High Production Forestry in Nova Scotia

Phase 1 Final Report

In response to recommendations outlined in
An Independent Review of Forest Practices in Nova Scotia

July 2021

NOVA SCOTIA

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Phase 1 Final Report

Department of Lands and Forestry
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Executive Summary

An *Independent Review of Forest Practices in Nova Scotia* (Lahey 2018) recommended implementation of the Triad model for ecological forestry to ensure the sustainability of all forest values in Nova Scotia. This report discusses high production forestry, the Triad component that focuses on timber production.

"*Sustainable forest management (SFM) maintains and enhances the long-term health of forest ecosystems for the benefit of all living things while providing environmental, economic, social, and cultural opportunities for present and future generations*" (CCFM 2008). The difficulty in applying and achieving SFM, particularly on public land, is in satisfying the diverse and often conflicting expectations society has for what is a finite amount of forested land. Society values economic development, but also old growth forest; it values species for hunting, but also endangered species; and it values recreational opportunities, but also employment opportunities (Davis et al. 2001).

One approach to satisfying these demands is to divide the land into zones, each managed to provide a specific set of desired values. Triad zoning exemplifies this concept (Seymour and Hunter 1999; Lahey 2018) and divides the forest into three zones; a *Conservation* zone with no resource extraction (for conservation of biodiversity and natural processes); an *Ecological Matrix* zone where there is a mix of biodiversity conservation and timber production, and a *High Production Forest* zone managed primarily for timber production. The Government of Nova Scotia has committed to implementing a Triad management system on public land and work is underway to determine how this will be designed and implemented (NSDLF 2018).

The purpose of this *Phase 1 Final Report* is to share information related to the creation of a High Production Forest (HPF) zone in the province, including criteria for identifying and initially ranking potential HPF area, management practices and anticipated timber yields, and potential timber supply scenarios. This final report also reflects feedback received by the Nova Scotia Department of Lands and Forestry (NSDLF) during and after public stakeholder sessions held in spring, 2020.

High Production Forest is an important zone in the Triad system. The production of primary and secondary forest products supports the livelihood of many Nova Scotians and, in some communities, is a significant economic driver that supports many direct and indirect jobs and services. The high yields expected from high production forestry will help ensure an adequate supply of timber to support the economy while allowing for reduced management intensity within the Ecological Matrix zone. Further, the Lahey report (2018) notes that "…*expanding the area of production forestry, as well as improving harvest scheduling and silvicultural practices to ensure high yields, is arguably the only strategy that would allow harvests to be increased substantially at some time in the future*" [p. 66 Addendum].

In keeping with the Triad concept, three key criteria were used to identify area potentially suitable for inclusion in the HPF zone. The first criterion was that HPF sites should not include any land where conservation and non-timber values take primacy. Thus, protected natural areas, sensitive habitats, wildlife special management zones, and known old growth forest areas were not considered for inclusion. Second, the HPF zone should not include rich ecosites which commonly support tolerant hardwood forests as conversion of such sites to softwood plantations is ecologically inappropriate. Third, of the area remaining after application of these two criteria, the HPF zone should include land capable of supporting fast softwood tree growth, and thus must have the inherent fertility and drainage characteristics conducive to such growth.

Application of these three criteria to Nova Scotia Crown land results in approximately 246,000 ha (~16% of forested land) being potentially suitable for the HPF zone. If fully allocated, this area could generate close to 1.3 million green metric tonnes (gmt) per year of high-quality spruce timber after full program implementation.

Realizing and sustaining high timber yields in the HPF zone will involve the use of intensive silvicultural practices, comparable in some ways to an agricultural model but with a much longer crop rotation. This will include management regimes comprising mechanical and/or chemical site preparation, planting of improved growing stock, and competition control with herbicides and manual thinning to lessen natural vegetative competition. The periodic use of soil amendments, a common practice in agriculture, may also be included to sustain site productivity over successive rotations. The resulting cumulative effects of these practices are expected to result in minimum production rates of 6 m^3/ha/yr of high-value forest products at time of harvest – approximately double that currently achieved in natural forests.

Harvesting methods in the HPF zone are expected to include commercial thinning and clearcutting which result in even-aged stand structures. This will differ from the Ecological Matrix zone where irregular shelterwood and selection harvests are expected to be employed to help maintain or create more complex stand structures with late successional tree species, biological legacies, and multiple age classes – all of which serve to prioritize biodiversity objectives in the matrix forest (Davis et al. 2001; Nyland 2002).

Once potential HPF candidate areas are identified and the size of the HPF zone is determined, the area brought under HPF management will increase gradually overtime, taking many years to fully implement. This gradual implementation will provide opportunity to monitor stand development and enable refinement of cultural practices and revision of yield forecasts (if and when needed). The actual annual area to be brought under HPF management through plantation establishment will depend upon targets and transition periods chosen by the Province. As with annual planting rate, the HPF timber supply profile generated through time will depend upon the size of the zone and the transition period chosen. Sample scenarios are provided in this report to illustrate potential patterns of timber supply from different HPF management regimes over various zone area and transition periods.

In summary, establishment of a High Production Forest zone is an integral component of the Triad model of ecological forestry. This report summarizes work accomplished to date on this project and provides a basis for subsequent work including site selection.

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Project Overview

<u>Project Stages and Chronology</u>

- March 2019 – Project team formed.

- *Background work (research report reviews, field visits, interviews):*
  - May 2019 – Field visit to Sussex, NB tree nursery and Black Brook, NB forest management area – review of tree improvement program, plantation management, growth and yield, and intensive forest management strategies.
  - September 2019 – Field visit to northern NS (Cumberland region) – review of plantation development, management, and growth and yield results.
  - December 2019 – Field visit to northern NS (Pigeon Hill) – review of tree improvement test sites.
  - December 2019 – Field visit to western NS (St. Margaret's Bay) – review of plantation sites.
  - April 2020 – Field visit to northern NS (Chignecto) – review of mature plantation sample plots and growth and yield results.
  - May 2020 – Field visit to eastern NS (Perch Lake) – review of species stock type trials and growth and yield calibration in mature plantations.

- *Analysis/Modeling work:*
  - March-May 2019
    - Literature review on HPF site selection.
  - June-August 2019
    - Assessment of suitability and ranking criteria (productivity, past management, and distance to sawmill).
  - September-December 2019
    - Creating suitable area criteria and building overall Triad area classification.
    - Sensitivity analysis of suitability and ranking criteria.
    - Creating analysis sections for Discussion paper.
  - January-March 2020
    - Incorporation of tree improvement gains into yield forecasts.
    - Updates to suitable area definition (Triad land base table).
    - Updates to the Nova Scotia Growth and Yield model.
    - Initial setup of strategic-level model and scenario development.
    - Initial carbon analyses.
  - April-September 2020

- Preliminary strategic-level modelling results for a range of HPF scenarios.
- Further updates to suitable area definition (Triad land base table).
- Validation of HPF related yield curves.
- Incorporation of carbon into HPF strategic-level modelling.

Consultation Process

In recognition of the diverse interests among Nova Scotians, the HPF project team consulted with internal and external stakeholders, First Nations communities, and the general public to ensure their ideas and concerns were considered in the design process. Initial stakeholder consultations were held as part of the *Ecological Forestry Forum* hosted by NSDLF in Truro, NS on June 25, 2019. This was followed by a *Phase 1 Discussion Paper* open for public comment from February 20 to March 13, 2020. In total, 510 comments were received through this process. The project was also presented at the *Western Woodlot Owners Conference* on March 7, 2020 and there were four consultation meetings held with NSDLF staff in March 2020. Finally, an additional 150 comments were provided by targeted stakeholders in four virtual "face to face" consultations on May 19th and 20th, 2020 with another 283 comments received from NSDLF staff.

High Production Forestry in Nova Scotia

HPF and Triad Management

High Production Forest (HPF) is one of three distinct management zones within the Triad model of ecological forestry recommended by Lahey (2018) for adoption in Nova Scotia and recently outlined by Dr. Graham Forbes (https://novascotia.ca/ecological-forestry/Triad-A-New-Vision-for-NS-Forests.pdf). The other two zones are Conservation and Ecological Matrix. The Conservation zone, with no resource extraction, serves as a benchmark for ecological integrity, biodiversity, and natural processes. The Ecological Matrix zone (the largest zone) has the goal of sustaining and/or enhancing natural forest ecosystem conditions and function through a focus on biodiversity management, but where some timber harvesting can occur. The HPF zone is intensively managed for timber production to provide high yields from a relatively small portion of the land base. Together, the Conservation, Ecological Matrix, and HPF zones function to achieve an optimal combination of conservation and production objectives, and success of the Triad model requires implementation of all three zones at appropriate scales to ensure all societal values and objectives are met.

Phase 1 Project Objectives

Establishment of an HPF zone is a large undertaking that will take many years to fully implement. Objectives of this first phase of the HPF project work were:

- To establish a working definition of high production forestry.
- To outline the basic principles and key assumptions associated with high production forestry.
- To establish initial criteria for selecting and ranking potential HPF sites.
- To estimate the area of Crown forest land potentially suitable for HPF management.
- To outline the silvicultural needs associated with HPF management.
- To analyze potential yields associated with HPF management and their related impacts on provincial wood supply.

What We Heard

An exhaustive account of all feedback received during Phase 1 stakeholder sessions is beyond the scope of this report. However, the HPF project team has reviewed and discussed all comments and have addressed many of these in this final report. Many comments received were highly specific, and on several topics there was either a wide range of opinion or strong interest from one but not all segments of the stakeholder community. Comments that were related to high production forestry, but not to this phase of the project, were collected for future consideration (these were mainly related to HPF implementation which will be the focus of Phase 2 work). Other comments that were not specific to high production forestry were forwarded (as appropriate) to other Forest Practices Review project teams.

Below is a summary of themes and issues addressed in this final report as a direct result of stakeholder feedback. Additional detail, including specific information relevant to stakeholder comments, is available in corresponding report sections.

1. *Objectives of High Production Forestry*

Stakeholders expressed a range of views on the basic concept of high production forestry and how it was defined in the Discussion Paper. A clear working definition of high production forestry is presented in this report along with the rationale for current focus on spruce species for HPF management.

2. ***Biodiversity and Environment***
Stakeholders asked for a clear statement regarding HPF management and biodiversity and how this related to biodiversity goals in Conservation and Ecological Matrix lands. A high-level discussion of high production forestry in relation to biodiversity objectives has been added to this report.

3. ***Amount and Type of Land***
Numerous comments focused on the figure of 18% of Crown land listed as potential HPF land in the Phase 1 Discussion Paper. Although this number was simply the outcome of initial land suitability assessment, it was viewed by many as a target or an already finalized objective. To help resolve confusion among stakeholders over area values reported in the Discussion Paper, a more detailed land base description and potential breakdown by Triad management zone is contained in this report. Areas are provided in two ways. First, by land base category (including total land base, forested land base, and working land base); and second, by FEC Forest Group or forest condition. The latter breakdown includes information on zoning of existing plantations.

4. ***Ranking Criteria***
Most of the feedback on initial site ranking criteria centred around transportation considerations. It was suggested that mills be consulted on maximum trucking distance and that NSDLF consider not just distance, but also the types of road networks involved and their related restrictions. Stakeholders also asked whether mills could be weighted by capacity to utilize fibre. As a result, more details related to existing road and mill infrastructure have been added to initial ranking criteria that can be used in future (Phase 2) site selection decision-making.

5. ***Silvicultural Practices***
The inclusion of Norway spruce as a potential HPF species generated numerous, mostly negative, comments. There were also concerns that example silviculture strategies described in the Phase 1 Discussion Paper were too prescriptive and that managers should have flexibility with respect to treatments and species planted. Many comments received were based on the assumption that operational decisions with respect to HPF management had already been made, when in reality the scenarios described in the Discussion Paper were only examples of the type of management regimes that could be followed and the type of treatments that would be necessary to achieve desired production targets. Such scenarios are needed to show the scope and potential of HPF management, and many more scenario runs have been conducted since release of the Discussion Paper to generate information discussed in this report. In addition, more information has been added on use of herbicides and soil amendments as part of HPF management.

6. *Yield Projections*
Numerous stakeholders felt that yield targets discussed in the Phase 1 Discussion Paper were very aggressive and optimistic and that high production forestry was unproven in our region. More details were requested with respect to the validity of yield forecasts and the sustainability of such high production. As a result, additional information and references to empirical data have been added to support yield assumptions and targets associated with HPF management, including new information on growth and yield research and detailed discussions on tree improvement and nutrient management research.

7. *Climate Change*
There was some concern that high production forestry may not align with provincial climate change goals, and some stakeholders asked to see an account of projected carbon budgets, including a comparison between natural and high production forests. Although a detailed discussion of forest carbon management is beyond the scope of Phase 1 objectives, a preliminary analysis of carbon budgets is included in the *Wood Supply Analysis* section of this report. A section discussing the role of HPF in climate change adaptation is also provided. The Department is committed to ongoing modelling and analysis of forest carbon budgets in all three zones of the Triad, as well as research and planning in climate change adaptation.

8. *Economics and Implementation*
Many stakeholders expressed concern about the economics of high production forestry. It was argued that public buy-in will require a solid business case with all the costs (including who pays) and a high level of certainty in terms of costs and returns before making these investments. While a detailed economic analysis is beyond the scope of Phase 1 objectives, a preliminary stand-level economic assessment based on potential silviculture costs and yield returns has been conducted and added to this report. In addition, a section has been added on projected wood supply availability during the HPF transition phase.

Basic Principles and Assumptions

Definition of High Production Forestry

Land zoned as HPF has the primary goal of efficiently and economically producing high-value forest products to meet societal needs, while allowing a larger proportion of public land to be managed for ecological objectives. The HPF model is comparable to agriculture, as the land is intensively managed to increase the quantity and quality of a defined set of products over a specified time. Rotations are expected to be short (e.g., 30-50 years) compared with those in natural forests and will be based on producing high value saw timber products.

In Nova Scotia, growth rates of planted forests under HPF management will be expected to equal or exceed 6 m^3/ha/yr at time of final harvest which is 50-100% greater (or more) than those found in unmanaged natural forests . Achieving and sustaining these high yields will require site preparation, use of improved seed and seedling stock, control of competing vegetation during the establishment phase (0-10 years), and periodic use of soil amendments to maintain site productivity.

Red spruce (*Picea rubens*), white spruce (*P. glauca*), and Norway spruce (*P. abies*) have been initially selected for HPF management due to the historic demand for spruce sawlogs and studwood, the infrastructure that currently exists for these products, the availability of improved growing stock, and the array of management options that exist for these species. However, one of the attributes of high production forestry is management flexibility, and if future conditions dictate a need or desire to shift to other products or species, this can be accommodated under revised HPF management regimes.

Key Assumptions

1. *Growth and Yield*

There is currently about 98,000 ha of planted forest on Nova Scotia Crown land with a variety of species represented (spruces, pines, and larches). Although technically plantations, these sites cannot be called high production forest because they were not all established and managed to achieve HPF objectives. As a result, real and projected yields from these plantations are highly variable (as was noted during stakeholder discussions). A more reliable indicator of potential yields associated with HPF management comes from provincial growth and yield models developed using local empirical data obtained from long-term research permanent sample plots.

Research Permanent Sample Plots: The Department's research permanent sample plot (RPSP) program was established in 1978 and continues to this day. Over this 40+ year period there have been more than 1,200 RPSPs established across the province with 952 plots still active and scheduled for re-measurement every five years. In terms of treatments being monitored, 23% are in plantations, 34% in pre-commercial thins, 16% in commercial thins, 13% in other treatments, and 14% in untreated controls. Data from these plots have been (and continue to be) used to develop and update growth and yield models for managed forests across the province providing empirical, long-term realized results from which to base HPF yield projections. Data collected from RPSPs are stored in a secure database known as the *Forest Research Information System* (FRIS) and are used in the development of research reports and forest management tools (including the *Nova Scotia Growth and Yield Model*) that are publicly available through the NSDLF website***.***

2. *Tree Improvement*

Tree improvement refers to the structured process of selecting, breeding, and growing trees that display superior performance in one or more desired traits such as growth, stem form, reduced susceptibility to pests and diseases, or drought resistance. To qualify for improvement, desired traits need to be heritable (i.e., passed on reliably from one generation to the next), and under strong genetic rather than environmental control.

Initially, superior individuals (so-called "plus" trees) are identified in the wild and their seed or scions brought into a controlled breeding population or breeding garden. Trees in the breeding garden are mated to each other and their progeny tested for desirable traits across multiple years and test sites. In the meantime, a subset of top performing plus trees is propagated and planted into seed orchards which provide tree nurseries with improved seed. Data from progeny tests are used to identify and select the highest performing parent trees which are then bred to create the next generation breeding and seed orchard populations. Each of these cycles of breeding and testing results in cumulative improvement in desired traits.

<u>Tree Improvement in Nova Scotia</u>: Nova Scotia has a long-standing and successful cooperative tree improvement program which was initiated in the late 1970s when the then Department of Lands and Forests and several industry partners established the *Nova Scotia Tree Improvement Working Group* (NSTIWG). All NSTIWG members conduct progeny tests and some also operate seed orchards, while the Department coordinates all activities, analyzes data, and coordinates breeding work. Across Nova Scotia there are more than 100 progeny test sites managed by NSTIWG. At present, there are active improvement programs for five economically important conifer species in the province. The improvement programs for white spruce, red spruce, and black spruce (*Picea mariana*) are currently in their second generation, while Norway spruce and eastern white pine (*Pinus strobus*) programs are in their first generation. Gains in potential growth for these species are estimated at approximately 20% per generation.

<u>Tree Improvement and HPF</u>: Tree improvement plays a critical role in achieving HPF production goals by providing superior, fast-growing trees for plantation establishment. However, the genetic gains associated with tree breeding programs can only be fully realized when combined with silvicultural practices that ensure planted trees have optimal growing conditions. In addition, gains achieved through selection and breeding will continue to accumulate as tree improvement programs progress from one generation to the next. Moreover, recent advances in DNA-marker assisted selection tools have significantly reduced the time needed for testing.

Whereas a typical breeding and testing cycle used to take about 30 years, marker-assisted selection can reduce this time by more than half, significantly reducing program times and costs. This in turn will allow forest managers to adapt more quickly to changing conditions and to deploy the best and most adapted planting stock available during plantation establishment.

3. *Use of Herbicides*

To fully realize potential growth on HPF sites requires control of competing vegetation until planted seedlings are *free-to-grow* (i.e., free from non-crop tree competition with the ability to successfully grow without further intervention). On the medium to rich sites being targeted for HPF management, competition is often dominated by fast-growing herbaceous cover or woody shrubs that are most efficiently controlled early on by herbicides. Although herbicide has not been used as a forest management tool on Crown land in Nova Scotia since 2010 the regulated use of herbicides as an HPF management tool was discussed and supported by Lahey (2018). In most cases, one application of herbicide per rotation (i.e., every 30-50 years) would be expected and applied two years after planting. Sites with heavy competition may require a second application in year-4 or year-5, but this is not expected to be a common occurrence with the use of site preparation techniques, fast-growing seedlings, and exclusion of the richest ecosites from HPF consideration. Use of herbicide as a preparatory treatment prior to planting may also be needed in some cases (e.g., to control grasses on old field sites), though it is expected most site preparation will be done mechanically using disc trenching or other means. All forestry-related use of herbicides in Nova Scotia must abide by federal and/or provincial regulations and guidelines and this will also be the case under HPF management.

4. *Nutrient Management*

By definition, HPF sites are expected to produce merchantable volumes at rates of 6 m^3/ha/yr or more at time of final harvest. This type of production is nutrient-demanding and will likely match or exceed the natural long-term nutrient supply rates on many sites. Therefore, soil monitoring and development of nutrient management plans are necessary components of high production forestry.

Over the last several years, NSDLF has been directly involved with several soil and site productivity related projects including: (i) development of a forest soil classification system (Neily et al. 2013), (ii) development and calibration of a forest nutrient budget model (Keys et al. 2016), (iii) development of a forest soil and tree tissue sampling program, (iv) research on ground disturbance and soil damage assessment, (v) research on forest liming, and (vi) research on soil amendment use in spruce plantations (Keys et al. 2018). All this work, combined with ongoing research, will be used to develop science-based and effective soil monitoring and nutrient management regimes for HPF sites.

Nutrient Budgets: Nutrient management starts with knowing what nutrients are available, what the demands are, and what the natural supply rates are. The Department's nutrient budget model (NBM-NS) can be used to model species and site-specific nutrient demands and supplies under various HPF management scenarios. In addition, soil sampling program data (augmented by site-specific sampling) can be used to estimate current nutrient stores by soil/site type. Results can then be used to develop silviculture and amendment prescriptions aimed at restoring, balancing, and/or maintaining soil nutrient conditions over time (to be confirmed by soil monitoring and periodic testing). As part of this assessment, it has already been determined that HPF management cannot and will not include removal of nutrient-rich foliage and slash through either full-tree or whole-tree harvesting practices. This will also enhance biodiversity on HPF sites by periodically providing potential habitat for insects, amphibians, reptiles, small mammals, and birds.

Soil Amendments: Soil amendments come in many forms and provide a range of potential benefits. For example, as a result of decades of acid deposition, many forest soils in Nova Scotia are very low in base cations (calcium, magnesium, potassium) and would benefit from a "lime" application in the form of traditional dolomitic lime, wood ash, and/or alkaline stabilized biosolids (Pugliese et al. 2014; Lawrence et al. 2016; Keys et al. 2018). An early liming treatment will likely be part of many HPF management regimes. When available, use of wood ash generated from the Province's new *Small-Scale Wood Energy Initiative* would be a natural extension of this program. Another potential liming option is use of crushed basalt that, in addition to being a slow-release nutrient source, has the potential to promote carbon sequestration through bicarbonate (HCO_3^-) production – a natural extension of the weathering process (Beerling et al. 2018).

Options with respect to nitrogen and phosphorous amendments include inorganic fertilizers and organic residues (e.g., manures or treated sewage). Organic amendments could also be used to offset potential losses in soil organic matter and related carbon stores. Occasional use of N-fixing nurse crops (e.g., *Alnus spp*.) may be another option to increase mineral soil nitrogen and carbon stores (Mayer et al. 2020). In future, there may also be options related to biochar use (Page-Dumroese et al. 2016).

Although use of soil amendments may be part of HPF management, its important to note that such use will be infrequent and/or of low rates compared to agriculture. When needed, most applications will occur in association with (i) site preparation, (ii) after planting but before crown closure, or (iii) after commercial thinning. In addition, many of these amendments will be "slow-release" so as not to cause ecosystem shock or excessive leaching.

Monitoring: Periodic monitoring of soil conditions is a necessary and important component of sustainable high production forestry. In addition to soil chemistry (including carbon stores), this includes monitoring of physical properties such as bulk density and aeration porosity that can be negatively impacted by increased machine traffic. Ongoing soil monitoring will allow confirmation of effective treatments, abandonment of ineffective treatments, and testing of alternative management approaches.

5. *Biodiversity*

Adopting a Triad model approach to forest management requires designation of three main zones across the landscape – a Conservation zone, an Ecological Matrix, and an HPF zone. Each of these zones captures and represents a range of biodiversity values, but at different levels.

The Conservation zone includes designated parks, nature reserves, and wilderness areas that provide important wildlife habitat and represent the range of natural biodiversity across the landscape. This biodiversity focussed zone is also expected to include officially designated old growth forests and portions of Crown land being considered for designation as protected areas. The Ecological Matrix zone has a mixed objective to promote biodiversity while also allowing for low intensity management and harvesting practices that maintain natural stand structure and composition characteristics. Despite the management focus on timber productionplanted forests still provide some ecosystem services and biodiversity value (Brockerhoff et al. 2008), and this should be the case for the HPF zone as well. In addition, establishment of HPF sites will promote landscape scale biodiversity by excluding lands with conflicting and/or high conservation values and by concentrating intensive management onto a smaller land base (Bauhus and Schmerbeck 2010). Areas excluded outright from the potential HPF zone include protected natural areas, sensitive habitats, wildlife special management zones, and old growth forests. Core habitat for species at risk is also an important biodiversity consideration, and HPF zone suitability will continue to be assessed as core habitat areas are defined across the province.

In addition, lands that have been zoned as HPF will still be subject to legislative requirements under existing Acts and Regulations such as the *Wildlife Act* and *Endangered Species Act*. Legacy trees (wildlife clumps) and watercourse special management zones (i.e., buffers) are also required within HPF management areas as currently outlined in provincial *Wildlife Habitat and Watercourse Protection Regulations*. These watercourse buffers may be eligible for some forest management using Ecological Matrix style practices, but they would not be subject to HPF management regimes. Finally, forest management practices in the HPF zone will follow special management practices and guidance documents around wildlife and wildlife habitat. Examples of these include the identification of old growth forests protected under the Old Forest Policy, applying Special Management Practices for Endangered Mainland Moose (and other species), Forest Wildlife Guidelines and Standards, and the Forest Biodiversity Stewardship Field Guide.

6. *Climate Change Adaptation*

The most recent Intergovernmental Panel on Climate Change (IPCC) scenarios that predict future climatic change – called Representative Concentration Pathways – show potential increases in mean annual temperatures of approximately 2 ^{o}C to 6 ^{o}C and increases in mean total annual precipitation of approximately 100 mm to 300 mm for Nova Scotia by the year 2100 (McKenney et al. 2013; IPCC 2014). These types of "rapid" environmental change will undoubtably impact our forests because of the long-lived nature of trees and the longer planning horizons associated with forest management (Lindner et al. 2010). An alteration of natural disturbance regimes is one impact of climate change that has been both predicted and documented in recent years. Of concern are increases in the frequency and severity of natural disturbances such as windstorms, pest outbreaks, drought, and wildfire (Seidl et al. 2017; Taylor et al. 2020).

The two main approaches for integrating climate change into forest management are adaptation and mitigation. Adaptation is the adjustment of forest management to avoid adverse climate change impacts, while mitigation is management to increase carbon sinks or to reduce greenhouse gas emissions (IPCC 2014). Despite global mitigation efforts, some degree of climate change is inevitable, and adaptation will be necessary alongside mitigation to reduce vulnerability and adverse impacts (Williamson and Nelson 2017).

Given the uncertain and evolving nature of climate change, a multi-faceted and adaptive approach to forest management is critical. The Triad model is one such multi-faceted approach for managing a diverse set of forest values and trade-offs in a changing climate (Nitschke and Innes 2008). Although even-aged plantations in the HPF zone are likely to be more susceptible to some disturbance agents (e.g., pest outbreaks) than more complex natural forests, the spatial distribution and range of development within the HPF zone will promote some landscape-level resilience. In addition, HPF stands will provide opportunities for climate change adaptation through planting of improved stock and short rotations. Managers will have the ability to adjust silvicultural regimes and to do so more frequently in managed plantations so that species and genotypes are better suited to future climatic conditions (Paquette and Messier 2010; Pawson et al. 2013).

Suitability and Ranking of Potential HPF Sites

There is an important distinction between estimating the amount of land that is potentially suitable for HPF management and ranking that land for actual site selection. Suitability criteria are needed to ensure potential HPF land meets minimum site productivity needs while not conflicting with overarching biodiversity objectives. Ranking criteria are important because no decision has been made on the amount of land that will be put into the HPF zone, and if less area is allocated than is available, a ranking process is needed to aid site selection. Selection of HPF sites will also need to be compatible with landscape management objectives.

Suitability Criteria

There are approximately 1.85 million hectares (ha) of Crown land in Nova Scotia that reduces to about 1.82 million ha after removal of roads and other converted lands (Table 1).

Table 1. Net Crown land area for Triad zoning.

Land Base Category	Area (000's ha)
Gross Crown Land Base (Forested and Non-forested)	1,854
minus Roads	20
minus Converted Non-vegetated[1]	8
minus Converted Vegetated[2]	1
Net Total	**1,824**

[1] Urban, sanitary landfill, gravel pits, pipeline corridor, powerline corridor, rail corridor, etc.
[2] Christmas trees, orchards, blueberry fields, etc.

To estimate the amount of this Crown land potentially suitable for HPF management, a series of additional “removal” criteria were applied to (i) meet biodiversity objectives and (ii) address productivity and/or land use constraints. As part of this process, only medium to rich ecosites (ecosites AC10 and AC11 as described in Nova Scotia’s forest ecosystem classification system, Neily et al. 2013) were considered for HPF eligibility (Figure 3). The majority of rich and very rich ecosites (AC13, AC14, AC16, AC17) were removed to meet biodiversity objectives (i.e., to avoid conversion of natural tolerant hardwood sites and floodplain sites to softwood plantations). Less productive ecosites, such as those that naturally support pines and black spruce, were removed for site productivity constraints (including AC6, AC7, AC9, low productivity AC10 and AC11 sites, and all MB ecosites). In addition, all very poor, dry, and wet ecosites were removed for productivity and/or biodiversity reasons. Any sites not considered for the HPF zone and not part of the Conservation zone, but eligible for forest management activities, were automatically assigned to the Ecological Matrix zone. This included watercourse buffers embedded or adjacent to potential HPF areas (estimated at < 1% of forested Crown land area).

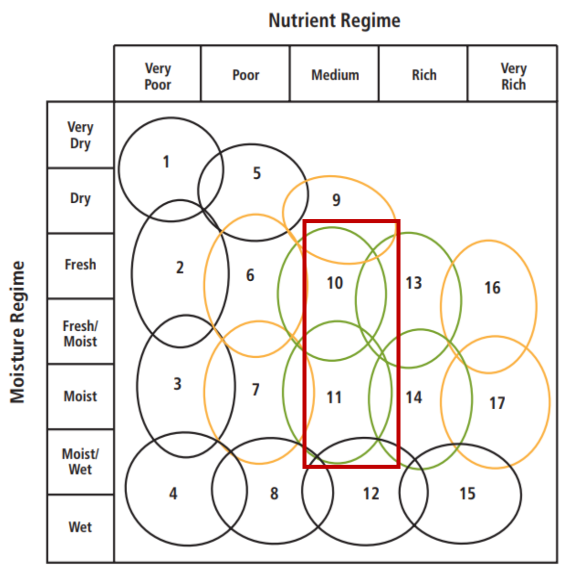

Figure 3. Edatopic grid showing relative moisture and nutrient regimes for Acadian group ecosites (from Neily et al. 2013). Ecosites suitable and targeted for high production forestry with red spruce, white spruce, and Norway spruce are nutrient medium-rich, fresh to moist sites outlined by the red box. For more information on ecosite characteristics, see Neily et al. (2013)

This approach resulted in approximately 16% (246,000 ha) of *forested* Crown land being classed as potentially suitable for the HPF zone, with 33% (514,000 ha) currently assigned to the Conservation zone and the remaining 51% (783,000 ha) assigned to the Ecological Matrix zone (Table 2). For comparison purposes, in the Phase 1 Discussion paper, *total* Crown land area was the reference used when discussing potential HPF land area. At that time, 18% of total Crown land was considered suitable, but after more detailed land base assessment and further consideration of eligibility criteria, this has been reduced to 13% (Table 2). The area removed from HPF consideration was all operable land added to the Ecological Matrix zone within the *working forest*.

Note: Results shown in Table 2 address concerns expressed during stakeholder sessions that Conservation and Ecological Matrix lands were mainly associated with inoperable forest land. Indeed, potential HPF land only makes up about 30% of the working forest and this percentage is likely to decrease as further removals are applied at the landscape and operational planning levels (e.g., from core habitat assessments and onsite suitability assessments).

Table 3 shows the estimated distribution of Triad zone forest lands by currently mapped forest group (Neily et al. 2013) or stand condition (if forest group could not be assigned). This shows the expected dominance of spruce hemlock (SH) and Mixedwood (MW) vegetation types in the potential HPF zone (since these vegetation types are generally associated with medium fertility sites), but also that the SH and MW groups are well represented in the Conservation and Ecological Matrix zones.

Table 2. Potential Triad zoning of the 1,824,000 ha net total Crown land area from Table 1.

Triad Zone	Land Base Category	Total Land Base[1]		Forested Land Base[2]		Working Land Base[3]	
		Area (000's ha)	%	Area (000's ha)	%	Area (000's ha)	%
	Land Base Total	**1,824**	**100%**	**1,542**	**100%**	**824**	**100%**
Conservation	Legislated and Proposed Protected	611	33.5%	495	32.1%	-	-
	Old Forest Policy[4]	19	1.1%	19	1.2%	-	-
	Total	**630**	**35%**	**514**	**33%**	**-**	**-**
Ecological Matrix	Non-Forested Vegetated	140	7.7%	-	-	-	-
	Naturally Non-Vegetated	8	0.4%	-	-	-	-
	Brush and Moose Meadows	5	0.3%	<1	<0.1%	-	-
	Regional Crown Exclusions[5]	34	1.9%	33	2.1%	-	-
	Wildlife Habitat Buffers[6]	46	2.5%	43	2.8%	-	-
	Wildlife SMP Zones[7]	41	2.2%	41	2.7%	36	4.4%
	Watercourse Buffers[8]	41	2.2%	38	2.5%	20	2.5%
	Inoperable Removals[9]	43	2.4%	38	2.5%	-	-
	Rare/High Land-use Pressure Ecosections[10]	41	2.2%	41	2.6%	36	4.4%
	Maritime Boreal Ecosites	84	4.6%	83	5.4%	81	9.8%
	Biodiversity Sensitive Forest Groups[11]	61	3.3%	61	4.0%	-	-
	Low Spruce Productivity Ecosites	285	15.6%	285	18.5%	285	34.6%
	TH/MW/IH on Rich Sites	83	4.7%	83	5.4%	83	10.1%
	Extreme Wind Exposure Sites[12]	4	0.2%	4	0.3%	4	0.5%
	Natural Regeneration on Unsuitable Sites[13]	32	1.8%	32	2.1%	32	3.9%
	Total	**948**	**52%**	**783**	**51%**	**578**	**70%**
Suitable for High Production	Alders and Old Field[14]	<1	<0.1%	<1	<0.1%	<1	0.1%
	High Production Forestry Potential	245	13%	245	15.9%	245	29.8%
	Total	**246**	**13%**	**246**	**16%**	**246**	**30%**

[1] Total land base includes forested and non-forested areas.
[2] Forested land base includes only forested areas.
[3] Working land base excludes offshore/lake islands, areas of very low site productivity, steep slopes, non-forested areas (except alder and old field sites potentially suitable for HPF management), and areas where harvesting is prohibited.

[4] Does not include old forest already in existing and proposed protected areas.
[5] Potential ownership layer errors, not recommended for license, right-of-ways, operability constraints, Aboriginal negotiated Crown land.
[6] Lynx habitat, moose habitat, coastal plains flora, boreal felt lichen and other special site habitat buffers.
[7] Wood turtle area, deer wintering area, marten patches, moose shelter patches.
[8] Regulation 20m buffers, Crown policy 20m buffers around open water wetland, and Crown policy main river 100m buffers for mapped watercourses (unmapped buffers are identified at the operational planning level).
[9] Offshore/lake islands, very low site productivity, steep slopes.
[10] Ecosections that represent <2% of an ecodistrict or are heavily converted (>75% of an ecodistrict) to an unnatural state for anthropogenic use.
[11] Wet Deciduous, Wet Coniferous, Karst, and Floodplain Forest Groups.
[12] As identified in the provincial wind exposure map (Keys et al. 2018).
[13] Proportion of sites deemed unsuitable for HPF zone based on PTA data submissions.
[14] Due to current or past use, but potentially eligible for conversion to HPF plantations.

Table 3. Estimated distribution of Triad zone forested lands by current forest group or condition. Very small areas of unmappable Cedar and Open Woodland forest groups would be included in the Conservation and/or Ecological Matrix zones.

	Forested Land Base	Triad Zone (000's ha)			Total
		Conservation	Ecological Matrix	Suitable for HPF[1]	
FEC Forest Group	Coastal	17	20	-	**37**
	Flood Plain	1	1	-	**1**
	Highland	28	42	-	**70**
	Intolerant Hardwood	45	69	16	**130**
	Karst	2	2	-	**4**
	Mixedwood	50	52	46	**147**
	Old Field	2	2	3	**6**
	Spruce Hemlock	81	99	53	**233**
	Spruce Pine	138	196	-	**334**
	Tolerant Hardwood	72	82	-	**154**
	Wet Coniferous	28	63	-	**90**
	Wet Deciduous	12	27	-	**39**
Forest Condition	Plantation	7	34	56	**98**
	Unclassified Regeneration (<20 years old)	20	73	52	**145**
	Treated (PCT, CT, Selection)	2	18	13	**33**
	Unclassified Spruce	8	2	6	**16**
	Wind Disturbed Sites	2.7	2.3	-	**5**
	Total	**514**	**783**	**245**	**1542**

[1] Covertype information reflects current stand conditions. Intolerant hardwood (IH) and mixedwood (MW) stands included in HPF suitable area are assumed to be early to mid-successional vegetation types that would typically succeed to softwood dominated vegetation types over time.

Ranking Criteria

Phase 1 of the high production forestry project does not include specific assignment of sites for HPF management but does include initial criteria for ranking and targeting areas for further assessment and analysis. Ranking is currently guided by two main criteria.

- Whenever possible, consideration should be given to sites already converted from natural forest (e.g., existing tree plantations, abandoned agricultural fields, and other areas already modified by humans). Such sites are typically productive, accessible, and in a landscape with existing infrastructure and road networks.

- Sites should promote economic efficiency such that wood procurement and processing to finished product is profitable. This includes consideration of where suitable land may be located and concentrated in relation to existing road and sawmill infrastructure (Norfolk and Erdle 2005). This criterion recognizes that establishment of the HPF zone will take many years and initial site selection should consider the location of existing processing facilities which can be tied to reduced trucking costs and related carbon emissions.

For this exercise, the province was divided into a 10-metre (m) resolution raster with cells nested within larger 100 m and 1 km square cells. These varying resolutions were developed for use at different stages in the selection process. At this Phase 1 planning level, the 1 km resolution is best for identifying areas to target for further analysis.

Plantations and Old Fields

Existing plantations and old fields (including rich alder sites) are higher ranking because many softwood plantations are found on medium-rich sites and old fields tend to have high potential productivity from past management. These areas also have a history of intensive management and are associated with nearby road networks. However, this criterion does not address the problem of plantations that may be found on inappropriate ecosites for which the objective may be restoration and management in the Ecological Matrix zone. Identifying such candidates for restoration is better addressed at the landscape or operational planning scales. This criterion was scored by calculating the hectares of past management within each 1 km cell.

Distance to Sawmills

Following the example of Ward (2012), “roadsheds” were delineated for the entire province. Whereas a watershed is a catchment basin for precipitation, a roadshed is a catchment basin for wood flow. A roadshed boundary determines the point where wood harvested is likely to flow based on harvest block conditions and distance to nearby woods roads. The pour points in this case are intersections of woods roads and paved roads. With a transport distance matrix linking roadsheds to the province's processing facilities, the average distance to the two closest sawmills for each roadshed was calculated. This criterion was scored by calculating an average delivery distance within the 1 km cell.

Only existing sawmills acquiring greater than 10,000 m^3 of softwood (NSDLF 2019) were used as possible destinations in this analysis:

- Elmer Lohnes Lumbering Ltd. (Bridgewater, Lunenburg Co.)
- Taylor Lumber Company Ltd. (Middle Musquodoboit, Halifax Co.)
- Harry Freeman & Son Ltd. (Greenfield, Queens Co.)
- J.A. Turner & Sons Ltd. (West Northfield, Lunenburg Co.)
- Ledwidge Lumber Co. Ltd. (Oldham, Halifax Co.)
- Turner and Turner Lumber Ltd. (West Northfield, Lunenburg Co.)
- Williams Brothers Ltd. (Barney's River, Antigonish Co)
- Scotsburn Lumber Ltd. (Scotsburn, Pictou Co.)
- Elmsdale Lumber Co. Ltd. (Elmsdale, Hants Co.)
- Sproule Lumber Ltd. (Valley, Colchester Co.)

Although many smaller sawmills exist and play a key role in supporting the provincial forest industry, larger sawmills were chosen for this criterion due to their higher capacity and presumed ability to utilize large, localized increases in softwood timber supply. This does not preclude smaller sawmills from accessing timber from HPF sites, but initial site ranking is not being related to small sawmill location. Similarly, pulp and paper mills were not used in this analysis since the objective of high production forestry is to produce high quality (high value) sawtimber. In response to stakeholder comments, distance ranking for sawmills was changed to a weighted average based on consumption rather than just average delivery distance. More details on how site ranking data were compiled and analyzed can be found in Appendix B.

Growth and Yield Analysis

Several management scenario examples for HPF sites have been developed to assess potential yields and associated impacts on wood supply. Results were based on:

- Output from the Nova Scotia Growth and Yield (NSGNY) model incorporating over 35 years of plantation RPSP data.
- Relevant Forest Research Reports (FRR) produced by NSDLF:
    a. FRR #22 - *Revised Normal yield Tables for Nova Scotia Softwoods*

b. FRR #24 - *Norway Spruce: Growth Potential for Nova Scotia*
c. FRR #35 - *Yields of Selected Older Forest Plantations in Nova Scotia*
d. FRR #43 - *Nova Scotia Softwood Growth and Yield Model Ver. 1.0 User Manual*
e. FRR #77 - *Growth Potential of "Old Field" Plantations in Nova Scotia*

- Recent field verification of plantation yields.
- Discussions with regional tree improvement specialists.
- Discussions with regional silviculture practitioners and forest managers.

As part of this ongoing work, several updates were made to the NSGNY model since release of the Phase 1 Discussion Paper in February 2020:

- New diameter increment functions were developed for red, white, and Norway spruces based on the most up-to-date data.
- The site index for Norway spruce was reduced, resulting in slightly lower yields than previously modelled.
- Post-establishment stocking adjustments were added to yield projections to reflect non-competition induced mortality.

<u>Management Scenarios</u>

Management scenario examples (Table 4) were designed to align with HPF goals of producing quality, high value logs for the sawmill sector. These scenarios are *not* intended to be definitive prescriptions with exact timing of interventions. Actual timing of competition control, commercial thinning, and final harvest may vary based on site conditions. In addition, future market conditions may shift preference to larger or smaller product dimensions. Management scenarios presented do, however, reflect realistic management regimes and potential yields based on empirical data and knowledge.

The red spruce scenario is designed to maximize sawlog volume with a piece size diameter at breast height (dbh) of 12 inches (30 cm) at year 50. White spruce scenarios are designed to achieve average diameters of 10 inches (25 cm) at age 45 or 8 inches (20 cm) at age 40 which maximizes both sawlog and studwood volume. Norway spruce scenarios are also designed to achieve average diameters of 10 inches (25 cm) at year 40 or 8 inches (20 cm) at year 35, but with a focus on studwood only (due to market limitations). In all cases, initial plantation density was set at 1,736 stems/ha (2.4 m spacing) with an assumed establishment stocking of 85%.

These sample management regimes provide flexibility in application of commercial thinning or shortening/lengthening the rotation to meet market demands. The mix of species, products, and piece-size distribution at time of final harvest also produces a more diverse HPF zone that reduces risk while increasing product diversity and future availability.

Table 4. Treatments and timing used in management scenario growth and yield analyses. Piece size is related to diameter at breast height (dbh) targets.

Species	**Red Spruce**	**White Spruce**	**White Spruce**	**Norway Spruce**	**Norway Spruce**
Piece Size	**30 cm dbh**	**25 cm dbh**	**20 cm dbh**	**25 cm dbh**	**20 cm dbh**
Treatment	**Year**	**Year**	**Year**	**Year**	**Year**
Post-Harvest Site Preparation	0	0	0	0	0
Planting (1,736 stems/ha)	1	1	1	1	1
Competition Control	3	3	3	3	3
Plantation Cleaning (PCT)	8	8	8	8	8
Commercial Thin 1*	25	25	na	25	na
Commercial Thin 2**	35	na	na	na	na
Final Harvest	50	45	40	40	35

*** Commercial Thin 1 = 30% basal area removal + 10% trails. ** Commercial Thin 2 = 30% basal area removal.**

<u>Model Outputs</u>

Management scenario outputs for merchantable volume and cumulative mean annual increment (MAI) are presented in Figures 5 and 6. Total harvested volume per rotation is expected to exceed 300 m^3/ha (commercial thin plus final harvest) for all scenarios except the 20 cm Norway spruce scenario which is closer to 250 m^3/ha at 35 years. For all scenarios, MAI at time of final harvest will be approminately 7.0 m^3/ha/yr.

In addition to gains resulting from intensive management, these yields also incorporate initial gains expected from current tree improvement efforts. Stakeholder concerns about unrealistically high yield expectation for the HPF zone may be allayed with recognition that these predicted volumes are within the range of measured RPSP data in mature plantations, none of which included any “next-generation” tree improvement gains (see Appendix C for details).

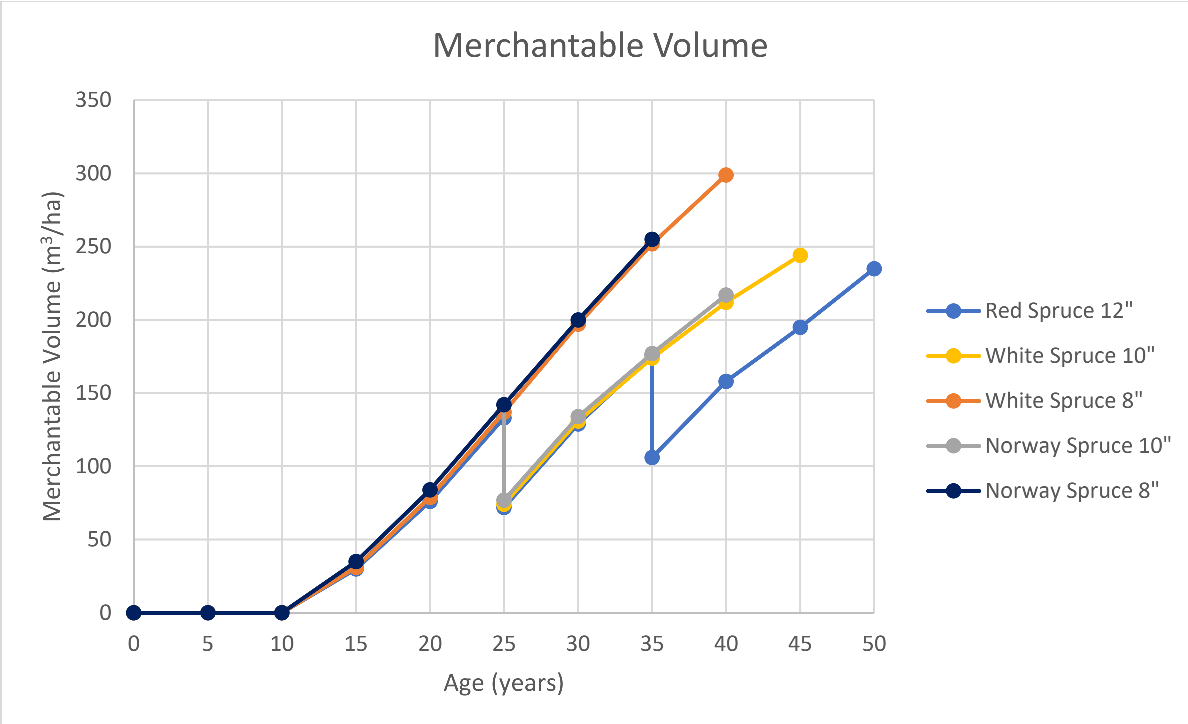

Figure 5. Merchantable volume yield projections for sample HPF management scenarios.

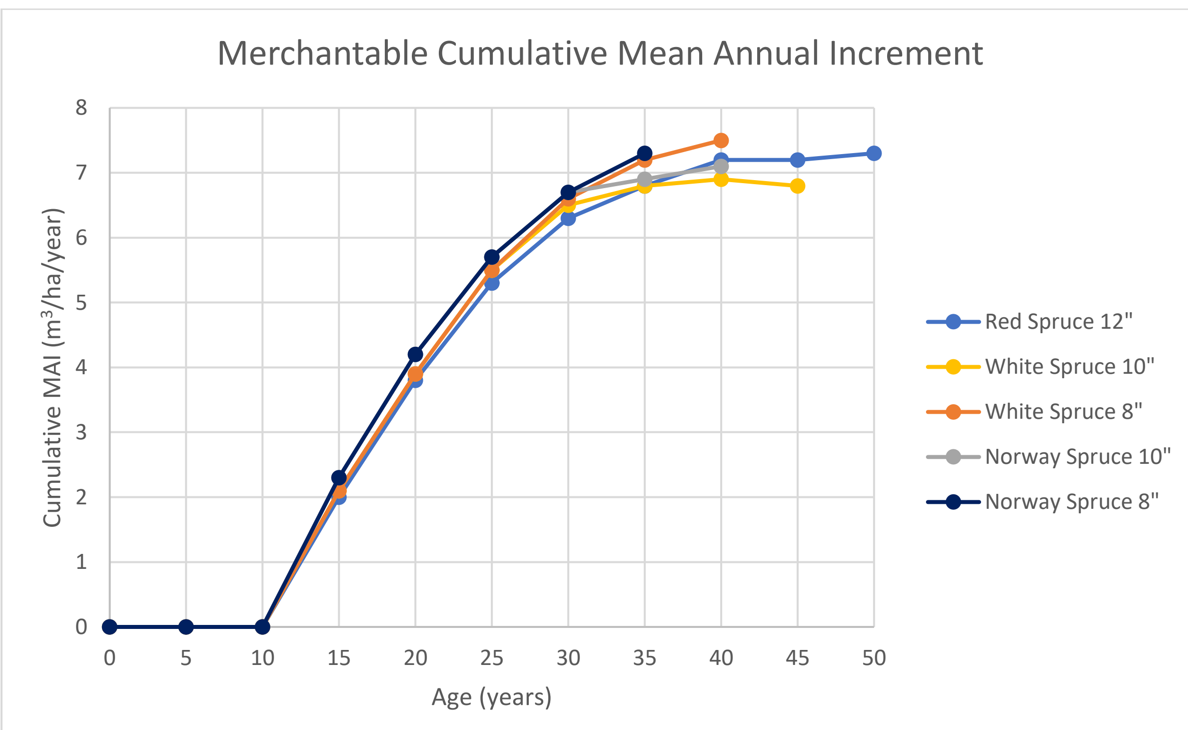

Figure 6. Merchantable cumulative mean annual increment (MAI) projections for sample HPF management scenarios.

Wood Supply Analysis

How much suitable land to allocate to high production forestry, and how fast to transition this area, are two fundamental decisions to be made in implementing Triad management on Crown land. To assist with this decision-making, and to address questions on this topic received during stakeholder sessions, several preliminary wood supply analyses were conducted to quantify expected outcomes for a set of scenarios covering a range of area/transition options.

<u>Parameters and Indicators</u>

Nine wood supply scenarios were examined using combinations of three area allocations (100%, 75%, and 50% of suitable HPF area) and three transition periods (25, 35, and 45 years). Yields presented in Figure 5 were used for plantations, with traditional yields used for natural stands prior to harvest and subsequent planting. Forecasts were made over a 100-year time horizon using 5-year time steps. The model objective was set to maximize sustainable sawlog/studwood harvest from land assigned to the HPF zone while incorporating some basic constraints to minimize wide fluctuations in available wood supply from period to period (especially through the implementation phase). This relatively simple formulation was chosen to provide a clear comparison of HPF management strategies.

While there are many indicators that could be used to assess HPF management scenarios, five are presented here based, in part, on questions raised during stakeholder sessions.

1. **Wood Supply (Spruce-Fir gmt/yr)**: This indicator is influenced by a non-declining flow constraint over the 100-year planning horizon. The sawable component of this indicator is the basis for the objective function used in model runs (60-70% for existing forest and 80-90% in HPF plantations).

2. **Wood Supply (Hardwood gmt/yr)**: This indicator is influenced by a sequential flow constraint during the transition to HPF management. After full transition there would be no hardwood harvest in the HPF zone as this entire area would be under spruce plantation management.

3. **Area of HPF Establishment (ha/yr)**: Sites being transitioned to HPF management are all assumed to get the full suite of management activities including site preparation, planting, herbicide, soil amendments, weeding, and commercial thinning where necessary.

4. **Seedlings Required (#/yr)**: This indicator is the number of spruce seedlings that would be required to meet plantation establishment demands each year.

5. **Silviculture Costs ($/yr)**: This indicator is a combination of estimated HPF establishment costs (modelled at $1,925/ha) plus commercial thinning costs ($550/ha) when needed.

Results

Results show allocated HPF area has the greatest impact on spruce-fir wood supply levels across the range of scenarios (Table 5 and Figure 7).

Table 5. Assessment indicators for HPF land allocation and transition period scenarios.

	100% Allocation ***(246,000ha)***			**75% Allocation** ***(184,500ha)***			**50% Allocation** ***(123,000ha)***		
Indicator[1]	**25yr**	**35yr**	**45yr**	**25yr**	**35yr**	**45yr**	**25yr**	**35yr**	**45yr**
Spruce-Fir Supply	506	367	321	472	359	310	316	321	271
(000's gmt/yr)	*1,279*	*1,280*	*1,276*	*971*	*962*	*957*	*647*	*641*	*639*
Hardwood Supply	179	178	122	153	103	79	100	55	41
(000's gmt/yr)	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
HPF Area Establishment	6.5	5.1	4.0	5.4	3.9	3.0	3.6	2.6	2.0
(000's ha/yr)	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*	*na*
Seedlings Required	11.2	8.9	7.0	9.4	6.7	5.2	6.3	4.5	3.5
(millions/yr)	*8.6*	*8.5*	*8.5*	*6.6*	*6.7*	*6.4*	*4.4*	*4.5*	*4.2*
Silviculture Costs	13.2	10.9	8.8	10.9	8.3	6.7	7.4	5.8	4.7
(millions of $/yr)	*11.9*	*11.6*	*11.6*	*9.1*	*8.6*	*8.7*	*6.0*	*5.8*	*5.8*

[1] Top row values for each indicator show short-term planning estimates (0-20 years). Bottom row values (shaded & italicized) for each indicator show long-term planning estimates (40-100 years).

Long-term (40-100 year) wood supply tends to be proportional to the amount of suitable land allocated to the HPF zone. Allocating 50% of suitable area to the HPF zone results in an estimated supply level that is about 50% less then the full allocation scenario. This result assumes that all suitable land can be managed to the same productivity level. In contrast, short-term (0-20 years) spruce-fir supplies are less sensitive to land allocation. For example, the 35-year transition scenarios showed decreases of only 2% and 13% moving from 100% allocation to 75% and 50% allocation respectively. This moderation of impacts is due to variation in site conditions combined with more choice in site selection. When less area is being allocated, short-term impacts can be partially offset by choosing higher volume stands for conversion.

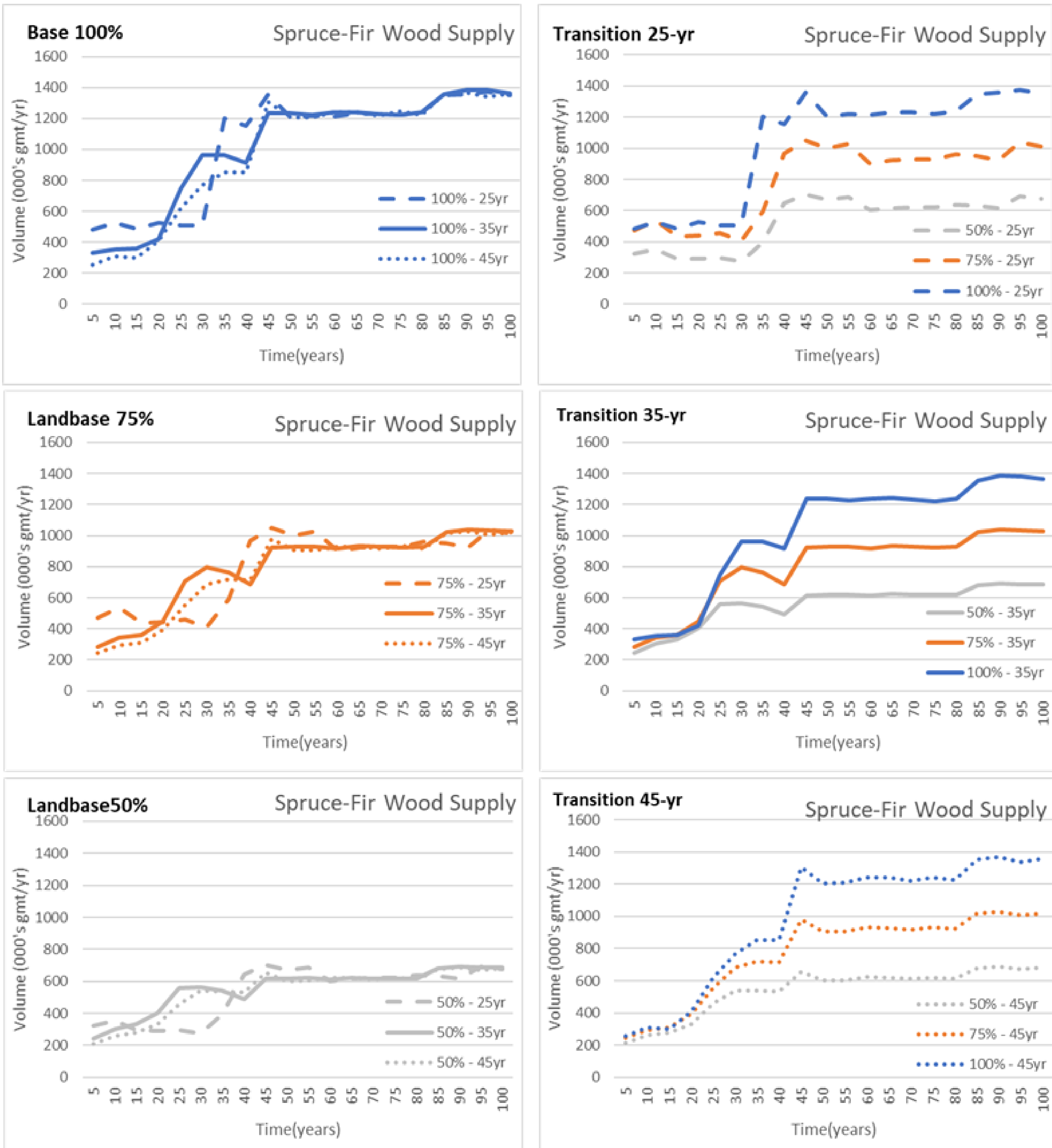

Figure 7. Spruce-Fir harvest indicator across various HPF land allocation and transition period scenarios.

Short-term hardwood wood supply ranged from a 41,000 to 179,000 gmt/yr across the range of scenarios (Table 5). In general, the lower the land allocation percentage, the less hardwood that needs to be harvested because of more options in stand selection. To a lesser extent, this is also the case with transition period impacts. The longer the transition period, the less hardwood that needs to be harvested on HPF land.

Annual HPF area establishment with related seedling requirements and silviculture costs generally increase with shorter conversion periods and decrease with lower land allocation percentages (Table 5). HPF area establishment ranges from a high of about 6,500 ha/yr for the 100% allocation / 25-year transition scenario to a low of about 2,000 ha/yr for the 50% allocation / 45-year transition scenario. Likewise, the required short-term silviculture investment ranges from a high of $13.2 million/yr to a low of $4.7 million/yr with related seedling requirements of 11.2 million/yr and 3.5 million/yr (Table 5). Short-term and long-term capacity to carry out HPF management activities, as well as the availability of associated capital, will undoubtably be key considerations when deciding on a preferred implementation strategy.

Sensitivity Analysis

To address stakeholder concerns around HPF management regime assumptions, a sensitivity analysis was conducted to assess the impacts of adjusting three key management assumptions in relation to a base case scenario: (i) predicted yields, (ii) species mix, and (iii) piece-size objectives. The base case had species constraints that kept Norway spruce at <10% of the total HPF program, with the balance (90%) equally divided between red spruce and white spruce. Piece-size mix was <10% for 20 cm, with the balance equal parts 25 cm and 30 cm. Model runs assumed 100% land allocation and a 35-year transition period.

1. Forecasted Yields: For assessment of yield sensitivity, assumed productivity (site index) stemming from HPF management was increased and decreased by 20%. Results showed predicted long-term harvest level to be the only indicator affected by these changes which tended to increase or decrease proportionally to modelled changes (Table 6). Other indicators, including short-term harvest level, were largely unaffected by changes in predicted productivity. In practice, forecasted yields may or may not be realized for various reasons, and monitoring of HPF plantations for yield performance and timing of interventions will be essential for realizing the potential benefits of high production forestry.

2. Species and Piece-Size: This sensitivity analysis looked at the impacts of managing for different combinations of species and piece-size (diameter) options. Species scenarios included all red spruce, all white spruce, and a run with a minimum 20% Norway spruce. Piece-size scenarios included all 20 cm, all 25 cm, and all 30 cm management targets (with related commercial thinning requirements). Across all these scenarios, key indicators changed very little (maximum +/- 4%) compared to base case levels (Table 6). This suggests there is considerable flexibility in HPF management regimes that allow for various combinations of species and piece-size objectives to be met (assuming consistent site productivity levels).

Table 6. Sensitivity analysis for HPF management assumptions.

		Spruce-Fir Harvest (000's gmt/ha)		Hardwood Harvest (000's gmt/ha)	Silviculture Costs (millions $/yr))
Scenario	**Adjustments**	**Short-term**	**Long-term**	**Short-term**	**Short-term**
Base Case[1]		343	1,403	167	10.4
Yield	Site Index ↑ 20%	342	1,715	168	10.4
	Site Index ↓ 20%	343	1,148	166	10.4
Species Mix	100% Red Spruce	343	1,453	168	10.4
	100 White Spruce	342	1,354	166	10.4
	20% Norway Spruce	342	1,389	167	10.4
Diameter Mix	All 20 cm (no CT)	337	1,451	166	10.2
	All 25 cm (1 CT)	342	1,390	167	10.4
	All 30 cm (2 CT)	340	1,422	166	10.3

[1] The base case scenario assumed inputs associated with Table 5 assessment indicator output for 100% allocation and 35-year transition. Species mix constraints assumed Norway spruce at <10% with the balance (90%) equally divided between red spruce and white spruce. The piece-size mix was <10% for 20 cm with the balance equally divided between 25 cm and 30 cm.

Carbon Dynamics

An analysis of forest carbon dynamics related to a subset of modelled wood supply scenarios showed several key trends (see Appendix D for carbon modelling details). Carbon stored in living tree biomass tended to increase or remain relatively stable during the 100-year simulation (Figure 8). Total storage was generally between 13 and 14 million tonnes (t) with 100% allocation of potential HPF land, decreasing to approximately 10 million tonnes and 6.5 million tonnes with 75% and 50% land allocations. However, after HPF conversion all scenarios showed a relatively consistent per hectare carbon storage rate, ranging between 50 and 55 t/ha Figure 8).

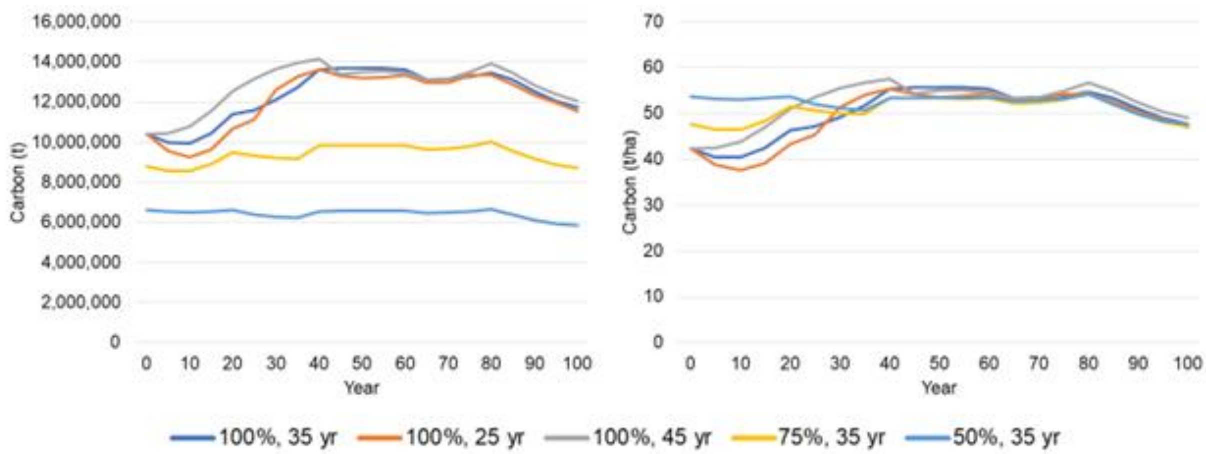

Figure 8. Estimated carbon storage in living tree biomass in the HPF zone for wood supply scenarios based on five combinations of HPF percent area allocation and transition period length.

Dead organic matter in the HPF scenarios included carbon stored in coarse and fine woody material, snags, litter, and dead coarse and fine roots (Figure 9). Results showed an increase in carbon storage in all scenarios from approximately 15 t/ha to 21 t/ha over the full transition period. Dead organic matter amounts tend to be highest following harvest, which then decrease through decomposition before increasing again as the stand matures and biomass turnover outpaces decomposition. Shorter rotations in the HPF zone likely explain the higher amounts of storage in dead organic matter.

Carbon storage in harvested wood products is a magnitude lower than that stored in onsite living and dead organic matter (Figure 10). However, these values were still increasing at the end of the 100-year simulation period due to the longevity of stored carbon in lumber products (see Appendix D for details).

At a landscape scale, there would tend to be lower total carbon storage in the HPF zone compared to Ecological Matrix and Conservation lands. This is expected under Triad management where the objective of the HPF zone is not to maximize carbon storage, but to produce high value forest products on a reduced land base allowing for more area to be managed for other ecological objectives. However, in this preliminary analysis, cumulative changes in carbon stocks for all pools combined showed the HPF zone to be a net carbon sink for the majority of the 100-year simulation period (Figure 11).

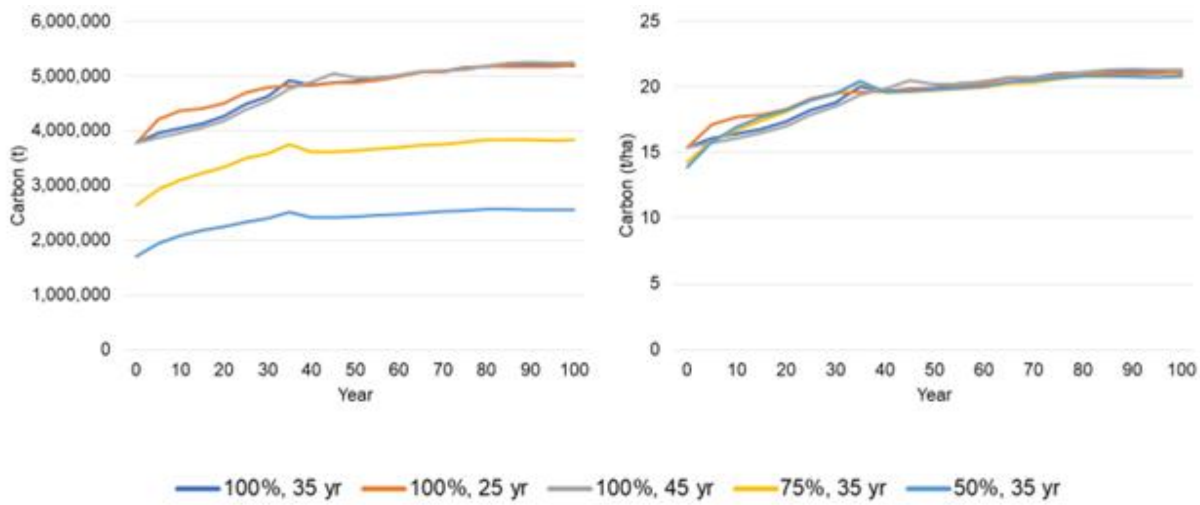

Figure 9. Estimated carbon storage in dead organic matter (excluding mineral soils) in the HPF zone for wood supply scenarios based on five combinations of HPF percent area allocation and transition period length.

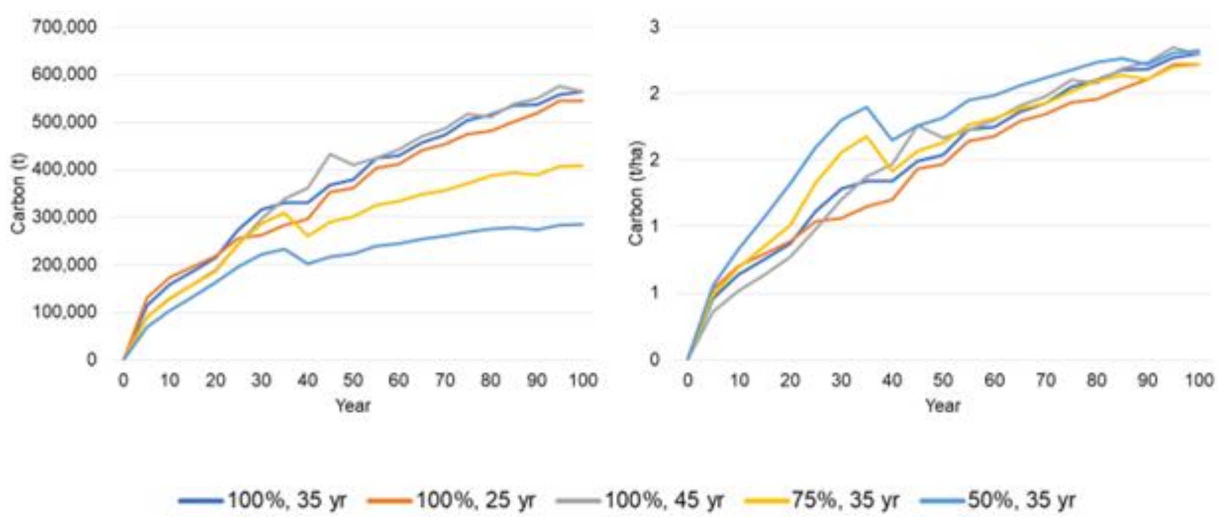

Figure 10. Estimated carbon storage in harvested wood from the HPF zone for wood supply scenarios based on five combinations of HPF percent area allocation and transition period length.

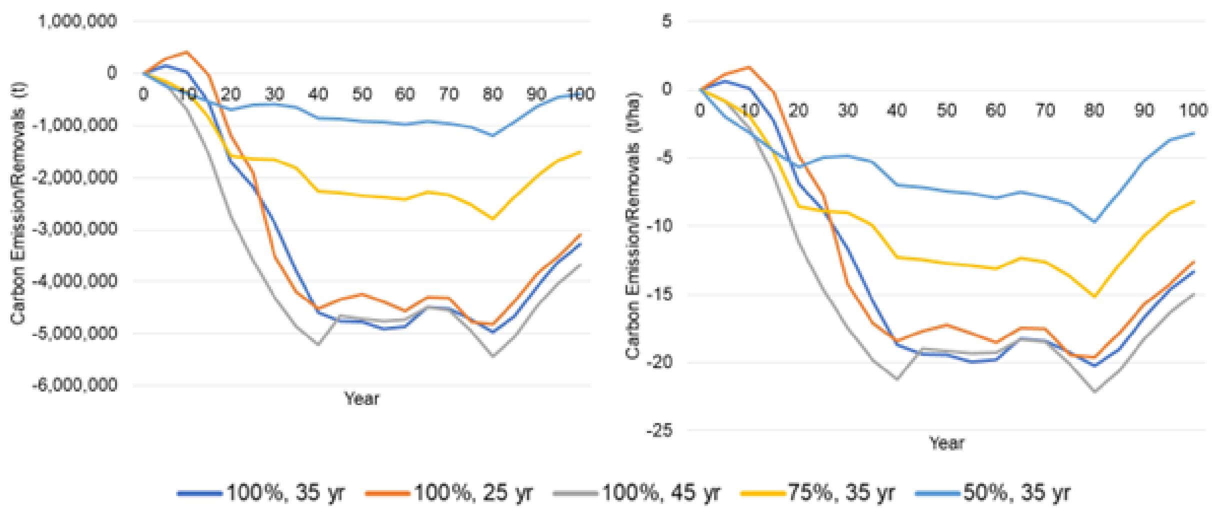

Figure 11. Cumulative carbon emissions and removals from living biomass, dead organic matter (excluding mineral soil), and harvested wood products in the HPF zone for wood supply scenarios based on five combinations of HPF percent area allocation and transition period length.

A contributing factor to this finding is the high ratio of longer-lived wood products being produced from HPF land and their associated carbon storage. However, as noted in Appendix D, these results are preliminary and subject to change through additional research and analysis, especially with respect to mineral soil carbon dynamics.

Economic Analysis

There are several potential benefits to the Triad management approach, many of which are non-monetary. However, a key socio-economic benefit is sustaining a natural resource-based industry in Nova Scotia while also achieving overarching ecological objectives, and this is where high production forestry plays a critical role. While a comprehensive economic analysis of Triad management is beyond the scope of this report, a preliminary stand-level economic assessment of HPF management scenarios has been conducted based strictly on estimated silviculture costs and expected yield returns.

<u>Management Scenarios</u>

To show a range of potential financial costs and return on silviculture investments, five management scenarios were included in this assessment (Table 7). Analysis included estimated costs for completing appropriate silviculture treatments, with revenue in the form of estimated stumpage paid to the Crown[1]. Internal rate of return (IRR) was the metric used to assess the economic viability of each scenario. IRR is a financial metric used to estimate the profitability of investments that accounts for the time-value of costs and benefits expressed as a real rate of return (meaning inflation has also been accounted for – assumed in this case at 2% per year). IRR is often compared to an investor's minimum acceptable return (MAR) to make decisions on investments. When IRR ≥ MAR, the investment is considered viable. For more details on IRR calculations and assumptions made in this analysis, see Appendix E.

All sample management scenarios showed positive IRR values based on the estimated costs and revenues used (Table 8) suggesting high production forestry is a viable investment based solely on fibre production (i.e., not including other direct and indirect social, environmental, and economic benefits). Having a market for pulpwood did not significantly impact calculated IRR, as the proportion of pulpwood is expected to be very low in all HPF management scenarios. This, in combination with low pulpwood stumpage value (compared to studwood and sawlogs), results in little contribution of pulpwood to the value of future harvests. However, this does not account for potential markets for sawmilling by-products, as these were not considered in this analysis.

Table 7. Estimated silviculture costs for five HPF management scenarios outlined in Table 4.

Species	**Red Spruce**	**White Spruce**	**White Spruce**	**Norway Spruce**	**Norway Spruce**
Piece Size	**30 cm dbh**	**25 cm dbh**	**20 cm dbh**	**25 cm dbh**	**20 cm dbh**
Treatment	**Cost ($/ha)**	**Cost ($/ha)**	**Cost ($/ha)**	**Cost ($/ha)**	**Cost ($/ha)**
Post-Harvest Site Preparation	300	300	300	300	300
Soil Amendment[1]	500	500	500	500	500
Plant Seedlings	600	600	600	600	600
Competition Control (Herbicide)	125	125	125	125	125
Plantation Cleaning (PCT)	400	400	400	400	400
Commercial Thin 1	550	550	na	550	na
Commercial Thin 2	550	na	na	na	na
Total	3,025	2,475	1,925	2,475	1,925

[1] **Anticipated maximum cost for site-specific soil amendment needs.**

[1] Average stumpage prices were taken from the *Report on Prices of Standing Timber for April 1, 2017– March 31, 2018* (NSDLF 2019).

Table 8. Internal rate of return (IRR) for sample HPF management scenarios with and without a pulpwood market.

Species Scenario	Market	IRR (%)
Red Spruce - 2 CT	Pulp Market	3.70%
	No Pulp Market	3.60%
White Spruce - 1 CT	Pulp Market	3.50%
	No Pulp Market	3.50%
White Spruce – no CT	Pulp Market	3.70%
	No Pulp Market	3.70%
Norway Spruce - 1 CT	Pulp Market	3.30%
	No Pulp Market	3.30%
Norway Spruce – no CT	Pulp Market	3.50%
	No Pulp Market	3.40%

To test economic sensitivity to changes in projected harvests, IRR was also calculated using adjusted yields (± 20%) and harvest timing (± 5 years). In all cases, calculated IRR was still positive even with lower yields and shorter rotations (Table 9).

Red and white spruce management scenarios were relatively insensitive to final harvest timing because of trade-offs between time-value and product-value. By delaying final harvest, higher value sawlog volumes increase and studwood volumes decrease, but this is counteracted by discounted future value. In contrast, shorter rotations produce a greater proportion of studwood, but this is compensated by shorter time to economic return. However, Norway spruce is more sensitive to a shorter rotation (Table 9) since it currently can only be marketed as studwood (a shorter rotation just means less product volume).

If yields are higher than expected, an increased IRR can be gained by harvesting earlier in red and white spruce plantations, but not Norway spruce (Table 9). If yields are lower than expected, delaying final harvest may result in marginal increases to IRR, but in general, results suggest harvesting of underperforming stands should not be delayed provided they meet minimum mean annual increment (MAI) criteria.

Table 9. Internal rate of return (IRR) for sample HPF management scenarios with adjusted yield projections and final harvest age.

Species/Scenario	Final Harvest Timing	IRR (%) Yield Expectations -20%	Base	20%
Red Spruce (2 CT)	-5yr	2.9%	3.6%	4.2%
	Base	3.0%	3.7%	4.2%
	+5 yr	3.0%	3.6%	4.2%
White Spruce (1 CT)	-5yr	2.8%	3.6%	4.2%
	Base	2.9%	3.5%	4.1%
	+5yr	2.9%	3.5%	4.0%
White Spruce (No CT)	-5yr	3.0%	3.7%	4.3%
	Base	3.1%	3.7%	4.2%
	+5yr	3.1%	3.6%	4.1%
Norway Spruce (1 CT)	-5yr	2.4%	3.2%	3.9%
	Base	2.6%	3.3%	3.9%
	+5yr	2.7%	3.5%	3.9%
Norway Spruce (No CT)	-5yr	2.3%	3.1%	3.8%
	Base	2.8%	3.5%	4.1%
	+5yr	2.9%	3.5%	3.9%

Next Steps

The main objectives of this report were (i) to present and substantiate key assumptions associated with high production forestry, (ii) to estimate the amount of crown land potentially suitable for this component of Triad management, and (iii) to use this information to predict and discuss expected outcomes covering a range of possible management options. Building on this work, the Department will initiate moving from a strategic modelling exercise to tactical and operational implementation. This will require policy decisions on total area to be committed to HPF management and the time frame for implementation.

In addition, although key ranking criteria have been discussed as part of this report, the process for identifying HPF sites has yet to be finalized. Final identification and ranking of sites will need to be informed by an analysis of biodiversity and other values at a landscape level (including defining core habitat for species at risk), site visits to verify suitability, and consideration of other *Forest Practices Review* related objectives. Taken together, these factors will likely result in additional adjustments to the potential suitable HPF area.

Successful management of the transition phase raises other questions and requirements. Wood supply modeling results discussed in this report have characterised potential short-term and long-term fibre supplies, however these supplies will vary regionally and through time. Distribution of HPF lands among licensees and allowable harvest levels are of key concern to industry stakeholders. Additional analysis is needed to more fully understand how much fibre will be available, from where, when, and at what cost.

There is also need for more clarity around tactical and operational decision making with respect to HPF management. For example, who will decide what tree species to plant, what products to manage for, and when to harvest? Also, to what extent will HPF management be prescribed versus outcomes based? These are just a few of the questions raised by stakeholders that will require further discussion, planning, and integration with other *Forest Practices Review* recommendations.

Full implementation and establishment of the HPF zone will take decades, and this does confer certain benefits in terms of allowing for adaptive management. However, the process can begin immediately by classifying some highly ranked candidate sites now (such as existing, high-yielding plantations on productive sites near sawmills) so that HPF management regimes can be tested and fine-tuned in anticipation of further site selections. Ongoing research by the Department will provide additional information to support optimal implementation of Triad management (including high production forestry) across the province.

<u>Note</u>: The initial draft of this report was shared with William Lahey and his evaluation team in November 2020 and was reviewed by the Ministerial Advisory Committee in January 2021.

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Appendix A. Project Team

Department of Lands and Forestry Staff:

- Ryan McIntyre, RPF, BSc. (Forestry) – Team lead, expertise in forest management, operations & planning, and silviculture.
- Rob O'Keefe, BSc. (Forestry) – Senior Forest Resource Analyst, expertise in strategic and landscape level forest planning, wood supply forecasts, and growth and yield modelling.
- Kevin Keys, PhD, RPF, PAg – Senior Research Forester, expertise in forest soils, site classification, and soil/site productivity.
- Kim George, BSc. (Biology) – Regional Biologist, expertise in wetlands, wildlife habitat, and biodiversity considerations for forest management activities.
- Jamie Ring, RPF, BSc. (Forestry), Technical Diploma (Forestry, Fish and Wildlife) – Forest Analyst, expertise in growth and yield and wood supply modelling.
- Matthew Retallack, PhD – Policy Analyst, expertise in natural resources management, policy, and governance.

External Members:

- Thom Erdle, PhD, RPF – Professor, Faculty of Forest and Environmental Management (UNB), expertise in forest management planning, growth and yield, and strategic and landscape level wood supply modelling and planning.
- Graham Forbes, PhD – Professor Faculty of Forestry and Environmental Management (UNB), expertise in wildlife ecology and management, biodiversity and ecosystem management, and conservation biology and planning.

Associate Team Members (NSDLF Staff):

- James Steenberg, PhD – Forest Carbon and Climate Change Analyst, expertise in carbon modelling, climate change impacts and adaptation, and greenhouse gas emissions.
- Tim McGrath, MSc. (Forestry) – Senior Research Forester, expertise in silviculture systems, growth and yield, and applied forestry research studies.
- Dave Steeves, MSc. (Forestry) – Tree Improvement Specialist, expertise in genetics and tree improvement.
- Simon Bockstette, PhD – Tree Improvement Forester, expertise in genetics and tree improvement.

Appendix B. Site Ranking Methodology

Ranking is the process of combining selection criteria values across selection criteria to assign a relative ranking to all 1 km cells within the analysis area.

Normalizing Indicators

The range and units of values within each selection criterion varies (for example suitable area can range from 0 to 100 ha, while distance to sawmill ranges from 5 to 357 km). When calculating a combined value of these two using absolute values, delivery distance will have a larger influence on the final score simply due to its scale. Furthermore, the units are not compatible (hectares vs kilometers). To address bias and unit differences, values were normalized between 0 and 1 using min-max feature scaling (the minimum was assigned a value of 0, the maximum was assigned a value of 1).

$$\textit{Normalized Value}(x') = \frac{x' - Min(x)}{Max(x) - Min(x)}$$

Where:
- *Normalized Value(x')* = normalized score (between 0 and 1)
- *x' = indicator variable value*
- *Min(x)* = minimum value of indicator variable
- *Max(x)* = maximum value of indicator variable

For indicators where the maximum score is desirable (e.g. plantation and old field area), the normalized ranking was reversed (so that the maximum value is transformed to a value of 0, and the minimum value is transformed to a value of 1). Values were multiplied by 100 so that scores ranged from 0 to 100 (instead of carrying decimal places).

Calculating Combined Rank Values

Cells were assigned rank values based on the Manhattan distance from the origin. The ideal cell (best possible candidate) with three criteria would have the coordinates (0,0,0) in a 3-dimensional space – resulting in a score of 0. The worst possible candidate would have the coordinates (100,100,100) in that same space – resulting in a score of 300. Cells were assigned a rank value using the sum of the normalized (0 to 100) scores of each selection criterion.

For composite scoring, two common methods are Euclidean (straight-line distance from the origin to a point in n-dimensional space) and Manhattan (block distance, the vector sum of all indicators) (Aggarwal et al. 2001). Where Euclidean distance is the square root of the sum of the squares, higher emphasis is placed on outliers (the square term exaggerates the distance from the origin the further an indicator value is from the origin). Manhattan distance places equal emphasis on outliers and central values (relative differences across all values are maintained), i.e., the weight applied increases or decreases the effect that indicator has on the total score at a 1:1 ratio. For these reasons, Manhattan distance was chosen to calculate composite scores.

Cell Ranking Example

Understanding what makes one cell rank higher than another is also important in understanding and applying any of the ranking results. Figure B1 provides an illustration of what a high-ranking cell would look like. Note that a ranking score of 0 is the best score (as explained above). Likewise, the further the score departs from 0 (the ideal condition) the lower the cell ranking. The "High-Ranking" example has past management at 77 ha within the cell and a score of 0 indicating the best past management score, no other cell has more than 77 ha of past management. Similarly, scores of 100 represent the worst case for any criteria. The overall cell score is simply the sum of the three criteria scores.

High Ranking Cell

Suitable Ecosite Area
  78 ha (of a maximum 100ha)
  Score = 20
Past Management Area
  77 ha (of a maximum 100ha)
  Score = 0
Distance to Sawmill
  47 km
  Score = 11

Combined Score = 31
Cell Rank = 2 out of 20338

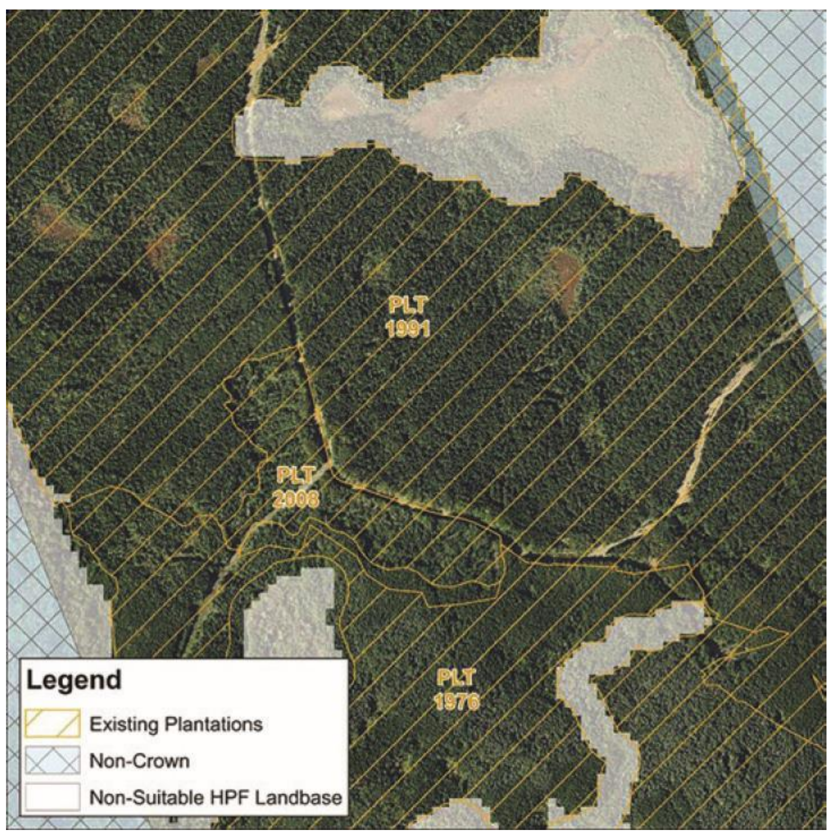

Figure B1. High-ranking cell based on suitable ecosite area, past management area, and distance to sawmills.

Appendix C. Measured and Forecasted Yield Data for Spruce Plantations

Data from long-term research permanent sample plots (RPSPs) provide the foundation for Nova Scotia's growth and yield modelling work. Many of these plantation trials were established with only plus tree growing stock, not the 2nd generation improved stock available today. Improved stock results in higher average yields, and these expected gains have been incorporated into yield projections for red and white spruce. However, these expected gains are still within the bounds of what is observed in the measurement data (see Figures below).

Of note, forecasts presented were also compared to output from the Open Stand Model (OSM), a growth and yield model extensively used in New Brunswick and Maine and calibrated with regional empirical data. Results showed comparable yields for white spruce at rotation (within 5% of predicted harvest volume per hectare).

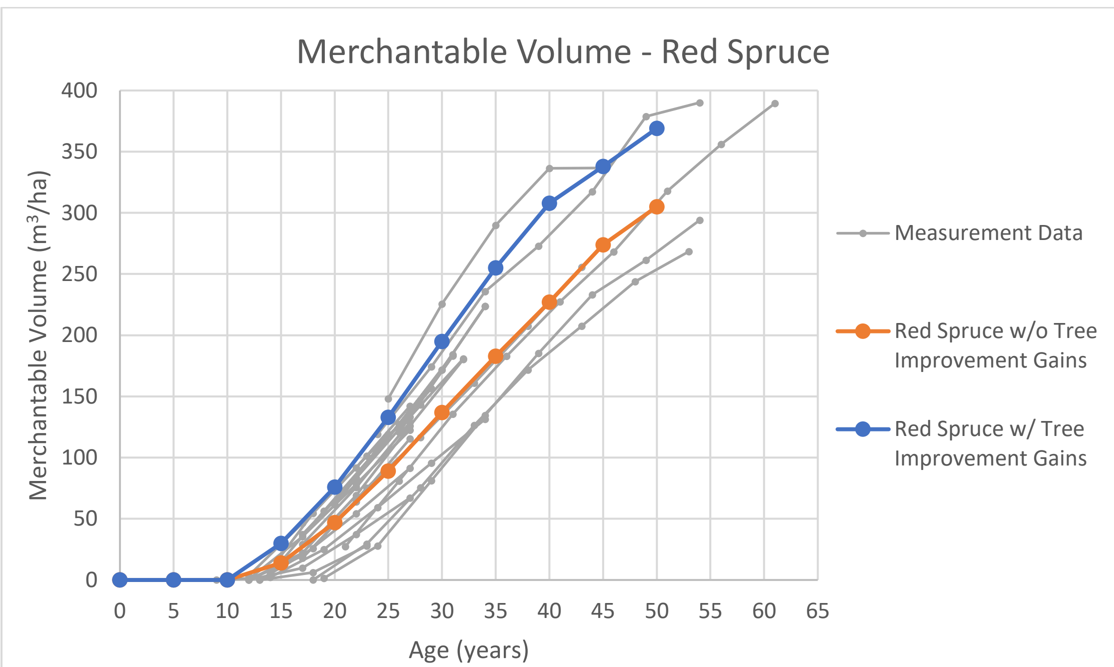

Figure C1. Average yield projections (with and without tree improvement gains) together with measured plantation research plot data for red spruce (24 plots, 108 measurements).

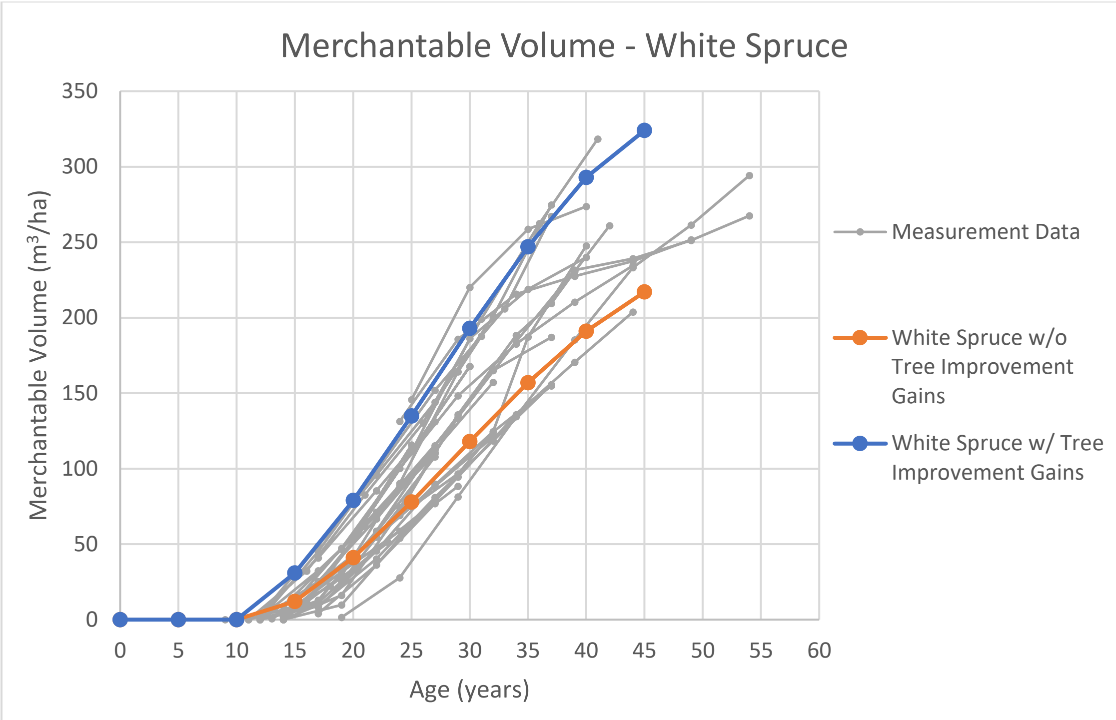

Figure C2. Average yield projections (with and without tree improvement gains) together with measured plantation research plot data for white spruce (31 plots, 153 measurements).

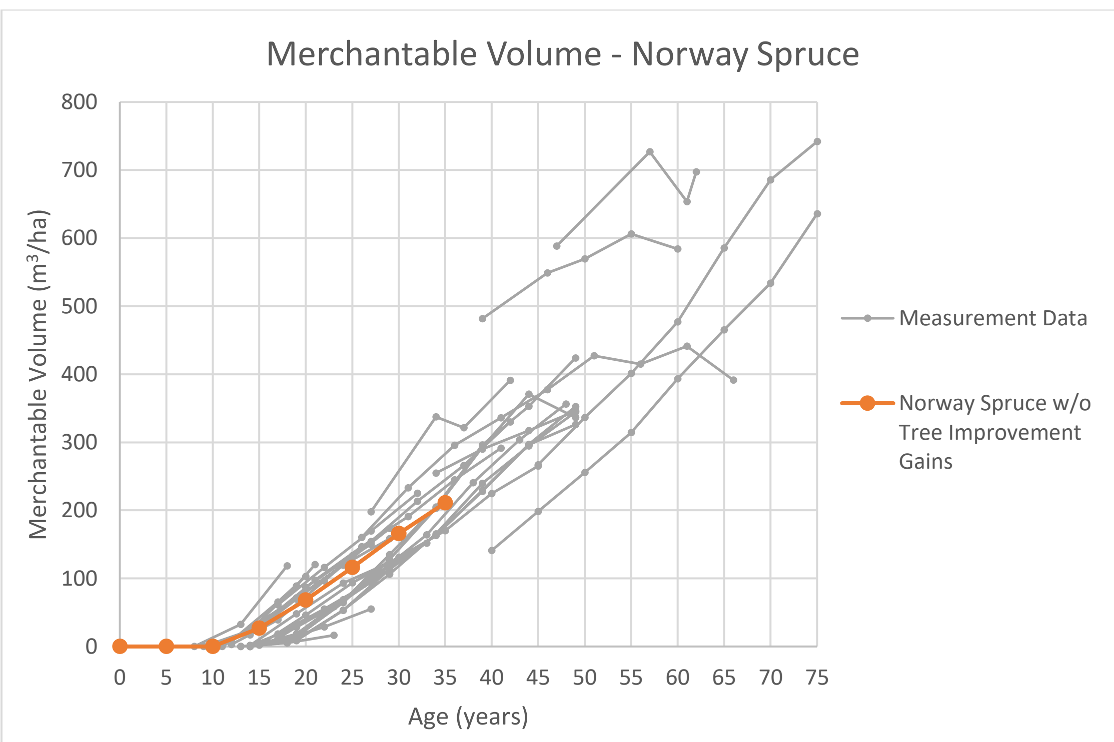

Figure C3. Average yield projections and measured plot data for Norway spruce (40 plots, 218 measurements).

Appendix D. Carbon Modelling

For carbon modelling described in the Wood Supply Analysis section of his report, three primary forest carbon pools were considered: (i) carbon in the living biomass of trees, (ii) carbon in dead organic matter, and (iii) carbon in harvested wood products.

The living biomass pool includes aboveground biomass in merchantable and non-merchantable wood, bark, and foliage, and belowground biomass in fine and coarse roots. Aboveground biomass was estimated for white spruce and red spruce HPF scenarios using diameter at breast height (cm) and average height (m) as inputs for Canadian national tree aboveground biomass equations (Lambert et al. 2005). Norway spruce aboveground biomass was calculated using diameter at breast height only using equations from Ter-Mikaelian and Korzukhin (1997). Biomass estimates were generated from Nova Scotia Growth and Yield Model output scaled up to stand level estimates (t/ha). These values were then converted to carbon estimates by multiplying by a factor of 0.5. Related biomass and carbon estimates in fine and coarse roots were calculated using belowground biomass functions in the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) (Li et al. 2003; Kurz et al. 2009).

The dead organic matter pool includes carbon stored in snags, coarse and fine woody material, litter, dead roots, and the forest floor. Dead organic matter estimates for all of these were calculated using related functions in CBM-CFS3 (Kurz et al. 2009). These functions account for biomass turnover (e.g., litterfall), as well as dead organic matter decomposition under Nova Scotia climate conditions. Mineral soil organic carbon estimates were excluded from this preliminary analysis due to high levels of uncertainty associated with forest soil carbon values in general, and plantation soil carbon values in particular (Mayer et al. 2020). Soil carbon dynamics in CBM-CFS3 are sensitive to carbon storage values used to initialize yield curves, which in this case were an average across softwood, mixedwood, and hardwood covertypes. If, for example, a plantation was established on a site with low initial soil carbon storage, an initial increase in soil carbon could occur. In contrast, if initial soil carbon storage was higher, a decrease could occur. Some of this uncertainty will be reduced during the HPF implementation phase when modelling can become spatially explicit and specific site history information becomes available. It is recognized, however, that long term declines in mineral soil carbon are a concern in intensively managed forests (Gabriel et al. 2018; Mayer et al. 2020), and soil carbon will be included in HPF monitoring programs.

Estimated carbon stores in harvested wood products used decomposition rates from the Intergovernmental Panel on Climate Change (IPCC) guidelines for emissions accounting (IPCC 2006), with products being placed in one of three pools: (i) solid wood products, (ii) pulp and paper products, and (iii) residues/bioenergy. Solid wood products have a half life of 35 years, pulp and paper products a half life of 2 years, while residues/bioenergy are associated with an immediate release of carbon to the atmosphere. For sawable material, the following mill efficiency values were used (Athena Sustainable Materials Institute 2018): 37% solid wood products, 38% pulp and paper products, and 25% other residues/bioenergy. An additional 10% of harvested sawlogs and studwood were allocated to pulpwood to account for expected losses (e.g., defects). For harvested pulpwood, all bark was allocated to residues/bioenergy and all wood was allocated to pulp and paper products.

Lastly, cumulative emissions and removals of carbon from the atmosphere were assessed simply as the difference in carbon storage between the previous time period and the current time period plus the cumulative emissions up to that time period. These estimates help in determining whether the Province’s managed forests and forest products are contributing to climate change mitigation efforts. Future modelling work will also aim to include a life cycle analysis of carbon emissions/removals associated with new management practices, increased yields of longer-lived wood products, and new supply chain efficiencies.

Appendix E. Economic Analysis Functions

The internal rate of return (IRR) was used as a measure of investment viability instead of net present value (NPV) since NPV requires assumptions on what discount rate(s) to include in the analysis. IRR is a single number, allowing different stakeholder groups with different minimum acceptable return (MAR) rates to decide whether investments are acceptable from an economic standpoint. When the discount rate/MAR is greater than the IRR, NPV will be less than zero, meaning the investment is not viable. When the discount rate/MAR is less than or equal to the IRR, NPV will be greater than or equal to zero, meaning the investment is viable.

$$NPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t}$$

Where *NPV* = Net Present Value,
t = year,
n = end of rotation,
B_t = Revenue in year *t,*
C_t = Costs in year *t,*
r = real discount rate

$$r = \frac{1+i}{1+f} - 1$$

Where *r* = real discount rate,
i = nominal discount rate,
f = inflation rate

IRR is the discount rate that sets NPV equal to zero.

$$0 = NPV = \sum_{t=0}^{n} \frac{B_t}{(1+IRR)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+IRR)^t}$$

Where *IRR* = Internal Rate of Return,
NPV = Net Present Value,
t = year,
n = end of rotation,
B_t = Revenue in year *t,*
C_t = Costs in year *t*