Chapter 5. Forest Inventory-Based Analysis and Projections of Forest Carbon Stocks and Changes in Alaskan Coastal Forests

By Xiaoping Zhou[1], Svetlana A. Schroder[2], A. David McGuire[3], and Zhiliang Zhu[4]

5.1. Highlights

- Baseline (average of 2004–2013) estimates derived from U.S. Department of Agriculture Forest Service forest inventory show that forests in south-central and southeast coastal Alaska contain 1,018 teragrams of carbon (TgC) in both live and dead tree biomass. Over 80 percent of the forest carbon in coastal Alaska is in the Chugach and Tongass National Forests.
- Projected to 2099 using a forest simulation model, forest carbon stock would increase by 1 percent, 8 percent, and 27 percent under the scenarios of current forest management (including harvesting) with current climate, climate change with forest management, and climate change without forest management, respectively. To conduct the simulations of climate change, the A1B scenario from the Intergovernmental Panel on Climate Change's Special Report on Emissions Scenarios was used to drive the version 3.1-T47 of the Canadian Centre for Climate Modelling and Analysis' Coupled Global Climate Model general circulation model.
- Managed with present forest harvest and present climate, the forest carbon would increase by 10 TgC by the end of the century compared with the baseline (2004–2013). Forest carbon stock would increase by 86 TgC under the climate change with harvesting scenario and by 276 TgC under the climate change without harvesting scenario.

5.2. Introduction

Alaska represents over 15 percent of the total U.S. land area and over 15 percent of U.S. forest land (Oswalt and others, 2014). Coastal Alaska includes two inventory regions by the U.S. Forest Service: southeast Alaska, and south-central Alaska and Kodiak Island (fig. 5.1, Barrett and Christensen, 2011). The two regions are part of the North Pacific Landscape Conservation Cooperative (LCC), except for Kodiak Island, which is in the Western Alaska LCC. Coastal Alaska contains two main forest types: boreal forest and temperate maritime forest. In this region of Alaska, approximately 88 percent of the forest land is publicly owned. The substantial amounts of forest land in reserved status and of old-growth forests make coastal Alaska forests different from those in the other coastal regions. The forests in coastal Alaska store about 1,018 teragrams of carbon (TgC). Smith and others (2013) estimated the average total live tree carbon (aboveground and belowground) to be approximately 12.5 kilograms of carbon per square meter (kgC/m^2) in coastal Alaska compared with an average of 6.9 kgC/m^2 for all U.S. forest land. In addition, they estimated the average carbon stored in dead trees (standing dead and down dead wood) to be 2.8 kgC/m^2 in coastal Alaska compared with 1.1 kgC/m^2 on all U.S. forest land.

The analysis presented in this chapter supports the ecosystem carbon assessment (Zhu and others, 2010) in Alaska, as required by the Energy Independence and Security Act of 2007 (EISA). It uses detailed field-plot data measured by the U.S. Department of Agriculture (USDA) Forest Service

[1]U.S. Department of Agriculture Forest Service, Portland, Oreg.

[2]University of Washington, Seattle, Wash.

[3]U.S. Geological Survey, Fairbanks, Alaska.

[4]U.S. Geological Survey, Reston, Va.

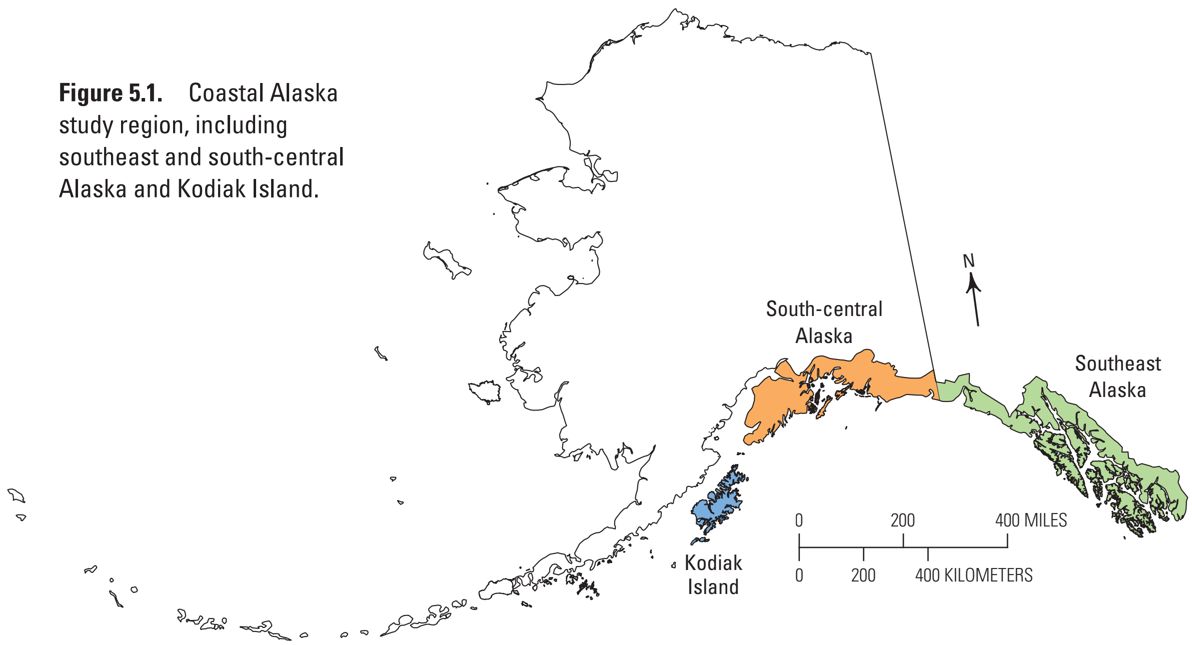

Figure 5.1. Coastal Alaska study region, including southeast and south-central Alaska and Kodiak Island.

as baseline to project the future forest ecosystem carbon under different management activities and climate change assumptions. Such a study will assess the forest carbon from different angles for this heavily forested region. The major objectives of this study are to estimate how much carbon is stored in the coastal forests of Alaska by forest carbon pools except the soil organic carbon, and to assess the responses of carbon storage in this region to potential management activities and climate change.

5.3. Data and Methods

There are over 62,000 square kilometers (km^2) of forest land in coastal Alaska, of which about 89 percent is publicly owned. The USDA Forest Service, Forest Inventory and Analysis (FIA) Program provides information needed to assess the condition of America's forests. FIA collects tree-level field data and provides the public forest inventory data in a standard accessible format for those interested in further analysis. The inventories were conducted on a periodic basis before 1999. With the passage of the 1998 Farm Bill, FIA was required to collect data annually on plots within each State (O'Connell and others, 2014). The USDA Forest Service regional research stations are responsible for measuring the plots and publishing summary reports for each of the States. Note that FIA plots are measured on a moving panel system and it takes about 5 years to measure all the plots in the eastern States and 10 years in the western States.

FIA ground plots are designed to cover a 1-acre (0.00405-km^2) sample area. The recent annual inventories use a national standard, fixed-radius plot layout for sample tree selection and measurement (O'Connell and others, 2014). The variables reported in the FIA database are very detailed, including plot variables, condition variables, and tree-level variables. The plot variables provide information relevant to the entire 1-acre field plot, such as plot location; the condition variables provide information on landscape attributes that define the condition, such as the reserved status, owner group, forest type, and others; and the tree-level variables provide information for each tree 1 inch (2.54 centimeters) in diameter and larger found on the plot, including tree species, diameter at breast height, and height (Barrett and Christensen, 2011). The Pacific Northwest Research Station (PNW) is responsible for collecting and compiling the forest inventory of Alaska, California, Oregon, and Washington. The first full 10-year cycle of annual inventory for coastal Alaska, which was completed by PNW–FIA in 2013 (2004–2013), was used in this study for analyzing current forest conditions and as a baseline for making future projections.

A total of 2,163 plots were used in this study (table 5.1). The current carbon pools were analyzed using tree-level data from the Alaska coastal forest inventory database (Barrett and Christensen, 2011) and were reported by land ownership, forest type, and stand age group.

The USDA Forest Service Forest Vegetation Simulator (FVS) is a widely used modeling tool for predicting forest stand dynamics in U.S. forests (Dixon, 2002). It has been used to summarize current stand conditions, predict future stand conditions under various management alternatives, and update inventory statistics. Basic modules for growth, mortality, regeneration, and volume are built into each variant of the FVS, whereas other linkable extensions are available for modeling specific changes, such as fire and fuels, insects and

Table 5.1. Number of plots and trees by inventory year as measured by the U.S. Department of Agriculture Forest Service Forest Inventory and Analysis Program in the study region.

Inventory year	Number of plots	Number of trees
2004	214	7,055
2005	270	9,754
2006	214	7,795
2007	217	7,234
2008	211	8,126
2009	203	7,295
2010	224	8,385
2011	202	6,984
2012	207	7,340
2013	201	6,989
Total	**2,163**	**76,957**

diseases, and climate-induced effects. In this study, tree-level FIA data were used as inputs into the FVS to produce vegetation projections and corresponding carbon volumes. Because the forest inventory data were collected in different years, the plots collected before 2012 were grown to that point using the FVS model. The FVS simulates vegetation in cycle-by-cycle lists, where a cycle is a period of time for which increments of tree characteristics are predicted.

FVS variants account for the local peculiarities of vegetation and fuel types in different forests throughout the United States. For this study, we used the current Alaska variant of the FVS (Keyser, 2008), which includes models designed specifically for the southeast Alaska coastal forest types found in the study region.

The height and diameter growth rates were adjusted using a previously published validation procedure (Robinson and others, 2005; Leites and others, 2009). To accomplish this, we compiled the FIA data and ran a simulation. The results of the simulation run were compared with the forest inventory data, and we adjusted the growth rates to minimize model-data discrepancies. The comparison showed that the FVS overestimated diameter and height growth, which is consistent with the results reported by Peterson and others (2014). The subsequent growth-rate adjustment reduced the bias in diameter growth to 4.7 percent and height growth to 3 percent.

The carbon modeling simulation was run using the FVS Alaska variant with two modifications. First, we did not use the built-in regeneration model. Instead, we simulated natural regeneration based on the basal area in each plot by species. Using this algorithm, we were able to include regrowth more evenly compared with adding it every 50 years as the built-in regeneration model simulates. Second, we adjusted mortality in the model by using data on historical mortality rates (Haynes, 2003) and updating decay classes to match the classes for different species in Alaska (Keyser, 2008). Decomposition rates were not modified from those in the Alaska variant of the FVS.

For each of the scenarios we ran 25 simulations for each ecological region to assess uncertainty. We ran the model in a stochastic mode and seeded a random number into each simulation run by using the "RANNSEED" keyword in the FVS. This procedure was conducted to achieve random effects via distribution of the errors associated with prediction of the logarithm of basal area increments (Dixon, 2002). In the Alaska variant of the FVS, the inclusion of random effects alters the equations for calculating diameter and crown ratio and thus provides a basis for quantifying uncertainty. There is a random component in the estimate of the height growth as well (Keyser, 2008). For each simulation the output tables (that is, the carbon pools and tree lists) were summarized in 5-year intervals and exported to a separate database for further analysis. The data were then processed and analyzed to describe future projections for different scenarios.

5.4. Management and Climate Scenarios

Three scenarios were developed and analyzed in this assessment: (1) current management with no climate change, (2) climate change with management, and (3) climate change with no management. These scenarios are described below.

The major forest activity associated with management in the study region is forest harvest. Currently, the forest plans for both the Tongass (2008 forest plan) and Chugach (2002 forest plan) National Forests are being revised and amended (visit http://www.fs.usda.gov/tongass/ and http://www.fs.usda.gov/chugach/ for more information and updates). The planned amendment for the Tongass National Forest would make changes to young-growth management, as well as changes to make renewable energy development more permissive. However, no concrete projections of future harvesting rates have yet been made. Therefore, for this study, the most recent 5-year average of harvest volume available was applied to the whole projection for the management scenario (Alexander, 2012; Zhou, 2013) (fig. 5.2). The management scenario also assumed that the harvest would only take place on timberlands (that is, non-reserved, accessible areas with productivity of at least 1.4 cubic meters per hectare per year where merchantable volume is at least 175 cubic meters per hectare). The model also assumes harvesting would not take place on slopes greater than 35 percent owing to the logistical challenges and higher costs associated with working in these areas. Wildfire was evaluated for the coastal region based on the fire incident data from the Alaska Interagency Coordination Center (AICC), but was not modeled because of its low occurrence rate. The effects of insects and disease were modeled using the average mortality rate from the FIA historical database.

For the climate change simulations used in this study, we chose to use one of the climate scenarios from the Intergovernmental Panel on Climate Change's (IPCC's) Special Report on Emissions Scenarios (Nakićenović and Swart, 2000). Version 3.1-T47 of the Canadian Centre for Climate Modelling and Analysis' Coupled Global Climate Model (CGCM3.1; Flato, 2005) general circulation model data for IPCC scenario A1B was coupled with the FVS to simulate climate change effects on forest carbon. It is important to note that the climate extension (Climate-FVS) is not readily available for the Alaska variant, but we were able to obtain a custom version of this extension from the USDA Forest Service's Forest Management Service Center (Crookston, 2014). The FVS simulations were performed using the climate data and species viability scores for that climate; species viability scores were used to adjust the growth of different species in each plot given changed climate conditions. The species viability scores used in this study were calculated by West Virginia University's Forest Resources Management, School of Natural Resources.

The FVS output allows tracking of changes in various carbon pools. It was used to calculate total carbon storage for the study area by weighting each plot with the area it represents in the FIA sample using the statistical analysis software (SAS Institute Inc., 2008).

Forest carbon pools analyzed in this study include live tree biomass (aboveground and belowground), understory vegetation, dead wood (standing dead and down dead wood), forest floor (litter carbon), and soil organic carbon (SOC). The definition of each pool is listed in table 5.2 (Smith and others, 2013; O'Connell and others, 2014). The SOC pool, which is available from FIA data, was not included in projected results because the FVS does not simulate the SOC in the carbon module.

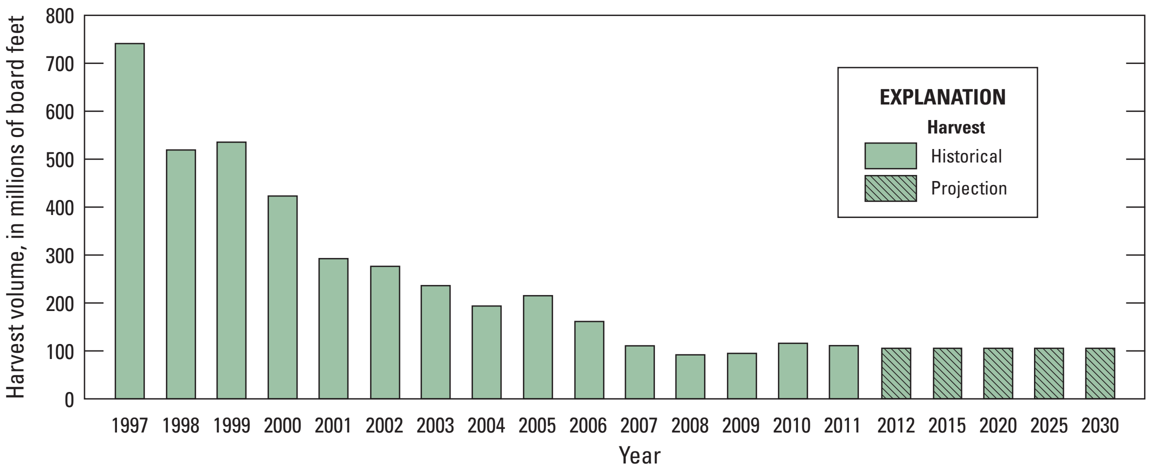

Figure 5.2. Coastal Alaska historical annual harvest and projected harvest.

Table 5.2. Forest carbon pools analyzed in this study.

[cm, centimeter; m, meter]

Carbon pool category	Definition
Aboveground and belowground live tree	Aboveground and belowground portions of the live trees with diameters greater than 2.54 cm at 1.37 m above the forest floor.
Standing dead wood	Standing dead trees, including coarse roots.
Down dead wood	Woody material greater than 7.6 cm in diameter on the ground and stumps and their roots greater than 7.6 cm in diameter.
Understory vegetation	Aboveground and belowground portions of seedlings and woody shrubs.
Forest floor or litter	Organic material on the floor of the forest, including fine woody debris, humus, and fine roots in the organic forest floor layer above mineral soil.
Soil organic carbon	Fine organic material below the soil surface to a depth of 1 m (does not include roots).

5.5. Results and Discussion

5.5.1. Current Status of Forest Carbon Pools

The baseline forest carbon was derived from the USDA Forest Service EVALIDator program (Miles, 2015). The total forest carbon without soil organic carbon (SOC) in coastal Alaska was estimated to be 1,018 TgC (2004–2013), of which about 557 TgC was live biomass carbon (aboveground and belowground), 175 TgC was dead wood carbon (standing dead and down dead wood), and 275 TgC was forest floor carbon. The estimates of forest carbon without SOC are reported below by land ownership, forest type, and stand age class.

5.5.1.1. Current Forest Carbon Pools by Land Ownership Group

The two largest land owners, the Chugach and Tongass National Forests, represent 71 percent of the forest land and contain 80 percent of the forest carbon in coastal Alaska (fig. 5.3). The Tongass National Forest, which is the largest national forest in the country, has 64 percent of the total coastal forest land and over 74 percent of the total Alaska coastal forest carbon. Nearly 18 percent of the forest land in coastal Alaska is in other public ownership (other Federal or State and local government), and over 11 percent of forest land is in private ownership.

5.5.1.2. Current Forest Carbon Stock by Forest Type

The major forest types in coastal Alaska are western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), mountain hemlock (*Tsuga mertensiana* (Bong.) Carrière), Sitka spruce (*Picea sitchensis* (Bong.) Carrière), yellow-cedar (*Callitropsis nootkatensis* (D. Don) D.P. Little), and western red cedar (*Thuja plicata* Donn ex D. Don). These five forest types account for over 90 percent of the coastal forest carbon, of which over 38 percent is stored in the western hemlock forest type (table 5.3).

5.5.1.3. Current Forest Carbon Pools by Stand Age Class

Over 44 percent of coastal Alaska forest land is more than 200 years old, and 58 percent of forest carbon is stored in this age class. The age class of 200 to 300 years old occupies approximately 20,000 km^2 of forest land and stores the greatest proportion of the forest carbon (fig. 5.4).

5.5.2. Projected Changes in Forest Carbon (Not Including Soil Organic Carbon)

The analysis of the FVS simulations conducted for the scenario of current management without considering climate change (fig. 5.5) indicated that forest carbon (live tree, dead wood, forest floor, and understory carbon) in coastal Alaska would decrease by 3.9 teragrams of carbon per year (TgC/yr) until the 2050s and then would increase by 1.8 TgC/yr throughout the remainder of the century. The carbon in live

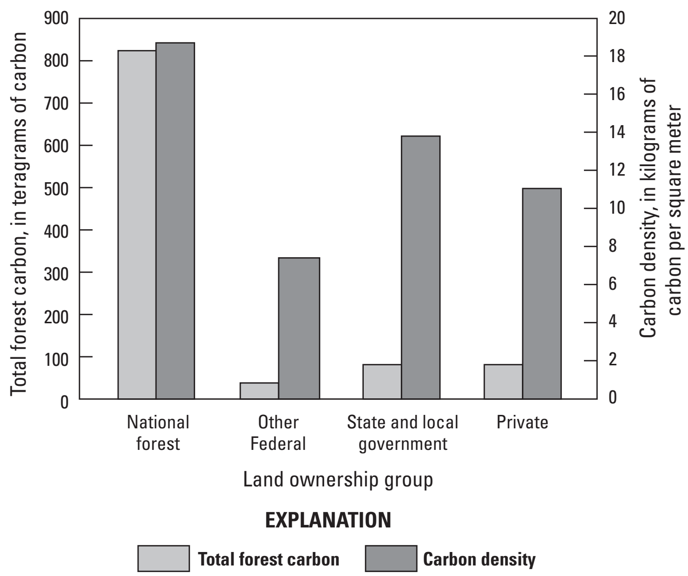

Figure 5.3. Coastal Alaska current forest carbon stock and carbon density by land ownership group (not including soil organic carbon). Data source: USDA Forest Service Forest Inventory and Analysis Program.

Table 5.3. Coastal Alaska current forest carbon distribution by forest type (not including soil organic carbon).

[Data source: USDA Forest Service Forest Inventory and Analysis Program. kgC/m^2, kilogram of carbon per square meter]

Carbon	Forest type						
	Western hemlock	Mountain hemlock	Sitka spruce	Yellow-cedar	Western red cedar	Other softwood	Other hardwood
Distribution (percent)	37.8	17.9	16.2	13.2	8.6	4.5	2.8
Density (kgC/m^2)	23.63	13.97	20.34	14.32	20.92	5.91	6.36

trees (aboveground and belowground) would decrease by 1.2 TgC/yr until the early 2040s and then would increase by 2.6 TgC/yr through 2099. Although the projected harvesting rate was set to the same level for every 5-year cycle, the model does not distribute it evenly, and the intensity of the harvest of live trees at the beginning would contribute to the decrease of live tree carbon. In general, the live trees are the major carbon pool for the region. Carbon in the forest floor would decrease from 2010 to 2050 at the rate of 0.8 TgC/yr before stabilizing until 2070 after which it slightly increases through 2099. Whereas the total forest carbon (not including SOC) would increase by 1 percent, live tree carbon was projected to increase by almost 27 percent by the end of this century under this scenario.

The analysis of the FVS simulations conducted for the scenario of climate change with management (fig. 5.6) indicated that forest carbon stock would increase by 8.5 percent in total forest carbon with a 38-percent increase in live tree carbon storage by the end of the century. The timing of the trajectory was similar to the first scenario. Total forest carbon stock would decrease until the mid-2040s at 3.6 TgC/yr followed by an increase throughout the remainder of the century of 2.5 TgC/yr. Similarly, the live tree carbon would decrease by 0.4 TgC/yr until the early 2040s and then increase by 3.2 TgC/yr. Changes in understory carbon, which is only about 0.5 percent of the total forest carbon, is not influential in the calculation. Carbon in the forest floor would decrease until 2060 at 0.6 TgC/yr then slightly increase or remain constant.

Finally, the analysis of the FVS simulations conducted for the scenario of climate change with no management (fig. 5.7) indicated that forest carbon would decrease by 2.7 TgC/yr for the first decade and then increase by 3.2 TgC/yr throughout the remainder of the century. The live tree carbon was projected to slowly increase through the whole projection period at the rate of 4.0 TgC/yr. The carbon stored in forest floor was relatively stable. At the end of century, the total forest carbon would increase by nearly 27 percent and the live tree carbon by about 68 percent.

Because the management scenarios assume a relatively low rate of harvesting, the estimated amount of carbon

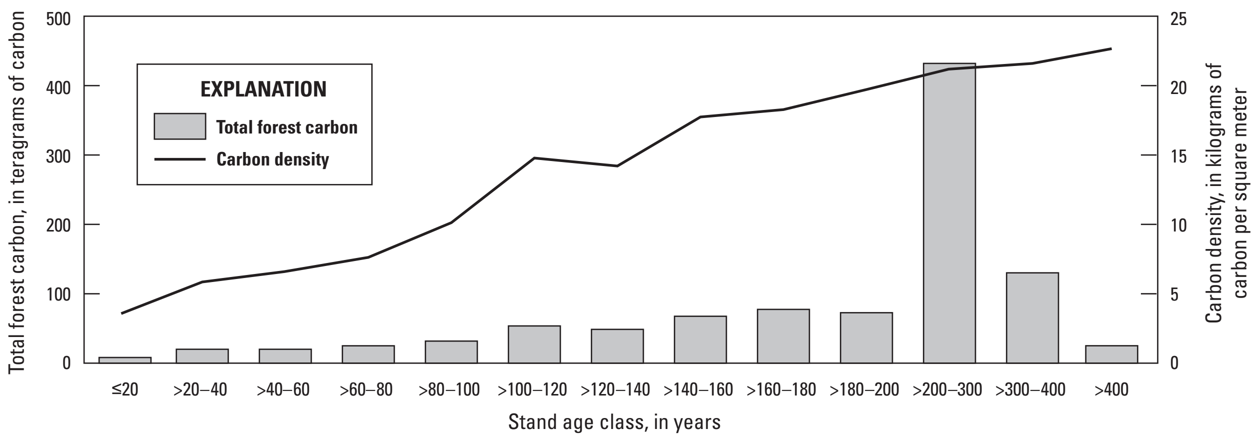

Figure 5.4. Coastal Alaska baseline (2003–2014) forest carbon and carbon density by stand age class (not including soil organic carbon). Data source: USDA Forest Service Forest Inventory and Analysis Program.

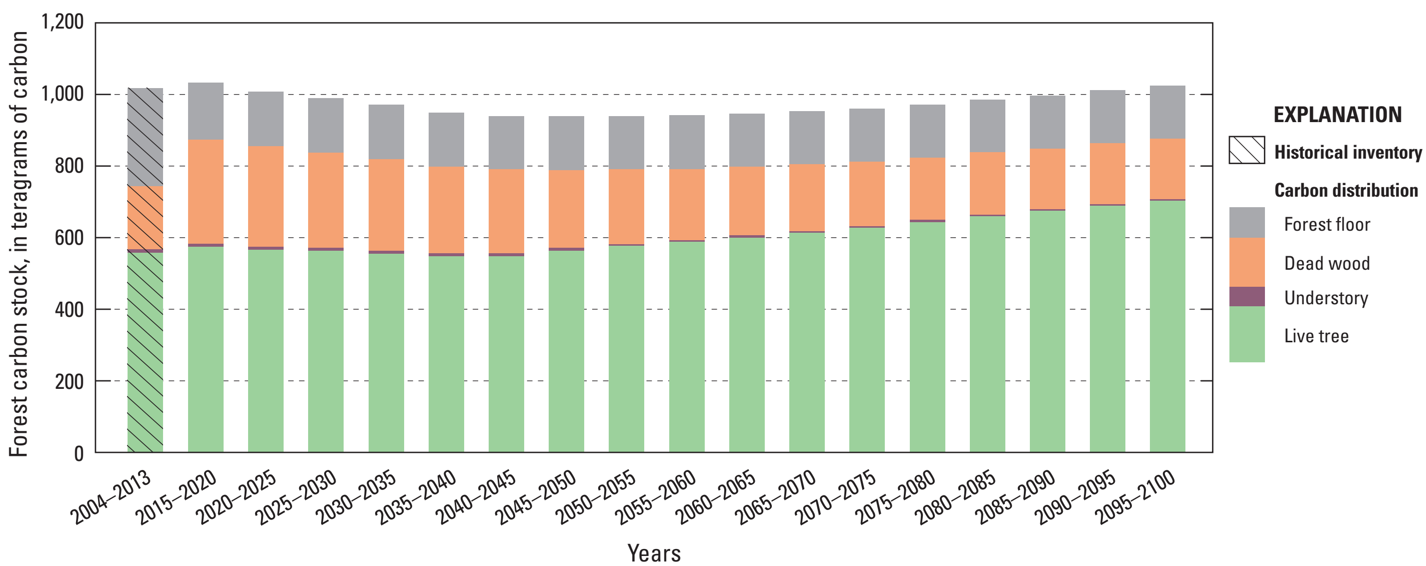

Figure 5.5. Results of projected forest carbon stock (not including soil organic carbon) in coastal Alaska under the scenario of forest management with no climate change. Data source: USDA Forest Service Forest Inventory and Analysis Program.

removed ranged from 0.1 to 0.3 TgC/yr under the climate change scenario and from 0.1 to 0.2 TgC/yr at the present climate in coastal Alaska.

All the scenarios described above showed a significant decrease in the dead wood carbon pool for the first 50- to 60-year period. Such a decrease, especially at the beginning of the projection period, can be explained by the harvest and the relatively fast decomposition in the region. The tree mortality rate derived from the historical database could also be lower compared to the current rate observed in coastal Alaska. Because actual decomposition rates for coastal Alaska are not currently available, we instead used rates derived for the Pacific Northwest region, thus our models may have overestimated this parameter.

Although 25 simulations were run to assess uncertainty for each scenario, little variability was shown in each of the above described scenarios.

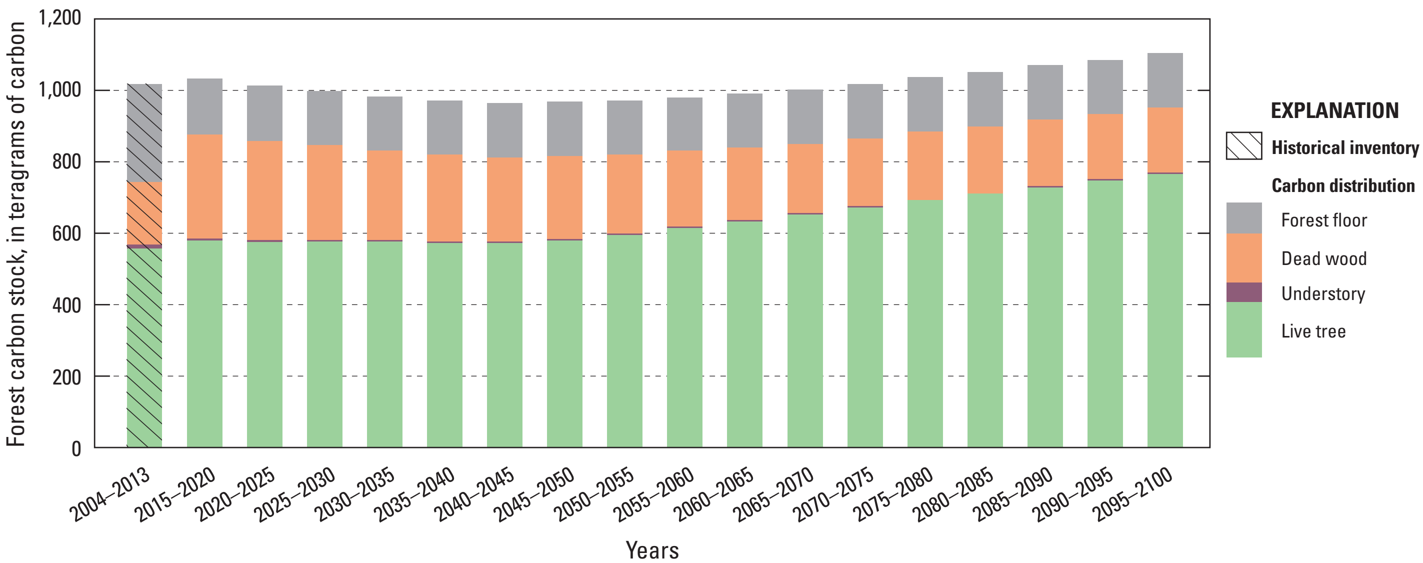

Figure 5.6. Results of projected forest carbon stock (not including soil organic carbon) in coastal Alaska under the scenario of climate change with forest management. Data source: USDA Forest Service Forest Inventory and Analysis Program. To conduct the simulations of climate change, the A1B scenario from the Intergovernmental Panel on Climate Change's Special Report on Emissions Scenarios (Nakićenović and Swart, 2000) was used to drive the version 3.1-T47 of the Canadian Centre for Climate Modelling and Analysis' Coupled Global Climate Model (CGCM3.1; Flato, 2005) general circulation model.

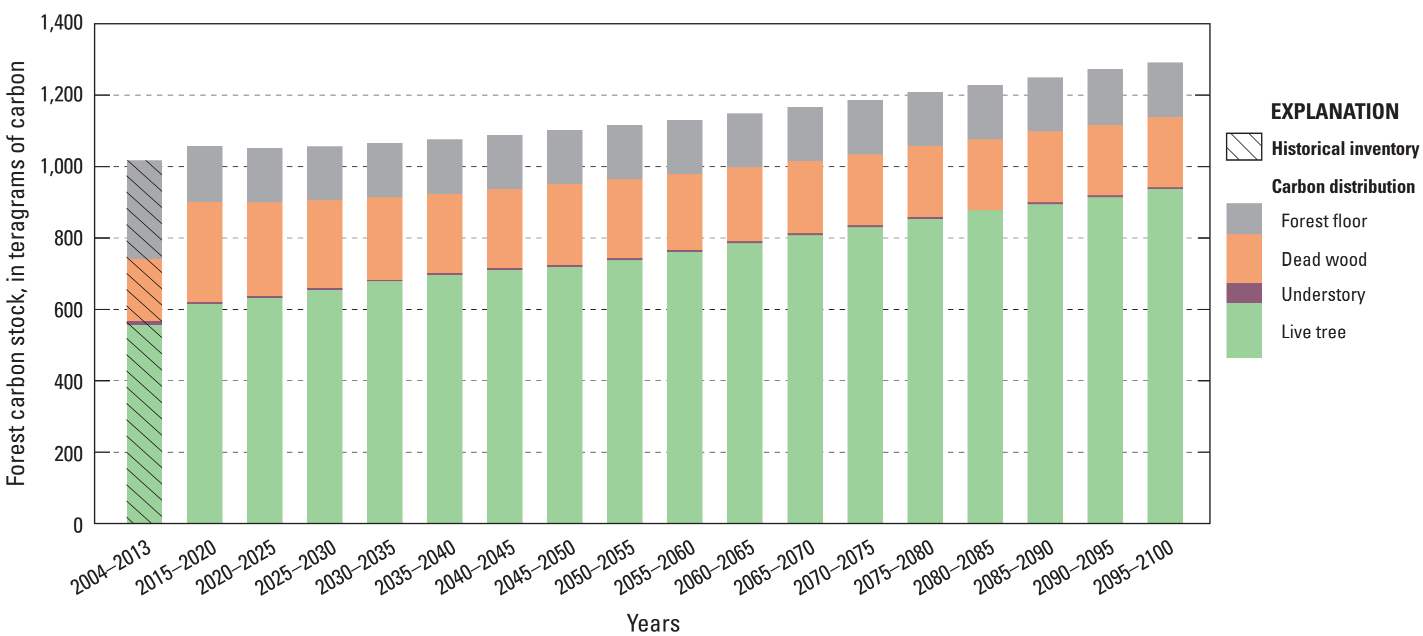

Figure 5.7. Results of projected forest carbon stock (not including soil organic carbon) in coastal Alaska under the scenario of climate change with no forest management. Data source: USDA Forest Service Forest Inventory and Analysis Program. Details regarding the simulations of climate change can be found in figure 5.6.

5.6. Conclusions

Overall, the results show that the balance of forest carbon in the study region in Alaska is sensitive to management actions and climate change. Managed with present forest harvest and present climate, the forest carbon would increase by 10 TgC by the end of the century compared to the baseline (2004–2013). Forest carbon stock would increase by 86 TgC under the climate change with management and by 276 TgC under the climate change with no management (fig. 5.8).

The results suggest relative effects of forest management and climate change on forests of the Alaska coastal region. Forest management by itself would have a negative effect on the balance of forest carbon, whereas the climate change simulation under scenario A1B with CGCM3.1 would lead to increased carbon stock. Since the majority of the forest lands are publicly owned in coastal Alaska, forest policies of State and Federal agencies focused on conservation and carbon sequestration could substantially increase carbon storage in the region by the end of the century. It is important to note that there are several uncertainties in this study. First, the FVS is designed as a growth and yield model—the carbon tool in the current FVS calculates major forest carbon estimates but may not include all ecosystem processes in reporting carbon emission and sequestration, such as soil organic carbon and management-related emissions. Second, the scenario for forest harvest that we used is just one of many possible scenarios. It essentially represents a "business as usual" scenario. Future forest harvest could be substantially affected by amendments to the forest plan for the Tongass National Forest as well as the global market for wood products. Third, there is substantial uncertainty about future projections on climate change, which may affect the species viability and the growth rate for coastal Alaska.

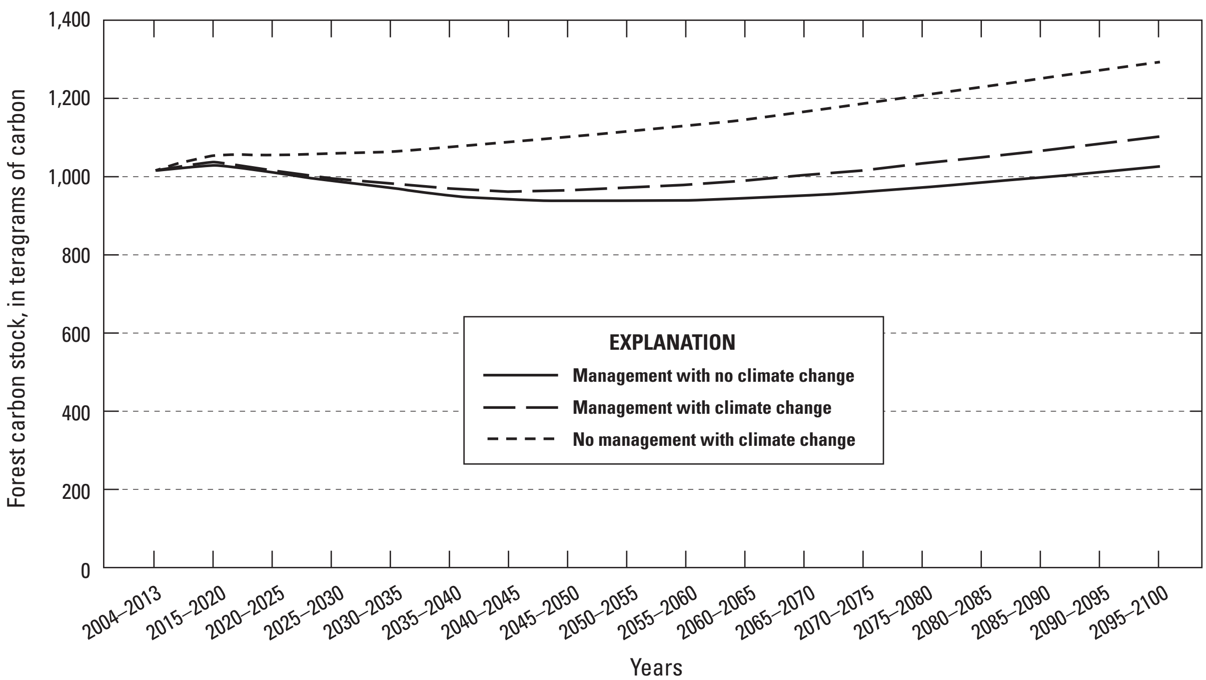

Figure 5.8. Projected coastal Alaska forest carbon stock (not including soil organic carbon) under three scenarios: management with no climate change, climate change with management, and climate change with no management. Data source: USDA Forest Service Forest Inventory and Analysis Program. To conduct the simulations of climate change, the A1B scenario from the Intergovernmental Panel on Climate Change's Special Report on Emissions Scenarios (Nakićenović and Swart, 2000) was used to drive the version 3.1-T47 of the Canadian Centre for Climate Modelling and Analysis' Coupled Global Climate Model (CGCM3.1; Flato, 2005) general circulation model.

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