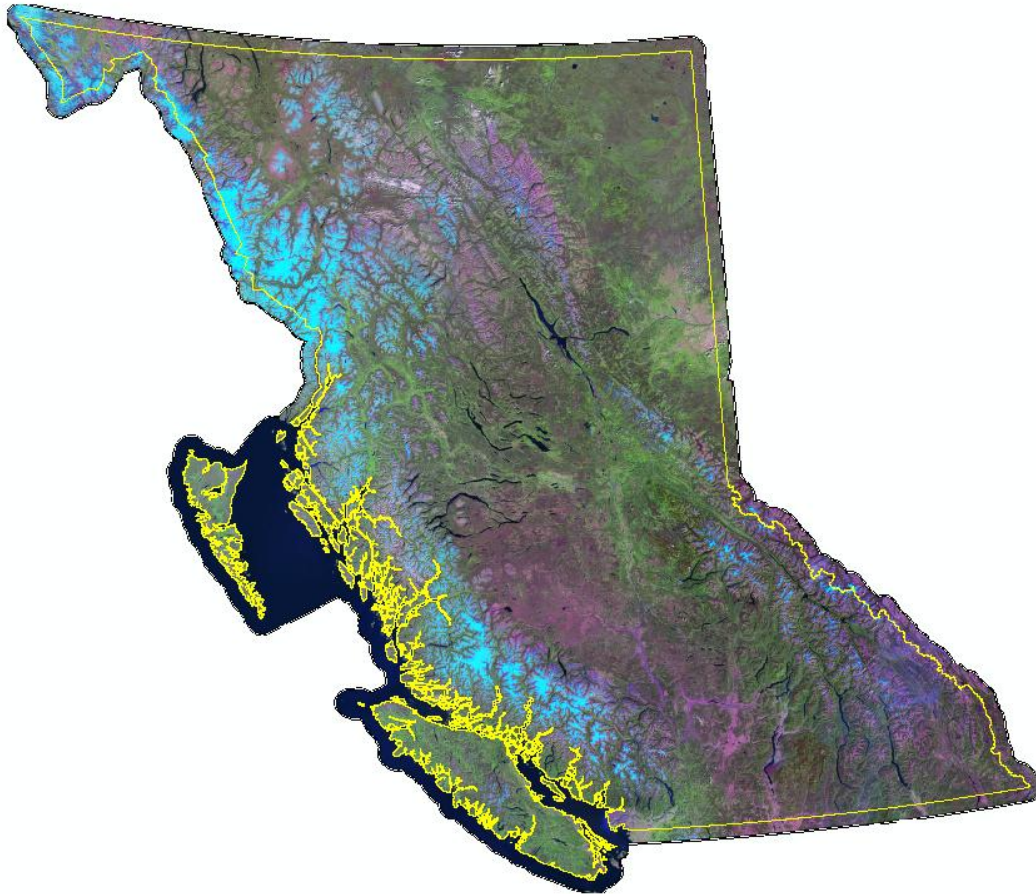


The BC Vegetation Resources Monitoring Program:

**Reporting and Monitoring
British Columbia's Forest Resources
(2000 – 2009)**



Forest Analysis and Inventory Branch
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Executive Summary

Sustainable forest management and new provincial, national and international monitoring initiatives require a forest inventory database that is flexible, robust, and based on a statistically valid sample design. Current databases such as the Vegetation Resources Inventory (VRI) are limited in capability for reporting on the provincial forest resource and changes over time. In the late 1990's it was recognized that a suitable database to meet these requirements was not available. In an effort to address this issue, the BC Ministry of Forests worked in partnership with the Canadian Forest Service and inventory leaders from all the provinces and territories to develop a National Forest Inventory (NFI). For the year of 2000, BC completed the first provincial component of the NFI photo database in 2003 and the corresponding ground sample component in 2006. The photo database was then updated for disturbance changes in 2006 and 2009. This is now referred to as the BC Vegetation Resources Monitoring Program or VRMP and is based on samples from 2419 photo plots and 268 fixed-area ground plots. Both types of plots have re-measurement schedules designed to meet both provincial and national monitoring requirements.

This report presents statistically valid estimates of BC's forest resources current to 2009. These estimates were generated from the VRMP photo plot database and include total area, net volume, total biomass carbon for stem, branch, foliage, and roots (TBC), and total ecosystem carbon (TEC); the total of TBC plus dead organic matter and soil carbons. VRMP also includes forest inventory classifiers of land cover, land type, vegetation type, leading species and age class, and spatial units of province, terrestrial eco zone, Biogeoclimatic Ecosystem Classification (BEC) zone, and the Ministry of Forests region. For each classifier and spatial unit, the relative standard error and confidence intervals are provided.

The functionality of the VRMP database for forest resource monitoring was tested by generating estimates of forest resource changes due to natural and man-made disturbances and growth, for the period of 2000-2009. Although some classifiers had high relative standard error, the overall results showed that periodic changes in the provincial forest resource can be effectively monitored through scheduled re-measurements of the established plots and the incorporation of this data into the VRMP database.

Based on this application of VRMP, in 2009 British Columbia's forest resources were calculated to have a total net volume of 9.4 billion cubic metres (relative standard error RSE = 2.2%), a total TBC of 5.4 billion tonnes (RSE=1.8%) and a TEC of 15.5 billion tonnes (RSE=1.7%). After adjustment for the decomposition process change due to the MPB mortality (assuming a conservative 0.5% of dead organic matter annual decay rate), the final estimate of TEC is 15.2 billion tonnes. By comparing this to the same calculations for the forest resources in 2000, it can be shown that British Columbia has experienced reductions of 320.6 million cubic metres in total net volume (RSE=-26.2%), and 165.9 million tonnes in total biomass carbon (RSE=-23.5%), while an increase of 237.8 million tonnes in total ecosystem carbon (RSE=32.6%). After the decay adjustment, the net TEC loss

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between 2000-2009 is 112.3 million tonnes. The majority of these reductions are attributable to Mountain Pine Beetle (MPB) mortality and depletions from harvesting and forest fires.

It is the first time that such estimates of the province's forest resource and its changes have been obtained using a statistically valid sample. The VRMP sampling design is both flexible and robust such that it can be easily modified or expanded to accommodate various provincial monitoring needs.

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List of Acronyms

ALR	Agricultural Land Reserve
AOI	Area of Interest
BC	British Columbia
BEC	Biogeoclimatic Ecosystem Classification
CFS	Canadian Forest Service
FAIB	Forest Analysis and Inventory Branch
FC	Forest Cover
FIP	Forest Inventory Planning
FMLB	Forest Management Land Base
IHS	Intensity, Hue and Saturation, an image colour enhancement
ETM/TM	Enhanced Thematic Mapper/Thematic Mapper, Landsat 7/5
LRDW	Land Resource Data Warehouse
MFR	BC Ministry of Forests and Range
NAD	North American Datum
NFI	National Forest Inventory
NTA	No Type Available
PFC	Pacific Forestry Centre
PSYU	Public Sustainable Yield Unit
RESULTS	Reporting Silviculture Update and Land Status Tracking System
SS	No Typing Available
TBC	Total Biomass Carbon
TEC	Total Ecosystem Carbon
TFL	Tree Farm License
TRIM	Terrain Resource Information Management
TSA	Timber Supply Area
VRI	Vegetation Resources Inventory
VRMP	Vegetation Resources Monitoring Program

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Introduction

Accurate and timely reporting of the forest resource in the province of British Columbia (BC) is a fundamental function of the BC Forest Inventory and Monitoring Program. This function is particularly critical for the province to meet provincial, national and international obligations, and initiatives related to sustainable forest management and climate change.

Past approaches to reporting the forest resource involved compiling the existing provincial forest inventories at different points in time. There were several problems and challenges with this approach such as mixed inventory vintages, inconsistent inventory standards, and missing inventory data. For example, of the total area of British Columbia in 2009, 4% does not have inventory data; 60% is in the former Forest Inventory Planning (FIP) standard that was used prior to 1998 and 40% is to the current Vegetation Resources Inventory (VRI) standard implemented in 1996. For the forested land where the forest inventory data is available, about 41 % of this area has inventory data that is greater than 20 years old, and 26% of this area has inventory data that is greater than 30 years old.

The above-mentioned problems and challenges make it difficult to provide a consistent and statistically defensible report on the provincial forest resource. They also make it very difficult to monitor the changes and trends over time of the forest resource in BC. A provincial sampling approach, such as using Canada's National Forest Inventory (NFI) as implemented in BC is a more viable option.

The NFI is an initiative designed and implemented jointly by the federal, provincial and territorial jurisdictions working in partnership, with the purpose of assessing and monitoring the extent, state and sustainable development of Canada's forests [1]. The Ministry of Forests and Range (MFR), Forest Analysis and Inventory Branch (FAIB), has been working in partnership with Canadian Forest Service (CFS) on the implementation of NFI ground and photo plots in BC since the late 1990's. The first NFI photo database BC was established for the year 2000, while the ground plots were completed in 2006. The photo plot database has been updated numerous times between 2000 and 2009. This provides a unique opportunity for the province to utilize it to report new statistics and changes for meeting provincial monitoring needs. Detailed methods for the preparation and processing of the databases, analysis, and summary reports are described in the MFR FAIB reports [2, 3]. It is important to note that the monitoring framework established through this initiative warrants recognition as the standard for provincial forest monitoring across Canada. To this end the BC implementation of the NFI is now referred to as the Vegetation Resources Monitoring Program, or VRMP.

This report provides a summary of the British Columbia forest resource statistics in 2009 and the changes during the periods 2000-2009. These statistics are based on the data from the VRMP photo plots established in BC. It is

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the first time that estimates of such forest resource and its changes have been obtained based on a valid statistical sample.

The ground plot data were not used in this report, but is expected to be used in the future for comparing and supplementing the photo-plot based estimates of tree related attributes. Further to this, the ground plot data can be used to produce estimates of attributes that are not available in the photo plot database such as biomass.

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National Forest Inventory

The NFI design consists of two types of probability samples for points across Canada: permanent photo plots and ground plots. The photo plots are located on a systematic 20 km by 20 km grid across Canada with each plot size of 2 km by 2 km representing about 1% of Canada's land mass. A simple random subsample of 10% of these systematic photo plots, at or near the grid point, falling in forested area is selected for ground plots. There is a total of about 25,646 photo plots and 1,135 ground plots in Canada. The photo plots and ground plots are stratified by the 15 terrestrial eco-zones. These are then further divided by provinces or territories to form NFI units that are used for estimation and reporting purposes.

The photo plots are the primary source of data for reporting, while the ground plots provide additional attribute information not available in the photo plots. The photo plots are identified, delineated, and interpreted on conventional mid-scale aerial photography for land cover classes including forest stand attributes and other spatial classes such as land use, ownership, and protection status. The ground plots consist of nested circular plots, line transects and soil pits. The attributes and data collected in ground plots, such as large and small trees, herbs and shrubs, coarse woody debris, soil and site conditions complement and enhance the attributes and data from the photo plots.

Establishment of the NFI database was completed in 2006. The first NFI report for Canada is in preparation for publication,

The re-measurement of all NFI photo and ground plots is based on a 10- year NFI data cycle. All the photo and ground plots in the country are divided into two random panels, with half of the total photo and ground plots contained in each. Each panel is completely re-measured in five years. The implementation plan includes re-measurement of the first panel of the photo and ground plots between 2007 and 2011, and re-measurement of the other panel between 2012 and 2016. Reporting from these re-measurements will be completed every 5 years.

The detail about the NFI design, analysis, and reporting can be found at <https://nfi.nfis.org/index.php>.

Vegetation Resources Monitoring Program for BC Forest Monitoring and Reporting

The NFI provides a flexible sampling framework that provinces and jurisdictions can modify, expand or change to accommodate their provincial monitoring needs. BC as an active partner of NFI has not only made significant contributions to the development of the NFI design, standards, procedures, and implementation, but also established its own program, databases, and analysis capabilities through the creation of VRMP. These have been done to meet the specific goal of providing data to support provincial forest monitoring and reporting initiatives.

The first VRMP photo plot database was established in 2000 consisting of a total of 2,419 NFI plots in BC. The photo plot data was initially generated from data drilling the existing provincial databases that contained inventory files of varying vintage and standards. This includes the former Forest Inventory Planning standard (FIP) which was used prior to 1996. This standard was then replaced with the currently used Vegetation Resources Inventory (VRI) standard. To date, approximately 45% of the forested landbase has been inventoried to this standard. For the development of the photo plot database, where no inventory coverage was available (4% of the landbase), the areas were inventoried to the VRI standard through interpretation of existing midscale photography. Satellite remote sensing data (Landsat 5/7 TM) was then used to update all changes due to harvesting. Road feature data was also captured from the existing road inventory updated twice in 2000 and 2005, respectively, using a manual interpretation of Landsat image data.

In 2009, a new VRMP photo plot database was created with the following additions and changes made to the earlier 2000 version:

- Updates on harvesting changes were conducted using Landsat 5 imagery from 2005, 2007, and 2008
- Updates on harvesting changes were done using the Ministry of Forests and Range's 'Reporting Silviculture Update and Land Status Tracking System' (RESULTS) data in 2008,
- Updates on forest fire changes were done using Landsat 5 imagery from 2002 to 2008,
- Updates due to Mountain Pine Beetle mortality were completed for 2007,
- The new volume projection model (VDYP7) was applied to the databases for both years 2000 and 2009. This replaced the formerly used projection model (VDYP6),
- Biomass and carbon data were generated , and
- Some photo plots were replaced with new VRI data completed between 2000 and 2008 and the new data generated from the NFI re-measurement pilot project (2006).

The detail of creating the VRMP photo databases from the above processes is described in the next section.

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The VRMP ground plot installation commenced in 2000 and was completed in 2006 with a total of 268 plots. These ground plots were randomly selected from all the photo plot centers falling in forested land. In 2009, interest was expressed to use VRMP data for biomass modeling. This would be done by expanding the ground plot program on to the non-forested landbase and by intensifying the number of plots in the forested landbase. Currently this plan is on hold pending funding considerations.

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The VRMP Photo Databases

Database Structure

There are 2 components in the VRMP photo database maintained by the MFR: the spatial polygons/plots/layers in ArcGIS shape files, and the attribute tables in MS Access format. The structure and content of the databases allow for a smooth and standard updating, upgrading, overlaying, re-measurements, NFI conversion, quality assurance, database maintenance, data analysis and reporting.

The spatial layers include forest cover polygons (key-area, polygon, layer, history, volume, and biomass), disturbance polygons including harvesting, fire, and MPB disturbance, the administrative boundary maps, watershed and land map, road networks, base maps, BEC/ECO zones maps, eco-province maps, etc., all in the 2km by 2km photo plots for the entire province.

The MFR MS Access attribute database consists of three linked data tables: *Key-area*, *Polygon*, and *Layer*. The *Key-area table* consists of general plot attributes, including polygon area. The *polygon table* consists of general polygon attributes, including the land cover classification. The *layer table* consists of stand layer attributes including volume per hectare by tree species. These tables are linked by the plot number, provincial plot identification and polygon identification. There are also other tables available such as history, volume projection, biomass and carbon calculation, and disturbance. The number and kind of attributes included in the tables can easily be changed to facilitate the data analysis and reporting. The linkages of these tables are done through primary and secondary identifiers (ID's) required for both NFI standard formats such as NFI photo plot ID and polygon ID, and in the MFR specific format such as MFR ID. These ID's are linked directly to the MFR's source databases.

The data utilized for this report were polygon areas, land cover classification, *rank one layer* merchantable net volume per hectare, projected stand age/height, site index, leading species, disturbance type and percentage, above ground biomass, total biomass carbon, and total ecosystem carbon. The *rank one layer* describes the dominant tree species and the polygon tree volume. Definitions of these and other relevant attributes are in Appendix III. It should be noted that these attribute tables do include many attributes that are not part of the standard NFI photo database., All of these are used as the data source for statistical analysis and provincial applications.

VRMP photo database 2000

The year 2000 photo plot database was created by first 'drilling' the provincial FIP inventory database for the year 2000. This FIP database was created from the interpretation of specific attributes of stand, land cover class, and ownership by using of mid-scale aerial photos. This drilled database was then updated manually using

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Landsat TM Imagery, for depletion changes due to harvesting. A total of 43 photo plots that had data gaps (no inventory data available) were enhanced by doing an updated photo interpretation of old 1998 photography. Finally, the net merchantable volume for these plots to the end of 2000 was projected by using the FAIB Variable Density Yield Prediction 6 (VDYP6)¹ model.

Update for cuts, fires, and MPB mortality

Since the first update in 2000, the photo databases have undergone several spatial and attribute updates. Harvest depletion update was done in 2005, 2007 and 2008 using manual delineation and interpretation of harvesting changes by using the Landsat TM imagery. In addition, a new update was performed in 2008 for harvested areas captured by the MFR tracking system RESULTS. Where Landsat update changes overlapped with RESULTS update changes, the RESULTS update was used.

Large forest fires (greater than 100 ha) that occurred between 2000 and 2008 were manually interpreted from Landsat imagery and the resulting delineated fire polygons were then used to overlay with the forest cover layer. The fire polygon resultants were then areas-weighted and averaged, and then each forest cover polygon in the 2009 photo database was assigned a burn percentage.

The cumulative mortality up to 2007 for mountain Pine Beetle (MPB) was first created from MFR Research Branch data that were in a GIS format of 400m by 400m raster cells coded with a percentage of kill from 0 to 100. This MPB layer was vectorized and then overlaid with the forest cover polygons. The area weighted average of percentage kill was calculated and assigned to each of the forest cover polygons. This percentage kill was then applied to the pine volume in the polygon and the total polygon volume was recalculated based on the MPB volume loss.

Upgrade by New VRI polygons and re-measurement pilot

The 2009 photo plot database includes all the new VRI polygons inventoried before 2009 (18% of the total area of all the 2419 photo plots). In addition, as part of the NFI re-measurement pilot project completed in 2007, approximately 100 VRMP photo plots were replaced through a new interpretation of 2005 colour photographs using the VRI standards.

Upgrade to the new VDYP7 volume prediction model

A new volume prediction model (VDYP7) was implemented by the BC Forest Inventory and Monitoring Program in 2007. The volume differences between the new model VDYP7 and the old VDYP6 vary across the province, thus the VDYP7 projection was applied to both the 2000 and 2009 photo databases for consistency and

¹ See www.for.gov.bc.ca/hts/vdyp.

integrity for future reporting and monitoring purposes. Accordingly, the photo database was modified to accommodate the input data requirements of the new model.

Stand level total biomass carbon and total ecosystem carbon

The carbon budget model- Canadian Forest Sector version 3 (CBM-CFS3) was used to calculate the photo plot (vegetated treed) total biomass carbon (TBC) that includes stem, branch, foliage, and roots, and total ecosystem carbon (TEC) that includes TBC plus dead organic matter and soil carbon. The CBM-CFS3 is a stand-to-landscape level carbon budget model that uses input data from the forest inventory, disturbances, and growth and yield to derive ecosystem carbon. Details of the modeling procedures are described in Kurz *et al* [4]. The 30 year average annual temperature (climatic data obtained from MFR research branch) for each of the analysis units was used to drive the dead organic matter decay function at the time of stand initialization. The growth and yield data were obtained from VDYP7 output for each vegetated stand. Within each photo plot, a stand, defined as ‘a polygon or multiple polygons that have the same species composition and site index’ was treated as one inventory record.

After model initialization, the carbon pools at time *step zero* in the model represented total stand carbon in the year 2000. For the 2009 data, disturbances such as fires and harvesting are captured in the inventory, but disturbances due to the MPB infestation are not included. The MPB infested stands were processed by using provincially modeled results of accumulative beetle kill from 2000 to 2009. The CBM model operates as if the MPB disturbance events occurred in year 2008 so during the model simulation the stand age was rolled back by one year to accommodate MPB events. Also during model simulation, it was assumed that in the MPB attacked stands, stems turned into snags, foliage turned into litter and roots turned into litter or soil.

The carbon pools at time *step one* were used to calculate stand carbon for year 2009. This calculation significantly overestimates the dead organic carbon pool because the actual decomposition of litter, snags, and dead roots occurs over time but is lumped into one year for the operation of the model. This significant limitation can be improved by using data sources that include the year of death and spatial data for the location of the mortality. This type of data is now available for some pine stands in the province, but was not accessible while the photo data were processed during this study.

Rates of decay for different types of dead organic matter vary considerably. For example, very recalcitrant materials like polarized lignin in soil have been shown to decay at a rate of 0.33% per year whereas very soluble and cellulosic rich materials like needles and leaves can decay at a rate of 50% per year. For back calculations² outside the CBM model, a conservative factor of 0.5% per year was used to estimate the losses of dead organic matter carbon due to MPB disturbances for the year 2009. This over simplified approach probably does not

² Manual calculations done to check the model output

accurately represent any particular part of the carbon pool decomposition process, but it does provide an overall estimate of carbon losses due to major MPB events on BC forest lands. This part of the carbon modelling would be greatly improved with a detailed study of the impact of MPB tree mortality on forest ecosystem carbon dynamics. This could be carried out through a time series data analysis of MPB stands in BC impacted over the past decade. It should also be noted that for areas such as vegetated wet lands, vegetated non-treed, and vegetated treed with non merchantable volume, carbon cannot be estimated by CBM. Therefore, the data compiled by Boudewyn *et al* [5] was used to estimate stand carbon for these polygon types.

Road data

Road building inevitably presents a disturbance to the natural environment and involves crossing streams and rivers which in turn impacts stream habitat and organisms such as fish. Therefore, the total road length and density, and the number of stream crossings are two of the important environmental indicators required to be monitored.

As the part of establishing the first VRMP photo plot database of roads and stream crossings for year 2000, the road network inside of a 3km by 3km plot centered on each of the 2419 photo plots was captured by extracting all the roads from the provincial base map (TRIM) current to 2000. All these 3km by 3km plots were updated for new roads from a visual interpretation of Landsat 7 ETM imagery acquired in 1999 and 2000. The updated road plots were then overlaid with the streams/rivers layer extracted from the TRIM database and the resultant layer was cut into the final 2km by 2km photo plots of the year 2000 photo plot database.

The new roads built between 2003 and 2005 that were tracked by the MFR Resource Tenures and Engineering Branch (from the layer: WHSE_Forests_Tenure_ABR.Road_Section_line stored in the Land and Resource Data Warehouse) were also overlaid onto the VRMP photo plots. The year 2005 photo plot database for roads/stream crossings was created from updating the year 2000 layer for new roads and stream crossings using the same method (i.e. Landsat 5 TM image interpretation).

Figure 1 illustrates the updating process for one VRMP photo plot with existing forest polygons and roads as well the new road segments and new harvesting openings that were captured from the colour Landsat TM image shown in the background.

Although not discussed in this report, further detail about the data collection methods, estimates, and use of the VRMP road data by the Ministry of Environment for the *State of Environment Report* can be found in Reference [6].

The VRMP photo database 2009

The VRMP photo database 2009 includes all the updates/upgrades/changes mentioned in the sections above with a new volume projection date as January 1, 2009. This is the BC baseline data for future monitoring and reporting.

Processing and conversion of the VRMP photo data to the NFI standards

The standard NFI photo plot database consists of 5 spatial layers: NFI photo plot, ownership, land cover, land use, and protection status, associated with a number of attribute tables. The detailed standards and procedures for creating these layers and tables can be found in References [2,7].

Updating

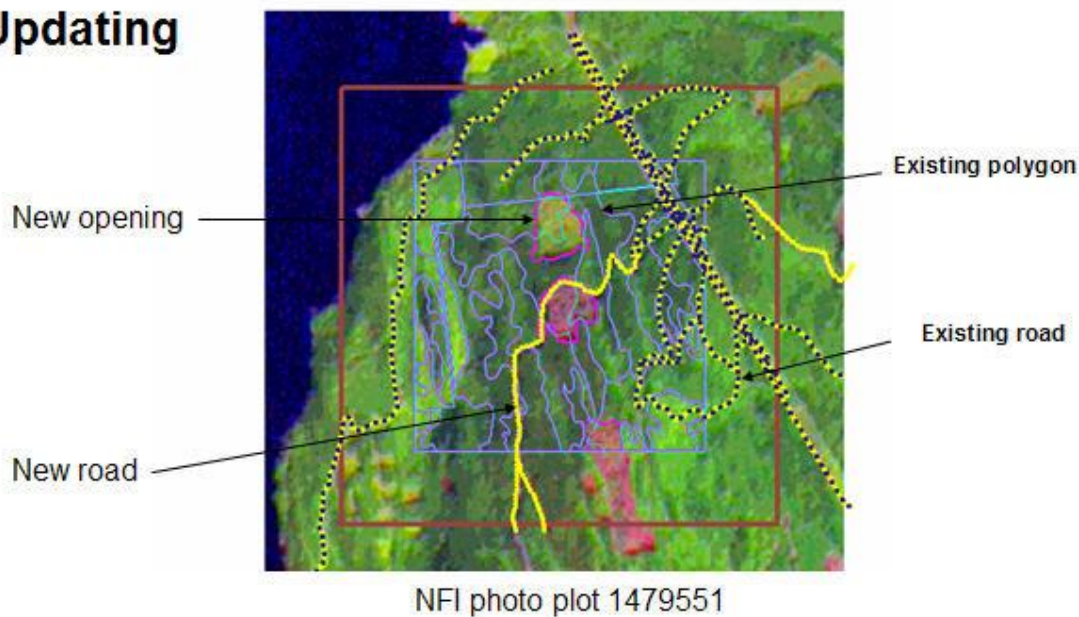


Figure 1 Updating the VRMP photo plot for new openings and new roads (yellow line). The smaller square 2km by 2km is the actual photo plot and the bigger square is the 3km by 3km plot for roads.

The VRMP photo database 2000 has an ownership layer created from the old FIP inventory. In 2008, FAIB created a new ownership layer which was used to create the ownership layer in the VRMP photo database 2009. Because of the differences in the new and old ownership datasets, some processes and conversion rules had to be modified.

The protection status layer was created from an overlaying the forest cover, ownership, PSYU, parks and protected areas. The PSYU layer was used for the VRMP photo database 2000 because it contained some parks and protected areas. It was not used for the 2009 data as all the parks and protected areas were already available in the new ownership layer. Although the effort was made to maintain consistency between the protection status

conversions of 2000 and 2009, because of the different input data sets, there might be some differences in the coding.

The land use layer was created from overlaying the forest cover, ownership, agriculture, and recreation.

Although the effort was made to create the land use data as close as possible to the NFI standards, cautions must be taken when using this layer as there are problems in the source data and conversion rules. The province now has more updated databases that could be used to create better land use data. It is also recommended that the next update should concentrate on recreating this land use layer using the improved source data and conversion rules.

The land cover layer was created directly from the forest cover data. The conversion rules and processes used were those established for the 2000 and 2009 datasets. For example, the NFI standard for polygon volume is whole stem volume while in the VRMP, net merchantable volume is used. A conversion was made based on the linear relationship between the whole stem volume and net volume extracted from the province's ground plot database. The detailed conversion rules developed for the 2000 data can be found in [2]. These conversion rules were modified slightly for the 2009 data as some new input datasets were used.

A set of SAS program codes written to facilitate the processing and conversion of the VRMP attribute data to the NFI standards. BC has submitted the standard NFI photo plot data to the NFI project office at PFC in 2000 and 2006. The 2006 data was used for the first NFI baseline forest reporting.

Statistical Analysis

Overview

The first question to be answered is: how much forest resource is there in BC in 2009? For the analysis and reporting purposes, individual polygons are classified according to some pre-set criteria (called “classifiers”), and for each class 4 items (called “estimators”) were used to report out using the VRMP photo database: area, volume, biomass, and carbon. The target population is the entire province, however, 3 sub-provincial units: Coast/Interior (grouped by BEC zones), eco zones, and MFR Regions were also defined as sub-populations and the same estimates were made for each of the sub-populations (Table 1). All the estimates were calculated as the totals associated with confidence intervals (95% probability) and relative standard errors, by classifier-class. The total volume is net volume at the primary utilization level estimated using the VDYP7 yield model. The primary utilization level on the Coast is diameter at breast height (dbh) 17.5 cm+ and 12.5 cm+ in the Interior.

Table 1. Spatial units for the VRMP analysis and estimation.

<i>Type</i>	<i>Unit (population)</i>	<i>Descriptions (area)</i>
Province	Province	The entire province including land and fresh water (94,657,697 ha)
BEC zones	Coast	BEC zone = CDF, CWH, MH, or CMA (18,822,801 ha)
	Interior	BEC zone = all other BEC zones (75,816,838 ha)
Eco zones	Boreal Cordillera	NFI eco zone in BC = Boreal Cordillera (18,556,720 ha)
	Boreal Plains	NFI eco zone in BC = Boreal Plains (4,118,644 ha)
	Montane Cordillera	NFI eco zone in BC = Montane Cordillera (44,646,243 ha)
	Pacific Maritime	NFI eco zone in BC = Pacific Maritime (20,722,875 ha)
	Taiga Plains	NFI eco zone in BC = Taiga Plains (6,599,238 ha)
MFR Regions	RCO	MFR Coast Forest Region = (15,101,998 ha)
	RNI	MFR Northern Interior Forest Region = (54,131,602 ha)
	RSI	MFR Southern Interior Forest Region = (25,409,560 ha)

The VRMP is a monitoring system capable of reporting changes over time. Although the first standard statistically valid re-measurement has not been completed yet, a demonstration of this type of change analysis is given using both the 2000 and 2009 VRMP photo datasets. The change estimates are only made for the three sub-provincial units, although other estimates could be made on the classifiers upon request.

Data classification

Although the data can be classified in many ways, there are two critical factors in selecting classifiers that affect the precisions of estimates: the area of interest (AOI) and likelihood of occurrence of the classifier-classes of interest in the AOI. For example, it is not feasible to report on a TFL basis with reasonable precision because of

the relatively small number of plots in a TFL. Similarly, there is a limit on the number and levels of classifiers. The classifier-classes should be chosen so that class estimates can be achieved with reasonably good precision.

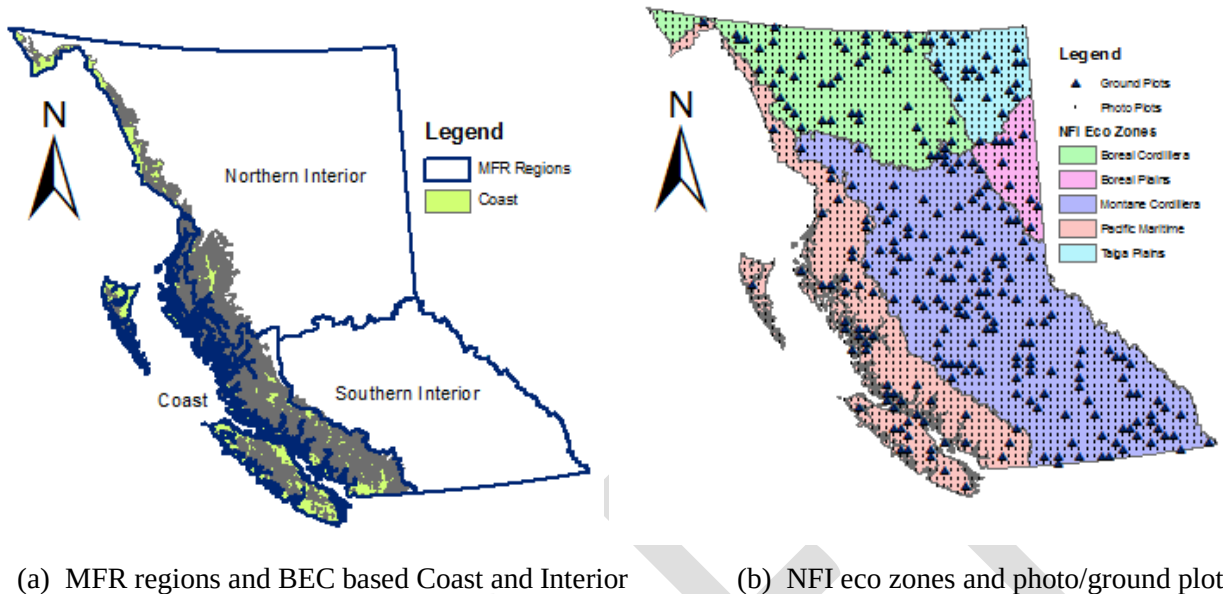


Figure 2 Spatial units based on the province, MFR regions, BEC Coast and Interior, NFI eco zones. The locations of VRMP photo and ground plots are shown in (b).

For this analysis, the following classifiers are used: land-cover, land-type, vegetation-type, leading-species and age-class. Each of these classifiers has several classes. Definitions of the classifier-classes and classification rules are given in Table 2. Land-cover is based on level 1 and 2 of the BC Land Cover Classification Scheme (BCLCCS) [8]. Land-type, age class, and leading species were determined in the same way as defined in the MFR State of Forest reporting [9].

Table 2 Classifier-class definitions and database classification rules. BCLCCS refers to British Columbia Land Cover Classification Scheme.

<i>Classifier</i>	<i>Class</i>	<i>Descriptions (classification rules)</i>
Land cover	Non-vegetated Land	BCLCCS level 1 = "N" and level 2 = "V"
	Non-vegetated Water	BCLCCS level 1 = "N" and level 2 = "W"
	Vegetated Non-treed	BCLCCS level 1 = "V" and level 2 = "N"
	Vegetated Treed	BCLCCS level 1 = "V" and level 2 = "T"
Land type	Alpine	BCLCCS level 2 ≠ "W" and level 3 = "A"
	Fresh Water	BCLCCS level 1 = "N", and level 2 = "W" and level 5 ≠ "OC"
	Grassland	BCLCCS level 1 = "V" and level 2 = "N" and level 3 = "U" and level 4 = "HG"
	Shrub	BCLCCS level 4 = "SL" or level 4 = "ST"
	Wetland	BCLCCS level 2 ≠ "T" and level 2 ≠ "W" level 3 = "W"
	FMLB	Site Index > 5 or data source = "cut"
	Other	None of above

Species	Aspen	The first leading species = "AT"
	Douglas fir	The first leading species = "F*"
	Hemlock	The first leading species = "H*"
	Lodgepole pine	The first leading species = "PL", or "PLI"
	Spruce	The first leading species = "S*"
	True fir	The first leading species = "B*"
	Western red cedar	The first leading species = "CW"
	Other broadleaf	The first leading species = "A", "ACT", "AC", "D", "DR", "E*", "M", "R", or "Q"
	Other conifer	The first leading species = "L*", "PY", "PW", "PA", or "YC"
	Non Vegetated Treed	None of above
Age class	1 -20	Projected age > 0 and < 21
	21 -140	Projected age > 20 and < 141
	141 - 250	Projected age > 140 and < 251
	> 251	Projected age > 250
	Non age	None of above
Vegetation type	Broadleaf	BCLCCS level 4 = "TB"
	Conifers	BCLCCS level 4 = "TC"
	Mixed	BCLCCS level 4 = "TM"
	Not treed	None of above

Estimation

The estimator total is obtained as the product of the 'per-hectare estimator in a classifier-class' and the 'population total land area' (the province or sub-provincial units). The per-hectare values are estimated using the generalized ratio-of-means (ROM) estimator [10]. Estimation of change follows a similar approach. These estimation procedures are similar to those developed by the NFI Project Office for point-in-time estimation [11]. Note that for the change estimation there was no panelling; all the 2419 photo plots were used. For all the estimation, a total land area (including fresh water) for the province was 94,657,697 ha. This provincial total area was obtained from the 1:50 000 Watershed Atlas, which is a computerized base map of aquatic features in the province (see www.env.bc.ca/fish/watershed_atlas_maps/index.html).

Procedures for estimation of area, volume, TBC, and TEC totals in 2009

The procedures for the estimation of estimator area and volume (same to total biomass carbon and total ecosystem carbon) totals by classifier-class in 2009 include the following steps:

1. Obtain the *Key_area*, *Polygon*, and *Layer* data tables for 2009 from the photo-plot database.
2. Sum the volume per hectare of all trees species in the rank 1 layer in the *Layer* table, and multiply the total volume per hectare by the polygon area, to obtain the polygon total volume.

3. Classify each polygon into classifier-classes of interest (e.g., land cover classes).
4. Calculate a_{ki} , the total area (or total volume) in the k th classifier-class in the i th photo plot ($i = 1, 2, 3, \dots, n = 2419$), by summing the total area (or total volume) of all polygons in the k th classifier-class in the i th plot. If a classifier-class does not appear in a photo plot, then area (or volume) is assigned a value of 0 for that plot.
5. Calculate a_{Tki} , the total area of all polygons in the i th photo plot, by summing the total area of all polygons in the i th photo plot ($i = 1, 2, 3, \dots, n = 2419$).
6. Calculate the provincial average area proportion (or volume per hectare) of the k th classifier-class, $\hat{y}_k$, and associated statistics (variance, relative standard error, and confidence interval, respectively):

[1]

$$\hat{y}_k = \frac{\sum_{i=1}^n w_i a_{ki}}{\sum_{i=1}^n w_i a_{Tki}}$$

[2]

$$\text{var}(\hat{y}_k) \doteq \frac{1}{\left(\sum_{i=1}^n w_i a_{Tki} / \sum_{i=1}^n w_i \right)^2} \left(\frac{\sum_{i=1}^n (w_i a_{ki})^2 + \hat{y}_k^2 \sum_{i=1}^n (w_i a_{Tki})^2 - 2 \hat{y}_k \sum_{i=1}^n w_i^2 a_{ki} a_{Tki}}{\left(\sum_{i=1}^n w_i \right) \left(\sum_{i=1}^n w_i - 1 \right)} \right)$$

[3]

$$SE\%(\hat{y}_k) = \frac{\sqrt{\text{var}(\hat{y}_k)}}{\hat{y}_k} 100$$

[4]

$$\hat{y}_k \pm t_{\alpha/2, n-1} \sqrt{\text{var}(\hat{y}_k)}$$

where $t_{\alpha/2, n-1}$ is the t -value at the α level and $n-1$ degrees of freedom.

7. Estimate the provincial total area (or total volume) in the k th classifier-class, $\hat{Y}_k$, and associated statistics (variance, relative standard error and confidence interval, respectively):

[5]

$$\hat{Y}_k = 94657697 \times \hat{y}_k$$

[6]

$$\text{var}(\hat{Y}_k) = (94657697)^2 \times \text{var}(\hat{y}_k)$$

[7]

$$SE\%(\hat{Y}_k) = \frac{\sqrt{\text{var}(\hat{Y}_k)}}{\hat{Y}_k} \times 100$$

[8]

$$\hat{Y}_k \pm t_{\alpha/2, n-1} \sqrt{\text{var}(\hat{Y}_k)}$$

8. Output the statistics for provincial reporting.

Procedures for estimation of change in area, volume, TBC, and TEC totals between 2000 and 2009

The procedures for the estimation of changes in provincial total area and volume totals (same to the total biomass carbon and total ecosystem carbon) by classifier-class during the period 2000- 2009 include the following steps:

1. Obtain the *Key_area*, *Polygon*, and *Layer* data tables for 2000 and 2009 from the photo-plot database.
2. Sum the volumes per hectare of all trees species in the rank 1 layer in the *Layer* tables, and multiply the total volume per hectare by the polygon area to obtain the polygon total volume, for 2000 and 2009.
3. Classify each polygon into classifier-classes of interest (e.g., land cover classes) in 2000 and in 2009.
4. Calculate $a_{2000,ki}$ and $a_{2009,ki}$, the total area (or total volume) in the k th classifier-class in the i th photo plot in 2000 and 2009, respectively, by summing the total area (or total volume) of all polygons in the k th classifier-class in the i th plot. If a classifier-class does not appear in the photo plot, then area (or volume) is assigned a value of 0 for that plot.
5. Calculate $a_{2000,Tki}$ and $a_{2009,Tki}$, the total area of all polygons in the i th photo plot in 2000 and 2009, respectively ($i = 1, 2, 3, \dots, n = 2419$).
6. Merge the polygon total area and total volume for 2000 and 2009 by photo plot.
7. Calculate Δa_{ki} , the periodic change in total area (or total volume) over the period 2000-2009 in the k th classifier-class in the i th photo plot ($i = 1, 2, 3, \dots, n = 2419$). That is, $\Delta a_{ki} = a_{2009,ki} - a_{2000,ki}$.
8. Proceed with the estimation of area and volume change using the same formulae as for the area and volume totals in 2009 (Eq. [1] to [8]), replacing a_{ki} with Δa_{ki} , and setting $a_{Tki} = a_{2009,Tki}$. Note that where the change estimate is negative, we take the absolute value of the relative standard error (RSE%).
9. Output the statistics for provincial reporting.

Results: Status of BC Forest Resources in 2009 and the Changes between 2000 and 2009

Provincial Totals in 2009

For the total provincial area of 94,657,697 ha (including land and fresh water), in 2009 the total net volume is estimated as 9.4 billion m³ (RSE% = 2.2%), the total biomass carbon (TBC) is estimated as 5.4 billion tonnes (RSE%=1.8%), and the total ecosystem carbon (TEC) is estimated as 15.5 billion tonnes (RSE%=1.7%). After considering the decomposition process due to MPB infestation, the TEC is adjusted and the final TEC is 15.2 billion tonnes. The detailed statistical analysis and all the estimates are shown in Appendix 1. All the TEC values except the provincial total are not adjusted for the decomposition change due to MPB.

For the four land cover classes: vegetated treed (VT), vegetated non-treed (VN), non-vegetated land (NL), and non-vegetated water (NW), the most dominant land cover type is the vegetated treed area covering approximately 51.8 million ha (or 54.7% of the provincial land area) accounting for 100% of the provincial total volume (9.41 billion m³, RSE% = 2.2%), 99.6% of the total biomass carbon (5.4 billion tonnes, RSE% = 1.9%), and 99.8% of the total ecosystem carbon (15.5 billion tonnes, RSE% = 1.7%) (Figure 2).

The land cover classes are defined as close as possible to the land classification used in the State of British Columbia's Forests Report [9]. Forests are classified as the productive Forest Management Land Base (FMLB) which is comparable to vegetated treed (VT) class. There is an estimated area of 56.4 million ha (RSE% = 1.2%) in the VT, for which all the net volume, TBC and TEC are found (Figure 3).

Among the species classes, pine and spruce have the largest areas of the total vegetated treed area, 12.8 million ha (24.5%) and 11.8 million ha (22.8%), respectively. However, the hemlock with an area of 5.4 million ha (10.4% of the total vegetated treed area) accounts the largest proportion of volume (2.1 billion m³, RSE%=6.3%, 22.3% of the provincial total volume), TBC (1104.9 million tonnes, RSE%=5.9%, 20% of the provincial total), and TEC (2859.4 million tonnes, RSE%=5.9%, 19% of the provincial total) (Figure 4).

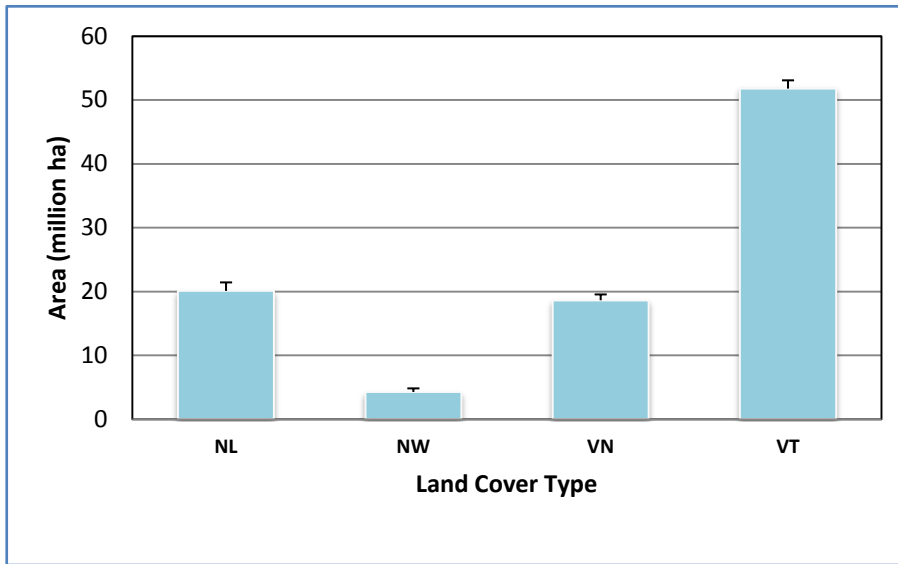
The conifer vegetation type accounts for the largest proportion of area, volume, biomass and carbon in the province. It is estimated that the area of the conifers is 44.6 million ha (RSE%=1.4%, 86% of the total vegetated treed area), the volume is 8.3 billion m³ (RSE%=2.4%, 88.3% of the total), TBC is 4.7 billion tonnes (RSE%=2.1%), and TEC is 1.3 billion tonnes (RSE%=1.9%, 84.6% of the total) (Figure 5).

The provincial vegetated class is predominantly in the age class of 21 to 140 years. The estimated area of this class is 27.1 million ha (RSE%=2.2%, 52.3% of the total), estimated volume is 3.7 billion m³ (RSE%=3.3%, 39.4% of the total), estimated TBC is 2.4 billion tonnes (RSE%=2.8%, 43.1% of the total), and the estimated TEC is 7.7 billion tonnes (RSE%=2.6%, 48.5% of the total). However, the over mature age classes (stands older

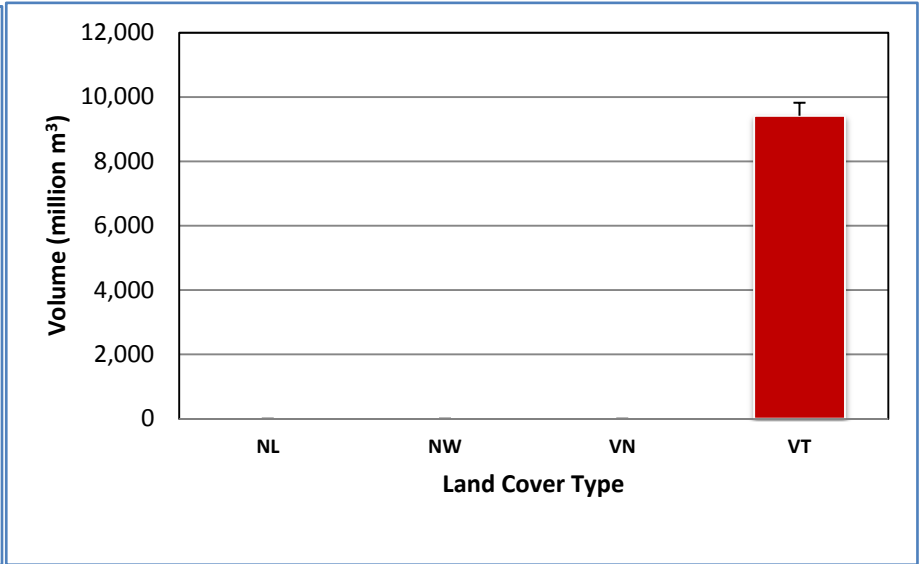
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than 140 years old representing 46.4% of the total vegetated treed area) account for the largest proportions of volume (5.7 billion m³, 60.3% of the total), TBC (3.1 billion tonnes, 56.4% of the total), and TEC (7.7 billion tonnes, 50.4% of the total) (Figure 6)

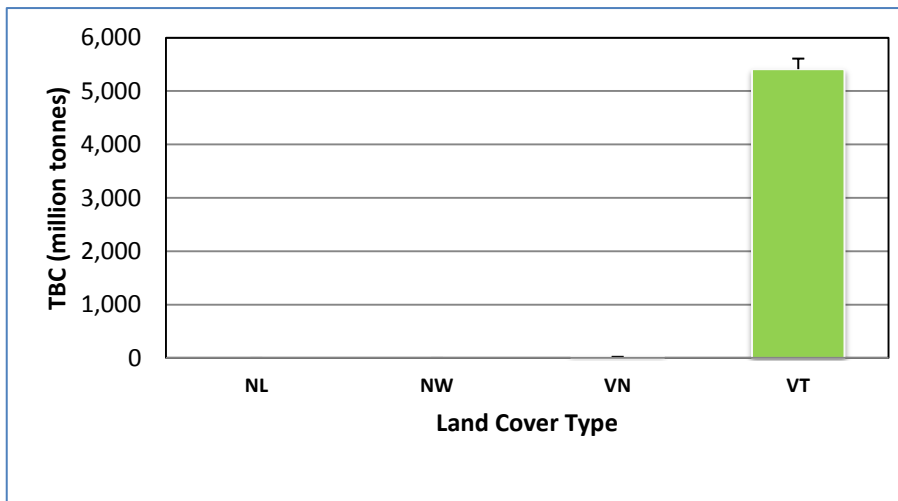
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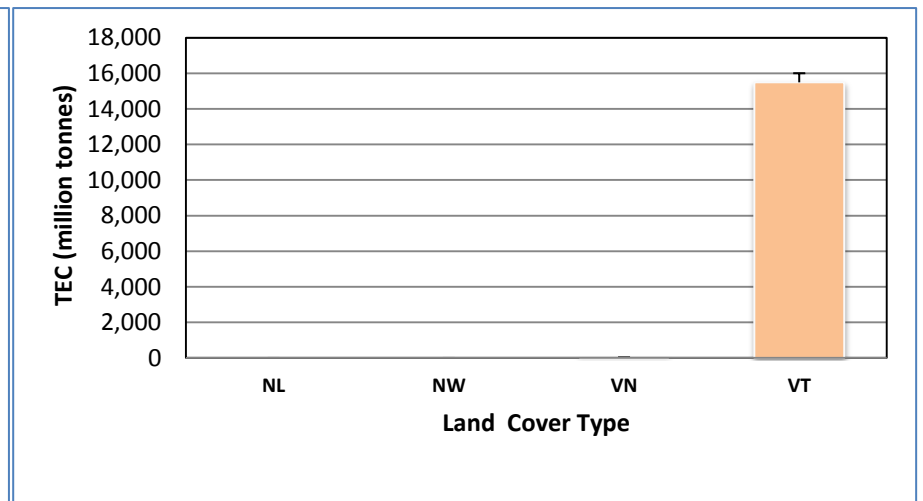
(a) Total area



(b) Total net volume

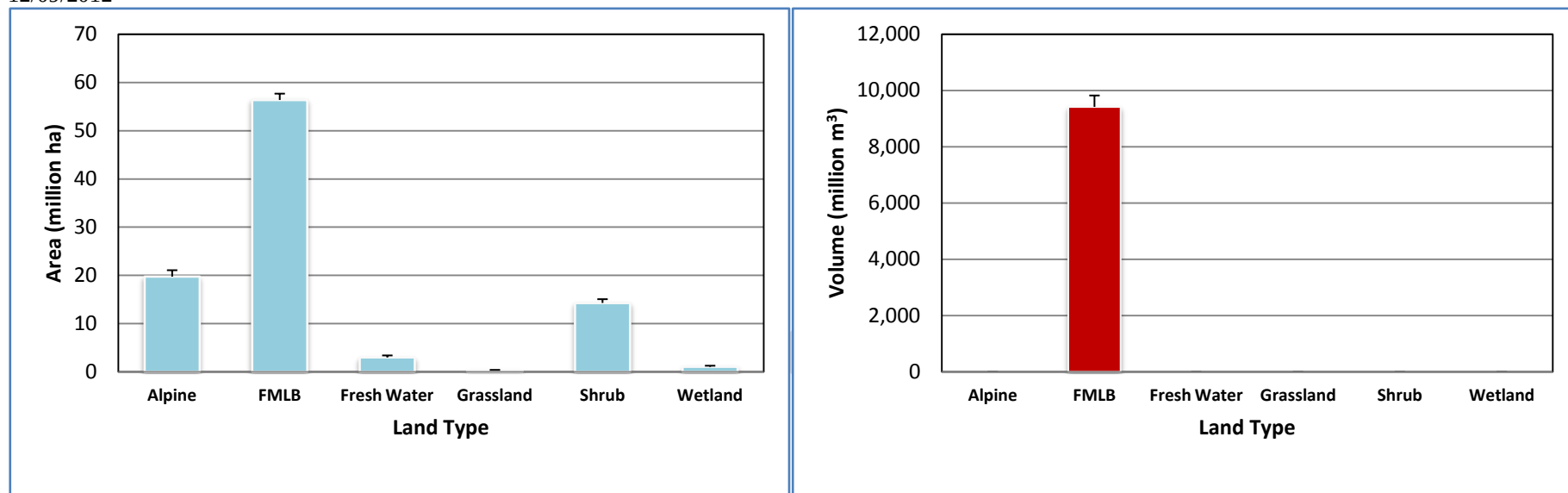


(c) Total biomass carbon



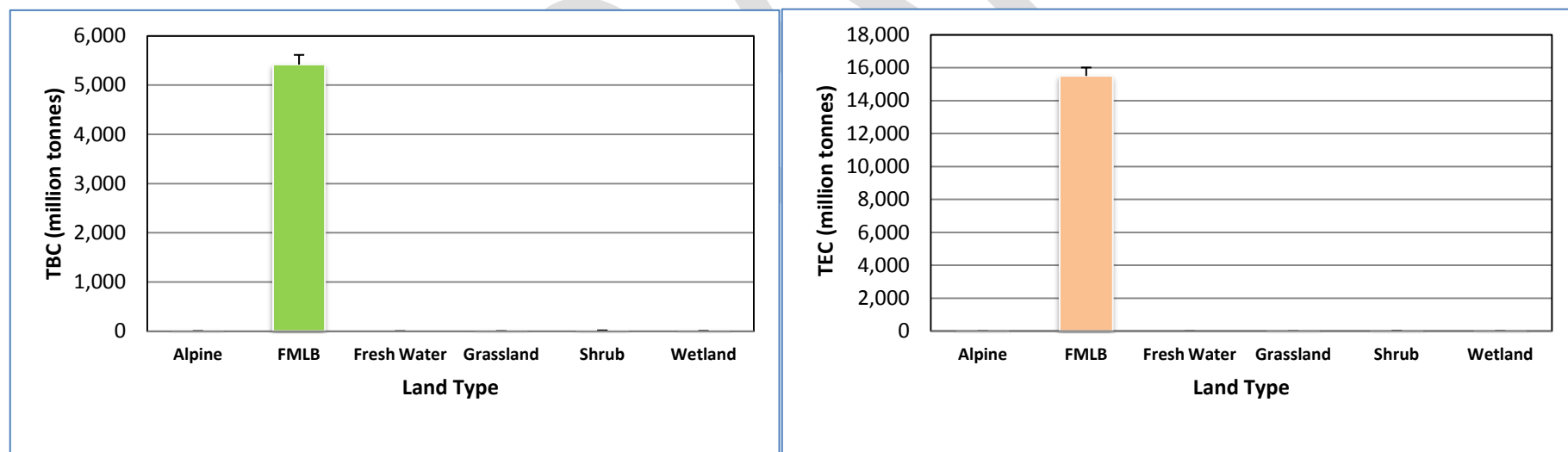
(d) Total ecosystem carbon

Figure 3 Estimates of area, total biomass carbon, and total ecosystem carbon by land cover types.



(a) Total area

(b) Total net volume



(c) Total biomass carbon

(d) Total ecosystem carbon

Figure 4 Estimates of area, volume, total biomass carbon, and total ecosystem carbon by land types.

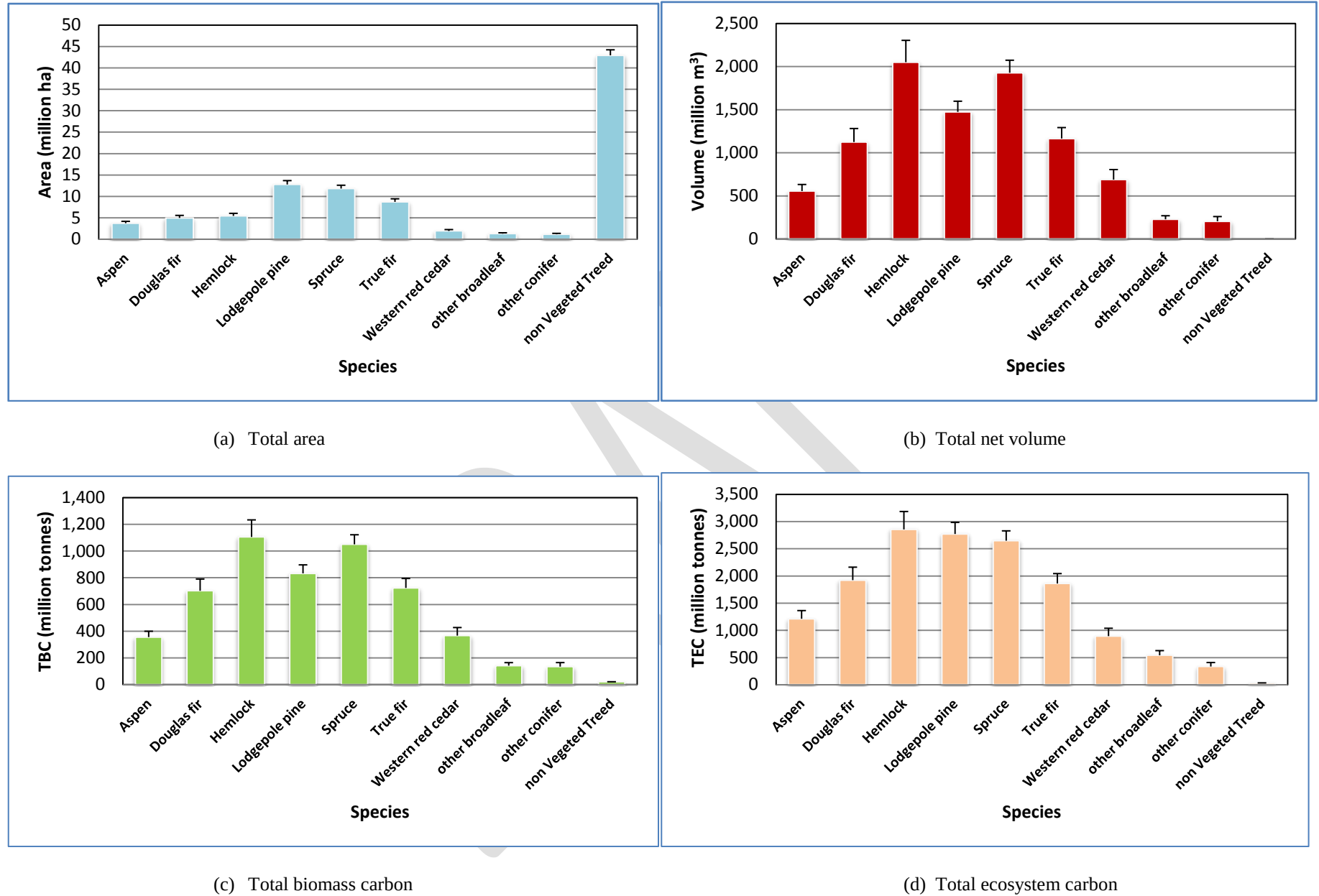


Figure 5 Estimates of area, volume, total biomass carbon, and total ecosystem carbon by leading species.

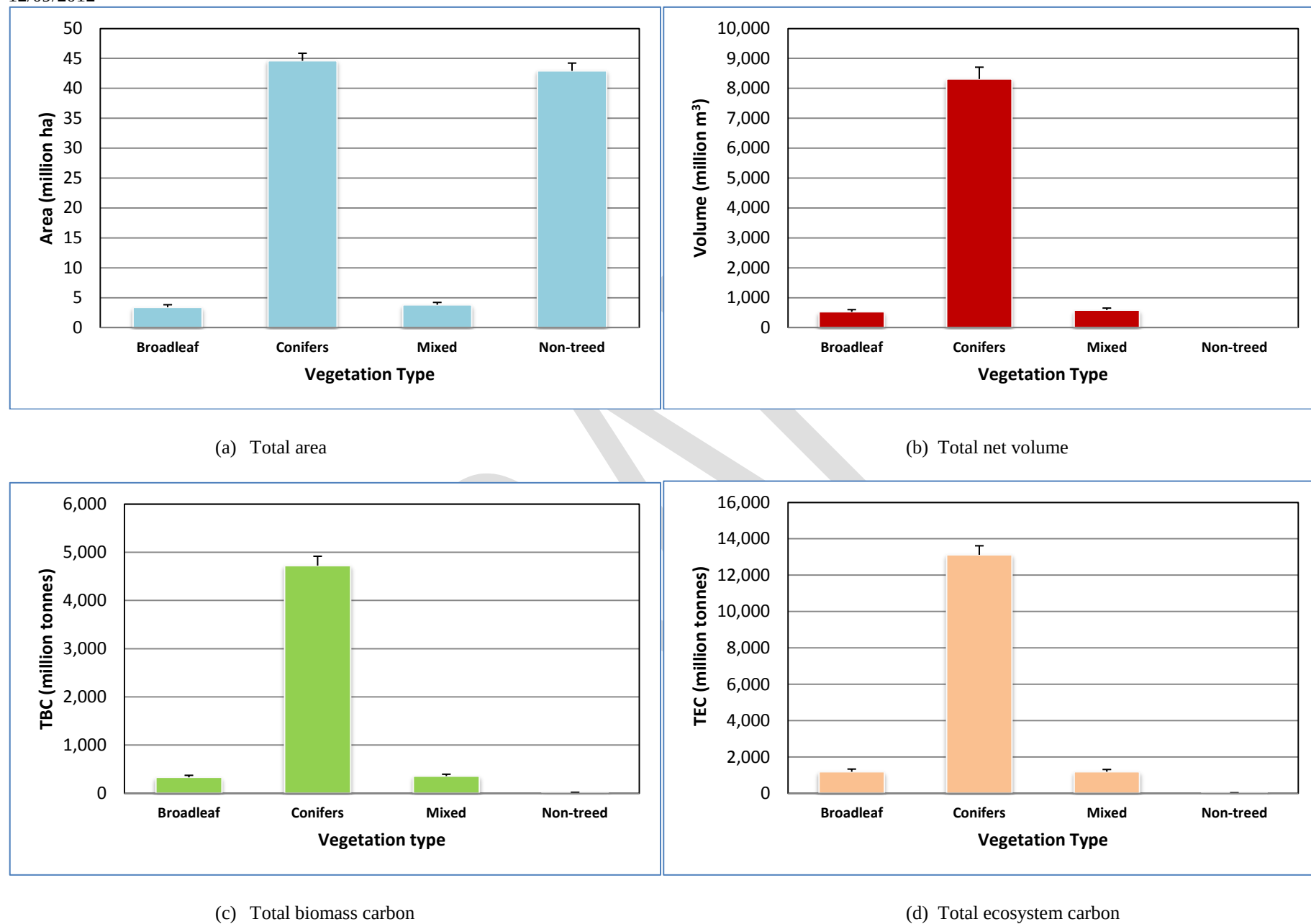


Figure 6 Estimates of area, volume, total biomass carbon, and total ecosystem carbon by vegetation types.

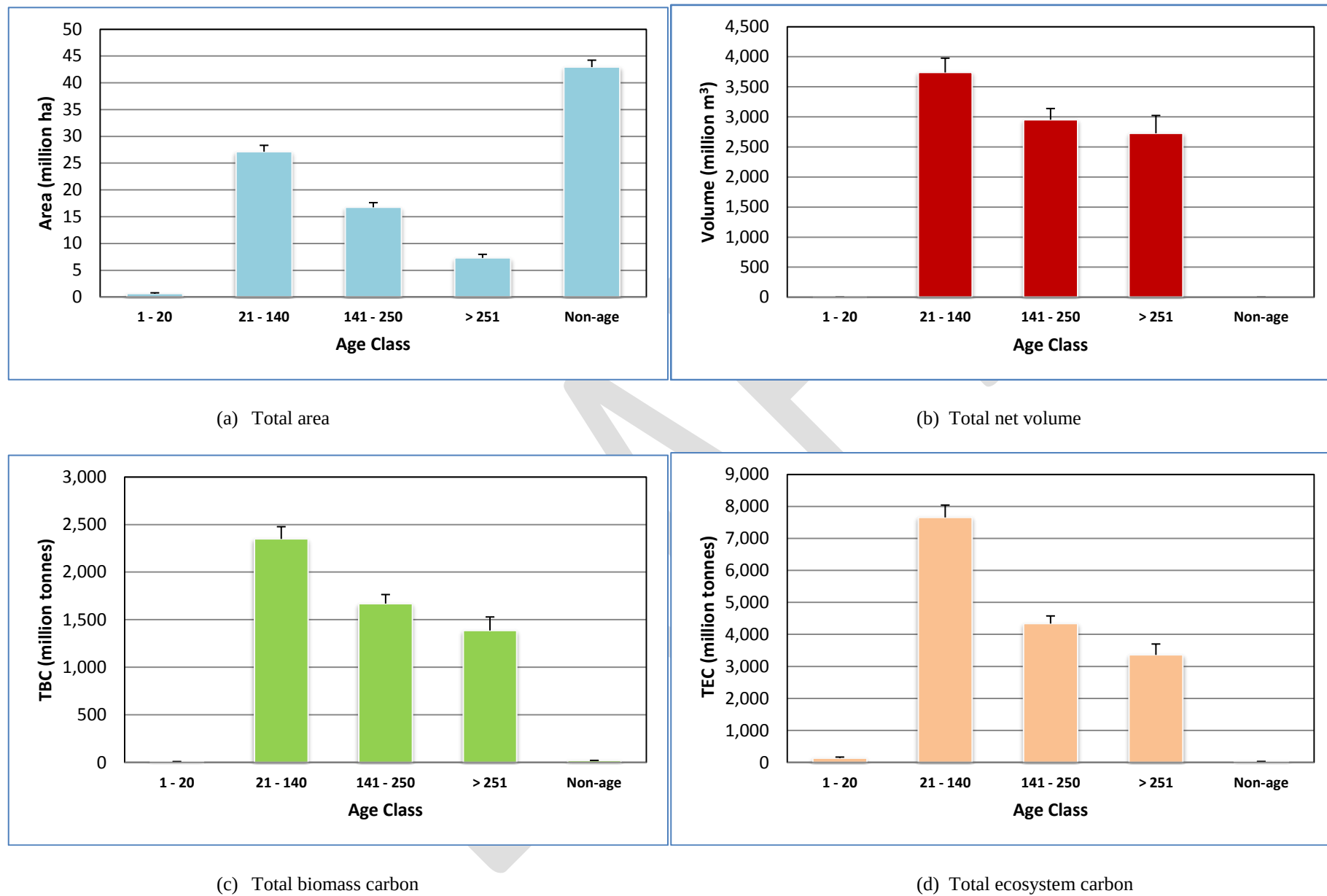


Figure 7 Estimates of area, volume, total biomass carbon, and total ecosystem carbon by age classes

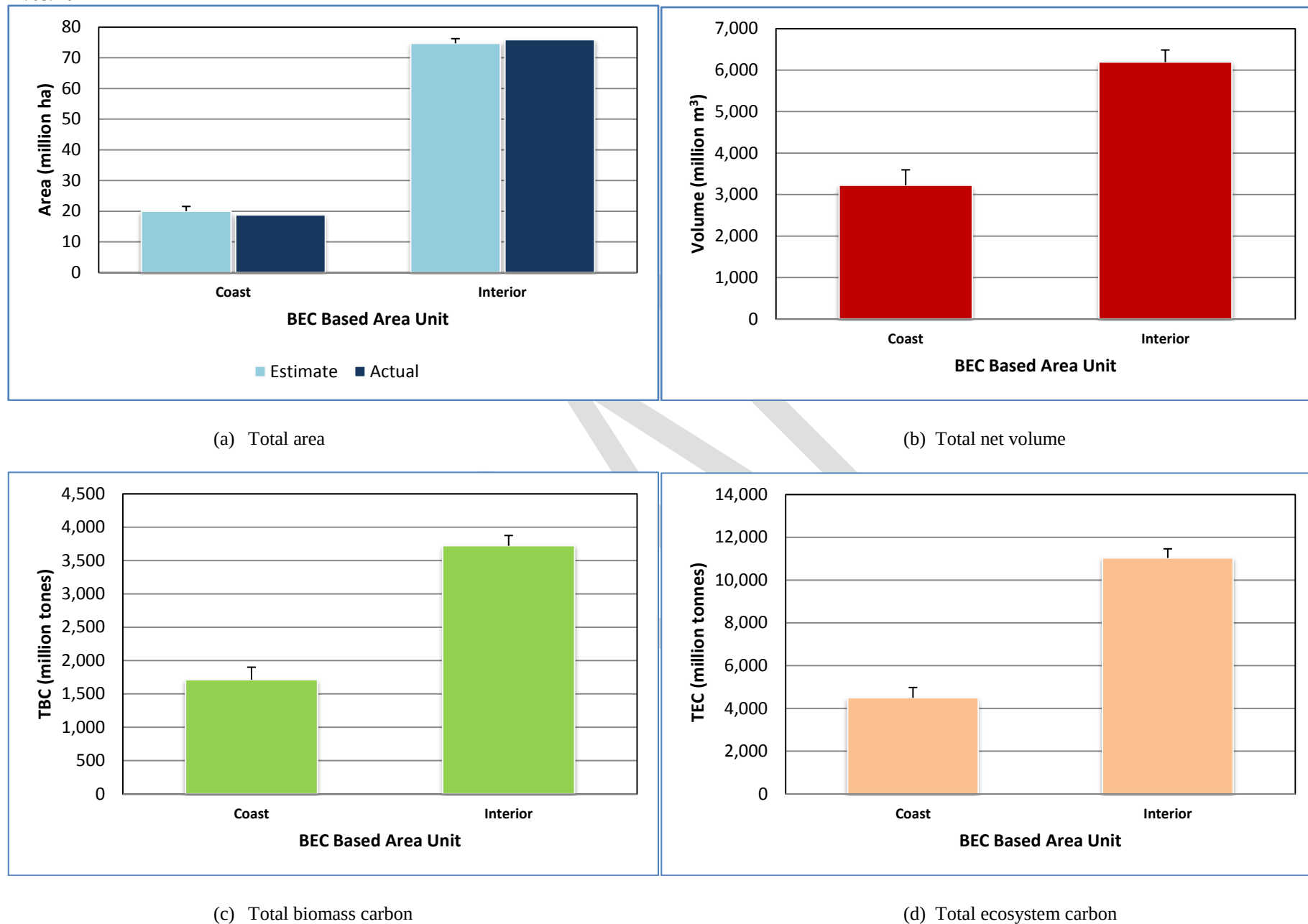
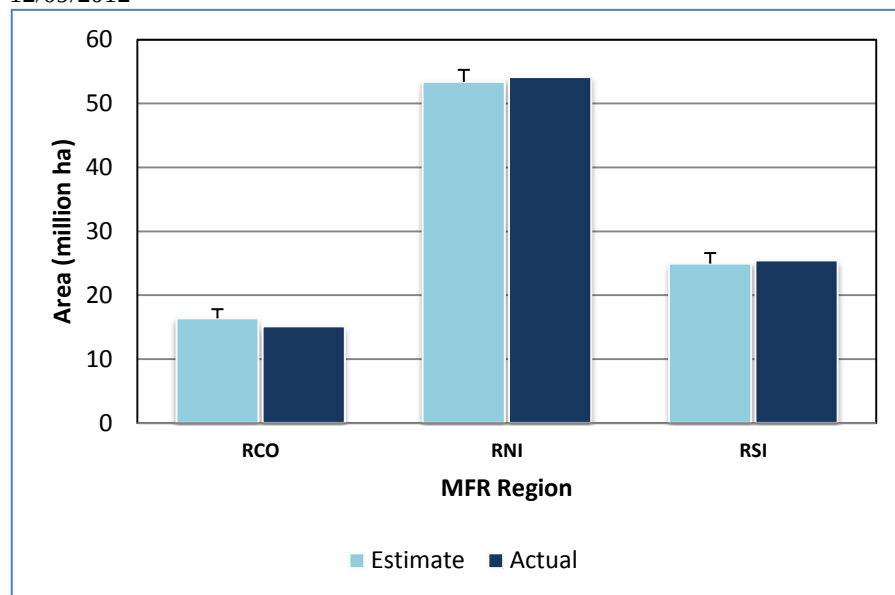
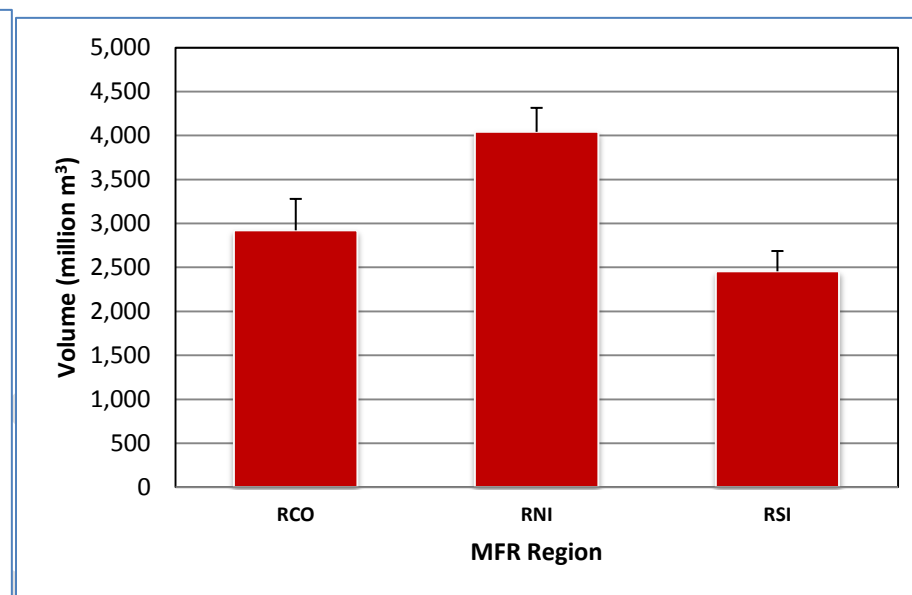


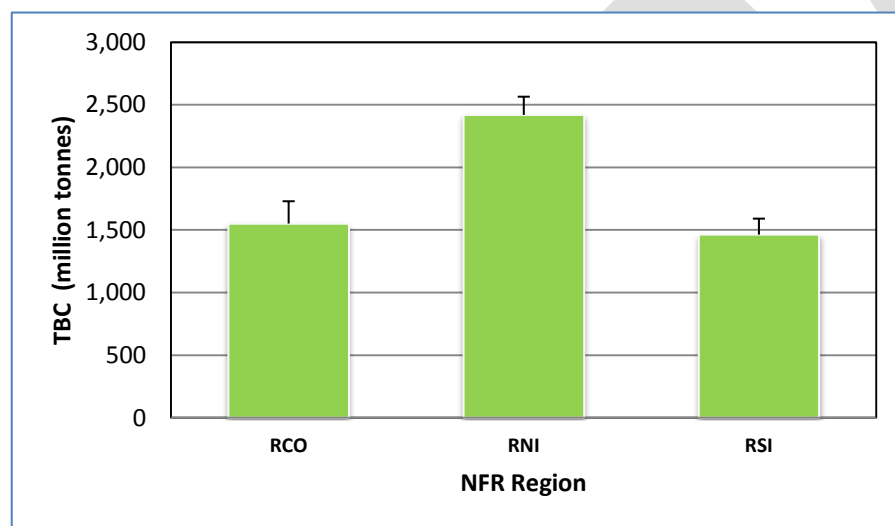
Figure 8 Estimates of area, volume, total biomass carbon, and total ecosystem carbon by coast and interior regions.



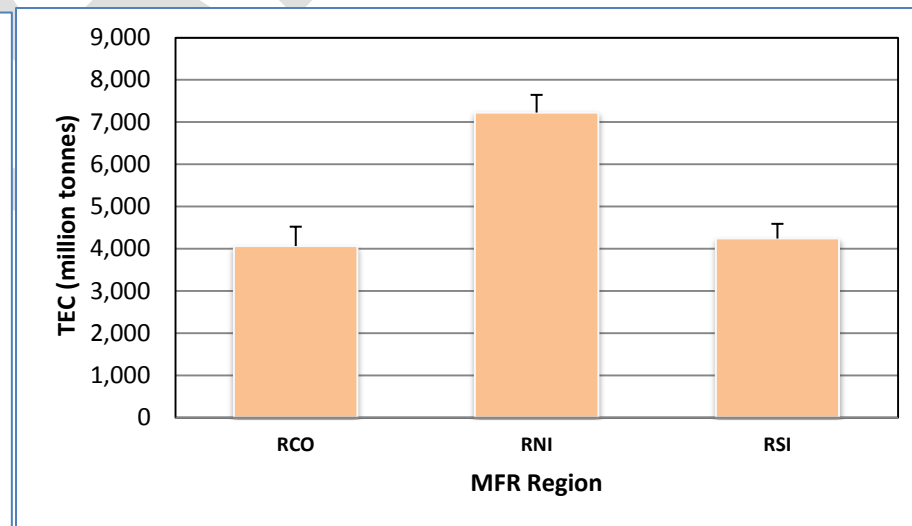
(a) Total area



(b) Total net volume



(c) Total above ground biomass



(d) Total ecosystem carbon

Figure 9 Estimates of area, volume, total biomass carbon, and total ecosystem carbon by MFR regions.

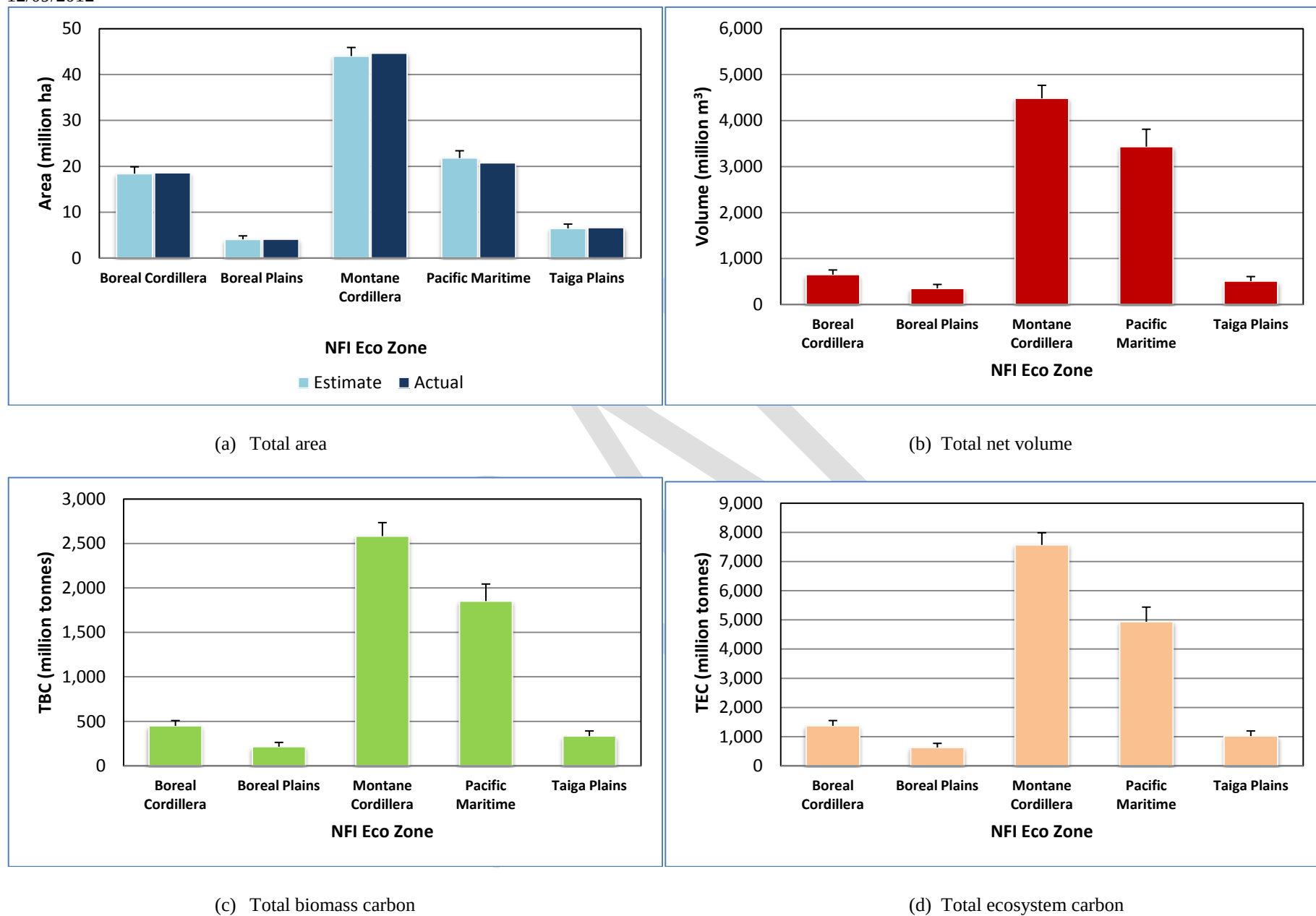


Figure 10

Estimates of area, volume, total biomass carbon, and total ecosystem carbon by NFI eco zones.

Sub-Provincial Total in 2009

Figures 7-9 show the summary of the estimates of area, volume, TBC, and TEC by the spatial units at sub-provincial level. The actual areas originally derived from the GIS overlaying are also given beside the area estimates. Further estimations within each spatial unit could be conducted upon request. However, as discussed later on in this report, caution is recommended in selecting the appropriate level of detail for the estimates so that acceptable precision of the estimates can be obtained.

Total Changes of Forest Resources between 2000 and 2009

A primary objective of the VRMP design is to demonstrate how much the forest resource is changing over time. By reporting from the two VRMP photo databases, 2000 and 2009, the total change of net volume in BC during this timeframe is -320.7 million m³ (RSE = -26.2%), the change in TBC is -166.0 million tonnes (RSE = -23.5%), and the change in TEC is 237.8 million tonnes (RSE = 32.6%) (see Appendix). After decay adjustment, the net TEC loss is 112.3 million tonnes. The net losses of volume, biomass, and carbon are largely attributed to harvesting, fires and MPB mortality. These totals are significantly greater than the corresponding increases due to forest growth. All the TEC estimates presented below are before decay adjustment.

The changes in forest resources are mainly from two sources: decreases from disturbances (natural or human caused) and increases due to forest growth. Figure 10 shows the estimated areas of these changes due to the disturbance types during the period of 2000 to 2009. About 2.2 million ha were harvested or burned (RSE%=7.1%), 18.2 million ha were attacked by MPB, 16.5 million ha were replaced by the new VRI (RSE%=4.1%), and 57.7 million ha remained relatively undisturbed (RSE%=1.5%).

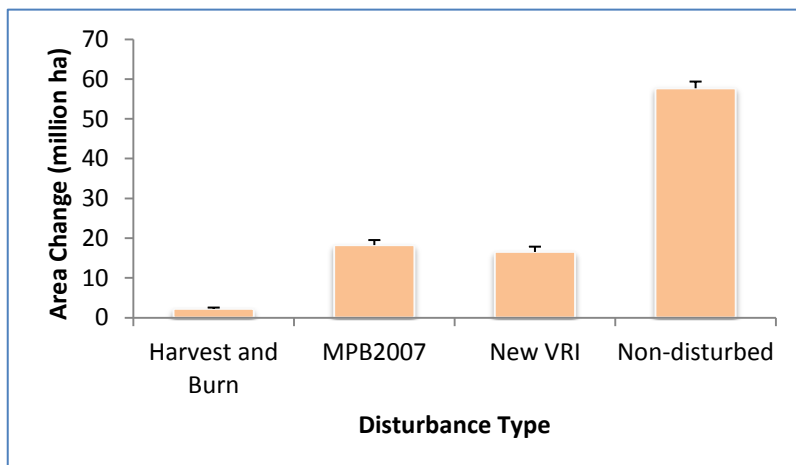


Figure 11. Disturbance changes during 2000-2009 (MPB2007 is the area of MPB infested estimated from the MFR MPB Model data for 2007).

Volume reduction due to MPB mortality is shown in Figure 12. The net volume in 2009 without the MPB epidemic is shown as “*before MPB*” below. Due to the MPB mortality, the actual net volume is shown as “*after MPB*”. The difference is the net loss of volume is about 620.3 million m³. Note the MPB data used is from the MFR MPB Model output for 2007, so the actual volume loss in 2007 due to MPB should be a little bit less than 620.3 million m³ (which would be offset by two additional years of growth).

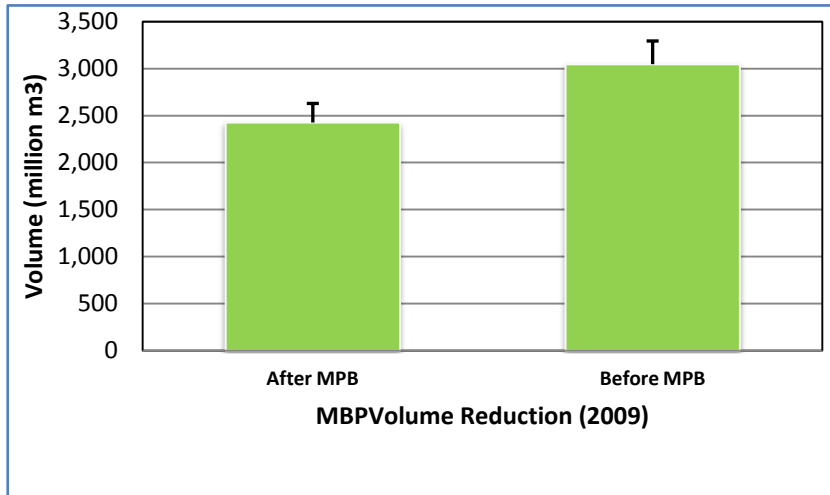
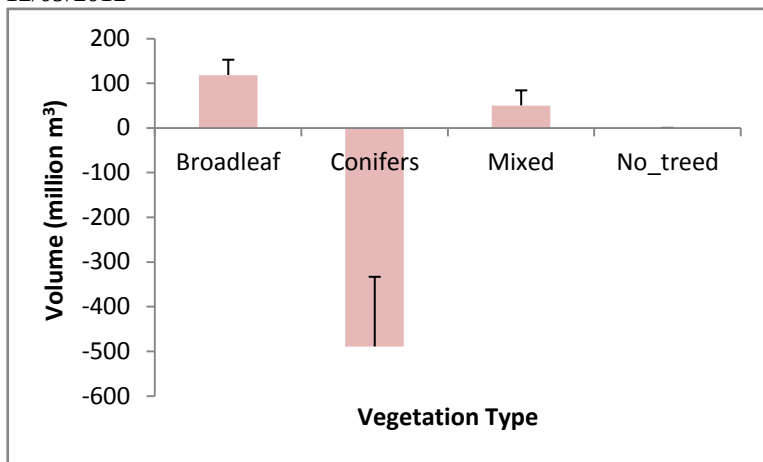


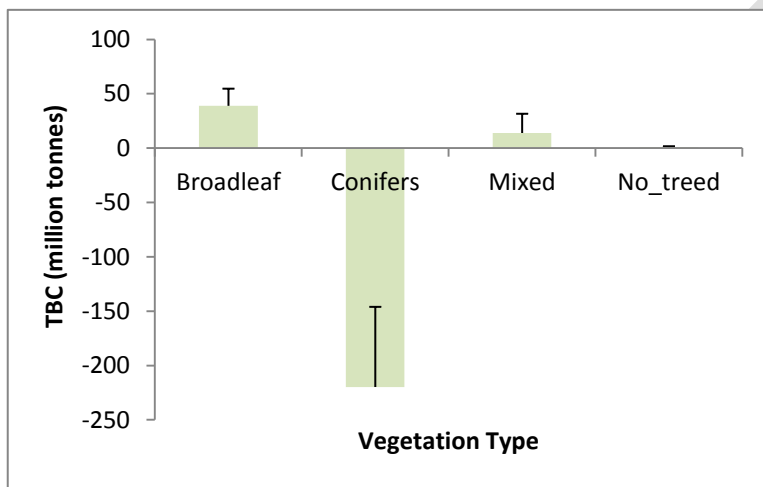
Figure 12 Volume loss due to MPB mortality during 2000-2009 (before MPB volume: the 2009 volume if no MPB kill; after MPB volume: the 2009 volume after MPB reduction, the net volume loss is 620.3 million m³).

Changes estimates of volume, biomass, and carbon for the vegetation classes are also shown in Figure 12. Within the vegetated tree class, conifers vegetation type demonstrated the biggest volume loss of 489.1 million m³ (RSE%= -16.2%), a TBC loss of 219.7 million tonnes (RSE%=-17.1%), and TEC increase of 131.7 million tonnes (RSE%=54.0%). The biggest reduction in volume and TBC and increase in TEC can be explained by the loss to MPB mortality and the subsequent salvage harvesting. The frequency of large scale burns in this class is also reflected by these change estimates.

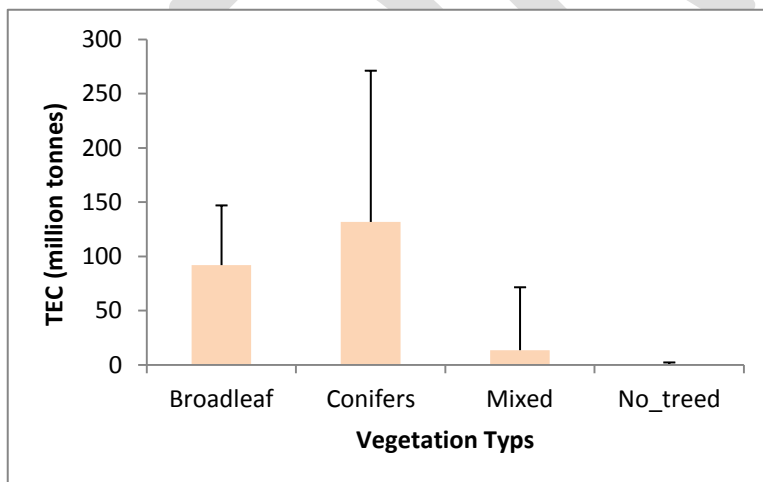
Figures 13 – 15 show the estimates of changes in volume, TBC, and TEC for 3 sub-provincial spatial units (BEC based coast/interior, eco zones, and MFR regions) during 2000-2009. The similar trends can be observed in that the biggest changes are related to MPB, harvesting and wildfire disturbances. For example, the biggest loss in volume, TBC, and TEC are found in the Interior, Montane Cordillera eco zone, and MFR RSI/RNI regions. This is where MPB mortality is heaviest and consequentially where harvesting and fire incidence is the most extensive.



(a) Total net volume

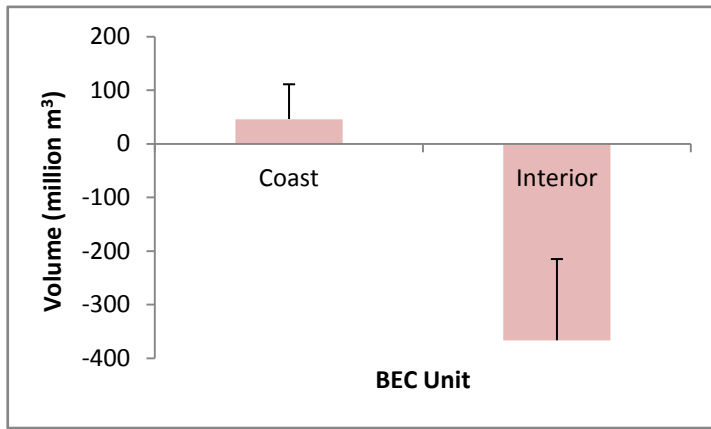


(b) Total biomass carbon

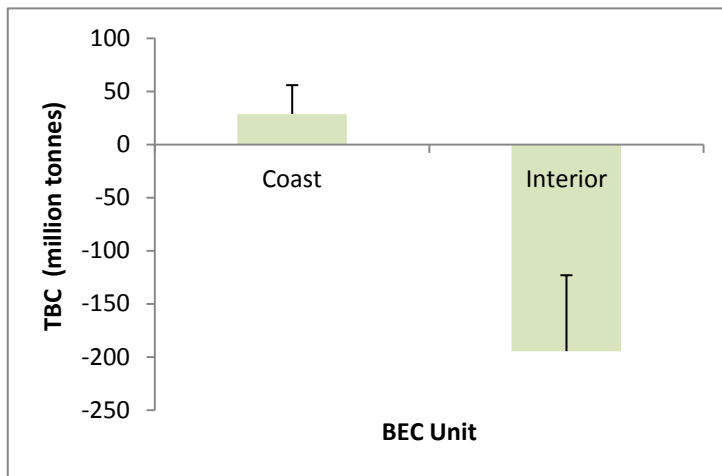


(c) Total ecosystem carbon

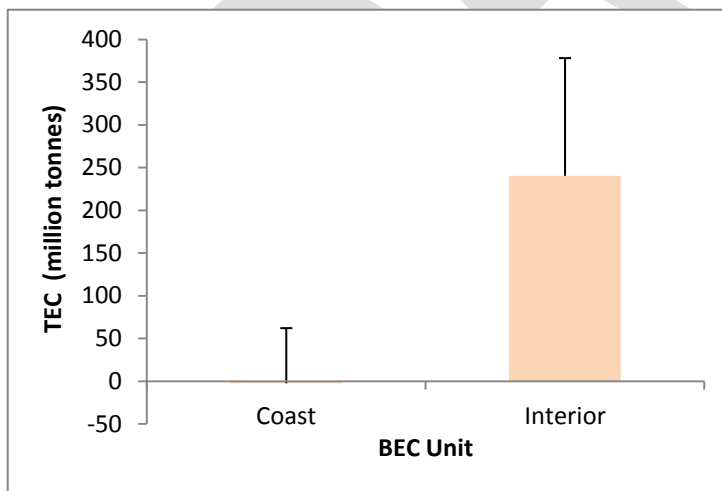
Figure 13 Changes in volume, TBC, and TEC by vegetation types during 2000-2009.



(a) Total net volume

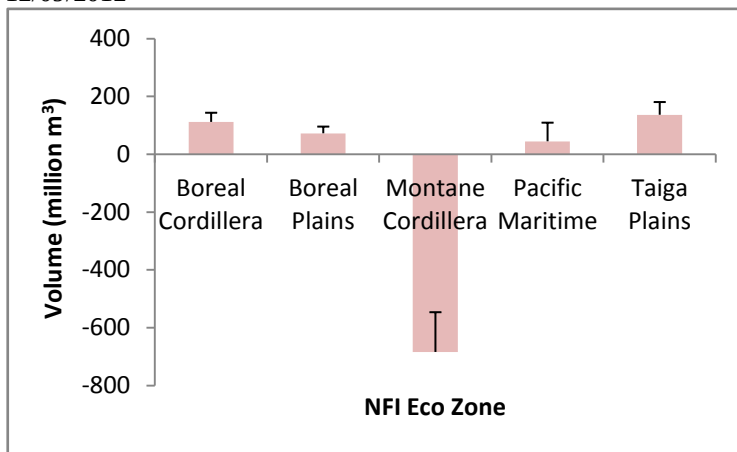


(b) Total biomass carbon

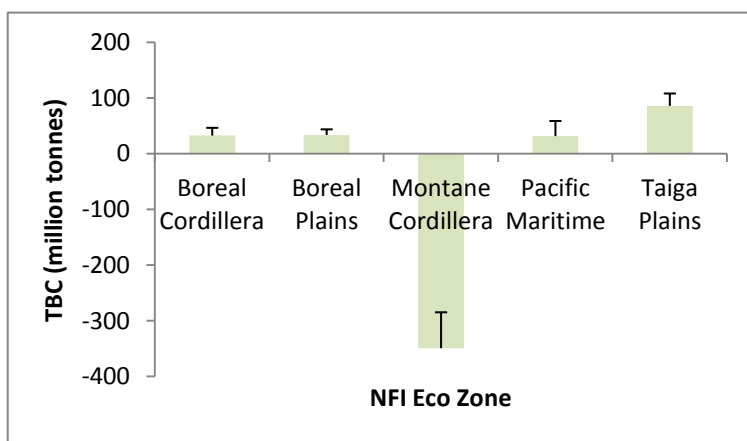


(c) Total ecosystem carbon

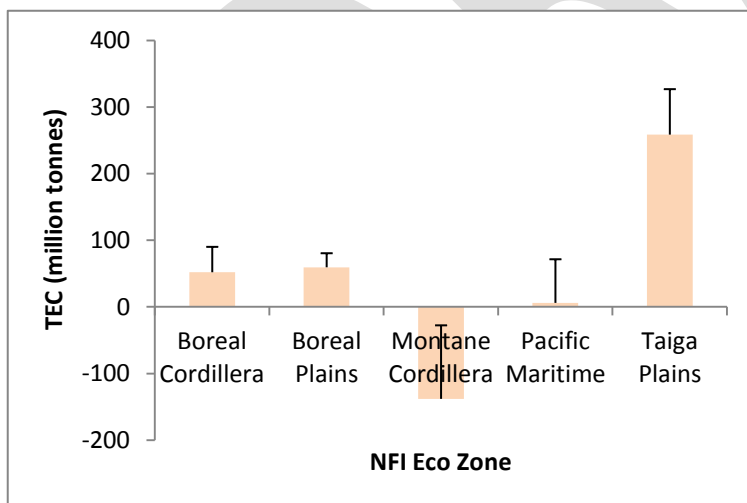
Figure 14 Changes in volume, TBC, and TEC by BEC units during 2000-2009.



(a) Total net volume

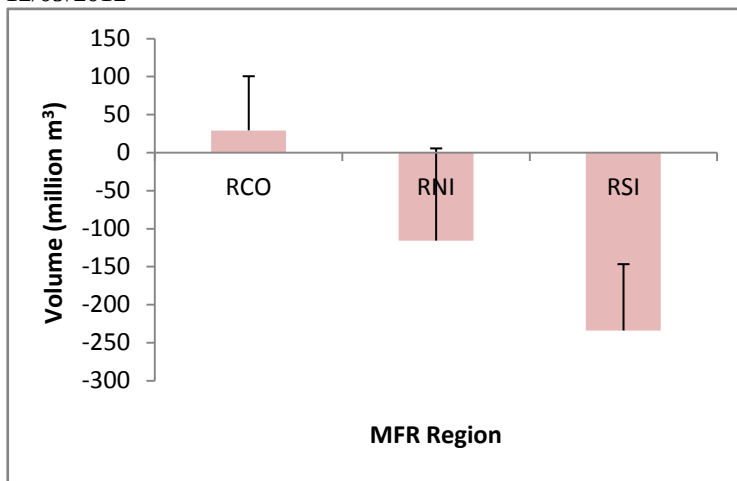


(b) Total biomass carbon

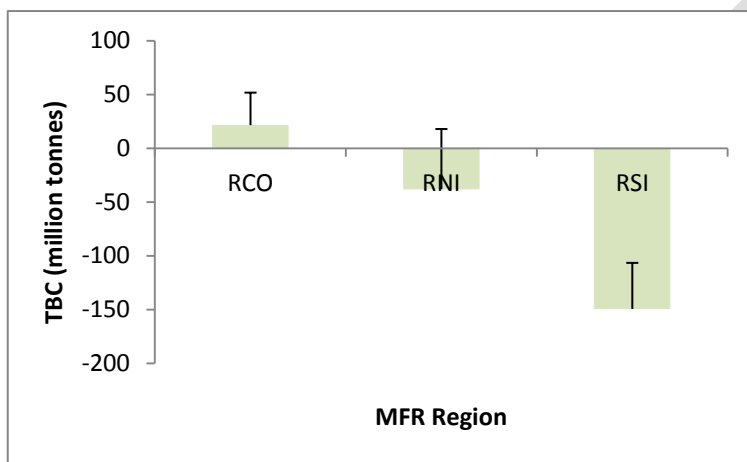


(c) Total ecosystem carbon

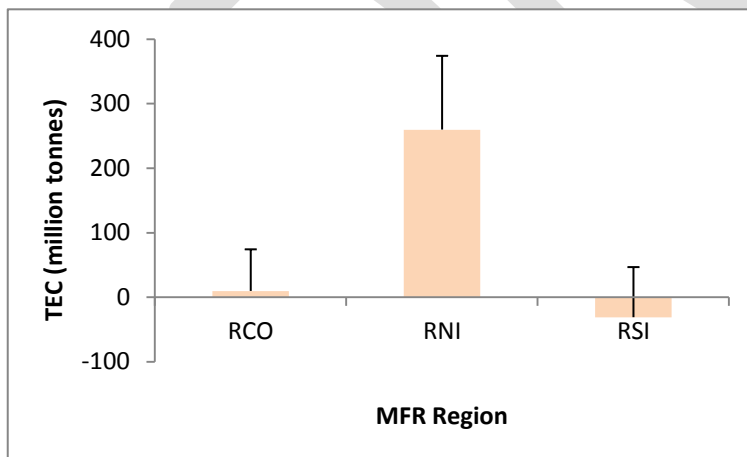
Figure 15 Changes in volume, TBC, and TEC by NFI eco zones during 2000-2009.



(a) Total net volume



(b) Total biomass carbon



(c) Total ecosystem carbon

Figure 16 Change in volume, TBC, and TEC by MFR Regions during 2000-2009 (RCO: Coast Forest Region, RNI: Northern Interior Forest Region, and RSI: Southern Interior Forest Region).

Discussion

This report presents the estimates of the provincial forest resources in 2009 and the changes that have occurred between 2000 and 2009 using the VRMP photo databases. The provincial forest resource statistics are made by applying the pre-determined classifiers and by using the same growth and yield model which is based on samples with good statistical precision. It is the first time that such information has become available for the province.

Classification of individual polygons is a critical process because it not only defines the necessary categories for reporting but also it affects the precision of the estimates. Defining the area of interest (AOI) and probability for occurrence of the classifiers of interest directly determines the precision of the estimates. Other classifiers could be defined upon request, but for future analysis it is suggested that a list of core classifiers and classifier-classes be established to ensure provincial monitoring and reporting that is consistent and with acceptable precision.

Caution should, however, be exercised in interpreting the change estimates obtained through future re-measurements of the VRMP photo plots. For example, inconsistencies in the estimation of forest resource changes could occur due to actual change owing to growth or mortality, because of volume growth projection errors, different delineation and attribution between photo interpreters, and measurement errors due to different photo interpretation standards and techniques. In addition, the confidence intervals of the change estimates of some classifier-classes are quite large. Relative standard errors for some classifier-classes are very high because of the very high variation in area or volume change relative to the very small changes in area or volume that occurred over the change period. The change estimates presented in this report are good approximations of the actual changes. However, a valid analysis would follow the standard periodical NFI re-measurement schedule which is not available at the present time. Nonetheless, these sample-based change estimates are a great improvement to those available in the past when inventories of different vintages and precision created limitations for compiling. It is recommended that the level of precision of the photo interpreted estimates be reviewed by checking a subset of the photo plot attributes on the ground; possibly by using the VRMP ground plots or by using higher resolution photography or imagery.

Biomass and ecosystem carbon estimates were added to the analysis using the models developed by CFS. Biomass is sensitive to disturbance. For example, natural and anthropogenic disturbances such as fire, insects, and harvesting, directly affect the quantity of both above ground and below ground biomass. Ecosystem carbon, also referred to as ecosystem carbon stocks, indicates the current carbon storing status of a given ecosystem. The net ecosystem carbon stock changes indicate whether an ecosystem is a net source (losing carbon over a given time period) or a net sink (gaining carbon in a given time period). Therefore measuring net ecosystem carbon stock changes provides an important method for application to carbon offset systems such as the carbon cap and trade system, and to the understanding of forest ecosystem carbon management and climate change implications.

As this is the first attempt at using a carbon budget model in the NFI photo database, most model default parameters were adopted in this analysis. The NFI photo database also provides an alternative data source by using CBM to estimate BC forest ecosystem carbon dynamics. In CBM, the above ground biomass estimation closely adhered to the parameters of the empirical growth and yield model volume (VDYP7). Below ground biomass (roots) were estimated by the best available data [12]. The CBM model incorporates conversion models developed by Boudewyn *et al* [5], that convert net volume into biomass but it is recognized that further improvement or enhancement of the models to fit BC data is required. FAIB is currently working on the development and enhancement of ‘volume to biomass’ conversion models that will be specific to BC. Once these new models are developed, the output will be incorporated into the next VRMP reporting cycle.

Forest ecosystem carbon dynamics are sensitive to the type and timing of the disturbance. For example, wild fires can turn most biomass into dead organic carbon while immediately emitting greenhouse gases such as CO₂ and N₂O. By contrast, pest infestations may kill trees gradually, thereby reducing growth and increasing decomposition rates due to the large amount of dead organic materials that are generated during the infestation process.

For this study, decomposition of dead organic matter changed at a negative exponential decrease over time and the rate was affected by many factors, including temperature, moisture, micro biota, and mass quality. For accurate modelling of the impacts of MPB on forest ecosystem carbon dynamics, data about two important factors should be carefully considered. These are the time and magnitude of the infestation. For this analysis, the process was simplified by assuming that all MPB infestation happened in one year and that tree mortality completed within the year of infestation.

This was required for the modelling because:

1. the annual time step resolution model can only accommodate one disturbance at one time step, i.e., it cannot implement infestation, reduce growth, and then harvest the same stand within the same year
2. spatially explicit MPB infestation time series data were not available at the time when the NFI photo data were compiled
3. NFI photo data were designed to use state of art variables such as total net merchantable volume captured at two different timeframes to allow detection of the changes between these two time points. The photo data was not designed to require information about the causes and processes of the changes
4. time and resources were limited to fully explore the possibility of modelling implications in a large scale, long-term monitoring project like VRMP.

In order to account for the decay of DOM, data from annual MPB events (2000 – 2009) should be considered to reflect the actual decay rates of different dead organic materials, i.e., fast decay rates for materials like needles and leaves, intermediate decay rates like branches and twigs, and slow decay rates for organic materials like stems and soil. The conservative annual decay rate of 0.5% that was applied for all dead organic matter generated some uncertainty

regarding the dead organic carbon pools calculated in this report. In order to quantify the MPB impacts on forest ecosystem carbon dynamics, carbon modelling of MPB infestations should utilize updated spatially explicit time series data. This would strengthen understanding of the interactions between MPB infestation and forest ecosystem carbon dynamics.

For this reason, it is recommended that the NFI photo data carbon modelling enhancement should be revisited in 2011 to further study annual how forest ecosystem carbon dynamics change in the context of the historically large scale MPB infestation in BC. Additionally, it is recommended that the application of these estimates should be done with caution. This is because the decomposition rate factor that was used for different types of dead MPB organic matter in this study is likely to be oversimplified and because field measurements for the model calibration were limited.

In addition to the overall point and interval statistics presented here, VRMP can also be used to produce a spatial representation of the photo-plot sample data by using spatial interpolation methods such as krigging, and possibly also by incorporating existing data from the provincial inventories. This existing data could potentially be used to increase the precision of VRMP based forest resource statistics by using the ratio-of-means relationship between the VRMP photo plot estimates and the corresponding existing provincial inventory estimates. This ratio would then be used to adjust the NFI-based sample average that was obtained from photo plots alone. The adjusted estimated sample average is then expanded to the population total.

The estimates of change in this report do not include disturbances such as deforestation and afforestation but it is expected that these data sources will be incorporated into the VRMP photo plot database when they become available. This will expand the options for future reporting from VRMP.

The forest resource statistics generated from the VRMP photo plot database may be also used by the MFR to prepare the next *State of British Columbia's* forest report [9]. As well, the NFI sampling design (grid-based systematic design) is flexible and robust and can, thus, be modified or expanded to accommodate various provincial or sub-provincial inventory and monitoring needs (e.g. Future Forest Ecosystem Initiatives, FREP, and State of Environment Reporting). For example, a report of the road length and stream crossings state and change statistics for 2000 to 2005 has been produced with data from the VRMP database. Another recent application of VRMP has been by the Ministry of Environment to report on environmental trends in British Columbia in 2006 [6].

In conclusion, FAIB has now established the baseline VRMP photo plot database, from which future change reports can be generated while following the standard NFI re-measurement schedule. An important recommendation for the improvement of the VRMP database will be to have photo plots that are based on the former FIP standards re-inventoried to new VRI standards. Additionally, it should be noted that unless there is adequate and consistent

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resourcing committed to the long term VRMP program, particularly for VRMP update and re-measurement, future forest resource monitoring will be extremely limited..

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Summary

This report demonstrates the utility of the newly implemented BC Vegetation Resources Monitoring Program (VRMP) that was developed to support provincial forest resource monitoring and Canada's National Forest Inventory. Also included are statistics about the status of BC's forest resources in 2009 and the changes between 2000 and 2009, generated from data from the 2419 VRMP photo plots that are located in BC. It is the first time that such periodic change estimates of the province's forest resources have been obtained using a statistically valid sample.

The statistics include estimates of area, volume, total biomass carbon, and total ecosystem carbon by selected classifiers along with the relative standard errors and confidence intervals. Despite the high relative standard errors of change estimates for some classifiers, the estimation of forest resources and changes over time using the VRMP is efficient and effective. It also avoids the limitations of compiling data from inventories that were completed at different times and to differing standards. The VRMP sampling design provides the estimate precisions of the state and change of the provincial forest resources. Its design is flexible and robust and thus can be modified or expanded to accommodate various provincial or sub-provincial inventory and monitoring needs (e.g. Future Forest Ecosystem Initiatives, FREP, State of Environment Reporting). It is important to note that continued resourcing is required to support VRMP photo and ground plot re-measurement, database maintenance and database update over time. These efforts are critical if VRMP is expected to respond to future provincial monitoring and reporting requirements.

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Appendix 1: Estimates of area, volume, total biomass carbon, and total ecosystem carbon in 2000 and 2009 and changes during the period of 2000 to 2009

This Appendix provides detailed provincial statistics for area, volume, total biomass carbon, and total ecosystem carbon in 2000 (Table 3), 2009 (Table 4), and the changes during the period of 2000 to 2009 (Table 5) for various classifiers and classifier-classes. Relative standard error (RSE%) is a measure of the precision of the estimated totals: the lower the RSE%, the more precise the estimated total. Confidence interval (CI) is the product of RSE% and a t -value corresponding to the 95% probability level (or $\alpha = 0.05$) and 2,418 degrees of freedom. The confidence interval expresses the range within which we expect the true population total of the attribute to lie with a given probability (95%). The sample size for each classifier-class is 2,419 photo plots.

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Table 3 Estimates of area, volume, total biomass carbon, and total ecosystem carbon by the classifiers in BC in 2000 (α is the confidence level).

Classifier	Classifier-class	Area in 2000			Volume in 2000			Total Biomass Carbon in 2000			Total Ecosystem Carbon in 2000		
		Total (ha)	Confidence Interval ($\pm$, $\alpha=0.05$)	Relative Standard Error (%)	Total (m ³)	Confidence Interval ($\pm$, $\alpha=0.05$)	Relative Standard Error (%)	Total (tonne)	Confidence Interval ($\pm$, $\alpha=0.05$)	Relative Standard Error (%)	Total (tonne)	Confidence Interval ($\pm$, $\alpha=0.05$)	Relative Standard Error (%)
Province	Province	94,657,697			9,731,084,086	421,783,579	2.2	5,595,653,827	201,740,814	1.8	15,277,888,780	520,728,604	1.7
	Non-vegetated Land	22,836,923	1,388,970	3.1	0	0	0.0	0	0	0.0	0	0	0.0
	Non-vegetated Water	4,205,039	562,518	6.8	0	0	0.0	0	0	0.0	0	0	0.0
	Vegetated Non-treed	17,393,068	920,305	2.7	0	0	0.0	19,508,096	1,179,504	3.1	28,994,341	1,944,640	3.4
	Vegetated Treed	50,222,667	1,310,543	1.3	9,732,077,769	421,926,998	2.2	5,576,717,127	202,018,474	1.8	15,250,454,529	521,207,731	1.7
Land type	Alpine	22,309,956	1,395,631	3.2	0	0	0.0	37,647	73,025	98.9	55,780	108,199	98.9
	FMLB	54,589,767	1,337,813	1.2	9,731,084,086	421,783,579	2.2	5,578,064,521	201,909,845	1.8	15,251,491,327	520,981,191	1.7
	Fresh water	2,446,437	378,451	7.9	0	0	0.0	0	0	0.0	0	0	0.0
	Grassland	41,203	52,893	65.5	0	0	0.0	37,906	48,663	65.5	51,296	65,855	65.5
	Shrub	13,688,340	803,981	3.0	0	0	0.0	12,770,711	757,540	3.0	17,408,487	1,045,867	3.1
	Wetland	1,581,993	279,743	9.0	0	0	0.0	4,743,042	845,245	9.1	8,881,889	1,582,821	9.1
Species	Aspen	4,036,618	473,550	6.0	457,463,103	66,358,699	7.4	333,504,367	42,267,472	6.5	1,242,040,758	153,439,529	6.3
	Douglas fir	5,334,931	622,804	6.0	1,023,218,967	143,622,909	7.2	667,339,571	83,382,089	6.4	1,880,281,105	230,582,262	6.3
	Hemlock	5,697,087	633,869	5.7	2,047,550,113	258,439,335	6.4	1,105,657,422	129,551,025	6.0	2,877,386,270	335,269,399	5.9
	Lodgepole pine	14,709,160	1,004,358	3.5	2,094,457,796	175,994,740	4.3	1,166,770,422	88,845,203	3.9	3,149,041,922	227,309,321	3.7
	Spruce	13,663,547	875,195	3.3	1,879,633,458	150,018,292	4.1	998,327,943	71,415,388	3.6	2,583,063,271	178,329,709	3.5
	True fir	8,698,448	707,978	4.2	1,125,720,475	124,455,742	5.6	688,841,859	68,325,399	5.1	1,797,195,114	174,863,449	5.0
	Western red cedar	2,164,227	355,815	8.4	714,089,967	123,095,180	8.8	369,175,165	61,296,225	8.5	911,103,093	147,637,815	8.3
	Other broadleaf	1,181,408	200,365	8.6	177,065,731	34,886,217	10.0	116,787,162	19,955,667	8.7	475,219,114	81,319,973	8.7
	Other conifer	1,274,343	230,385	9.2	211,884,476	59,387,515	14.3	135,888,722	31,487,905	11.8	342,023,287	75,465,266	11.3
	Non vegetated treed	37,897,927	1,348,573	1.8	0	0	0.0	13,361,194	1,051,664	4.0	20,534,847	1,785,494	4.4
age	141 - 250	15,191,305	846,549	2.8	3,066,045,417	208,112,095	3.5	1,690,674,443	102,757,348	3.1	4,096,028,812	244,220,712	3.0
	1 - 20	1,730,578	281,365	8.3	298,791	220,443	37.6	17,640,243	4,071,235	11.8	384,036,200	66,615,613	8.8
	21 - 140	26,267,523	1,191,579	2.3	3,920,680,185	246,643,521	3.2	2,485,423,320	132,628,256	2.7	7,450,759,529	381,256,605	2.6
	> 251	7,023,853	667,987	4.8	2,744,059,694	308,346,389	5.7	1,382,362,262	146,413,823	5.4	3,318,025,243	347,965,692	5.3

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	Non age	44,444,439	1,310,172	1.5	0	0	0.0	19,553,560	1,183,090	3.1	29,038,998	1,946,636	3.4
					9,731,084,086								
Vegetation type	Broadleaf	3,243,702	422,177	6.6	405,455,603	60,573,082	7.6	291,590,943	38,522,140	6.7	1,092,402,629	141,110,942	6.6
	Conifers	43,091,693	1,294,386	1.5	8,794,585,986	416,466,259	2.4	4,941,761,148	200,895,557	2.1	12,985,514,528	507,600,779	2.0
	Mixed	3,882,145	427,658	5.6	531,042,497	65,183,037	6.3	342,795,632	38,484,907	5.7	1,170,980,243	130,031,391	5.7
	Non-treed	44,440,158	1,310,252	1.5	0	0	0.0	19,506,104	1,179,425	3.1	28,991,381	1,944,496	3.4
					9,731,084,086								
	Coast	19,998,120	1,532,674	3.9	3,174,510,423	376,348,292	6.0	1,683,630,779	185,863,415	5.6	4,492,645,436	485,254,418	5.5
	Interior	74,659,577	1,532,674	1.0	6,556,573,663	317,157,534	2.5	3,912,023,048	162,709,434	2.1	10,785,243,344	429,896,573	2.0
Eco zone	Boreal Cordillera	18,359,281	1,491,961	4.1	536,670,423	88,278,380	8.4	416,167,189	56,483,152	6.9	1,319,876,208	175,990,011	6.8
	Boreal Plains	4,059,941	762,091	9.6	277,486,178	71,182,648	13.1	180,966,791	42,010,580	11.8	568,760,639	129,636,211	11.6
	Montane Cordillera	44,013,744	1,882,635	2.2	5,162,882,850	316,340,017	3.1	2,930,445,866	165,048,271	2.9	7,701,971,780	423,642,426	2.8
	Pacific Maritime	21,777,640	1,588,384	3.7	3,384,174,066	382,955,397	5.8	1,819,816,012	191,279,654	5.4	4,926,769,684	506,485,858	5.2
	Taiga Plains	6,447,092	949,041	7.5	369,870,568	84,558,337	11.7	248,257,969	47,495,426	9.8	760,510,469	143,958,509	9.7
MFR Region	Coast	16,288,607	1,423,777	4.5	2,889,878,396	360,561,784	6.4	1,528,663,272	178,122,641	5.9	4,049,011,381	462,805,765	5.8
	Northern Interior	53,446,764	1,873,181	1.8	4,153,960,202	293,544,112	3.6	2,455,312,446	152,065,094	3.2	6,960,706,760	416,705,392	3.1
	Southern Interior	24,922,326	1,661,562	3.4	2,687,245,489	245,010,210	4.6	1,611,678,109	134,939,969	4.3	4,268,170,639	350,142,205	4.2

Table 4 Estimates of area, volume, total biomass carbon, and total ecosystem carbon by the classifiers in BC in 2009 (α is the confidence level).

Classifier	Classifier-class	Area in 2009			Volume in 2009			Total Biomass Carbon in 2009			Total Ecosystem Carbon in 2009		
		Total (ha)	Confidence Interval ($\pm$, $\alpha=0.05$)	Relative Standard Error (%)	Total (m ³)	Confidence Interval ($\pm$, $\alpha=0.05$)	Relative Standard Error (%)	Total (tonne)	Confidence Interval ($\pm$, $\alpha=0.05$)	Relative Standard Error (%)	Total (tonne)	Confidence Interval ($\pm$, $\alpha=0.05$)	Relative Standard Error (%)
Province	Province	94,657,697			9,412,357,243	403,995,252	2.2	5,430,762,772	196,915,263	1.8	15,518,649,419	511,653,917	1.7
Land cover	Non-vegetated Land	20,068,469	1,330,396	3.4	0	0	0.0	0	0	0.0	0	0	0.0
	Non-vegetated Water	4,237,354	564,937	6.8	0	0	0.0	0	0	0.0	0	0	0.0
	Vegetated Non-treed	18,600,323	914,537	2.5	0	0	0.0	20,361,395	1,084,553	2.7	29,698,419	1,703,390	2.9
	Vegetated Treed	51,751,550	1,295,186	1.3	9,412,357,243	403,995,252	2.2	5,410,401,378	197,126,317	1.9	15,488,951,000	511,953,104	1.7
Land type	Alpine	19,723,354	1,336,352	3.5	0	0	0.0	741,154	273,584	18.8	1,098,165	405,368	18.8
	FMLB	56,337,850	1,303,426	1.2	9,412,357,243	403,995,252	2.2	5,499,638,154	198,018,634	1.8	15,016,055,813	509,500,695	1.7
	Fresh water	2,971,990	432,986	7.4	0	0	0.0	0	0	0.0	0	0	0.0
	Grassland	282,947	122,271	22.0	0	0	0.0	260,313	112,490	22.0	352,274	152,229	22.0
	Shrub	14,274,235	785,685	2.8	0	0	0.0	13,855,780	759,057	2.8	19,174,010	1,060,719	2.8
	Wetland	1,067,322	209,387	10.0	0	0	0.0	3,120,207	625,084	10.2	5,842,955	1,170,543	10.2
Species	Aspen	3,724,978	438,394	6.0	555,014,023	76,367,228	7.0	355,546,496	43,789,006	6.3	1,264,613,619	151,011,007	6.1
	Douglas fir	4,962,339	590,053	6.1	1,124,002,995	156,403,091	7.1	701,928,025	87,760,755	6.4	1,939,526,585	238,376,170	6.3
	Hemlock	5,426,703	602,044	5.7	2,049,224,435	253,272,521	6.3	1,104,875,345	127,523,581	5.9	2,859,381,120	329,751,253	5.9
	Lodgepole pine	12,763,360	902,587	3.6	1,473,473,630	123,352,492	4.3	832,190,967	63,714,694	3.9	2,975,800,625	213,208,678	3.7
	Spruce	11,814,518	776,919	3.4	1,926,521,297	145,596,269	3.9	1,049,732,596	71,473,630	3.5	2,763,392,404	181,198,482	3.3
	True fir	8,708,940	716,767	4.2	1,164,398,686	126,929,862	5.6	723,176,632	71,049,024	5.0	1,905,950,382	182,509,077	4.9
	Western red cedar	1,924,404	315,387	8.4	687,348,230	117,138,825	8.7	366,506,594	60,476,505	8.4	893,175,074	144,457,531	8.2
	Other broadleaf	1,284,144	207,498	8.2	227,763,275	41,200,112	9.2	141,852,160	22,642,260	8.1	548,051,529	85,639,461	8.0
	Other conifer	1,142,164	215,609	9.6	204,610,670	54,994,655	13.7	134,592,564	30,245,114	11.5	339,059,663	73,210,278	11.0
	Non vegetated treed	42,906,147	1,295,186	1.5	0	0	0.0	20,361,395	1,084,553	2.7	29,698,419	1,703,390	2.9
Age	1 - 20	628,885	133,330	10.8	224,175	185,949	42.3	7,147,837	2,074,155	14.8	136,627,569	30,929,628	11.5
	21 - 140	27,109,104	1,192,977	2.2	3,735,887,481	238,583,136	3.3	2,348,059,927	128,575,025	2.8	7,655,122,075	385,615,087	2.6
	141 - 250	16,732,116	869,724	2.7	2,950,926,635	186,072,555	3.2	1,669,006,556	94,899,197	2.9	4,337,780,156	239,047,486	2.8
	> 251	7,281,444	669,733	4.7	2,725,318,952	295,801,474	5.5	1,386,187,057	142,182,689	5.2	3,359,421,200	340,566,132	5.2

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	Non age	42,906,147	1,295,186	1.5	0	0	0.0	20,361,395	1,084,553	2.7	29,698,419	1,703,390	2.9
Vegetation type	Broadleaf	3,378,536	429,229	6.5	523,773,861	74,316,510	7.2	330,595,715	42,502,833	6.6	1,184,516,449	148,178,277	6.4
	Conifers	44,579,044	1,265,193	1.4	8,307,194,203	396,200,621	2.4	4,722,984,807	194,453,859	2.1	13,119,742,188	495,978,504	1.9
	Mixed	3,793,970	403,905	5.4	581,389,179	68,799,382	6.0	356,820,856	38,927,262	5.6	1,184,692,363	125,524,124	5.4
	Non-treed	42,906,147	1,295,186	1.5	0	0	0.0	20,361,395	1,084,553	2.7	29,698,419	1,703,390	2.9
BEC group	Coast	20,010,206	1,532,674	3.9	3,221,142,861	373,444,708	5.9	1,712,526,596	186,089,631	5.5	4,491,056,832	480,793,198	5.5
	Interior	74,647,491	1,532,674	1.0	6,191,214,382	292,065,702	2.4	3,718,236,176	154,127,480	2.1	11,027,592,587	427,854,759	2.0
Eco Zone	Boreal Cordillera	18,377,476	1,492,585	4.1	648,358,067	101,054,236	7.9	448,751,322	59,943,170	6.8	1,372,552,499	178,512,361	6.6
	Boreal Plains	4,059,583	762,044	9.6	349,633,048	84,939,358	12.4	214,500,658	48,960,013	11.6	628,491,705	141,264,576	11.5
	Montane Cordillera	43,995,144	1,881,963	2.2	4,481,085,741	283,308,818	3.2	2,582,916,247	151,383,268	3.0	7,568,002,833	417,493,848	2.8
	Pacific Maritime	21,780,360	1,588,489	3.7	3,430,270,441	380,047,492	5.6	1,852,290,432	191,721,052	5.3	4,935,368,016	502,936,724	5.2
	Taiga Plains	6,445,134	948,859	7.5	506,165,828	99,468,685	10.0	334,125,001	57,765,484	8.8	1,019,437,634	174,646,287	8.7
MFR Region	Coast	16,364,928	1,426,630	4.4	2,920,576,896	357,352,510	6.2	1,550,948,456	178,372,925	5.9	4,060,662,222	459,248,762	5.8
	Northern Interior	53,373,350	1,873,357	1.8	4,040,395,609	272,736,561	3.4	2,418,552,171	145,657,010	3.1	7,223,968,449	419,120,122	3.0
	Southern Interior	24,919,418	1,662,271	3.4	2,454,553,106	230,627,815	4.8	1,463,091,311	127,370,676	4.4	4,239,253,996	348,460,152	4.2

Table 5 Estimates of volume, total biomass carbon, and total ecosystem carbon changes by the classifiers in BC between 2000 and 2009 (α is the confidence level).

Classifier	Classifier-class	Total Volume change 2000-2009			Total Biomass Carbon Change 2000-2009			Total Ecosystem Carbon Change 2000-2009		
		Total (m ³)	Confidence Interval ($\pm$, $\alpha=0.05$)	Relative Standard Error (%)	Total (tonne)	Confidence Interval ($\pm$, $\alpha=0.05$)	Relative Standard Error (%)	Total (tonne)	Confidence Interval ($\pm$, $\alpha=0.05$)	Relative Standard Error (%)
Province	Province	-320,631,308	164,902,472	-26.2	-165,986,177	76,471,685	-23.5	237,770,612	152,029,640	32.6
MFR Regions	RCO	29,142,678	71,203,267	124.6	21,466,328	30,226,207	71.8	9,481,913	64,449,209	346.6
	RNI	-115,758,733	121,158,736	-53.4	-38,075,508	55,929,601	-74.9	259,533,059	114,204,942	22.4
	RSI	-234,069,163	87,212,721	-19.0	-149,450,123	42,873,939	-14.6	-31,202,967	77,606,998	-126.8
NFI Eco Zones	Boreal Cordillera	111,373,063	31,660,105	14.5	32,363,120	13,961,666	22.0	51,975,348	38,096,033	37.4
	Boreal Plains	71,980,393	23,192,461	16.4	33,437,762	10,219,444	15.6	59,429,016	21,084,145	18.1
	Montane Cordillera	-684,357,223	137,464,986	-10.2	-349,085,881	64,411,558	-9.4	-138,059,205	110,355,723	-40.8
	Pacific Maritime	44,287,394	64,450,478	74.2	31,507,978	27,072,136	43.8	5,981,891	65,488,088	558.3
	Taiga Plains	136,062,705	44,045,785	16.5	85,735,191	22,231,465	13.2	258,523,283	68,260,316	13.5
BEC Zones	Coast	46,006,654	64,818,483	71.8	28,566,315	27,085,689	48.4	-2,467,857	64,512,249	-1333.1
	Interior	-366,606,590	151,460,787	-21.1	-194,552,492	71,402,610	-18.7	240,238,469	137,777,764	29.2
Vegetation Type	Broadleaf	118,238,907	34,181,383	14.7	38,947,705	15,764,213	20.6	91,900,026	55,050,650	30.5
	Conifers	-489,112,967	155,781,585	-16.2	-219,743,491	73,741,710	-17.1	131,686,272	139,416,873	54.0
	Mixed	50,242,751	33,632,695	34.1	13,958,136	17,665,941	64.5	13,482,948	57,994,513	219.3
	No_treed	0	0	0.0	851,473	911,654	54.6	701,365	1,467,490	106.7

