The Economic Value of Old-growth Forests in British Columbia

Frequently Asked Questions and Methods Updates

March 31, 2025

ESSA

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Purpose of this Document

This document accompanies the Summary Report titled *The Economic Value of Old-growth Forests in BC: Analysis of Old-growth Management Scenarios in Two Timber Supply Areas*. We have provided it as supplementary materials to assist in answering frequently asked questions about the study, and to summarize updates to our forest carbon simulation modelling and economic methods relative to the initial pilot study. We encourage readers who are interested in a more detailed understanding of our methods to review the full technical report for the Port Renfrew pilot, which is available on the Ancient Forest Alliance's website here: https://ancientforestalliance.org/old-growth-economic-report/.

1 Frequently Asked Questions (FAQs)

1. What is the main finding of the study regarding the economic value of old-growth forests in BC?

The study found that protecting old-growth forests in BC offers significantly more economic value than logging them, primarily due to their substantial carbon sequestration and storage benefits. Fully protecting old-growth forests in the Prince George and Okanagan Timber Supply Areas (TSAs) over the next 100 years would generate an estimated $43 billion more net benefits for BC residents compared to foregoing any extra deferrals (our comparison case assumed no extra deferrals, equivalent to business-as-usual prior to the BC deferral recommendation). This estimate is based on a limited number of ecosystem services (timber production, carbon sequestration, recreation opportunities, tourism opportunities, non-timber forest products, and education/research opportunities), and would be higher had we assessed additional ecosystem services (e.g., water quality regulation, water supply, air quality regulation, food production, etc.).

Prince George TSA: This TSA is projected to act as a net carbon sink over the next century, with carbon sequestration benefits improving under all old-growth deferral scenarios relative to the no extra deferrals case. Fully protecting old growth would generate over $33 billion in additional net benefits, even accounting for timber production losses.

Okanagan TSA: This TSA is currently a net carbon source, but increased old-growth protection can significantly mitigate these emissions. Fully protecting old growth would result in over $10 billion in additional net benefits over 100 years, offsetting losses in timber production.

2. Why were the Okanagan and Prince George TSAs chosen for this study?

We worked with our Scientific Advisory Team to select these two TSAs. We wanted to choose very different ecosystems compared to the original Port Renfrew pilot study and focused on the interior due to its different disturbance regime and biogeoclimatic conditions. We chose the Prince George TSA for its size, since it would provide us with significant coverage of the province, as well as the fact that it has a relatively high economic dependency on forestry. We chose the Okanagan TSA as a contrast due to its more diverse economy.

3. Do these results represent actual dollar amounts to be expected in the future?

Yes and no. Our study contains two types of economic evaluation results stated in dollars shown in separate tables.

The first set of results are from a welfare economics approach called cost-benefit analysis, which focuses on broad economic benefits to society. We use this approach to assess both market and non-market benefits of forests as a dollar value, where dollars are used only as a common unit for comparison. For example, in the case of market-based ecosystem services like timber production, the basic approach is to multiply the volume of harvested timber by log prices and harvest costs using actual market data, then take the difference between revenues and costs to get net benefits in dollars. For carbon sequestration, we convert the volume of carbon to dollars using a metric called the “social cost of carbon”, which is derived from estimates of the global cost of damages caused by carbon in the atmosphere contributing to climate change (avoiding these damages would save society money). In the case of recreation opportunities, we convert the annual number of visitors to dollars using a provincial survey where respondents stated their willingness to pay for increases in recreational opportunities. These values are not the same as money you can deposit in a bank account, although if these contributions of nature are realized, some will result in real money flowing through an economy through market-based sales or cost savings (e.g., via avoiding damages or the cost of replacement).

The second type of economic result in our study focuses on economic impacts and includes only the two ecosystem services in our study that have market values: timber production and tourism. The standard approach to this method estimates the ripple effects of inputs from timber production and tourism on the regional economy through direct indirect, and (sometimes) induced economic activity. This method alone is an insufficient indicator of what is best for society, but is useful for communicating potential impact on jobs, GDP, and income in the evaluated market-based sectors. Because this approach is reliant on market data, it cannot capture the possible opportunity costs to society of the impact these sectors are having on other, non-market ecosystem services provided by old growth forests. We note that employment for the forest sector in BC has declined since 2001 (see Government of Canada: https://cfs.cloud.nrcan.gc.ca/statsprofile/employment/forest-sector-employment.html), while tourism employment has increased (https://www2.gov.bc.ca/gov/content/tourism-immigration/tourism-resources/tourism-research). In 2022, tourism contributed $7.2 billion to BC’s GDP, more than any other resource industry, including forestry at $1.7 billion (https://news.gov.bc.ca/factsheets/bcs-tourism-industry-a-resilient-economic-driver).

4. Can non-timber ecosystem services offset the economic losses for timber production caused by deferrals?

Yes. Our simulations indicate that proactively deferring harvest of old growth will maintain the benefits of these forests. When market and non-market ecosystem services are considered, this would leave society better off overall, despite trade offs with timber production. We acknowledge, however, that deferrals may impact some communities more than others, so while the overall benefit at the provincial level is a net positive, this may not be the case for individual communities. Our assessment did not evaluate the ease with which individual communities could shift toward other economic opportunities. We’ve shown that, over the next 100 years, compared to business-as-usual, fully protecting old-growth forests in the Prince George TSA would contribute an additional $4.7 billion in net economic benefit, accounting for net timber losses totaling about $2.9 billion. The same protection in the Okanagan TSA would contribute an additional $1.5 billion in net economic benefit, accounting for net timber losses of about $1.2 billion.

5. Why are old-growth forests economically valuable beyond timber production?

Old-growth forests provide a range of important ecosystem services that are often overlooked in traditional timber-focused economic assessments. These services are either irreplaceable or would be very costly to replace to an equivalent level of service provision. Examples include carbon storage and sequestration, recreation and tourism opportunities, provision of non-timber forest products, food production, water quality regulation, water supply, air quality regulation, education and research opportunities, and habitat provision.

6. What is conservation financing, and how can it support old-growth protection?

Conservation financing involves raising and managing funds to support the stewardship of nature. Such financing increasingly extends beyond ecosystems to include human economic and social dimensions. This type of funding can help compensate those affected by reduced timber harvest while supporting the long-term protection and management of old-growth forests. Examples sources of conservation financing include government and philanthropic grants, social finance investments by foundations, conservation trusts, market-based mechanisms (e.g., carbon markets, payments for ecosystem services), debt-based instruments, revenue-sharing arrangements, and user-fees. For an overview, we suggest reviewing Coast Funds' 2024 *Finance for Forests Technical Report*:
https://coastfunds.ca/news/finance-for-forests-report/

7. What is the significance of the 2021 old-growth deferral recommendations?

In 2021, following an extensive review process, the province of BC recommended deferring logging in 2.6 million hectares of priority old-growth forests. This policy shift presented a significant opportunity to set the stage to establish long-term protection at-risk old-growth forests and incorporate the broader economic value of old-growth forests into management decisions to move towards more sustainable practices. As of the Province's most recent March 2024 update[1], 1.23 million ha or ~47% of the identified priority areas for deferral have been deferred from harvest (BCMOF, 2024). An additional 1.21 million ha identified by First Nations have been deferred. Coordination is ongoing with First Nations to apply temporary deferrals.

8. How do the Allowable Annual Cut (AAC) decisions currently consider old-growth forests and their economic value?

The AAC is set using a process called a Timber Supply Review (TSR) that occur every 5 or 10 years. These reviews consider changes in the timber harvesting landbase and use models to forecast future timber supply. Old-growth forests are considered in TSRs in a few common ways: 1. The TSR uses information about forest ages to assess available timber and forecast timber supply, some of which will come from old-growth forests. 2. The TSR removes old-growth forests previously designated as protected or not harvestable (e.g., old-growth management areas) from its estimation of available timber supply. 3. Other landscape and biodiversity objectives that relate to old-growth forests are considered during the TSR and may inform rationales for further

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[1] Old Growth Deferrals – Frequently Asked Questions https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/old-growth-forests/deferral-areas

removing old-growth forests from the AAC determination. However, ecosystem services provided by old-growth forests and their economic value are not directly quantified in TSRs to inform the AAC decision.

9. Do BC’s AAC determinations used in the model account for timber volume losses due to disturbance?

Allowable Annual Cut (AAC) determinations are responsive to timber losses due to wildfire at the time of the next AAC determination, which is typically once every 10 years, but sometimes five years. The AAC determined by the province is not currently adjusted based on future projections of wildfire activity or extent. In our 100-year simulation of the business-as-usual (no extra deferrals) case, we apply the province’s current AAC levels and then adjust these proportionally for the other scenarios depending on the level of old growth deferral. Thus, harvest levels set by the Province may overestimate actual harvest due to future wildfire-related timber losses that are not accounted for in the current AAC.

10. How does wildfire impact the economic value of old-growth forests?

This study highlights the risks to the economic value of old-growth forests from wildfire. It also acknowledges that old-growth forests contribute to forest health and maintaining a natural range of variation in the landscapes. Forest management in these TSA has historically sought to increase the annual allowable cut by suppressing fire and prioritizing the harvest of old-growth forests and then reforesting to ensure a long-term timber supply. However, fire suppression and the harvest of old-growth forests has resulted in a departure from the landscapes’ natural range of variation. The adverse impacts of fire can be minimized through forest management that aims to restore more natural wildfire disturbance, but it must also be careful to retain old-growth forests and large trees, which store the highest amounts of carbon.

11. How does the study’s modeling work?

The study uses a sophisticated modeling system that combines forest simulation with economic valuation methods. This system simulates forest growth, disturbances (wildfire, pests, harvest), and carbon dynamics in a software program called the Carbon Budget Model of the Canadia Forest Sector (CBM-CFS3) to represent changes in the forest landscape over time. Economic methods are then used to estimate how these changes will affect the economic benefits from various ecosystem services under different old-growth protection scenarios. We also implemented CBM-CFS3 in the cloud to take advantage of additional computing power and developed several scripts in R and Python to support post-processing of CBM-CFS3 output data for quality assurance purposes and to generate tabular and graphical results. Paired with the appropriate input data as was the case during this study, CBM-CFS3 qualifies as a Tier 3 carbon modelling approach per the Intergovernmental Panel on Climate Change’s (IPCC’s) standards (i.e., the highest level of carbon modelling complexity).

12. Which species are planted following harvesting in CBM-CFS3?

We assumed that the same pre-harvest species composition was retained following harvesting. Once a stand was harvested, the age was reset, and the same species regrew along the same pre-harvest growth curve.

13. How realistically does the model represent forest operations in this area (e.g., retaining patches of trees to preserve habitat / habitat connectivity)?

The model assumes clear-cut harvest of 85% of merchantable trees but does not specifically designate individual trees / patches of trees to be retained. We modelled harvest using CBM-CFS3's default disturbance types. Clear-cut harvesting is the predominant harvest method used in these areas, so we modelled 50% harvesting as a clear-cut of 85% of merchantable trees without slash burning and without salvage harvesting of dead stem snags. We modelled the other 50% of harvesting with residual slash (i.e., branches and woody debris) burned after harvest. We did not conduct thinning or any other alternative harvest or stand tending methods, which are used to a much lesser extent in the study area.

14. Does the model include the impact of road construction for harvesting / forestry operations on carbon?

No, the impacts of road construction or other impacts of forestry operations on carbon storage and sequestration were not included. Therefore, the carbon benefit of deferring harvest on old-growth forests and reducing the annual allowable cut is likely underestimated. The impacts of road construction are also not considered in the model's selection of which stands to harvest next as it moves through the priority sequence of stand harvests.

15. How does the model prioritize stands for harvesting?

CBM-CFS3 has 4 different options for prioritization: 1) stands with highest merchantable carbon are harvested first, 2) oldest stands harvested first, 3) stands are harvested depending on the amount of time since they were last disturbed, 4) random selection of stands for harvesting. In this study, we had CBM-CFS3 harvest eligible stands with the highest merchantable carbon first. Since CBM-CFS3 is an aspatial model, it cannot prioritize by location or other spatial attributes of a stand.

16. How did you estimate the area of old growth on the landscape?

Old growth at the start of the simulation: For the BC Policy Deferral and Enhanced Deferral scenarios, we used maps available from the province to identify priority old growth stands ineligible for harvest during those simulations (https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/old-growth-forests/information-and-analysis). These same stands remained ineligible throughout the 100-year simulation. For the 100% Old Growth Deferral scenario, in the first year of the simulation we flagged all stands classified as old growth as ineligible for harvest. We set the old-growth age threshold at 140yrs, which is the standard threshold used by the province in BC's interior forests.

Old growth at the end of the simulation: Some stands that were younger than 140 years at the beginning of the simulation escaped harvest, grew into old growth, and were included in the old growth area estimates at the end of the simulation. Most of these stands would have regrown from natural disturbance rather than harvest-based disturbance, but some may have regrown after harvesting. Note that forest stands that are historically harvested but then age into old growth status do not typically possess the same ecological integrity as stands regrowing from natural disturbance, but there are likely very few of these stands in our estimates because harvest-based disturbance in BC was rare prior to the 20th century.

17. How does CBM-CFS3 handle soil carbon?

There are several belowground dead organic matter (DOM) and live biomass pools in CBM-CFS3 which account for carbon stored in the soil. The initial sizes of these pools are determined during the initialization phase of modelling prior to the start of the simulation using information about the mean annual temperature, mean annual precipitation, historical disturbance regime, and soil type, if applicable. The soil carbon pools decay at default rates in CBM-CFS3 depending on temperature and precipitation, which remained constant throughout the simulation.

18. Does CBM-CFS3 account for the random nature of disturbances (e.g., by randomizing different fire rates across years)?

We did not implement stochasticity (i.e., randomness) in disturbances. Our modelling was purely deterministic (i.e., a set amount of fire per year). CBM-CFS3 can implement some randomness in the application of disturbances, however, we did not use that functionality here to ensure consistency and comparability across scenarios.

19. Can CBM-CFS3 simulate climate change?

The CBM-CFS3 does not innately incorporate climate models, nor can it simulate the impact of climate change on forest growth. Previous studies have modelled climate change scenarios in CBM-CFS3 by manipulating variables impacted by climate change (e.g., temperature). The user can manually change climate variables affecting the carbon cycle such as mean annual temperature, which has consequences for decay rates and the transfer of carbon to different pools. The user can also manipulate natural disturbance rates over time and set regenerating / replanted species following a harvest or disturbance event. As a sensitivity analysis, we doubled wildfire rates to test the effect if changing wildfire rates, but we did not simulate climate change in the model.

2 Methods Updates

In 2020, the ESSA team was engaged by the Ancient Forest Alliance to complete an economic valuation of ecosystem services provided by old-growth forests in a pilot study area around Port Renfrew on Vancouver Island (Morton et al. 2020). In 2022/23, we extended many of the same methods for a study of the Okanagan and Prince George Timber Supply Areas (TSAs). The results of the second study are available in a Summary Report that accompanies this document. We encourage readers who are interested in a more detailed understanding of our methods to review the full technical report for the Port Renfrew pilot, which is available on the Ancient Forest Alliance's website here: https://ancientforestalliance.org/old-growth-economic-report/. In this document we review the new methods and assumptions we applied for forest carbon simulation and economic valuation, which we summarize below:

Summary of key differences in forest carbon modelling:

- Updated version of CBM-CFS3 forest carbon modelling software
- Introduction of cloud computing and automated post-processing
- New old growth protection scenarios
- Custom simulation of tree stand growth
- Use of biogeoclimatic zones for stand classification
- New harvest assumptions
- Introduction of natural disturbances (fire, pine beetle)
- Sensitivity analysis with doubled fire rates

Summary of key differences in economic valuation:

- In-depth review of valuation methods for all ecosystem services assessed
- Data updates for all ecosystem services assessed

2.1 Differences in Forest Carbon Modelling

In this section, we describe updates we applied to the forest carbon modelling component of the project compared to the Port Renfrew pilot study. Broadly, we applied these updates to achieve improvements in computing time; and address data gaps for the new study areas to remain current in terms of policy relevance, and to better represent the unique forest ecosystems. Table 1 below summarizes key similarities and differences between the two studies.

Table 1. Key similarities and differences between the New Study and the Port Renfrew Pilot Study.

	Port Renfrew Pilot Study	New Study
Forest carbon model: CBM-CFS3*	✓	✓
100-year time horizon	✓	✓
Cloud computing & automation of post-processing	✗	✓
BC biogeoclimatic zones used for stand classification	✗	✓
Custom simulation of tree growth (VDYP, TIPSY)	✗	✓
BC Old Growth Technical Advisory Panel recommendations in old growth protection scenarios†	✗	✓
Harvest assumptions based on Annual Allowable Cut (AAC)‡	✓	✓
Wildfire disturbance	✗	✓
Insect/pest disturbance	✗	✓
Stochastic / dynamic disturbances	✗	✗
Sensitivity analyses§	✓	✓
Carbon in biomass, litter, and soils	✓	✓
Climate change	✗	✗
Old growth classified using 140-year age threshold	✓	✓

**CBM-CFS3 version 1.2.7271.303 for pilot study, version 1.2.8728.385 for new study*
†Different scenarios used for new study (see below)
‡Different AAC limits applied to new study
§Applied to wildfire disturbance in new study

2.1.1 Modelling Software Update

We modelled forest stand growth and carbon sequestration using the Carbon Budget Model of the Canadian Forest Service (CBM-CFS3). To estimate stand volume growth over time, we computed a custom set of growth trajectories ("growth curves") in VDYP to input into CBM-CFS3. In this case, we used a newer version of CBM-CFS3 (version 1.2.8728.385) which included bug fixes from the previous 2019 version (1.2.7271.303) used in the Port Renfrew pilot study, including a fix to the calculation of carbon in young trees. Overall, this fix would slightly increase the amount of carbon in young trees, compared to the previous model version.

2.1.2 Introduction of Cloud Computing and Automated Post-processing

Due to the size of the data compared to the Port Renfrew pilot study, we implemented a specialized cloud computing and automation setup to conduct model runs and post-processing in parallel in the cloud. We ran a Python version of the CBM-CFS3 on virtual computers created using Amazon Web Services. We read output databases from the model into custom scripts in R, which helped us parallelize processing of summarized output variables for quality assurance and final data visualization.

2.1.3 New Old Growth Protection Scenarios

In 2021, the province of BC convened a Technical Advisory Panel to identify and map priority old-growth forest areas for deferral from harvesting. We used maps included in the Priority Deferrals Report (Old Growth Technical Advisory Panel, 2021) to define deferral scenarios at 2 levels (described below): BC Policy Deferral and Enhanced Deferral. We also included a business-as-usual scenario (No Extra Deferral) and a maximum deferral scenario (100% Old Growth Deferral) which protected all stands classified as old growth in the study areas. These scenarios differ from those examined in the pilot study, which were based on different proportional levels of old-growth protection (30%, 50%, 70% and 100%) applied at the beginning of the simulation, as well as scenario variants with increasing protection over time, and a no harvest scenario. We describe the new scenarios below:

No Extra Deferral

In the No Extra Deferral scenario, we followed the business-as-usual case, with no new old-growth deferral areas added during the simulation. We retained the deferral or protected status of all stands which were deferred prior to the 2021 provincial recommendation to defer an additional 2.6 million hectares province-wide (see BC Policy Deferral scenario).

BC Policy Deferral

The BC Policy Deferral scenario follows the 2021 provincial recommendation to defer 2.6 million acres of priority old-growth forest province-wide (Map 1; Old Growth Technical Advisory Panel, 2021). Within the target TSAs we examined, this amounts to 314,117 ha of newly protected areas (62,294 ha in Okanagan, and 251,823 ha in Prince George).

Enhanced Deferral

In the Enhanced Deferral scenario, we defer additional priority old-growth areas including big-tree old growth, ancient forest, remnant old ecosystems, and recruitment forest. Provincially, this would result in 7.6 million hectares of deferred old growth forest (Maps 1, 2 and 7; Old Growth Technical Advisory Panel, 2021). Within the target TSAs we examined, this protection amounted to 390,176 ha (90,361 ha in Okanagan and 299,815 ha in Prince George).

100% Old Growth Deferral

In the 100% Old Growth Deferral scenario, we deferred all old growth stands within the THLB older than 140 years. This includes all areas deferred in the BC Policy Deferral and Enhanced Deferral scenarios, and any additional stands which meet the 140+ year old age criterion. We modelled this scenario using a "protection disturbance" in CBM-CFS3 which switched any old growth stands in the THLB to a protected status indicator. We apply this protection at the beginning of the simulation, before any harvesting occurs. Stands younger than 140 years old at the beginning of the simulation which aged into old growth (based on the 140+ year old age criterion) during the simulation were not deferred. In total, 1,025,978 ha of additional old growth area is deferred in this scenario (249,728 ha in Okanagan and 776,250 ha in Prince George) at the beginning of the simulation.

2.1.4 Custom Simulation of Tree Stand Growth

"Growth curves" are mathematical functions that project the growth and yield of a forest stand, or group of stands, over time. CBM-CFS3 requires these growth curves as input data to predict harvesting eligibility and changes in carbon across a study area. Unlike the Port Renfrew pilot, for which the Ministry of Forests provided ready-calculated growth curves for selected stands, we custom computed our own growth curves in version 7 of Variable Density Yield Projection (VDYP7) software and version 4.4 of the Batch Table Interpretation Program for Stand Yields (TIPSY) using information from the 2021 Vegetation Resources Inventory (VRI).

Due to the large number of stands in each study area, the potential number of unique growth curves was vast and would have been infeasible to compute within our project timeline. We therefore grouped stands based on similar characteristics ("stand classification") to reduce the total number of unique growth curves for modelling. The stand characteristics we used for stand classification included:

- Forest Inventory Zone (FIZ)
- First and second leading species
- Percent compositions of the first and second leading species (rounded to the nearest 10% and adjusted to add to 100%)
- Site index (a measure of productivity) classified as high (site index ≥ 18), medium (site index = 11-17) or low (site index ≤ 10). Any stands with a missing stand index were automatically assigned a medium index category.
- Biogeoclimatic Ecosystem Classification (BEC) zones

We assigned the same growth curve to stands with the same set of summary characteristics. We developed most growth curves used in the main CBM-CFS3 simulation with VDYP7 in the Windows command line. We provide input file specifications for VDYP7 in Appendix 1. When stands were disturbed, we assumed they would grow back in the same way following the disturbance, and with the same species composition present before the disturbance. Therefore, we used the same VDYP7 growth curves before and after disturbance.

Limitations to using VDYP include the fact that it is typically used on unmanaged stands and tends to model growth conservatively. Our results for the Okanagan and Prince George TSAs may therefore underestimate stand growth. In addition to generally conservative growth estimates, VDYP7 can further underestimate stand growth because it may initially fail to assign volume estimates to young stands with small trees that do not meet height and diameter thresholds, instead these years are assigned zero volume. This issue can also lead to growth curves starting at an unreasonably high volume later in the simulation once those thresholds are met. We partially addressed this behaviour by reducing the minimum quadratic mean diameter threshold to 7.5+ cm which allowed volumes to be assigned to stands reasonably early in their development. We also used VDYP's "back projection" functionality, which estimates both prior and future stand growth from current conditions. This allowed us to flesh out a full time series for growth from age 0 to 300 regardless of inventory year or current age. For the remaining stands which had significant data gaps, we used "filler" TIPSY-generated growth curves. Growth curves generated by TIPSY tend to simulate faster growth and larger whole stem volumes typically associated with second growth stands, which means it can more accurately predict growth in second growth stands than VDYP, but may overestimate the growth of unmanaged, first growth stands.

2.1.5 Use of Biogeoclimatic Zones for Stand Classification

As mentioned in the previous section, we added BC Biogeoclimatic Ecosystem Classification (BEC) zones as a new classifier to help group stands for growth curve reduction and to permit simulation of spatially variable disturbance rates and mean annual temperatures between BEC zones. This differs from the Port Renfrew pilot study, where the Coastal Western Hemlock BEC zone covered most of the study area. We downloaded BEC zone boundaries from the BC Data Catalogue and intersected these with the BC Vegetation Resource Inventory (VRI) data to ensure that each stand was associated with a BEC zone.

2.1.6 New Harvest Assumptions

We limited harvest based on deciduous and non-deciduous Annual Allowable Cut (AAC) allocations in the TSRs. We used an AAC of 2,462,800 m3/yr for the Okanagan TSA in the first 10 years of the simulation, adjusted down to 2,290,000 m3/yr to reflect the planned step-down in the third decade of the Timber Supply Review (BCMOFLNRO, 2022). For the Prince George TSA, we set the harvest target to 6,600,000 m3/yr; this is the current AAC with the salvage portion (750,000 m3/yr) removed. We did not include salvage logging in the harvest target since a low level of salvage logging of wildfire and Mountain Pine Beetle (MPB)-killed stands was already inherently included in how the model represented those disturbances; this avoided double counting. We also split the AAC based on supply blocks defined by the province, with 1.5 million m3/yr harvested in the North section (supply blocks A and B) of the TSA, and 5.1 million m3/yr harvested in the South section of the TSA (all supply blocks except A and B) (BCMOFLNRO, 2017).

The Port Renfrew pilot study simulated harvesting using CBM-CFS3 default settings associated with a coastal BC clear-cut with slash burn disturbance and only included harvest of softwood, since less than 1% of the land base in the study area was covered by deciduous stands. For this study, deciduous stands were more prevalent, and we included harvest of both softwood and hardwood (deciduous) stands in accordance with the province’s restrictions on deciduous harvest as part of the AAC determination. For all stands harvested during the simulation, we applied a 50% clear cut with slash burn and 50% clear cut without salvage. Following a wildfire, we assumed salvage logging of snags with 60% of snags going towards wood products.

2.1.7 Introduction to Natural Disturbances

In the Port Renfrew pilot study, we did not account for any natural disturbances due to relatively low natural disturbance rates in BC coastal forests. Since wildfire and mountain pine beetle are much more prevalent in BC’s Interior (Meyn et al., 2010; Aukema et al., 2006), we included these disturbance types in our simulations of the Prince George and Okanagan TSAs.

Wildfire

We calculated wildfire rates using the Canadian National Fire Database (CNFDB; Canadian Forest Service, 2021a) fire perimeters dataset, which contains BC wildfire data from 1917 to 2020. We extracted 100 years (1920 to 2020) of these data for our simulations. We only calculated wildfire rates for the forested land base, which we defined as areas with a leading species identified in the BC Vegetation Resource Inventory (VRI) polygon layer. To determine the wildfire rate, we calculated the total area within the fire perimeters using the *sf* package in R. We subdivided each of the TSAs by BEC zone (creating TSA-BEC zones) to allow for spatial variability in disturbance rates. We summed these areas for each TSA-BEC zone over the 100-year period. We then divided this total area by 100 years to determine the average annual disturbance rate to apply in our CBM-CFS3 simulations. We assumed that missing data for a given year was due to no fires occurring and thus kept those years as real data points rather than excluding them.

To avoid over-representing fire disturbance, we also adjusted the wildfire rate to remove “skips” (unburned patches in a fire scar) using the National Burned Area Composite (NBAC; Canadian Forest Service, 2021b), which is derived from remotely sensed data spanning 1984 to 2020. This dataset (rather than typical fire perimeters) allowed us to detect burn severity to delineate and remove skips. Within each TSA-BEC zone, we subset the CNFDB data between 1984-2020 and divided the total area burned for the full time period in the NBAC by the total area burned for the full time period in the CNFDB to determine, on average, the proportion of a given CNFDB fire scar that burns. We then multiplied the 100-year-average CNFDB fire rates by this proportion to down-adjust our fire rates (i.e., proportions between 0-1 which probabilistically determine how much of the forested study area will burn each year). In CBM-CFS3, we then simulated wildfire as a stand-replacing fire disturbance using the adjusted annual fire rates.

Mountain Pine Beetle

We assumed Mountain Pine Beetle (MPB) only affects lodgepole pine stands older than 80 years, which is the age at which stands become susceptible to MPB infestation, as defined by the province (BCMOFLNRO, n.d.). In CBM-CFS3, we modelled MPB disturbance as a low impact disturbance, with default parameters representing 5% mortality of softwood trees from beetle kill at the landscape level (Kull et al., 2014). We did not apply a variable MPB disturbance rate that dynamically accounts for changes in the landscape from harvesting or fire because, on such complex landscapes, CBM-CFS3 cannot handle the sheer number of records that are created through this process. Instead, we used the initial landscape to estimate the approximate area of MPB kill for every decade in the simulation. We calculated the area of lodgepole pine-leading stands in 10-year age groups. For the first 10 years of the simulation, we calculated the area disturbed by multiplying the area of the 80+ year age group by 0.005 (0.5% annual disturbance rate). We then subtracted this area from the 80+ year old age class. To determine the area disturbed for the next 10 years of the simulation, we added the remaining area of the 80+ year age class to the 70+ year age class (which becomes 80+ years old in the second decade of the simulation). We then multiplied the area of these combined classes by 0.005 to estimate the MPB-disturbed area in the second decade of the simulation. We repeated this method for the remainder of the simulation period and the remaining age classes.

2.1.8 Sensitivity Analysis with Doubled Fire Rates

While we did not simulate how natural disturbance might shift under climate change, we wanted to test the effects of increased fire, so we performed a sensitivity analysis with doubled fire rates over the simulation period. We did not change mountain pine beetle disturbance rates or harvesting practices during this analysis. While increasing burned area and fire frequency are projected in central BC under climate change (Nitschke & Innes, 2013; Meyn et al., 2018; Parisien et al., 2023), it is important to note that a doubling of fire rates is not necessarily a projected outcome under climate change, but rather was used as a hypothetical test to determine the sensitivity of the model to increasing fire rates.

2.2 Differences in Economic Valuation Methods

In this section we describe updates we applied to the economic valuation component of the project compared to the Port Renfrew pilot study. Broadly, we applied these updates to better represent ecosystem service provision for services relevant in the new study areas and evaluated candidate methods for the inclusion of new ecosystem services during a future phase of work.

Table 2 lists all old growth forest ecosystem services considered for economic valuation during the pilot study and the new study. The two studies quantify the economic value of a similar subset ecosystem services, but we excluded habitat provision from the new study because we could not readily transfer our methods, which were focused exclusively on coho salmon in the pilot study. We also removed real estate amenity provision. As noted in Morton et al. (2020)

there are potential issues with double counting benefits by including changes in real estate amenity values. As such, we did not include these values in the totals reported for the pilot study, and we did not include them in the current analysis.

Table 2: Comparison of ecosystem services selected for this project and the Port Renfrew project.

	Port Renfrew Pilot Study	New Study
Carbon storage & sequestration	✓	✓
Timber production	✓	✓
Recreation opportunities	✓	✓
Tourism opportunities	✓	✓
Non-timber forest product provision	✓	✓
Habitat provision (coho salmon only)	✓	×
Education & research opportunities	✓	✓
Real estate amenity provision*	✓	×
Water quality regulation†	×	×
Flood mitigation†	×	×
Water supply†	×	×
Air quality regulation†	×	×

**Candidate method examined and applied during pilot study, but not used for valuation totals to avoid double counting*
†Candidate methods examined during new study, but not applied

We also drew on the pilot study, additional literature review, feedback from our advisory team, and characteristics of each Timber Supply Area (TSA) to identify additional ecosystem services for investigation. This included **water quality regulation**, **flood mitigation**, **water supply**, and **air quality regulation**, which were of special interest in the study areas given recent flooding and wildfire events in the province. We wanted to investigate the feasibility, using our model system and available data, of capturing the effects of old-growth harvests on hydrologic processes influencing water-related services and air pollutant concentrations affecting human health. We did not evaluate these new ecosystem services in this study, but we did develop candidate approaches for future inclusion. The following sections summarize differences between the two studies only for the evaluated ecosystem services.

2.2.1 Carbon Storage & Sequestration

Following the same methods as the pilot, we assessed the monetary value of carbon sequestration over the 100-year time horizon of our old growth management scenarios in four steps. First, for each TSA, using CBM-CFS3 outputs for above and belowground carbon pools we obtained the annual change in the study areas' stored carbon. Second, we estimated the net change in carbon stored annually in timber that is converted to wood products using the British Columbia Harvested Wood Products Carbon Calculator tool (BCMOFLNRO, 2016). This tool, based on Dymond (2012), captures carbon emissions from the wood product's life cycle including manufacturing, export,[2] and recycling, and estimates how products made from spruce-pine-fir,[3] cedar, or hardwood logs (e.g., paper, lumber, plywood, etc.) decay over time, gradually releasing carbon into the atmosphere. The tool requires the selection of an input or initially harvested wood product (i.e., roundwood, lumber, plywood, oriented strand board, or medium density fibreboard). Given our harvests are focused on logs we set the initial product as roundwood. Third, we calculated the total annual change in carbon sequestered in year *t* as the sum of the change in forest and wood product carbon pools from year *t-1* to year *t* (Equation 1).

$$Carbon\ Sequestration_t = \begin{pmatrix} Forest\ Carbon\ Stock_t \\ +Product\ Carbon\ Stock_t \end{pmatrix} - \begin{pmatrix} Forest\ Carbon\ Stock_{t-1} \\ +Product\ Carbon\ Stock_{t-1} \end{pmatrix} \quad [1]$$

Fourth, we assigned dollar values to units of sequestered carbon using the Government of Canada's official social cost of carbon estimate. This decision required a review of carbon pricing options to update our prior data. Different monetary estimates of the value of carbon sequestration are available including from the social cost of carbon, carbon taxes, carbon market prices.

The social cost of carbon (SCC) is a common approach because carbon emissions are not a localized problem, and the SCC estimates the monetary value of worldwide total damage caused by a ton carbon released into the atmosphere. Values for SCC vary in the literature with the Canada Gazette (2020) noting a range of $135 to $440 per tCO2 (converts to $495 to $1613 per tC). A recent study by Rennert et al. (2022) finds the SCC ranges from $44 to $413 per tCO2 with a mean of $185 (2020 USD), which converts to $923 per tC (2022 CAD). The USEPA released their latest global SCC estimates in 2022 which forecast the costs until the year 2080 (USEPA 2022). Following this release, the Government of Canada (2023) revised their estimates of the SCC of carbon in accordance with those from the United States. Estimates differ based on modeling assumptions, although assuming a Ramsey 2% discount rate — the recommended key assumption — annual present value SCC estimates range from $263.45 in 2020 to $554.63 per metric tonne of CO2e (2022 CAD).[4] While these values are for tCO2e it is easy to convert

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[2] Due to a lack of data for non-North American jurisdictions the life cycle of carbon in wood product exports outside of the United States are assumed to be the same as those in North America

[3] The spruce-pine-fir category captures non-cedar coniferous tree species such as Douglas fir, larch, hemlock, balsam fir, as well as white or yellow pinee.

[4] The annual present values do not necessarily represent the present value stream of the SCC to the current year (i.e., the year of this report). Rather they represented the present value of the SCC estimates in the year that the carbon was released. For example, the present value of a tonne of carbon dioxide released in 2080 is the present value in that year. These values still need discounted to the year of the current analysis in order to estimate the present value of a stream of annual benefits or costs.

them to tC (Figure 1).[5] Since there is no forecast value beyond 2080, to be conservative we assumed no change in the SCC rather than assume the value continues to increase.

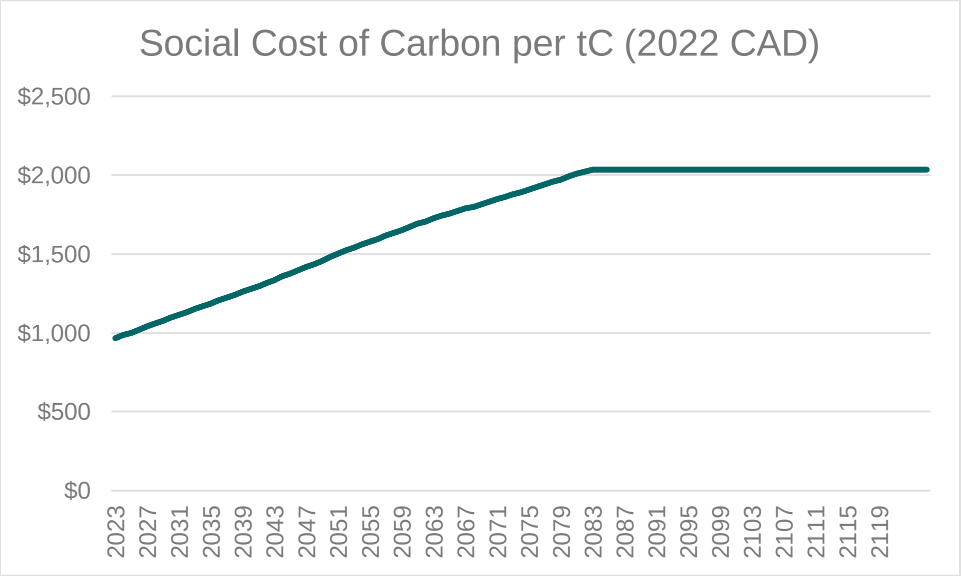

Figure 1: Social Cost of Carbon (tC).

Other options, as outlined by Hope et al. (2021) in their research related to afforestation projects in Ontario, include the value of a carbon tax, such as that used by the province or federally, or carbon credits in voluntary offset markets (the latter of which Hope et al. (2021) assumes to be $5 per metric tonne of CO2e for an offset [$18.35 per metric tonne of C]). This value for voluntary offsets is at least twice as high as the current market price for voluntary offsets geared toward the aviation ($1.67 per metric tonne CO2e) and tech ($0.87 per metric tonne CO2e) industries as well as from nature-based offsets ($1.50 per metric tonne CO2e) according to CarbonCredits.com — although these prices were as high as $3 in early 2023 at the time of writing (market prices checked at 10am Pacific on April 26, 2023). Local carbon pricing initiatives are also informative. As part of their attempt to maintain carbon neutral government operations, the province purchases carbon offset credits each year and some of these credits result from organizations implementing improved forest management (Government of BC, 2023a). Over the past several years they purchased several such credits from the Great Bear Carbon Credit Limited Partnership or Nanwakolas Offset Limited Partnership whose credits result from improved forest management or forest conservation in the Great Bear Rainforest. Payments to these groups in recent years have been $12 per metric tonne of CO2e which works out to $44.04 per metric tonne of carbon (assume that these values are in 2022 CAD). Another alternative is to use the value of the BC carbon tax. As of April 2023, British Columbia's carbon tax is $65 per tCO2e which converts to $238.55 per tC (Government of BC, 2023b). In addition, this tax is scheduled to increase $15 annually until it reaches $170 per tCO2e ($624 per tC) in 2030.

For the purposes of this study, we followed standard economic practice for cost benefit analysis by applying the social cost of carbon (see Figure 1).

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[5] Future analyses should check for updates to the forecast value of the SCC since these values are interim.

2.2.2 Timber Production

Like the pilot study we estimate the annual *net* timber production value using market prices, but with region-specific values. To get a net value, we subtract the cost of production from revenues, both estimated by multiplying total annual harvest volumes from the CBM-CFS3 model by dollar estimates per m^3. Following prior studies, we relied on Log Market Report data to obtain timber revenues in BC (Knowler and Dust 2008; Chan et al. 2011; Robinson et al. 2013; Griess et al. 2015; Sun et al. 2015; Xu et al. 2018). Species-specific revenue, or price per m^3 of logs harvested in BC's Interior are published monthly by the Province in the Interior Log Market Report along with the volume of each species harvested (B.C. Ministry of Forests, Timber Pricing Branch 2022). Prices are reported for several species and for certain wood product groupings including sawlogs, peelers, poles/house, minor products (e.g., posts or shingles), and pulpwood. Given the volatility of wood product prices, we estimated an average price for each species using all publicly available Interior Log Market Report price data from 2015 to 2022. We took the average price per species ($/$m^3$) per year, converted those values to 2022 CAD, then took the average across each year from 2015-2022 (Table 3). Since the Interior Log Report data do not include log prices by grade we do not estimate a grade-weighted average, which deviates from the pilot study.[6]

Table 3: Annual Average Log Prices

Species	Price ($/$m^3$)
Cedar	$207.24
Douglas Fir-Larch	$97.90
Hemlock-Balsam	$77.16
Spruce-Pine-Fir (SPF)	$96.84
White Pine	$94.88
Yellow Pine	$35.53
Deciduous	$44.66
Other	$71.88

Source: Estimated by authors using Interior Log Report data from 2015-2022.We assume these values include salvage logs destined for pulp (not specified in source data).

To estimate total harvest costs per year we follow Knowler and Dust (2008), using the sum of fixed costs, including the unavoidable costs of equipment and overhead, and variable costs, which include charges for avoidable items such as harvest activities, head office functions, and silviculture / tree planting. Unlike log prices, total cost data is not made available by the province.

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[6] The Interior Log Market Report differs from the Coastal Log Market Reports in that logs are not divided into different grades and rather product groupings. As such, we do not estimate a grade weighted average using data from the Province's Harvest Billing System as was done for the Port Renfrew pilot study. Certain studies use a grade weighted average and others do not.

As such, we used total harvest cost per m^3 estimates from Xu et al. (2018) who report these values for the Northern and Southern Interior Regions at $48 and $52 for softwood and $38 and $41 for hardwood (2014 CAD).[7] These values inflate to $57.27 (Northern) and $62.04 (Southern) per m^3 in 2022 CAD for softwood and $46.67 and $50.35 for hardwood. The Prince George TSA is in the Northern Interior Region and the Okanagan TSA is in the Southern Interior Region, so we apply cost data accordingly.

We also made two adjustments to our cost values. First, it is likely that the cost of harvests will decline over time since harvests of second growth timber could be cheaper (e.g., fewer roads must be built, improvements in harvesting technology). Following Knowler and Dust (2008), we assumed that harvest costs would decline after the first year of their time horizon by $0.10 annually (2008 CAD), which inflates to $0.13 (2022 CAD). Second, since stumpage costs paid by firms to the provincial government represent a transfer of economic rent from one agent to another, they should not count towards total harvest costs (Knowler and Dust 2008). The 2015 Interior Appraisal Manual lists average stumpage rates for coniferous sawlogs for the Prince George and Okanagan TSAs at $23.84/m^3 and $19.83/m^3, respectively while the rate for deciduous species is listed at $0.50/m^3 (assumed 2015 CAD). These values respectfully inflate to $28.10/m^3, $23.38/m^3, and $0.59/m^3 in 2022 CAD. We subtract these stumpage rates from the costs reported in Xu et al. (2018) yielding coniferous (deciduous) harvest costs per m^3, less stumpage, of $29.16 ($44.75) for Prince George and $38.66 ($48.33) for the Okanagan (2022 CAD).

2.2.3 Recreation Opportunities

In the new study, we relied on similar methods to estimate the economic benefits arising from recreation opportunities in old growth forests. Our work in the pilot study was based on Knowler and Dust's (2008) analysis in the Lower Mainland as well as van Kooten and Bulte (1999). However, because the pilot relied on a dated recreation survey, we completed a thorough review of data and methods to ensure no improvements were possible. We ended up relying on the same survey, but in addition to updating our data to region-specific values for population, visitor counts, and willingness-to-pay values, we attributed a specific proportion (29%) of recreation value to the old growth age class thanks to new research conducted on Vancouver Island by Dupont (2022). This was an improvement over our previous methods which relied on the study area's existing forest age class distribution to apportion value. We also added hunting license values due to the availability of new data.

Outdoor recreation is a vital activity for British Columbians, with surveys consistently showing high participation rates. In the late 1980s, 41% of residents visited forests 15 days annually (Ministry of Forests 1991). More recent studies (2009–2022) reveal 50-90% participation in recreational pursuits more broadly (NRG Research and Tourism BC 2013, Kux and Haider 2014, ORCBC 2022a), with non-motorized recreation alone generating $3.6 billion in 2012. Regional

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[7] The Northern Region contains the Skeena, Northeast, and Omineca Natural Resource Regions (NRR), while the Southern Interior Region is comprised of the Cariboo, Thompson-Okanagan, and Kootenay-Boundary NRRs.

preferences, such as in the Fraser Valley and on Vancouver Island, highlight hiking, camping, and nature viewing as top pursuits, with a notable 29% of forest-based recreation on the Island occurring in old-growth forests (Dupont 2022). Additionally, visits to the Ancient Forest/Chun T'oh Whudujut Provincial Park near Prince George have surged (Connell 2019),[8] reflecting growing interest in exploring BC's unique natural landscapes.

Dupont's (2022) survey on southern Vancouver Island found that 58% of respondents preferred recreating in old-growth forests, with 35% favoring forests with giant trees. Only 1.5% preferred young forests, while 39% had no preference. Respondents were willing to pay for access to old-growth recreation sites, a pattern supported by travel cost studies by Englin and Mendolsohn (1991) and Englin et al. (2016), which estimated willingness to pay for trails in old-growth forests in the Pacific Northwest and Jasper National Park.

Like the pilot study, to estimate net economic benefits from recreation in old-growth forests, we relied on economic benefit transfer using the 1989/1990 BC Ministry of Forests survey, adjusted for inflation. This is consistent with past studies that used benefit transfer to for similar purposes (e.g., e.g., van Kooten 1995, van Kooten and Wang 1998, van Kooten and Bulte 1999, Knowler and Dust 2008, Morton et al. 2020). The survey tracked the number of recreational user-days and asked respondents about expenditures on recreational pursuits and willingness to pay to preserve recreational opportunities in Crown forests. While dated, there has not been a more recent and similarly comprehensive study.[9] We accepted this limitation, noting that willingness to pay values can remain consistent over relatively long periods of time (e.g., Neher et al. 2017 for whitewater rafting, Price et al. 2016 for drinking water quality in Edmonton). We did not account for distance decay effects, which arise when willingness to pay declines (or changes) with distance from the site at which the changes occur.

To get per-hectare annual recreation values for the two TSAs, we followed the same approach as the pilot but used the provincial survey's data for the "Prince George Forest Region (PGFR)" (Prince George TSA) and the "Kamloops Forest Region (KFR)" (Okanagan TSA). We first summed the total recreational use values for each region across the following activity types: boating, motoring, fishing, camping/swimming, hiking/skiing, hunting, and "all others", adjusted for inflation, divided by the total number of adult recreational user-days (RUD) indicated in the survey, then multiplied this by the average annual RUDs for BC adults in each forest region. To distribute these values across old-growth (age class 11, age 201 years and above) and second-growth forests (age class 1 to 10, forests with an age below 201 years) we used Dupont's (2022) 29% for old-growth (71% for second growth). While Dupont's result was likely a function of locally specific recreationist preferences and old-growth abundance, we felt it provided improved specificity compared to our previous method. We then divided the resulting values by the area

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[8] Another study by Connell et al. (2015) documents the values local households have for ancient cedars in the inland temperate rainforest. Hall (2013) also valued the economic benefits of the Ancient Forest Trail related eco-tourism.

[9] There have been more recent provincewide surveys about outdoor recreation in the British Columbia (e.g., NRG Research Group and Tourism BC 2013; Kux and Haider 2014; ORCBC 2022a; Dupont 2022). However, NRG Research Group and Tourism BC (2013) as well as ORCBC (2022a) do not report user days, Kux and Haider (2014) do not limit their survey to recreation in Crown forests, and Dupont (2022) is focused on the area around Port Renfrew. Recent efforts have been made to implement a comprehensive survey of outdoor recreationists in the province and future phases of the current research should be aware of the potential for additional survey data soon (ORCBC 2022b).

of old-growth and second-growth forest in each TSA. This scaling produced estimates "per 1,000 BC adult per hectare" of $21.58 and $1.61 in the PGFR, and $66.64 and $12.36 in the KFR (2022 CAD) (Table 4). Since our recreation estimates are population-based, we change them dynamically with projected changes in the province's population over our simulation time horizon (100 years). To do so, we used the average across all ten Statistics Canada's (2023) population growth scenarios to 2043, then assumed the same rate of growth as federal projections to 2068 because no provincial data are available beyond 2043. Beyond 2068 we assumed the population would grow at the same rate as the final projection year of the federal estimate.

Like the pilot, we also estimated fishing license revenue collected by the province and added these amounts to the total recreational use value. We obtained data for freshwater license sales from the four most recent annual reports of the Freshwater Fisheries Society (www.gofishbc.com) (prior reports were not available) and inflated these values to 2022 CAD. We then took a weighted average using the number of licenses sold each year to residents and non-residents yielding an average annual value of $11.4 million (2022 CAD). Since our focus is on values for residents, we weight this total by a recent estimate of 80% as the share of license sales to residents (Southwick Associates, 2020), resulting in an average annual residential license sales value of $9.16 million for all of BC (2022 CAD). We allocated the provincial total by the management regions containing each TSA – the Prince George TSA falls within the Omineca Natural Resource Region (OmNRR) and the Okanagan TSA falls within the Okanagan Natural Resource Region (OkNRR) – by multiplying by the share of total resident angling days spent in each management region reported in Southwick Associates (2020), which is 4.4% (OmNRR) and 11.1% (OkNRR), then dividing the resulting NRR-specific value by the adult population of in British Columbia – 4.39 million adults in 2022. We then distributed these values across old- and second-growth forests using Dupont (2022) to get per-capita estimates. We then divide these estimates by the area of old-growth and second-growth forests in each NRR to get fishing license values per 1,000 adults per hectare for old-growth and second growth in each TSA. We added the resulting values to the recreation use estimates derived earlier (see Table 4).

Unlike the pilot, we estimated hunting license revenue collected by the province because new data were released on the number of hunting licenses sold each year at the provincial level (Government of BC 2022a). We used a similar approach to fishing licenses. Hunting license sales are divided into those sold to residents and non-residents as well as by license type (e.g., basic, species specific, junior, senior, etc.). Although information on the value of license sales is not included, the government separately publishes license prices, which we assumed are in 2022 CAD (Government of BC 2022b, 2022c). We estimated the annual total value of resident license sales over the previous ten license years (2012/13 to 2021/22) by multiplying the number of resident licenses sold in each year by the corresponding license price (this price includes the Habitat Conservation Trust Foundation surcharge). This yielded an average annual resident hunting license sales value of nearly $7.78 million (2022 CAD) for the entire province. We divided this total annual value among the NRRs by multiplying the value by the share of all resident hunting days in each region, 13% in OmNRR and 15% in OkNRR, then divided that value by the adult population of the province in 2022, resulting in annual hunting license revenue per BC adult. As for fishing licenses, we then distributed these values across old- and second-growth forests using Dupont (2022), then calculated values on a per-hectare basis by dividing by the area of old-growth and second-growth forests used for hunting in each NRR to get hunting license values per 1,000 BC adults per hectare for old-growth and second growth in each TSA. We added these hunting license values to the general recreation values and fishing license values (see Table 4).

Table 4: Summary of recreation values used in the new study.

	Value (per 1,000 adults/ha)	
	Prince George TSA	Okanagan TSA
Old-growth		
Recreation Use Value	$21.5845882	$66.6429174
Fishing Licence	$0.0000691	$0.0001406
Hunting License	$0.0000284	$0.0001567
Total old-growth	**$21.58**	**$66.64**
Second-growth		
Recreation Use Value	$1.61119261	$12.3563831
Fishing Licence	$0.0000051	$0.0000261
Hunting License	$1.6119456	$0.0000786
Total second-growth	**$1.61**	**$12.36**

2.2.4 Tourism Opportunities

Like the pilot study, we relied on output data from our economic impact assessment (separate, complimentary study) to estimate producer surplus for the Tourism Opportunities ecosystem service (see Section 2.2.7).

2.2.5 Non-Timber Forest Products

Non-timber forest products (NTFPs) harvested in BC include plants (or parts of plants), fungi, and saps for uses such as floral greenery, medicine, food, arts and crafts, plants for landscaping, or inputs into soaps (Tedder et al. 2002; Mitchell and Hobby 2010). While NTFPs are harvested commercially and recreationally, and are important as a food source and for cultural heritage, there is little data or information on their harvest since the sector is not well regulated or monitored by government — what information is available is typically dated.[10,11] In the late

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[10] There are instances where these harvests are regulated, but not by federal or provincial governments. The Tsilkqot'in National Government requires that mushroom pickers obtain permits for harvests in their traditional territory, which extends south of Prince George (Dickson 2018).

[11] There has been some new research. Wang et al. (2022) published a book chapter about the economics of NTFPs in Canada with a case study on mushroom harvests in B.C. However, they do not conduct an economic analysis of mushroom harvests, instead providing a qualitative description of mushroom harvests.

1990’s, it was estimated that annual revenue from harvests of over 200 different NTFPs, and related eco-tourism, was in excess of $250 million dollars with the number of people employed at least seasonally in the sector pegged at 32,000 (de Guess 1995; Wills and Lipsey 1999). However, these jobs are typically low paying (Wills and Lipsey 1999; Hobby et al. 2010). The wild fungi / mushrooms and floral greenery are the largest, most organized, and “industrial” of the NTFP harvests in the province although they still rely on individuals doing piece work or small-scale harvesters (Tedder et al. 2002: 110). Other harvests are cottage industries or artisanal, although certain harvests (seed cones) used as inputs into arts and crafts are also “industrial”. Wild mushrooms — notably pines but also chanterelles, morels, and others — as well as floral greenery, such as salal and coniferous boughs, are the most common commercially harvested NTFPs in BC. The average annual values of these commercial harvests in the province were $27.5 million for mushrooms and $38 million for floral greenery (Cocksedge and Hobby 2006). Beyond their commercial value, NTFPs have important Indigenous uses and recreational harvests of wild foods are important in rural areas (Mitchell and Hobby 2010).

There is some research on NTFPs more local to the case study TSAs, notably Prince George, but also to the north of the Okanagan. In their review of NTFP harvests in the Prince George area, Burton (2006) found that harvests of conifer seeds and seed cones was the NTFP harvest that resulted in the highest economic contribution, about $700,000 per year — although the these seeds and cones were not destined to be used in crafting and instead to grow seedlings for planting operations.[12] Powell (2005) notes that wild mushrooms represent the largest sector by participation in the Cariboo-Chilcotin, which spans the area south of Prince George, specifically pines and morels. They also note that other NTFPs are not commonly harvested commercially in the region, nor is eco-tourism related to NTFPs widespread. In the Robson Valley Forest District (RVFD) to the east of the Prince George TSA, Berch et al. (n.d.) and Ehlers et al. (2004) conducted an inventory of plant and fungi NTFPs, including their distribution, abundance, and preferred stand characteristics such as dominant tree species and age classes. They identify many species of mushrooms and greenery, highlighting three floral greenery plants with commercial potential (deer fern, Falsebox, and Oregon grape) as well as three fungi species that can be eaten as food (pines, hedgehogs, and morels).

In addition to Morton et al. (2020), there are multiple studies in the US Pacific Northwest, British Columbia, and Alaska that have incorporated the value of various NTFPs into their economic analyses. In British Columbia, Knowler and Dust (2008) estimated the producer surplus captured by harvesters using data on market prices and biological productivity gleaned from mushroom buyers, the literature, and local experts, while van Kooten and Bulte (1999) relied on existing per hectare values from other studies. In Washington, Starbuck et al. (2004) assessed the value of recreational huckleberry and mushroom picking in the Gifford Pinchot National Forest by using a travel cost survey to estimate recreational pickers’ willingness to pay, while Mojica et al.’s (2017) analysis of ecosystem service values in the Mt. Baker-Snoqualmie National Forest incorporated data from an existing US Forest Service study that estimated the value of NTFPs

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[12] Other types of harvests could be of higher value, but a lack of data makes the comparison impossible. Burton (2006) found that, while mushroom harvest were likely in the region, it was difficult to gather data on the amount harvested and thus an economic value given the decentralized nature of the harvests.

harvested in this National Forest. Finally, in Alaska Phillips et al. (2008) used the replacement cost approach to value NTFP harvests, specifically wild foods, in the Chugach and Tongass National Forests (harvest data was multiplied by the retail cost of replacement foods [e.g., the price of a pound of salmon at the grocery store]). They also estimated the value of Indigenous subsistence using an estimate of lost subsistence value stemming from the Exxon Valdez oil spill that was used to award damages to an Alaskan Indigenous Nation.

Following Knowler and Dust (2008) and the Port Renfrew pilot study by Morton et al. (2020) we measure the producer surplus of NTFP harvesters. We do not include the recreational value of NTFP collection, as done by Starbuck et al. (2004), since there is scant data on recreational harvests. Such a recreational value would be measured via consumer surplus and may be captured in our recreational estimates since there is a 'Gathering / Collecting' category in the BC Ministry of Forests' (1991) recreation survey. Given their commercial importance, we focus on three key species of mushrooms, specifically pines, chanterelles, and morels (Morton et al. [2020] incorporated the producer surplus of these mushroom harvests, as well as that of salal). Although there are other commercial wild mushroom harvests, these three mushroom species have the highest values and are commonly harvested (Kearns and Halseth 2009). We do not include salal for floral greenery since it is a coastal plant (Boateng and Comeau 2002). Future analyses may wish to expand the set of NTFPs included in the analysis although it is a difficult task given the lack of current information on harvests in BC.

We estimated the annual producer surplus (PS) of NTFP harvests per hectare, then applied these to the land area outputs from CBM-CFS3. Estimating this PS for harvests of each of the three mushroom species required several steps including estimating:

1) total revenue per day per harvester for each mushroom species ($ per day per harvester);
2) total cost per day per harvester for each mushroom species ($ per day per harvester);
3) total PS per day per harvester for each mushroom species by taking the difference between revenues in Step 1 and costs in Step 2 ($ per day per harvester);
4) PS per unit of mushroom by taking the ratio of PS from Step 3 by the predicted daily units harvested per harvester ($ per kilogram);
5) the typical annual units harvested per hectare for each mushroom species (kilograms per hectare); and
6) PS per year per hectare by multiplying PS per unit from Step 4 by the anticipated annual number of units harvested per hectare from Step 5 ($ per hectare).

We outline each of these steps, including key assumptions, in detail below.

Estimating daily harvester revenues involved multiplying the price per unit by the number of units an experienced mushroom harvester can pick per day. To establish the number of units we used the daily harvest rates (kg/day) for pines and chanterelles from Knowler and Dust (2008) and from Olivotto (2009) for morels (Table 5).[13] We assumed that harvesters consumed 2% of this harvest, to which the retail price is applied, meaning that only 98% was sold to buyers at wholesale prices (Godoy et al. 1993; Knowler and Dust 2008). Wholesale prices for pines and chanterelles are taken from Knowler and Dust (2008) while the midpoint of the reported ranges of wholesale prices from Cocksedge and Schroeder (2006) are used for morels. We spot checked retail prices for the three mushrooms on April 26, 2023 at West Coast Wild Foods (http://www.wcwf.com/).The resulting total daily revenue estimated for harvests of each mushroom species was: $174.57 for chanterelles; $209.09 for pines; and $336.15 for morels (2022 CAD).

Table 5: Parameters used to estimate per hectare producer surplus for each mushroom species

NTFP	**Daily Harvest** (kg)	**Prices per kg** (2022 CAD)		**Biological Productivity** (kg/ha)	**Share of Productivity Harvested**	**Habitat**	
		Wholesale	**Retail**			**Age Class**	**Dominant Species**
Pine	2.7	$75.96	$150.00	4.5	50%	3 to 7	Not cedar
Chanterelle	14.2	$10.76	$87.45[a]	5.0	50%	3 to 7	Not cedar
Morell	20.0	$15.52	$79.90	1.5	35%	> 2	All

[a] Estimated as the mean of the price for white ($75.00/kg), yellowfoot ($75.00/kg), golden (79.90/kg), and blue ($120.00/kg) chanterelle mushrooms.

To estimate the total cost per harvester per day, we followed Knowler and Dust (2008) by treating the cost of harvest as the 'variable opportunity cost of harvesting', which is the wage a harvester would earn if they were engaged in similarly skilled work elsewhere, plus an estimate of the fixed costs per day. A harvest hand was assumed to represent a similarly skilled position and this job's median wage in British Columbia is $15.65 (assumed 2022 CAD). We used this value as our estimate of the opportunity cost of harvesting NTFPs. Fixed daily costs were taken from Knowler and Dust (2008), set at $30 (2006 CAD), which inflates to $42.33 (2022 CAD). The total cost per day was calculated by taking the product of the hourly opportunity cost, Knowler and Dust's (2008) estimate of the typical number of hours worked each day by a harvester (6.7 hours) to which we added the daily fixed costs yielding a total cost per day of $147.19 (2022 CAD).
Given our estimates of revenue and costs for the three mushroom species, the total producer surplus per day per harvester is easily calculated by taking the difference between total daily cost and the total daily revenue, which works out to $27.38 for chanterelles, $61.90 for pines, and $188.96 for morels. Though these values may seem low they represent the returns to the harvester beyond the value of their labour. Producer surplus (PS) per unit is then estimated by dividing daily PS by the predicted daily harvest of a harvester (Table 5). Per unit producer surplus values are thus: $1.93/kg for chanterelles; $22.93/kg for pines; and $9.45/kg for morels.

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[13] Harvest rates for pines and chanterelles is also provided by Olivotto (2009) although does not distinguish between rates for the two mushrooms, while there are substantial differences in the harvest rates for these two species reported by Knowler and Dust (2008). As such we rely on the latter source.

We estimated the typical annual units of mushrooms harvested per hectare by multiplying each mushroom species' 'biological productivity', as represented by the average units growing per hectare per year (fresh kg/ha), by predictions about the share of 'biological productivity harvested each year (Table 5). We used estimates of 'biological productivity' in kg/ha for Pacific Northwest pines and chanterelles from Pilz and Molina (2001), and Alexander et al.'s (2002) analysis in Oregon for morels (values for morels growing in natural stands were used; Alexander et al. (2002) also presents such information for disturbed stands, for instance by fire. Alexander et al. (2002) also estimated the portion of the mushrooms' biological productivity that is commercially harvested (Table 5).[14] Multiplying these shares by the biological productivity of each mushroom species results in the estimated fresh weight harvested per hectare per year (2.5 kg/ha per year for chanterelles, 2.25 kg/ha per year for pines, and 0.525 kg/ha per year for morels).

Finally, the estimated producer surplus per unit harvested can be multiplied by the estimated units harvested per hectare per year to generate an estimate of producer surplus per hectare per year for each mushroom. This calculation yields producer surplus values of $4.82/ha/yr for chanterelles, $51.58/ha/yr for pines, and $4.96/ha/yr for morels (2022 CAD).[15] We applied these per hectare per year producer surplus estimates to the area of forest stands which these species prefer in each year of our study's time horizon. The preferred stands corresponded with each mushroom's preferred habitat as defined by a stand's age and dominant species from Knowler and Dust (2008), Alexander (2002), Pilz and Molina (2001), as well as Cocksege and Schroeder (2006) (Table 5).

2.2.6 Education and Research

The potential use of old growth forests for education and research in the Prince George and Okanagan TSAs is high given that the UNBC and UBC-Okanagan are located nearby, in addition to other colleges and K to 12 schools. The education and research services of forests and nature have been valued by a few studies although we are aware of none in BC (aside from Morton et al. 2020). Loomis and Richardson (2000) as well as Phillips et al. (2008) valued academic scientific research occurring in American roadless or Alaskan old-growth forests via benefit transfer, while Haegele et al. (2016) valued United States National Parks Service educational programs via a choice experiment. Hutchenson et al. (2018) used the travel cost method to value the environmental education services of New York City's Hudson River Park. In Estonia, Oras et al. (2019) used a variety of techniques to estimate the value of nature-based education in the country.

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[14] In closed plot trials Alexander et al. (2002) observed much lower shares (22% in 1995 and 12% in 1996 but selected 50% for commercial harvests for pines and chanterelles as they thought this better represented their observations on commercial harvests in open areas. The value they used for morels was for 'natural morels' in undisturbed stands.

[15] These producer surplus estimates drop quite a bit if it is assumed that only 15% of the biological productivity of pines or chanterelles is commercially harvested (better reflecting the closed plot trials of Alexander et al. [2002]). Producer surplus becomes $1.45/ha/yr for chanterelles; $15.48/ha/yr for pines; and $2.13/ha/yr for morels.

Although BC's old growth forests are used for education purposes, such as the Lynn Canyon Ecology Centre's elementary school educational programming in North Vancouver (Lynn Canyon Ecology Centre n.d.), there is limited data on the use of forests for educational purposes in each of the new study's TSAs, especially those outside protected areas. However, it is possible to estimate the amount and value of scientific research conducted in old growth forests in each region following an approach developed by Black (1996) and applied by Loomis and Richardson (2000) to estimate the value of scientific publications in roadless areas of the United States as well as by Phillips et al. (2008) in Alaska's Tongass National Forests.

Doing so involves estimating the number of peer reviewed research studies relying on old growth forests published over a period in each TSA to arrive at an annual estimate of studies per hectare of old growth forest. First, we counted the number of studies conducted over the past 10 years (2012 to 2022) by searching through the Web of Science for the terms "British Columbia" and "old growth". This returned 51 studies, but only 26 were relevant to the Interior region of BC where the two TSAs are located, yielding an average annual estimate of 2.6 studies per year. Second, we divided the average annual number of studies by the area of old growth in the South and North Interior regions which we estimated as 8,301,953 hectares yielding an estimate of 0.0000003 studies per hectare of old growth forest per year. Third, we then used this result to estimate the annual number of peer reviewed research studies forecast to be conducted in each TSA's old growth forests over our 100-year time horizon. Lastly, we multiplied the number of forecasted studies by a monetary value. Loomis and Richardson (2000) used a value of $12,000 (2,000 USD) per study, as did Phillips et al. (2008) in Alaska, which is equivalent to $28,464 (2022 CAD) per scientific study after inflation. Multiplying this per study value by the estimated number of studies per hectare per year results in an annual value per hectare of research conducted in old growth forests of $0.01. We applied this value to the age classes that are considered to represent old-growth forests in each of the TSAs.

2.2.7 Economic Impact Assessment

Like the pilot study, we also completed economic impact assessment for Timber Production and Tourism Opportunities in the two TSAs so we could compare impact on jobs, income, GDP and overall economic output across these two sectors. To do so we followed the same methods as the pilot but substituted relevant regional data to regionally downscale multipliers from Statistics Canada Input-Output models.

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