would be sequestered by conversion to lumber requires an examination of the lumber lifecycle – a study that is beyond the scope of this paper. The other part of the of conversion depends on the alternative destiny of the wasted wood and the nature of the substitutes for the waste material that is otherwise utilized. In the Russian Far East, there are no wood-to-energy conversion facilities currently in operation, so direct electricity production is not a factor. However, some mills use wood waste to heat water that is then used in industrial and private building heating, or even in lumber kilns. If, because of reduced wood waste availability, additional trees are harvested to replace it, or if coal is substituted for the reduced wood waste then the net amount of carbon released to the atmosphere will not be decreased, it will just be replaced and net carbon storage will be reduced when additional trees are cut. Similarly, one must observe the reaction to a reduced amount of wood waste that is otherwise used for home heating and cooking. Is wood waste replaced by increased harvest of wood from the forest or is coal substituted as a heating and cooking source? Where these situations result in a change in fuel supply from sawmill waste to other wood alternatives the net decrease in carbon release to the atmosphere is zero. If it is replaced by coal, then there may be a slight increase in net carbon releases. Pragmatically, the real impact is in that amount of wood waste that is (a) simply burned without energy, heat, or other useful recovery, or is (b) left to decompose (such as saw dust). Such waste wood is decomposing faster, and releasing its carbon sooner, then it would have had it stayed longer in the growing tree. Increases in lumber recovery will cause a direct reduction in the amount of carbon released to the atmosphere where there exists no alternative uses for wood waste created during sawmilling. In every scenario, however, improvements to lumber recovery result in an increase to the carbon storage interval in solid wood that originated as atmospheric and terrestrial carbon.

In point of this discussion, it is important to emphasize that the dominant modification outlined in this research was a reduction in wood waste at the planer. This wood waste is realized as planer-dust produced after sawing (similar to sawdust). It is not a home heating fuel or mill source of energy through burning. It is left to decompose in large piles and landfills or incinerated without energy recovery in any form. Therefore, the secondary impact caused by reducing this waste product will not be seen as an increase in the harvest of other wood products or coal.

While it is not documented in this paper, the efforts to improve lumber recovery also will lead to net increases in revenue and reductions in costs that are greater than the costs of implementing the recommendations. Therefore, increasing lumber recovery has two significant results: increased profitability of the mill and enhanced long-term sequestration of carbon held in forest products. The former should produce incentives for achieving the latter, while both contribute to mitigating global climate change.

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Table 1: Duration of carbon sequestered in end uses of wood and paper (Skog & Nicholson 1998).

End Use	Half-life of carbon (years)
Single-family homes (pre-1980)	80
Single-family homes (post-1980)	100
Multifamily homes	70
Mobil homes	20
Nonresidential construction	67
Pallets	6
Manufacturing	12
Furniture	30
Railroad ties	30
Paper (free sheet)	6
Paper (all other)	1

Table 2: Summary of two sets of 50 Korean pine log diameters and volumes.

First Set of 50 Logs Each 4.04 meters long			Second Set of 50 Logs Each 4.04 meters long		
Small end Diameter (cm.)	**Number of Logs in Category**	**Log Volume (cubic meters) G.O.S.T.**	**Small end Diameter (cm.)**	**Number of Logs in Category**	**Log Volume (cubic meters) G.O.S.T.**
16	0	--	16	2	0.20
18	0	--	18	2	0.24
20	1	0.15	20	0	--
22	1	0.18	22	2	0.36
24	1	0.21	24	4	0.84
26	0	--	26	3	0.75
28	2	0.58	28	1	0.29
30	6	1.98	30	3	0.99
32	7	2.66	32	5	1.90
34	2	0.86	34	4	1.72
36	1	0.48	36	6	2.88
38	9	4.77	38	5	2.65
40	4	2.32	40	1	0.58
42	2	1.28	42	1	0.64
44	6	4.20	44	2	1.40
46	3	2.31	46	2	1.54
48	1	0.84	48	1	0.84
50	4	3.64	50	3	2.73
52	0	--	52	0	--
54	0	--	54	1	1.07
56	0	--	56	2	2.32
Total Volume		**26.46**			**23.94**

Table 3: A sample of thickness measurements along boards cut to a target of 50mm thickness and 22mm thickness at Khorsky DOK. Each board had 10 thickness measurements taken to 0.1 mm accuracy.

	Thickness measurement (mm) along each sample point									
Board Number	1	2	3	4	5	6	7	8	9	10
1-50	53.5	53.7	54.4	53.8	53.9	54.7	53.9	53.9	53.9	53.8
2-50	52.6	53.6	53.5	52.4	53.3	53.8	52.5	53.2	53.5	53.4
3-50	53.1	51.2	53.8	53.2	53.1	47.1	47.2	47.3	48.1	46.9
4-50	53.1	53.8	53.3	54.3	53.7	54.5	54.2	53.2	53.3	53.2
5-50	52.5	53.3	53.1	54.9	53.5	53.7	53.7	54.1	54.0	53.3
6-50	48.3	47.3	48.9	52.7	52.8	54.2	53.7	49.9	47.7	48.7
1-22	25.3	25.8	24.2	25.2	23.3	23.8	25.4	25.2	25.8	25.2
2-22	23.1	23.4	22.8	23.1	23.7	23.4	23.0	22.6	22.7	23.1
3-22	22.2	23.0	23.0	25.0	27.2	26.4	23.4	22.7	22.5	22.2
4-22	23.2	23.8	23.4	23.2	19.5	20.1	24.3	25.3	25.1	24.7
5-22	23.2	23.0	23.4	21.6	22.7	22.5	22.0	23.6	23.1	23.4
6-22	22.5	23.3	22.1	22.3	22.4	22.7	22.5	22.1	22.7	22.8

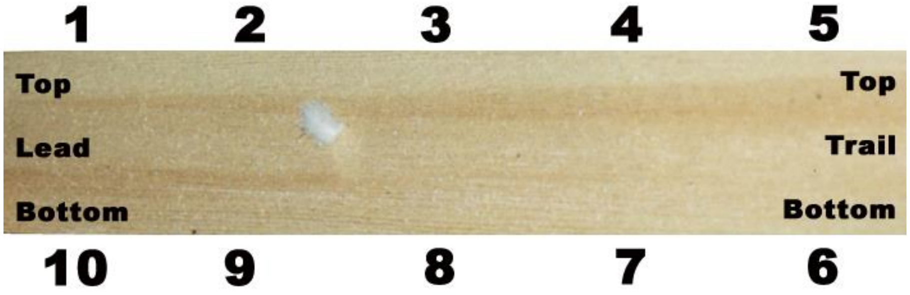

Figure 1: Board measurement locations for piece variability determinations.

Figure 2: One of the two Fuji bandsaws (resaw) at Khorsky DOK. Since the log feed mechanism was broken, all logs were fed by hand into this machine.

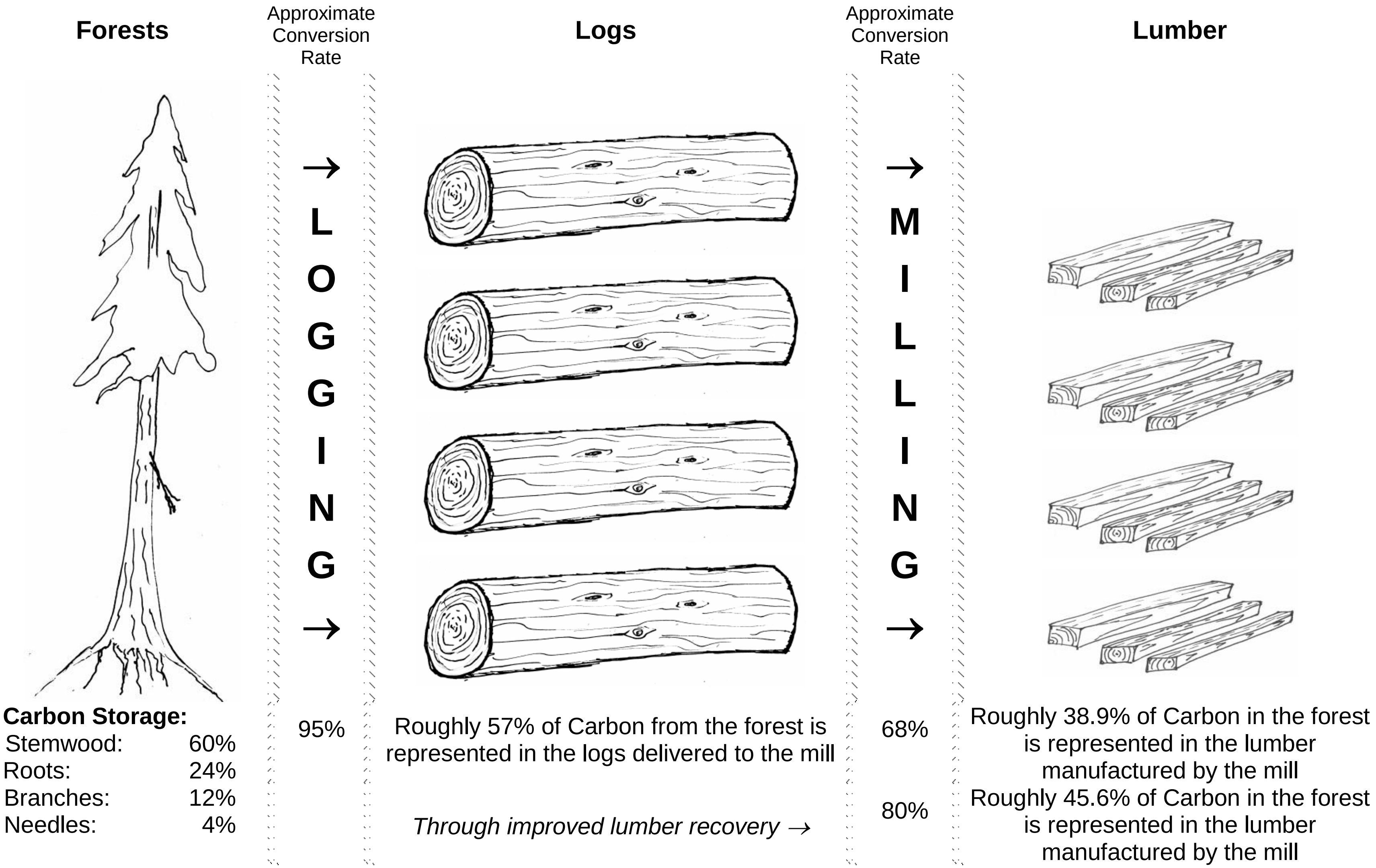

Figure 3: Recovery of carbon stored in the forest as it flows from the boreal forest, into logs, and into lumber processed by a Russian sawmill.