Economic Trade-Offs between Carbon Offset and Timber Opportunities in British Columbia's Central Coast: A Decision Analysis Approach

by

Heather Munro

B.Sc. (Civil Engineering), Queen's University, 2011

Research Project Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Resource Management (Planning)

Report No. 602

in the
School of Resource and Environmental Management
Faculty of Environment

SIMON FRASER UNIVERSITY

Fall 2014

Approval

Name:	**Heather Munro**
Degree:	**Master of Resource Management (Planning)**
Report No.:	**602**
Title:	***Economic Trade-Offs between Carbon Offset and Timber Opportunities in British Columbia's Central Coast: A Decision Analysis Approach***
Examining Committee:	**Chair:** Julia Fryer Master of Resource Management Candidate

Kenneth Lertzman
Senior Supervisor
Professor

Andrew Fall
Supervisor
Adjunct Professor

Laurie Whitehead
Supervisor
Lands Manager
Heiltsuk Integrated Resource Management Department

Date Defended/Approved: September 4, 2014

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Abstract

Emerging carbon offset markets create economic opportunities to manage carbon in forests but represent a complex mix of decision-making challenges and are poorly understood among forest managers. I use a decision analysis to assess alternative forest management options in the context of Ecosystem-Based Management (EBM) in Heiltsuk traditional territory on the Central Coast of British Columbia. I use timber supply (SELES-STSM) and carbon budget projections (CBM-CFS3) while considering uncertainty in carbon offset and log prices. Carbon offsets provide strong economic opportunities that can compensate for foregone timber harvest revenue within existing carbon markets, but these benefits vary over time and are sensitive to uncertainty in price trends, costs, leakage, and discount rate. These findings can help forest managers and policy makers understand the opportunities and trade-offs of managing forests for timber harvest and carbon storage to better meet their objectives and obtain a more diverse range of benefits.

Keywords: carbon offsets; harvest level; decision analysis; forest management; ecosystem-based management (EBM); CBM-CFS3

Dedication

To my parents and my sisters whose unending support I truly could not have done without and helped me make the most of this experience.

Acknowledgements

Firstly, I would like to thank my senior supervisor Dr. Kenneth Lertzman for his support, expertise and guidance throughout this project. I would also like to thank my supervisors Dr. Andrew Fall and Laurie Whitehead for their contributions and insights which made this research possible and greatly enriched this work. Thanks to the various people at the British Columbia Ministry of Forests, Lands and Natural Resource Operations, Pacific Carbon Trust, and several carbon accounting companies that shed light on the implications of timber harvest and carbon offset projects in British Columbia. I would also like to thank Jordan Benner for his help with ArcGIS. A sincere thank you to the Heiltsuk First Nation and the Heiltsuk Integrated Resource Management Department for supporting and informing this project, the study was greatly enriched by their input. Lastly, I thank those that funded this project including the Tula Foundation via the Hakai Network for Coastal People, Ecosystems, and Management; Pacific Institute for Climate Solutions; Natural Sciences and Engineering Council of Canada; and Simon Fraser University.

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List of Acronyms

BC FCOP	British Columbia Forest Carbon Offset Protocol
CBM-CFS3	Carbon Budget Model of the Canadian Forest Sector
CNC	Central and North Coast
EBM	Ecosystem-Based Management
ENPV	Expected Net Present Value
EVIU	Expected Value of Including Uncertainty
EVPI	Expected Value of Perfect Information
GBR	Great Bear Rainforest
HWP	Harvested Wood Products
LUO	Land Use Objectives
NPV	Net Present Values
PCT	Pacific Carbon Trust
RONV	Range of Natural Variation
SCC	South Central Coast
SELES-STSM	Spatially Explicit Landscape Event Simulator Spatial Timber Supply Model
TFL	Tree Farm License
TSA	Timber Supply Area
VOI	Value of Information

1. Introduction

Forests are an important component of the global carbon cycle, functioning as a large carbon reservoir and annually sequestering globally significant amounts of carbon from the atmosphere (Canadell and Raupach 2008, Pan et al. 2011). The annual average change in global carbon stocks of established forests from 2000 to 2007 was an uptake of 2.3±0.5 Pg C/yr, which represents roughly 30% of the global fossil fuel emissions (Pan et al. 2011). However, forest ecosystems can shift between being net carbon sinks and sources, largely depending on the type, frequency, and severity of disturbances such as timber harvest and fire (Kurz et al. 2008a). For example, a major mountain pine beetle outbreak in the south-central region of British Columbia, Canada resulted in widespread tree mortality that both during and immediately after the outbreak converted the forest from a small sink to a large source of net carbon (Kurz et al. 2008b). Thus, we can think about managing carbon in forests through the regulation of forest activities and practices (Canadell and Raupach 2008). Forest management approaches intended to enhance carbon storage can include either increased or decreased timber harvest, largely depending on a variety of ecosystem characteristics, particularly the age and structure of the forests in question and the incidence of natural stand-replacing disturbances (Golden et al. 2011, Sharma et al. 2013, Smyth et al. 2014).

Managing forests for carbon presents an economic opportunity to participate in emerging carbon offset markets (Charnley et al. 2010, Pojar 2010). The value of the global voluntary carbon market in 2012 reached $523 million with 101 million tonnes of carbon offsets (Mt CO_2-e) contracted, of which 32% by volume was represented by forestry and land-use projects (Peters-Stanley and Yin 2013). Carbon markets diversify the economic opportunities available in forest management and can be used to support implementation of sustainable forest management objectives and strategies that increase net carbon storage by offsetting associated costs and foregone revenue (Freedman et al. 2009). Methodologies for carbon offset projects are guided by independent certification standards which directly affect project costs, carbon accounting, and attainable offset prices (Foley et al. 2009). Project development involves generation and validation of a project design document, verification of implementation, documentation, monitoring, offset issuance and tracking by a registry.

Quantifying forest carbon dynamics and the effects of forest management on these dynamics has received considerable attention in the literature (Goodale et al. 2002, Birdsey et al. 2006, Eriksson et al. 2007, Hennigar et al. 2008, Nunery and Keeton 2010, McKinley et al. 2011, Pan et al. 2011, Stinson et al. 2011, Post et al. 2012). Carbon is often included in forest valuation to assess alternative forest management strategies (Healey et al. 2000, Krcmar and van Kooten 2005, Knowler and Dust 2008, Seidl et al. 2007, Rodrigues 2011, Schwenk et al. 2012), and as a factor in determining optimal rotation length (van Kooten et al. 1995, Murray 2000, Backéus et al. 2005, Chladná 2007, Sohngen and Brown 2008, Baskent and Keleş 2009, Keleş 2010, Asante et al. 2011, Couture and Reynaud 2011, Petrasek et al. 2013, Susaeta et al. 2013). However, realistic economic assessments of opportunities for carbon offset projects and the trade-offs embodied in these choices remain challenging. This reflects the diversity of forest stand structures and dynamics, landscape character and historical land-use legacies (Richards and Stokes 2004, Foley et al. 2009, Smyth et al. 2014), uncertainty in future products markets and the early stage of development of carbon markets and standards in general (Kangas and Kangas 2004, Foley et al. 2009, Peters-Stanley and Yin 2013), and the complexity of the social choices inherent in these decisions (Seidl and Lexer 2013).

Forest managers require further research and decision support tools to properly assess the economic potential of alternative management options that include carbon offset projects and to make good decisions about trade-offs among management objectives (Chladná 2007, Foley et al. 2009, Ryan et al. 2010, Burton et al. 2013). Some agencies, for example Natural Resources Canada, have specifically identified that policy development needs research focusing on the implications of managing carbon on forest management practices, associated costs and benefits of carbon management, and its relationships to other forest management goals such as timber harvesting (Bernier et al. 2012). Research is also needed which examines how carbon offset price impacts forest management decisions as well as the opportunity to use carbon offset projects as incentives to support conservation actions (Sutherland et al. 2009, Golden et al. 2011).

The high degree of uncertainty and lack of information that often characterizes management of the environment is a major challenge for managers (Polasky et al. 2011). The main sources of uncertainty in forest planning include growth and yield predictions, future environmental conditions, ecological consequences of alternative plans, preferences of involved stakeholders and decision makers, and market conditions for timber and associated harvesting costs (Kangas and Kangas 2004). A consideration of uncertainty and risk should play an important role in managing forest ecosystems as they are inherently complex, have long time horizons, and decisions often embody challenging value trade-offs and numerous stakeholders (Keeney 1982, Mendoza and Martins 2006, Pasalodos-Tato et al. 2013). Decisions must be made despite the uncertainty and lack of sufficient information which characterize environmental management, but they can be informed by a formal assessment of risks if they incorporate uncertainty (Apostolakis 2004, Burgman 2005, Polasky et al. 2011). Forest managers need to integrate uncertainty into their decision making processes, but further research into uncertainty is required to support informed decision making (Hildebrandt and Knoke 2011). In particular, uncertainty must be integrated in order to generate more robust net revenues (Ascough II et al. 2008) where forest carbon management requires further attention as it is an emerging component of forest economics and there are significant uncertainties that remain despite the substantial scientific progress in the past few decades (Bernier et al. 2012).

Decision sciences are continuing to develop in environmental management to help better support the multidimensional choices that must be made which are often characterized by uncertain science, diverse stakeholders, and difficult trade-offs (Gregory et al. 2012). Decision analysis is an analytic tool adapted for resource management several decades ago (Walters and Hilborn 1976, Holling 1978, Walters 1986) to inform decision making by evaluating management options quantitatively while explicitly including uncertainty (Keeney 1982, Clemen 1996). Instead of using point estimates and central tendencies, decision analysis includes the distributions for hypothesized uncertain states of nature to calculate outcomes of alternative management options. Decision analysis increases the probability of selecting a management action with a more desirable outcome, provides insights into how robust management decisions are to assumptions and uncertainties, and informs resource allocations aimed at reducing uncertainty (Morgan and Henrion 1990). Decision analysis has been applied to certain aspects of forest management including silvicultural treatments (Martell and Fullerton 1988), logging impacts on birds and mammals (Crome et al. 1996), and forest road deactivation (Allison et al. 2004). Although carbon offset opportunities have been included in studies using decision analysis, such as Puerta-Ortega et al. (2013), who assessed the feasibility of a carbon capture and storage project, and Biallas (2009), who included carbon offset sales in their assessment of optimal entrance fees for protected areas in Belize, the uncertain states of nature in these studies do not include price scenarios for carbon offsets or timber. There is an opportunity to use decision analysis in the development of realistic decision support tools for forest managers and policy makers to help address risk and uncertainty particularly in emerging forest carbon offset opportunities.

Although forest management in British Columbia has traditionally been driven by timber production (British Columbia Ministry of Forests Mines and Lands 2010, Pojar 2010), carbon management is a significant opportunity that is rapidly evolving into practice both because of initiatives by the provincial government and a global interest in carbon offset markets. The British Columbia Forest Carbon Offset Protocol (BC FCOP) was developed in 2011 to guide the design, development, quantification and verification of high-quality forest carbon projects in British Columbia that demonstrate carbon emission reductions or increased carbon storage that are “additional” to a baseline business-as-usual scenario and implement afforestation, reforestation, improved forest management, or conservation (British Columbia Ministry of Environment 2011). Previous to 2014, the carbon market for offset projects under the BC FCOP was through the Pacific Carbon Trust (PCT), a British Columbia Crown corporation that oversaw and purchased carbon offsets from British Columbia projects for the public and private sector. The PCT has since closed and been transitioned to the Climate Investment Branch in the Ministry of Environment’s Climate Action Secretariat. The PCT used the Markit Environmental Registry, which had a 38% market share globally in 2012, to track, retire, report, and provide independent review of carbon offsets (Peters-Stanley and Yin

2013). Although there have been several forest carbon offset projects under the BC FCOP through PCT (see Appendix A), research on the effectiveness of forest carbon storage strategies in British Columbia (Man et al. 2013, McLaughlin 2013), and several protocols between First Nations and the provincial government that create certainty for carbon rights on provincial Crown land (Sparrow 2012), the implications for forest planning and operations are still largely unknown among forest managers (Greig and Bull 2009).

The economic opportunity to generate income from forests with carbon management is relevant not only to industrial foresters but to other stakeholders and decision makers as well, including local communities such as First Nation's, who are playing an increasingly important role in resource decision making (Sparrow 2012). Carbon offset projects may be more consistent than timber harvest with other values and objectives for forests, such as conservation, ecotourism and cultural tourism, and maintaining traditional food resources, biodiversity, and sustainable forest management practices. If this is the case, then carbon offset projects could be used as an alternative revenue stream to support these other values and objectives in forest management decision making.

I examine the implications of alternative management options that implement Ecosystem-Based Management (EBM) for an area in Heiltsuk Territory within the Great Bear Rainforest (GBR) on the Central Coast of British Columbia, Canada. I use timber supply projections from SELES-STSM, carbon budget modelling (CBM-CFS3), and decision analysis to address the following key questions:

- What are the trade-offs in terms of net present value of carbon offsets and timber harvesting for a set of management options designed to implement improved forest management through EBM?
- To what degree does uncertainty in future timber and carbon markets affect the rank order of those management options?
- What factors of the analysis have the most influence on the rank order?
- What is the value of reducing uncertainty in the analysis?
- What are the lessons that can be drawn from these analyses to help support Heiltsuk decision making?

2. Methods

2.1 Study Area

The Great Bear Rainforest (GBR) is an area of the coastal temperate rainforest on the British Columbia Coast incorporating Central Coast, North Coast, and Haida Gwaii (see Figure 1). The GBR is a globally significant conservation opportunity being one of the world's largest remaining temperate rainforests encompassing 6.4 million hectares on British Columbia's coast in the Pacific Northwest (Clapp 2004). Ecologically rich and rare, the GBR has also been internationally recognized for its biodiversity protection, sustainable economic development, and inclusive governance arrangements (Price et al. 2009, DellaSala et al. 2011, Moore and Tjornbo 2012, Riddell et al. 2012). As is typical for coastal temperate rainforests, the GBR is characterised by high annual rainfall, cool growing season temperatures, large rugged mountains, and relatively rare drought and fire disturbances (Meidinger and Pojar 1991, Schoonmaker et al. 1997, Orians and Schoen 2013). The natural disturbance regime is dominated by fine-scale gap-phase dynamics allowing development of a structurally and biologically complex, multi-aged, multi-canopy old growth forest, with large volumes of living and dead wood (Lertzman et al. 1996, Lertzman et al. 1997, Gavin et al. 2003, MacKinnon 2003, Daniels and Gray 2006).

The GBR, along with other Pacific Northwest forests, has the highest carbon densities in North America (Foley et al. 2009) largely due to the relatively cool temperatures, moderately high precipitation, and minimal human disturbance of older forests (Keith et al. 2009). However, the conversion of the old growth forests, which dominate the unmanaged landscapes, to managed forests results in considerable loss of carbon to the atmosphere that is unlikely to be regained (Harmon et al. 1990, Luyssaert et al. 2008, Trofymow et al. 2008). Over the past century, industrial logging in British Columbia has largely converted the most valuable and easily accessible forest in the region to managed second growth (Prescott-Allen 2005, Green 2007, Pearson 2010).

Provincial Crown land encompasses 94% of British Columbia, of which roughly half is forested. Of that forested land, roughly half forms the Timber Harvesting Land Base (THLB), where it is deemed both acceptable and economically feasible to harvest timber (British Columbia Ministry of Forests Mines and Lands 2010). Timber harvest in the THLB on provincial Crown land is regulated by the provincial government through 37 Timber Supply Areas (TSAs), 34 Tree Farm Licences (TFLs), and more than 800 woodlot licences and community forests. The harvest of timber in British Columbia has been important for economic development and continues to be an economic base for many rural British Columbia communities (British Columbia Ministry of Forests Mines and Lands 2010). However, land-use decisions and logging practices in coastal regions of British Columbia over the past few decades caused major conflict and dispute between environmental groups, logging companies, First Nations and the provincial government over concern for ecological integrity which attracted global attention (Smith et al. 2007). Additionally, over the past 25 years there have been a series of supreme court decisions that have affirmed the rights of First Nations in their traditional territories and facilitated their engagement in resource management decision making (Moore and Tjornbo 2012). In the GBR, these conflicts were at least partly resolved by agreements between First Nations and the Province affirming a commitment to implement Ecosystem-Based Management (EBM), a government-to-government process for land-use planning, revenue sharing, and tenure opportunities for First Nations (Price et al. 2009). Resolution of these major environmental conflicts in the GBR has received much recent attention in the literature (Howlett et al. 2009, Dempsey 2011, Moore and Tjornbo 2012, Ratio and Saarikoski 2012, Saarikoski et al. 2013)

EBM is defined by the Coast Information Team in the EBM Planning Handbook (2004, pg. 4) as "…an adaptive approach to managing human activities that seeks to ensure the coexistence of healthy, fully functioning ecosystems and human communities." Guiding principles of EBM are to promote ecological integrity, aboriginal interests, human well-being, the precautionary principle, collaborative planning and management, and fair distribution of benefits. EBM was implemented in the GBR using the Central and North Coast (CNC) Order (2009) and South Central Coast (SCC) Order (2009) which outline Land Use Objectives (LUO) for First Nations, aquatic habitats, and biodiversity. Novel elements of EBM development in the GBR include coalitions between groups formerly in opposition, explicit models relating management strategies to LUO, and use of ecological thresholds and natural variability to establish management targets (Price et al. 2009).

The LUO include representation targets for old growth forest (defined as 250 years or older). These targets are specified as a proportion of the range of natural variation (RONV), by site series surrogate and landscape unit (Schedule 4 of CNC Order 2009, SCC Order 2009). The default targets in the LUO are referred to in this study as “risk-managed” targets which retain a lower proportion of RONV (ranging from 30% to 70%) than do the higher “low risk” targets (setting all at 70%). Although the application of EBM reduces operable timber supply (Farenholtz and Rowan 2007), subsequent increased long-term carbon storage is eligible as an improved forest management carbon offset project under BC FCOP.

The traditional territory of the Heiltsuk First Nation is an area of high ecological and cultural importance located entirely within the GBR on the Central Coast of British Columbia, Canada, and is subject to EBM (Figure 1). The Heiltsuk are a Coastal First Nation with rich culture, history and traditions that are derived from their respect, reverence, and inextricable connection to the natural environment and resources of their Territory (Heiltsuk Cultural Heritage Centre 2003, Heiltsuk Tribal Council 2005, Brown and Brown 2009). This ancient, complex, and sacred relationship underpins Heiltsuk stewardship and management of their Territory and has the vision to continue balancing their needs with sustaining the land and resources while following customary laws, traditional knowledge, oral traditions, and consideration of current scientific information (Heiltsuk Tribal Council 2005). Today, Heiltsuk territory includes roughly 600,000 hectares of productive forest dominated by old growth (approximately 89%), which is mostly much older than 250 years (MacKinnon 2003, Pearson 2010), as research in similar ecosystems has also shown (Lertzman et al. 1996, Gavin et al. 2003). Forest stands are dominated by western redcedar (*Thuja plicata*), yellow-cedar (*Callitropsis nootkatensis*), western hemlock (*Tsuga heterophylla*), amabilis fir (*Abies amabilis*), Sitka spruce (*Picea sitchensis*), and red alder (*Alnus rubra*). Within the Territory there are three Timber Supply Areas (Midcoast TSA, Northcoast TSA, and Pacific TSA block 25) and one Tree Farm License (TFL 25 block 5). This study includes only the Midcoast TSA and Pacific TSA block 25 due to the large data requirements of the timber supply and carbon budget modelling and access to that data (Figure 1). The British Columbia Provincial Government and Heiltsuk have revenue sharing agreements relating to timber harvest and carbon offsets generated on Crown land within the Territory (Heiltsuk Forestry Agreement 2004, Reconciliation Protocol 2010, Atmospheric Benefit Sharing Agreement 2011).

I simulated the forest land-base on a portion of the Heiltsuk Territory, which includes the Midcoast TSA and Pacific TSA block 25. I examined four management options using a timber supply model and carbon budget model in order to examine the economic opportunities and trade-offs related to carbon offsets and timber harvest in the context of the implementation of EBM following the CNC Order (2009). Specifically, two of these management options are outside the current acceptable policy space in the GBR, but provide context for understanding the other options and are useful for understanding decision options in other areas. These options include a baseline of Pre-EBM forest management (option M1), and complete conservation with no timber harvest occurring on the landscape (option M4). The remaining two management options reflect current choices being addressed by the landscape planning process. These include management for two levels of old growth targets outlined under EBM implementation (options M2 and M3).

After obtaining the results from the timber supply and carbon budget analyses, I applied a decision analysis to investigate the impact of uncertainty in future timber and carbon offset prices on the relative economic benefits of the management options. The objective of this study is to provide insights for forest managers and policy makers into the opportunities and trade-offs for improved forest management in existing and future markets when managing for timber harvest and forest carbon while considering uncertainty in price trends.

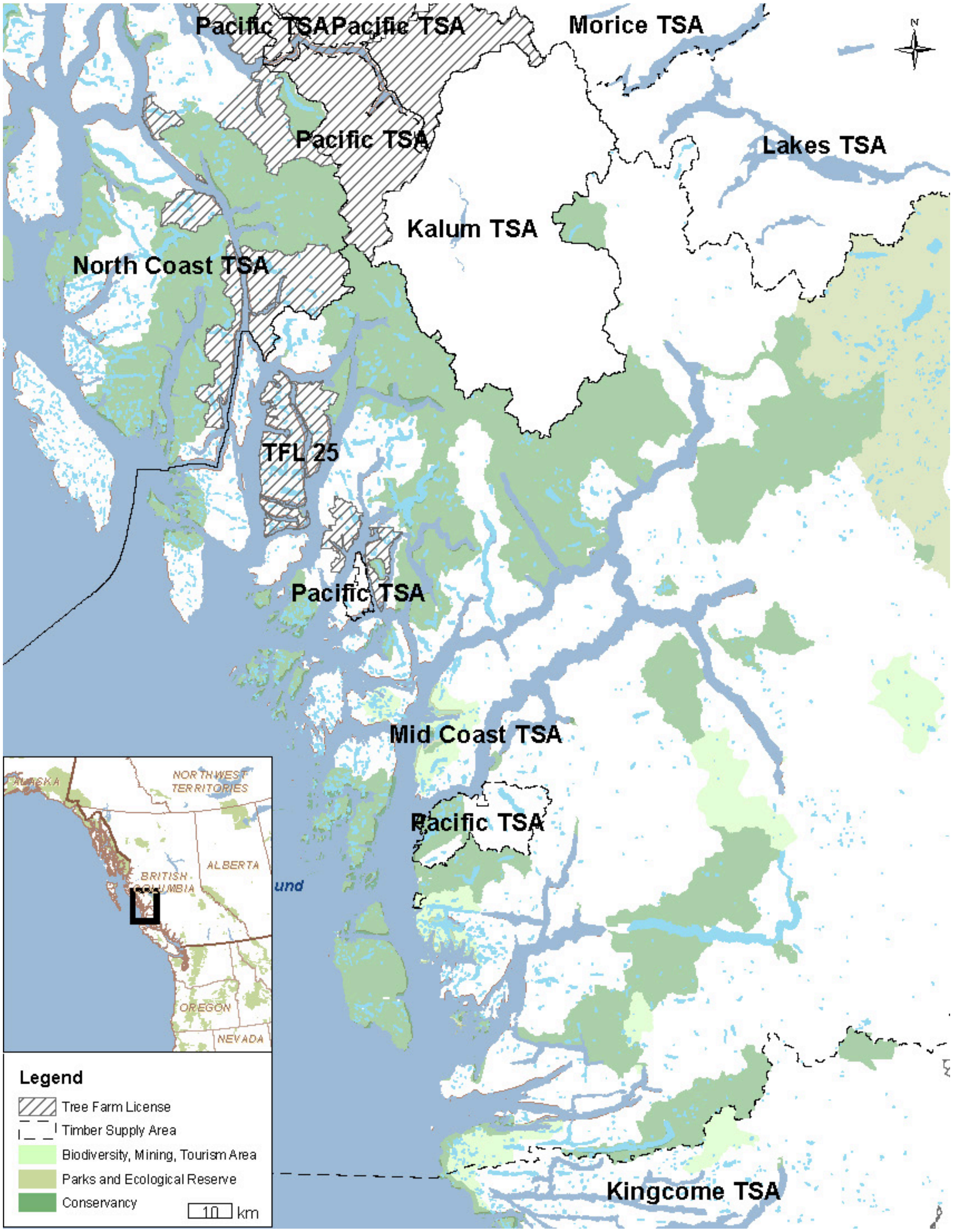

Figure 1. **Coastal portion of the study area.**

Map of the coastal portion of Heiltsuk Territory area with Tree Farm Licenses (TFLs), Timber Supply Areas (TSAs), and protected areas identified. The study area includes the Mid Coast TSA and Pacific TSA block 25. The insert map provides context for the location of the study area within British Columbia, Canada.

2.2 Simulation Models

Dr. Andrew Fall ran 250-year timber supply simulations for this study using the Spatially Explicit Landscape Event Simulator Spatial Timber Supply Model (SELES-STSM) (Fall and Fall 2001) as has been used elsewhere in the GBR process. These projections were run for each management option where 2008 is the reference year to coincide with EBM implementation under the 2009 SCC and CNC Orders. SELES-STSM required land-base inventory data and parameters for timber growth and yield available from British Columbia Ministry of Forests, Lands and Natural Resource Operations (2013a), and the most recent timber supply reviews for the Midcoast TSA and Pacific TSA (Forsite Consultants Ltd. 2010, British Columbia Ministry of Forests Lands and Natural Resource Operations 2014a). The modelled sustainable harvest levels used a 1 hectare resolution, decadal time steps for 400 years, spatial blocks randomly sized (5 ha to 20 ha), and a harvest preference for older stands closer to road access (Fall and Crockford 2006). Spatial constraints applied accounted for road and helicopter access and forest cover objectives for visual quality, site productivity, and ungulate winter range. Management options that applied EBM required further spatial constraints to meet the LUO in the SCC and CNC Orders (2009) as described further in Fall (2011) and Williams and Buell (2006).

I used the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3), version 1.2 to simulate annual carbon dynamics in the forest ecosystem (Kurz et al. 2009). CBM-CFS3 is an aspatial stand- and landscape-level modelling framework that tracks and transfers carbon stocks between tree biomass and dead organic matter pools. Data requirements for the model include inventory data and growth and yield data (British Columbia Ministry of Forests, Lands and Natural Resource Operations 2013a), and a schedule of disturbance events from SELES-STSM outputs which include natural disturbances (as stand-replacing wildfire), roads and landings (as temporary stand removal for construction), clear-cut harvesting (of 85% merchantable trees with burn of post-harvest organic residue in burn piles and as broadcast burns), and clear-cut harvesting (of 85% merchantable trees with 50% salvage of dead stem snags for use in the forest products sector). I used default CBM-CFS3 parameters for the Pacific

Maritime region of Coastal British Columbia. Carbon offset calculations utilized CBM-CFS3 outputs of annual total ecosystem carbon stocks.

Calculation of carbon offsets in this study followed the BC FCOP quantification methodology and requirements (British Columbia Ministry of Environment 2011). Both SELES-STSM and CBM-CFS3 have been pre-approved and recommended under the BC FCOP to be used as a landscape dynamic model and ecosystem carbon projection model (British Columbia Ministry of Environment 2011). Harvested wood products (HWP) in-use and in-landfill were not accounted for in CBM-CFS3 and must be accounted for separately (see Appendix B). As permitted by BC FCOP for improved forest management projects (British Columbia Ministry of Environment 2011), carbon pools not considered include: production inputs; transportation; fossil fuel combustion; biomass combustion; and harvested wood transport, processing, combustion, and residual disposal. Leakage is an estimate of the degree to which emissions outside the project boundary increase in order to compensate for the project. The calculations under this methodology for calculating eligible carbon offsets include leakage, and a permanence buffer intended to capture the risk of natural or human-induced events reversing the emission reductions in the first 100 years.

Eligible carbon offsets for a project were calculated as the net emission reductions, calculated as the annual change in total ecosystem carbon, HWP in-use, and HWP in-landfill, relative to the baseline of what would have otherwise occurred, less leakage and a permanence buffer (British Columbia Ministry of Environment 2011). I used a conservative leakage estimate of 46% to be consistent with the detailed leakage analysis conducted and approved under BC FCOP for The Great Bear (North and Central-Mid Coast) Forest Carbon Project (Carbon Credit Corporation 2011). As recommended by BC FCOP, I used the Voluntary Carbon Standard Association (2012) non-permanence risk tool to calculate a permanence buffer of 10% for the carbon projects in this study (see Appendix C).

2.3 Decision Analysis Framework

I used a decision analysis to evaluate and rank management options based on revenues and costs from carbon offset projects and timber harvest activities in the study area. All monetary values are expressed in Canadian dollars and were adjusted for inflation as recommended by the Treasury Board of Canada Secretariat (2007) using the Consumer Price Index (Bank of Canada 2013a) to the reference year of this study (2008). United States prices were adjusted using the 2008 average exchange rate supplied by the Bank of Canada (2013b). A base discount rate of 4% was used to calculate net present values (NPVs) to be consistent with other studies examining long-term resource planning and forestry from both private and public perspectives (Gregory 1987, Heaps and Pratt 1989, van Kooten and Bulte 1999, Mathey and Nelson 2010).

The decision analysis was an excel-based model that incorporated the eight components of decision analysis from Peterman and Peters (1998):

1. Management objective.— The management objective was to select the management option that "maximizes the expected net present value (ENPV)" from carbon offset projects and timber harvest activities on the land-base.

2. Management options.— I considered four alternative management options: (M1) Pre-EBM, (M2) EBM "Risk-managed" Old Growth Targets, (M3) EBM "Low Risk" Old Growth Targets, and (M4) No Harvest. Pre-EBM (M1) is the baseline for forest carbon stocks and thus ineligible for carbon offsets. The EBM "Risk-managed" (M2) Old Growth Target option implements the default representation targets for old growth RONV by site series surrogate within each landscape unit as outlined in Schedule 4 of the CNC Order (2009) which range from 30% to 70%. The EBM "Low Risk" Old Growth Target option (M3) applies 70% of RONV for all site series surrogates in all landscape units. No Harvest (M4) represents complete conservation of the land-base with no harvesting of timber. The management reality, however, is that neither M1 nor M4 are available as policy choices in the future: both are precluded by the Great Bear Agreements and subsequent legislation including the CNC Order (2009) and SCC Order (2009). Nonetheless, these management options do serve a useful role in defining context for the two EBM options (M2 and M3) and for understanding the various decision trade-offs. I therefore present my results illustrating scenarios both when only the EBM options are available, as the current management focus includes the relative merits of these two options, and when all options are considered.

3.0 Uncertain states of nature.— Prices are a key influence in economic modelling of forest policy (Bernier et al. 2012); however, predicting future timber and carbon prices is highly speculative and sensitive to assumptions as they cannot be truly known. Thus, a range of possible scenarios for both log prices and carbon offset prices were considered. As the scenarios are 100-year forecasts based on historic variability and estimates, linear trends were used to approximate the trajectories.

3.1 Timber harvest costs and log price scenarios.— Historically the net economic potential of timber harvest has varied considerably based on the price for logs and associated timber harvest costs. These prices and costs fluctuate largely depending on log market conditions, species, grade, and access for harvest.

I employed an average timber harvest cost of \$85.11/m^3. This was calculated as the difference between total timber harvest costs of \$94.19/m^3 specified for the Central Coast Land and Resource Management Plan area (Farenholtz and Rowan 2007), which is consistent with previous estimates (Pierce Lefebvre Consulting 2003, Price Waterhouse Coopers 2006), less the average stumpage of \$9.08/m^3 as paid by major licensees in British Columbia between 1998 and 2007 (Forsite Consultants Ltd. 2009). There are increased timber harvest costs associated with both management options implementing EBM. These incremental costs were accounted for by applying an additional average cost of \$3.51 /m^3, as estimated in an economic operability analysis for the Central Coast (Farenholtz and Rowan 2007). This estimate only accounts for incremental variable costs but is consistent with other estimates including the current EBM specified operation adjustment used in stumpage appraisal that considers some additional costs (\$2.75 /m^3, British Columbia Ministry of Forests, Lands and Natural Resource Operations 2014b) and previous estimates from British Columbia Timber Sales (\$3 /m^3 to \$9 /m^3, Farenholtz and Rowan 2007).

As SELES-STSM outputs did not provide grade profiles of harvested timber and timber prices are specified by grade, I calculated historical average monthly old growth and second growth timber prices for 1998 to 2013, weighted by species- and grade-volume profiles for the study area (see Appendix D). British Columbia coastal price and harvested volume data were obtained from the Coastal Log Market Reports and the Harvest Billing System (British Columbia Ministry of Forests, Lands and Natural Resource Operations 1998-2013, British Columbia Ministry of Forests, Lands and Natural Resource Operations 2013b). Although only 10% to 20% of coastal harvest is reported in the Coastal Log Market Reports, it is generally believed the prices accurately reflect the overall British Columbia coast price level (Simons 1993, Knowler and Dust 2008, Forsite Consultants Ltd. 2009). As price and volume data are not yet available for second growth logs, I used conversion parameters for old growth prices developed by the Coastal Appraisal Advisory Committee which are widely used (British Columbia Ministry of Forests 2004, Forsite Consultants Ltd. 2009, see Appendix E).

Possible log price scenarios all used a common initial price for year 0 of the average annual old growth timber price for the past 10 years (2003 to 2013, \$90.02/m^3). The upper and lower bound forecast were approximated by using linear scenarios that set the log price at 100 years to the maximum and minimum monthly average timber prices (\$167.64/m^3 and \$48.54/m^3, respectively). Figure 2c illustrates all 10 log price scenarios (LP1-LP10) spread evenly across the lower and upper bound estimates.

3.2 Carbon Offset Project Costs and Price Scenarios.— The net economic potential of forest carbon offset projects is highly variable as project costs and achievable prices vary considerably (Foley et al. 2009), particularly as the carbon market continues to develop. There are a range of costs associated with carbon offset project development including those to generate and validate a project design document, verify implementation, document, monitor, issue offsets and track offsets by a registry.

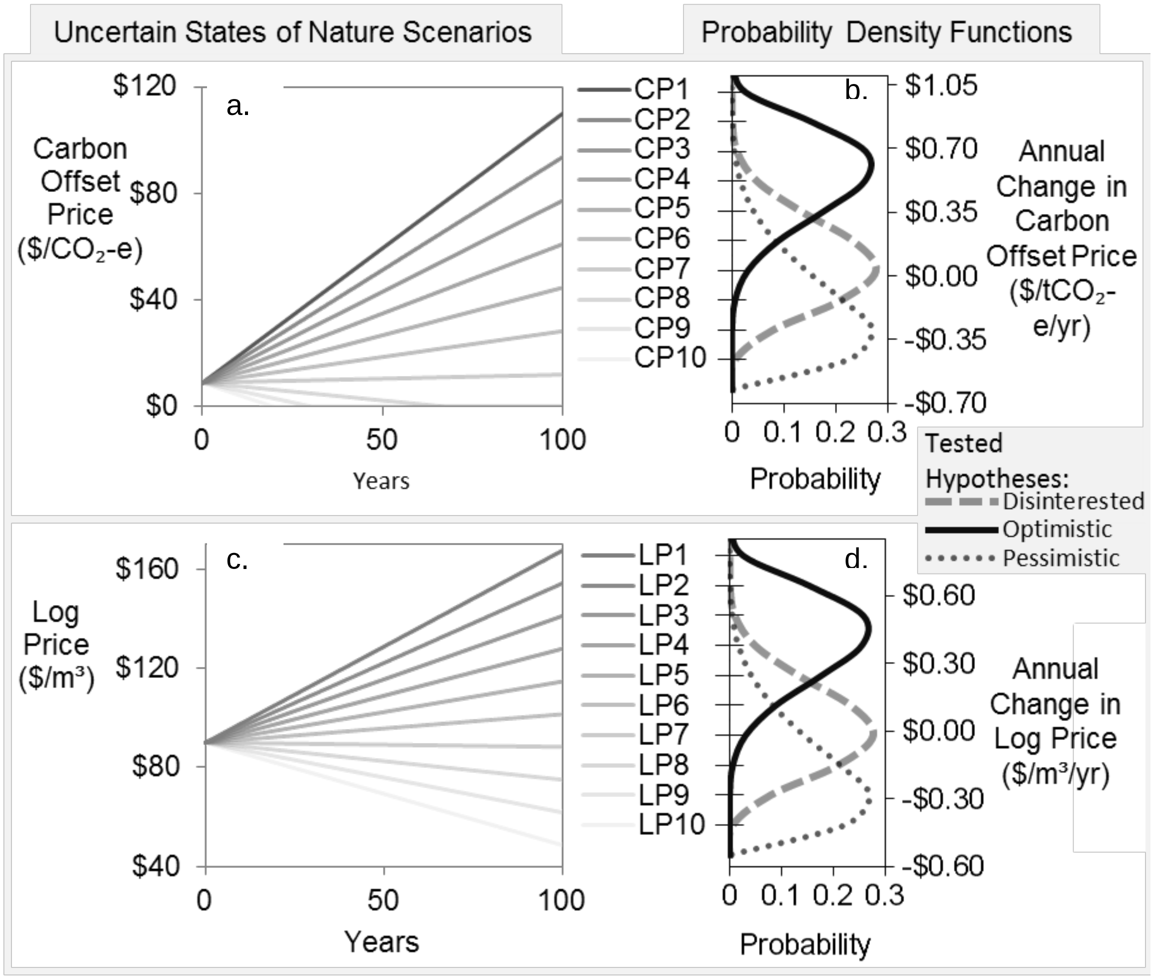

Figure 2. Uncertain states of nature price scenarios and probability density functions.

"a" indicates all 10 price scenarios for carbon offsets ($/tCO$_2$-e, CP1-CP10) over 100 years. The associated degree of belief in each carbon offset price scenario is shown graphically as a probability density function in "b" where the three different hypotheses tested are shown. These hypotheses represent general beliefs in possible price trends by placing a higher probability on the associated price scenarios. The three hypotheses are "pessimistic" emphasising prices decreasing, "disinterested" emphasising fairly consistent prices, and "optimistic" emphasising prices increasing. In "c" all 10 scenarios for log prices ($/m^3, LP1-LP10) are shown over 100 years. The degree of belief in each log price scenario is captured in "d" by three hypothesized probability density functions that use the general beliefs mentioned previously of being "pessimistic", "disinterested", or "optimistic" about price trends.

The price of a carbon offset is a function of the market in which it is sold, the standards it meets, and its inherent attractiveness (Deo et al. 2012, Peters-Stanley and Yin 2013). The PCT purchased BC FCOP improved forest management project carbon offsets for \$7.00/tCO$_2$-e to \$12.00/tCO$_2$-e and sells them for \$25.00/tCO$_2$-e (Pacific Carbon Trust 2013). A market survey report of the voluntary carbon markets found that improved forest management project offset prices for 2012 range from \$7.00/tCO$_2$-e to \$46.00/tCO$_2$-e (Peters-Stanley and Yin 2013).

Estimates for the value of carbon sequestration vary considerably in the literature. A meta-analysis of 232 published estimates of the social cost of carbon found a mean of \$39.82/tCO$_2$-e and modal estimate of \$4.90/tCO$_2$-e (Tol 2009). The Stern Review on the Economics of Climate Change (Stern 2006) estimates the social cost of carbon to be \$109.10/tCO$_2$-e. Revised model runs of the Stern Review by Nordhaus (2007) show the optimal carbon price in 2015 to be \$10.85/tCO$_2$-e rising to \$63.86/tCO$_2$-e in 2100. Other estimates of carbon price based on alternative technology, retrofitting, and recapturing range from \$1.85/tCO$_2$-e to \$24.09/tCO$_2$-e (Bergman et al. 1997).

The carbon offset price scenarios used a common initial price of \$9.00/tCO$_2$-e, equal to the price for which PCT purchased The Great Bear (North and Central-Mid Coast) Forest Carbon Project offsets in 2012. The range in carbon value estimates across scenarios was captured by setting the upper bound scenario to a 100 year maximum carbon offset price of \$110.00/tCO$_2$-e and the lower bound scenario to drop and remain at a price of \$0.00/tCO$_2$-e after the first 20 years. The remaining 8 scenarios (CP1-CP10) were spread equally between the upper and lower bound scenarios (Figure 2a).

4. Probabilities on uncertain states of nature.— Similar to the approach used by Crome et al. (1996), I assessed three hypothesised probability density functions using beta distributions for both uncertain states of nature to compare the influence on results of the possible general groups of belief in future carbon and timber markets. These three hypothesised probability density functions include: “optimistic” where prices increase, “disinterested” where prices remain fairly consistent central in the range considered, and “pessimistic” where prices decrease. The probability density functions for log price scenarios (*s*) and carbon offset price scenarios (*q*) are graphically represented in Figure 2d and Figure 2b, respectively.

5. Model outcomes.— The management options were each associated with a set of 100 outcomes expressed in terms of NPV based on model outputs and all possible combinations of the 10 log price scenarios (LP2-LP10) and 10 carbon offset price scenarios (CP1-CP10). These outcome NPVs represent total revenue and costs associated with carbon offsets and timber harvest activities (Formula 1).

$$NPV^{msq} = NPV_{Logging}^{ms} + NPV_{Carbon}^{mq} \qquad (1)$$

where:

$NPV^{msq} =$ net present value of outcome ($)

$NPV_{Logging}^{ms} =$ net present value of outcome from timber harvest activities ($)

$NPV_{Carbon}^{mq} =$ net present value of outcome from carbon offset project ($)

$m =$ management option “Pre-EBM”, “EBM Risk-managed Old Growth Targets”, “EBM Low Risk Old Growth Targets”, or “No Harvest”

$s =$ log price scenario (LP)

$q =$ carbon offset price scenario (CP)

The contribution of timber harvest activities to outcome NPV was calculated using SELES-STSM outputs of annual volume harvested, log price scenarios (LP1-LP10), and costs of bringing timber to market (Formula 2).

$$NPV_{Logging}^{ms} = \sum_{t=1}^{T=100} \frac{(LP_t^s - LC - LC_{EBM}) \cdot X_t^m}{(1+i)^t} \qquad (2)$$

where:

$LP_t^s =$ log price ($/m^3)

$LC =$ average cost to bring timber to market excluding stumpage ($/m^3)

$LC_{EBM} =$ average incremental cost to harvest under EBM in M2 and M3 ($/m^3)

$X_t^m =$ volume of timber harvested in a year (m^3)

$T =$ time period being evaluated (100 years)

$t =$ time (years)

$i =$ discount rate (%)

Outcome NPV derived from carbon offsets was calculated as the difference between revenue generated from saleable carbon offsets using carbon offsets price scenarios (CP1-CP10), and the costs of bringing offsets to market (Appendix F) (Formula 3).

$$NPV_{Carbon}^{ms} = \sum_{t=1}^{T=100} \frac{\left[CP_t^q \cdot O_t^m - C^f \cdot O_t^m - C_t^g - C_t^h\right] \cdot (1-b)}{(1+i)^t} \tag{3}$$

where:

CP_t^q = carbon offset price (\$/tCO$_2$-e)

O_t^m = saleable carbon offsets generated in a year (tCO$_2$-e)

C^f = carbon offset insurance, issuance and registry costs (\$/tCO$_2$-e)

C_t^g = carbon offset project generation costs including project design document generation and validation (every 25 years beginning in year 1), and project report generation and verification (every 5 years beginning in year 1) (\$)

C_t^h = carbon monitoring plot network establishment (year 1) and annual monitoring (\$)

b = sales and marketing costs (% of sales)

It was assumed that if carbon offset prices become low enough to result in a loss for a given year (NPV_{Carbon}^{ms} <0 at time *t*), then no carbon offsets were sold for that year (NPV_{Carbon}^{ms}=0 at time *t*) where monitoring costs continue for the contracted 100 years after last sale of carbon offsets. Similarly, when log prices result in larger costs than benefits for a given year ($NPV_{Logging}^{ms}$<0 at time *t*), then it is assumed that the timber was still harvested off the landscape but with no benefit or costs being incurred in that year ($NPV_{Logging}^{ms}$=0 at time *t*).

The overall ENPV of a management option is a NPV that incorporates a range of possible scenarios and the degree of belief in their occurrence. ENPV was calculated as the sum of outcome NPVs for each associated carbon offset price scenario (CP1-CP10) and log price scenario (LP1-LP10) weighted by their joint probability (Formula 4).

$$ENPV^{m} = \sum_{s=1,p=1}^{s=10,p=10} NPV^{msq} \cdot p^{s} \cdot p^{q} \quad (4)$$

where:

$p^{s} =$ probability of log price scenario

$p^{q} =$ probability of carbon offset price scenario

$ENPV^{m} =$ expected net present value

6. Decision tree.— The decision tree illustrates the structure of the decision analysis, shown in Figure 3.

7. Ranking of management actions.— The four alternative management options are ranked based upon the management objective.

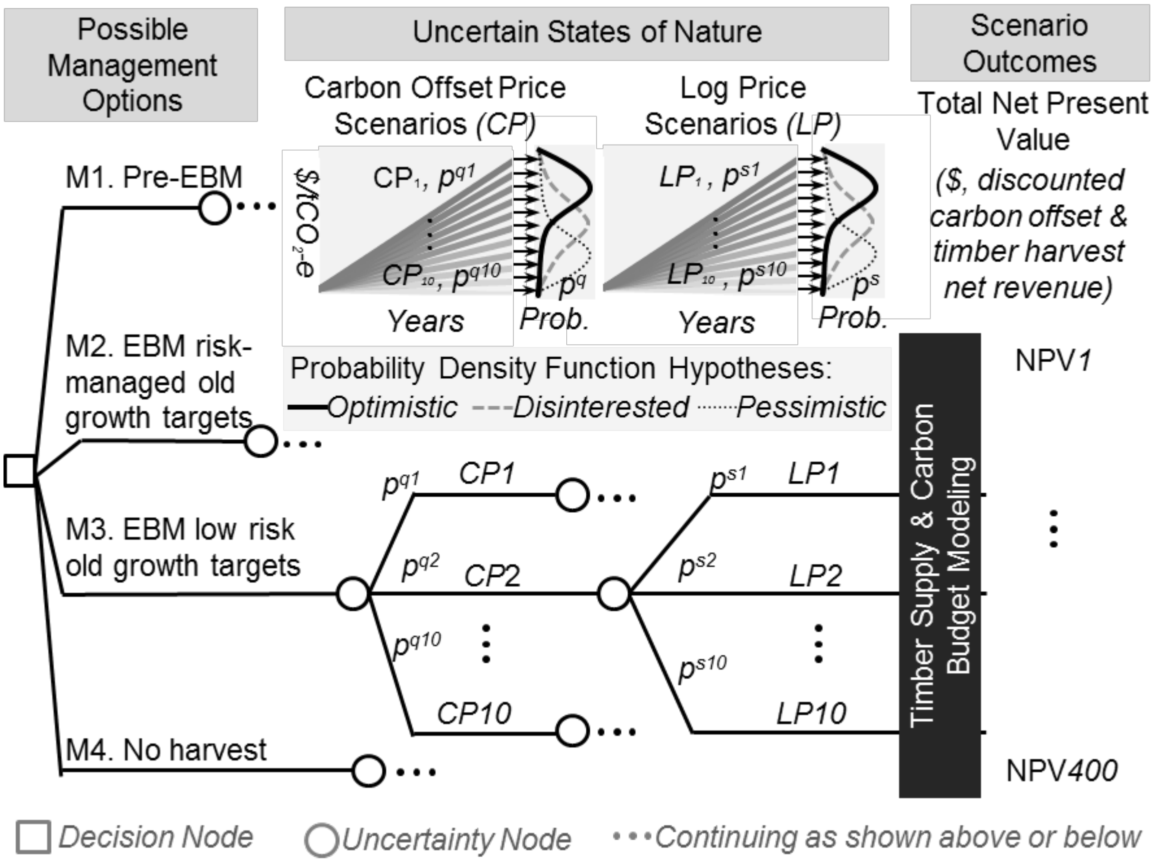

Figure 3. **The structure of the decision tree.**

The decision tree lays out the structure of the decision analysis. Emanating from the square "decision node" on the left are the four possible management options considered: Pre-EBM (M1), EBM "Risk-managed" Old Growth Targets (M2), EBM "Low Risk" Old Growth Targets (M3), and No Harvest (M4). The following circular nodes are "uncertainty nodes" for each of the two uncertain states of nature considered in this decision analysis: carbon offset price and log price. The first "uncertainty node" for each of the management options is for carbon offset price where each of the 10 price scenarios considered (CP1-CP10) create a branch with an associated probability (p^{q1}-p^{q10}). For these possible carbon offset price scenarios under each management option, there follows the second "uncertainty node" for the uncertain state of nature of log price. There are 10 log price scenarios (LP1-LP10) that branch from this node with associated probabilities of occurring (p^{s1}-p^{s10}). The price scenarios for both uncertain states of nature and their associated probability density function hypotheses are shown in more detail and further described in Figure 2. The Net Present Value (NPV) for all 100 combinations of price scenarios under each of the 4 management options (NPV_1-NPV_{400}) use projections from timber supply and carbon budget modelling and discount the annual net returns to present from across the 100 year planning horizon.

8. Sensitivity analyses.— The sensitivity of management option rank order were tested for a range of assumptions, including (1) planning horizon, (2) discount rate, (3) leakage, (4) carbon offset project costs, (5) timber harvest costs, (6) increased cost or value associated with timber harvested under EBM, and (7) management objective.

Planning Horizon

As a model domain parameter, planning horizon is often ignored during uncertainty analysis, but potentially has considerable impact (Morgan and Henrion 1990). I considered a 100 year horizon in the base case but examined the sensitivity of conclusions to a planning horizon of 25 years to reflect the period of time a project design document is validated, and 250 years in order to capture the minimum age of a forest for old growth classification under the 2009 CNC and SCC Orders. As required by the Greenhouse Gas Reduction Targets Act Emissions Offsets Regulation (3(2)r, B.C. Reg. 393/2008), offsets developed under the BC FCOP must ensure that “the atmospheric effect of a greenhouse gas reduction achieved by the project will endure for a period of at least 100 years”. After this 100 year period it may be possible to resell the offset for another 100 year period. I also evaluated the impact of this resale potential after 100 years on conclusions; it is a management uncertainty that only impacts the 250 year planning horizon case.

Discount Rate

Although discount rate is widely accepted as one of the most contentious and controversial aspects of cost-benefit analysis (Treasury Board of Canada Secretariat 2007), it should not be treated as an uncertain state of nature because it is a value parameter and not an empirical quantity (Morgan and Henrion 1990). Discount rate selection is especially critical in forest planning as it is the most crucial economic parameter in evaluation of public forest management options (Price 1988). This is largely due to the long time periods involved (Hawkins et al. 2006), which is extensively discussed in the literature (Luckert 2005). I considered a range of discount rates from a low of 0% (Price 1991) to a high rate of 12% traditionally used by The World Bank (Operational Core Services Network Learning and Leadership Center 1998).

Leakage

The appropriate value for leakage varies widely by standard and study. For instance, the verified carbon standard requires leakage on the order of 10% to 25% as compared to that required in BC FCOP of 40% to 60%. A study by Murray et al. (2004) estimates leakage from forest preservation to be in the range of 8% to 16% whereas Wear and Murray (2004) has estimates on the order of 84%. I tested leakage values from 0% up to 90% to capture this range.

Carbon Offset Project Costs

As there have been only a few forest carbon offset projects to date under the BC FCOP, the associated costs are not yet well established, especially with respect to how costs vary with project size, location, and the expectations for changes in the future as consultants gain experience with these projects. In my analyses I considered the high and low estimates of carbon project costs obtained from discussions with experts (see Appendix F) as well as a larger range to capture the extreme cases representing no cost up to extremely high costs (5 times larger than the current average cost estimates).

Timber Harvest Costs

I examined the influence of varying assumptions regarding highly variable timber harvest costs. This adjustment to costs is expressed as a proportion of the average timber harvest cost used in the baseline scenarios. I tested an increase of +40% to a decrease of -40% in order to capture historical estimates for 1992 to 2005 (Pierce Lefebvre Consulting 2003, Price Waterhouse Coopers 2006). Future timber harvest costs are likely to increase as conventional logging continues to include more expensive helicopter logging in order to access limited supplies of high value timber.

Increased Cost and Value of Timber Harvested Timber under EBM

A range of incremental timber harvest costs and price premiums associated with operating under EBM examined include a range from no additional costs ($0.00/m^3) to the highest incremental cost forecast of 25.07/m^3 from Farenholtz and Rowan (2007) that increased costs by +29.5%. This range helps capture the variability and uncertainty associated with EBM incremental costs. The opportunity to remove EBM incremental costs ($0.00/m^3) and create a price premium up to +$2.00/m^3 that increases EBM timber value to an equivalent -2.3% reduction in harvests costs was also included.

Management Objective

Although "maximizing ENPV" was the main management objective I considered, I also examined an alternative objective: "minimizing regret". This approach, also referred to as "minimax regret" and "minimization of maximal regret", is widely accepted in decision theory and has been used in the literature to compare alternatives without known probability density functions (Yager 2004, Loulou and Kanudia 1999). This represents a highly risk averse preference for outcomes: the intent of a "minimal regret" objective is to minimize the worst possible outcome by ranking the worst outcomes from each alternative management option and identifying the option which provides the "least bad" outcome. This provides a useful complement to the main results that use the objective of "maximizing ENPV" and typically produces different results (Polasky et al. 2011).

9. Value of Information (VOI).— VOI is one of the most useful applications of decision analysis (Bratvold et al. 2009) as it aids decision makers with the allocation of resources by evaluating the benefits of gathering additional information to reduce uncertainty (Howard 1966). Two types of VOI are calculated with decision analysis results: the expected value of including uncertainty (EVIU), and the expected value of perfect information (EVPI). EVIU measures the expected cost of ignoring uncertainty in one or more variables and is calculated as the difference between ENPV results from the decision analysis which explicitly model uncertainty and those from a deterministic analysis which only uses fixed nominal values (Dakins 1999). Although uncertainty can never be completely eliminated, EVPI is an ultimate bound of the maximum possible reduction in costs if uncertainty is removed (Dakins 1999).

2.4 Interpretation of Decision Analysis Results

I will first describe the basic results from the simulations of carbon and timber that feed into the decision analysis. These results provide the baseline conditions and assumptions that the decision analysis builds upon. I estimated NPV across all carbon offset price scenarios (CP1-CP10) and log price scenarios (LP1-LP10), and weighted by hypothesized probability density functions (“pessimistic”, “disinterested”, “optimistic”) to calculate ENPV for each of the four management options (M1-M4). The “disinterested” probability density function hypothesis represents the most moderate belief regarding trends prices. Thus, the “disinterested” probability density function hypotheses for carbon offset price scenarios and log price scenarios were used for the sensitivity analyses that examine how the optimal management options in the decision tables change with discount rate, planning horizon, leakage, carbon project and timber harvest costs, and EBM harvested timber value.

The results of the decision analysis take the form of a series of tables which rank the management options based on NPV or ENPV. The objective is not to produce a single ranking and optimal management option, but rather to demonstrate how management options perform against each other as measured by NPV and ENPV (or “minimizing regret”) over a range of possible future prices. Thus, in order to inform decision-making, the important aspect of the NPV and ENPV results is not their absolute values but their relative values to the other management options. Additionally, these results should not be used to identify a single optimal solution but as a basis for informing a broader discussion of strategy and tactics. For this reason, results are presented in tables that show which management options are optimal over a range of conditions and not only single estimates. The most important component of these tables is the conditions under which the optimal management option changes from one to another, as this indicates how robust an optimal management option is to changes in parameters.

3. Results

3.1 Annual Timber Harvest

Because the Great Bear Agreements which enabled EBM also allocated a significant portion of the landbase to conservancies and other protected areas, the THLB is largest under the Pre-EBM option (M1), encompassing 219,232 ha. Under both EBM options (M2, M3) 69.2% (151,690 ha) of this remains in the THLB, with none (0 ha) remaining in the THLB under the No Harvest option (M4). Although both EBM management options share the same THLB, targets for old growth retention are met as spatial constraints across the landscape, including areas within the THLB. Consequently, the EBM option with “Risk-managed” Old Growth Targets (M2) realizes higher annual timber harvest than the “Low Risk” Targets option (M3) due to the lower targets for old growth retention in M2 (variable from 30% to 70% versus 70% of RONV in all site series surrogate / landscape unit combinations).

Annual harvested timber volume (m^3/yr) simulated by SELES-STSM for each forest management option (M1-M4) ranges from the highest rate after 250 years into the simulation of 1,316,300 m^3/yr with the Pre-EBM scenario (M1), to the lowest rate throughout the No Harvest option (M4) of 0 m^3/yr (Figure 4). The EBM options fall between these bounds with annual harvest rates at 250 years that are 62.6% (823,400 m^3/yr) and 56.5% (743,400 m^3/yr) of the highest rate, for “Risk-managed” (M2) and “Low Risk” (M3) Old Growth Targets options, respectively. Annual harvested timber volume is fairly consistent throughout the simulated 250 year period in each management option, fluctuating by 10.6% (M1), 13.8% (M2), 25.2% (M3), and 0% (M4), respectively. These fluctuations are driven by the constraints applied in the timber supply modelling as alternative management options alter harvest rates, and the heterogeneity of available timber across the landscape through time.

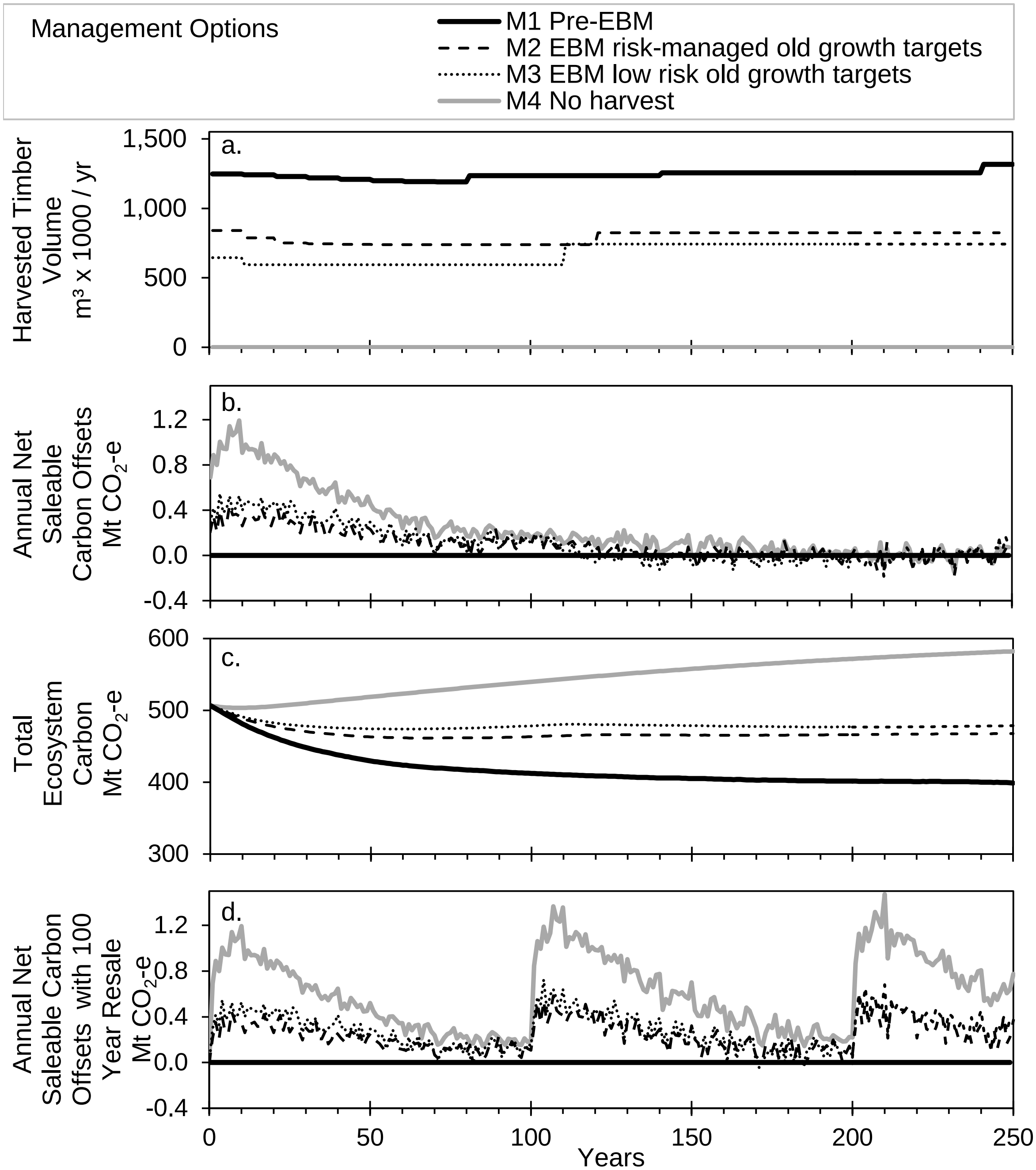

Figure 4. **Harvested timber, annual saleable carbon offsets, and total ecosystem carbon for each management option.**

Base results that feed into the decision analysis are shown graphically for the study area over the 250 years modeled for all four management options (M1 Pre-EBM, M2 EBM “Risk-managed” Old Growth Targets, M3 EBM “Low Risk” Old Growth Targets, and M4 No Harvest). “a” shows annual harvested timber volume (m^3/yr) from SELES-STSM results, and total ecosystem carbon from CBM-CFS3 results is shown in “c” expressed in carbon dioxide equivalents (CO_2-e). The calculated annual net saleable carbon offsets (Mt CO_2-e) under the BC FCOP without resale of offsets after 100 years of previous sale are shown in “b” and including resale potential are shown in “d”.

3.2 Total Ecosystem Carbon

Total ecosystem carbon, expressed in carbon dioxide equivalents (Mt CO_2-e), for the landscape under each management option (M1-M4), begins at a common initial year-0 starting condition (506.6 Mt CO_2-e). After this, the alternative management options have significant effects on changing total ecosystem carbon over time (Figure 4). The No Harvest option (M4) represents an upper bound of total ecosystem carbon, which, in this scenario, increases over the first 100 years by +6.5% (+32.9 Mt CO_2-e) and has increased after the total 250 years by +14.9% (+75.5 Mt CO_2-e). The Pre-EBM option (M1) represents the lower bound of total ecosystem carbon exhibiting the largest decreases in total ecosystem carbon where there is a total reduction after 100 years of -18.6% (-94.4 Mt CO_2-e) and after 250 years of -21.2% (-107.6 Mt CO_2-e). The "Risk-managed" (M2) and "Low Risk" (M3) EBM options maintain total ecosystem carbon levels between the extremes, with reductions over the first 100 years of -8.6% (-43.4 Mt CO_2-e) and -5.6% (-28.3 Mt CO_2), respectively, that rebound slightly by year 250 to total reductions of -7.7% (-39.2 Mt CO_2-e) and -5.5% (-27.9 Mt CO_2-e) relative to the initial conditions. Relative to the management option with highest total ecosystem carbon (M4), other options reduce total ecosystem carbon at 100 years by -11.3% (M3), -14.1% (M2), and -23.6% (M1), and after 250 years by -17.8% (M3), -19.7% (M2), and -31.5% (M1). These reductions conversely represent an increase in total ecosystem carbon from the Pre-EBM business as usual option (M1) at 100 years of +12.4% (M2), +16.1% (M3), and +30.9% (M4), and after 250 years of +17.2% (M2), +20.0% (M3), and +45.9% (M4).

3.3 Net Saleable Carbon Offsets

The annual net saleable carbon offsets (Mt CO_2-e/yr) calculated following the BC FCOP for all three management options that generate offsets (M2, M3, and M4) vary considerably over the 250 year simulation (Figure 4). The maximum number of annual net saleable carbon offsets is generated during the first decade of the 250 year simulation when ignoring the resale potential of offsets. Saleable offsets peak under EBM "Risk-managed" Old Growth Targets (M2) at year 7 (0.442 Mt CO_2-e/yr). Under

EBM “Low Risk” Old Growth Targets (M3) they peak at year 4 (0.547 Mt CO_2-e/yr), and under the No Harvest option (M4) at year 10 (1.194 Mt CO_2-e/yr).

Summed over the first 25 years, the management option that supports the highest total ecosystem carbon, No Harvest (M4), generates the largest number of average annual net saleable carbon offsets (0.886 Mt CO_2-e/yr). EBM options with “Low Risk” (M3) and “Risk-managed” (M2) Old Growth Targets produce 48.0% (0.425 Mt CO_2-e/yr) and 35.9% (0.318 Mt CO_2-e/yr), respectively, of the No Harvest (M4) average annual net saleable carbon offsets,. As offsets are largely generated early in the simulations, when a 100 year time frame is considered, average annual net saleable carbon offsets decrease considerably for management options (M2, M3, M4) relative to their 30 year averages (-35.6%, -38.0%, -42.9%). These average offsets produced are reduced even further relative to the 30 year time frame when all 250 years are considered (-71.3%, -75.8%, -72.9%). However, this changes dramatically if there is the potential to resell carbon offsets every 100 years (-24.6%, -32.2%, -30.1%; assuming a 250 planning horizon). Overall, EBM options with “Risk-managed” (M2) and “Low Risk” (M3) Old Growth Targets produce 40.5% and 52.1%, respectively, of the 100 year cumulative net saleable carbon offsets generated when no timber is harvested (M4, 50.553 Mt CO_2-e).

3.4 Age Class Distribution

The management option selected changes the age-structure of the forest land-base over time (Figure 5). Areas in the age class distributions in Figure 5 only include the portion of the Midcoast TSA and Pacific TSA block 25 in the THLB under the Pre-EBM option (M1) because the management regimes tested only alter carbon dynamics in these areas. The age class distribution of the forested landscape has a common initial profile at year 0 for all management options (M1-M4) where 69.5% of the area has aged over 200 years and 22.1% less than 40 years. After 100 years into the management option simulations, the effects of management regime on age class distribution become evident. The Pre-EBM option (M1) has the highest timber harvest rates and thus has the youngest forest profile after 100 years into the simulation, with only 13.3% of forested area aged above 200 years and 36.3% below 40 years. In contrast, the option with no disturbances from timber harvest (M4) results in the most mature forested landscape, where after 100 years 69.8% is aged over 200 years and only 2.0% below 40 years. The moderate levels of timber harvest under both EBM options of “Risk-managed” and “Low Risk” Old Growth Targets (M2, M3) after 100 years reduces the forested area aged over 200 years (to 35.8%, 43.5%), and maintains a similar portion below 40 years (22.0%, 18.0%).

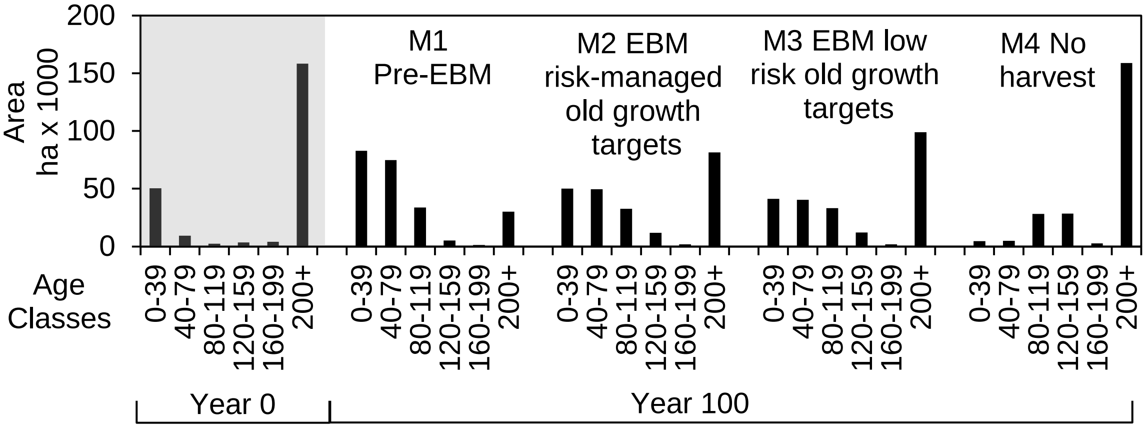

Figure 5. Age class distributions.

The initial age class distribution for the study area is shown for year 0 where all management options share this common profile. After 100 years into the simulation, the age class distributions are shown for each management option (M1 Pre-EBM, M2 EBM “Risk-managed” Old Growth Targets, M3 EBM “Low Risk” Old Growth Targets, and M4 No Harvest). The age class distributions only include the portions of the Mid Coast TSA and Pacific TSA block 25 that are within the Timber Harvesting Land Base (THLB) in the M1 option, where the THLB is forest that is deemed both acceptable and economically feasible to harvest timber.

3.5 Decision Analysis Tables

One way to define the optimal management option is to identify the option with the highest total discounted NPV from combined net saleable carbon offsets and timber harvest (Formula 1-Formula 4). The expected values for discounted NPV are shown in Table 1 for all 100 combinations of ten log price scenarios (LP1-LP10) and ten carbon offset price scenarios (CP1-CP10). These 100 price scenario combinations can be referred to as the *price trend space.* In this space, management options that are optimal in “X/100” of the price scenario combinations occupy “X%” of the price trend space. The price trend space over which a management option is optimal is interesting because it defines the range of values over which it is robust to changes in carbon offset price and log price. These regions of robustness can be seen visually in the sub-tables in Table 1.

In the base case analysis, that uses a 100 year planning horizon and considers all four management options (M1-M4), only the extreme management options, Pre-EBM (M1) and No Harvest (M4), emerge as optimal over some range of price trend space. Although in the base case, Pre-EBM (M1) and No Harvest (M4) options occupy almost equal optimal price scenario space (53% and 47% respectively), which option appears as optimal is more sensitive to the range of log price scenarios considered than carbon offset price scenarios. This is demonstrated by optimal management options across carbon offset price scenarios being dependent on log price scenario, as compared to the optimal option remaining the same across most optimistic (LP1-LP3) and pessimistic (LP9-LP10) log price scenarios, regardless of the carbon offset price.

What would the optimal solution be without the extreme options (M1 and M4) as possibilities (Table 1)? This is important because they are not considered feasible options for the GBR where all players have already agreed to EBM implementation via the CNC and SCC Orders (2009). Excluding only Pre-EBM (M1) results in No Harvest (M4) expanding the price scenario space over which it is optimal and the EBM “Risk-managed” Old Growth Targets option (M2) occupying the remaining optimal price scenario space (41%) previously held by the full harvest option of Pre-EBM (M1). If both extreme options (M1 and M4) are excluded and only the two EBM options are compared (M2 and M3), the option with higher old growth targets (M3 “Low Risk”) is optimal over a larger price scenario space (56%) than the “Risk-managed” Targets option (M2): maintaining the opportunities for carbon projects is favoured over a greater range of values than increasing the opportunity for traditional extractive forest products

Table 1. Sensitivity of optimal management option to horizon year.

		Optimal Management Options with Maximum Net Present Value for all Combinations of Price Scenarios using specified Horizon Year																																							
		25 years										100 years										250 years* no resale										250 years* resale									
		Carbon Offset Price Scenarios (CP1-CP10)																																							
	Log Price Scenarios (LP1-LP10)	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
All Options (M1-M4)	1	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	2	4	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	3	4	4	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	4	4	4	4	4	1	1	1	1	1	1	4	4	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1	1	4	4	1	1	1	1	1	1	1	1
	5	4	4	4	4	4	1	1	1	1	1	4	4	4	4	1	1	1	1	1	1	4	4	4	1	1	1	1	1	1	1	4	4	4	4	1	1	1	1	1	1
	6	4	4	4	4	4	4	4	1	1	1	4	4	4	4	4	1	1	1	1	1	4	4	4	4	4	1	1	1	1	1	4	4	4	4	4	1	1	1	1	1
	7	4	4	4	4	4	4	4	4	1	1	4	4	4	4	4	4	4	1	1	1	4	4	4	4	4	4	4	1	1	1	4	4	4	4	4	4	4	1	1	1
	8	4	4	4	4	4	4	4	4	4	1	4	4	4	4	4	4	4	4	4	1	4	4	4	4	4	4	4	4	4	1	4	4	4	4	4	4	4	4	4	1
	9	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	10	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
No M1 Option (M2-M4)	1	4	4	4	4	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	2	4	4	4	4	4	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	3	4	4	4	4	4	4	2	2	2	2	4	4	2	2	2	2	2	2	2	2	4	2	2	2	2	2	2	2	2	2	4	4	2	2	2	2	2	2	2	2
	4	4	4	4	4	4	4	4	2	2	2	4	4	4	4	2	2	2	2	2	2	4	4	4	2	2	2	2	2	2	2	4	4	4	4	2	2	2	2	2	2
	5	4	4	4	4	4	4	4	4	2	2	4	4	4	4	4	4	2	2	2	2	4	4	4	4	4	2	2	2	2	2	4	4	4	4	4	4	2	2	2	2
	6	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	4	4	4	4	4	4	4	2	2	2	4	4	4	4	4	4	4	2	2	2
	7	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	8	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	9	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	10	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
EBM Options (M2 and M3)	1	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	2	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	3	3	3	3	3	2	2	2	2	2	2	3	2	2	2	2	2	2	2	2	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	4	3	3	3	3	3	3	2	2	2	2	3	3	3	2	2	2	2	2	2	2	3	3	3	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2
	5	3	3	3	3	3	3	3	2	2	2	3	3	3	3	3	2	2	2	2	2	3	3	3	3	3	2	2	2	2	2	3	3	3	3	3	2	2	2	2	2
	6	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	2	2	2	3	3	3	3	3	3	3	2	2	2	3	3	3	3	3	3	3	2	2	2
	7	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	8	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	9	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	10	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

The optimal management option under each condition is shown where Pre-EBM (M1) is white “1”, EBM “Risk-managed” Old Growth Targets (M2) is light grey “2”, EBM “Low Risk” Old Growth Targets (M3) is grey “3”, and No Harvest (M4) is dark grey “4”. Optimal management options are determined by ranking the options based on maximizing Net Present Value (NPV). Each sub-table shows the optimal management option for all 100 combinations of carbon offset price scenarios (CP1-CP10) and log price scenarios (LP1-LP10). Along the horizontal axis, the effect of planning horizon is tested on the optimal management option sub-tables by showing the base case of 100 years, a short horizon of 25 years, and a long horizon of 250 years with and without the resale of carbon offsets after 100 years since previous sale. Optimal management option sub-tables on the vertical axis show the effect of limiting the management options that are considered from all management options (M1-M4, “All Options”), only EBM and No Harvest (M2-M4, “No M1 Option”), and only EBM options (M2 and M3, “EBM Options”).

3.6 Effect of Planning Horizon on Optimal Management Option

The length of the planning horizon impacts the optimal management option, particularly in the price trend space that borders a change in optimal management option (Table 1). This impact occurs because economic benefits vary annually throughout the simulation, especially with respect to annual carbon offsets generated (Figure 4). When only the first 25 years are considered, which is the period over which carbon offset project design documents are generally validated, management options with more benefits derived from carbon offsets (M4>M3>M2) are favoured as these benefits are largely produced early in the simulation. Conversely, if we extend the planning horizon to include the full 250 years and exclude the potential resale of carbon offsets, management options are favoured that have a larger portion of timber harvest benefits (M1>M2>M3). This is because the projected timber harvest rates are fairly consistent throughout the simulation (Figure 4; assuming we are accurate in our ability to project long-term timber yields). However, if the potential for resale of carbon offsets every 100 years is included, the benefits derived from carbon projects after 100 years increases drastically (Figure 4) and results in similar optimal management options across price scenarios to the base case that considers a planning horizon of 100 years. The EBM options comparison is an exception to this trend, where including carbon offset resale results in the option with less benefits derived from carbon offsets (M2) to be optimal across a larger price trend space (+2%). This is likely a result of their similarity and timing of discounted benefits.

3.7 Influence of Degree of Belief in Uncertain States of Nature

The 100 possible NPVs calculated for each management option were distilled into ENPV by weighting the NPVs based on the degree of belief in each associated carbon offset price scenario (CP1-CP10) and log price scenario (LP1-LP10). The main general bodies of belief in future price trends are meant to be captured by three hypothesised probability density functions that emphasize scenarios with prices increasing (“optimistic”) over time, relatively constant (“disinterested”), and decreasing (“pessimistic”) (Figure 2b and Figure 2d). Thus there are scenarios where each of timber and carbon experience a range of future trends from good to poor. All 9 combinations of the hypothesised probability density functions for carbon offset price scenarios and log price scenarios (three each) are presented in Table 2, showing the resultant ENPV of each management option. The relative values of ENPV for the ranked management options indicate the strength of the rankings.

When “disinterested” probability density function hypotheses are applied to both carbon offset price scenarios and log price scenarios, the No Harvest option (M4) is optimal (Table 2). Depending on belief in future carbon offset or log price trends, management options with a greater proportion of NPV derived from carbon offsets or timber harvest benefit correspondingly. The rank order of management options is highly variable depending on the general belief in direction of carbon offset and log price trends. Across the probability density functions tested, there is a wide range in ENPVs (21.4%, 18.9%, 21.8%, 34.6% of the maximum ENPV) calculated for each of the management options (M1, M2, M3, M4, respectively) where the minimum optimal management option ENPV (M4; $116,030,089) is 26.6% of the maximum optimal option ENPV (M1; $435,933,948). When considering only the EBM options (M2 and M3), “Low Risk” Old Growth Targets (M3) is optimal for “disinterested” and “pessimistic” log price probability density function hypotheses regardless of which carbon offset price hypothesis is used (“pessimistic”, “disinterested”, or “optimistic”). Also, the minimum optimal management option ENPV (M3; $72,022,559) is 21.8% of the maximum optimal option ENPV (M2; $330,406,920).

Table 2. **Ranked management options for probability density function hypotheses.**

Log Price Scenario Probability Density Function Hypotheses	Rank Order	Carbon Offset Price Scenario Probability Density Function Hypotheses					
		Pessimistic		Disinterested		Optimistic	
		Management Option and Expected Net Present Value with Expected Value of Perfect Information in italics					
Pessimistic	*1.*	M4	$116,030,089	M4	$182,448,833	M4	$335,266,392
			$32,718,110		*$18,547,504*		*$4,025,197*
	2.	M1	$93,461,709	M3	$105,985,858	M3	$185,266,690
	3.	M3	$72,022,559	M1	$93,461,709	M2	$149,432,484
	4.	M2	$62,921,256	M2	$88,745,632	M1	$93,461,709
Disinterested	*1.*	M1	$177,795,024	M4	$182,448,833	M4	$335,266,392
			$25,019,700		*$51,286,707*		*$10,727,707*
	2.	M4	$116,030,089	M1	$177,795,024	M3	$211,596,798
	3.	M3	$98,352,667	M3	$132,315,966	M2	$182,931,792
	4.	M2	$96,420,565	M2	$122,244,940	M1	$177,795,024
Optimistic	*1.*	M1	$435,933,948	M1	$435,933,948	M1	$435,933,948
			$1,511,451		*$3,823,243*		*$25,247,078*
	2.	M2	$246,934,710	M2	$272,759,086	M4	$335,266,392
	3.	M3	$217,162,790	M3	$251,126,088	M2	$333,445,938
	4.	M4	$116,030,089	M4	$182,448,833	M3	$330,406,920

The four management options (M1 Pre-EBM, M2 EBM “Risk-managed” Old Growth Targets, M3 EBM “Low Risk” Old Growth Targets, and M4 No Harvest) are ranked for all 9 combinations of probability density function hypotheses (“pessimistic”, “disinterested”, and “optimistic”) of log price scenario trends and carbon offset price trends, where these hypotheses are further described in Figure 2. Management options are ranked (“rank order”) based on maximizing their Expected Net Present Value (ENPV). The top ranking management option is considered optimal and shown in boldface with shading following that used in Table 1 and the calculated ENPV. The lower ranked management options are listed below in grey with their respective ENPVs. The Expected Value of Perfect Information (EVPI) for each optimal management option is shown in italics.

3.8 Value of Information (VOI)

The EVPI describes the upper bound of ENPV that having perfect information on future prices could achieve above the ENPV of the optimal management option (Table 2). EVPI is largest when both probability density function hypotheses for carbon offset and log price scenarios are “disinterested”, and represents a maximum +28.1% increase above the optimal management option without perfect information ENPV (M4). In the extreme combinations of hypothesised probability density functions, where carbon projects are highly favoured by “optimistic” carbon offset price scenarios and “pessimistic” log price scenarios, or timber harvest is highly favoured by “pessimistic” carbon offset price scenarios and “optimistic“ log price scenarios, the increased benefit in having perfect information is greatly diminished (+1.2%, +3.5%). As one might expect, having perfect information provides the most value in the more uncertain middle ground of future prices where small changes to the value of commodities do not drive clear economic choices. The EVIU is $0.00 for the specific probability density function hypotheses considered in Table 2, meaning that the deterministic decision based on the most likely price scenarios is the same as that of including uncertainty.

3.9 Effect of Discount Rate on Optimal Management Option

Discount rates are used to weigh costs and benefits as they occur through time so that various management regimes can be compared (Moore et al. 2008). This strongly influences the rank order of management options when the management objective is to “maximize ENPV” (Table 3). As carbon offsets are largely produced early in the 100 year planning horizon in contrast to fairly consistent annual timber harvest (Figure 4), increasing discount rates favours management options with larger carbon projects (M4>M3>M2), similar to the effect of shortening the planning horizon. Consequently, when the base discount rate (4%) is reduced slightly (by -0.3% to 3.7%), the optimal management option under “disinterested” probability density function hypotheses shifts from No Harvest (M4) to Pre-EBM (M1). However, No Harvest (M4) remains optimal above a 0.5% discount rate if the Pre-EBM option (M1) is excluded. In this case, the EBM “Risk-managed” Old Growth Targets option (M2) is optimal below that rate. If only the two EBM options (M2 and M3) are considered, “Low Risk” Old Growth Targets (M3) remains optimal above a 0.6% discount rate.

Table 3. Sensitivity of leakage, carbon project and timber harvest costs.

			Leakage %										Carbon Project Costs											Timber Harvest Costs										
													as a % of Average Costs											*as a % of Average Costs*										
		Discount Rate	0	10	20	30	46	50	60	70	80	90	0	50	100	150	200	250	300	350	400	450	500	60	80	90	95	97	100	103	105	110	120	140
All Management Options – M1-M4	Maximize ENPV	0%	4	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	4	4	4	4
		2%	4	4	4	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	4	4	4	4	4
		4%	4	4	4	4	$\boxed{4}$	1	1	1	1	1	4	4	$\boxed{4}$	1	1	1	1	1	1	1	1	1	1	1	1	1	$\boxed{4}$	4	4	4	4	4
		6%	4	4	4	4	4	4	1	1	1	1	4	4	4	4	4	1	1	1	1	1	1	1	1	1	1	1	4	4	4	4	4	4
		8%	4	4	4	4	4	4	1	1	1	1	4	4	4	4	4	4	1	1	1	1	1	1	1	1	1	1	4	4	4	4	4	4
		10%	4	4	4	4	4	4	1	1	1	1	4	4	4	4	4	4	1	1	1	1	1	1	1	1	1	1	4	4	4	4	4	4
		12%	4	4	4	4	4	4	1	1	1	1	4	4	4	4	4	4	1	1	1	1	1	1	1	1	1	1	4	4	4	4	4	4
	Minimal Regret	0%	4	4	4	4	4	4	4	4	1	1	4	4	4	4	4	4	1	1	1	1	1	1	1	1	1	1	4	4	4	4	4	4
		2%	4	4	4	4	4	4	4	4	1	1	4	4	4	4	4	4	4	1	1	1	1	1	1	1	1	1	4	4	4	4	4	4
		4%	4	4	4	4	$\boxed{4}$	4	4	4	1	1	4	4	$\boxed{4}$	4	4	4	4	1	1	1	1	1	1	1	1	1	$\boxed{4}$	4	4	4	4	4
		6%	4	4	4	4	4	4	4	1	1	1	4	4	4	4	4	4	4	1	1	1	1	1	1	1	1	1	4	4	4	4	4	4
		8%	4	4	4	4	4	4	4	1	1	1	4	4	4	4	4	4	4	1	1	1	1	1	1	1	1	1	4	4	4	4	4	4
		10%	4	4	4	4	4	4	4	1	1	1	4	4	4	4	4	4	4	1	1	1	1	1	1	1	1	1	4	4	4	4	4	4
		12%	4	4	4	4	4	4	4	1	1	1	4	4	4	4	4	4	4	1	1	1	1	1	1	1	1	1	4	4	4	4	4	4
No M1 Option – M2-M4	Maximize ENPV	0%	4	4	4	4	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4
		2%	4	4	4	4	4	4	4	2	2	2	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2	2	4	4	4	4	4	4
		4%	4	4	4	4	$\boxed{4}$	4	4	4	2	2	4	4	$\boxed{4}$	4	4	4	4	4	4	4	4	2	2	2	2	4	$\boxed{4}$	4	4	4	4	4
		6%	4	4	4	4	4	4	4	4	2	2	4	4	4	4	4	4	4	4	4	4	4	2	2	2	4	4	4	4	4	4	4	4
		8%	4	4	4	4	4	4	4	4	4	2	4	4	4	4	4	4	4	4	4	4	4	2	2	2	4	4	4	4	4	4	4	4
		10%	4	4	4	4	4	4	4	4	4	2	4	4	4	4	4	4	4	4	4	4	4	2	2	2	4	4	4	4	4	4	4	4
		12%	4	4	4	4	4	4	4	4	4	2	4	4	4	4	4	4	4	4	4	4	4	2	2	2	4	4	4	4	4	4	4	4
	Minimal Regret	0%	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	2	2	2	4	4	4	4	4	4	4	4
		2%	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	4	4	4	4	4	4	4	4
		4%	4	4	4	4	$\boxed{4}$	4	4	4	4	4	4	4	$\boxed{4}$	4	4	4	4	4	4	4	4	2	2	2	4	4	$\boxed{4}$	4	4	4	4	4
		6%	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	4	4	4	4	4	4	4	4
		8%	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	4	4	4	4	4	4	4	4
		10%	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	4	4	4	4	4	4	4	4
		12%	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	4	4	4	4	4	4	4	4
EBM Options – M2 and M3	Maximize ENPV	0%	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3
		2%	3	3	3	3	3	3	3	2	2	2	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	3	3	3	3	3	3
		4%	3	3	3	3	$\boxed{3}$	3	3	3	2	2	3	3	$\boxed{3}$	3	3	3	3	3	3	3	3	2	2	2	2	3	$\boxed{3}$	3	3	3	3	3
		6%	3	3	3	3	3	3	3	3	2	2	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	3	3	3	3	3	3	3
		8%	3	3	3	3	3	3	3	3	2	2	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	3	3	3	3	3	3	3
		10%	3	3	3	3	3	3	3	3	2	2	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	3	3	3	3	3	3	3
		12%	3	3	3	3	3	3	3	3	2	2	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	3	3	3	3	3	3	3
	Minimal Regret	0%	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	3	3	3	3	3	3	3	3
		2%	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	3	3	3	3	3	3	3	3
		4%	3	3	3	3	$\boxed{3}$	3	3	3	3	3	3	3	$\boxed{3}$	3	3	3	3	3	3	3	3	2	2	2	3	3	$\boxed{3}$	3	3	3	3	3
		6%	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	3	3	3	3	3	3	3
		8%	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	3	3	3	3	3	3	3
		10%	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	3	3	3	3	3	3	3
		12%	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	3	3	3	3	3	3	3

Optimal management options are shown following the shading used in Table 1. Management options are ranked based on management objectives as specified of either “minimizing regret” (“minimal regret”), or “maximizing Expected Net Present Value (ENPV)” (“maximize ENPV) where “disinterested” probability density functions are used. Sensitivity of the optimal management option is shown in sub-tables horizontally for different values for leakage, carbon project costs, and timber harvest costs, against a range of discount rates. For each range of parameters tested, the base case results are shown in bold within a box. Similar to Table 1, also tested vertically in sub-tables is limiting the management options considered.

3.10 Effect of Leakage on Optimal Management Option

Net saleable carbon offsets generated under a management option are increased when leakage is reduced. Thus reducing leakage favours options with larger carbon projects (M4>M3>M2) (Table 3). Conversely, a small increase (>+1.4%) in the base leakage value (46%) causes the option that generates no carbon offsets (M1 Pre-EBM) to become optimal. No Harvest (M4) remains optimal at low discount rates (0%) only when very low leakage values are used (<11.9%) whereas high discount rates (12%) allow for larger leakage values (<56.7%). Similar to trends in Table 1, excluding Pre-EBM (M1) causes No Harvest (M4) to be optimal up to significantly higher leakage values (<39.3%, <74.2%, <84.7%) across discount rates (0%, 4%, 12%). Above these leakage values, EBM “Risk-managed” Old Growth Targets (M2) is optimal and remains so over “Low Risk” Targets (M3) above similar leakage values (>37.7%, >70.8%, >80.0%) and discount rates (0%, 4%, 12%). The “minimal regret” management objective strongly favours management options with larger carbon benefits (M4>M3>M2) regardless of leakage (0%-90%) and discount rates (0%-12%) except when Pre-EBM (M1) is included, which is optimal across discount rates (0%, 12%) only with high leakage values (>71.7%, >65.9%).

3.11 Effect of Carbon Project and Timber Harvest Costs on Optimal Management Option

If carbon project costs increase, management options with larger value from carbon offset sales become less optimal (Table 3). Consequently, a relatively small increase in costs (>+27.4%) changes the optimal management option from the full carbon project (M4 No Harvest) to none (M1 Pre-EBM). Pre-EBM (M1) remains optimal at low discount rates (<2.8%) regardless of carbon project costs (0%) and at higher discount rates (8%, 12%) only when carbon project costs are increased considerably (>+169.8%, >+185.5%). If Pre-EBM (M1) is excluded as an option, the optimal management option, No Harvest (M4), is insensitive to changes in carbon project costs (<+400%) unless lower discount rates are used (<2.4%) which results in EBM "Risk-managed" Old Growth Targets (M2) being optimal. Comparing EBM options, "Low Risk" Old Growth Targets (M3) remains optimal over the range of cost adjustments considered (-100%, +400%) above moderate discount rates (>0.3%, >2.7%). Using the "minimal regret" objective favours carbon based management options (M4>M3>M2) regardless of adjustments in carbon project costs (0%-450%) and discount rates (0%-12%), unless Pre-EBM (M1) is considered which is then optimal when carbon project costs increase drastically (>299.4%, >326.8%) despite the discount rate used (0%, 12%).

Changes in timber harvest costs ($/m^3) significantly impact the optimal management option. A slight reduction in harvest costs (>-0.2%, >-1.5%) causes full timber harvest (M1, Pre-EBM) to be optimal over No Harvest (M4) at moderate to high discount rates (4%, 12%) (Table 3). At low discount rates (0%), No Harvest (M4) only remains optimal if timber harvest costs increase (>+4.7%). When Pre-EBM (M1) is excluded as an option, No Harvest (M4) remains optimal with larger decreases in timber harvest costs (<-4.3%, <-5.7%) at moderate to high discount rates (4%, 12%), and only a small increase in timber harvest costs is needed to make M4 optimal (>+1.1%) at low discount rates (0%). If only the EBM options are considered as options, "Risk-managed" Old Growth Targets (M2) is optimal only when timber harvest costs are reduced (>-0.2%, >-1.5%) for moderate to high discount rates (4%, 12%) and at very low discount rates (0%) below a slight increase in timber harvest costs (<+4.7%). When using the "minimal regret" objective, the optimal management options are highly sensitive to changes in carbon project costs similar to the trends shown for high discount rates (12%) when "maximizing ENPV", and insensitive to changes in discount rate (0%-12%).

3.12 Effect of Timber Harvesting Costs and Value Under EBM on the Optimal Management Option

Increasing the value of logs harvested under EBM ($/m^3) increases the value of timber harvest in the EBM options (M2 and M3), whereas increasing timber harvest costs under EBM ($/m^3) reduces the value (Table 4). Although No Harvest (M4) or Pre-EBM (M1) are optimal across the EBM timber harvest costs tested (0.0%-29.5%), excluding Pre-EBM (M1) results in EBM “Risk-managed” Old Growth Targets (M2) becoming optimal when incremental EBM timber harvest costs are below +5.2% of average costs (at a 0% discount rate), where +4.1% ($3.51/m^3) is the base incremental cost used. Comparing EBM options, “Risk-managed” Old Growth Targets (M2) is only optimal when incremental EBM timber harvest costs remain low (<+5.4%, <+0.9%, <+0.3%) across discount rates (0%, 4%, 12%). When using “minimal regret” as the management objective, the optimal management option is No Harvest (M4). If M4 is excluded as an option, then the optimal “minimum regret” choice switches to EBM “Low Risk” Old Growth Targets (M3), across all discount rates (0%-12%) and incremental EBM timber harvest costs tested (0.0%-29.5%).

When there is no incremental cost of harvesting timber under EBM, even slight increases in the value of timber harvested under EBM can increase the ranking of EBM options (M2 and M3) relative to the options of Pre-EBM and No Harvest (M4; Table 4). “Risk-managed” Old Growth Targets (M2) becomes optimal when EBM timber value increases, as a percent of average costs, by a minimal +0.2%, and at extreme discount rates of 0% and 12% by >+2.3% and >+1.6%, respectively. Removing Pre-EBM (M1) as a possibility results in the EBM “Risk-managed” Targets option (M2) expanding its optimal space to include low discount rates (<3.7%) across all increases in EBM harvested timber value (≥0.0%).

Table 4. **Sensitivity of optimal management option to incremental EBM timber harvest costs and value.**

		Discount Rate	Incremental EBM Timber Harvest Costs as a Percent Increase in Average Costs ($85.11/$m^3$)														
			29.5%	25.2%	21.0%	16.8%	12.6%	8.4%	4.2%	0.0%	-0.3%	-0.7%	-1.0%	-1.3%	-1.7%	-2.0%	-2.3%
All Management Options – M1-M4	Maximize ENPV	0%	M1	M1	M1	M1	M1	M1	M1	M1	M1	M1	M1	M1	M1	M1	M2
		2%	M1	M1	M1	M1	M1	M1	M1	M1	M1	M1	M2	M2	M2	M2	M2
		4%	M4	M4	M4	M4	M4	M4	M4	M4	M2	M2	M2	M2	M2	M2	M2
		6%	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M2	M2	M2	M2	M2
		8%	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M2	M2	M2
		10%	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M2	M2	M2
		12%	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M2	M2	M2
	Minimal Regret	0%	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M2
		2%	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M2
		4%	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M2
		6%	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M2
		8%	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M2	M2
		10%	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M2	M2
		12%	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M2	M2
No M1 Option – M2-M4	Maximize ENPV	0%	M4	M4	M4	M4	M4	M4	M2	M2	M2	M2	M2	M2	M2	M2	M2
		2%	M4	M4	M4	M4	M4	M4	M4	M2	M2	M2	M2	M2	M2	M2	M2
		4%	M4	M4	M4	M4	M4	M4	M4	M4	M2	M2	M2	M2	M2	M2	M2
		6%	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M2	M2	M2	M2	M2
		8%	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M2	M2	M2
		10%	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M2	M2	M2
		12%	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M2	M2	M2
	Minimal Regret	0%	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M2
		2%	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M2
		4%	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M2
		6%	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M2
		8%	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M2	M2
		10%	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M2	M2
		12%	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M2	M2
EBM Options –M2 and M3	Maximize ENPV	0%	M3	M3	M3	M3	M3	M3	M2	M2	M2	M2	M2	M2	M2	M2	M2
		2%	M3	M3	M3	M3	M3	M3	M3	M2	M2	M2	M2	M2	M2	M2	M2
		4%	M3	M3	M3	M3	M3	M3	M3	M2	M2	M2	M2	M2	M2	M2	M2
		6%	M3	M3	M3	M3	M3	M3	M3	M2	M2	M2	M2	M2	M2	M2	M2
		8%	M3	M3	M3	M3	M3	M3	M3	M2	M2	M2	M2	M2	M2	M2	M2
		10%	M3	M3	M3	M3	M3	M3	M3	M2	M2	M2	M2	M2	M2	M2	M2
		12%	M3	M3	M3	M3	M3	M3	M3	M2	M2	M2	M2	M2	M2	M2	M2
	Minimal Regret	0%	M3	M3	M3	M3	M3	M3	M3	M3	M3	M3	M3	M2	M2	M2	M2
		2%	M3	M3	M3	M3	M3	M3	M3	M3	M3	M3	M3	M2	M2	M2	M2
		4%	M3	M3	M3	M3	M3	M3	M3	M3	M3	M3	M2	M2	M2	M2	M2
		6%	M3	M3	M3	M3	M3	M3	M3	M3	M3	M3	M2	M2	M2	M2	M2
		8%	M3	M3	M3	M3	M3	M3	M3	M3	M3	M3	M2	M2	M2	M2	M2
		10%	M3	M3	M3	M3	M3	M3	M3	M3	M3	M2	M2	M2	M2	M2	M2
		12%	M3	M3	M3	M3	M3	M3	M3	M3	M3	M2	M2	M2	M2	M2	M2

Optimal management options are tested across a range of adjustments that increase the cost of EBM harvested timber (left, positive percent), exclude any incremental costs to harvesting timber under EBM (center column, zero percent), and decrease the cost of EBM harvested timber effectively increasing the achievable price (right, negative percent), relative to timber harvested under non-EBM (M1). The vertical structure of the sub-tables is identical to that used in Table 3 (for management objectives, management options, and discount rates considered) and follows the same shading for optimal management options from Table 1 and Table 3.

When we substitute “minimal regret” as the objective instead of “maximizing ENPV”, the optimal management option switches from No Harvest (M4) to EBM “Risk-managed” Old Growth Targets (M2) when the value of EBM harvested timber exceeds +2.3% to +1.9% for discount rates 0% to 12%. If only the two EBM options are possible choices, the “Risk-managed” Old Growth Targets (M2) is always optimal across all discount rates (0%-12%) and increased EBM harvested timber values (≥0.0%) when the goal is “maximizing ENPV”. In contrast, if “minimal regret” is selected as the management objective, “Low Risk” Targets (M3) remain optimal only for small increases in EBM timber values (<+1.1%, <+0.9%, <+0.5%) across discount rates (0%, 4%, 12%).

4. Discussion

4.1 Carbon Project Trade-offs and Price Uncertainty

The opportunity to create and sell forest carbon offsets through increased net carbon sequestration has associated costs and trade-offs, particularly foregone timber harvest and financial returns when timber harvest is reduced (Krcmar and van Kooten 2005, Baskent and Keleş 2009). To support EBM implementation in the Central Coast of British Columbia, this study aims to provide a realistic assessment of some of the trade-offs involved in carbon offset project opportunities under the BC FCOP. The trade-offs, relative to Pre-EBM (M1), of implementing full conservation (M4) or EBM with "Low Risk" (M3) or "Risk-managed" (M2) Old Growth Targets, include significant increases in total ecosystem carbon (+45.9%, +20.0%, +17.2%) and substantial foregone annual timber harvest (-100.0%, -45.3%, -36.3%) throughout the simulation (250 years). However, both harvesting timber (M1) and full conservation (M4) are strong economic options across a range of assumptions based on timber and carbon benefits in existing market conditions while considering uncertainty in future log and carbon offset prices. If M1 and M4 are excluded, reflecting the current management reality in the GBR, both EBM options (M2 and M3) are economically strong across a range of assumptions, while producing carbon offsets and maintaining some timber harvest. Comparing these EBM options, "Low Risk" Old Growth Targets (M3) is optimal across a slightly larger portion of the price trend space (56%) than "Risk-managed" Old Growth Targets (M2, 44%). However, only a slight increase to the value of EBM harvested timber (≥+2.3% of average timber harvest costs) results in EBM "Risk-managed" Old Growth Targets (M2) being optimal over all other management options (M1, M3, M4) across a wide range of discount rates (0%-12%) (when using "disinterested" probability density function hypotheses) (Table 4). Therefore, either of the EBM options could be considered "optimal" depending on the measures and beliefs in price trend used. This highlights how results from this study, particularly those that identify "optimal" management options, must be interpreted collectively, as the intent is to better understand the influence of parameters and beliefs in order to inform a broader discussion of strategy and tactics.

Consistent with other research, the feasibility of carbon projects is strongly influenced by future prices for timber and carbon offsets which are highly uncertain (Knowler and Dust 2008, Sohngen and Brown 2008, Keleş 2010, Susaeta et al. 2013). However, in this study, the optimal management option is more robust to carbon offset price scenarios (CP1-CP10) than log price scenarios (LP1-LP10) (Table 1), which is likely due to the range of scenarios used and contrast in the timing of economic benefits. Although the degree of belief in price scenarios for the decision analysis are generalized here by three contrasting probability density functions (prices increasing [“optimistic”], remaining steady [“disinterested”], or decreasing [“pessimistic”]), other functions could be developed to better capture new information, beliefs, and the changing decision making paradigm (Figure 1). This is important to consider because the ranking of management options, based on “maximizing ENPV”, is highly variable depending on the probability density functions used (Table 2). Additionally, changing prices significantly influence the economic benefits derived from the forested landscape, as would be expected and is shown by the range in ENPVs (Table 2). When carbon offset and log price trends are believed to be moderate (“disinterested”), the EVPI is substantial (+28.1%), indicating it is of high value for forest managers to observe and respond to market trends as best as possible. Additionally, EVIU should not be ignored despite there being no explicit value (0%) for the hypothesised probability density functions assessed, since EVIU could be substantial for alternate beliefs. Decision analyses are just one tool to help provide more robust conclusions by integrating uncertainty in decision making. However, further attention is needed to address all aspects of uncertainty in forest management, including societal demands on forests and future environmental conditions (Hildebrandt and Knoke 2011, Seidl and Lexer 2013).

The question of when it is economically favourable to conserve forests is important, particularly for that of limited old growth. Similar to this study, other studies in coastal British Columbia have found that including non-timber values, such as carbon, in the valuation of net economic benefits, supports the protection of old growth forests (Van Kooten and Bulte 1999, Knowler and Dust 2008). This can be true even to the extent where the option of not harvesting timber at all (e.g. M4) can be economically optimal (van Kooten et al. 1995) (Figure 1). However, these results often require conditions of low timber prices and high carbon prices. Consequently, some studies find that carbon offset projects are financially unviable at current carbon prices (Sohngen and Brown 2008, Keleş 2010, Rodrigues 2011). One example is a study by Deo et al. (2012) on the potential for carbon offset production via reforestation of pine on private land, using current costs, carbon valuation, and offset regimes in central British Columbia. However, despite this result for the private land reforestation case by Deo et al. (2012), I found that No Harvest (M4) on crown land in Central Coast of British Columbia is the most optimal management option when using "disinterested" hypotheses for both uncertain states of nature. Further studies are needed to inform management that assess different strategies across a range of circumstances (such as Man et al. 2013 and Deo et al. 2012). This is especially true because forested landscapes vary considerably in their carbon storage capacity and disturbance regimes that will dictate what strategies are effective and feasible (Sharma et al. 2013, Smyth et al. 2014).

4.2 Planning for the Future

Discount rate is a crucial parameter in assessing the feasibility of carbon projects (Healey et al. 2000, Krcmar and van Kooten 2005, Knowler and Dust 2008, Rodrigues 2011). If all four of my scenarios are considered, the optimal management option (M4 No Harvest) is highly sensitive to even a small decrease in discount rate (from 4.0% to 3.7%) resulting in full harvest (M1) becoming optimal (when using "disinterested" probability density function hypotheses) (Table 3, Table 4). Similar to increasing the discount rate, a shorter planning horizon (when carbon offset resale is not permitted) of 25 years favours not harvesting (M4), increasing the price scenario space for this management option from 47% to 59% (Table 1). These relationships are driven by the contrast in timing of economic benefits between consistent (at least theoretically) long term annual timber harvest volumes that only fluctuate from the average by 4.7% to 13.5%, and variable carbon offset sales which fluctuate by 205.7% to 219.3% producing half of the offsets in the first third of the 100 year planning horizon (Figure 4). It is important to note, however, that the reality of annual harvest in volatile economic markets is that it also fluctuates more widely than is represented by this timber supply model. For instance, annual timber harvest in the coast area region of British Columbia has fluctuated by 162% over the past 10 years (British Columbia Ministry of Forests, Lands and Natural Resource Operations 2004-2013). Understanding the two extreme options (M1, M4) in relation to discount rates provides context for comparing the EBM options, where just as before the option with higher annual timber harvest (M2>M3) becomes optimal (M2) at low discount rates (below 0.6% for “disinterested” probability density function hypotheses, Table 3) and is favoured by longer planning horizons (where increasing from 25 years to 100 years increases the optimal decision space of M2 by +15%, Table 1).

Increasing the planning horizon beyond the 100 years of contractual carbon storage under the BC FCOP raises the issue of whether carbon offsets can be resold: the potential for resale strongly influences the optimal management option (Table 1). Therefore, policy needs to clarify whether stored carbon that has been sold as offsets is eligible to be sold again as new offsets. Additionally, using longer planning horizons raises concerns with respect to accuracy of simulations and parameters, especially when low discount rates are used. Determining how benefits in the future are valued in the present and the appropriate planning horizons to use warrants further consideration that explores how different stakeholders and decision makers value the future while also taking into account the uncertainty associated with making projections for the future.

4.3 Optimal Revenue Source

Alternative management options can be compared by the degree to which revenue is generated from harvesting timber or carbon offsets. Revenue sourced from timber or carbon is favoured largely depending on one’s expectations in future prices for carbon offsets and logs (as shown in Table 2). This relationship is illustrated conceptually in Figure 6 as a gradient in source revenue that is optimal, based on the beliefs in carbon offset prices and log prices. Although this relationship is fairly implicit, changes in parameters can act as pressures on this gradient causing it to shift, either in favour of carbon or timber. These relationships are drawn from the sensitivity analyses (Table 3 and Table 4). For instance, source revenue from timber is favoured (shifting the gradient down and left), if lower discount rates or lower timber harvest costs are used. Similarly, higher carbon offset project costs, higher leakage rates, and longer planning horizons (assuming no carbon resale) also favour revenue sourced from timber. The reverse change in these parameters favours carbon. These results highlight the importance of parameter selection and understanding the potential implications for the results of using high or low values, particularly in the context of the range of possible beliefs in future prices that may be expected (Figure 6).

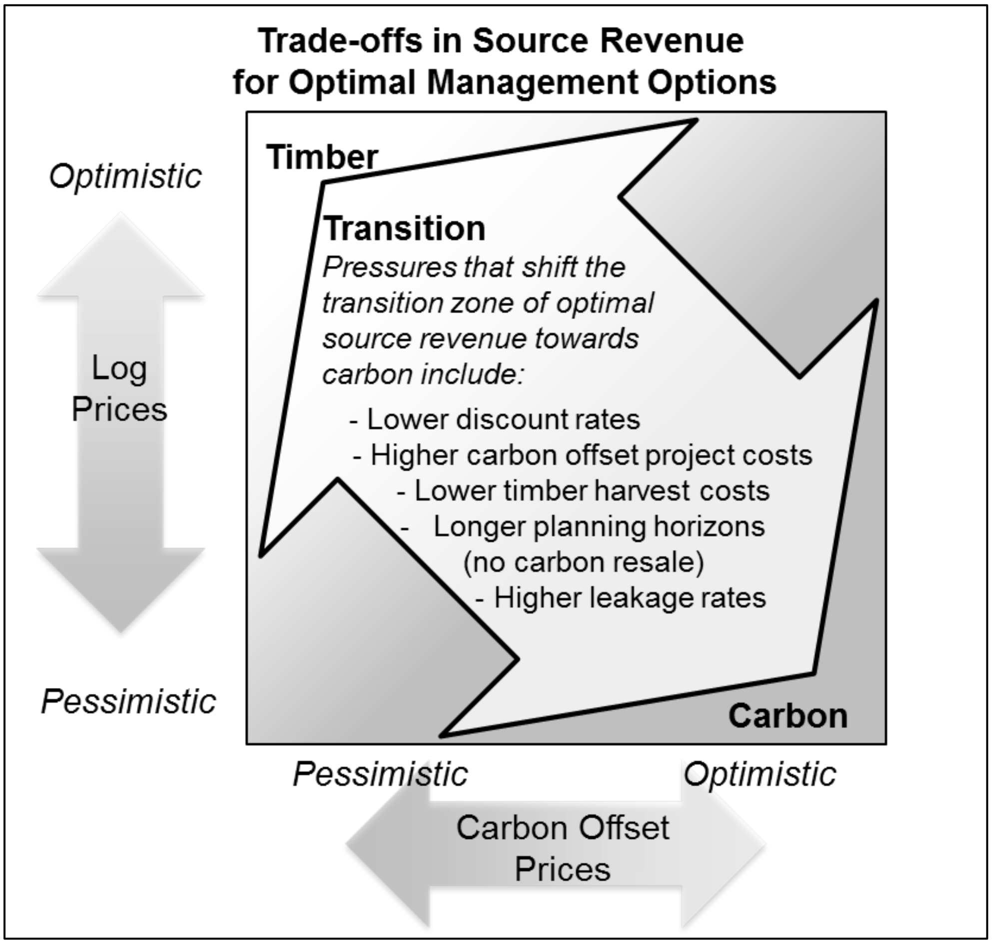

Figure 6. Drivers of optimal source revenue across price trends.

Management options are deemed optimal in this study largely depending on the source of their revenue ("carbon" or "timber") and pricing conditions (of "carbon offset prices" and "log prices"). The axes represent a range of beliefs in prices from being "optimistic" to "pessimistic". The vertical axis shows this range in beliefs for logs and the horizontal axis shows it for carbon offset prices. The source of revenue that is favoured, under the range of pricing conditions shown, is presented as a diagonal gradient from "carbon" (dark grey) to "timber" (light grey). Changes to key parameters (discount rates, timber harvest or carbon offset project costs, planning horizon, leakage) can act as pressures on this revenue source gradient (or "transition"), shifting the gradient either away from (and so in favour of) "carbon" or "timber", as described in the figure.

4.4 Carbon Accounting and Forest Valuation

Selection of the standard used to develop a carbon offset project is important because standards outline the required methodology and can strongly affect the project development costs, available markets, and the quantity of carbon offsets produced from a project. Although in this study I only use the BC FCOP, I do test the sensitivity of optimal management options to changes in key parameters that can vary across standards. I showed a high sensitivity in carbon project feasibility to increases in leakage (>+1.4%) and carbon project costs (>+27.4%) (Table 3). Similarly, reductions particularly in leakage drive carbon project based management options (M4>M3>M2) to be optimal across discount rates. It is important to note that although current markets for BC FCOP offsets are fairly new and limited, climate policy strategies may expand the current markets available.

The global carbon market, however, will likely continue to be composed of a patchwork of regional bottom-up schemes (Klinsky 2013) where price is largely dictated by demand for different types and quality of offsets (Peters-Stanley and Yin 2013). Consequently, the selection of an accounting protocol is critically important for project feasibility (Galik and Cooley 2012). Although some studies have investigated accounting methodology and protocols (Chladná 2007, Seidl et al. 2007, Foley et al. 2009, Gunn et al. 2011, Rodrigues 2011, Petrasek et al. 2013), we need a better understanding in order to inform managers of the options and implications of different standards for various types of projects, their sizes and locations, especially as markets and opportunities continue to develop.

It is important in forest management to understand the limitations of economic assessments and consider the environmental and social dimensions when measuring the performance of alternative management options (Bernier et al. 2012, D'Amato et al. 2011). In economic assessments, only what is counted is actually considered (Victor 2001). Additionally, total economic benefits do not describe who actually receives the benefits and the partitioning of benefits among participants in the system is a critical factor in social acceptability and equity (Benner et al., 2014). In this study, only returns from the harvest of timber and generation of carbon offsets are included in the assessment of total economic benefits of alternative management options. Therefore, it is critical when interpreting results that the impacts of the management options on other values and the division of benefits are not ignored. For instance, other non-timber values, such as cultural values or biodiversity, may be supported by managing forests for carbon and reducing timber harvest. Age class distributions are an example that I show where the alternative management options result in very different profiles for the THLB (Figure 5), which has significant impacts on forest structure and types of habitat available. With respect to the division of economic benefits in this study, there are several entities involved and the division is not equal. This results, for each individual entity, in drastically different rankings of the alternative management options than already discussed (see Appendix F) and is a key concept when considering the complexity involved in applying results in the real decision making context of British Columbia’s Central Coast.

The choice of management objective is an additional factor which is shown to be critical by this research. Similar to what has been found by other studies (Krcmar and van Kooten 2005, Schwenk et al. 2012), different management objectives can produce drastically different rankings of the alternative management options. In this study, the “minimizing regret” management objective consistently favours management options with larger carbon benefits (M4>M3>M2) relative to the “maximizing ENPV” objective (Table 3 and Table 4). This trend is largely a result of the relative worst case carbon offset price scenario (CP10) and the worst case log price scenario (LP10) used. However, it does highlight the need for thoughtful consideration by forest managers in the selection of management objectives so that they actually reflect their decision making paradigm in order to produce meaningful results.

Although carbon offset projects are a significant and growing economic opportunity in forest management, there are major challenges with regards to the validity of these offsets that cannot be ignored. Issues that have been identified include baseline identification, leakage, harvested wood products, permanence, liabilities, governance, insurance, additionality, modelling uncertainties, unintended consequences, risks of reversals, duration, and transaction costs (Greig and Bull 2011, Bernier et al. 2012, van Kooten et al. 2012, van Kooten et al. 2014). However, these issues have been discussed and can largely be addressed by established methodologies (Freedman et al. 2009, Galik and Jackson 2009, Ingerson 2011, Malmsheimer et al. 2011, Shaw et al. 2014). Also, new research and tools like remote sensing can continue to help address these issues. Nonetheless, understanding these issues and the potential implications, such as with sensitivity analyses for leakage as shown in this study (Table 3), is important when developing any carbon offset projects.

4.5 Mitigation and Adaptation to Changing Climate

Although it is widely accepted that climate change will increasingly affect forests, this study does not include possible changes in climate or its impacts over the 250 years. The effects and magnitude of responses of the forest management system to climate change are extremely complex, vary geographically, and remain highly uncertain (Kirilenko and Sedjo 2007, Bonan 2008, Metsaranta et al. 2011, Smyth et al. 2014). Additional challenges stem from systems shifting to new states not previously encountered where historical data are not necessarily representative (Hamann and Wang 2006). However, implications of changing climate on carbon projects and timber harvesting are an important factor that should be considered when applying results from this study and are a possible extension for further research. For instance, expected trends in forest response and market response to changing climate could be incorporated explicitly into the analysis of uncertainty with the application of uncertain states of nature that capture these possible responses and test potential probability density functions.

Forests not only are impacted by climate change and can be utilized for mitigation such as through carbon markets, but can also be managed for adaptation. Adaptive management, which necessitates land managers to monitor results of continuous actions in an effort to understand and learn from experience, is an important component of sustainable forest management and EBM (Holling 1978, Spittlehouse and Stewart 2003, Golden et al. 2011, Yousefpour et al. 2014). The voluntary carbon market can provide economic opportunities to support implementation of not only EBM as shown in this study, but also adaptive strategies if the strategies result in increased total ecosystem carbon. This study does not assess adaptive management, only EBM as it is implemented under the CNC and SCC orders (2009). However, there is a need for research that is directed at examining adaptive strategies that already exist to cope with changing climate (Millar et al. 2007) and explore how carbon offset project opportunities can be used specifically to support their implementation, not only in the context of EBM.

This is needed at multiple scales as there is widespread discussion about adaptive management for forests in a global context (Adams 2013, Bettinger et al. 2013), nationally for Canada (Lemprière et al. 2008, Williamson et al. 2009, Bernier et al. 2012, Johnston and Hesseln 2012), in British Columbia (Hamann and Wang 2006, Peng et al. 2014), and for the US Pacific Northwest (Spies et al. 2010, Raymond and McKenzie 2012, Wimberly and Liu 2013). Additionally, a range of scales is required to examine the effectiveness of forestry practices on carbon sequestration and climate change mitigation, improve understanding of issues like leakage, and inform policy in order for it to be effective across diverse landscapes (Harmon 2001, Smyth et al. 2014).

4.6 Opportunities in Forest Management

Decision analyses are meant to be a tool to provide insights into a problem and inform decision-making but do not make decisions and thus are not a substitute for creative, innovative thinking (Keeney 1982). Although in this study I only considered the opportunities of harvesting timber and generating carbon offsets from forests, there are many other opportunities and values that can and should be addressed by forest management. Just as including carbon markets or increasing the value of EBM harvested timber significantly changes the results in this study (Table 4), including new opportunities could also likely affect the results. Forest managers should continue to use creative, innovative thinking to find other potential opportunities as they develop, including within existing and new carbon markets, carbon standards and accounting methods, strategies, and certifications. However, opportunities need to be fully assessed in order to understand all of their implications. For example, in this study the alternative management options with very different levels of timber harvest have a significant influence not only on total ecosystem carbon, but age class distributions as well (Figure 5).

Diversification of products and revenue streams is a strategy that can help managers cope with economic uncertainty in markets to achieve more robust net revenues. However, it has been slow to be adopted in forest management (Hildebrandt and Knoke 2011). Opportunities in forest management to diversify revenue streams include emerging carbon markets, but among forest managers the implications of this are poorly understood (Greig and Bull 2009, Charnley et al. 2010, Pojar 2010). In my study, the EBM options (M2 and M3) generate the most diverse revenue streams, producing 40.5% (M2) and 52.1% (M3) of the maximum possible 100 year cumulative net saleable carbon offsets (M4 No Harvest), and 62.6% (M2) and 56.5% (M3) of the maximum 250 year annual harvest rates (M1 Pre-EBM). However, despite this, the bounding options specializing in full timber harvest (M1) or conservation (M4) emerge from the analysis as economically optimal because of fixed costs associated with carbon offset projects (economies of scale) and incremental EBM timber harvest costs (acting as a disincentive for M2 and M3). Nonetheless, a more diverse approach of EBM (M2 and M3) can reduce risks in uncertain timber and carbon markets and could potentially better meet objectives across the landscape. Other opportunities can be used to support the EBM options, as I show with the potential to increase the value of timber harvested under EBM (Table 4). Even slight increases to the value of EBM harvested timber (≥+2.3% of average timber harvest costs) can result in EBM being optimal over all other management options in this study across a wide range of discount rates (0%-12%) when "disinterested" hypotheses for both uncertain states of nature are used.

4.7 Management Implications and Recommendations

In this study I show that implementing EBM (M2, M3) significantly increases total ecosystem carbon in the study area compared to pre-EBM (M1) and generates saleable carbon offsets that help compensate for foregone timber harvest. However, the economic benefits from carbon offsets vary considerably, up to 219.3% annually relative to theoretically more consistent annual timber harvest rates, which, in the simulations, vary only up to 13.5%. Either of the extreme management options, maximum timber harvests (M1) or full conservation (M4), can be economically optimal based on timber and carbon benefits in existing market conditions, depending largely on trends in future log and carbon offset prices. Consequently, when these extremes are included as options in the analysis, the mixed carbon and timber options that apply EBM (M2 and M3) are not optimal in any of the price scenarios (using baseline parameters). This is due to economies of scale with respect to fixed costs considered in carbon offset projects, and the incremental costs of harvesting timber under EBM. However, neither of the extreme options (M1 or M4) are possible outcomes in the real decision making context of the part of the British Columbia coast modelled here. Thus, when only EBM options (M2 and M3) are considered as possible options, “Risk-managed” (M2) and “Low Risk” (M3) Old Growth Targets are both competitive options being economically optimal across relatively equal portions of the price trend space.

Other factors considered in this analysis that have a significant influence on the optimal management option (or revenue source as shown in Figure 6) are the discount rate, leakage, and costs. Additional model runs requested by the Heiltsuk Integrated Resource Management Department to reflect current management conditions and possible opportunities also followed these trends in Figure 6, where the higher timber harvest costs ($\$135/m^3$) and higher carbon offset prices ($\$20/tCO_2$-e) both favoured source revenue from carbon. The management objectives tested have very different goals and major implications on the results, where managing to “maximize ENPV” focuses on achieving the best outcomes in contrast to “minimal regret” that is concerned with avoiding the worst outcomes. The value of reducing uncertainty in the analysis is substantial, where having perfect information (EVPI) about trends in carbon offset and log prices with relatively moderate (“disinterested”) degrees of belief could increase ENPV by 28.1%. Participating in carbon offset markets is a real economic opportunity in forest management, but understanding the risks and trade-offs is critical, particularly due to the continuously evolving nature of decision making in forest management. Several recommendations emerge from this study for further research, for local communities, and for policy development.

1. If forest managers across British Columbia are to be informed and able to seriously consider managing forests for carbon offsets, a comprehensive study is needed that identifies what strategies are feasible for forest carbon offset projects, across which types of sites, and under which accounting standards. Additionally, this information must be presented in a clear accessible manner and reassessed through time to keep up with evolving societal demands on forests and changes in market and environmental conditions, which will potentially have major impacts on the desirability of carbon project opportunities (Hildebrandt and Knoke 2011, Seidl and Lexer 2013).
2. Local communities, including First Nation communities such as the Heiltsuk, should be able to use the economic value of carbon as a component of an economic strategy and as at least a partial replacement of timber harvest. Despite price uncertainties, carbon is a

real opportunity that can be used to diversify forest management and support implementation of EBM and adaptive management. It should be a useful part of a strategy for diversified income streams that can support other opportunities and the vision in their Land Use Plan (Heiltsuk Tribal Council 2005). Consideration needs to be given to selecting appropriate discount rates, planning horizons, and management objectives, that reflect the goals and values of decision makers so that results can more accurately inform management when planning for the future.

3. Managers need to give careful consideration to the various carbon standards available (which impacts leakage rate, project costs, etc.), possible trends in future prices, implications of changing climate and possible ways that carbon offsets can be used to support and implement adaptation strategies, all of their values and management objectives including all benefits and costs, how the timing of benefits is valued (discount rate), and other possible opportunities.
4. Policy makers need to clarify whether carbon offsets can be resold after the contracted 100 years of storage under the BC FCOP. This is a management uncertainty that strongly influences the economics of carbon projects when using low discount rates and long-time horizons.
5. Since the incremental costs of harvesting timber under EBM are a significant driver of the ranking of the EBM options, research is needed that focuses on the cost structure of EBM options, both to better understand the actual costs and to design management systems which reduce costs while still achieving EBM goals.
6. There is a major opportunity to stratify the land-base strategically and use a mix of strategies and policies that are most effective for each portion of the land-base. In this way, managers can optimize alternative revenue streams across the land-base so that EBM forestry may be practiced in areas that it is feasible and carbon can be focused on elsewhere. However, data, analyses, and decision support tools are needed to help management make these decisions.

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Appendix A.

Forest Carbon Offset Projects in British Columbia through the Pacific Carbon Trust

Project Title	Crediting Period	Credits Issued (t CO_2-e)	Land-base (ha)	Location	Standard	Protection
Darkwoods Forest Carbon Project (3Green Tree Ecosystem Services Ltd. 2013)	April 1, 2008 to December 31, 2010	849,016	54,792	Private Land, Southeastern BC	Verified Carbon Standard	Improved forest management prevents "liquidation harvest"
TimberWest Strathcona Ecosystem Conservation Program Project (Cortex Consultants 2013)	January 1, 2009 to December 31, 2012	1,273,953	24,639	Private Land, Vancouver Island	BC FCOP	Improved forest management protects old growth forest from harvest
The Great Bear (South Central Coast) Forest Carbon Project (Offsetters 2012)	April 1, 2009 to December 31, 2011	246,725	1,560,000 (total) 780,000 (productive forest)	Crown Land, South Central Coast	BC FCOP	Improved forest management (EBM implementation through South Central Coast Order (2009)) protects forest from commercial harvest
The Great Bear (North and Central-Mid Coast) Forest Carbon Project (Carbon Credit Corporation 2011)	April 1, 2009 to December 31, 2011	315,815	4,727,000 (total) 1,918,000 (productive forest)	Crown Land, North and Central-Mid Coast	BC FCOP	Improved forest management (EBM implementation through Central and North Coast Order (2009)) protects forest from commercial harvest

Appendix B.

Harvested Wood Product Calculations

Long term (100-year) carbon storage in harvested wood products (HWP) in-use and in-landfill are calculated following the equations and assumptions outlined in the British Columbia Forest Carbon Offset Protocol (British Columbia Ministry of Environment 2011; Smith et al. 2006). Both equations (1 and 2) are shown below as well as data sources for the variables.

$$CO_{2,HWP_{in-use},t} = m_{k,t} \times (1 - f_{Production\,loss,k}) \times f_{C,wood} \times f_{C,in-use,k} \times \frac{MW_{CO_2}}{MW_C} \tag{1}$$

$$CO_{2,HWP_{in\,landfill},t} = m_{k,t} \times (1 - f_{Production\,loss,k}) \times f_{C,wood} \times f_{C,in\,landfill,k} \times \frac{MW_{CO_2}}{MW_C} \tag{2}$$

where,

$CO_{2,HWP_{in-use},t}$ = tonnes of Carbon dioxide stored in in-use HWP that will endure for 100 years

$CO_{2,HWP_{in\,landfill},t}$ = tonnes of Carbon dioxide stored in in-landfill HWP that will endure for 100 years

$m_{k,t}$ = tonnes of harvested wood dry mass minus bark processed into HWP (volume harvested results from SELES-STSM and fraction calculated and approved under BC FCOP for The Great Bear (North and Central-Mid Coast) Forest Carbon Project from Carbon Credit Corporation, 2011)

$f_{Production\,loss,k}$ = fraction of wood mass lost as waste during HWP production (use same value calculated and approved under BC FCOP for

The Great Bear (North and Central-Mid Coast) Forest Carbon Project from Carbon Credit Corporation, 2011)

$f_{C,wood}$ = fraction of dry mass of wood that is carbon (BC FCOP default)

$f_{C,in-use,k}$ = fraction of carbon in in-use HWP that remains after 100 years (Table 9, Smith et al. 2006)

$f_{C,in\ landfill,k}$ = fraction of carbon in in-landfill HWP that remains after 100 years (Table 9, Smith et al. 2006)

MW_{CO_2} = molecular weight of CO_2 (44 g/mole)

MW_C = molecular weight of carbon (12 g/mole)

Appendix C.

Permanence Buffer Calculations

Permanence buffer of 10%, also referred to as “non-permanence risk rating”, is calculated using the Voluntary Carbon Standard Association (2012) non-permanence risk tool recommended by BC FCOP to account for risk of natural or human-induced events reversing the emission reductions in the first 100 years.

The risk rating is based on an assessment of several risk factors (internal risks, external risks, and natural risks) which are added to determine the total risk rating. The tables from the tool are conservatively filled out below.

Internal Risk

Project Management		
a)	Species planted (where applicable) associated with more than 25% of the stocks on which GHG credits have previously been issued are not native or proven to be adapted to the same or similar agro-ecological zone(s) in which the project is located.	0
b)	Ongoing enforcement to prevent encroachment by outside actors is required to protect more than 50% of stocks on which GHG credits have previously been issued.	0
c)	Management team does not include individuals with significant experience in all skills necessary to successfully undertake all project activities (ie, any area of required experience is not covered by at least one individual with at least 5 years experience in the area).	2
d)	Management team does not maintain a presence in the country or is located more than a day of travel from the project site, considering all parcels or polygons in the project area.	2
e)	Mitigation: Management team includes individuals with significant experience in AFOLU project design and implementation, carbon accounting and reporting (eg, individuals who have successfully managed projects through validation, verification and issuance of GHG credits) under the VCS Program or other approved GHG programs.	0
f)	Mitigation: Adaptive management plan in place.	-2
Total Project Management (PM) [as applicable, (a + b + c + d + e + f)]		2

Financial Viability		
a)	Project cash flow breakeven point is greater than 10 years from the current risk assessment.	3
b)	Project cash flow breakeven point is greater than 7 and up to 10 years from the current risk assessment.	
c)	Project cash flow breakeven point greater than 4 and up to 7 years from the current risk assessment.	
d)	Project cash flow breakeven point is 4 years or less from the current risk assessment.	
e)	Project has secured less than 15% of funding needed to cover the total cash out before the project reaches breakeven.	3
f)	Project has secured 15% to less than 40% of funding needed to cover the total cash out required before the project reaches breakeven.	
g)	Project has secured 40% to less than 80% of funding needed to cover the total cash out required before the project reaches breakeven.	
h)	Project has secured 80% or more of funding needed to cover the total cash out before the project reaches breakeven.	
i)	Mitigation: Project has available as callable financial resources at least 50% of total cash out before project reaches breakeven.	-2
	Total Financial Viability (FV) [as applicable, ((a, b, c, or d) + (e, f, g, or h) + i)]	4

Opportunity Cost		
a)	NPV from the most profitable alternative land use activity is expected to be at least 100% more than that associated with project activities; or where baseline activities are subsistence-driven, net positive community impacts are not demonstrated.	8
b)	NPV from the most profitable alternative land use activity is expected to be between 50% and up to 100% more than from project activities.	
c)	NPV from the most profitable alternative land use activity is expected to be between 20% and up to 50% more than from project activities.	
d)	NPV from the most profitable alternative land use activity is expected to be between 20% more than and up to 20% less than from project activities; or where baseline activities are subsistence-driven, net positive community impacts are demonstrated.	
e)	NPV from project activities is expected to be between 20% and up to 50% more profitable than the most profitable alternative land use activity.	
f)	NPV from project activities is expected to be at least 50% more profitable than the most profitable alternative land use activity.	
g)	Mitigation: Project proponent is a non-profit organization.	-2
h)	Mitigation: Project is protected by legally binding commitment to continue management practices that protect the credited carbon stocks over the length of the project crediting period.	
i)	Mitigation: Project is protected by legally binding commitment to continue management practices that protect the credited carbon stocks over at least 100 years.	-8
	Total Opportunity Cost (OC) [as applicable, (a, b, c, d, e or f) + (g + h or i)]	0

Project Longevity		
a)	Without legal agreement or requirement to continue the management practice.	
b)	With legal agreement or requirement to continue the management practice.	0
	Total Project Longevity (PL)	0

Total Internal Risk	
Total Internal Risk (PM + FV + OC + PL)	6

External Risk

Land Tenure and Resource Access/Impacts		
a)	Ownership and resource access/use rights are held by same entity(s).	0
b)	Ownership and resource access/use rights are held by different entity(s) (eg, land is government owned and the project proponent holds a lease or concession).	
c)	In more than 5% of the project area, there exist disputes over land tenure or ownership.	
d)	There exist disputes over access/use rights (or overlapping rights).	5
e)	WRC projects unable to demonstrate that potential upstream and sea impacts that could undermine issued credits in the next 10 years are irrelevant or expected to be insignificant, or that there is a plan in place for effectively mitigating such impacts.	
f)	Mitigation: Project area is protected by legally binding commitment (eg, a conservation easement or protected area) to continue management practices that protect carbon stocks over the length of the project crediting period.	-2
g)	Mitigation: Where disputes over land tenure, ownership or access/use rights exist, documented evidence is provided that projects have implemented activities to resolve the disputes or clarify overlapping claims.	-2
	Total Land Tenure (LT) [as applicable, ((a or b) + c + d + e + f + g]	1

Community Engagement		
a)	Less than 50 percent of households living within the project area who are reliant on the project area, have been consulted.	
b)	Less than 20 percent of households living within 20 km of the project boundary outside the project area, and who are reliant on the project area, have been consulted.	
c)	Mitigation: The project generates net positive impacts on the social and economic well-being of the local communities who derive livelihoods from the project area.	-5
	Total Community Engagement (CE) [where applicable, (a + b + c)]	-5

Political Risk		
a)	Governance score of less than -0.79	
b)	Governance score of -0.79 to less than -0.32	
c)	Governance score of -0.32 to less than 0.19	
d)	Governance score of 0.19 to less than 0.82	
e)	Governance score of 0.82 or higher	0
f)	Mitigation: Country is implementing REDD+ Readiness or other activities, as set out in this Section 2.3.3.	
	Total Political (PC) [as applicable ((a, b, c, d or e) + f)]	0

Total External Risk	
Total External Risk (LT + CE + PC)	0

Natural Risk

Natural Risk	
Score for each natural risk applicable to the project (determined by (LS x M))	
Fire (F)	0
Pest and Disease Outbreaks (PD)	1
Extreme Weather (W)	0
Geological Risk (G)	0
Other natural risk (ON)	
Total Natural Risk (as applicable, F + PD + W + G + ON)	1

Total Risk

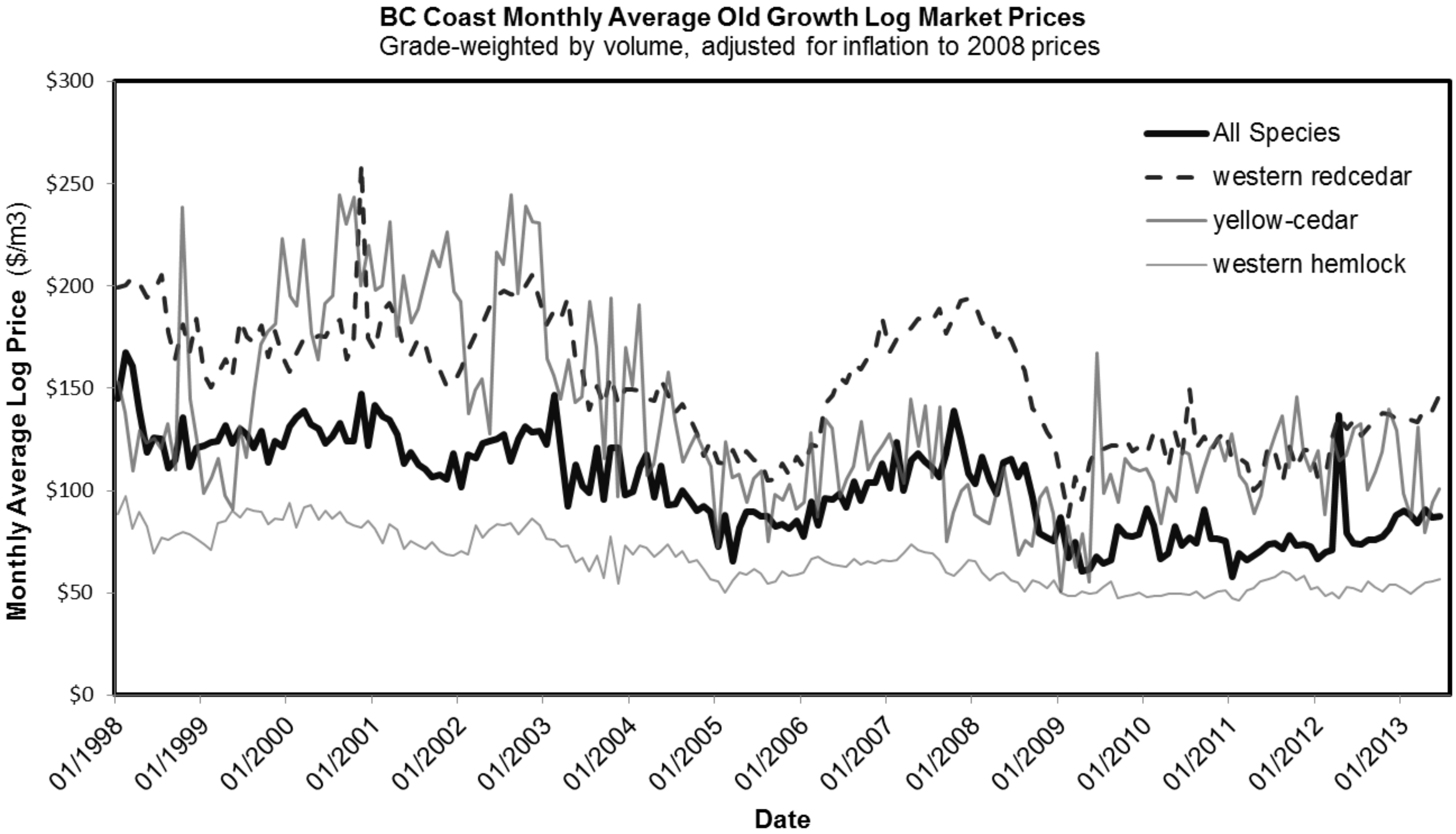
Risk Category		Rating
a)	Internal Risk	6
b)	External Risk	0
c)	Natural Risk	1
	Overall risk rating (a + b + c) where the minimum vale is 10	10

Appendix D.

British Columbia Central Coast Old Growth Historical Average Monthly Timber Prices

The historical average monthly old timber prices I calculated for 1998 to 2013 are graphically shown and have been weighted by species- and grade-volume profiles. Western redcedar (*Thuja plicata*), yellow-cedar (*Callitropsis nootkatensis*), and western hemlock (*Tsuga heterophylla*) are shown as well as all species combined prices that have been weighted by the volume, grade and species profile harvested. The following data sources were used to calculate the prices:

- Average monthly old growth timber prices by species and grade for 1998 to 2013 in the Central Coast of British Columbia were obtained from Coastal Log Market Reports (British Columbia Ministry of Forests, Lands and Natural Resource Operations, 1998-2013).
- Harvested volume data by grade and species for the North Island and Central Coast Forest District was obtained from the Harvest Billing System (British Columbia Ministry of Forests, Lands and Natural Resource Operations, 2013b).
- Prices were adjusted for inflation to the reference year of this study (2008) using the Consumer Price Index (Bank of Canada, 2013a).

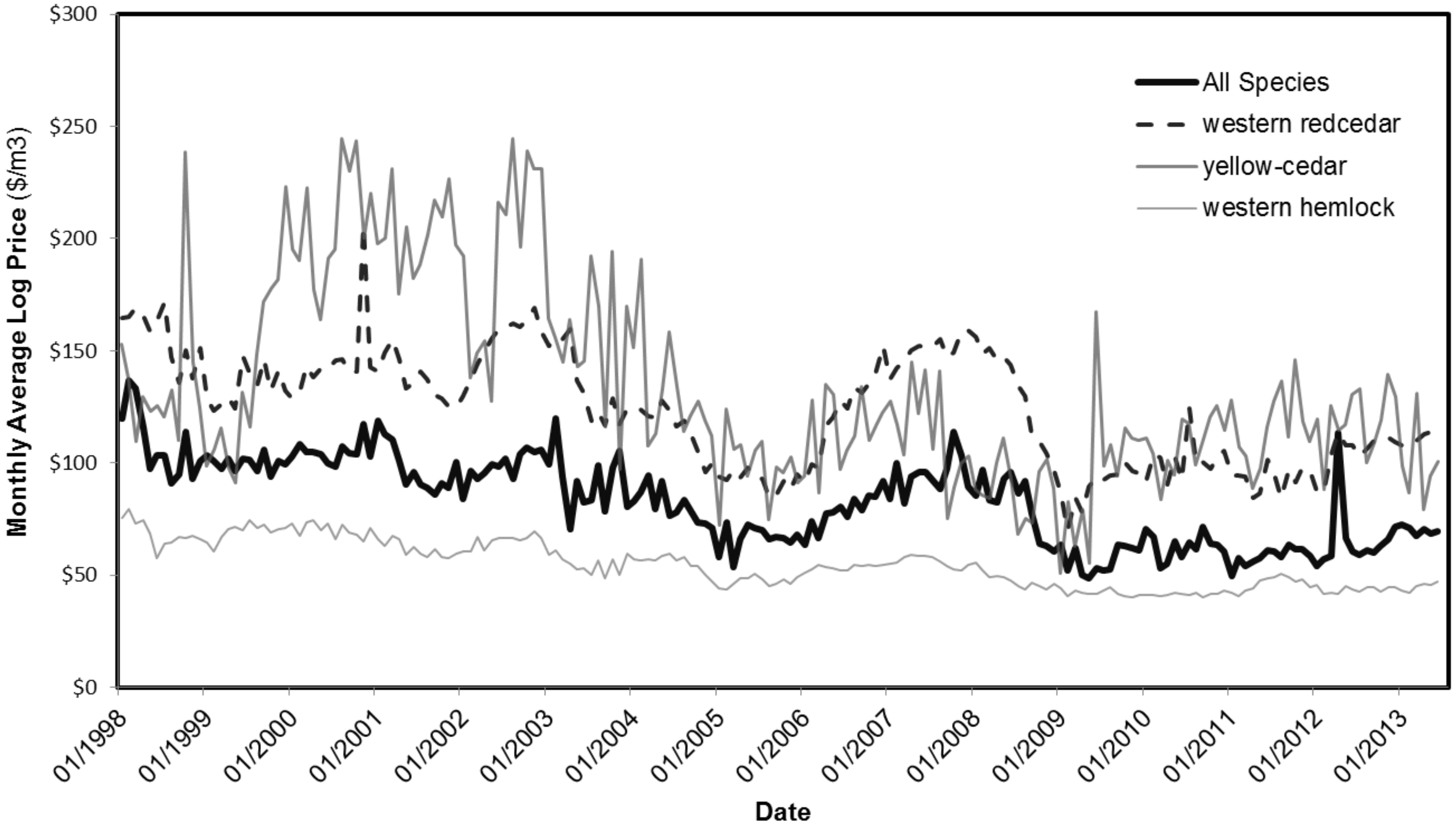

BC Coast Monthly Average Old Growth Log Market Prices
Grade-weighted by volume, adjusted for inflation to 2008 prices
Monthly Average Log Price ($/m3)
$300
$250
$200
$150
$100
$50
$0
01/1998
01/1999
01/2000
01/2001
01/2002
01/2003
01/2004
01/2005
01/2006
01/2007
01/2008
01/2009
01/2010
01/2011
01/2012
01/2013
Date
All Species
western redcedar
yellow-cedar
western hemlock

Appendix E.

British Columbia Central Coast Second Growth Historical Average Monthly Timber Prices

Second growth historical average monthly timber prices I calculated for 1998 to 2013 are graphically shown. As price and volume data are not yet available for second growth logs, these second growth prices were calculated using the old growth prices in Appendix D and conversion parameters developed by the Coastal Appraisal Advisory Committee (British Columbia Ministry of Forests, 2004).

BC Coast Monthly Average Second Growth Log Market Prices
Grade-weighted by volume, adjusted for inflation to 2008 prices



Appendix F.

Division of Economic Benefits

Results tables are produced in this Appendix where the division of economic benefits derived from the study area follows current established agreements as described below and assumes they continue into the future for the 100 year planning horizon of this study.

British Columbia Provincial Government

- 33% from 2009-2010, and 50% from 2011-2025, revenue from carbon offset sales (Atmospheric Benefit Sharing Agreement Section 3.2)
- 25% of stumpage from First Nation Forest Tenures (Heiltsuk First Nation Forest Consultation and Revenue Sharing Agreement 2011-2014, Appendix B Section 2.0 and 2.1)
- 95% of stumpage (Heiltsuk First Nation Forest Consultation and Revenue Sharing Agreement 2011-2014, Appendix B Section 1.0 to 1.4)

First Nations

- 77% from 2009-2010, and 50% from 2011-2025, revenue from carbon offset sales (Atmospheric Benefit Sharing Agreement Section 3.2)
- 5% of stumpage (Heiltsuk First Nation Forest Consultation and Revenue Sharing Agreement 2011-2014, Appendix B Section 1.0 to 1.4)
- 75% of stumpage from First Nation Forest Tenures (Heiltsuk First Nation Forest Consultation and Revenue Sharing Agreement 2011-2014, Appendix B Section 2.0 and 2.1)
- First Nation Forest Licence estimated (14.2%) using the current commitments to First Nations in the study area as listed below, averaged over 5 years as a percent of the total volume harvested under the first year of the EBM option with “risk-managed” old growth targets as this is the option currently in effect as of 2009 (Reconciliation Protocol 2010, Schedule D Section 1.1 and 1.7)
    - 47,000 m^3 /yr replaceable long term volume based forest licence Mid Coast TSA Heiltsuk
    - 5,600 m^3 /yr replaceable long term volume based forest licence Mid Coast TSA Wuikinuxv
    - 299,000 m^3 over 5 years additional tenure of non-replaceable volume from Mid Coast TSA Heiltsuk
    - 35,600 m^3 over 5 years additional tenure of non-replaceable volume from Mid Coast TSA Wuikinuxv

Non-First Nation Timber Harvesting Companies

- All remaining non-First Nation Forest Licence

The stumpage rate used (1.9%) was calculated for coastal British Columbia as a percentage of log price using the average monthly sawlog stumpage rates by species for the Coast Region from 2010 to 2013 weighted by the monthly harvested volumes by species for the North Island and Central Coast Forest District where data was obtained from the Harvest Billing System (British Columbia Ministry of Forests, Lands and Natural Resource Operations, 2013b) and the 10 year average old growth price was used as calculated in Appendix D.

Optimal Management Options with Maximum Net Present Value for all Combinations of Price Scenarios for each Entity

Carbon Offset Price Scenarios (CP1-CP10, $/tCO$_2$-e/yr)

	Log Price Scenarios (LP1-LP10, $/m³/yr)	British Columbia Provincial Government									
		1	2	3	4	5	6	7	8	9	10
All Management Options	1	4	4	4	4	4	4	4	4	1	1
	2	4	4	4	4	4	4	4	4	1	1
	3	4	4	4	4	4	4	4	4	1	1
	4	4	4	4	4	4	4	4	4	1	1
	5	4	4	4	4	4	4	4	4	1	1
	6	4	4	4	4	4	4	4	4	1	1
	7	4	4	4	4	4	4	4	4	1	1
	8	4	4	4	4	4	4	4	4	1	1
	9	4	4	4	4	4	4	4	4	1	1
	10	4	4	4	4	4	4	4	4	1	1
No M1 Option	1	4	4	4	4	4	4	4	4	2	2
	2	4	4	4	4	4	4	4	4	2	2
	3	4	4	4	4	4	4	4	4	2	2
	4	4	4	4	4	4	4	4	4	2	2
	5	4	4	4	4	4	4	4	4	2	2
	6	4	4	4	4	4	4	4	4	2	2
	7	4	4	4	4	4	4	4	4	2	2
	8	4	4	4	4	4	4	4	4	2	2
	9	4	4	4	4	4	4	4	4	2	2
	10	4	4	4	4	4	4	4	4	2	2
EBM Options M2 & M3	1	3	3	3	3	3	3	3	2	2	2
	2	3	3	3	3	3	3	3	2	2	2
	3	3	3	3	3	3	3	3	2	2	2
	4	3	3	3	3	3	3	3	2	2	2
	5	3	3	3	3	3	3	3	3	2	2
	6	3	3	3	3	3	3	3	3	2	2
	7	3	3	3	3	3	3	3	3	2	2
	8	3	3	3	3	3	3	3	3	2	2
	9	3	3	3	3	3	3	3	3	2	2
	10	3	3	3	3	3	3	3	3	2	2

	Log Price Scenarios (LP1-LP10, $/m³/yr)	First Nations									
		1	2	3	4	5	6	7	8	9	10
All Management Options	1	4	4	4	4	4	4	1	1	1	1
	2	4	4	4	4	4	4	1	1	1	1
	3	4	4	4	4	4	4	4	1	1	1
	4	4	4	4	4	4	4	4	1	1	1
	5	4	4	4	4	4	4	4	4	1	1
	6	4	4	4	4	4	4	4	4	1	1
	7	4	4	4	4	4	4	4	4	4	4
	8	4	4	4	4	4	4	4	4	4	4
	9	4	4	4	4	4	4	4	4	4	4
	10	4	4	4	4	4	4	4	4	4	4
No M1 Option	1	4	4	4	4	4	4	2	2	2	2
	2	4	4	4	4	4	4	2	2	2	2
	3	4	4	4	4	4	4	4	2	2	2
	4	4	4	4	4	4	4	4	2	2	2
	5	4	4	4	4	4	4	4	4	2	2
	6	4	4	4	4	4	4	4	4	4	2
	7	4	4	4	4	4	4	4	4	4	4
	8	4	4	4	4	4	4	4	4	4	4
	9	4	4	4	4	4	4	4	4	4	4
	10	4	4	4	4	4	4	4	4	4	4
EBM Options M2 & M3	1	3	3	3	3	3	2	2	2	2	2
	2	3	3	3	3	3	3	2	2	2	2
	3	3	3	3	3	3	3	2	2	2	2
	4	3	3	3	3	3	3	3	2	2	2
	5	3	3	3	3	3	3	3	2	2	2
	6	3	3	3	3	3	3	3	3	2	2
	7	3	3	3	3	3	3	3	3	3	2
	8	3	3	3	3	3	3	3	3	3	3
	9	3	3	3	3	3	3	3	3	3	3
	10	3	3	3	3	3	3	3	3	3	3

	Log Price Scenarios (LP1-LP10, $/m³/yr)	Non-First Nation Timber Harvesting Companies									
		1	2	3	4	5	6	7	8	9	10
All Management Options	1	1	1	1	1	1	1	1	1	1	1
	2	1	1	1	1	1	1	1	1	1	1
	3	1	1	1	1	1	1	1	1	1	1
	4	1	1	1	1	1	1	1	1	1	1
	5	1	1	1	1	1	1	1	1	1	1
	6	1	1	1	1	1	1	1	1	1	1
	7	1	1	1	1	1	1	1	1	1	1
	8	1	1	1	1	1	1	1	1	1	1
	9	1	1	1	1	1	1	1	1	1	1
	10	1	1	1	1	1	1	1	1	1	1
No M1 Option	1	1	1	1	1	1	1	1	1	1	1
	2	1	1	1	1	1	1	1	1	1	1
	3	1	1	1	1	1	1	1	1	1	1
	4	1	1	1	1	1	1	1	1	1	1
	5	1	1	1	1	1	1	1	1	1	1
	6	1	1	1	1	1	1	1	1	1	1
	7	1	1	1	1	1	1	1	1	1	1
	8	1	1	1	1	1	1	1	1	1	1
	9	1	1	1	1	1	1	1	1	1	1
	10	1	1	1	1	1	1	1	1	1	1
EBM Options M2 & M3	1	1	1	1	1	1	1	1	1	1	1
	2	1	1	1	1	1	1	1	1	1	1
	3	1	1	1	1	1	1	1	1	1	1
	4	1	1	1	1	1	1	1	1	1	1
	5	1	1	1	1	1	1	1	1	1	1
	6	1	1	1	1	1	1	1	1	1	1
	7	1	1	1	1	1	1	1	1	1	1
	8	1	1	1	1	1	1	1	1	1	1
	9	1	1	1	1	1	1	1	1	1	1
	10	1	1	1	1	1	1	1	1	1	1

	Log Price Scenarios (LP1-LP10, $/m³/yr)	Total (All Entities)									
		1	2	3	4	5	6	7	8	9	10
All Management Options	1	1	1	1	1	1	1	1	1	1	1
	2	1	1	1	1	1	1	1	1	1	1
	3	1	1	1	1	1	1	1	1	1	1
	4	4	4	1	1	1	1	1	1	1	1
	5	4	4	4	4	1	1	1	1	1	1
	6	4	4	4	4	4	1	1	1	1	1
	7	4	4	4	4	4	4	4	1	1	1
	8	4	4	4	4	4	4	4	4	4	1
	9	4	4	4	4	4	4	4	4	4	4
	10	4	4	4	4	4	4	4	4	4	4
No M1 Option	1	2	2	2	2	2	2	2	2	2	2
	2	2	2	2	2	2	2	2	2	2	2
	3	4	4	2	2	2	2	2	2	2	2
	4	4	4	4	4	2	2	2	2	2	2
	5	4	4	4	4	4	4	2	2	2	2
	6	4	4	4	4	4	4	4	2	2	2
	7	4	4	4	4	4	4	4	4	4	4
	8	4	4	4	4	4	4	4	4	4	4
	9	4	4	4	4	4	4	4	4	4	4
	10	4	4	4	4	4	4	4	4	4	4
EBM Options M2 & M3	1	2	2	2	2	2	2	2	2	2	2
	2	2	2	2	2	2	2	2	2	2	2
	3	3	2	2	2	2	2	2	2	2	2
	4	3	3	3	2	2	2	2	2	2	2
	5	3	3	3	3	3	2	2	2	2	2
	6	3	3	3	3	3	3	3	2	2	2
	7	3	3	3	3	3	3	3	3	3	3
	8	3	3	3	3	3	3	3	3	3	3
	9	3	3	3	3	3	3	3	3	3	3
	10	3	3	3	3	3	3	3	3	3	3

Note. Optimal management options based on maximum net present value (NPV) across all 100 combinations of carbon price scenarios (CP1-CP10) and log price scenarios (LP1-LP10) for a planning horizon of 100 years where all management options are considered (M1 Pre-EBM, M2 EBM “Risk-managed” Old Growth Targets, M3 EBM “Low Risk” Old Growth Targets, and M4 No Harvest), Pre-EBM (M1) is excluded, and EBM options are compared (M2 and M3).

		Discount Rate	Portion of Timber Harvest First Nation Forest License %										Stumpage as a % of Log Price										
			0	10	14.2	30	46	50	60	70	80	90	0	1.9	4	6	8	10	12	14	16	18	20
British Columbia Provincial Government	All Options	0%	4	4	4	4	4	4	4	4	4	4	4	4	1	1	1	1	1	1	1	1	1
		2%	4	4	4	4	4	4	4	4	4	4	4	4	1	1	1	1	1	1	1	1	1
		4%	4	4	4	4	4	4	4	4	4	4	4	4	1	1	1	1	1	1	1	1	1
		6%	4	4	4	4	4	4	4	4	4	4	4	4	4	1	1	1	1	1	1	1	1
		8%	4	4	4	4	4	4	4	4	4	4	4	4	4	1	1	1	1	1	1	1	1
		10%	4	4	4	4	4	4	4	4	4	4	4	4	4	1	1	1	1	1	1	1	1
		12%	4	4	4	4	4	4	4	4	4	4	4	4	4	1	1	1	1	1	1	1	1
	No M1 Option	0%	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2	2	2	2
		2%	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2	2	2	2
		4%	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2	2	2	2
		6%	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2	2	2
		8%	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2	2	2
		10%	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2	2	2
		12%	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2	2	2
	No M1 or M4 Option	0%	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2
		2%	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2
		4%	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2
		6%	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2
		8%	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2
		10%	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2
		12%	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2
First Nations	All Options	0%	4	4	4	1	1	1	1	1	1	1	4	4	4	4	1	1	1	1	1	1	1
		2%	4	4	4	4	1	1	1	1	1	1	4	4	4	4	4	1	1	1	1	1	1
		4%	4	4	4	4	4	1	1	1	1	1	4	4	4	4	4	4	4	1	1	1	1
		6%	4	4	4	4	4	4	1	1	1	1	4	4	4	4	4	4	4	4	1	1	1
		8%	4	4	4	4	4	4	1	1	1	1	4	4	4	4	4	4	4	4	1	1	1
		10%	4	4	4	4	4	4	1	1	1	1	4	4	4	4	4	4	4	4	4	1	1
		12%	4	4	4	4	4	4	1	1	1	1	4	4	4	4	4	4	4	4	4	1	1
	No M1 Option	0%	4	4	4	2	2	2	2	2	2	2	4	4	4	4	2	2	2	2	2	2	2
		2%	4	4	4	4	2	2	2	2	2	2	4	4	4	4	4	2	2	2	2	2	2
		4%	4	4	4	4	4	2	2	2	2	2	4	4	4	4	4	4	4	2	2	2	2
		6%	4	4	4	4	4	4	2	2	2	2	4	4	4	4	4	4	4	4	2	2	2
		8%	4	4	4	4	4	4	2	2	2	2	4	4	4	4	4	4	4	4	2	2	2
		10%	4	4	4	4	4	4	2	2	2	2	4	4	4	4	4	4	4	4	4	2	2
		12%	4	4	4	4	4	4	2	2	2	2	4	4	4	4	4	4	4	4	4	2	2
	No M1 or M4 Option	0%	3	3	3	2	2	2	2	2	2	2	3	3	3	2	2	2	2	2	2	2	2
		2%	3	3	3	3	2	2	2	2	2	2	3	3	3	3	2	2	2	2	2	2	2
		4%	3	3	3	3	3	2	2	2	2	2	3	3	3	3	3	2	2	2	2	2	2
		6%	3	3	3	3	3	2	2	2	2	2	3	3	3	3	3	3	2	2	2	2	2
		8%	3	3	3	3	3	2	2	2	2	2	3	3	3	3	3	3	2	2	2	2	2
		10%	3	3	3	3	3	2	2	2	2	2	3	3	3	3	3	3	2	2	2	2	2
		12%	3	3	3	3	3	2	2	2	2	2	3	3	3	3	3	3	2	2	2	2	2

		Discount Rate	Portion of Timber Harvest First Nation Forest License %										Stumpage as a % of Log Price										
			0	10	14.2	30	46	50	60	70	80	90	0	1.9	4	6	8	10	12	14	16	18	20
Non-First Nation Timber Harvesting Companies	All Options	0%	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		2%	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		4%	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		6%	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		8%	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		10%	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		12%	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	No M1 Option	0%	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		2%	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		4%	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		6%	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		8%	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		10%	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		12%	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	No M1 or M4 Option	0%	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		2%	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		4%	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		6%	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		8%	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		10%	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		12%	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Note. Optimal management options across portion of timber harvest First Nation License and stumpage rates, with base values in bold, for management objectives “maximizing expected net present value (ENPV)” using “disinterested” probability density functions, considering all management options (M1 Pre-EBM, M2 EBM “Risk-managed” Old Growth Targets, M3 EBM “Low Risk” Old Growth Targets, and M4 No Harvest), excluding M1, and comparing EBM (M2 and M3).