Regional and Forest-Level Estimates of Carbon Stored in Harvested Wood Products From the United States Forest Service Northern Region, 1906-2010

Nathaniel Anderson, Jesse Young, Keith Stockmann, Kenneth Skog, Sean Healey, Daniel Loeffler, J. Greg Jones, James Morrison

United States Department of Agriculture / Forest Service

Rocky Mountain Research Station

General Technical Report
RMRS-GTR-311

October 2013

Anderson, N.; Young, J.; Stockmann, K.; Skog, K.; Healey, S.; Loeffler, D.; Jones, J.G.; Morrison, J. 2013. **Regional and forest-level estimates of carbon stored in harvested wood products from the United States Forest Service Northern Region, 1906-2010**.Gen. Tech. Rep. RMRS-311. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 114 p.

Abstract

Global forests capture and store significant amounts of CO_2 through photosynthesis. When carbon is removed from forests through harvest, a portion of the harvested carbon is stored in wood products, often for many decades. The United States Forest Service (USFS) and other agencies are interested in accurately accounting for carbon flux associated with harvested wood products (HWP) to meet greenhouse gas monitoring commitments and climate change adaptation and mitigation objectives. National-level forest carbon accounting has been in place for over a decade, but there is an increasing need for accounting at the scale of smaller administrative units, including USFS Regions and individual national forests. This paper uses the Intergovernmental Panel on Climate Change (IPCC) production accounting approach and the California Forest Project Protocol (CFPP) to estimate HWP carbon storage from 1906 to 2010 for the USFS Northern Region and its eleven national forests, which span northern Idaho, Montana, South Dakota, and eastern Washington. For the Northern Region as a whole, carbon stocks in the HWP pool were increasing at one million megagrams of carbon (MgC) per year in the mid-1960s, with peak cumulative storage of 28 million MgC occurring in 1995. Net positive flux into the HWP pool over this period is primarily attributable to high harvest levels in the middle of the twentieth century. Harvest levels declined after 1970, resulting in less carbon entering the HWP pool. Since 1995, emissions from HWP at solid waste disposal sites have exceeded additions from harvesting, resulting in a decline in the total amount of carbon stored in the HWP pool. The Northern Region HWP pool is now in a period of negative net annual stock change because the decay of products harvested between 1906 and 2010 exceeds additions of carbon to the HWP pool through harvest. Though most individual national forests mirror Regional-level trends in harvest and carbon flux, the timing and magnitude of change differs among forests with some forests departing notably from Regional trends. Together with estimates of ecosystem carbon, Regional and Forest-level estimates of HWP carbon flux can be used to inform management decisions and guide climate change adaptation and mitigation efforts by the agency. Though our emphasis is on national forests in the Northern Region, we provide a framework by which these accounting methods can be applied more broadly at sub-national scales to other regions, land management units, and firms.

Keywords: harvested wood products, carbon accounting, carbon management, greenhouse gas emissions, carbon sequestration

Publishing Services

Telephone (970) 498-1392

FAX (970) 498-1122

E-mail rschneider@fs.fed.us

Web site http://www.fs.fed.us/rmrs

Mailing Address Publications Distribution
Rocky Mountain Research Station
240 West Prospect Road
Fort Collins, CO 80526

Authors

Nathaniel Anderson (corresponding author) is a Research Forester with the U.S. Forest Service, Rocky Mountain Research Station, Missoula, Montana.

Jesse Young is a Forestry Research Technician with the U.S. Forest Service, Rocky Mountain Research Station, Missoula, Montana.

Keith Stockmann is an Economist with the U.S. Forest Service, Northern Region, Missoula, Montana.

Kenneth Skog is a Project Leader with the Economics and Statistics Research unit of the U.S. Forest Service, Forest Products Laboratory, Madison, Wisconsin.

Sean Healey is a Research Ecologist with the Forest Inventory and Analysis Program, U.S. Forest Service, Rocky Mountain Research Station, Ogden, Utah.

Daniel Loeffler is an Economics Research Associate with the College of Forestry and Conservation, University of Montana, Missoula, Montana.

J. Greg Jones is a Research Forester (retired), U.S. Forest Service, Rocky Mountain Research Station, Missoula, Montana.

James Morrison is a Regional Climate Change Coordinator (retired), U.S. Forest Service, Northern Region, Missoula, Montana.

Acknowledgments

Funding was provided by the USFS, Northern Region Resource Information Management Board, NASA, and the USDA National Institute of Food and Agriculture. Forest Inventory and Analysis Timber Product Output officers Todd Morgan, Pat Healey, and Chuck Keegan assisted with estimating the dates when various processing operations commenced in our study area. Critical reviews by Chris Woodall, Cindy Swanson, Larry Scott Baggett, Andrew Pugliese, Greg Kujawa, and Marilyn Buford were all very helpful. We also thank the three anonymous peer reviewers whose comments helped improve this work.

Website

Online tools to help forest managers monitor carbon in HWP and quantify tradeoffs associated with different levels of harvesting have been developed from this work. For tools and resources, please visit: http://maps.gis.usu.edu/HWP/.

Contents

Background **1**

Objectives 3

Methods **3**

Accounting Approaches 3
Data Sources 7
Computational Methods 9
Uncertainty 12
A Note about Life Cycle Assessment 14

Results for the Northern Region **15**

Regional-Level Estimates **21**

National Context 21
Applications of These Approaches 22
Harvested Wood Products Carbon by National Forest 24
Conclusions 25

National Forest Reports **26**

Beaverhead-Deerlodge National Forest 26
Bitterroot National Forest 35
Custer National Forest 43
Flathead National Forest 51
Gallatin National Forest 58
Helena National Forest 66
Idaho Panhandle National Forest 74
Kootenai National Forest 81
Lewis and Clark National Forest 88
Lolo National Forest 96
Nez Perce-Clearwater National Forest 103

References **111**

Regional and Forest-Level Estimates of Carbon Stored in Harvested Wood Products From the United States Forest Service Northern Region, 1906-2010

Nathaniel Anderson, Jesse Young, Keith Stockmann, Kenneth Skog, Sean Healey, Daniel Loeffler, J. Greg Jones, James Morrison

Background

Recent estimates of net annual storage, or flux, indicate that the world's forests are an important carbon sink, removing more carbon from the atmosphere through photosynthesis than they emit through combustion and decay (Pan and others 2011). The forest sector of the United States (U.S.) currently stores about 48 billion megagrams of carbon (MgC) (USEPA 2010), or the equivalent of about 20 years of U.S. fossil fuel emissions at the 2008 rate. The net additions to ecosystem and harvested wood products (HWP) pools have been estimated at 216 million MgC yr^{-1} (USEPA 2010), with U.S. forests functioning as a sink and offsetting about 11 percent of the country's annual fossil fuel emissions.

About 5 percent of total U.S. forest sector carbon stocks and 11 percent of the annual flux is attributable to carbon in HWP. Though the HWP fraction of the pool is small compared to ecosystem carbon, it is an important component of national level carbon accounting and reporting. As defined by the Intergovernmental Panel on Climate Change (IPCC), HWP are products made from wood including lumber, panels, paper, paperboard, and wood used for fuel (Skog 2008). The HWP carbon pool includes both products in use and products that have been discarded to solid waste disposal sites (SWDS). Additions to the HWP pool are made through harvesting, while emissions are from decay and combustion of wood products.

Increasing social and managerial interest in mitigating rising atmospheric CO_2 concentrations and the resulting impacts on climate has focused attention on the ecosystem service of forest carbon storage, including storage in HWP. Forest management can affect the quantity of carbon stored in both ecosystems and forest products over time, and management activities in the United States frequently include silvicultural treatments that produce HWP. Credible information on forest ecosystem and HWP carbon stocks and fluxes can inform forest managers and the public of the tradeoffs between carbon storage and other forest management objectives, and between the short-term and long-term carbon consequences of alternative forest management strategies (Galik and Jackson 2009; McKinley and others 2011; Ryan and others 2010).

As governments contemplate mitigation and adaptation options, there is growing interest among forest managers in monitoring and managing forests for sequestration of carbon as an ecosystem service. For example, during 2010, the U.S. Forest Service (USFS) developed a climate change scorecard that is to be completed annually for each of the 155 national forests and national grasslands managed by the agency (USFS 2011). The scorecard includes four categories of scored elements: organizational capacity, engagement, adaptation, and mitigation and sustainable consumption. Elements under mitigation and sustainable consumption direct individual national forests to develop a baseline assessment of carbon stocks, as well as an assessment of the influence of disturbance and management activities on these stocks. These assessments are meant to guide adaptation actions and continued monitoring. Managers are explicitly expected to begin integrating carbon stewardship with management of their forest for traditional multiple uses and other ecosystem services.

These requirements necessitate robust and accessible monitoring systems that provide quantitative metrics to gauge progress. Policies and guidelines regarding the appropriate level of accuracy needed for completing carbon assessments and for informing forest management decisions at the individual national forest level are currently under development. Fortunately, national and state level monitoring systems provide a solid foundation for forest level accounting.

HWP carbon monitoring systems have been implemented at the national level (IPCC 2006; Skog 2008; USEPA 2010), as well as at the level of an individual harvest (Smith and others 2006). Robust inventory-based methods for estimating carbon stocks and flux in forest ecosystems are well established in the United States with several tools available to forest managers (Galik and others 2009; Smith and others 2004, 2006; Zheng and others 2010). However, many of the tools used to estimate carbon stored in forests, such as the Carbon On Line Estimator Version 2.0 (Van Deusen and Heath 2007) and the U.S. Forest Carbon Calculation Tool (Smith and others 2007), do not provide estimates of HWP carbon and other tools are restricted to national level HWP accounting (e.g., WOODCARB II, Skog 2008).

While these tools are relevant for public and industrial timber producers interested in documenting the carbon fluxes associated with harvesting activities (Healey and others 2009), they do not serve the needs of forest managers at their current scales of analysis. Managers need similarly accessible and practical tools for estimating and monitoring carbon stocks and flux in HWP (Ingerson 2011) at the agency or firm level.

Objectives

There is a clear need for the means to monitor the contribution of HWP to carbon pools and greenhouse gas mitigation at sub-national scales. Currently, forest managers do not have the tools they need to accomplish monitoring goals that have been established at the national level. Developing these tools is an important step in facilitating carbon assessment and stewardship and in informing management actions on the ground. Our objectives with this study are to (1) use established accounting approaches to make estimates of HWP carbon stocks and fluxes for the USFS Northern Region as a demonstration of sub-national HWP accounting; (2) provide similar estimates for each of the eleven national forests that make up the Region; (3) provide a framework with clear metrics and estimation methods that can be applied to other regions and land management units; and (4) provide guidance to managers concerning the differences between alternative approaches with regards to data and resource requirements. We do not develop a system for evaluating the future impacts of specific management actions, nor do we advocate any particular course of action to improve carbon stewardship.

Methods

The methods used to estimate carbon stored in HWP for the Northern Region and for individual national forests are discussed in four parts: accounting approaches, data sources, computational methods, and uncertainty. The first part provides a general overview of the frameworks used for carbon accounting, including defining the scope of analysis, relevant carbon pools, and associated fluxes. The "Data Sources" section describes the origins of the data used in this analysis, with an emphasis on understanding what inputs are required and how data quality can vary over time. Computational methods provides detailed information about the calculations that transform harvest data into carbon accounting metrics, including annual flux; and finally, we describe the quantitative treatment of uncertainty in light of limitations of the approaches, data, and computational methods. Following the description of these methods, we provide a brief comparison to Life Cycle Assessment (LCA), which is a well-established methodology that is commonly used to evaluate the environmental impact of manufactured products, including HWP, especially with regards to energy inputs and greenhouse gas emissions.

Accounting Approaches

We use the IPCC production accounting approach, which has been adopted by the U.S. Environmental Protection Agency (EPA; hereafter referred to as the IPCC/EPA approach), and the California Forest Project Protocol (CFPP; Climate Action Reserve 2009) to estimate annual changes in HWP pools from 1906 to 2010 for the USFS Northern Region (fig. 1). The Northern Region contains approximately 10.9 million hectares of Federally owned land in the States of Montana, Idaho, North Dakota, South Dakota, and eastern Washington; approximately 8.1 million hectares are forested. We chose this region because

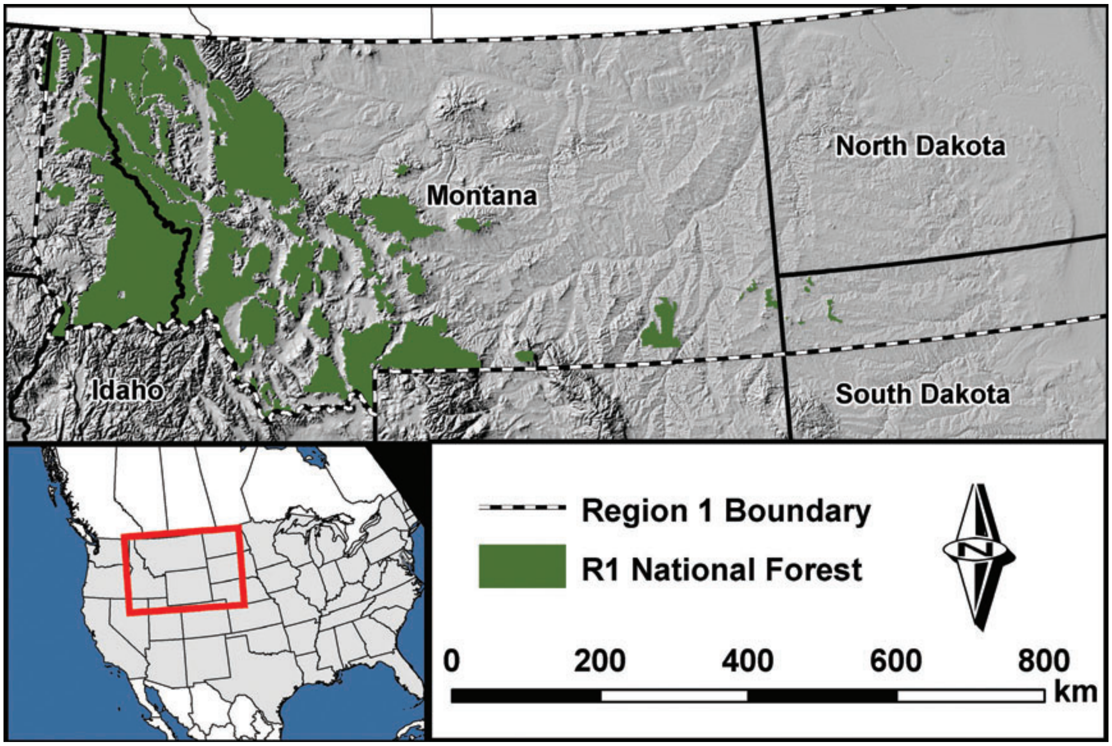

Figure 1—Map of the study area. The U.S. Forest Service Northern Region (Region 1) administers approximately 8.1 million hectares of Federaly owned forestland in the States of Montana, Idaho, South Dakota, and northeastern Washington.

it represents a management unit of the desired sub-national scale, and managers in this region are particularly interested in developing tools to meet carbon stewardship objectives.

In the IPCC/EPA production accounting approach, the annual carbon stock change for the total forest sector (ΔS) is a function of carbon flow among the atmosphere, forest ecosystems, and HWP, and is calculated as:

$$\Delta S = (NEE - H) + (\Delta C_{R1})$$

where

NEE = the annual net ecosystem exchange between the atmosphere and Northern Region forests from all ecosystem processes including photosynthesis, decay, and natural and anthropogenic fire;

H = the annual harvest of wood from Northern Region forests for products; and

ΔC_{R1} = the annual change in carbon stored in HWP that was made from wood harvested from Northern Region forests (table 1, fig. 2).

Table 1—Variable definitions for the IPCC/EPA production accounting approach shown in Figure 2 (Skog 2008). Units for all variables are MgC yr^{-1}.

Variable	Definition
ΔS	Annual carbon stock change, which is calculated as $\Delta S=(NEE-H)+(\Delta C_{R1})$ in the production accounting approach.
NEE	Annual net ecosystem carbon exchange, the annual net carbon that moves from the atmosphere to forests.
H	Annual harvest of wood for products, which includes wood and residues removed from harvest sites, but excludes resides left at harvest sites.
HWP	Harvested wood products in use or at solid waste disposal sites.
E_{R1}	Annual emission of carbon to the atmosphere in the Northern Region from products made from wood harvested in the Northern Region.
E_{IM}	Annual emission of carbon to the atmosphere in the Northern Region from products made from wood harvested outside of the Northern Region and imported into the Northern Region.
P_{EX}	Annual exports of wood and paper products out of the Northern Region, including roundwood, chips, residue, pulp and recovered (recycled) products.
P_{IM}	Annual imports of wood and paper products into the Northern Region, including roundwood, chips, residue, pulp and recovered (recycled) products.
$E_{EX\ R1}$	Annual emission of carbon to the atmosphere in areas outside of the Northern Region from products made from wood harvested in the Northern Region.
E_{OTHER}	Annual emission of carbon to the atmosphere in areas outside of the Northern Region from products made from wood harvested outside the Northern Region.
C_{R1}	Stock of harvested wood products carbon in use or at solid waste disposal sites where products used wood from the Northern Region harvests.
$\Delta C_{IU\ R1}$	Annual change in carbon stored in harvested wood products in products in use where products used wood from the Northern Region harvests.
$\Delta C_{SWDS\ R1}$	Annual change in carbon stored in harvested wood products at solid waste disposal sites where products used wood from the Northern Region harvests.
ΔC_{R1}	Annual change in carbon stored in harvested wood products in products in use and at solid waste disposal sites where products used wood from the Northern Region harvests. $\Delta C_{R1} = \Delta C_{IU\ R1} + \Delta C_{SWDS\ R1}$

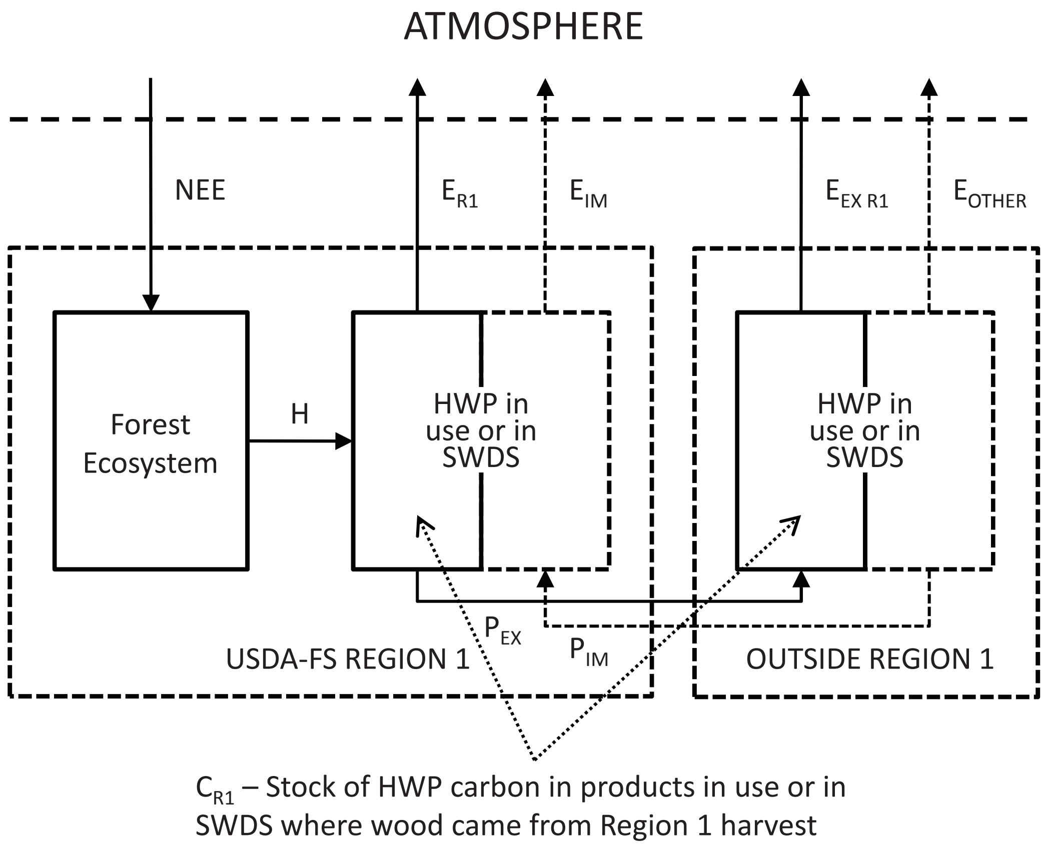

Figure 2—Carbon flows and stocks associated with forest ecosystems and harvested wood products (HWP). These flows are used to illustrate the IPCC/EPA production accounting approach (adapted from Skog 2008).

As discussed previously, the HWP pool is a relatively small but important fraction of the forest carbon flux in the United States, accounting for about 11 percent of the annual carbon stock change of 216 million MgC yr^{-1}. In this approach, the annual change in carbon stored in HWP (ΔC_{R1}) is the sum of the net change in carbon stored in products in use ($\Delta C_{IU\ R1}$) and the net change in carbon stored in products at solid waste disposal sites ($\Delta C_{SWDS\ R1}$).

Most people are familiar with imports and exports in the context of international trade, but the concept can be applied to any area of interest. For example, HWP manufactured in a USFS region may be used locally by consumers inside the region or exported outside the region for use elsewhere. Similarly, HWP produced outside the region may be imported for use within the region. It is important to understand the treatment of imports and exports in the production accounting approach. Figure 2 shows that carbon emissions attributed to HWP from the Northern Region (indicated with solid boxes) include both emissions to the atmosphere from the Northern Region products that were used within the region (E_{R1}) and emissions to the atmosphere from wood products harvested in the Northern Region that were exported outside the region ($E_{EX\ R1}$). Exports

(P_{EX}) include wood and paper products, as well as roundwood, chips, residue, pulp, and recovered (recycled) products from wood harvested in the Northern Region. Under the production accounting approach, imports from other regions (indicated with dotted lines around the right side portions for both boxes showing HWP in use or in SWDS) are not included in Northern Region accounting because the emphasis is on the location of harvest (H). Emissions (E_{R1} and $E_{EX\ R1}$) are further categorized as emitted with energy capture (e.g. fuelwood) and emitted without energy capture (e.g. decomposition and burning for waste disposal).

Referring back to the equation for the annual carbon stock change for the total forest sector (ΔS), by estimating stocks and emissions for Region 1 HWP carbon on an annual basis, we can calculate the annual stock change in the HWP carbon pool (ΔC_{R1}), which is the relevant metric for this accounting approach.

The CFPP was designed for application to smaller geographic areas and uses a simpler accounting approach focused on carbon storage for a single harvest year rather than net annual carbon change due to current year additions to product pools and current year emissions from those pools. The relevant metric for CFPP accounting approach is 100-year average carbon stored from the current year's harvest, known as "the 100-year average." Like the production approach, the CFPP approach is applied to a specified area of land, and includes carbon stored in both products in use and SWDS. The approach uses mill efficiency factors and decay curves for individual product classes to estimate the average amount of carbon that is likely to remain stored in wood products from a given year's harvest over a 100-year period (Miner 2006; Smith and others 2006). The specific calculations used in both approaches are discussed in detail in the "Computational Methods" section.

Data Sources

For both approaches, data quality impacts the uncertainty and reliability of our estimates, and the data used in this analysis provide a good illustration of the challenges associated with using historical data in carbon accounting. Northern Region harvesting activity since 1980 has been reported in detailed cut and sold reports. These reports include the value and volume of timber sold and harvested in the Region, which are reported by both fiscal and calendar year (USDA 2010a). In addition, the total harvest is partitioned by sale value, timber product class (e.g. softwood sawlogs), tree species, and by each national forest within the region.

Beginning in 2001, volumes have been reported in both thousand board feet (mbf) and hundred cubic feet (ccf). Between 1980 and 2000, volumes were reported in mbf only; regional conversion factors for specific timber products were used to convert volumes from mbf to ccf (table 2).

Table 2—Conversion factors used in this analysis.

Conversion	Units
2.2	ccf per mbf, timber harvest
1.75 to 2.56	ccf per mbf, timber products
33 to 42	lbs per cubic foot, primary products
2204.6	lbs per Mg
0.95 to 1.0	Mg wood fiber per Mg product
0.5	Mg carbon per dry Mg wood fiber
0.711 to 0.919	MgC per ccf, primary products

Records for annual harvest prior to 1980 are more difficult to obtain. Paper records are available in the Northern Region archives for fiscal years 1946 to 1979, but these do not report the harvest by timber product classes and vary in their reporting for individual national forests. Furthermore, the forestland included in the Northern Region and the administrative designations of specific forests has changed over time. Whenever possible, we used forest-specific data to standardize harvest totals from 1946 to 1979 to the modern boundary of the Northern Region. For example, the harvest for Colville National Forest, which was transferred to the Pacific Northwest Region in 1975, was removed from the harvest totals reported for the Northern Region from 1946 through 1974.

Documents from the archives also report the annual harvest in mbf for fiscal years 1906 to 1920, calendar years 1921 to 1936, and fiscal years 1937 to 1945. In these records, the harvest is divided into three administrative designations for years 1914 to 1945, but data for individual forests and timber products are not reported for the period 1906 to 1945. Again, we adjusted annual harvest data in an attempt to standardize the harvest to the modern boundaries of the Northern Region. For years prior to 1946, the annual harvest reported for the Northern Region was reduced by 5.3 percent, which is the average proportion of the Northern Region annual harvest attributable to Colville National Forest from 1946 to 1971. The proportion of the harvest attributable to Colville National Forest stayed relatively constant over this period, ranging from a low of 2.4 percent in 1946 to a high of 7.2 percent in 1965.

For the period 1906 through 1979, annual harvest totals for the Northern Region reported in mbf were converted to ccf using a conversion factor of 2.2 ccf per mbf (table 2). Harvest records during this period do not partition the harvest among different timber product classes. To split the harvest among the different product classes, we first worked with our local Timber Product Output specialists (USDA 2009a) to estimate the dates when various processing operations commenced in our study area. Next, we applied the average annual proportion of the harvest represented by each timber product class from 1980 through 2009 to the annual harvest for each year 1906 through 1979 (table 3). By standardizing boundaries and units and partitioning the harvest among different timber product classes, we created a continuous dataset spanning 1906 through 2009 that meets the criteria for estimation established by the IPCC (IPCC 2006).

Table 3—The average annual proportion of the Northern Region harvests distributed to timber product classes between 1980 and 2009.

Product class	Mean (%)	Std. error
Sawtimber, softwood	78.7	1.70
Pulpwood, softwood	6.9	0.78
Fuelwood, softwood	8.6	1.11
Non-saw, softwood	2.0	0.82
Other products	3.8	0.41

Computational Methods

A series of complex calculations use harvest data to estimate carbon storage metrics for the Northern Region and each of its national forests. Figure 3 provides a flow chart of the computational methods used to calculate annual stock changes and emissions from HWP for the IPCC/EPA production accounting approach. This approach does not apply simple storage ratios to the harvest; rather it tracks carbon through the product life cycle from harvest to timber products to primary products to end use to disposal, applying appropriate ratios and half-lives at each stage.

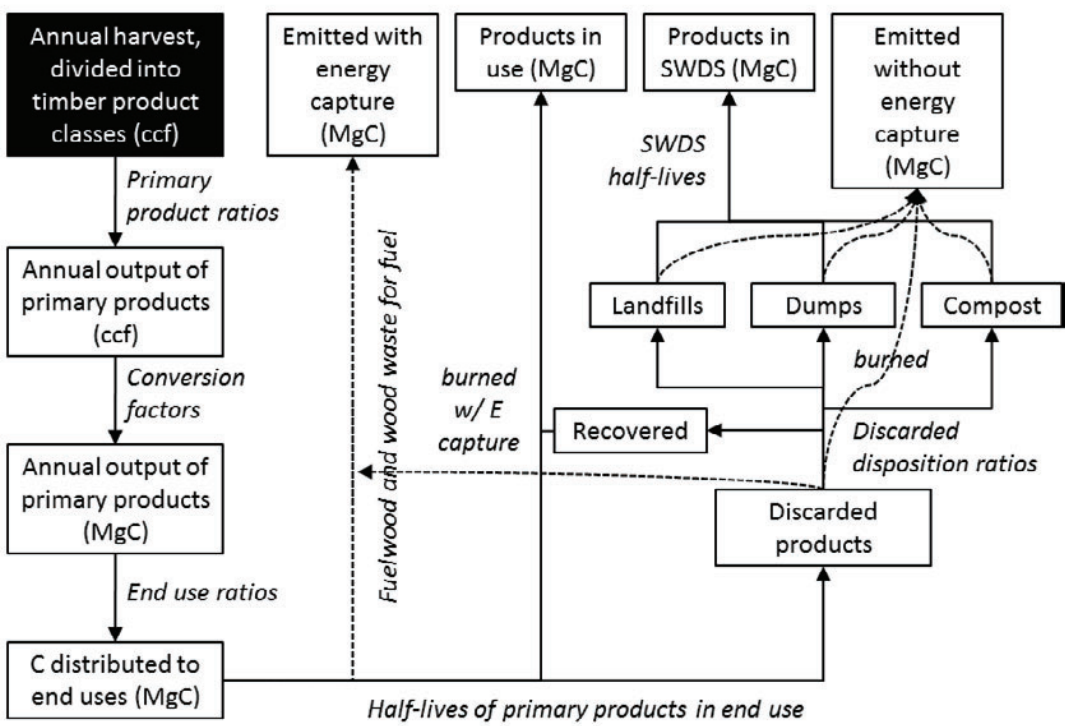

Figure 3—A schematic of calculations to quantify HWP storage and emissions. The calculations quantify HWP in use and in SWDS, emissions with energy capture, and emissions without energy capture using the IPCC/EPA approach.

Annual volumes of output for specific timber product classes (e.g. softwood sawlogs) are distributed to specific primary products (e.g. softwood lumber, softwood plywood, etc.) using average primary product ratios for the Rocky Mountain Region from Smith and others (2006). Primary product outputs are converted from their reporting units to MgC using standard conversion factors for primary products (Smith and others 2006; table 2).

The recalcitrance of carbon in harvested wood products is highly dependent on the end use of those products. For example, carbon in lumber used in new single family home construction has a longer duration of use than carbon in lumber used for shipping containers, which is released into the atmosphere more quickly through combustion and decay. From 1950 through 2006, annual primary product output was distributed to specific end uses according to annual wood product consumption estimates in McKeever (2009).

Estimates for 1950 were used for 1906 through 1949 and estimates for 2006 were used for 2007 through 2009. We acknowledge that this is not ideal, but no other data are available for these periods. For each end use and vintage year, the amount of carbon remaining in use at each inventory year is calculated based on the product half-life and the number of years that have passed between the year of harvest and the inventory year. The half-life value expresses the decay rate at which carbon in the products in use category passes into the discarded category. The carbon remaining in HWP in a given inventory year is calculated for each vintage year end use based on a standard decay formula:

$$N_t = N_0 \exp(-t \ln(2)/t_{1/2})$$

where

N_t = the amount of carbon remaining in use in inventory year t;

N_0 = the amount of carbon in the end use category in the vintage year of harvest;

t = the number of years since harvest;

$t_{1/2}$ = the half-life of carbon in that end use, and

exp = notation for the exponential function.

In our calculations, the starting amount (N_0, at t = 0) is adjusted downward by 8 percent to reflect a loss when placed in use, which is assumed to enter the discarded carbon category. This loss in use accounts for waste when primary products (e.g. softwood lumber) are put into specific end uses (e.g. new single family residential housing). Fuelwood products are assumed to have full emissions with energy capture in the year they were produced.

For carbon of a particular vintage in a given inventory year, the balance of carbon in HWP that is not in use and not emitted with energy capture is assumed to be in the discarded products category (fig. 3). Carbon in the discarded products category is partitioned into five disposition categories: burned, recovered, composted, landfills, and dumps. The proportion of discarded products that ends up in each of these five categories is different for paper and solid wood products, and has changed over time. For example, prior to 1970 wood and paper waste was generally discarded to dumps, where it was subject to higher rates of decay than in modern landfills. Since then, the proportion of discarded wood going to dumps has dropped to below 2 percent, while the proportion going to landfills has risen to 67 percent, with the remainder going to the other disposition categories. Similarly, composting and recovery (i.e. recycling and reuse) have become a more prominent part of waste management systems. In 2004, approximately 50 percent of paper waste was recovered, compared to 17 percent in 1960. The disposition of carbon in paper and solid wood products to these categories is based on percentages in Skog (2008).

Carbon from burned and composted discarded products is assumed to be emitted without energy capture. Carbon in the recovered category reenters the products in use category. Carbon in products discarded to landfills and dumps are subject to decay determined by their respective half-lives. The half-life value for discarded products in dumps and landfills expresses the decay rate at which carbon in these categories is emitted to the atmosphere. However, only a fraction of discarded products in landfills is considered to be subject to decay. Seventy-seven percent of solid wood carbon and 44 percent of paper carbon in landfills is identified as fixed carbon, not subject to decay (Skog 2008). For a given vintage year, the carbon remaining in SWDS in a given inventory year from that vintage year is the sum of fixed carbon and the carbon remaining after decay. We do not account for the difference between methane and carbon dioxide emissions from landfills in terms of CO_2 equivalents, nor do we account for methane remediation that includes combustion and subsequent emissions with energy capture. All landfill and dump emissions are considered emissions without energy capture.

These methods were used to calculate annual gross stocks and gross emissions for all inventory years 1906 through 2009. Results for each inventory year were used to calculate net change in stocks of carbon in the two Northern Region HWP pools, products in use and SWDS, as well as net change in emissions from SWDS and fuelwood.

In addition, we present the 100-year average carbon storage for products in use, products in SWDS, and all HWP using the CFPP. In this approach, the amount of carbon delivered from a harvest to mills is determined by applying conversion factors by wood type. However, not all of the carbon that is delivered to the mill ends up in HWP. The amount of delivered carbon that ends up in HWP is determined by mill efficiency factors of 67.5 percent for softwood and 56.8 percent for hardwoods, with the balance of carbon assumed to be immediately emitted to the atmosphere. These mill efficiency factors determine the total carbon transferred into HWP in the year of manufacture. For each harvest year (i.e. vintage), the average carbon stored over 100 years in wood products harvested in that year is calculated based on 100-year average storage factors applied to the HWP carbon in seven wood product classes, with different factors applied for the in-use and in-landfills HWP carbon categories (Climate Action Reserve 2009). The total average carbon stored in HWP over 100 years for each harvest year is calculated as the sum of the in-use and landfill averages, and only includes HWP carbon harvested in that harvest year.

In our calculations, we departed slightly from the CFPP protocol. Averages for each harvest year are determined based on storage factors for primary wood product classes as described previously. However, the carbon in HWP to which these factors are applied is based on conversion, residue production, and product recovery factors incorporated in the IPCC/EPA production accounting approach, not on the conversion factors and generalized mill efficiency factors included in the CFPP. In other words, the results presented here apply the CFPP protocol to the same HWP carbon pool used in the production accounting approach. Using the same pool removes variability that would be attributable to applying different conversion factors and allows a more clear comparison of the two accounting systems.

Uncertainty

Interpretation of the results should be made in light of some constraints. Though we attempted to normalize annual harvests to the modern boundary of the Northern Region using forest-specific harvest data, in actuality the annual harvest is from a land base that is somewhat variable over time. The U.S. Forest Service has commonly engaged in land exchanges, divestments, and acquisitions in the Northern Region since 1906, which means that the system boundary for this analysis is not consistent. In addition, conversion factors, the distribution of timber products to primary products, and the distribution of primary products to end uses have changed over time. Though we have used annual data whenever possible, there is some uncertainty associated with applying averages to annual harvests in the early years of this harvest series.

Uncertainty is quantified using the methods described in Skog (2008). We identified the most critical sources of uncertainty in our analysis (table 4), developed probability distributions for each, and carried out Monte Carlo simulations to determine the effect of uncertainty in these variables on estimates of HWP stocks and 100-year average. The 18 random variable distributions in table 4 represent four major sources of uncertainty: conversion factors, reported harvest, product distribution variables, and product decay parameters.

Table 4—Sources of uncertainty and associated data.

Source of uncertainty	Specific factor	Years	Relevant products	90% CI
Conversion factors	mbf:ccf	1906-1979	Timber products	±30%
	mbf:ccf	1980-2009	Timber products	±15%
	ccf:MgC	1906-2009	Primary products	±5%
Reported harvest	Harvest in mbf	1906-1945	Timber products	±30%
	Harvest in mbf	1946-1979	Timber products	±20%
	Harvest in mbf or ccf	1980-2009	Timber products	±15%
Product distribution	Roundwood to softwood sawtimber	1906-1979	Timber products	±30%
	Roundwood to softwood sawtimber	1980-2009	Timber products	±15%
	Softwood sawtimber to lumber	1906-1949	Timber products	±30%
	Softwood sawtimber to lumber	1950-1979	Timber products	±20%
	Softwood sawtimber to lumber	1980-2009	Timber products	±15%
	Lumber going to new housing	1906-2009	Primary products	±15%
	Panels going to new housing	1906-2009	Primary products	±15%
	Residues going to pulp	1906-2009	Primary products	±15%
Product decay	Product half-life or storage factor	1906-2009	All end-use	±15%
	Fraction of discards to landfills	1906-2009	Discarded	±15%
	Landfill decay limits	1906-2009	Landfilled	±15%
	Landfill half life	1906-2009	Landfilled	±15%

Because we apply different distributions to different time periods for some variables, the 18 distributions cover 12 different variables. Multiple time-delineated distributions are used for timber products conversion factors, reported harvest, proportion of roundwood going to softwood sawtimber, and proportion of softwood sawtimber going to lumber manufacturing, with time periods separated at benchmark years related to data quality. Analysis for the IPCC/EPA approach uses all 18 distributions, but analysis for the CFPP approach uses 15 because only one of the product decay variables (product half-life/storage factor) is used in CFPP calculations.

The probability distributions of these random variables were developed based on estimates in Skog (2008) and on professional judgment, and are assumed to be triangular and symmetric. The distributions are also assumed to be independent of one another. However, in the simulation, a correlation coefficient of 0.5 was applied to reported harvest for the three time periods to quantify the assumption that if the harvest was systematically overestimated or underestimated in one period, it was likely in error in the same direction in the other two periods (table 4). A similar approach was used for product half-lives in the product decay category to quantify the assumption that if half-lives for one category were underestimated or overestimated, the other categories were likely in error in the same direction. In general, uncertainty was assumed to be greater farther back in time. For example, reported harvest is divided into three time periods based on data quality, with uncertainty in the reported harvest increasing from ±15 percent for the period from 1980 to 2009, to ±20 percent for the period from 1946 to 1979, to ±30 percent for the period from 1906 to 1945.

The effect of uncertainty on the HWP stocks and 100-year average was evaluated for the Northern Region using Monte Carlo simulation in @Risk software version 5.7 (Palisade Corporation 2010). Simulation means and 90 percent confidence intervals are the results of 2,200 iterations with Latin hypercube sampling, which was determined to be the average number of draws needed to reach a stable standard deviation for the estimate of HWP stocks. Confidence intervals for the individual national forests are based on the proportional intervals of the mean value determined by the Northern Region simulation, not on independent simulations.

A Note about Life Cycle Assessment

At this point it may be apparent that these approaches do not account for all emissions associated with HWP. For example, carbon emissions from fossil fuels used in transportation and manufacture of HWP are not deducted from the HWP pool. Similarly, though HWP emissions with energy capture are quantified in the IPCC/EPA approach, they are not assumed to substitute for an equivalent amount of fossil fuel carbon, potentially reducing fossil fuel emissions in some scenarios (Jones and others 2010). Furthermore, these approaches do not incorporate carbon fluxes associated with product substitution, such as the substitution of HWP for metal or concrete (or vice versa) in building applications, and the associated land-use changes that may ensue.

Though these types of emissions and tradeoffs are outside the scope and purpose of both approaches, there are well-developed methods of life cycle assessment (LCA) that account for all carbon emissions associated with manufactured products and that facilitate the comparison of different levels of consumption and substitution of wood products for alternative products (Rebitzer and others 2004). The IPCC/EPA and CFPP approaches provide information that can be used in an LCA, but in general an LCA is used to address different questions.

If management decisions require information about harvesting, transportation and processing emissions, as well as product substitutions and other trade components not included in the two approaches used here, a consequential LCA is required. However, for sub-national carbon accounting, IPCC/EPA and CFPP approaches have several benefits over LCA. They are relatively easy to apply and congruent with U.S. national carbon accounting standards, which is particularly important in developing tools that can be used by USFS managers to meet carbon monitoring goals.

Results for the Northern Region

Between 1906 and 1943, the annual timber harvest in the Northern Region remained below 400,000 MgC yr^{-1} (328.5 million cubic feet yr^{-1}) and decreased during the Great Depression in the 1930s (fig. 4). After World War II, annual harvest levels increased steadily, with some volatility, to maximum harvest levels in the late 1960s and early 1970s. Growth in the annual harvest was particularly rapid between 1950 and 1956, when the annual harvest tripled from half a million MgC yr^{-1} to 1.5 million MgC yr^{-1} by 1956. At its peak in 1969, the annual timber harvest in the Region exceeded 2.4 million MgC yr^{-1}.

Beginning in the mid-1970s, the annual harvest decreased steadily, with a brief increase in harvesting in the late 1970s followed by a particularly steep decrease during the economic recession of 1981-1982. Between 1982 and 1987 the harvest level rose sharply, but then fell nearly every year from 1988 to 2002. Harvest levels since 2000 have been relatively stable between 200,000 MgC yr^{-1} to 400,000 MgC yr^{-1}, which is similar to the harvest levels of the early twentieth century.

All else being equal, higher harvest levels result in more carbon removed from the ecosystem pool and added to the HWP pool (fig. 2). Figure 5 shows the cumulative carbon in both the products in use and SWDS constituents of the HWP pool for the Northern Region using the production accounting approach. Using a format that matches the reporting for selected inventory years found in the most recent EPA report (USEPA 2010), Table 5 shows how the disposition of HWP carbon is broken into the four IPCC/EPA categories: emitted with energy capture, emitted without energy capture, products in use, and products in SWDS. For each inventory year shown in the first column, the second column shows aggregate carbon emitted with energy capture (i.e. fuelwood), the third column

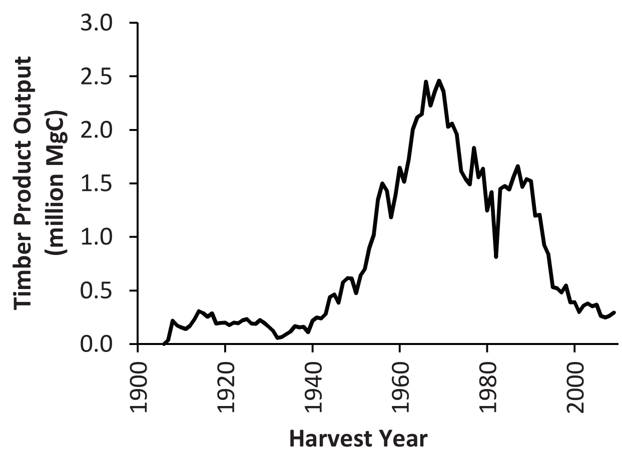

Figure 4—Annual timber product output in the Northern Region, 1906 to 2010. Harvest estimates are based on data collected from USDA Forest Service Archives and Cut/Sold reports.

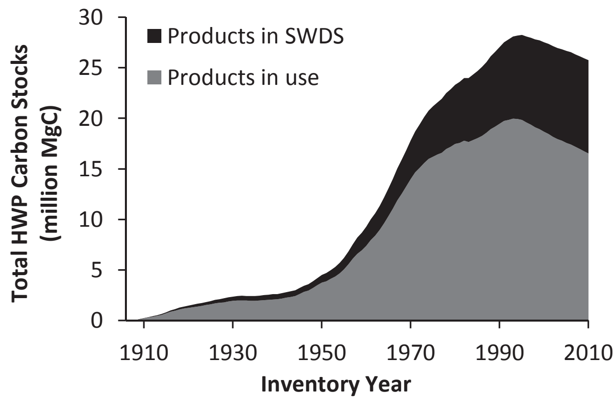

Figure 5—Cumulative total carbon stored in HWP manufactured from Northern Region timber using the IPCC/EPA approach. Carbon in HWP includes both products that are still in use and carbon stored at solid waste disposal sites (SWDS), including landfills and dumps.

Table 5—Northern Region cumulative disposition of HWP carbon for selected years using the IPCC/EPA production accounting approach. This table shows the fate of all carbon removed from the ecosystem by harvesting.

Inventory year	Emitted with energy capture	Emitted without energy capture	Products in use	SWDS	Total in HWP Pool[a]
	- - - - - - - -	- - - - - - - -	- - - (*MgC*) - - -	- - - - - - - -	- - - - - - - -
1910	154,281	12,332	235,801	23,865	259,666
1920	957,662	196,962	1,271,481	219,922	1,491,403
1930	1,689,268	601,197	1,954,753	422,240	2,376,993
1940	2,125,441	1,118,607	2,116,591	511,967	2,628,558
1950	3,597,873	1,833,130	3,755,737	754,204	4,509,941
1960	7,561,338	3,672,609	7,394,180	1,894,409	9,288,589
1970	15,294,381	8,049,313	14,002,272	3,822,113	17,824,385
1980	22,072,575	13,859,456	17,464,432	5,855,782	23,320,214
1990	27,098,481	19,166,028	19,466,986	7,584,521	27,051,507
1995	29,034,443	21,725,124	19,855,947	8,396,262	28,252,209
2000	29,951,361	23,991,595	18,692,672	8,844,219	27,536,891
2005	30,634,194	25,950,852	17,589,954	9,084,182	26,674,136
2006	30,773,608	26,313,165	17,416,848	9,121,609	26,538,457
2007	30,884,369	26,664,054	17,186,329	9,151,940	26,338,269
2008	30,989,500	27,004,208	16,960,188	9,179,261	26,139,449
2009	31,112,619	27,333,955	16,743,418	9,204,640	25,948,058
2010	31,258,742	27,653,986	16,545,328	9,229,516	25,774,844

[a] Sum of products in use and SWDS.

shows aggregate carbon emitted through decay or combustion from SWDS, and the fourth and fifth columns show carbon stored in products in use and products in SWDS, respectively. The final column, the "Total in HWP pool," is the sum of products in use (column 4) and carbon in SWDS (column 5). It is important to understand that the estimate for each inventory year includes the portion of HWP carbon still in use and in SWDS for all previous harvest years back to 1906, in addition to carbon harvested in the inventory year.

Some of the cumulative emissions from the burned and decayed HWP (table 5, second and third columns) are theoretically taken out of the atmosphere by regrowth on harvested sites, but this effect is accounted for in the ecosystem carbon component of the IPCC/EPA approach (NEE), not in the HWP component (H and ΔC_{R1}).

The cumulative carbon stored in the Northern Region HWP peaked in 1995 at just over 28 million MgC. For reference, this is equivalent to 103 million $MgCO_2$, the CO_2 equivalent annual emissions from 20 million passenger vehicles. Since 1995, carbon stocks in the HWP pool for the Northern Region have been in decline (fig. 5). The 2010 HWP pool is estimated to have been about 25.8 million MgC (table 5).

Figure 6 and table 6 present the trend in terms of net annual change in HWP carbon stocks. Negative net annual change in HWP carbon stocks means the total carbon stored in the HWP pool in the inventory year is lower than in the previous year. A decline in the HWP pool results in a transition from a positive net annual change in carbon stocks to a negative net annual change in carbon stocks. In the mid-1960s, carbon stocks in HWP were growing by nearly one million MgC yr^{-1}, with peak stock growth occurring during 1967 with the addition of 1,042,158 MgC yr^{-1}. In the mid-1990s, the net change moves from positive to negative, and the HWP pool becomes a net source of atmospheric carbon. The year in the dataset with the largest emissions from Northern Region HWP carbon was 2002, when 228,241 MgC yr^{-1} were emitted. These estimates relate only to HWP and do not quantify carbon fluxes in the ecosystem pool.

The 100-year average calculated using the CFPP for the Northern Region, which is a projected average carbon stock over 100 years for harvest in a particular year, peaked in 1969 at 937,900 MgC (fig. 7). A declining trend in carbon storage in HWP since 1970 is also reflected by the 100-year averages (fig. 7, table 7). In recent years, the 100-year average for the Northern Region has been between 84,000 and 150,000 MgC. Though the two estimation methods differ in approach and calculations, they both show a clear and expected connection between timber harvest trends and carbon stored in the HWP pool.

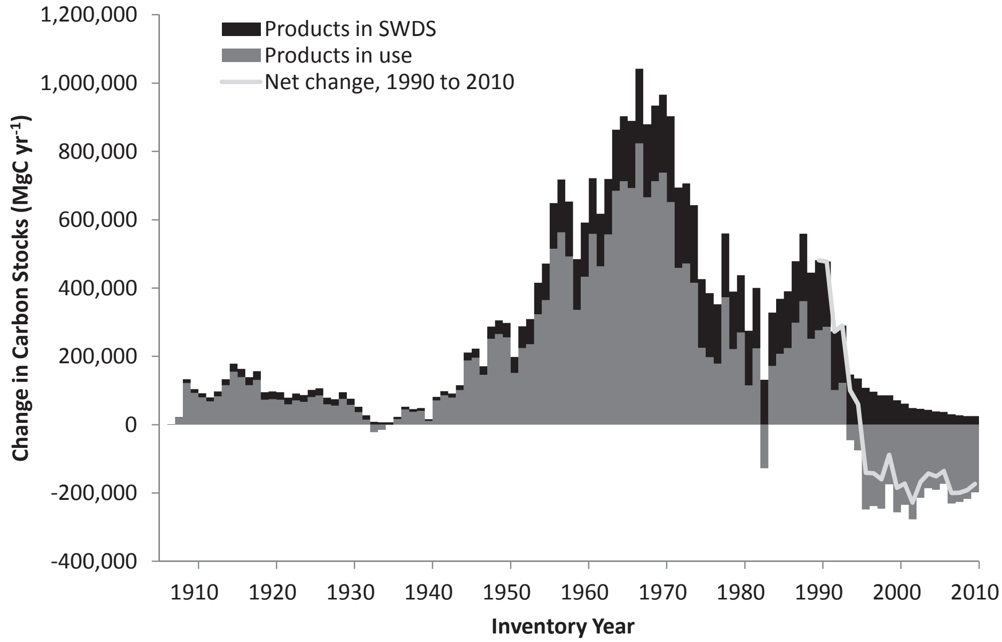

Figure 6—The net change in carbon stocks in HWP from the previous year using the IPCC/EPA production accounting approach. The net stock change is the sum of net change for SWDS (black bar) and products in use (gray bar). The total net change trend line from 1990 to 2010 shows a transition from net additions to carbon stocks in HWP to a period of net loss in carbon stocks in HWP.

Table 6—Northern Region annual net change in HWP carbon stocks for selected years for harvests beginning in 1906.

Inventory year	Stock change[a] (MgC yr^{-1})
1910	104,116
1920	97,021
1930	75,712
1940	16,051
1950	298,029
1960	591,785
1970	966,125
1980	437,628
1990	481,517
1995	59,764
2000	-184,812
2005	-151,437
2006	-135,679
2007	-200,187
2008	-198,821
2009	-191,391
2010	-173,214

[a]Net annual change in C in products in use and SWDS.

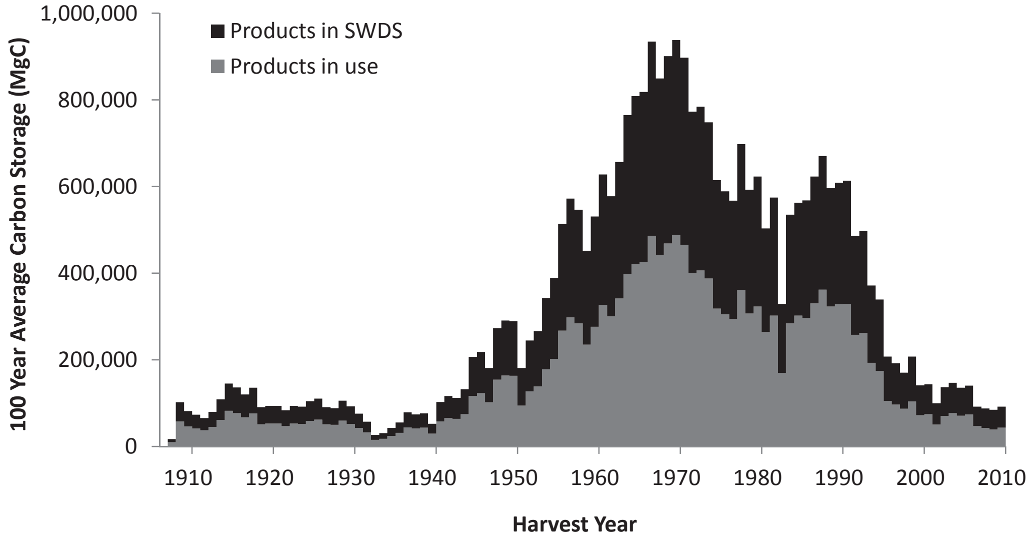

Figure 7—Northern Region harvest 100-year average carbon HWP storage using the California Forest Project Protocol. The 100-year average is calculated independently for each harvest year and considers only carbon harvested in that year.

Table 7—The Northern Region 100-year average carbon stored in products in use, SWDS, and total for selected years using CFPP.

Harvest year	Products in use	Landfills and dumps	Total
	- - - - - - - -	*(MgC)*	- - - - - - - -
1910	41,496	32,052	73,547
1920	52,862	40,832	93,694
1930	42,777	33,042	75,819
1940	57,768	44,621	102,389
1950	94,131	86,792	180,923
1960	326,709	301,238	627,947
1970	465,096	432,400	897,496
1980	264,336	238,992	503,328
1990	329,250	284,424	613,675
1995	105,200	102,218	207,418
2000	74,469	68,948	143,417
2005	73,794	66,384	140,177
2006	47,100	44,673	91,774
2007	42,728	45,027	87,755
2008	39,187	45,567	84,754
2009	43,541	48,377	91,917

To quantify uncertainty, confidence intervals were estimated for both the IPCC/EPA HWP stock estimates and the CFPP 100-year average estimates using Monte Carlo simulation, representing 18 and 15 random variable distributions, respectively, with distributions determined from publications and expert opinion. Table 8 shows the resulting confidence intervals for the IPCC/EPA estimates for selected years. For 1995, the year of peak carbon stocks for the Northern Region, the 90 percent confidence interval ranges from 20,723,740 MgC to 37,108,160 MgC, with a mean value of 28,272,940 MgC. This is equivalent to a -26.7 percent to +31.2 percent difference from the mean. Table 9 shows the resulting confidence intervals for the 100-year average for selected years. For 1970, the year with the highest 100-year average shown, the 90 percent confidence interval ranges from 563,303 to 1,336,731 MgC, with a mean value of 898,820 MgC. This is equivalent to a -37.3 percent to a +48.7 percent difference from the mean.

Table 8—Confidence intervals for Northern Region cumulative carbon in HWP for selected years for harvests beginning in 1906. Means and confidence intervals were calculated using Monte Carlo simulation.

		90% Confidence interval (% difference from estimate)	
Inventory year	**Simulation mean**	**5%**	**95%**
	(MgC)		
1910	258,847	151,997	383,534
1920	1,490,397	859,969	2,254,610
1930	2,380,130	1,348,945	3,726,131
1940	2,623,487	1,559,630	4,011,111
1950	4,508,105	2,756,788	6,754,915
1960	9,289,140	5,897,037	13,271,680
1970	17,825,210	11,508,690	25,465,070
1980	23,305,620	14,966,770	33,457,600
1990	27,036,780	19,354,590	35,924,610
1995	28,272,940	20,723,740	37,108,160
2000	27,510,220	20,779,040	35,696,240
2005	26,645,420	19,809,180	34,370,610
2006	26,538,740	19,630,590	34,125,580
2007	26,341,320	19,707,340	33,850,080
2008	26,128,290	19,561,330	33,672,940
2009	25,924,090	19,690,110	33,639,540
2010	25,753,020	19,546,530	33,052,480

Table 9—Confidence intervals for the Northern Region 100-year average carbon stored in HWP for selected years using the California Forest Project Protocol. Means and confidence intervals were calculated using Monte Carlo simulation.

Inventory year	Simulation mean	90% Confidence interval (% difference from estimate) 5%	95%
	- - - - - - - - - - - - - - - - -	(MgC)	- - - - - - - - - - - - - - - - -
1910	73,654	41,230	117,343
1920	93,830	52,524	149,486
1930	75,929	42,504	120,967
1940	102,538	57,399	163,360
1950	181,181	113,537	270,498
1960	628,840	394,062	938,842
1970	898,820	563,303	1,336,731
1980	503,370	382,408	653,254
1990	613,729	463,510	803,920
1995	207,441	159,195	268,110
2000	143,439	108,755	186,617
2005	140,321	107,692	179,018
2006	91,865	70,445	116,970
2007	87,791	67,609	112,596
2008	84,825	66,493	106,480
2009	91,998	71,596	115,991

Regional-Level Estimates

National Context

Although these results rely on numerous calculations, the time series of annual harvest volume (fig. 4) is at the root of the trends in carbon stocks and flux for the Northern Region HWP pool. Several recent publications help put these HWP carbon estimates in the context of the total forest carbon, including both ecosystem carbon and HWP carbon. By dividing the 2010 stock estimate of 25.8 teragrams of carbon (TgC) in HWP by the sum of this HWP estimate and Heath and others's (2011) estimated 2010 Northern Region ecosystem carbon stock (1,530 TgC total in ecosystem plus 25.8TgC in HWP), we estimate that the Northern Region HWP carbon stocks represent roughly 1.7 percent of total forest carbon storage associated with national forests in the Northern Region. At the national level, based on the EPA's total U.S. HWP stock estimate of 2,436 TgC (USEPA 2010), the Northern Region HWP carbon stocks represented 1.1 percent of total U.S. HWP carbon stocks.

Research efforts are under way to provide additional estimates of forest ecosystem flux in the western United States (Healey and others 2009; Heath and others 2011; Van Deusen and Heath 2007). However, long-term data collection requirements will delay reporting until the National Forest Inventory and Analysis (FIA) program completes its second cycle of plot measurements. Although the third cycle has begun in some southern U.S. states, it will be 2020 at the earliest in the Northern Region before second measurement data are available. Our calculations of HWP carbon flux will allow the Northern Region to reasonably account for carbon that was harvested over the study period. Ideally, when changes in forest ecosystem carbon are quantified in subsequent research they can be linked with the HWP estimates described here.

Applications of These Approaches

These methods for estimating this important carbon pool will allow resource managers and the public to develop a more complete understanding of the dynamics of HWP as a component of the forest carbon pool, and may allow the evaluation of the effect of alternative harvesting intensities on carbon stocks and fluxes. Furthermore, comparison of the two approaches is useful in evaluating the feasibility, utility, uncertainty, and limitations of alternative metrics and estimation methods that could be used to meet carbon monitoring objectives. Because the CFPP 100-year average is calculated for a discrete harvest year, data for previous harvest years are not needed to make current or future year estimates. This contrasts with the IPCC/EPA approach, which requires harvest information for many prior years to make an estimate of net change to the carbon stocks in the inventory year. The CFPP emphasis on harvest year calculations rather than annual changes in total carbon stocks makes the CFPP approach easier to apply when information on historical harvest and product disposition is lacking.

Similar to what we expect for other USFS regions of the country, we had access to detailed recent information about wood harvest in agency "cut and sold" reports. We were also fortunate to have archived historic harvest volume records. Although we made assumptions about the initiation of several primary product classes based on historical information, and we assumed consistent primary product distributions from the inception of processing capacity through the inventory year, in general we had a strong set of historical data to use in our calculations. As expected, records of the partitioning of the harvest to timber and primary product classes improved markedly as our records approached the present.

We recommend that all applications of the IPCC/EPA approach consider the quality of the data and adjust their uncertainty analysis accordingly, particularly with regards to the distributions of random variables (e.g., table 4). However, though carbon of older vintages may be associated with higher uncertainty, it is also likely to have a smaller impact on current stocks and fluxes than more recent harvests. For example, we estimated the importance of the early harvests by quantifying the portion of the current HWP pool that is attributable to carbon harvested prior to 1950. In 1950 the HWP carbon pool was 4.5 million MgC. By inventory year 2010, only 1.7 million MgC of the carbon harvested before 1950 remained in products in use and SWDS, which accounted for 6.6 percent of the total stocks of 25.8 million MgC in 2010. This small contribution to current stocks is a result of two factors. There was greater harvesting activity for the period after than before 1950. Also, following the passage of the Resource Conservation and Recovery Act of 1976 (RCRA) and after a short lag, a much larger portion of discarded HWP goes into modern landfills where it is subject to lower rates of decay than in aerobic dumps or disposal by open burning, which were the dominant disposal methods prior to RCRA.

Obtaining historical information may present a challenge for some regions and national forests. It may be particularly difficult to reconstruct harvest data prior to the mid-1940s, though regression of trends after the period might be appropriate for extrapolation to earlier periods. Alternatively, regions could base their carbon accounting on national level parameters, making the assumption that national-level numbers are adequate for regional and sub-regional analysis. If national level values represent the best available data, the IPCC/EPA method requires only harvest volume information from the user. Many regional and forest type-specific default dynamics and decay functions are supplied by national level work (Skog 2008; Smith and others 2006). The simplicity associated with using national data in calculations may make the system functional and effective in meeting monitoring needs for forest managers both within and outside the USFS, regardless of data quality.

If time series data are not available or are very costly to procure, focusing on annual data may be more productive. The CFPP 100-year average is an example of an approach that does not require reconstructing the historical harvest. In general, the CFPP has ease of use superior to the IPCC/EPA production approach but does not provide the same detailed information about the HWP carbon pool. The CFPP approach does not estimate temporal trends in this pool, whereas the IPCC/EPA approach can show both total stock and annual stock change. In addition, our results show that the effects of uncertainty appear to be higher for the 100-year average than for the IPCC/EPA estimates, as measured as a percentage difference from the expected value, for this case study. As with the IPCC/EPA calculations, appropriate regional and forest type-specific variables may be found in published sources (Climate Action Reserve, 2009; Skog 2008; Smith and others 2006).

The choice about which protocol should be applied could focus on the tradeoff between the simplicity of data collection and ease of calculations compared to a need to address both total stocks and flux. Also, managers may need to be consistent in all using one protocol or another in order to make results comparable across regions and easily aggregated in analysis done at larger scales. The more resource intensive methods of the IPCC/ EPA estimates are worthwhile only if the additional detail is useful or if this reporting format is mandated.

We successfully applied the methods described by Skog (Skog 2008) to estimate the uncertainty associated with our HWP carbon stock estimates (table 8). However, it is unclear how the magnitude of this uncertainty would change, if at all, if the analysis were done on smaller management units (e.g. the individual national forest level). The change in uncertainty would, in large part, depend on assumptions made about the distributions of random variables used in the analysis. In some cases, a regional analysis may be sufficient to inform forest-level land management planning, forest management practices, and planning of long-term (programmatic) timber harvest levels and associated effects on carbon flux. A detailed sub-regional analysis may be needed where there are significant within-region differences in ecosystems and disturbance processes and harvest levels (e.g., western Washington compared to eastern Washington). In our case, Regional HWP carbon stocks can be meaningfully partitioned among the national forests in the Region based on harvest records.

Harvested Wood Products Carbon by National Forest

Eleven different national forests are included in the Northern Region of the USFS. Figure 8 shows the locations of these forests, with the greatest area of Northern Region land located in western Montana and northern Idaho. Among these forests, the Nez Perce-Clearwater, the Kootenai, the Idaho Panhandle, the Flathead, and the Lolo National Forests are the five highest HWP producing forests (fig. 9).

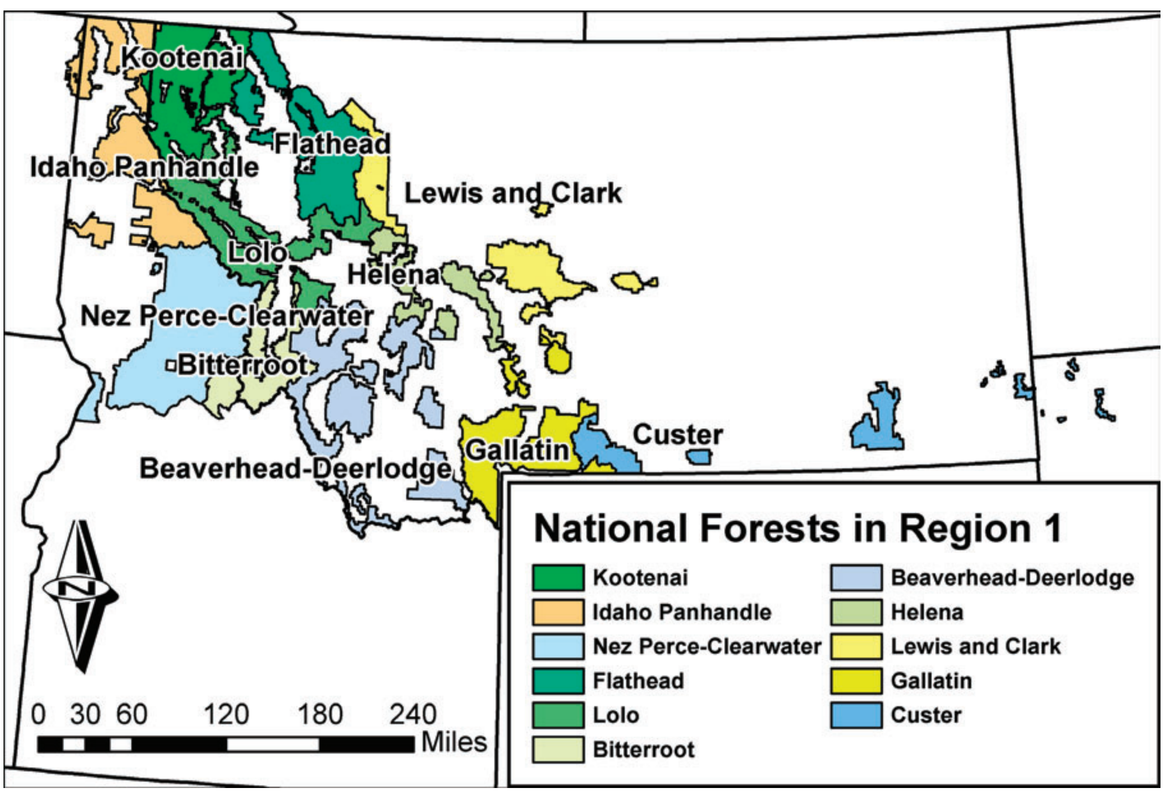

Figure 8—Map showing the locations of the eleven national forests that are administered in the Northern Region.

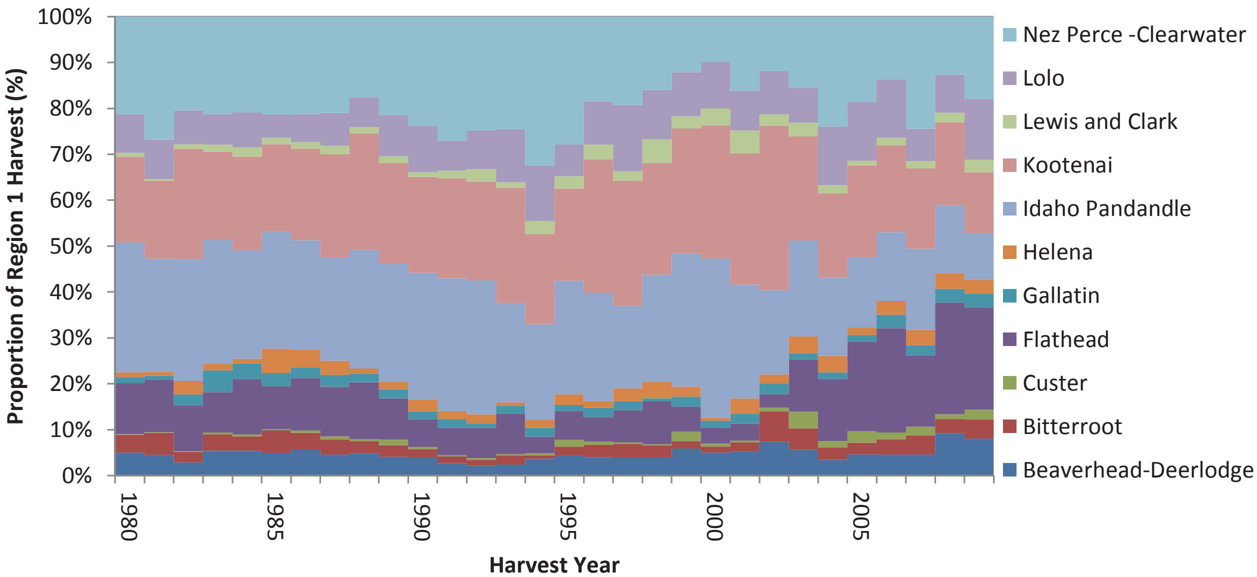

Figure 9—The proportion of the total Northern Region harvest attributable to each national forest in the Region, 1980 to 2009.

As we have pointed out, regional level accounting by itself may be adequate for forest level decision making. However, the USFS climate change scorecard (USFS 2011) does require individual national forests to develop a baseline assessment of carbon stocks, as well as an assessment of the influence of disturbance and management activities on these stocks. These assessments are meant to guide adaptation actions and continued monitoring, and managers are explicitly expected to begin integrating carbon stewardship with management for traditional multiple uses and other ecosystem services.

In the next section, we provide HWP carbon accounting for each national forest in the Northern Region using the IPCC/EPA and CFPP approaches. These estimates are intended to establish a baseline for HWP carbon accounting that meets climate change scorecard requirements, as well as serve as a foundation for future monitoring and assessment. For each national forest, estimates are provided in the context of geography (i.e. the system boundary), administrative history, ecology, and disturbance patterns, including harvesting activity.

Conclusions

HWP is an important carbon pool that should be considered in decision making associated with carbon monitoring and climate change adaptation and mitigation. Together with accounting and modeling methods that quantify ecosystem forest carbon, the approaches used in this study provide a powerful tool to monitor carbon stocks, stock change, and 100-year averages, as well as the ability to assess the possible outcomes of management actions intended to reduce the vulnerability of forest resources to climate change.

The Northern Region HWP pool is now in a period of negative net annual stock change because the decay of products harvested between 1906 and 2010 exceeds additions of carbon to the HWP pool through harvest. However, total forest carbon is a function of both HWP and ecosystem carbon, which may have increased over the study period. Analysis for individual forests shows that harvest trends for these forests are often similar to regional-level trends, but vary significantly from forest to forest.

Though our emphasis is on the Northern Region, we provide a framework by which the IPCC/EPA and CFPP methods can be applied broadly at sub-national scales to other regions and forests. However, there are clear tradeoffs between alternative approaches to estimating HWP carbon stocks. The CFPP 100-year average uses harvest year data and is easier to apply, but it does not provide information about total carbon stocks or annual stock change. In comparison, the IPCC/EPA production accounting approach is more data intensive because it includes past harvest and product disposition data for each inventory year, but it provides estimates of total stocks and stock change making it congruent with national accounting and reporting protocols.

The IPCC/EPA approach could be used to predict changes to the HWP component of the forest carbon pool resulting from planned or potential change in the amount of wood harvested. Quantifying uncertainty is an important component regardless of the approach used because it quantifies the confidence we have in estimates of carbon stocks or 100-year averages. We believe further research is necessary to help policy makers and managers better understand the implications of alternative forest management strategies on forest carbon stocks and stock change. An integrated approach might include consequential LCA that evaluates changes in harvest activity on carbon emissions including all sources of emissions and product substitutions.

National Forest Reports

Beaverhead-Deerlodge National Forest

Description

The Beaverhead-Deerlodge National Forest is located in southwestern Montana (fig. 10). The forest is approximately 120 miles from east to west, and 160 miles from north to south with non-Federal holdings throughout the area. The forest is bordered by the Lolo and Helena National Forests, as well as private lands to the north, the Gallatin National Forest and private lands to the east, Idaho to the south, and the Bitterroot, Lolo, and Salmon-Challis National Forests to the west, with significant state and private holdings bordering much of the forest's interior.

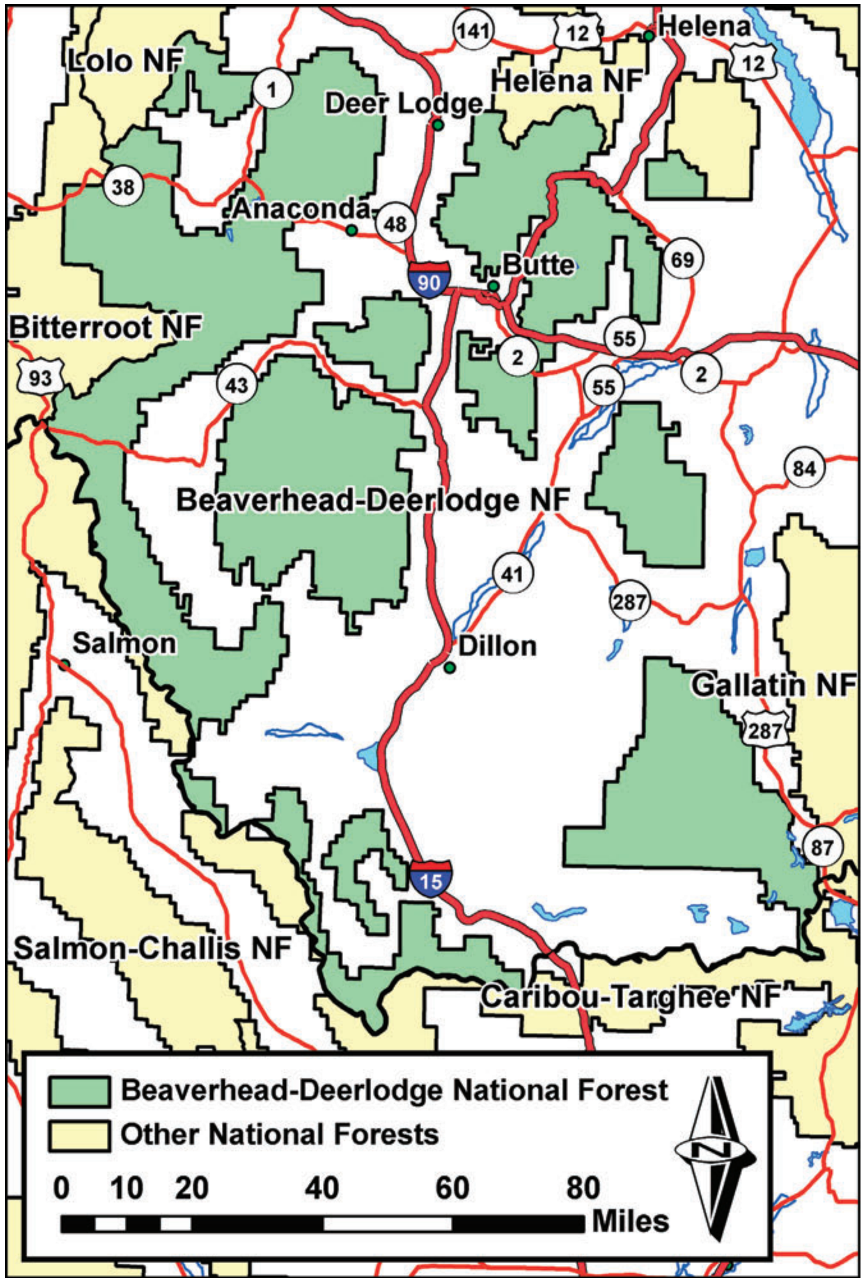

Figure 10—Location map of Beaverhead-Deerlodge National Forest.

The Beaverhead and Deerlodge National Forests were both established on July 1, 1908, from parts of the Big Hole, Bitter Root, and Hell Gate National Forests. On December 16, 1931, additional lands were added to both the Beaverhead and Deerlodge National Forests from the Madison National Forest (Davis 1983). On February 2, 1996, the two forests were merged into one administrative unit forming the Beaverhead-Deerlodge National Forest (USDA 2012a).

The Beaverhead-Deerlodge National Forest is the largest forest in the Northern Region covering 3,352,288 acres and containing over 70 unique forest habitat types (DeBlander 2001a). The most common habitat classification is cool and dry, covering 21 percent of the forest, followed by the classification of cold, which covers 14 percent of the forest. Lodgepole pine and Douglas-fir are the more dominant forest types in lower elevations, while lodgepole pine, subalpine fir, whitebark pine, Engelmann spruce, and Douglas-fir are present at higher elevations (DeBlander 2001a).

Land within the national forest boundary is 80 percent forested, with the remaining 20 percent either non-forested or water. Seven percent of the forested lands are protected under reserves in the Anaconda-Pintler and Lee Metcalf Wilderness areas, while 33 percent of non-reserved lands are considered suitable for timber production. The net annual growth of all forested lands is estimated to be over 97 million cubic feet. Forest cover is 47 percent lodgepole pine, 22 percent Douglas-fir, 12 percent spruce-fir, 11 percent whitebark pine, 5 percent Engelmann spruce, 2 percent limber pine, as well as trace amounts of aspen, juniper, and mountain brush woodland types (DeBlander 2001a). Stands of old growth forest are present on the Beaverhead-Deerlodge National Forest, estimated to cover 22.9 percent of forested lands (USDA 2007). Old growth sage brush is also present on the forest and is maintained in a mosaic burn pattern to ensure habitat preservation for old growth dependent species (USDA 1998).

Natural disturbances within the Beaverhead-Deerlodge National Forest are insect infestation, including significant impacts from mountain pine and bark beetle activity, and white pine blister (USDA 2012b; USDA 2009b). In 1996, 50 percent of tree mortality was caused by disease, 20 percent by insects, and 16 percent was due to the weather. Fifty percent of the mortality in 1996 occurred in lodgepole pine and subalpine fir (DeBlander 2001a). In 2009, it was reported that the mountain pine beetle was on the decline in lower elevations due to the depletion of host trees, but had spread to higher elevations and moved into the western portion of the forest (USDA 2009b, p 77). A partial aerial survey of the forest showed that 943,877 acres were infected with mountain pine beetle in 2009, which went down to 531,728 acres in 2010, and 210,620 acres in 2011, mostly occurring in lodgepole and five needle pine for all 3 years (USDA 2012b, p 45). Other bark beetle infestations were reported to be within endemic levels for most of the forest (USDA 2009b, p 77). White pine blister has also been observed on the forest infecting whitebark and lodgepole pine (USDA 2009b, p 74).

The forest was historically free of large fire disturbance for 125 years, leading to the decline of aspen stands, which depend on fire disturbances to open up space for new sprouts (USDA 1998). An example of this decline can be seen in the southern Gravelly Range where aspen declined 45 percent between 1947 and 1992. In an effort to respond to this decline as well as other aspen declines forest-wide, the forest burned 49,000 acres from 1989 to 1994 to restore Douglas-fir and aspen stands as well as shrub lands (USDA 1998). Other fire disturbances that continue to shape the forest are the recent fires in 2000 and 2007, which have allowed for aspen sprouts to take hold in the burnt area (USDA 2009b, p 45). Within the forest, 27 percent of plots show no visible signs of disturbances, 26 percent show signs of disease, 15 percent show evidence of cutting, 9 percent show evidence of fire, 6 percent show evidence of wind damage, 6 percent show signs of weather damage, 4 percent show signs of insect damage, 4 percent show signs of animal damage, and the remaining 3 percent show evidence of road building, land clearing, mining, or some other disturbance (DeBlander 2001a).

Harvest Trends

From 1906 to 1929, timber production averaged about 7,500 MgC per year before beginning a downward trend (fig. 11). Starting at the global minimum of 2,134 MgC in 1932, annual timber production began to grow exponentially, with some inter-annual variability until 1968 when timber production hit the global maximum at 120,597 MgC. Following 1968, timber production began to rapidly decline with some inter-annual variability until hitting a local minimum of 42,873 MgC in 1977. Following 1977, production began to quickly increase with high inter-annual variability until hitting a local maximum of 96,216 MgC in 1986. During the time period from 1977 to 1986, the lowest production was 25,969 MgC in 1982. After 1986, production rapidly declined until 1993 with 24,520 MgC in production that year. From 1993 to 2009, production continued to fall with a moderate amount of inter-annual varibuility, hitting a local maximum of 33,809 MgC in 1994, a local minimum of 11,167 MgC in 2007, and ending in 2009 with 23,530 MgC in production.

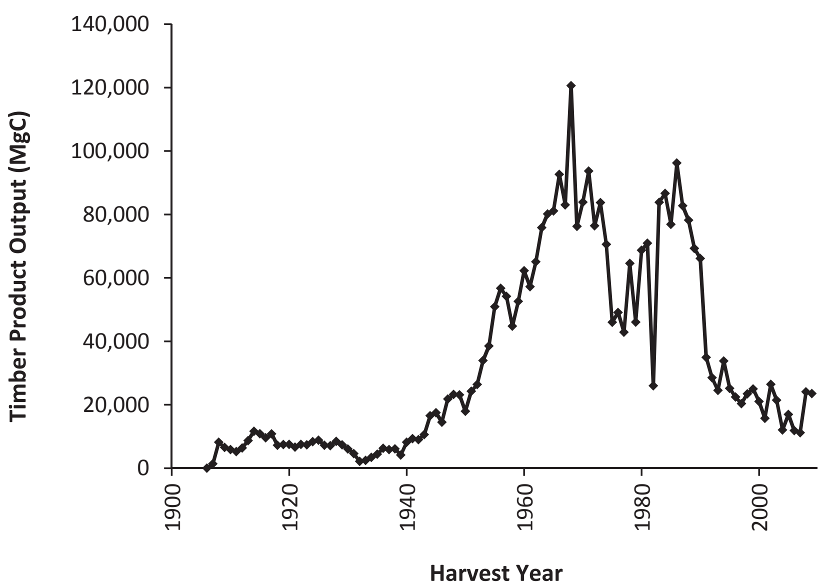

Figure 11—Annual timber product output for the Beaverhead-Deerlodge National Forest, 1906 to 2010.

Carbon in Harvested Wood Products

Starting in 1907, total carbon storage in HWP grew linearly until flattening out in 1931 with 75,319 MgC in use and 16,571 MgC in the SWDS for a total of 91,890 MgC (fig. 12). After 1940, carbon storage began to grow exponentially until 1969 with 517,760 MgC in use and 137,593 MgC in the SWDS for a total of 655,353 MgC. Following 1969, carbon storage continued to grow at a rapid rate until slowing in 1975 with 632,616 MgC in use and 192,147 MgC in the SWDS for a total of 824,763 MgC. From 1975 to 1982, carbon storage grew slowly at an increasing rate until a net loss was experienced in 1983 of –3,146 MgC with 676,924 MgC in use and 242,078 MgC in the SWDS for a total 919,002 MgC. After the net loss in 1983, carbon storage rapidly increased hitting the global maximum in 1992 with 825,220 MgC in use and 332,730 MgC in the SWDS for a total of 1,157,950 MgC. Following 1992, carbon storage began to decline at a slow, steady rate, with the exception of 1995 and 2003, ending in 2010 with 696,215 MgC in use and 396,251 MgC in the SWDS for a total of 1,092,466 MgC remaining in total carbon storage (table 10).

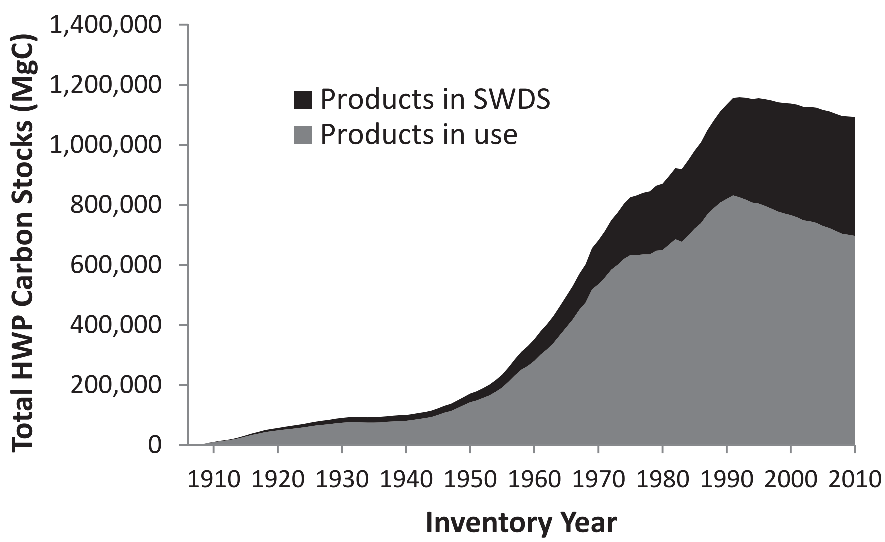

Figure 12—Cumulative total carbon stored in HWP manufactured from Beaverhead-Deerlodge National Forest timber.

Table 10—Beaverhead-Deerlodge National Forest cumulative disposition of HWP carbon for selected years. This table shows the fate of all carbon removed from the ecosystem by harvesting.

Inventory year	Emitted with energy capture	Emitted without energy capture	Products in use	SWDS	Total in HWP Pool[a]
	(MgC)				
1910	5,835	466	8,918	903	9,820
1920	36,218	7,449	48,087	8,317	56,404
1930	63,887	22,737	73,928	15,969	89,897
1940	80,383	42,305	80,048	19,362	99,411
1950	136,070	69,328	142,040	28,524	170,564
1960	285,966	138,896	279,644	71,645	351,289
1970	583,428	305,489	535,572	145,823	681,395
1980	829,647	527,229	649,210	221,135	870,344
1990	1,095,140	737,134	819,530	314,777	1,134,307
1995	1,159,127	840,501	804,130	350,757	1,154,887
2000	1,202,408	931,215	765,564	371,765	1,137,328
2005	1,239,503	1,012,360	729,694	386,096	1,115,790
2006	1,245,969	1,027,491	722,821	388,348	1,111,169
2007	1,250,995	1,042,124	713,141	390,235	1,103,375
2008	1,255,759	1,056,292	703,657	391,955	1,095,612
2009	1,267,090	1,070,276	700,269	394,092	1,094,362
2010	1,278,828	1,083,964	696,215	396,251	1,092,467

[a] Sum of products in use and SWDS.

From 1907 to 1929, net stock change averaged about 3,500 MgC ranging from a low point in 1907 of 18 MgC in use and 2 MgC in the SWDS for a total of 20 MgC, to the high point in 1915 of 5,874 MgC in use and 868 MgC in the SWDS for a total of 6,742 MgC (fig. 13). After 1929, net stock change began to decline until hitting a local minimum in 1933 with –835 MgC in use and 325 MgC in the SWDS for a net negative change in carbon stocks (emissions) of –510 MgC. Following 1933, net stock change experienced positive growth at an exponential rate with a moderate amount of inter-annual variability, hitting the global maximum in 1969 with 43,697 MgC in use and 10,133 MgC in the SWDS for a total of 53,830 MgC. After 1969, net additions rapidly declined with a moderate amount of inter-annual variability until hitting a local minimum in 1978 with –134 MgC in use and 5,176 MgC in the SWDS for a total net stock change of 5,042 MgC. After 1978, net stock change quickly increased with high inter-annual variability until hitting a local maximum in 1987 with 29,157 MgC in use and 11,421 MgC in the SWDS for a total of 40,578 MgC. During the time period from 1978 to 1987, the lowest net addition was recorded in 1983 with –8,412 MgC in use and 5,265 MgC in the SWDS for a total of –3,147 MgC. After 1987, net stock change began to rapidly decline, first showing signs of net negative growth in 1993, and hitting a local minimum in 1994 with –9,698 MgC in use and 5,667 MgC in the SWDS for a total net stock change of –4,031 MgC. From 1995 to 2010, net stock change experienced moderate inter-annual variability, averaging about –4,000 MgC per year and hitting a local maximum in 1995 with –3,108 MgC in use and 5,696 MgC in the SWDS for a total of 2,588 MgC, the global minimum in 2005 with –10,185 MgC in use and 2,236 MgC in the SWDS for a total of –7,949 MgC, and ending in 2010 with –4,054 MgC in use and 2,159 MgC in the SWDS for a total of –1,895 MgC (table 11).

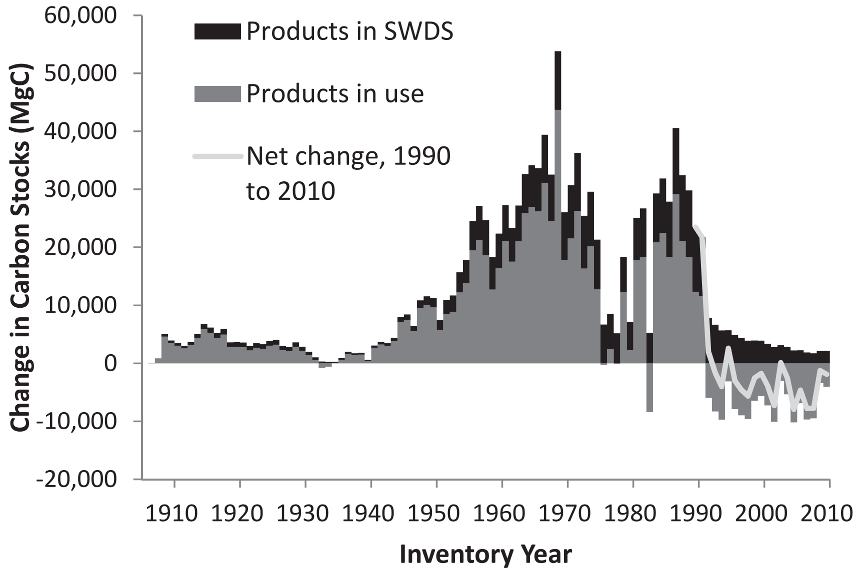

Figure 13—Beaverhead-Deerlodge National Forest net change in carbon stocks in HWP from the previous year.

Table 11—Beaverhead-Deerlodge National Forest annual net change in HWP carbon stocks for selected years for harvests beginning in 1906.

Inventory year	Stock change[a] (MgC yr^{-1})
1910	3,938
1920	3,669
1930	2,863
1940	607
1950	11,271
1960	22,381
1970	26,042
1980	7,169
1990	23,485
1995	2,589
2000	-1,735
2005	-7,949
2006	-4,621
2007	-7,794
2008	-7,764
2009	-1,250
2010	-1,895

[a]Net annual change in carbon in products in use and SWDS.

From 1906 to 1929, the 100-year average carbon storage was about 3,600 MgC, ranging from a low point in 1906 of 9 MgC in use and 6 MgC in the SWDS for a total of 15 MgC, to the high point in 1914 of 3,101 MgC in use and 2,395 MgC in the SWDS for a total of 5,496 MgC (fig. 14). Following 1929, average carbon storage experienced a short downward trend, hitting the global minimum in 1932 with 569 MgC in use and 439 MgC in the SWDS for a total of 1,008 MgC. After 1932, average carbon storage experienced positive growth at an exponential rate with a moderate amount of inter-annual variability until reaching the global maximum in 1968 with 23,937 MgC in use and 22,071 MgC in the SWDS for a total of 46,008 MgC. Following 1968, average carbon storage in the HWP began to rapidly decline with a moderate amount of inter-annual variability, hitting a local minimum in 1977 with 8,461 MgC in use and 7,866 MgC in the SWDS for a total of 16,327 MgC. Following 1977, average carbon storage quickly increased with high inter-annual variability until hitting a local maximum in 1986 with 20,409 MgC in use and 18,113 MgC in the SWDS for a total of 38,522 MgC. During the time period from 1977 to 1986, the lowest average carbon storage was recorded in 1982 with 5,428 MgC in use and 5,072 MgC in the SWDS for a total of 10,500 MgC. After 1986, carbon storage rapidly declined until 1993 with 5,098 MgC in use and 4,710 MgC in the SWDS for a total of 9,808 MgC. Following 1993, carbon storage continued to decline at a slow pace with moderate inter-annual variability, hitting a local minimum in 2007 with 1,936 MgC in use and 2,040 MgC in the SWDS for a total of 3,976 MgC, and ending in 2009 with 3,497 MgC in use and 3,886 MgC in the SWDS for a total of 7,383 MgC (tables 12, 13).

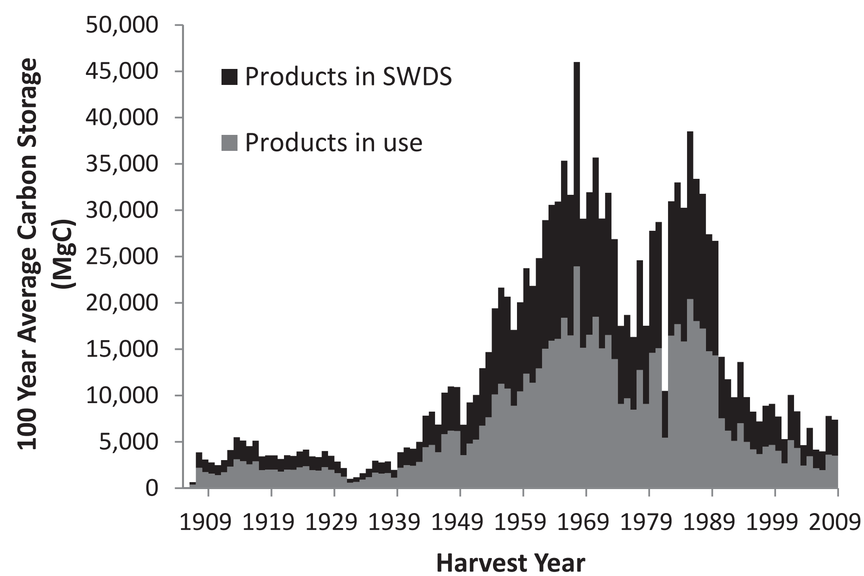

Figure 14—Beaverhead-Deerlodge National Forest harvest 100-year average carbon HWP storage using the California Forest Project Protocol.

Table 12—Beaverhead-Deerlodge National Forest 100-year average carbon stored in HWP for selected years.

Harvest year	Products in use[a]	Landfills and dumps[b]	Total
		(MgC)	
1910	1,569	1,212	2,782
1920	1,999	1,544	3,543
1930	1,618	1,250	2,867
1940	2,185	1,688	3,872
1950	3,560	3,282	6,842
1960	12,356	11,393	23,749
1970	16,554	15,390	31,944
1980	14,593	13,194	27,787
1990	14,325	12,375	26,699
1995	4,985	4,844	9,829
2000	4,016	3,718	7,734
2005	3,422	3,079	6,501
2006	2,138	2,027	4,165
2007	1,936	2,040	3,976
2008	3,607	4,194	7,801
2009	3,497	3,886	7,383

[a] The 100-year average carbon storage in products in use for the harvest year.
[b] The 100-year average carbon storage in SWDS for the harvest year.

Table 13—Beaverhead-Deerlodge National Forest confidence intervals for cumulative carbon in HWP for selected years for harvests beginning in 1906.

Inventory year	Total remaining in HWP pool	90% Confidence interval (% difference from estimate) 5%	95%
		(MgC)	
1910	9,820	5,766	14,550
1920	56,404	32,545	85,326
1930	89,897	50,949	140,735
1940	99,411	59,099	151,992
1950	170,564	104,303	255,572
1960	351,289	223,009	501,897
1970	681,395	439,937	973,440
1980	870,344	558,931	1,249,468
1990	1,134,307	812,007	1,507,189
1995	1,154,887	846,519	1,515,786
2000	1,137,328	859,047	1,475,755
2005	1,115,790	829,519	1,439,286
2006	1,111,169	821,927	1,428,828
2007	1,103,375	825,493	1,417,899
2008	1,095,612	820,246	1,411,974
2009	1,094,362	831,200	1,420,063
2010	1,092,467	829,182	1,402,117

Bitterroot National Forest

Description

The Bitterroot National Forest is located in western Montana and eastern Idaho (fig. 15). The forest is approximately 65 miles from east to west, and 85 miles from north to south with the Bitterroot River Valley running from north to south within the northern portion of the forest. The forest is bordered by the Lolo National Forest to the north, the Lolo and Beaverhead-Deerlodge National Forests to the east, the Salmon-Challis National Forest to the south, the Payette National Forest to the southwest, and the Nez Perce-Clearwater National Forest to the west.

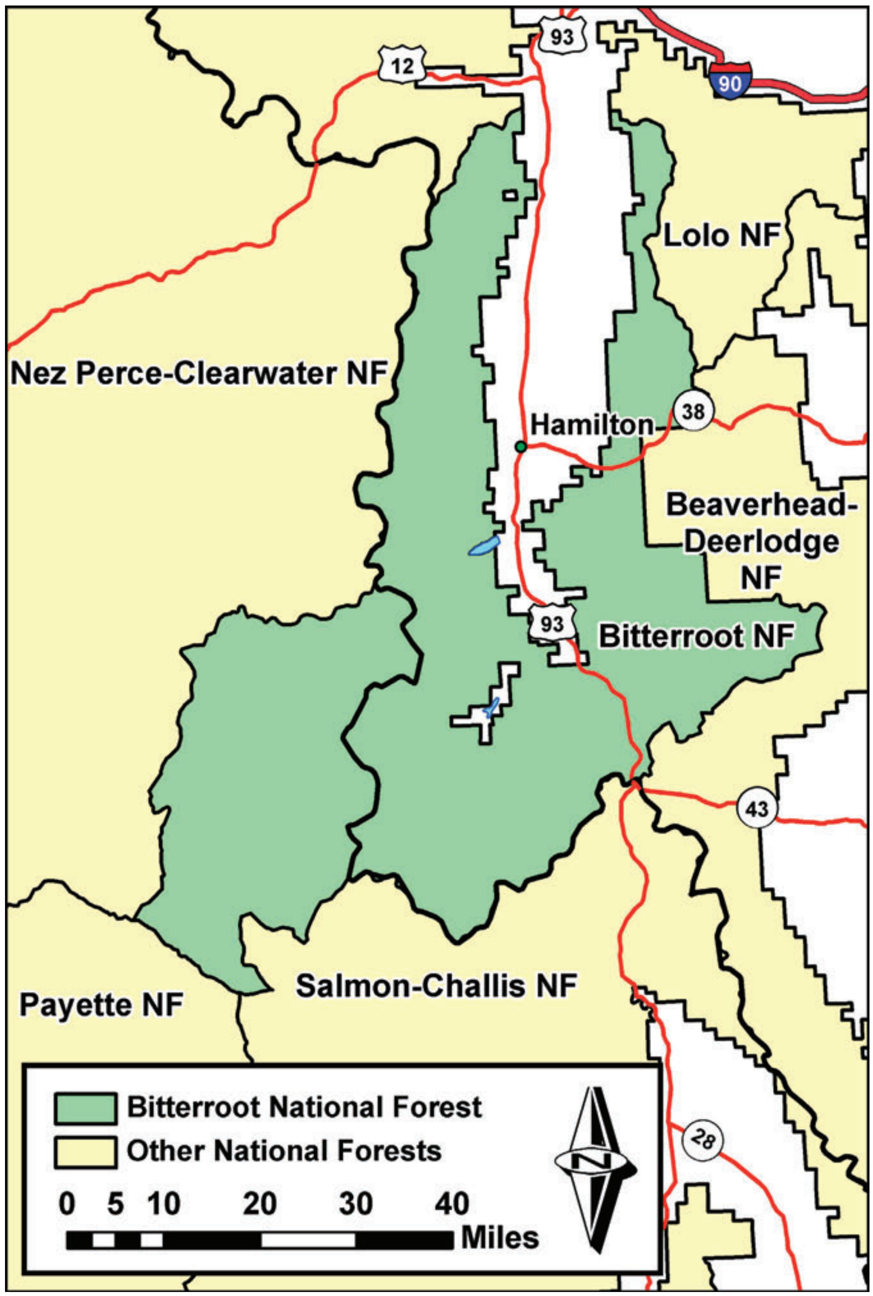

Figure 15—Location map of Bitterroot National Forest.

The Bitterroot National Forest was established as the Bitter Root National Forest on February 22, 1897. On July 1, 1908, the forest name was changed to the Bitterroot National Forest with the addition of some lands from the Big Hole and Hell Gate National Forests, as well as the transfer of some lands to the Beaverhead, the Nez Perce-Clearwater, and the Salmon National Forests. On October 29, 1943, a final addition to the Bitterroot National Forest was made as lands from the Selway National Forest were added (Davis 1983).

The Bitterroot National Forest is 1,580,550 acres and contains over 60 unique forest habitat types (Frescino 2000). The most common habitat type is classified as moderately warm and dry, covering over 460,000 acres with cover type consisting of mostly Douglas-fir and ponderosa pine. The next most common habitat type is cool and moderately dry followed by cool and moist. Due to higher elevations being associated with increased precipitation and lower temperatures, ponderosa pine, Douglas-fir, and lodgepole pine are the more successful forest types in lower elevations, while lodgepole pine, subalpine fir, Engelmann spruce, and whitebark pine are more successful at higher elevations. The forest is 92 percent forested, leaving the remaining 8 percent either non-forested or water (Frescino 2000). Forty-seven percent of the forested lands are protected under reserves, while 60 percent of non-reserved lands are considered suitable for timber production. The net annual growth of all forested lands is estimated to be over 42 million cubic feet. Forest cover is 43 percent Douglas-fir, 22 percent spruce-fir, 18 percent lodgepole pine, 9 percent ponderosa pine, 3 percent whitebark pine, 2 percent larch, 2 percent Engelmann spruce, and 1 percent grand fir (Frescino 2000). Stands of old growth forests are also present on the Bitterroot National Forest, estimated to cover 12.8 percent of the forested area with habitat levels increasing 2 percent between 2004 and 2006, and currently exceeding the 144,000 acres desired (USDA 2007, 2008a, p 22).

Natural disturbances within the Bitterroot National Forest are insect infestation, including significant impacts from Douglas-fir bark beetle and mountain pine beetle activity, and recent forest fires (USDA 2008a; USDA 2012b). Bark beetle infestations were near or over epidemic levels for 13 years prior to 2008, but have since declined with only 14,332 infected acres being detected in 2008, versus 114,400 acres in 2005. This decline may be the result of increased precipitation during 2005 and 2006 or more likely a lack of healthy host trees to infect (USDA 2008a, p 18). The mountain pine beetle is also present on the forest, causing concern associated with the infection and mortality of whitebark pine. A partial aerial survey of the forest showed that 16,367 acres were infected with mountain pine beetle in 2009, which went up to 73,642 acres in 2010 and 99,006 acres in 2011, mostly occurring in lodgepole and 5-needle pine in 2009 and 2010, and in lodgepole and ponderosa pine in 2011 (USDA 2012b, p 45). Other disturbances that continue to shape the forest include recent fire activity in 1996, 2000, 2003, 2005, 2006, and 2007 (USDA 2008a, p 15). Within the forest, 37 percent of plots show no visible signs of disturbances, 26 percent show signs of disease, 13 percent show evidence of fire, 11 percent show evidence of tree cutting, 5 percent show signs of weather damage, and the remaining 8 percent show evidence of insect damage, wind damage, or some other disturbance (Frescino 2000).

Harvest Trends

From 1906 to 1929, timber production averaged about 7,000 MgC per year before beginning a downward trend (fig. 16). Starting at the global minimum of 1,960 MgC in 1932, annual timber production began to grow exponentially with some inter-annual variability until 1969 when timber production hit the global maximum at 117,914 MgC. Following 1969, timber production began to rapidly decline until hitting a local minimum in 1974 of 37,617 MgC. After 1974, production averaged about 39,000 MgC per year until 1978 when production began to increase with some inter-annual variability, hitting a local maximum in 1981 of 75,447 MgC. In1982, production sharply decreased for one year to 20,413 MgC, followed by a sharp increase until hitting a local maximum of 76,660 MgC in 1985. After 1985, production rapidly fell, hitting a local minimum of 6,931 MgC in 1994. From 1995 to 2009, production experienced some inter-annual variability with an average of 11,000 MgC per year, a local minimum of 5,671 MgC in 2001, a local maximum of 23,804 MgC in 2002, and ending in 2009 with 12,223 MgC in production.

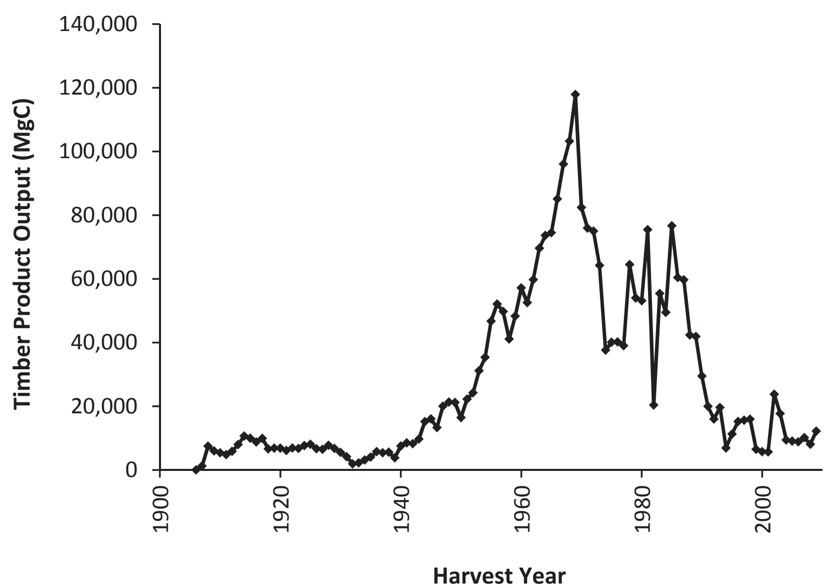

Figure 16—Annual timber product output for Bitterroot National Forest, 1906 to 2010.

Carbon in Harvested Wood Products

Starting in 1907 total carbon storage in HWP grew linearly until flattening out in 1931with 69,174 MgC in use and 15,219 MgC in the SWDS for a total of 84,393 MgC (fig. 17). After 1940, carbon storage began to grow exponentially until 1970 with 522,812 MgC in use and 137,841 MgC in the SWDS for a total of 660,653 MgC. Following 1970, carbon storage continued to grow at a rapid rate until slowing in 1974 with 586,553 MgC in use and 174,050 MgC in the SWDS for a total of 760,603 MgC. After 1979, carbon storage began to grow at an increased rate with the exception of 1983, until hitting the global maximum in 1991 with 689,244 MgC in use and 277,554 MgC in the SWDS for a total of 966,798 MgC. After 1991, carbon storage began to decline at a slow, steady rate with the exception of 2003, ending in 2010 with 550,705 MgC in use and 303,653 MgC in the SWDS for a total of 854,358 MgC remaining in total carbon storage (table 14).

From 1907 to 1929, net stock change averaged about 3,300 MgC ranging from a low point in 1907 of 16 MgC in use and 1 MgC in the SWDS for a total of 17 MgC, to the high point in 1915 of 5,395 MgC in use and 797 MgC in the SWDS for a total of 6,192 MgC (fig. 18). After 1929, net stock change began to decline until hitting a local minimum in 1933 with –767 MgC in use and 299 MgC in the SWDS for a net negative change in carbon stocks (emissions) of –468 MgC. Following 1933, net stock change experienced positive growth at an exponential rate with a moderate amount of inter-annual variability until hitting the global maximum in 1970 with 41,512 MgC in use and 10,415 MgC in the SWDS for a total of 51,927 MgC. After 1970, net additions rapidly declined

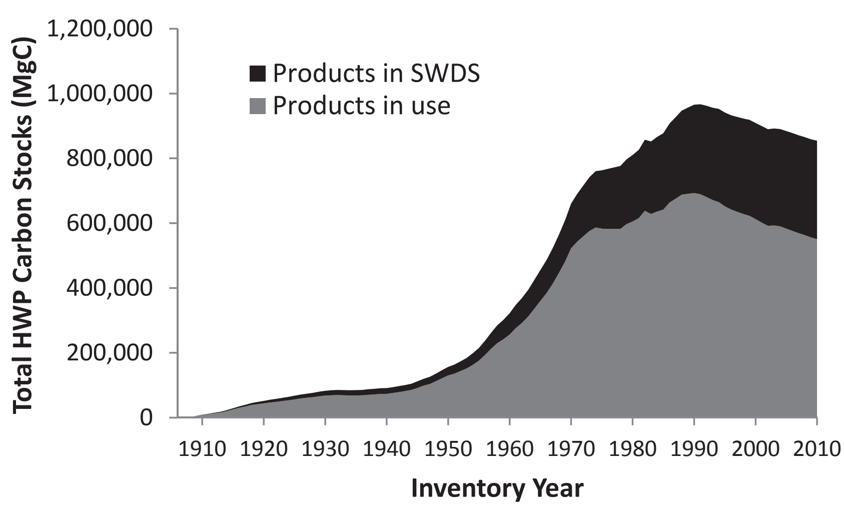

Figure 17—Cumulative total carbon stored in HWP manufactured from Bitterroot National Forest timber.

Table 14—Bitterroot National Forest cumulative disposition of HWP carbon for selected years. This table shows the fate of all carbon removed from the ecosystem by harvesting.

Inventory year	Emitted with energy capture	Emitted without energy capture	Products in use	SWDS	Total remaining in HWP pool[a]
	(MgC)				
1910	5,359	428	8,190	829	9,019
1920	33,264	6,841	44,164	7,639	51,803
1930	58,675	20,882	67,897	14,666	82,563
1940	73,826	38,854	73,518	17,783	91,301
1950	124,969	63,672	130,453	26,197	156,649
1960	262,637	127,565	256,831	65,801	322,632
1970	558,372	283,358	522,812	137,841	660,653
1980	773,187	492,085	605,262	204,972	810,234
1990	963,943	681,219	692,894	272,475	965,369
1995	995,305	765,933	651,846	289,497	941,343
2000	1,019,378	838,617	612,254	296,995	909,249
2005	1,043,112	902,426	583,099	301,039	884,139
2006	1,046,577	914,407	576,150	301,641	877,791
2007	1,050,325	926,064	569,082	302,152	871,234
2008	1,054,662	937,428	563,011	302,689	865,700
2009	1,058,480	948,435	555,876	303,108	858,983
2010	1,064,577	959,186	550,705	303,653	854,358

[a] Sum of products in use and SWDS.

until hitting a local minimum in 1975 with –3,495 MgC in use and 6,003 MgC in the SWDS for a total net stock change of 2,508 MgC. Following 1975, net stock change averaged a total of 4,500 MgC until 1979 when net stock change rapidly increased with a moderate amount if inter-annual variability until hitting another local maximum in 1982 with 22,862 MgC in use and 8,306 MgC in the SWDS for a total of 31,168 MgC. Net additions sharply decreased in 1983, hitting a local minimum with –10,079 MgC in use and 4,632 MgC in the SWDS for

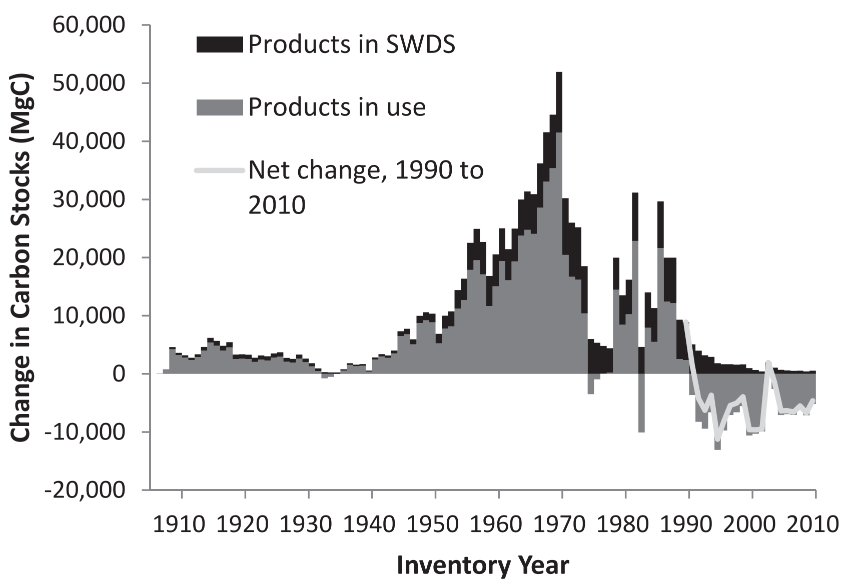

Figure 18—Bitterroot National Forest net change in carbon stocks in HWP from the previous year.

a total net stock change of –5,447 MgC. Net stock change experienced a period of rapid growth after 1983, hitting a local maximum in 1986 with 21,646 MgC in use and 8,012 MgC in the SWDS for a total of 29,658 MgC. Following 1986, net stock change experienced a rapid decline, first showing signs of sustained net negative growth in 1992 and hitting the global minimum in 1995 with –13,089 MgC in use and 1,842 MgC in the SWDS for a total net negative stock change of –11,247 MgC. After 1995, net additions averaged about –6,000 MgC per year while experiencing some inter-annual variability. In the period from 1995 to 2010, net additions hit a local maximum in 2003 with 745 MgC in use and 1,207 MgC in the SWDS for a total of 1,952 MgC, ending in 2010 with –5,170 MgC in use and 545 MgC in the SWDS for a total of –4,625 MgC (table 15).

From 1906 to 1929, the 100-year carbon storage averaged about 3,200 MgC ranging from a low point in 1906 of 7 MgC in use and 6 MgC in the SWDS for a total of 13 MgC, to the high point in 1914 of 2,848 MgC in use and 2,200 MgC in the SWDS for a total of 5,048 MgC (fig. 19). Following 1929, average carbon storage experienced a short downward trend, hitting the global minimum in 1932 with 522 MgC in use and 404 MgC in the SWDS for a total of 926 MgC. After 1932, average carbon storage experienced positive growth at an exponential rate with a moderate amount of inter-annual variability until reaching the global

Table 15—Bitterroot National Forest annual net change in HWP carbon stocks for selected years for harvests beginning in 1906.

Inventory year	Stock change[a] (MgC yr^{-1})
1910	3,616
1920	3,370
1930	2,630
1940	558
1950	10,352
1960	20,555
1970	51,927
1980	13,532
1990	8,913
1995	-11,247
2000	-9,619
2005	-6,397
2006	-6,347
2007	-6,557
2008	-5,534
2009	-6,716
2010	-4,625

[a] Net annual change in carbon in products in use and SWDS.

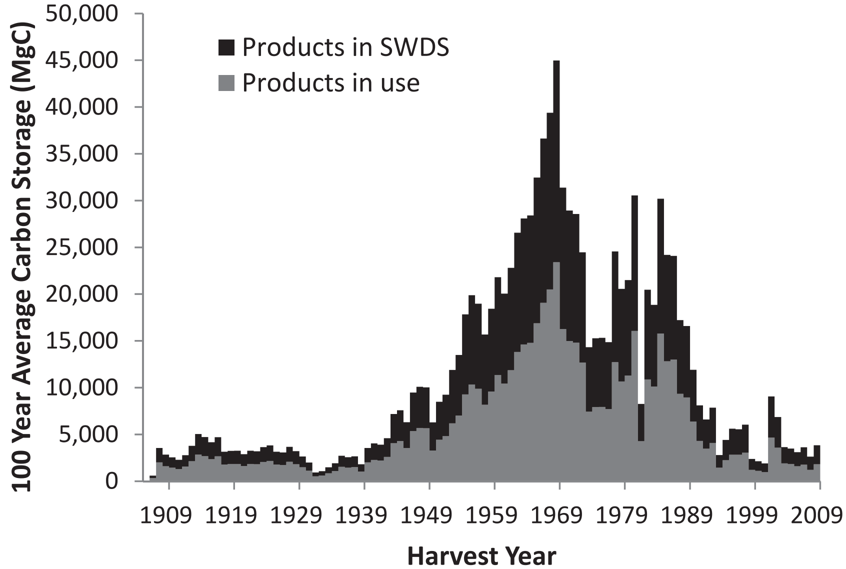

Figure 19—Bitterroot National Forest 100-year average carbon HWP storage using the California Forest Project Protocol.

maximum in 1969 with 23,405 MgC in use and 21,580 MgC in the SWDS for a total of 44,985 MgC. Average carbon storage in HWP began to rapidly decline following 1969 until hitting a local minimum in 1974, with 7,423 MgC in use and 6,902 MgC in the SWDS for a total of 14,325 MgC. Average carbon storage hovered about 15,000 MgC until 1978, when carbon stores rapidly increased until hitting a local maximum in 1981with 16,069 MgC in use and 14,485 MgC in the SWDS for a total of 30,554 MgC. Carbon storage dropped drastically in 1982, hitting a local minimum with 4,266 MgC in use and 3,987 MgC in the SWDS for a total of 8,253 MgC. After 1982, carbon storage rapidly increased until hitting a local maximum in 1985 with 15,786 MgC in use and 14,412 MgC in the SWDS for a total of 30,197 MgC. Carbon storage quickly declined after 1985 with some isolated inter-annual variability until hitting a local minimum in 2001 with 958 MgC in use and 945 MgC in the SWDS for a total of 1,904 MgC. In 2002, carbon storage hit a local maximum with 4,650 MgC in use and 4,406 MgC in the SWDS for a total of 9,056 MgC. However, carbon storage declined after 2002, averaging about 3,500 MgC from 2004 to 2009 and ending in 2009 with 1,817 MgC in use and 2,019 MgC in the SWDS for a total of 3,836 MgC (tables 16, 17).

Table 16—Bitterroot National Forest 100-year average carbon stored in HWP for selected years.

Harvest year	Products in use[a]	Landfills and dumps[b]	Total
	- - - - - - - - - - - - - - - *(MgC)*	- - - - - - - - - - - - - -	
1910	1,441	1,113	2,555
1920	1,836	1,418	3,254
1930	1,486	1,148	2,634
1940	2,007	1,550	3,556
1950	3,270	3,015	6,284
1960	11,348	10,463	21,811
1970	16,263	15,120	31,382
1980	11,290	10,208	21,498
1990	6,388	5,519	11,907
1995	2,237	2,173	4,410
2000	1,104	1,022	2,126
2005	1,834	1,650	3,484
2006	1,594	1,512	3,106
2007	1,763	1,857	3,620
2008	1,215	1,413	2,628
2009	1,817	2,019	3,835

[a] The 100-year average carbon storage in products in use for the harvest year.
[b] The 100-year average carbon storage in SWDS for the harvest year.

Table 17—Bitterroot National Forest confidence intervals for cumulative carbon in HWP for selected years for harvests beginning in 1906.

Inventory year	Total remaining in HWP pool	90% Confidence interval (% difference from estimate) 5%	95%
	- - - - - - - - - - - - - - - -	*(MgC)*- - - - - - - - - - - - - - - - -	
1910	9,019	5,296	13,363
1920	51,803	29,891	78,365
1930	82,563	46,793	129,254
1940	91,301	54,277	139,592
1950	156,649	95,794	234,722
1960	322,632	204,817	460,954
1970	660,653	426,545	943,808
1980	810,234	520,329	1,163,174
1990	965,369	691,071	1,282,716
1995	941,343	689,994	1,235,510
2000	909,249	686,775	1,179,808
2005	884,139	657,301	1,140,474
2006	877,791	649,298	1,128,732
2007	871,234	651,816	1,119,585
2008	865,700	648,119	1,115,674
2009	858,983	652,423	1,114,631
2010	854,358	648,457	1,096,518

Custer National Forest

Description

The Custer National Forest is spread across southern Montana, and north-western South Dakota (fig. 20). The forest spans an area approximately 330 miles from east to west, and 45 miles from north to south with the Crow and Northern Cheyenne Reservations as well as non-Federal holdings throughout the area. The forest is bordered by the Gallatin National Forest and Crow Reservation as well as privately held lands to the north, privately held lands to the east, the Gallatin National Forest and the state of Wyoming as well as privately held lands to the south, Yellowstone National Park to the southwest, and the Gallatin National Forest to the west.

The Otter National Forest was established on March 2, 1907, before having its name changed to the Custer National Forest on July 1, 1908. On January 13, 1920, the entire Sioux National Forest was added to the forest, followed by a final addition on February 17, 1932, of part of the Beartooth National Forest (Davis 1983).

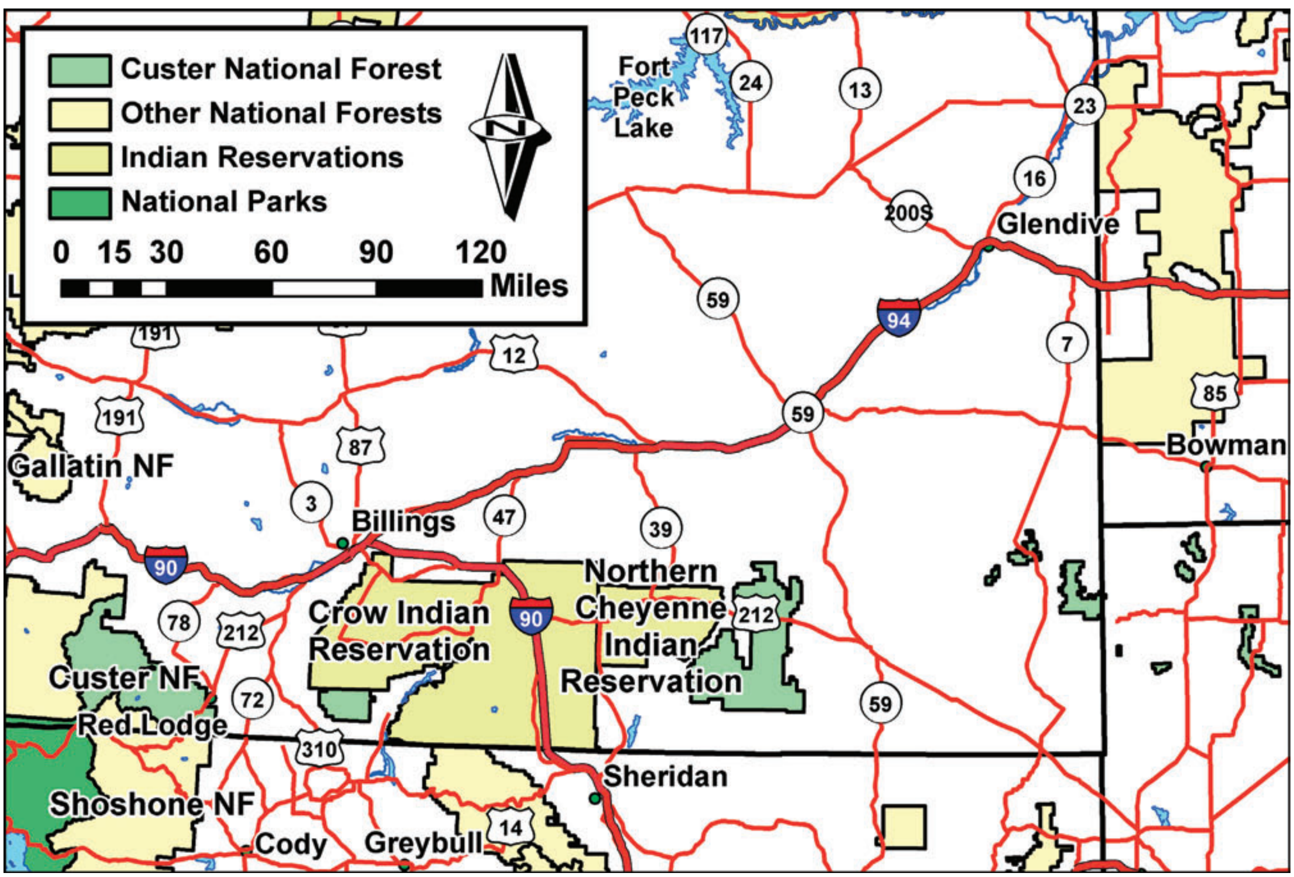

Figure 20—Location map of Custer National Forest.

The Custer National Forest is 1,187,143 acres and contains over 35 unique forest habitat types that have been categorized into eastside habitat type groups (DeBlander 2001b). The most common habitat classification is warm and very dry covering 39 percent of the forest, followed by the classification of cold covering 15 percent. Due to higher elevations being associated with increased precipitation and lower temperatures, forest cover type varies across the forest. Within the eastern portion of the forest (Ashland and Sioux Ranger Districts), which is below 5,000 feet in elevation, ponderosa pine and Rocky Mountain juniper are successful forest types. In the western portion of the forest (Beartooth Ranger District), which is primarily above 5,000 feet in elevation, lodgepole pine, Douglas-fir, aspen, and Rocky Mountain juniper are successful forest types in lower elevations, while in higher elevations lodgepole pine, whitebark pine, Engelmann spruce, and subalpine fir are successful forest types (DeBlander 2001b). The forest is 56 percent forested, leaving the remaining 44 percent either non-forested or water. Twenty eight percent of the forested lands are protected under reserves in the Absaroka-Beartooth Wilderness areas, while 59 percent of non-reserved lands are considered suitable for timber production. The net annual growth of all forested lands is estimated to be 7.1 million cubic feet. Forest cover is 51 percent ponderosa pine, 12 percent lodgepole pine, 11 percent Douglas-fir, 9 percent whitebark pine, 8 percent spruce-fir, 6 percent Engelmann spruce, 2 percent limber pine, and 1 percent aspen (DeBlander 2001b). Stands of old growth forest are also present on the Custer National Forest, estimated to cover 10.1 percent of forested lands (USDA 2007).

Natural disturbances within the Custer National Forest are fire, weather damage, and signs of sudden aspen decline (SAD) (DeBlander 2001b; Hamilton and others 2009). It was estimated that 9.2 million cubic feet of growing stock died in 1996, with 68 percent of tree mortality being the result of fire, and 11 percent resulting from weather damage (DeBlander 2001b). It was also estimated that 73 percent of tree mortality occurred in whitebark pine and Engelmann spruce, of which all the whitebark pine mortality and half of Engelmann spruce took place on a single burn in the Absaroka-Beartooth Wilderness (DeBlander 2001b). Other recent fire disturbances that continue to shape the forest include the fires in 2000, which are currently being studied to determine fire activity influence following insect infestations on ponderosa pine (USDA 2003, p 457). SAD has also been detected in the forest on southern aspects and lower elevations, in part due to acute drought conditions and hotter than normal temperatures (Hamilton and others 2009). Within the forest, 27 percent of plots show no visible signs of disturbances, 30 percent show evidence of fire, 11 percent show evidence of weather damage, 10 percent show signs of disease, 7 percent show signs of animal damage, 6 percent show evidence of cutting, 2 percent show evidence of wind or road building damage, 1 percent show signs of insect damage, and the remaining 4 percent show evidence of other disturbances (DeBlander 2001b).

Harvest Trends

From 1906 to 1929, timber production averaged about 350 MgC per year before beginning a downward trend (fig. 21). Starting at the global minimum of 99 MgC in 1932, annual timber production began to grow exponentially, with some inter-annual variability until hitting a local maximum of 6,622 MgC in 1967. After 1967, timber production experienced high inter-annual variability, hitting another local maximum of 7,802 MgC in 1972 before sharply declining the following year to a local minimum of 564 MgC in 1973. In 1974, production sharply rose to a local maximum of 5,701 MgC, before sharply declining to 1,180 MgC the following year. After 1975, production slowly increased with some inter-annual variability until 1983, when production began to rapidly increase with high inter-annual variability until reaching the global maximum of 21,513 MgC in 1989. Production sharply declined after 1989 until reaching 3,061 MgC in 1991. From 1991 to 2009, production slowly increased with high inter-annual variability, hitting a local minimum of 1,073 MgC in 1998, a local maximum of 13,669 MgC in 2003, and ending with 6,451 MgC in 2009.

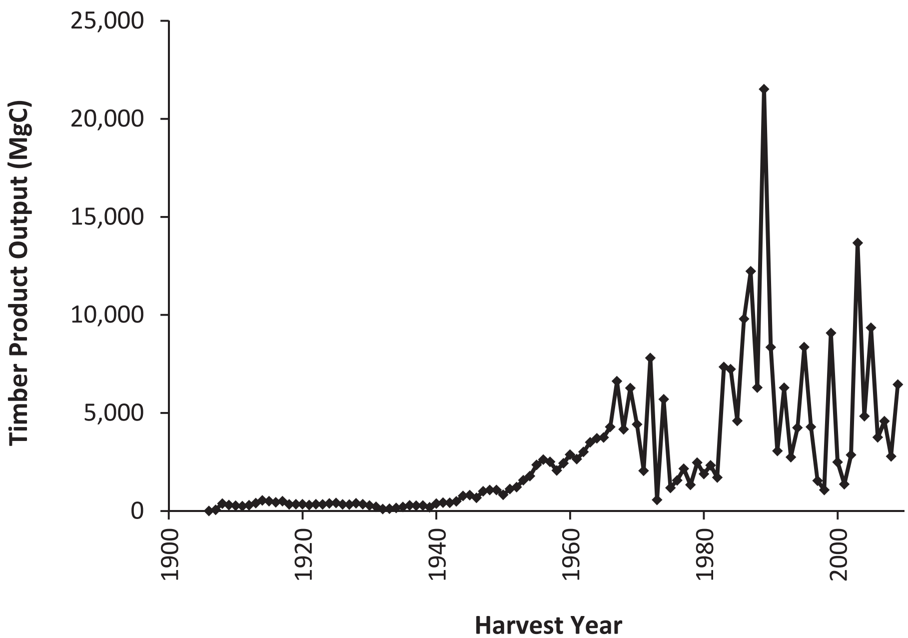

Figure 21—Annual timber product output for Custer National Forest, 1906 to 2010.

Carbon in Harvested Wood Products

Starting in 1907 total carbon storage in HWP grew linearly until flattening out in 1931 with 3,483 MgC in use and 766 MgC in the SWDS for a total of 4,249 MgC (fig. 22). Total carbon storage began to grow exponentially after 1940 with some isolated inter-annual variability occurring between 1967 and 1973, resulting in 30,810 MgC in use and 8,611 MgC in the SWDS for a total of 39,421 MgC in storage in 1973. From 1973 to 1983, carbon storage continued to grow at a slow pace with the exceptions of 1974, 1976, 1977, and 1979, resulting in 31,085 MgC in use and 11,256 MgC in the SWDS for a total of 42,341 MgC in storage in 1983. After 1983, carbon storage rapidly increased until 1991 with 61,209 MgC in use and 20,713 MgC in the SWDS for a total of 81,922 MgC. From 1991 to 2010, carbon storage continued to quickly increase with high inter-annual variability showing a net loss in 1998, 1999, 2002, and 2009, ending at the global maximum in 2010 with 70,727 MgC in use and 38,346 MgC in the SWDS for a total of 109,073 MgC remaining in total carbon storage (table 18).

From 1907 to 1929, net stock change averaged about 150 MgC ranging from a low point in 1907 of 1 MgC in use and 0 MgC in the SWDS for a total of 1 MgC, to the high point in 1915 of 272 MgC in use and 40 MgC in the SWDS for a total of 312 MgC (fig. 23). After 1929, net stock change began to decline until hitting a local minimum in 1933 with –39 MgC in use and 15 MgC in the SWDS for a net negative change in carbon stocks (emissions) of –24 MgC.

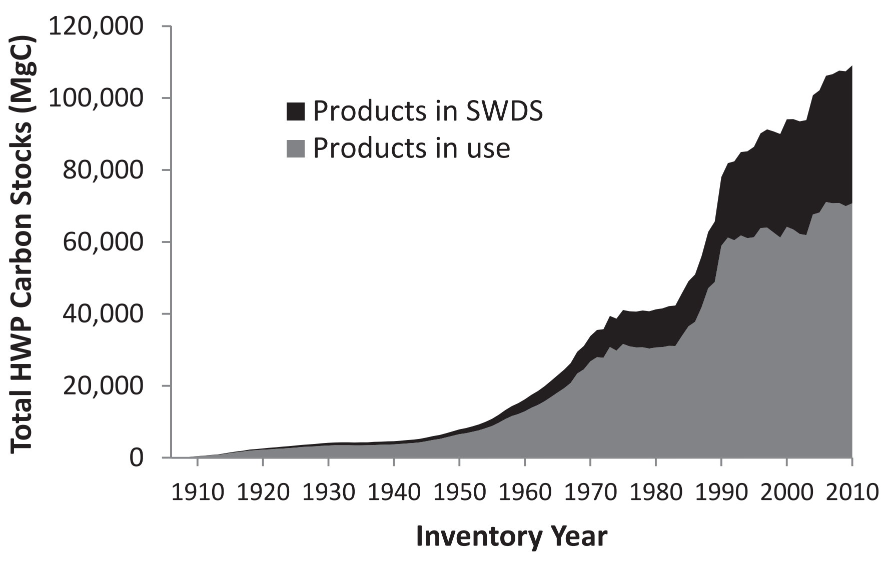

Figure 22—Cumulative total carbon stored in HWP manufactured from Custer National Forest timber.

Table 18—Custer National Forest cumulative disposition of HWP carbon for selected years. This table shows the fate of all carbon removed from the ecosystem by harvesting.

Inventory year	Emitted with energy capture	Emitted without energy capture	Products in use	SWDS	Total remaining in HWP pool[a]
	(MgC)				
1910	270	22	412	42	454
1920	1,675	344	2,223	385	2,608
1930	2,954	1,051	3,418	738	4,157
1940	3,717	1,956	3,701	895	4,597
1950	6,292	3,206	6,568	1,319	7,886
1960	13,222	6,422	12,930	3,313	16,243
1970	28,517	14,356	26,809	7,038	33,848
1980	39,473	25,228	30,656	10,594	41,250
1990	66,598	36,259	58,906	19,115	78,021
1995	74,980	44,117	61,338	25,129	86,467
2000	84,024	51,807	64,189	29,890	94,079
2005	93,540	59,424	68,159	34,013	102,172
2006	97,099	61,183	71,119	35,080	106,199
2007	98,689	62,881	70,744	35,921	106,665
2008	100,643	64,569	70,838	36,766	107,604
2009	101,954	66,184	69,958	37,504	107,462
2010	105,171	67,805	70,727	38,346	109,073

[a] Sum of products in use and SWDS.

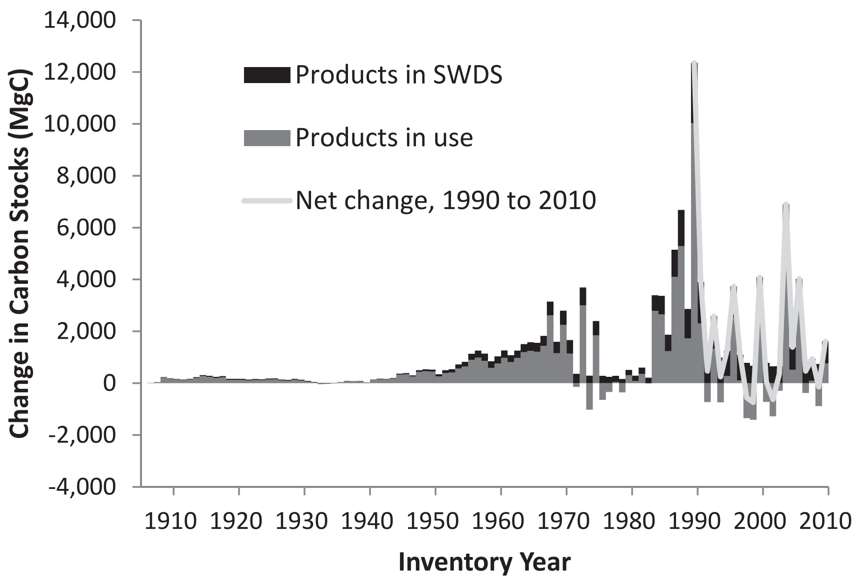

Figure 23—Custer National Forest net change in carbon stocks in HWP from the previous year.

Following 1933, net stock change experienced positive growth with a moderate amount of inter-annual variability until hitting a local maximum in 1973 with 3,000 MgC in use and 692 MgC in the SWDS for a total of 3,692 MgC. Net stock change hit a local minimum in 1974 with –1,019 MgC in use and 293 MgC in the SWDS for a total of –726 MgC, before slowly increasing with some inter-annual variability until 1983 with –10 MgC in use and 212 MgC in the SWDS for a total net stock change of 202 MgC. Following 1983, net stock change rapidly increased with a moderate amount of inter-annual variability until hitting the global maximum in 1990 with 10,026 MgC in use and 2,331 MgC in the SWDS for a total of 12,357 MgC. Net stock change sharply decreased after 1990, hitting a local minimum in 1992 with –729 MgC in use and 1,197 MgC in the SWDS for a total of 468 MgC. From 1992 to 2010, net stock change slowly increased with high inter-annual variability, hitting the global minimum in 1999 with –1,412 MgC in use and 672 MgC in the SWDS for a total of –740 MgC, a local maximum in 2004 with 5,737 MgC in use and 1,165 MgC in the SWDS for a total of 6,902 MgC, and ending in 2010 with 769 MgC in use and 843 MgC in the SWDS for a total of 1,612 MgC (table 19).

Table 19—Custer National Forest annual net change in HWP carbon stocks for selected years for harvests beginning in 1906.

Inventory year	Stock change[a] (MgC yr^{-1})
1910	182
1920	170
1930	132
1940	28
1950	521
1960	1,035
1970	2,796
1980	515
1990	12,357
1995	1,254
2000	4,085
2005	1,389
2006	4,026
2007	466
2008	939
2009	-142
2010	1,611

[a] Net annual change in carbon in products in use and SWDS.

From 1906 to 1929, the 100-year average carbon storage was about 160 MgC ranging from a low point in 1906 of 1 MgC in use and 0 MgC in the SWDS for a total of 1 MgC, to the high point in 1914 of 143 MgC in use and 111 MgC in the SWDS for a total of 254 MgC (fig. 24). Following 1929, average carbon storage experienced a short downward trend, hitting the global minimum in 1932 with 27 MgC in use and 20 MgC in the SWDS for a total of 47 MgC. After 1932, average carbon storage experienced positive growth with a moderate amount of inter-annual variability until reaching a local maximum in 1972 with 1,540 MgC in use and 1,431 MgC in the SWDS for a total of 2,971 MgC. The following year in 1973, total average carbon storage in HWP hit a local minimum with 111 MgC in use and 103 MgC in the SWDS for a total of 214 MgC, before slowly increasing with a moderate amount of inter-annual variability until 1982 with 357 MgC in use and 334 MgC in the SWDS for a total of 691 MgC. After 1982, average carbon storage rapidly increased, hitting the global maximum in 1989 with 4,592 MgC in use and 3,920 MgC in the SWDS for a total of 8,512 MgC. average carbon storage sharply decreased after 1989, hitting a local minimum in 1991 with 660 MgC in use and 582 MgC in the SWDS for a total of 1,242 MgC. From 1991 to 2009, carbon stores slowly increased with high inter-annual variability hitting a local minimum in 1998 with 204 MgC in use and 202 MgC in the SWDS for a total of 406 MgC, a local maximum in 2003 with 2,760 MgC in use and 2,527 MgC in the SWDS for a total of 5,287 MgC, and ending in 2009 with 959 MgC in use and 1,065 MgC in the SWDS for a total of 2,024 MgC (tables 20, 21).

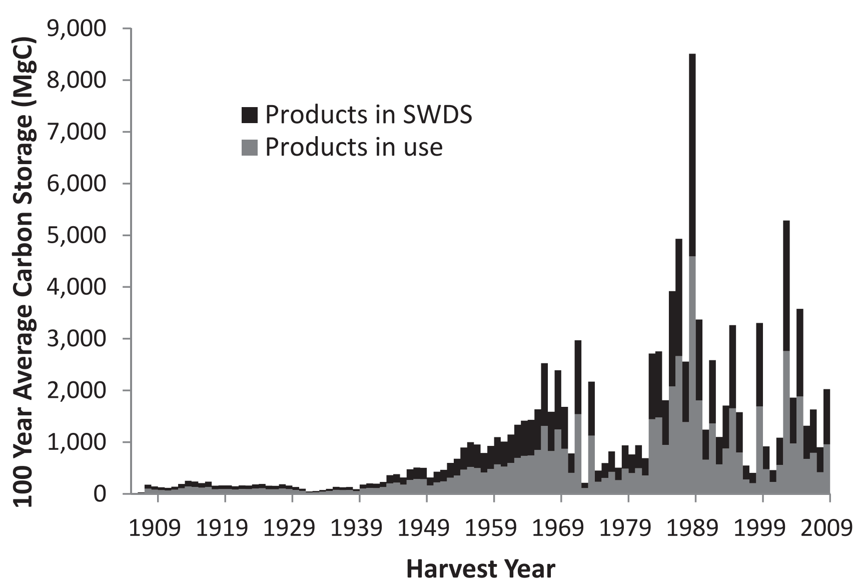

Figure 24—Custer National Forest harvest 100-year average carbon HWP storage using the California Forest Project Protocol.

Table 20—Custer National Forest 100-year average carbon stored in HWP for selected years.

Harvest year	Products in use[a]	Landfills and dumps[b]	Total
	- - - - - - - - - - - - - - - (*MgC*)	- - - - - - - - - - - - - -	
1910	73	56	129
1920	92	71	164
1930	75	58	133
1940	101	78	179
1950	165	152	316
1960	571	527	1,098
1970	872	810	1,682
1980	401	363	763
1990	1,809	1,563	3,372
1995	1,655	1,608	3,264
2000	476	441	918
2005	1,884	1,695	3,578
2006	676	641	1,318
2007	794	837	1,631
2008	417	485	902
2009	959	1,065	2,024

[a] The 100-year average carbon storage in products in use for the harvest year.
[b] The 100-year average carbon storage in SWDS for the harvest year.

Table 21—Custer National Forest confidence intervals for cumulative carbon in HWP for selected years for harvests beginning in 1906.

Inventory year	Total remaining in HWP pool	90% Confidence interval (% difference from estimate) 5%	95%
	- - - - - - - - - - - - - - - - - (*MgC*)-	- - - - - - - - - - - - - - - - -	
1910	454	267	673
1920	2,608	1,505	3,945
1930	4,157	2,356	6,508
1940	4,597	2,733	7,028
1950	7,886	4,822	11,816
1960	16,243	10,312	23,207
1970	33,848	21,854	48,355
1980	41,250	26,491	59,219
1990	78,021	55,852	103,669
1995	86,467	63,379	113,488
2000	94,079	71,060	122,073
2005	102,172	75,958	131,794
2006	106,199	78,555	136,559
2007	106,665	79,802	137,071
2008	107,604	80,559	138,675
2009	107,462	81,621	139,445
2010	109,073	82,786	139,989

Flathead National Forest

Description

The Flathead National Forest is located in northwestern Montana and stretches nearly 100 miles from the Canadian border to its southern boundary with Lolo National Forest near St. Ignatius, Montana (fig. 25). The forest is bordered by Glacier National Park to the northeast, Lewis and Clark National Forest to the east, Lolo National Forest to the south, and Kootenai National Forest to the northwest. The southwest is bordered by the Flathead Reservation of the Confederated Salish and Kootenai Tribes, as well as private land and other non-Federal holdings around Flathead Lake and north throughout the Flathead River Valley.

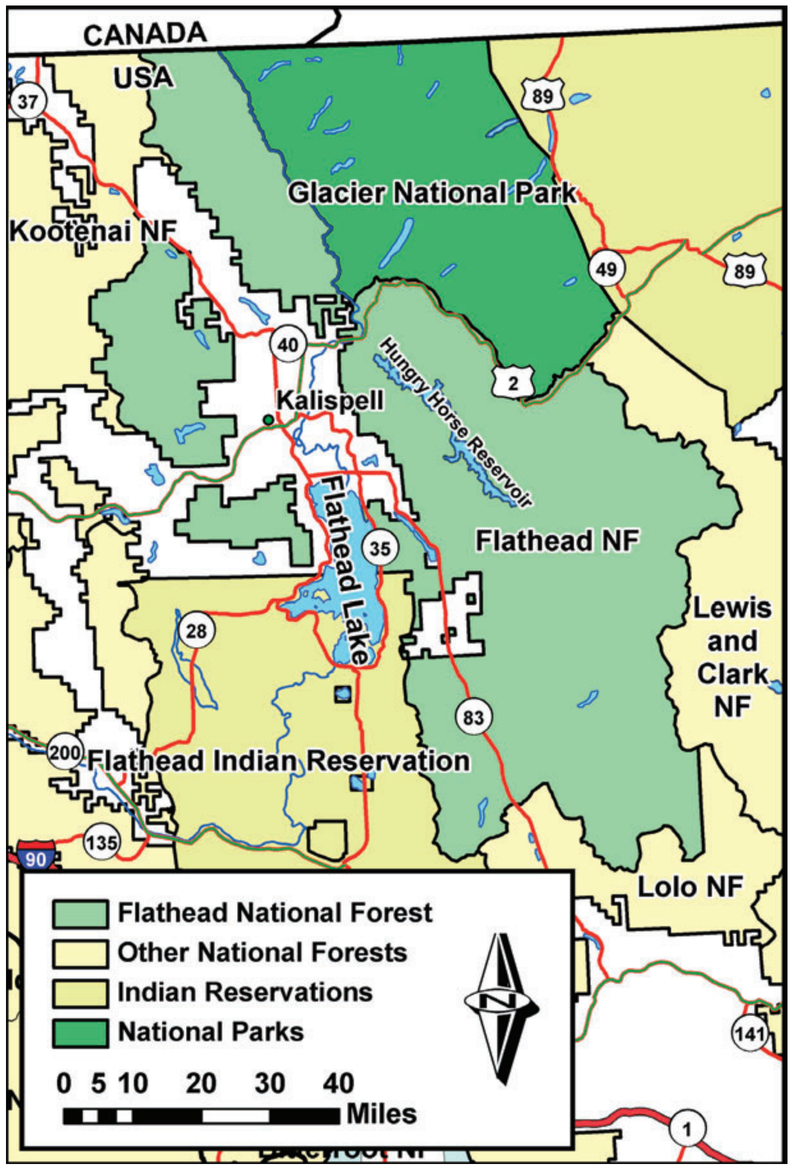

Figure 25—Location map of Flathead National Forest.

The Flathead National Forest was established on February 22, 1897, effective March 1, 1898. On June 9, 1903, the Flathead National Forest was discontinued and consolidated with the Lewis and Clarke National Forest until July 1, 1908, when the Flathead National Forest was reestablished from part of the Lewis and Clark National Forest. On June 22, 1935, part of the Blackfoot National Forest was added to the Flathead when the Blackfoot was discontinued (Davis 1983).

The Flathead National Forest is 2,351,950 acres and contains many diverse ecosystems common in western Montana due to a wide variation in local climates caused by large elevation changes (O'Brien 1999; USDA 1985, p VI-18). The most prevalent habitat type is classified as cool and moist, occurring on 48 percent of the forest (O'Brien 1999). The forest is 89 percent forested, leaving the remaining 11 percent either non-forested or water. Forty-six percent of the forested lands are protected under reserves, including wilderness designation, and 51 percent of non-reserved lands are considered suitable for timber production, with net annual growth of all forested lands estimated to be over 72 million cubic feet (O'Brien 1999). Forest ecosystems range from warm, dry ponderosa pine forests to cool, moist whitebark pine forests (USDA 1985, p VI-18). Forest cover is 47 percent spruce-fir, 19 percent Douglas-fir, 17 percent lodgepole pine, 6 percent Engelmann spruce, 5 percent larch, 3 percent whitebark pine, as well as traces of grand fir, ponderosa pine, and aspen (O'Brien 1999). Old growth forests are also present, estimated to cover 11.0 percent of the forested area (USDA 2007).

Natural disturbances within the Flathead National Forest are insect infestation including significant impacts from the mountain pine beetle, and forest fires (USDA 1985, 2012b). Infected timber from the mountain pine beetle jumped 260 percent to 315,000 acres in just one year from 1979 to1980. In 1985, 54 mmbf of lodgepole pine were considered to be at high risk of infection within 10 years (USDA 1985, p VI-25). A partial aerial survey of the forest showed that 32,076 acres were infected with mountain pine beetle in 2009, 77,697 acres in 2010, and 7,840 acres in 2011, mostly occurring in lodgepole pine for all 3 years (USDA 2012b, p 45). Large fire disturbances also occurred on the forest in 1910, 1926, and 1929 resulting in 75- to 95-year old lodgepole pine stands (USDA 1985, p VI-25). Within the forest, 24 percent of plots show no visible signs of disturbances, 22 percent show signs of disease, 14 percent have evidence of fire, 14 percent show evidence of cutting, 11 percent have signs of weather damage, and 15 percent have undergone road building, land clearing, or other disturbances (O'Brien 1999).

Harvest Trends

Flathead National Forest is among the top five timber producing National Forests in the Northern Region (fig. 9). From 1906 to 1929, timber production averaged about 22,000 MgC per year before beginning a downward trend (fig. 26). Starting at the global minimum of 6,223 MgC in 1932, annual timber production began to grow exponentially with some inter-annual variability until 1969, when timber

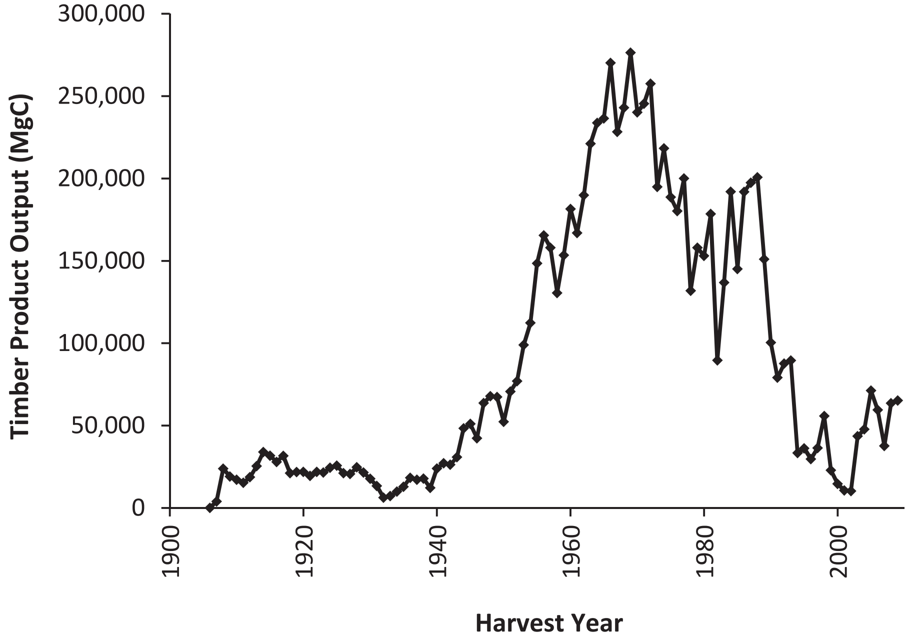

Figure 26—Annual timber product output for Flathead National Forest, 1906 to 2010.

production hit its global maximum at 276,375 MgC. After 1969 timber production began to fall with some inter-annual variability, hitting a local minimum of 89,617 MgC in 1982. The years following 1982, production sharply increased hitting a local maximum of 200,751 MgC in 1988. From 1988 production began to fall again until hitting a local minimum of 10,249 MgC in 2002. In 2003, production rose back up to 43,539 MgC and was at 65,197 MgC in 2009.

Carbon in Harvested Wood Products

Starting in 1907 total carbon storage in HWP grew linearly until flattening out in 1931with 219,623 MgC in use and 48,318 MgC in the SWDS for a total of 267,941 MgC (fig. 27). After 1940 carbon storage began to grow exponentially until 1973 with 1,724,923 MgC in use and 499,772 in the SWDS for a total of 2,224,695 MgC. Carbon storage continued to grow after 1973 at a steady rate until hitting a 4-year plateau starting in 1990 with 2,180,697 MgC in use and 849,897 MgC in the SWDS for a total of 3,030,594 MgC. The plateau ended in 1994 at the global maximum with 2,137,185 MgC in use and 908,423 MgC in the SWDS for a total of 3,045,609 MgC. Carbon storage fell after 1990 at a steady rate until slowing in 2005 with 1,824,997 MgC in use and 953,420 MgC in the SWDS for a total of 2,778,417 MgC. After 2005 carbon storage still fell but at very slow decline ending in 2010 with 1,789,615 MgC in use and 970,886 MgC in the SWDS for a total of 2,760,501 MgC remaining in total carbon storage (table 22).

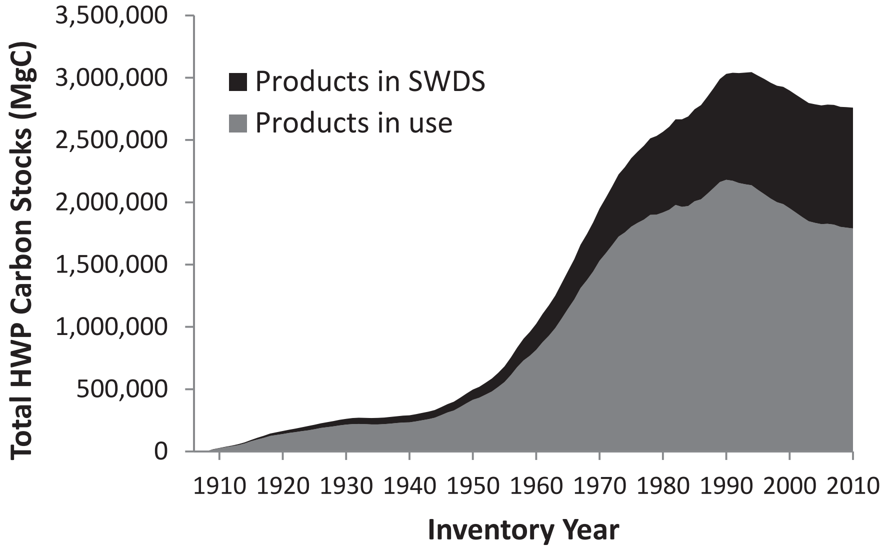

Figure 27—Cumulative total carbon stored in HWP manufactured from Flathead National Forest timber.

Table 22—Flathead National Forest cumulative disposition of HWP carbon for selected years. This table shows the fate of all carbon removed from the ecosystem by harvesting.

Inventory year	Emitted with energy capture	Emitted without energy capture	Products in use	SWDS	Total remaining in HWP pool[a]
	(MgC)				
1910	17,014	1,360	26,004	2,632	28,635
1920	105,609	21,721	140,216	24,253	164,469
1930	186,289	66,299	215,566	46,564	262,130
1940	234,389	123,358	233,413	56,459	289,872
1950	396,766	202,154	414,175	83,172	497,347
1960	833,849	405,008	815,415	208,912	1,024,327
1970	1,675,610	885,546	1,530,368	418,978	1,949,345
1980	2,430,781	1,528,080	1,918,450	647,981	2,566,432
1990	3,013,675	2,116,990	2,180,697	849,897	3,030,594
1995	3,146,344	2,388,696	2,099,221	917,028	3,016,249
2000	3,213,258	2,621,611	1,952,610	944,667	2,897,277
2005	3,261,391	2,819,207	1,824,997	953,420	2,778,417
2006	3,288,513	2,857,137	1,827,587	956,989	2,784,576
2007	3,313,718	2,894,652	1,820,953	960,402	2,781,355
2008	3,329,763	2,931,281	1,803,159	963,138	2,766,297
2009	3,359,717	2,967,628	1,796,744	966,867	2,763,610
2010	3,392,238	3,003,413	1,789,615	970,886	2,760,502

[a] Sum of products in use and SWDS.

From 1907 to 1929, net stock change averaged about 13,000 MgC ranging from a low point in 1907 of 51 MgC in use and 4 MgC in the SWDS for a total of 55 MgC, to the high point in 1915 of 17,129 MgC in use and 2,531 MgC in the SWDS for a total of 19,660 MgC (fig. 28). After 1929, net stock change began to decline until hitting a local minimum in 1933 with –2,433 MgC in use and 949 MgC in the SWDS for a net negative change in carbon stocks (emissions) of –1,486 MgC. Following 1933, net stock change experienced positive growth at an exponential rate with a moderate amount of inter-annual variability until hitting the global maximum in 1967 with 90,762 MgC in use and 24,165 MgC in the SWDS for a total of 114,927 MgC. After 1967, net additions rapidly declined with high inter-annual variability until hitting a local minimum in 1983 with –15,038 MgC in use and 15,229 MgC in the SWDS for a total net stock change of 191 MgC. This was followed by a period of rapid growth until hitting a local maximum in 1989 with 48,227 MgC in use and 25,289 MgC in the SWDS for a total of 73,516 MgC in net stock change. Net stock change experienced a steep decline after 1989 first showing signs of net negative growth in 1992 with –17,828 MgC in use and 14,585 MgC in the SWDS for a total of –3,243 MgC. This downward trend hit the global minimum in 2002 with –35,618 MgC in use and 1,411 MgC in the SWDS for a total of –34,207 MgC. Following 2002, yearly net stock change increased showing a positive net stock change in 2006 with 2,590 MgC in use and 3,569 MgC in the SWDS for a total of 6,159 MgC, followed by 4 years of net negative growth, ending in 2010 with –7,128 MgC in use and 4,020 MgC in the SWDS for a total of –3,108 MgC (table 23).

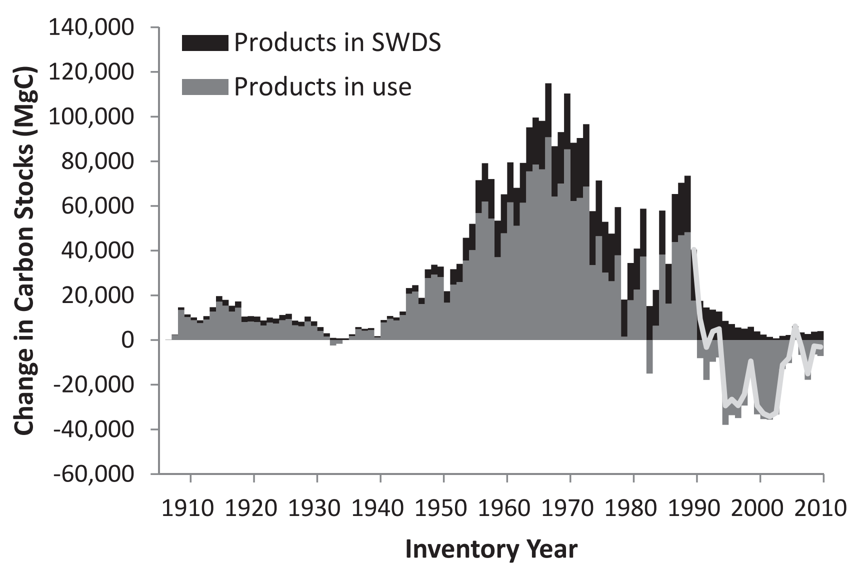

Figure 28—Flathead National Forest net change in carbon stocks in HWP from the previous year.

Table 23—Flathead National Forest annual net change in HWP carbon stocks for selected years for harvests beginning in 1906.

Inventory year	Stock change[a] (MgC yr^{-1})
1910	11,482
1920	10,699
1930	8,349
1940	1,770
1950	32,866
1960	65,261
1970	110,365
1980	34,497
1990	40,477
1995	-29,359
2000	-29,397
2005	-8,093
2006	6,159
2007	-3,221
2008	-15,058
2009	-2,687
2010	-3,109

[a] Net annual change in carbon in products in use and SWDS.

From 1906 to 1929, the 100-year average carbon storage hovered about 10,300 MgC with approximately 5,800 MgC in use and 4,500 MgC in the SWDS before beginning a short downward trend and hitting the global minimum in 1932 with 1,659 MgC in use and 1,281 MgC in the SWDS for a total of 2,940 MgC (fig. 29). After 1932 average carbon storage grew exponentially reaching the global maximum in 1969 with 54,857 MgC in use and 50,580 MgC in the SWDS for a total of 105,437 MgC. Following 1969, average carbon storage in HWP began to fall with high inter-annual variability hitting a local minimum in 1982, with 18,731 MgC in use and 17,503 MgC in the SWDS for a total of 36,234 MgC. Carbon stores grew rapidly after 1982, hitting a local maximum in 1988 with 44,214 MgC in use and 37,373 MgC in the SWDS for a total of 81,587 MgC. This was followed by a steady decline in carbon storage, hitting the most recent and lowest local minimum in 2001 with 1,804 MgC in use and 1,779 MgC in the SWDS for a total of 3,583 MgC. The average storage increased to about 20,000 MgC from 2003 to 2009, ending in 2009 with 9,690 MgC in use and 10,767 MgC in the SWDS for a total of 20,457 MgC (tables 24, 25).

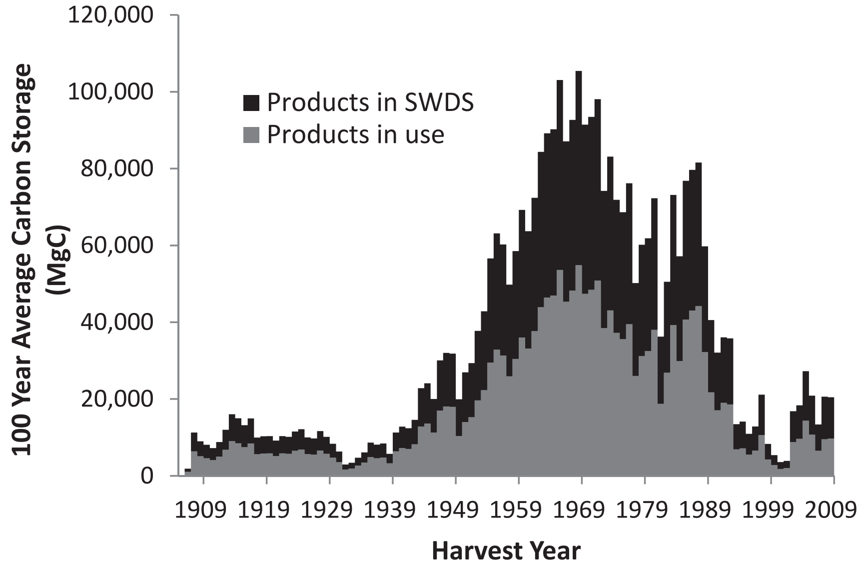

Figure 29—Flathead National Forest harvest 100-year average carbon HWP storage using the California Forest Project Protocol.

Table 24—Flathead National Forest 100-year average carbon stored in HWP for selected years.

Harvest year	Products in use[a]	Landfills and dumps[b]	Total
	- - - - - - - - - - - - - - - *(MgC)*	- - - - - - - - - - - - - -	
1910	4,576	3,535	8,111
1920	5,830	4,503	10,332
1930	4,717	3,644	8,361
1940	6,371	4,921	11,291
1950	10,381	9,571	19,952
1960	36,029	33,220	69,249
1970	47,382	44,051	91,433
1980	32,495	29,379	61,874
1990	21,753	18,792	40,545
1995	7,167	6,963	14,130
2000	2,799	2,591	5,390
2005	14,356	12,914	27,270
2006	10,718	10,166	20,884
2007	6,521	6,872	13,394
2008	9,534	11,086	20,620
2009	9,690	10,767	20,457

[a] The 100-year average carbon storage in products in use for the harvest year.
[b] The 100-year average carbon storage in SWDS for the harvest year.

Table 25—Flathead National Forest confidence intervals for cumulative carbon in HWP for selected years for harvests beginning in 1906.

Inventory year	Total remaining in HWP pool	90% Confidence interval (% difference from estimate) 5%	95%
	- - - - - - - - (MgC)	- - - - - - - -	
1910	28,635	16,815	42,429
1920	164,469	94,900	248,802
1930	262,130	148,563	410,369
1940	289,872	172,325	443,192
1950	497,347	304,137	745,221
1960	1,024,327	650,275	1,463,487
1970	1,949,345	1,258,577	2,784,832
1980	2,566,432	1,648,152	3,684,375
1990	3,030,594	2,169,486	4,026,844
1995	3,016,249	2,210,876	3,958,819
2000	2,897,277	2,188,373	3,759,399
2005	2,778,417	2,065,577	3,583,951
2006	2,784,576	2,059,739	3,580,625
2007	2,781,355	2,080,879	3,574,198
2008	2,766,297	2,071,029	3,565,077
2009	2,763,610	2,099,043	3,586,107
2010	2,760,502	2,095,220	3,542,941

Gallatin National Forest

Description

The Gallatin National Forest is located in southern Montana and is approximately 95 miles from east to west, and 115 miles from north to south with the Yellowstone River Valley running from northeast to southwest within the northern portion of the forest (fig. 30). The forest is bordered by the Lewis and Clark National Forest as well as privately held lands to the north, the Custer National Forest and privately held lands to the east, the Shoshone National Forest and Yellowstone National Park to the south, the Caribou-Targhee National Forest to the southwest, and privately held lands to the west.

The Gallatin National Forest was established on February 10, 1899. On July 1, 1908, additional lands were added from the Big Belt National Forest, followed by the addition of a portion of the Madison National Forest on December 16, 1931. On December 16, 1945, a final addition to the Gallatin National Forest was made as lands from the Absaroka National Forest were added (Davis 1983).

The Gallatin National Forest is 1,800,626 acres and contains over 60 unique forest habitat types that have been classified into eastside habitat type groups (DeBlander 2001c). The most common habitat type is classified as cool and dry and covers over 28 percent of the forest. The next most common habitat type is classified as cold, covering 20 percent of the forest. Due to higher elevations being associated with increased precipitation and lower temperatures, Douglas-fir and lodgepole pine are the more successful forest types in lower elevations

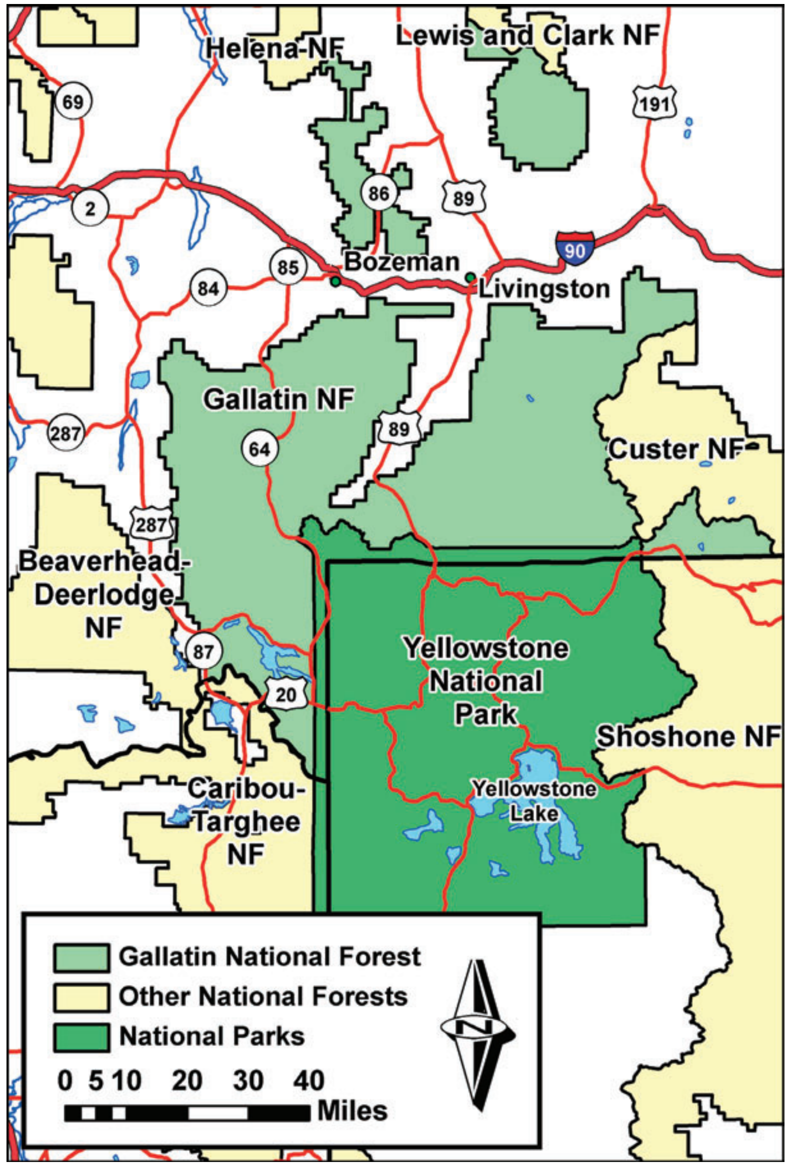

Figure 30—Location map of Gallatin National Forest.

(less than 7,000 feet), while lodgepole pine, subalpine fir, Engelmann spruce, whitebark pine, and Douglas-fir are more successful at higher elevations (greater than 7,000 feet) (DeBlander 2001c).The forest is 81 percent forested, leaving the remaining 19 percent either non-forested or water. Forty percent of the forested lands are protected under reserves in the Absaroka Beartooth and Lee Metcalf Wilderness areas, while 41 percent of non-reserved lands are considered suitable for timber production. The net annual growth of all forested lands is estimated to be over 39.1 million cubic feet. Forest cover is 27 percent Douglas-fir, 25 percent lodgepole pine, 25 percent spruce-fir, 13 percent whitebark pine, 8 percent Engelmann spruce, 1 percent limber pine, and 1 percent ponderosa pine (DeBlander 2001c). Stands of old growth forest are also present on the Gallatin National Forest, estimated to cover 25.5 percent of the forested area (USDA 2007).

Natural disturbances within the Gallatin National Forest are insect infestation including significant impacts from the mountain pine beetle activity, and recent forest fires (DeBlander 2001c; USDA 2012b, 1994). In 1997, it was estimated that mortality levels within the forest accounted for 22.2 million cubic feet of growing stock, with 72 percent of the mortality occurring in lodgepole pine and subalpine fir. Twenty-seven percent of the mortality was believed to be caused by disease, 26 percent by fire disturbances, and 15 percent by insect infestations (DeBlander 2001c). A partial aerial survey of the forest showed that 375,921 acres were infected with mountain pine beetle in 2009, which went down to 135,523 acres in 2010 and 45,882 acres in 2011, mostly occurring in lodgepole and 5-needle pine for all 3 years (USDA 2012b, p 45). Other disturbances that continue to shape the forest include the Hell-Roaring and Storm Creek fires of the greater 1988 Yellowstone fires (USDA 1994). Within the forest 29 percent of plots show no visible signs of disturbances, 26 percent show signs of disease, 14 percent show evidence of fire, 10 percent show signs of weather damage, 9 percent show evidence of tree cutting, 4 percent show signs of wind damage, 4 percent show signs of animal damage, and the remaining 4 percent show evidence of insect damage, road building, land clearing, or some other disturbance (DeBlander 2001c).

Harvest Trends

From 1906 to 1929, timber production averaged about 3,500 MgC per year before beginning a downward trend (fig. 31). Starting at the global minimum of 1,001 MgC in 1932, annual timber production began to grow exponentially, with some inter-annual variability until 1968 when timber production hit the global maximum at 89,317 MgC. Following 1968, timber production began to rapidly decline

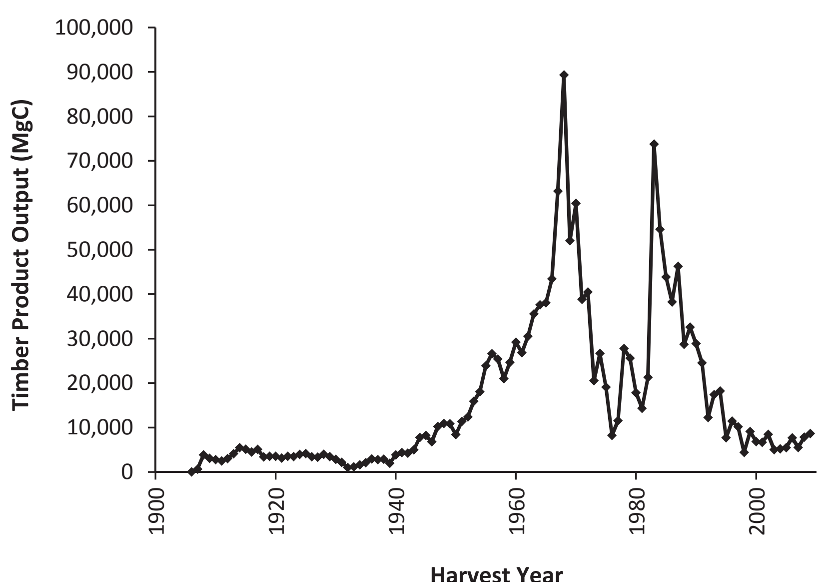

Figure 31—Annual timber product output for Gallatin National Forest, 1906 to 2010.

with some inter-annual variability until hitting a local minimum in 1976 of 8,233 MgC. Production quickly increased after 1976, hitting a local maximum 2 years later in 1978 of 27,768 MgC. Following 1978, production quickly decreased, hitting a local minimum in 1981 of 14,329 MgC, followed by a sharp increase hitting a local maximum of 73,743 MgC in 1983. Production rapidly decreased after 1983 at a declining rate with some inter-annual variability until hitting a local minimum of 4,409 MgC in 1998. From 1999 to 2009, production experienced some inter-annual variability with an average about 7,000 MgC per year, a local maximum of 9,090 MgC in 1999, a local minimum of 5,005 MgC in 2003, and ending in 2009 with 8,638 MgC in production.

Carbon in Harvested Wood Products

Starting in 1907, total carbon storage in HWP grew linearly until flattening out in 1931 with 35,323 MgC in use and 7,771 MgC in the SWDS for a total of 43,094 MgC (fig. 32). After 1940, carbon storage began to grow exponentially until 1969 with 272,274 MgC in use and 68,217 MgC in the SWDS for a total of 340,491 MgC. Carbon storage continued to grow at a rapid rate after 1969 until slowing in 1974 with 318,079 MgC in use and 95,047 MgC in the SWDS for a total of 413,126 MgC. From 1974 to 1983, carbon storage experienced some inter-annual variability, with negative growth present in 1977, 1978, and 1982, ending in 1983 with 314,434 MgC in use and 114,270 MgC in the SWDS for a total of 428,704 MgC. Following 1983, carbon storage began to quickly grow at a declining rate, hitting a local maximum in 1992 with 406,827 MgC in use and 162,686 MgC in the SWDS for a total of 569,513 MgC. Carbon storage declined 1,992 MgC in 1993 before hitting the global maximum in 1995 with 398,888 MgC in use and 172,174 MgC in the SWDS for a total of 571,062 MgC. After 1995, carbon storage began to decline at a slow, steady rate, ending in 2010 with 330,385 MgC in use and 190,455 MgC in the SWDS for a total of 520,840 MgC remaining in total carbon storage (table 26).

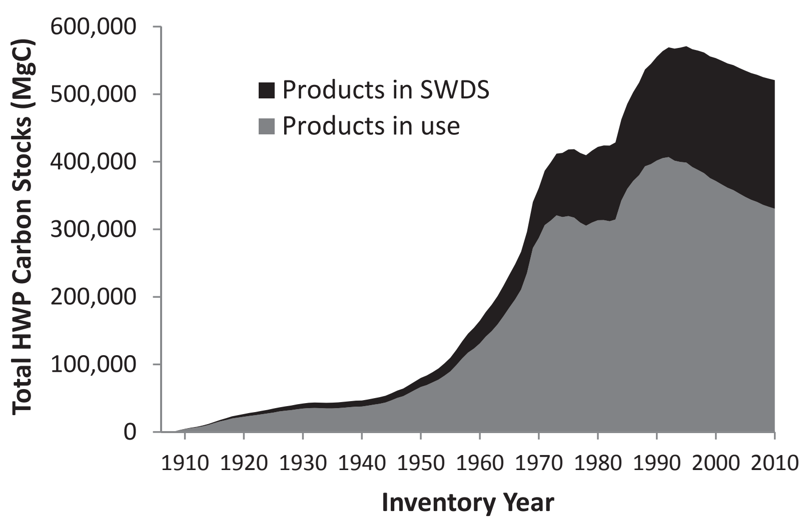

Figure 32—Cumulative total carbon stored in HWP manufactured from Gallatin National Forest timber.

Table 26—Gallatin National Forest cumulative disposition of HWP carbon for selected years. This table shows the fate of all carbon removed from the ecosystem by harvesting.

Inventory year	Emitted with energy capture	Emitted without energy capture	Products in use	SWDS	Total remaining in HWP pool[a]
	(MgC)				
1910	2,736	219	4,182	423	4,606
1920	16,986	3,493	22,552	3,901	26,452
1930	29,962	10,663	34,671	7,489	42,160
1940	37,698	19,840	37,541	9,081	46,622
1950	63,814	32,513	66,614	13,377	79,991
1960	134,112	65,139	131,147	33,600	164,748
1970	301,066	147,538	287,234	73,892	361,126
1980	405,709	261,091	313,471	108,646	422,117
1990	541,966	362,897	401,704	153,750	555,453
1995	576,447	414,024	398,888	172,174	571,062
2000	592,499	458,443	371,661	181,695	553,355
2005	604,885	496,688	347,977	186,861	534,838
2006	606,967	503,697	343,630	187,582	531,212
2007	610,221	510,564	340,431	188,342	528,773
2008	612,568	517,226	336,266	189,001	525,267
2009	616,257	523,749	333,174	189,715	522,889
2010	620,566	530,127	330,384	190,455	520,840

[a] Sum of products in use and SWDS.

From 1907 to 1929, net stock change averaged about 1,700 MgC ranging from a low point in 1907 of 8 MgC in use and 1 MgC in the SWDS for a total of 9 MgC, to the high point in 1915 of 2,755 MgC in use and 407 MgC in the SWDS for a total of 3,162 MgC (fig. 33). Net stock change began to decline after 1929 until hitting a local minimum in 1933 with –392 MgC in use and 153 MgC in the SWDS for a net negative change in carbon stocks (emissions) of –239 MgC. Following 1933, net stock change experienced positive growth at an exponential rate with a moderate amount of inter-annual variability until hitting the global maximum in 1969 with 37,021 MgC in use and 7,052 MgC in the SWDS for a total of 44,073 MgC. After 1969, net additions rapidly declined with some inter-annual variability, hitting a local minimum in 1977 with –7,341 MgC in use and 1,673 MgC in the SWDS for a total net stock change of –5,668 MgC. Net stock change experienced moderate inter-annual variability after 1977 averaging about a total of 2,600 MgC until 1984 when net stock change sharply increased, hitting a local maximum with 28,119 MgC in use and 5,849 MgC in the SWDS for a total of 33,968 MgC. From 1984 to 1999, net additions rapidly decreased at a declining rate while experiencing moderate inter-annual variability. Sustained net negative growth began in 1996, followed by the global minimum in1999 with –7,204 MgC in use and 1,504 MgC in the SWDS for a total net stock change of –5,700 MgC. After 1999, net additions continued to experience some inter-annual variability, averaging a total of –3,200 MgC per year, and ending in 2010 with –2,790 MgC in use and 740 MgC in the SWDS for a total of –2,050 MgC (table 27).

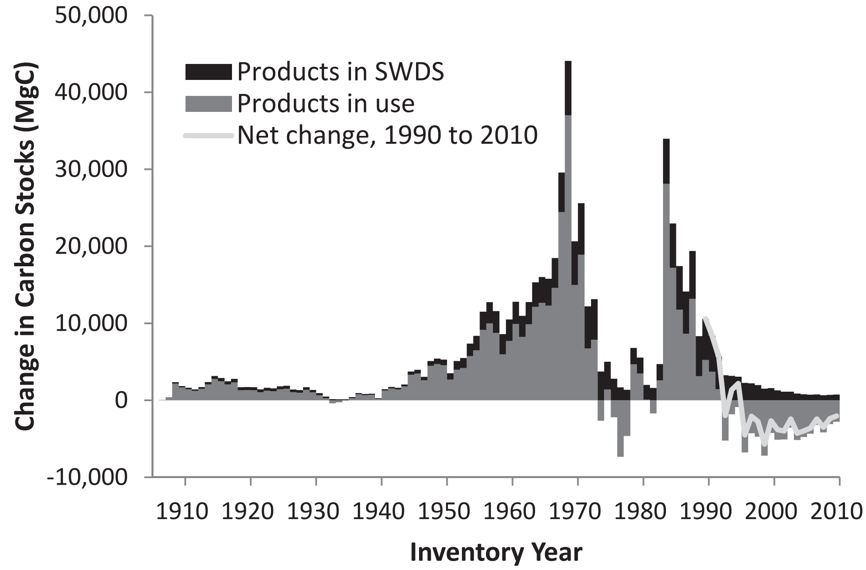

Figure 33—Gallatin National Forest net change in carbon stocks in HWP from the previous year.

Table 27—Gallatin National Forest annual net change in HWP carbon stocks for selected years for harvests beginning in 1906.

Inventory year	Stock change[a] (MgC yr^{-1})
1910	1,847
1920	1,721
1930	1,343
1940	285
1950	5,286
1960	10,496
1970	20,636
1980	5,544
1990	10,575
1995	2,177
2000	-2,678
2005	-3,977
2006	-3,625
2007	-2,439
2008	-3,507
2009	-2,377
2010	-2,050

[a] Net annual change in carbon in products in use and SWDS.

From 1906 to 1929, the 100-year average carbon storage was about 1,700 MgC ranging from a low point in 1906 of 4 MgC in use and 3 MgC in the SWDS for a total of 7 MgC, to the high point in 1914 of 1,454 MgC in use and 1,124 MgC in the SWDS for a total of 2,578 MgC (fig. 34). Average carbon storage experienced a short downward trend after 1929, hitting the global minimum in 1932 with 267 MgC in use and 206 MgC in the SWDS for a total of 473 MgC. After 1932, average carbon storage experienced positive growth at an exponential rate with a moderate amount of inter-annual variability until reaching the global maximum in 1968 with 17,729 MgC in use and 16,346 MgC in the SWDS for a total of 34,075 MgC. Average carbon storage in HWP began to rapidly decline after 1968 with moderate inter-annual variability until hitting a local minimum in 1976, with 1,625 MgC in use and 1,510 MgC in the SWDS for a total of 3,135 MgC. After 1976, average carbon storage experienced moderate inter-annual variability, averaging about a total of 8,400 MgC until 1983 when net stock change sharply increased, hitting a local maximum with 14,478 MgC in use and 12,765 MgC in the SWDS for a total of 27,243 MgC. Carbon stores rapidly decreased after 1983 at a declining rate while experiencing moderate inter-annual variability until hitting a local minimum in 1998 with 839 MgC in use and 832 MgC in the SWDS for a total of 1,671 MgC. After 1998, carbon storage continued to experience some inter-annual variability, averaging about a total of 2,500 MgC per year, and ending in 2009 with 1,284 MgC in use and 1,426 MgC in the SWDS for a total of 2,710 MgC (tables 28, 29).

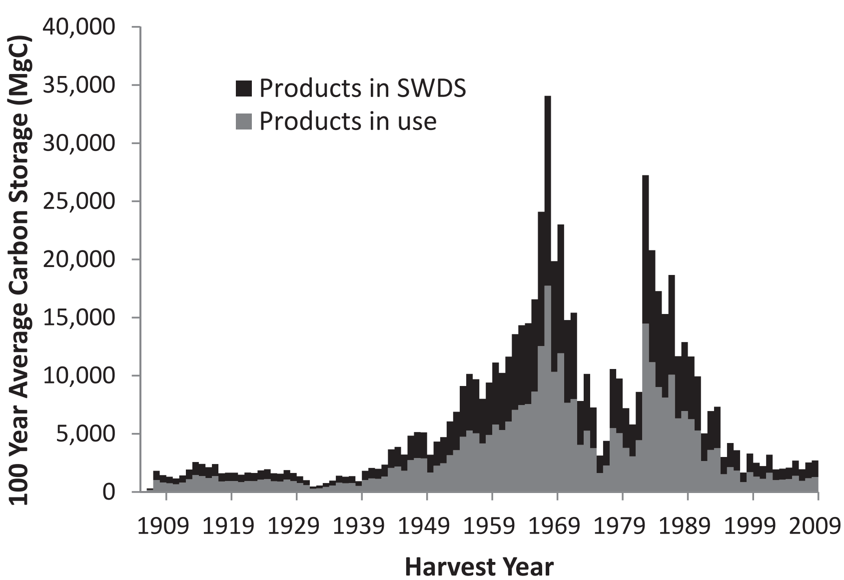

Figure 34—Gallatin National Forest harvest 100-year average carbon HWP storage using the California Forest Project Protocol.

Table 28—Gallatin National Forest 100-year average carbon stored in HWP for selected years.

Harvest year	Products in use[a]	Landfills and dumps[b]	Total
	- - - - - - - - (MgC) - - - - - - - -		
1910	736	568	1,304
1920	938	724	1,662
1930	759	586	1,345
1940	1,025	791	1,816
1950	1,670	1,539	3,209
1960	5,795	5,343	11,138
1970	11,927	11,089	23,016
1980	3,786	3,423	7,209
1990	6,254	5,402	11,656
1995	1,524	1,481	3,005
2000	1,305	1,209	2,514
2005	1,102	991	2,093
2006	1,384	1,313	2,697
2007	954	1,005	1,959
2008	1,174	1,365	2,539
2009	1,284	1,426	2,710

[a] The 100-year average carbon storage in products in use for the harvest year.
[b] The 100-year average carbon storage in SWDS for the harvest year.

Table 29—Gallatin National Forest confidence intervals for cumulative carbon in HWP for selected years for harvests beginning in 1906.

Inventory year	Total remaining in HWP pool	90% Confidence interval (% difference from estimate) 5%	95%
	- - - - - - - - (MgC) - - - - - - - -		
1910	4,606	2,705	6,825
1920	26,452	15,263	40,015
1930	42,160	23,894	66,002
1940	46,622	27,716	71,281
1950	79,991	48,916	119,858
1960	164,748	104,587	235,381
1970	361,126	233,158	515,904
1980	422,117	271,082	605,992
1990	555,453	397,627	738,048
1995	571,062	418,582	749,517
2000	553,355	417,961	718,013
2005	534,838	397,618	689,901
2006	531,212	392,935	683,074
2007	528,773	395,603	679,503
2008	525,267	393,249	676,940
2009	522,889	397,150	678,510
2010	520,840	395,317	668,467

Helena National Forest

Description

The Helena National Forest is located in west-central Montana, approximately 80 miles east of the Idaho-Montana border, and 130 miles south of the Canadian border (fig. 35). The forest is approximately 80 miles from east to west, and 60 miles from north to south with non-Federal holdings throughout the area. The forest is bordered by the Lolo and Lewis and Clark National Forests as well as privately held lands to the north, privately held lands to the east, the Gallatin National Forest to the southeast, the Beaverhead-Deerlodge National Forest as well as privately held lands to the south, privately held lands to the west, and the Lolo National Forest to the northwest. The Helena National Forest was established on April 12, 1906. On July 1, 1908, additional lands were added to the forest from the Big Belt National Forest as well as the entire Elkhorn National Forest (Davis 1983).

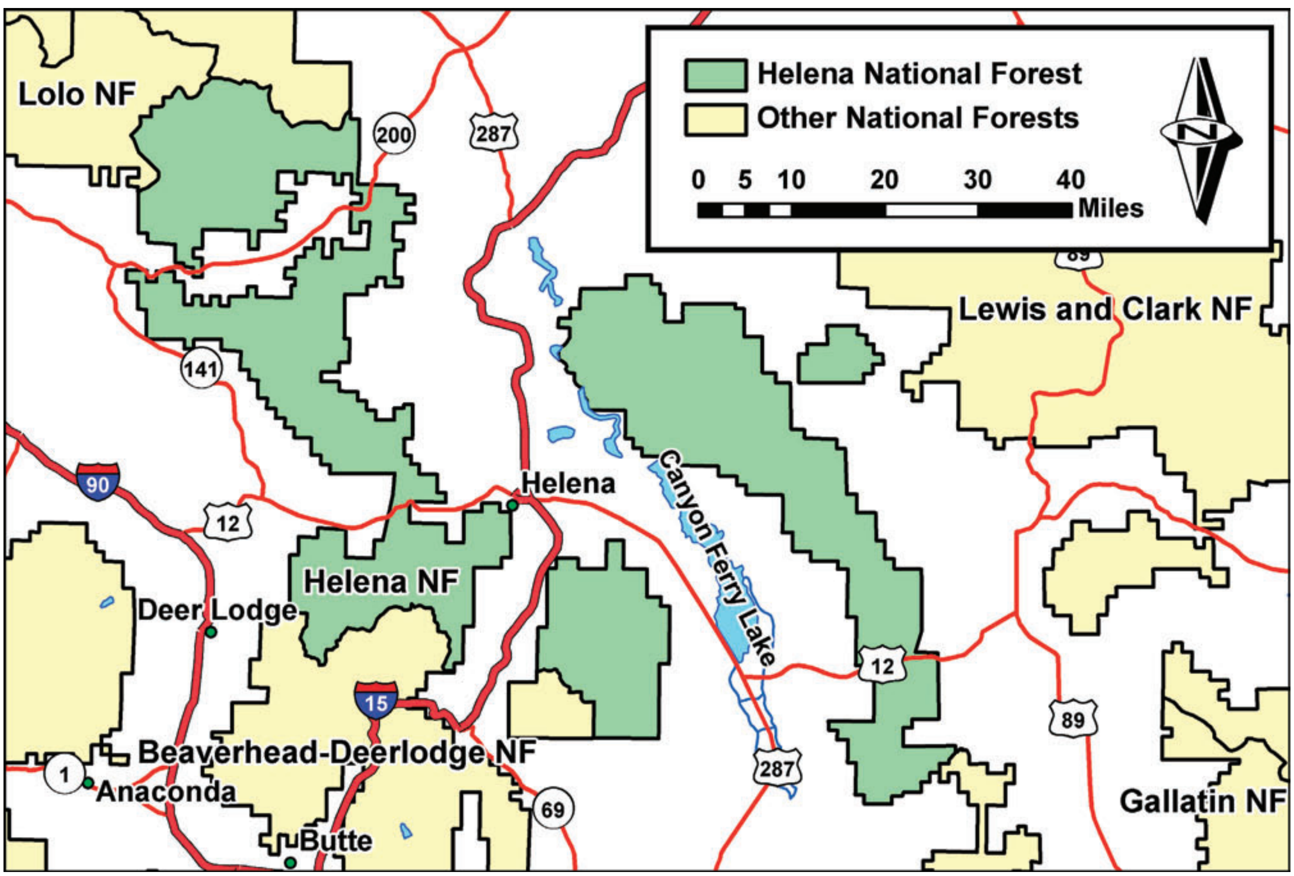

Figure 35—Location map of Helena National Forest.

The Helena National Forest is 975,402 acres and contains over 33 unique forest habitat types that have been categorized into 13 northern region biophysical habitat type groups (Wilson 2001). The most common habitat classification is cool and dry and covers 18 percent of the forest, followed by the classification of warm and very dry covering 16 percent, and cool and moderately dry covering 12 percent. Lodgepole pine and Douglas-fir are successful forest types at all elevations, but due to higher elevations being associated with increased precipitation and lower temperatures, ponderosa pine forest types are successful in lower elevations, while whitebark pine is successful at higher elevations (Wilson 2001). The forest is 93 percent forested, leaving the remaining 7 percent either non-forested or water. Eleven percent of the forested lands are protected under reserves in the Scapegoat and Gates of the Mountains Wilderness areas, while 31 percent of non-reserved lands are considered suitable for timber production. The net annual growth of all forested lands is estimated to be 20.2 million cubic feet (Wilson 2001). Forest cover is 41 percent Douglas-fir, 39 percent lodgepole pine, 9 percent spruce-fir, 5 percent whitebark pine, 5 percent ponderosa pine, and 1 percent Engelmann spruce (Wilson 2001). Stands of old growth forest are also present, estimated to cover 12.2 percent of the forested area (USDA 2011a, p 75).

Natural disturbances within the Helena National Forest are tree disease, weather damage, insect infestation including significant impacts from Douglas-fir and mountain pine beetle activity, and fire (Rothermel 1993; USDA 2008b; Wilson 2001). Between 1996 and 1997, it was estimated that 51 percent of tree mortality in the forest was the result of disease, 17 percent was due to weather damage, and 11 percent was contributed to insect damage, resulting in net negative growth for Engelmann spruce with 68 percent of tree mortality due to disease (Wilson 2001). Large fires within the Big Belt Mountains in 2000 led to an increase in Douglas-fir bark beetle activity in the area that has since declined, but is still observable in tree populations with budworm. Endemic levels of budworm can be seen across much of the forest, with concentrations in the Big Belt Mountains as well as Flesher Pass. Budworm levels become epidemic in 20-year cycles and are best regulated with late spring and early fall frosts (USDA 2008b). The mountain pine beetle is also active on the forest with infected acreage increasing from 14,000 acres in 2004 to an estimated 380,000 acres in 2008, with infected timber being detected in higher elevations and latitudes (USDA 2008b). A partial aerial survey of the forest showed that 575,960 acres were infected with mountain pine beetle in 2009, but decreased to 370,701 acres in 2010 and 193,767 acres in 2011, mostly occurring in lodgepole and ponderosa pine for all 3 years (USDA 2012b, p 45).

Fire disturbances that continue to shape the forest are the recent fires in 2000 as well as the historic fires of 1949, which included the Mann Gulch Fire where 13 firefighters lost their lives (Rothermel 1993; USDA 2008b). Within the forest, 28 percent of plots show no visible signs of disturbances, 28 percent show signs of disease, 19 percent show evidence of fire, 10 percent show evidence of cutting, 7 percent show evidence of wind or weather damage, 3 percent show signs of insect damage, and 5 percent show signs of animal damage (Wilson 2001).

Harvest Trends

From 1906 to 1929, timber production averaged 2,300 MgC per year before beginning a downward trend (fig. 36). Starting at the global minimum of 683 MgC in 1932, annual timber production began to grow exponentially with some inter-annual variability until hitting a local maximum of 45,105 MgC in 1968. Timber production was at 43,024 MgC in 1969 before rapidly declining until hitting a local minimum of 2,608 MgC in 1972. Following 1972, production sharply increased for 2 years, hitting a local maximum in 1974 of 42,510 MgC, before sharply decreasing in 1975 and hitting a local minimum of 5,700 MgC in 1978. From 1979 to 1984, production began to increase with some inter-annual variability until sharply rising to the global maximum in 1985 of 83,070 MgC. Production rapidly declined after 1985 with high inter-annual variability until hitting a local minimum of 2,454 MgC in 2000. After 2000, production averaged 8,500 MgC per year, hitting a local maximum of 13,784 MgC in 2003, and ending in 2009 with 8,809 MgC in production.

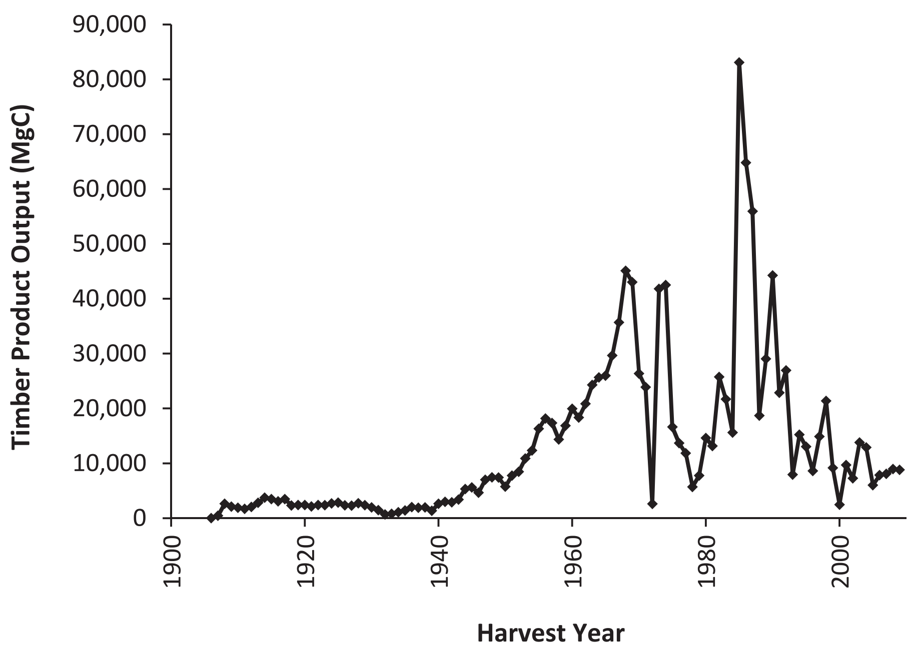

Figure 36—Annual timber product output for Helena National Forest, 1906 to 2010.

Carbon in Harvested Wood Products

Starting in 1907, total carbon storage in HWP grew linearly until flattening out in 1931 with 24,114 MgC in use and 5,305 MgC in the SWDS for a total of 29,419 MgC (fig. 37). After 1940, carbon storage began to grow exponentially until 1970 with 188,794 MgC in use and 49,033 MgC in the SWDS for a total of 237,827 MgC. Following 1970, carbon storage continued to grow at a slower pace until hitting a local maximum in 1972 with 198,371 MgC in use and 55,579 MgC in the SWDS for a total of 253,950 MgC, followed by a local minimum in 1973 with 191,307 MgC in use and 57,145 MgC in the SWDS for a total of 248,452 MgC. Carbon storage grew at a decreasing rate from 1974 to 1977 before beginning to decline in 1978, hitting a local minimum in 1980 with 209,319 MgC in use and 73,452 MgC in the SWDS for a total 282,771 MgC. After 1980, carbon storage began to slowly increase with some inter-annual variability until 1986 when carbon storage sharply increased, hitting a local maximum in 1993 with 334,238 MgC in use and 132,059 MgC in the SWDS for a total 466,297 MgC. Carbon storage averaged 464,000 MgC after 1993 until hitting the global maximum in 1999 with 320,245 MgC in use and 151,146 MgC in the SWDS for a total of 471,391 MgC. Following 1992, carbon storage began to decline at a variable rate with the exception of carbon storage gains from 2004 to 2005, ending in 2010 with 286,522 MgC in use and 170,745 MgC in the SWDS for a total of 457,267 MgC remaining in total carbon storage (table 30).

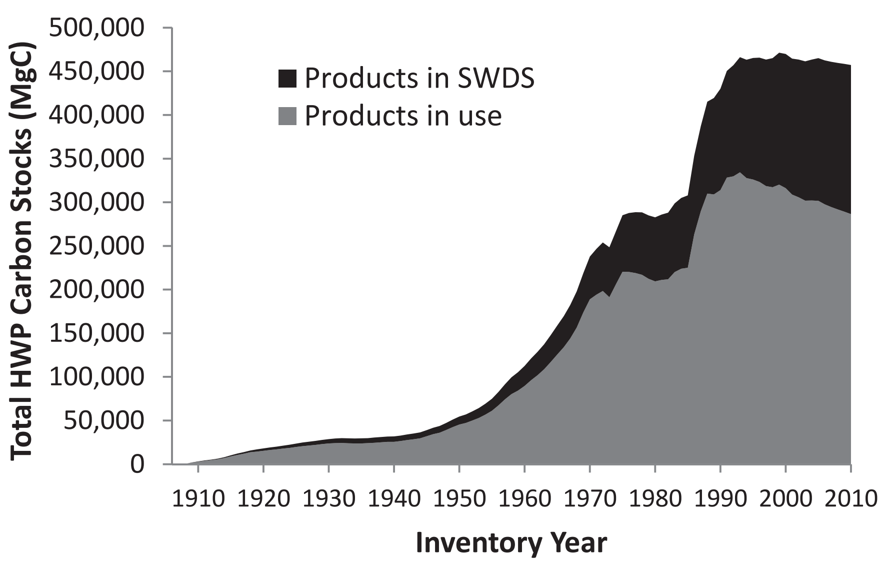

Figure 37—Cumulative total carbon stored in HWP manufactured from Helena National Forest timber.

Table 30—Helena National Forest cumulative disposition of HWP carbon for selected years. This table shows the fate of all carbon removed from the ecosystem by harvesting.

Inventory year	Emitted with energy capture	Emitted without energy capture	Products in use	SWDS	Total remaining in HWP pool[a]
	(MgC)				
1910	1,868	149	2,855	289	3,144
1920	11,595	2,385	15,395	2,663	18,058
1930	20,454	7,279	23,668	5,112	28,781
1940	25,735	13,544	25,628	6,199	31,827
1950	43,563	22,196	45,475	9,132	54,607
1960	91,553	44,468	89,529	22,938	112,467
1970	199,600	99,523	188,794	49,033	237,827
1980	271,831	175,059	209,319	73,452	282,772
1990	394,527	247,425	313,965	116,082	430,046
1995	434,350	289,636	326,088	139,144	465,232
2000	459,161	327,187	316,129	153,759	469,888
2005	476,872	360,370	301,655	163,385	465,040
2006	479,163	366,616	297,576	164,943	462,519
2007	482,482	372,727	294,468	166,455	460,923
2008	485,927	378,686	291,675	167,919	459,595
2009	490,137	384,502	289,154	169,356	458,510
2010	494,531	390,160	286,522	170,745	457,267

[a] Sum of products in use and SWDS.

From 1907 to 1929, net stock change averaged 1,000 MgC ranging from a low point in 1907 of 6 MgC in use and 0 MgC in the SWDS for a total of 6 MgC, to the high point in 1915 of 1,881 MgC in use and 278 MgC in the SWDS for a total of 2,159 MgC (fig. 38). After 1929, net stock change began to decline until hitting a local minimum in 1933 with –267 MgC in use and 104 MgC in the SWDS for a net negative change in carbon stocks (emissions) of –163 MgC. Following 1933, net stock change experienced positive growth at an exponential rate with

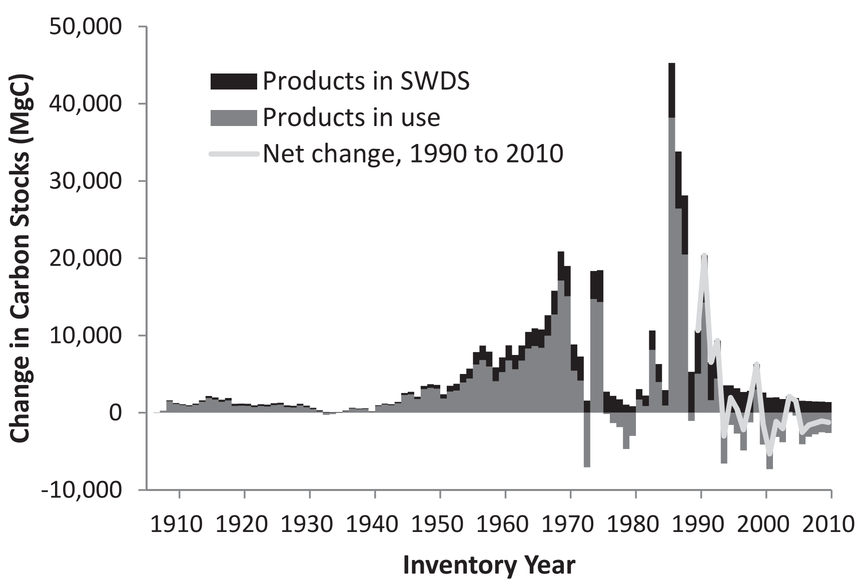

Figure 38. Helena National Forest net change in carbon stocks in HWP from the previous year.

a moderate amount of inter-annual variability until hitting a local maximum in 1969 with 17,101 MgC in use and 3,776 MgC in the SWDS for a total of 20,877 MgC. In 1970 net additions totaled 19,000 MgC before rapidly declining, hitting the global minimum in 1973 with –7,064 MgC in use and 1,565 MgC in the SWDS for a total net stock change of –5,499 MgC. The following year in 1974, net stock change sharply increased, hitting a local maximum in 1975 with 14,321 MgC in use and 4,132 MgC in the SWDS for a total of 18,453 MgC. Net stock change sharply decreased in 1976 until hitting a local minimum in 1979 with –4,684 MgC in use and 1,050 MgC in the SWDS for a total of –3,634 MgC. From 1980 to 1985, net stock change increased with a moderate amount of inter-annual variability, hitting a local maximum in 1983 before sharply increasing in 1986, hitting the global maximum with 38,180 MgC in use and 7,092 MgC in the SWDS for a total net stock change of 45,272 MgC. Net stock change rapidly declined after 1986 with high inter-annual variability, first showing signs of net negative growth in 1994 with –6,566 MgC in use and 3,546 MgC in the SWDS for a total of –3,020. After 1994 net stock change averaged about –2,500 MgC per year, hitting a local maximum in 1999 with 2,987 MgC in use and 3,295 MgC in the SWDS for a total of 6,282 MgC, a local minimum in 2001 with –7,301 MgC in use and 1,971 MgC in the SWDS for a total of –5,330 MgC, and ending in 2010 with –2,632 MgC in use and 1,388 MgC in the SWDS for a total of –1,244 MgC (table 31).

Table 31—Helena National Forest annual net change in HWP carbon stocks for selected years for harvests beginning in 1906.

Inventory year	Stock change[a] (MgC yr^{-1})
1910	1,261
1920	1,175
1930	917
1940	194
1950	3,609
1960	7,165
1970	19,000
1980	-2,141
1990	10,651
1995	1,955
2000	-1,503
2005	1,545
2006	-2,521
2007	-1,596
2008	-1,328
2009	-1,084
2010	-1,244

[a] Net annual change in carbon in products in use and SWDS.

The 100-year average carbon storage was about 1,100 MgC from 1906 to 1929 ranging from a low point in 1906 of 3 MgC in use and 2 MgC in the SWDS for a total of 5 MgC, to the high point in 1914 of 993 MgC in use and 767 MgC in the SWDS for a total of 1,760 MgC (fig. 39). Following 1929, average carbon storage experienced a short downward trend, hitting the global minimum in 1932 with 182 MgC in use and 141 MgC in the SWDS for a total of 323 MgC. After 1932, average carbon storage experienced positive growth at an exponential rate with a moderate amount of inter-annual variability until reaching a local maximum in 1968 with 8,953 MgC in use and 8,255 MgC in the SWDS for a total of 17,208 MgC. Total average carbon storage in HWP was 16,414 MgC in 1969 before rapidly declining, hitting a local minimum in 1972 with 515 MgC in use and 479 MgC in the SWDS for a total of 994 MgC. Average carbon storage sharply increased in 1973, hitting a local maximum in 1974 with 8,389 MgC in use and 7,799 MgC in the SWDS for a total of 16,188 MgC. In 1975, average carbon storage sharply decreased, hitting a local minimum in 1978 with 1,125 MgC in use and 1,046 MgC in the SWDS for a total of 2,171 MgC. From 1979 to 1984, carbon storage increased experiencing a moderate amount of inter-annual variability with a local maximum in 1982, before sharply increasing and hitting the global maximum in 1985 with 17,105 MgC in use and 15,617 MgC in the SWDS for a total of 32,722 MgC. Following 1985, carbon storage rapidly declined with high inter-annual variability until 1993 with 1,652 MgC in use and 1,526 MgC in the SWDS for a total of 3,178 MgC. After 1993 carbon storage averaged about 3,500 MgC, hitting a local maximum in 1998 with 4,067 MgC in use and 4,032 MgC in the SWDS for a total of 8,099 MgC, a local minimum in 2000 with 469 MgC in use and 434 MgC in the SWDS for a total of 903 MgC, and ending in 2009 with 1,309 MgC in use and 1,455 MgC in the SWDS for a total of 2,764 MgC (tables 32, 33).

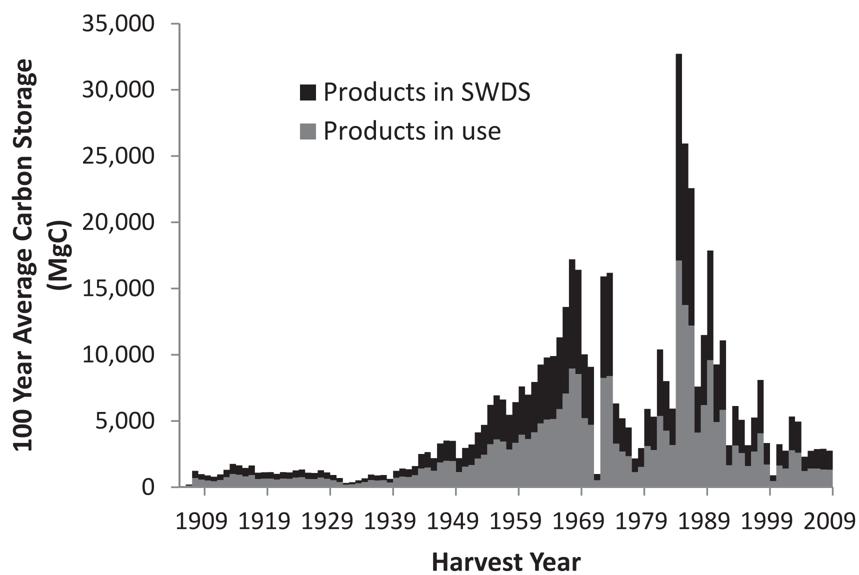

Figure 39—Helena National Forest harvest 100-year average carbon HWP storage using the California Forest Project Protocol.

Table 32—Helena National Forest 100-year average carbon stored in HWP for selected years.

Harvest year	Products in use[a]	Landfills and dumps[b]	Total
	- - - - - - - -	(MgC)	- - - - - - - -
1910	502	388	891
1920	640	494	1,134
1930	518	400	918
1940	699	540	1,240
1950	1,140	1,051	2,191
1960	3,956	3,647	7,603
1970	5,202	4,836	10,038
1980	3,104	2,807	5,911
1990	9,587	8,281	17,868
1995	2,578	2,505	5,083
2000	469	434	903
2005	1,213	1,091	2,304
2006	1,411	1,338	2,750
2007	1,400	1,475	2,875
2008	1,340	1,558	2,898
2009	1,309	1,455	2,764

[a] The 100-year average carbon storage in products in use for the harvest year.
[b] The 100-year average carbon storage in SWDS for the harvest year.

Table 33—Helena National Forest confidence intervals for cumulative carbon in HWP for selected years for harvests beginning in 1906.

Inventory year	Total remaining in HWP pool	90% Confidence interval (% difference from estimate) 5%	95%
	- - - - - - - -	(MgC)	- - - - - - - -
1910	3,144	1,846	4,658
1920	18,058	10,420	27,317
1930	28,781	16,312	45,057
1940	31,827	18,921	48,661
1950	54,607	33,393	81,823
1960	112,467	71,398	160,685
1970	237,827	153,551	339,759
1980	282,772	181,595	405,948
1990	430,046	307,853	571,415
1995	465,232	341,010	610,616
2000	469,888	354,916	609,709
2005	465,040	345,728	599,867
2006	462,519	342,123	594,743
2007	460,923	344,841	592,312
2008	459,595	344,083	592,305
2009	458,510	348,252	594,970
2010	457,267	347,065	586,875

Idaho Panhandle National Forest

Description

The Idaho Panhandle National Forest is located in northwestern Montana, northern Idaho, and northeastern Washington (fig. 40). The forest is approximately 80 miles from east to west and 150 miles from north to south, with non-Federal holdings throughout the area including the Kootenai and Coeur d'Alene Reservations. The forest is bordered by Canada to the north, the Kootenai and Lolo National Forests to the east, the Nez Perce-Clearwater National Forest as well as privately held lands to the south, and the Colville National Forest as well as some privately held lands to the west.

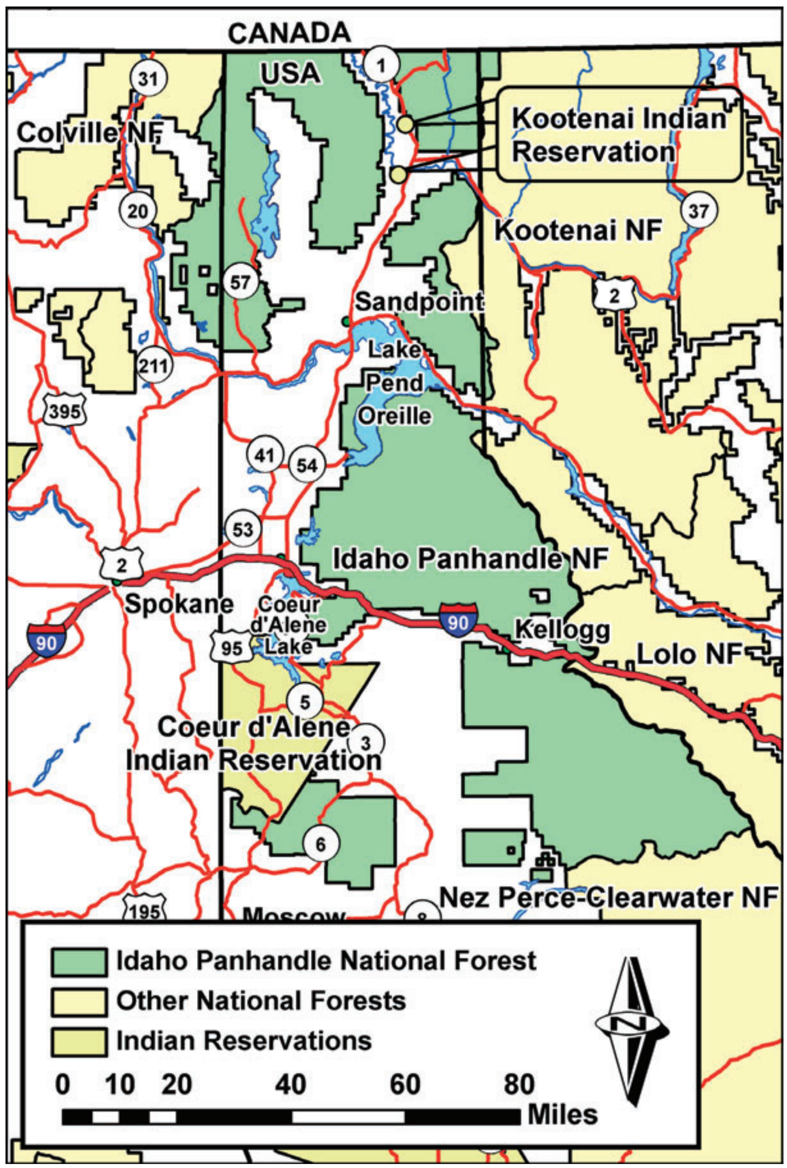

Figure 40—Location map of Idaho Panhandle National Forest.

The Kanisku National Forest was established from part of the Priest River National Forest on July 1, 1908. On September 30, 1933, additional lands were added from the Pend Oreille National Forest, followed by the addition of a portion of the Cabinet National Forest on July 1, 1954. On July 1, 1973, the forest was administratively combined with the Coeur d'Alene and St. Joe National Forests and has since been known as the Idaho Panhandle National Forest (Davis 1983).

The Idaho Panhandle National Forest is 2,500,700 acres with 2,351,100 acres in Idaho, 118,400 acres in Washington, and 31,200 acres in Montana. The forest is one of the most diverse and productive forests in Region 1 due to the combination of climate and volcanic ash-capped soils (USDA 2011b, p 6). The most common habitat type occurs between 1,500 feet and 5,500 feet, covering approximately 58 percent of the forested area (USDA 1987, p A-3). It contains shade tolerant and moisture dependent forest types like western hemlock and western redcedar, as well as other forest types like grand fir, subalpine fir, Engelmann spruce, western whitepine, lodgepole pine and Douglas fir (USDA 1987, p A-3). The second most common habitat group occurs between 1,800 feet and 6,000 feet, covering an estimated 21 percent of the forest under a broad range of habitat types (USDA 1987, p A-6). Douglas fir and ponderosa pine inhabit areas with warmer weather, while spruce and lodgepole pine inhabit areas that are colder. Western larch and lodgepole pine can also be found in this habitat group in areas that have experienced fire activity (USDA 1987, p A-6). The third most common habitat group covers 14 percent of the forest and is known as the subalpine zone, containing ponderosa pine and Engelmann spruce (USDA 1987, p A-8). The forest contains 2,470,395 acres of forested land and 8,082 acres of land that are either non-forested or water (USDA 1987, p A-1). Within the forested area 9,900 acres are protected under reserves in the Salmo-Priest Wilderness, while 1,584,163 acres of non-reserved lands are considered suitable for timber production (USDA 2011b, p 42; USDA 1987, p A-1). The net annual growth of all forested lands is estimated to be over 129 million cubic feet (USDA 1987, p A-11). Stands of old growth forest are also present on the Idaho Panhandle National Forest, estimated to cover 11.8 percent of forested lands (USDA 2009c, p 3).

Natural disturbances within the Idaho Panhandle National Forest are insect infestation including significant impacts from mountain pine beetle activity, as well as disease and historic forest fires (Harkins and others 1999; USDA 2009c). An aerial survey conducted in 2009 detected approximately 190,000 acres of timber infested with mountain pine beetle, mostly occurring in lodgepole pine (USDA 2009c, p 17). In that same year 403,000 acres of timber were detected with western spruce budworm, leaving infested trees susceptible to mortality through other diseases or infestations (USDA 2009c, p 17). Other diseases present are root disease found in the northern portion of the forest and affecting two million acres, as well as white pine blister rust that can be found throughout the forest, resulting in the mortality of 21,500 acres of timber that were detected by aerial survey in 2009 (USDA 2009c, p 17). Other disturbances that continue to shape the forest include the historic fires of 1910, 1931, and 1967, the first of which devastated three million acres (Harkins and others 1999).

Harvest Trends

Idaho Panhandle National Forest is among the top five timber producing national forests in the Northern Region (fig. 9). From 1906 to 1929, timber production averaged about 55,000 MgC per year before beginning a downward trend (fig. 41). Starting at the global minimum of 15,199 MgC in 1932, annual timber production began to grow exponentially, with some inter-annual variability until 1968 when timber production hit the global maximum at 819,846 MgC. Following 1968, timber production began to rapidly decline until 1971 when production leveled off for 3 years averaging 574,675 MgC per year from 1971 to 1973. Production sharply declined after 1973 hitting a local minimum in 1974 of 268,499 MgC. From 1975 to 1992, production averaged 397,422 MgC per year with a local maximum of 472,057 MgC in 1977, a local minimum of 238,715 MgC in 1982, and ending with 386,907 MgC in production in 1992. From 1992 to 2003, production began to rapidly decrease at a declining rate with some isolated inter-annual variability present from 1997 to 2002, ending in 2003 with 79,491 MgC in production. Production continued to slowly decline after 2003, ending in 2009 with 29,870 MgC in production.

Carbon in Harvested Wood Products

Starting in 1907 total carbon storage in HWP grew linearly until flattening out in 1931with 536,420 MgC in use and 118,015 MgC in the SWDS for a total of 654,435 MgC (fig. 42). After 1940, carbon storage began to grow exponentially until 1969 with 3,682,070 MgC in use and 980,051 MgC in the SWDS for a total of 4,662,121 MgC. Following 1969, carbon storage continued to grow at a rapid rate until 1974 with 4,472,275 MgC in use and 1,323,435 MgC in the

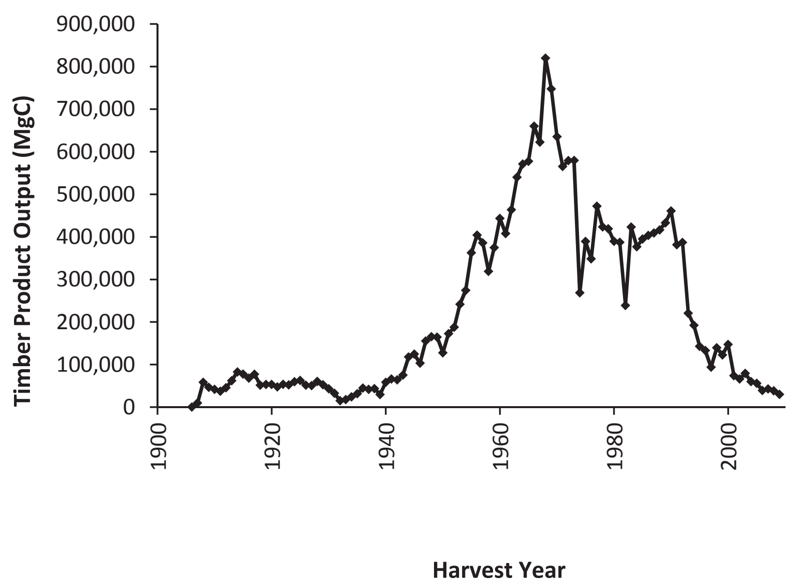

Figure 41—Annual timber product output for Idaho Panhandle National Forest, 1906 to 2010.

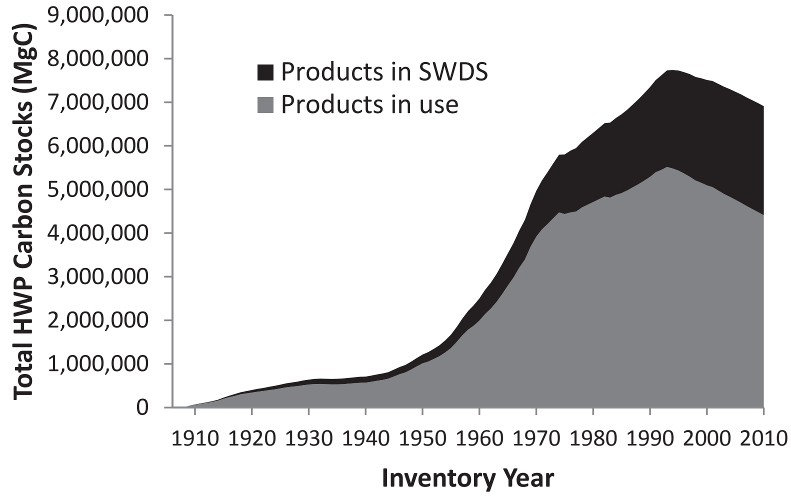

Figure 42—Cumulative total carbon stored in HWP manufactured from Idaho Panhandle National Forest timber.

SWDS for a total of 5,795,710 MgC. After a small gain of 8,931 MgC in 1975, carbon storage continued to quickly increase until hitting the global maximum in 1994 with 5,478,732 MgC in use and 2,259,034 MgC in the SWDS for a total of 7,737,766 MgC. Carbon storage began to decline in 1994 at a slow, steady rate ending in 2010 with 4,408,154 MgC in use and 2,501,519 MgC in the SWDS for a total of 6,909,673 MgC remaining in total carbon storage (table 34).

Table 34—Idaho Panhandle National Forest cumulative disposition of HWP carbon for selected years. This table shows the fate of all carbon removed from the ecosystem by harvesting.

Inventory year	Emitted with energy capture	Emitted without energy capture	Products in use	SWDS	Total remaining in HWP pool[a]
			(MgC)		
1910	41,556	3,322	63,513	6,428	69,941
1920	257,946	53,052	342,473	59,236	401,709
1930	455,004	161,932	526,512	113,730	640,242
1940	572,487	301,297	570,103	137,898	708,001
1950	969,086	493,753	1,011,607	203,145	1,214,752
1960	2,036,645	989,216	1,991,621	510,258	2,501,879
1970	4,228,865	2,183,121	3,918,444	1,050,064	4,968,507
1980	5,982,914	3,779,315	4,710,477	1,587,575	6,298,052
1990	7,364,974	5,219,682	5,288,082	2,060,105	7,348,187
1995	7,922,727	5,923,498	5,433,577	2,295,122	7,728,699
2000	8,156,892	6,540,288	5,094,803	2,414,647	7,509,451
2005	8,321,016	7,072,294	4,762,356	2,477,910	7,240,265
2006	8,342,347	7,168,479	4,693,697	2,485,059	7,178,756
2007	8,358,904	7,261,121	4,618,228	2,490,414	7,108,642
2008	8,377,179	7,350,599	4,548,679	2,495,054	7,043,733
2009	8,395,328	7,436,896	4,479,059	2,498,771	6,977,831
2010	8,410,227	7,520,024	4,408,154	2,501,519	6,909,673

[a] Sum of products in use and SWDS.

From 1907 to 1929, net stock change averaged about 26,000 MgC ranging from a low point in 1907 of 124 MgC in use and 11 MgC in the SWDS for a total of 135 MgC, to the high point in 1915 of 41,837 MgC in use and 6,183 MgC in the SWDS for a total of 48,020 MgC (fig. 43). After 1929, net stock change began to decline until hitting a local minimum in 1933 with –5,948 MgC in use and 2,318 MgC in the SWDS for a net negative change in carbon stocks (emissions) of –3,630 MgC. Following 1933, net stock change experienced positive growth at an exponential rate with a moderate amount of inter-annual variability until hitting the global maximum in 1969 with 289,184 MgC in use and 70,494 MgC in the SWDS for a total of 359,678 MgC. After 1969, net additions rapidly declined until 1972 when net additions leveled off for 3 years, averaging 196,520 MgC per year from 1972 to 1974. After 1974, net additions sharply decreased, hitting a local minimum in 1975 with –36,585 MgC in use and 45,516 MgC in the SWDS for a total net stock change of 8,931 MgC. From 1976 to 1993, total net stock change averaged 107,113 MgC per year, with a local minimum in 1983 with –24,071 MgC in use and 37,349 MgC in the SWDS for a total of 13,278 MgC, a local maximum in 1991 with 105,094 MgC in use and 55,050 MgC in the SWDS for a total net stock change of 160,144 MgC, and ending in 1993 with 63,451 MgC in use and 51,649 MgC in the SWDS for a total of 115,100 MgC. In 1994, net stock change sharply decreased with –35,781 MgC in use and 40,873 MgC in the SWDS for a total of 5,091, followed by the first signs of sustained net negative growth in 1995 with –45,155 MgC in use and 36,089 MgC in the SWDS for a total net negative growth of –9,067 MgC. From 1996 to 2010, net additions continued to decline with some isolated inter-annual variability between 1998 and 2003, a local maximum in 2001 with –41,260 MgC

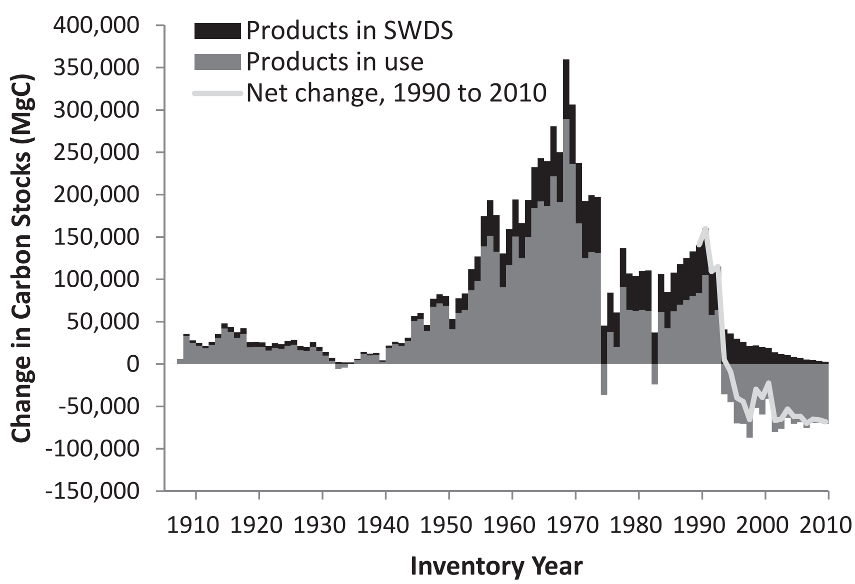

Figure 43—Idaho Panhandle National Forest net change in carbon stocks in HWP from the previous year.

in use and 18,899 MgC in the SWDS for a total of –22,361 MgC, the global minimum in 2007 with –75,468 MgC in use and 5,354 MgC in the SWDS for a total of –70,114 MgC, and ending in 2010 with –70,906 MgC in use and 2,748 MgC in the SWDS for a total of –68,158 MgC (table 35).

From 1906 to 1929, the 100-year average carbon storage averaged about 26,000 MgC ranging from a low point in 1906 of 59 MgC in use and 45 MgC in the SWDS for a total of 104 MgC, to the high point in 1914 of 22,085 MgC in use and 17,059 MgC in the SWDS for a total of 39,144 MgC (fig. 44). Average carbon storage experienced a short downward trend following 1929, hitting the global minimum in 1932 with 4,051 MgC in use and 3,129 MgC in the SWDS for a total of 7,180 MgC. After 1932, average carbon storage experienced positive growth at an exponential rate with a moderate amount of inter-annual variability until reaching the global maximum in 1968 with 162,730 MgC in use and 150,043 MgC in the SWDS for a total of 312,773 MgC. Following 1968, average carbon storage in HWP began to rapidly decline until 1971 when total average storage leveled off for 3 years, averaging 218,846 MgC per year from 1971 to 1973. Average carbon storage sharply declined after 1973 hitting a local minimum in 1974 with 52,987 MgC in use and 49,262 MgC in the SWDS for a total of 102,249 MgC. From 1975 to 1992, total carbon storage averaged 156,392 MgC per year, with a local minimum in 1982 with 49,894 MgC in use and 46,623 MgC in the SWDS for a total of 96,517 MgC, a local maximum in 1990 with 99,821 MgC in use and 86,230 MgC in the SWDS for a total of

Table 35—Idaho Panhandle National Forest annual net change in HWP carbon stocks for selected years for harvests beginning in 1906.

Inventory year	Stock change[a] (MgC yr^{-1})
1910	28,044
1920	26,133
1930	20,393
1940	4,323
1950	80,274
1960	159,397
1970	306,386
1980	104,234
1990	140,678
1995	-9,067
2000	-39,509
2005	-62,151
2006	-61,509
2007	-70,114
2008	-64,909
2009	-65,902
2010	-68,158

[a] Net annual change in carbon in products in use and SWDS.

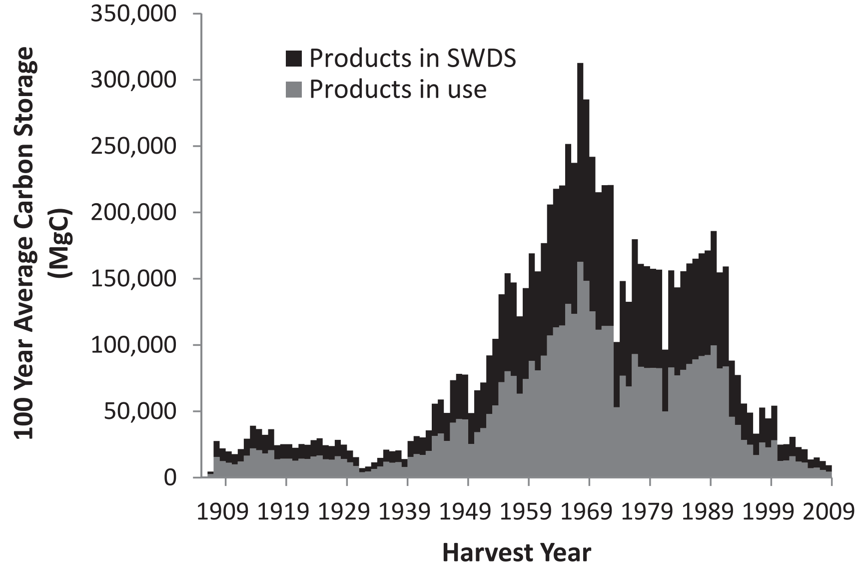

Figure 44—Idaho Panhandle National Forest harvest 100-year average carbon HWP storage using the California Forest Project Protocol.

186,051 MgC, and ending in 1992 with 83,853 MgC in use and 75,398 MgC in the SWDS for a total of 159,251 MgC. From 1992 to 2003, carbon storage began to rapidly decrease at a declining rate with some isolated inter-annual variability present from 1997 to 2002, ending in 2003 with 16,051 MgC in use and 14,693 MgC in the SWDS for a total of 30,744 MgC. After 2003, carbon storage continued to decline at a slow rate, ending in 2009 with 4,440 MgC in use and 4,932 MgC in the SWDS for a total of 9,372 MgC (tables 36, 37).

Table 36—Idaho Panhandle National Forest 100-year average carbon stored in HWP for selected years.

Harvest year	Products in use[a]	Landfills and dumps[b]	Total
	- - - - - - - - - - - - - - - (*MgC*)	- - - - - - - - - - - - - -	
1910	11,177	8,633	19,810
1920	14,238	10,998	25,236
1930	11,522	8,900	20,422
1940	15,560	12,019	27,578
1950	25,354	23,377	48,732
1960	87,999	81,138	169,137
1970	125,400	116,584	241,984
1980	82,747	74,814	157,561
1990	99,821	86,231	186,051
1995	28,309	27,507	55,816
2000	28,156	26,068	54,224
2005	11,291	10,157	21,448
2006	7,041	6,678	13,719
2007	7,428	7,827	15,255
2008	5,776	6,717	12,493
2009	4,440	4,933	9,372

[a] The 100-year average carbon storage in products in use for the harvest year.
[b] The 100-year average carbon storage in SWDS for the harvest year.

Table 37—Idaho Panhandle National Forest confidence intervals for cumulative carbon in HWP for selected years for harvests beginning in 1906.

Inventory year	Total remaining in HWP pool	90% Confidence interval (% difference from estimate) 5%	95%
	- - - - - - - -	*(MgC)*	- - - - - - - -
1910	69,941	41,070	103,632
1920	401,709	231,789	607,689
1930	640,242	362,859	1,002,309
1940	708,001	420,898	1,082,479
1950	1,214,752	742,843	1,820,176
1960	2,501,879	1,588,271	3,574,511
1970	4,968,507	3,207,873	7,098,002
1980	6,298,052	4,044,582	9,041,497
1990	7,348,187	5,260,284	9,763,764
1995	7,728,699	5,665,048	10,143,897
2000	7,509,451	5,672,044	9,743,985
2005	7,240,265	5,382,678	9,339,403
2006	7,178,756	5,310,094	9,231,004
2007	7,108,642	5,318,352	9,135,005
2008	7,043,733	5,273,395	9,077,640
2009	6,977,831	5,299,868	9,054,552
2010	6,909,673	5,244,439	8,868,157

Kootenai National Forest

Description

The Kootenai National Forest is located in the northwestern corner of Montana with its western border entering into the Idaho Panhandle in northeastern Idaho (fig. 45). The forest is approximately 65 miles from east to west and 100 miles from north to south, with non-Federal holdings throughout the area. The forest is bordered by Canada to the north, the Flathead National Forest as well as some private lands to the east, the Lolo National Forest to the south, and the Idaho Panhandle National Forest as well as some private lands to the west.

The Kootenai National Forest was established on August 13, 1906. On June 22, 1935, part of the Blackfeet National Forest was added, followed later by a final addition of part of the Cabinet National Forest on July 1, 1954 (Davis 1983).

The Kootenai National Forest is 2,246,495 acres with approximately 1,870,000 acres below 5,500 feet in elevation (USDA 2011c, p 4; Wilson and Miles 2000). The forest contains over 41 unique forest habitat types that have been categorized into 12 northern region biophysical habitat type groups, the most common of which is classified as moderately cool and moist and covers 26 percent of the forest. This habitat type is followed closely by moderately warm and dry covering 25 percent of the forest, and cool and moist covering 20 percent of the forest (Wilson and Miles 2000). Due to higher elevations being associated with increased precipitation and lower temperatures, Douglas-fir is the more successful forest type in lower elevations, while subalpine fir is more successful at higher elevations (Wilson and Miles 2000). The forest is 96 percent forested,

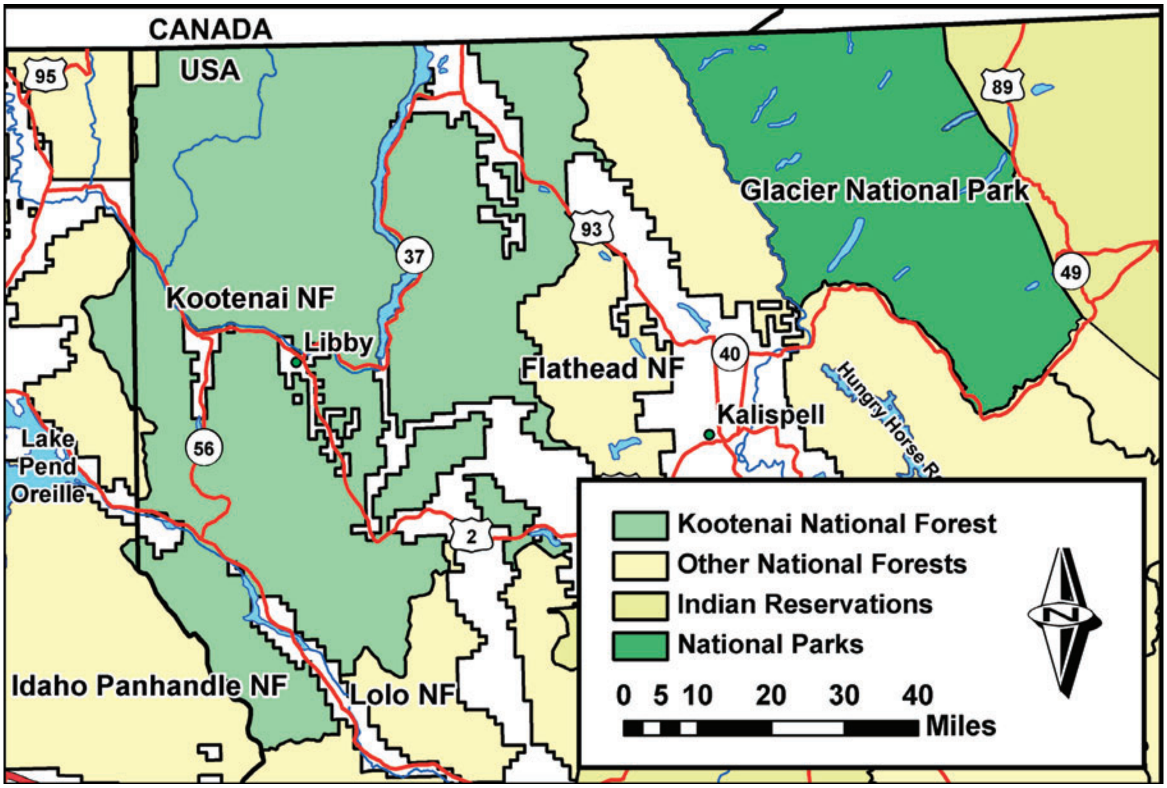

Figure 45—Location map of Kootenai National Forest.

leaving the remaining 4 percent either non-forested or water. Four percent of the forested lands are protected under reserves, all within the Cabinet Mountain Wilderness, and 60 percent of non-reserved lands are considered suitable for timber production. The net annual growth of all forested lands is estimated to be over 42.1 million cubic feet (Wilson and Miles 2000). Forest cover is 35 percent Douglas-fir, 17 percent lodgepole pine, 17 percent spruce-fir, 11 percent larch, 5 percent Engelmann spruce, 4 percent grand fir, as well as traces of western redceder, mountain hemlock, western hemlock, ponderosa pine, whitebark pine, and western whitepine (Wilson and Miles 2000). Stands of old growth forest are also present and estimated to cover 9 percent of the forest with good distribution across elevations (USDA 2011c, p 4).

Natural disturbances within the Kootenai National Forest are insect infestation including significant impacts from the mountain pine beetle, root disease, and forest fires (USDA 2012b, 2011d; Wilson and Miles 2000). From 1983 to 1996, 62 percent of tree mortality was due to infected timber from the mountain pine beetle, while disease and fires both accounted for 14 percent of the mortality (Wilson and Miles 2000). In total, 67 percent of tree mortality from 1983 to 1996 was experienced in lodgepole pine, with annual mortality exceeding annual growth (Wilson and Miles 2000). A partial aerial survey of the forest showed that mountain pine beetle infestations are declining with 46,181 acres infected in 2009, 12,097 acres in 2010, 16,217 acres in 2011, mostly occurring in lodgepole pine for all 3 years (USDA 2012b, p 45).

Other disturbances include root diseases (like armillaric and phellinus) and large fires. Root diseases are active pathogens on the forest, but have begun to kill fewer trees as the forest composition becomes less susceptible to infections (USDA 2011d, p 14). Large fires occurred in the 1880s, 1910, 1919,1920, 1931, 1958, 1973, 1991, 1994, and 2000 resulting in a vegetative composition that is widely diverse (USDA 2011d, p 75, 78, 81, 94). Within the forest, 29 percent of plots show no visible signs of disturbances, 33 percent show evidence of cutting, 10 percent show evidence of fire, 9 percent show signs of disease, 8 percent show signs of insect damage, and 11 percent show signs of other types of disturbances, such as animal damage (Wilson and Miles 2000).

Harvest Trends

Kootenai National Forest is among the top five timber producing National Forests in the Northern Region (fig. 9). From 1906 to 1929, timber production averaged about 33,000 MgC per year before beginning a downward trend (fig. 46). Starting at the global minimum of 9,348 MgC in 1932, annual timber production began to grow exponentially, with some inter-annual variability until 1966 when timber production hit a local maximum at 405,792 MgC. After 1966, timber production began to fall with some inter-annual variability until hitting a local minimum of 234,179 MgC in 1975. Production increased after 1975 hitting a local maximum 2 years later in 1977 with 388,152 MgC. Timber production rapidly fell after 1977 until hitting a local minimum of 216,360 MgC in 1982. After 1982, production quickly rose until hitting the global maximum of 408,752 MgC in 1987. Production remained high in 1988 before beginning a rapid decline until 1995 with 115,690 MgC in production. Following 1995, production continued to quickly decline with some inter-annual variability until ending at a local minimum of 38,871 MgC in 2009.

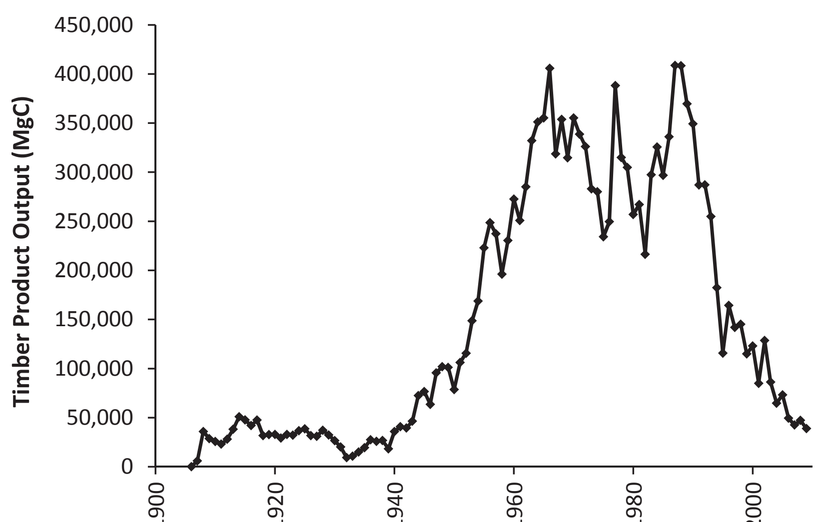

Figure 46—Annual timber product output for Kootenai National Forest, 1906 to 2010.

Carbon in Harvested Wood Products

Starting in 1907, total carbon storage in HWP grew linearly until flattening out in 1931with 329,911 MgC in use and 72,582 MgC in the SWDS for a total of 402,493 MgC (fig. 47). After 1940, carbon storage began to grow exponentially until 1967 with 1,969,066 MgC in use and 523,208 MgC in the SWDS for a total of 2,492,274 MgC. Following 1967, carbon storage continued to grow at a rapid rate until hitting the global maximum in 1995 with 3,792,307 MgC in use and 1,588,009 MgC in the SWDS for a total of 5,380,316 MgC. After 1995, carbon storage began to decline at a slow, steady rate—with the exceptions of 1997 and 1999—until 2001 when its rate of decline slightly quickened with the exception of 2003, ending in 2010 with 3,208,520 MgC in use and 1,878,443 MgC in the SWDS for a total of 5,086,963 MgC remaining in total carbon storage (table 38).

From 1907 to 1929, net stock change averaged about 15,000 MgC ranging from a low point in 1907 of 77 MgC in use and 7 MgC in the SWDS for a total of 84 MgC, to the high point in 1915 of 25,730 MgC in use and 3,803 MgC in the SWDS for a total of 29,533 MgC (fig. 48). After 1929, net stock change began to decline until hitting a local minimum in 1933 with –3,658 MgC in use and 1,426 MgC in the SWDS for a net negative change in carbon stocks (emissions) of –2,232 MgC. Following 1933, net stock change experienced positive growth at an exponential rate with a moderate amount of inter-annual variability until hitting a local maximum in 1967 with 136,340 MgC in use and 36,300 MgC in the SWDS for a total of 172,640 MgC. Net additions rapidly declined after 1967 until hitting a local minimum in 1976 with 26,049 MgC in use and 28,415 MgC in the SWDS for a total net stock change of 54,464 MgC. In 1978, net additions sharply increased for one year, hitting another local maximum with 111,340 MgC in use and 35,822 MgC in the SWDS for a total of 147,162 MgC. Net additions began to quickly decline following 1978, hitting a local minimum in 1983 with 21,231 MgC in use and 32,423 MgC in the SWDS for a total net stock change of 53,654 MgC. After 1983, net stock change experienced a period

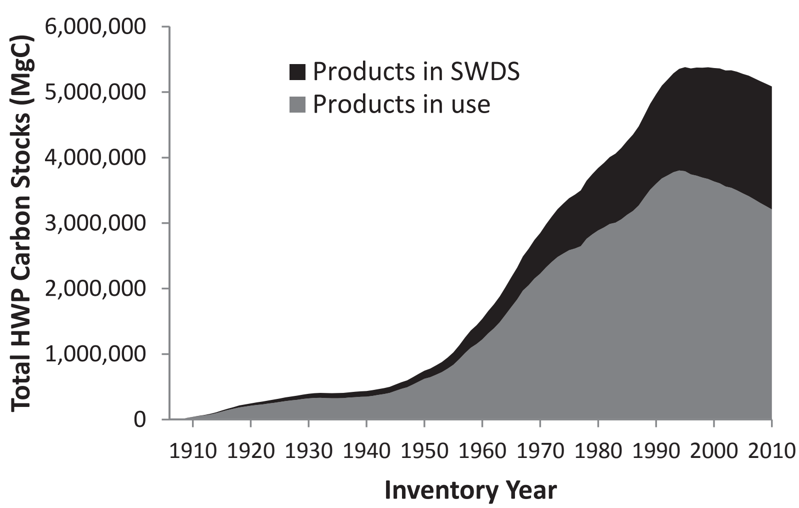

Figure 47—Cumulative total carbon stored in HWP manufactured from Kootenai National Forest timber.

Table 38—Kootenai National Forest cumulative disposition of HWP carbon for selected years. This table shows the fate of all carbon removed from the ecosystem by harvesting.

Inventory year	Emitted with energy capture	Emitted without energy capture	Products in use	SWDS	Total remaining in HWP pool[a]
	(MgC)				
1910	25,558	2,043	39,062	3,953	43,015
1920	158,643	32,628	210,629	36,432	247,061
1930	279,838	99,592	323,818	69,947	393,764
1940	352,093	185,305	350,627	84,811	435,438
1950	596,011	303,670	622,162	124,939	747,101
1960	1,252,585	608,392	1,224,894	313,821	1,538,715
1970	2,466,085	1,324,197	2,228,532	620,660	2,849,192
1980	3,618,542	2,254,335	2,888,664	952,679	3,841,342
1990	4,754,722	3,174,743	3,600,914	1,366,493	4,967,406
1995	5,217,221	3,659,634	3,792,307	1,588,009	5,380,317
2000	5,471,396	4,100,191	3,636,923	1,730,666	5,367,589
2005	5,658,757	4,490,990	3,452,573	1,824,319	5,276,892
2006	5,686,645	4,562,687	3,412,391	1,838,140	5,250,530
2007	5,707,619	4,631,682	3,360,220	1,849,852	5,210,073
2008	5,725,770	4,698,094	3,307,794	1,860,268	5,168,062
2009	5,748,009	4,762,123	3,259,130	1,869,895	5,129,025
2010	5,767,399	4,823,666	3,208,520	1,878,443	5,086,963

[a] Sum of Products in use and SWDS.

of rapid growth, hitting the global maximum in 1989 with 119,679 MgC in use and 54,109 MgC in the SWDS for a total of 173,788 MgC. Following 1989, net stock change experienced a rapid decline, first showing signs of net negative growth in 1996 with –48,550 MgC in use and 30,575 MgC in the SWDS for a total net negative growth of –17,975 MgC. Net additions were positive in 1997 with –18,691 MgC in use and 30,781 MgC in the SWDS for a total of 12,090 MgC, before beginning to slowly decline with a moderate amount of inter-annual variability ending in 2010 at the global minimum with –50,610 MgC in use and 8,548 MgC in the SWDS for a total of –42,062 MgC (table 39).

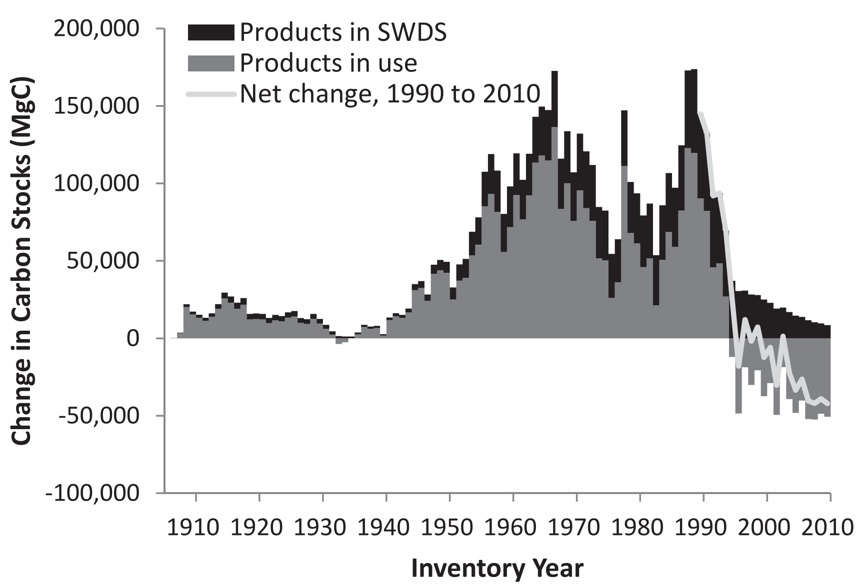

Figure 48. Kootenai National Forest net change in carbon stocks in HWP from the previous year.

Table 39—Kootenai National Forest annual net change in HWP carbon stocks for selected years for harvests beginning in 1906.

Inventory year	Stock change[a] ($MgC\ yr^{-1}$)
1910	17,248
1920	16,072
1930	12,542
1940	2,659
1950	49,370
1960	98,033
1970	107,199
1980	93,591
1990	144,898
1995	25,148
2000	-12,299
2005	-33,467
2006	-26,362
2007	-40,457
2008	-42,011
2009	-39,037
2010	-42,062

[a] Net annual change in carbon in products in use and SWDS.

From 1906 to 1929, the 100-year average carbon storage averaged about 15,000 MgC, ranging from a low point in 1906 of 36 MgC in use and 28 MgC in the SWDS for a total of 64 MgC, to the high point in1914 of 13,583 MgC in use and 10,492 MgC in the SWDS for a total of 24,075 MgC (fig. 49). Average carbon storage experienced a short downward trend following 1929, hitting the global minimum in 1932 with 2,491 MgC in use and 1,924 MgC in the SWDS for a total of 4,415 MgC. After 1932, average carbon storage experienced positive growth at an exponential rate with a moderate amount of inter-annual variability until reaching a local maximum in 1966 with 80,545 MgC in use and 74,266 MgC in the SWDS for a total of 154,811 MgC. Average carbon storage in HWP began to decline after 1966 with some isolated inter-annual variability until hitting a local minimum in 1975, with 46,215 MgC in use and 42,965 MgC in the SWDS for a total of 89,180 MgC. Average carbon storage sharply increased in 1977 for one year, hitting another local maximum with 76,600 MgC in use and 71,215 MgC in the SWDS for a total of 147,815 MgC. However, following the 1977 increase, carbon storage quickly declined until hitting a local minimum in 1982 with 45,221 MgC in use and 42,257 MgC in the SWDS for a total of 87,478 MgC. Carbon storage again quickly increased after 1982 to the global maximum in 1988 with 89,953 MgC in use and 76,036 MgC in the SWDS for a total of 165,989 MgC. After1988, carbon storage rapidly declined until 1995 with 22,904 MgC in use and 22,255 MgC in the SWDS for a total of 45,158 MgC. From 1995 to 2009, carbon storage continued to steadily decline with a moderate amount of inter-annual variability ending in 2009 with 5,777 MgC in use and 6,419 MgC in the SWDS for a total of 12,197 MgC (tables 40, 41).

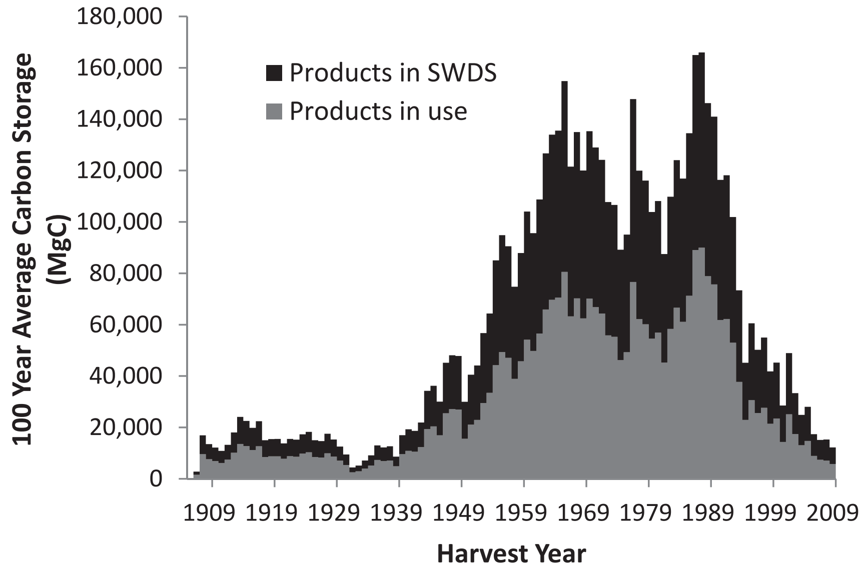

Figure 49—Kootenai National Forest harvest 100-year average carbon HWP storage using the California Forest Project Protocol.

Table 40—Kootenai National Forest 100-year average carbon stored in HWP for selected years.

Harvest year	Products in use[a]	Landfills and dumps[b]	Total
	- - - - - - - - - - - - - - - -	*(MgC)*	- - - - - - - - - - - - - - - -
1910	6,874	5,310	12,184
1920	8,757	6,764	15,521
1930	7,086	5,474	12,560
1940	9,570	7,392	16,961
1950	15,593	14,378	29,971
1960	54,121	49,902	104,023
1970	70,115	65,186	135,301
1980	54,562	49,331	103,893
1990	75,647	65,348	140,995
1995	22,904	22,255	45,158
2000	23,496	21,754	45,251
2005	14,761	13,279	28,041
2006	8,919	8,460	17,379
2007	7,377	7,774	15,151
2008	7,078	8,231	15,309
2009	5,777	6,419	12,197

[a] The 100-year average carbon storage in products in use for the harvest year.
[b] The 100-year average carbon storage in SWDS for the harvest year.

Table 41—Kootenai National Forest confidence intervals for cumulative carbon in HWP for selected years for harvests beginning in 1906.

Inventory year	Total remaining in HWP pool	90% Confidence interval (% difference from estimate) 5%	95%
	(MgC)		
1910	43,015	25,259	63,735
1920	247,061	142,556	373,744
1930	393,764	223,167	616,444
1940	435,438	258,862	665,751
1950	747,101	456,866	1,119,451
1960	1,538,715	976,824	2,198,409
1970	2,849,192	1,839,556	4,070,352
1980	3,841,342	2,466,893	5,514,639
1990	4,967,406	3,555,975	6,600,347
1995	5,380,317	3,943,711	7,061,652
2000	5,367,589	4,054,251	6,964,784
2005	5,276,892	3,923,035	6,806,798
2006	5,250,530	3,883,794	6,751,541
2007	5,210,073	3,897,932	6,695,237
2008	5,168,062	3,869,146	6,660,361
2009	5,129,025	3,895,646	6,655,510
2010	5,086,963	3,861,003	6,528,817

Lewis and Clark National Forest

Description

The Lewis and Clark National Forest is located in central Montana, with the Rocky Mountain district 60 miles to the northwest (fig. 50). The forest is approximately 200 miles from east to west and 150 miles from north to south, with non-Federal holdings throughout the area. The forest is bordered by the Blackfeet Reservation as well as privately held lands to the north, privately held lands to the east, the Helena and Gallatin National Forests as well as privately held lands to the south, the Flathead and Lolo National Forests to the west, and Glacier National Park to the northwest.

The Lewis and Clarke National Forest was established February 22, 1897, effective March 1, 1898. On June 9, 1903, additional lands were added to the forest from the Flathead National Forest. The spelling of the forest's name was changed March 2, 1907, to Lewis and Clark, as additional lands not previously controlled within the National Forest System were added. This was followed by the addition of the entire Jefferson National Forest on April 8, 1932. On July 1, 1908, the Flathead National Forest was reestablished and lands previously given to the Lewis and Clarke were retracted, followed by a final addition to the Lewis and Clark on July 1, 1945, when part of the Absaroka National Forest was added (Davis 1983).

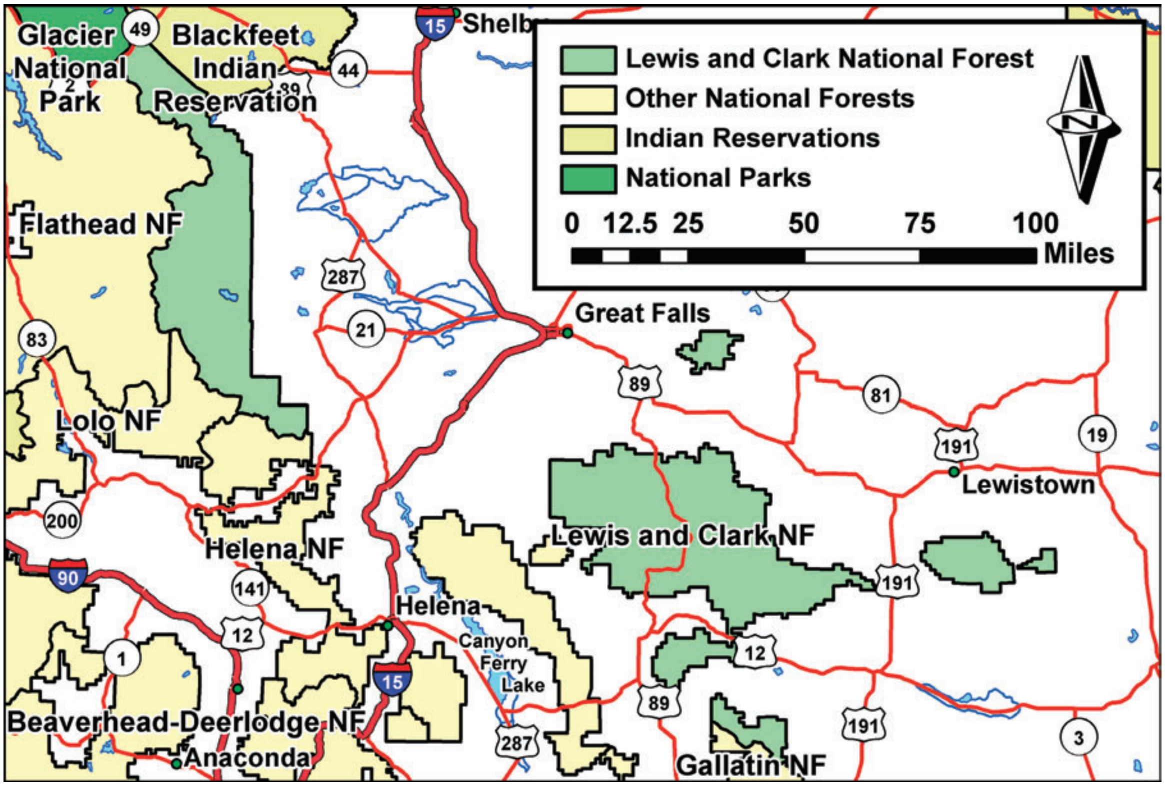

Figure 50—Location map of Lewis and Clark National Forest.

The Lewis and Clark National Forest is 1,862,291 acres and contains over 70 unique forest habitat types that have been categorized into eastside habitat type groups (DeBlander 2002). The most common habitat classification is warm and very dry covering 19 percent of the forest, followed by the classification cool and moist covering 18 percent. Due to higher elevations being associated with increased precipitation and lower temperatures, Douglas-fir, lodgepole pine, Engelmann spruce, and ponderosa pine are successful forest types in lower elevations, while Douglas-fir, Engelmann spruce, subalpine fir, and whitebark pine are successful at higher elevations (DeBlander 2002). The forest is 89 percent forested, leaving the remaining 11 percent either non-forested or water. Twenty-one percent of the forested lands are protected under reserves in the Bob Marshall and Scapegoat Wilderness areas, while 33 percent of non-reserved lands are considered suitable for timber production. The net annual growth of all forested lands is estimated to be 50.6 million cubic feet. Forest cover is 29 percent Douglas-fir, 28 percent lodgepole pine, 18 percent spruce-fir, 8 percent Engelmann spruce, 7 percent limber pine, 7 percent whitebark pine, 3 percent ponderosa pine, as well as traces of aspen and cottonwood (DeBlander 2002). Stands of old growth forest are also present, covering an estimated 13.3 percent of the forest (USDA 2007).

Natural disturbances within the Lewis and Clark National Forest are insect infestation including significant impacts from mountain pine beetle activity, as well as wind and fire (DeBlander 2002; USDA 2012c,d). It was estimated that in 1995, 8.9 million cubic feet of growing stock died, with 46 percent of tree mortality being the result of disease, 21 percent resulting from insect damage, and 9 percent from fire related causes. It was also estimated that 69 percent of tree mortality occurred in lodgepole pine and Engelmann spruce (DeBlander 2002). Mountain pine beetle activity within the forest has reached epidemic levels, resulting in high levels of tree mortality and hazardous conditions. Due to these hazardous conditions, the forest has decided to remove infected trees within the Little Belt Mountains in 220 sites, including recreational and non-recreational locations, as well as along 575 miles of road (USDA 2012c). A partial aerial survey of the forest showed that 366,837 acres were infected with mountain pine beetle in 2009, which went down to 329,432 acres in 2010 and 130,859 acres in 2011, mostly occurring in lodgepole pine for all 3 years (USDA 2012b, p 45). Extreme, high wind events are also common on the forest including one event that occurred on January 25, 2012, with gusts exceeding 100 mph, bringing down numerous trees in the Little Belt Mountain Range (USDA 2012d). Fire disturbances that continue to shape the forest include the recent fires in 2003, 2006, and 2007 on the Rocky Mountain Ranger District, which led to the decision to reduce fuels within the eastern portion of the forest (USDA 2010b). Within the forest, 31 percent of plots show no visible signs of disturbances, 22 percent show signs of disease, 22 percent show evidence of fire, 8 percent show evidence of wind damage, 5 percent show evidence of weather damage, 5 percent show evidence of cutting, 4 percent show evidence of other disturbances, and 3 percent show signs of insect or of animal damage (DeBlander 2002).

Harvest Trends

From 1906 to 1929, timber production averaged about 2,200 MgC per year before beginning a downward trend (fig. 51). Starting at the global minimum of 614 MgC in 1932, annual timber production began to grow exponentially with some inter-annual variability until hitting a local maximum of 31,531 MgC in 1967. Timber production experienced a moderate amount of inter-annual variability after 1967, hitting another local maximum of 32,012 MgC in 1973, before sharply declining the following year to a local minimum of 11,007 MgC in 1974. Production rose to a local maximum in 1975 of 18,471 MgC, before quickly declining with a moderate amount of inter-annual variability, hitting a local minimum of 6,031 MgC in 1981. Production rapidly increased after 1981 until hitting a local maximum of 32,022 MgC in 1984, followed by a period of high inter-annual variability, reaching the global maximum of 36,260 MgC in 1992. After 1992, production began to quickly decline with high inter-annual variability until hitting a local minimum of 3,509 MgC in 2005. Production slowly increased, averaging about 5,000 MgC per year before ending at the local maximum of 7,941 MgC in 2009.

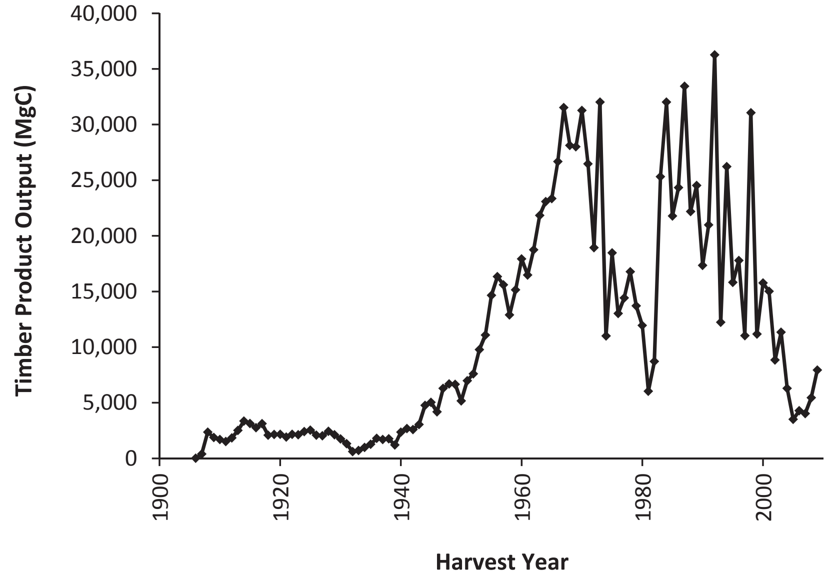

Figure 51—Annual timber product output for Lewis and Clark National Forest, 1906 to 2010.

Carbon in Harvested Wood Products

Starting in 1907 total carbon storage in HWP grew linearly until flattening out in 1931 with 21,680 MgC in use and 4,770 MgC in the SWDS for a total of 26,450 MgC (fig. 52). After 1940, carbon storage began to grow exponentially until 1971 with 167,395 MgC in use and 45,735 MgC in the SWDS for a total of 213,130 MgC. Carbon storage continued to grow after 1971 at a decreasing pace until reaching a period of decline, hitting a local minimum in 1982 with 188,973 MgC in use and 67,827 MgC in the SWDS for a total of 256,800 MgC. Carbon storage rapidly increased after 1982 at a decreasing rate with some inter-annual variability until hitting a local maximum in 2002 with 271,865 MgC in

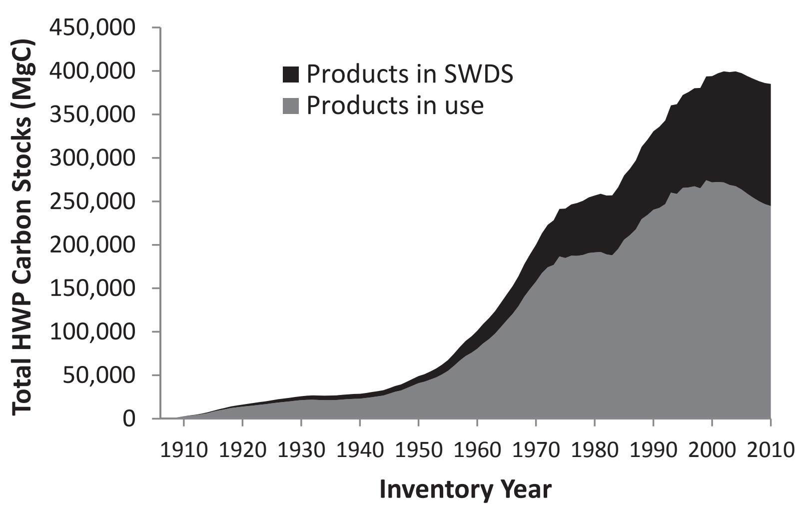

Figure 52—Cumulative total carbon stored in HWP manufactured from Lewis and Clark National Forest timber.

use and 127,639 MgC in the SWDS for a total 399,504 MgC. Carbon storage decreased in 2003 with a total of 398,687 MgC, before hitting the global maximum in 2004 with 267,536 MgC in use and 132,046 MgC in the SWDS for a total 399,582 MgC. After 2004, carbon storage began to slowly decline ending in 2010 with 244,706 MgC in use and 140,454 MgC in the SWDS for a total of 385,160 MgC remaining in total carbon storage (table 42).

From 1907 to 1929, net stock change averaged about 950 MgC, ranging from a low point in 1907 of 5 MgC in use and 0 MgC in the SWDS for a total of 5 MgC, to the high point in 1915 of 1,691 MgC in use and 250 MgC in the SWDS for a total of 1,941 MgC (fig. 53). After 1929, net stock change began to decline until hitting a local minimum in 1933 with –240 MgC in use and 94 MgC in the SWDS for a net negative change in carbon stocks (emissions) of –146 MgC. Following 1933, net stock change experienced positive growth at an exponential rate with a moderate amount of inter-annual variability until hitting a local maximum in 1968 with 11,131 MgC in use and 2,744 MgC in the SWDS for a total of 13,875 MgC. Net stock change quickly declined after 1968 with high inter-annual variability, hitting a local minimum in 1982 with –2,812 MgC in use and 934 MgC in the SWDS for a total net stock change of –1,878 MgC. Following 1982, net stock change rapidly increased until hitting a local maximum in 1985 with 10,657 MgC in use and 2,881 MgC in the SWDS for a total of 13,538 MgC, followed by a period of high inter-annual variability, reaching the global maximum in 1993 with 13,248 MgC in use and 4,090 MgC

Table 42—Lewis and Clark National Forest cumulative disposition of HWP carbon for selected years. This table shows the fate of all carbon removed from the ecosystem by harvesting.

Inventory year	Emitted with energy capture	Emitted without energy capture	Products in use	SWDS	Total remaining in HWP pool[a]
	- - - - - - - - - - - -	- - - - - - - - - (MgC)	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -
1910	1,680	134	2,567	260	2,827
1920	10,425	2,144	13,842	2,394	16,236
1930	18,390	6,545	21,280	4,597	25,877
1940	23,138	12,177	23,042	5,573	28,615
1950	39,167	19,956	40,886	8,210	49,096
1960	82,315	39,981	80,495	20,623	101,118
1970	170,601	88,366	157,651	42,501	200,152
1980	244,091	154,321	191,326	65,451	256,777
1990	320,560	214,335	240,367	90,217	330,584
1995	358,797	247,394	265,536	106,780	372,316
2000	390,764	280,517	271,872	122,201	394,073
2005	412,970	312,105	263,681	133,860	397,541
2006	414,307	317,783	258,656	135,379	394,034
2007	416,123	323,224	254,305	136,760	391,065
2008	417,841	328,427	250,160	138,012	388,172
2009	420,409	333,436	246,831	139,218	386,049
2010	424,370	338,305	244,706	140,454	385,160

[a] Sum of products in use and SWDS.

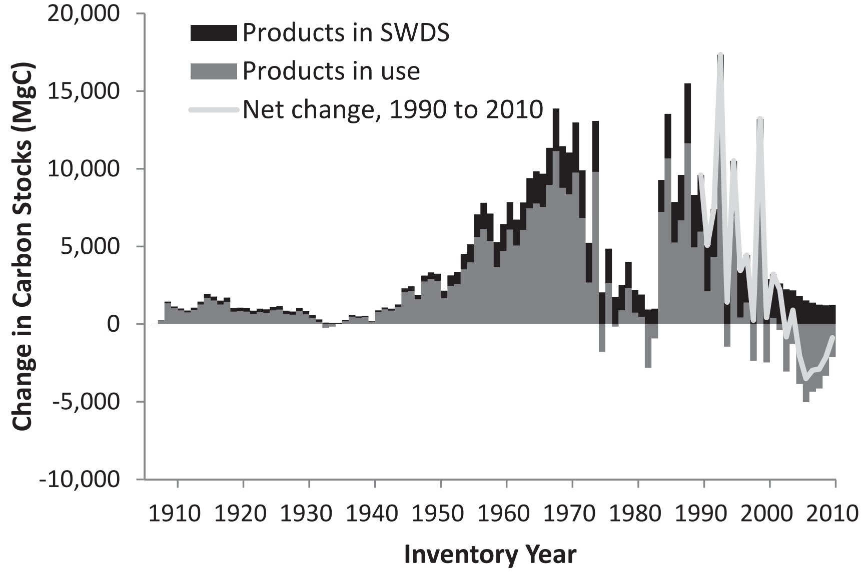

Figure 53—Lewis and Clark National Forest net change in carbon stocks in HWP from the previous year.

in the SWDS for a total of 17,338 MgC. After 1993, net stock change quickly decreased with high inter-annual variability, first showing signs of net negative growth in 2003 with a total of –817 MgC, and hitting the global minimum in 2006 with –5,025 MgC in use and 1,519 MgC in the SWDS for a total of –3,506 MgC. Net stock change began to quickly increase after 2006, ending in 2010 with –2,125 MgC in use and 1,236 MgC in the SWDS for a total of –889 MgC (table 43).

Table 43—Lewis and Clark National Forest annual net change in HWP carbon stocks for selected years for harvests beginning in 1906.

Inventory year	Stock change[a] (MgC yr^{-1})
1910	1,133
1920	1,056
1930	824
1940	175
1950	3,244
1960	6,442
1970	11,048
1980	2,180
1990	9,589
1995	10,504
2000	418
2005	-2,042
2006	-3,506
2007	-2,970
2008	-2,892
2009	-2,124
2010	-889

[a] Net annual change in carbon in products in use and SWDS.

From 1906 to 1929, the 100-year average carbon storage was about 1,000 MgC ranging from a low point in 1906 of 2 MgC in use and 2 MgC in the SWDS for a total of 4 MgC, to the high point in 1914 of 893 MgC in use and 689 MgC in the SWDS for a total of 1,582 MgC (fig. 54). Average carbon storage experienced a short downward trend after 1929, hitting the global minimum in 1932 with 164 MgC in use and 126 MgC in the SWDS for a total of 290 MgC. After 1932, average carbon storage experienced positive growth at an exponential rate with a moderate amount of inter-annual variability, reaching a local maximum in 1967 with 6,259 MgC in use and 5,771 MgC in the SWDS for a total of 12,030 MgC. However, total average carbon storage in HWP quickly declined after 1967 with high inter-annual variability until hitting a local minimum in 1981 with 1,284 MgC in use and 1,158 MgC in the SWDS for a total of 2,442 MgC. Following 1981, average carbon storage rapidly increased until hitting a local maximum in 1984 with 6,546 MgC in use and 5,652 MgC in the SWDS for a total of 12,198 MgC, followed by a period of high inter-annual variability, reaching the global maximum in 1992 with 7,859 MgC in use and 7,066 MgC in the SWDS for a total of 14,925 MgC. Carbon storage quickly decreased after 1992 with high inter-annual variability until hitting a local minimum in 2005 with 707 MgC in use and 636 MgC in the SWDS for a total of 1,343 MgC. Carbon storage slowing increased from 2005 to 2008, averaging about 1,500 MgC per year, before ending in 2009 with 1,180 MgC in use and 1,311 MgC in the SWDS for a total of 2,491 MgC (tables 44, 45).

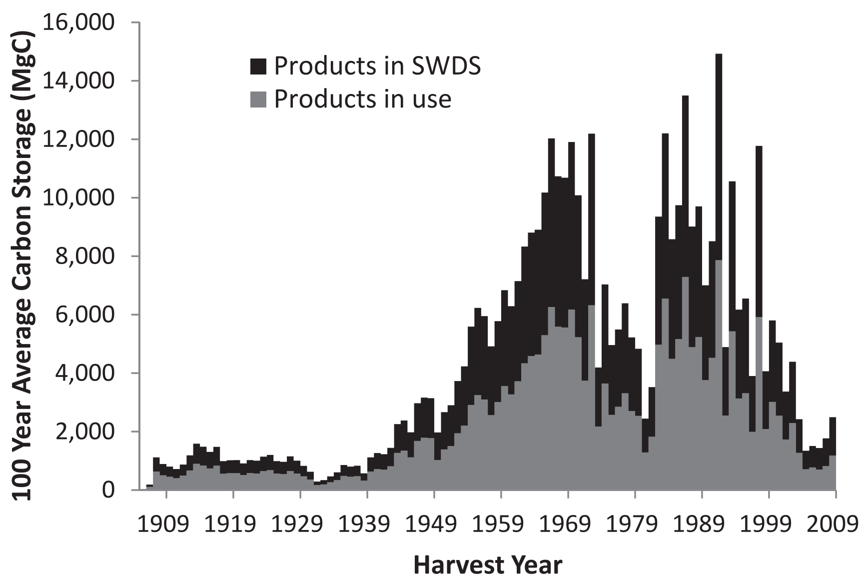

Figure 54—Lewis and Clark National Forest harvest 100-year average carbon HWP storage using the California Forest Project Protocol.

Table 44—Lewis and Clark National Forest 100-year average carbon stored in HWP for selected years.

Harvest year	Products in use[a]	Landfills and dumps[b]	Total
	(MgC)		
1910	452	349	801
1920	575	445	1,020
1930	466	360	825
1940	629	486	1,115
1950	1,025	945	1,970
1960	3,557	3,279	6,836
1970	6,170	5,737	11,907
1980	2,537	2,294	4,831
1990	3,757	3,246	7,003
1995	3,130	3,041	6,171
2000	3,011	2,788	5,798
2005	707	636	1,344
2006	772	733	1,505
2007	698	736	1,434
2008	817	950	1,768
2009	1,180	1,311	2,492

[a]The 100-year average carbon storage in products in use for the harvest year.
[b]The 100-year average carbon storage in SWDS for the harvest year.

Table 45—Lewis and Clark National Forest confidence intervals for cumulative carbon in HWP for selected years for harvests beginning in 1906.

Inventory year	Total remaining in HWP pool	90% Confidence interval (% difference from estimate) 5%	95%
	(MgC)		
1910	2,827	1,660	4,189
1920	16,236	9,368	24,561
1930	25,877	14,666	40,511
1940	28,615	17,011	43,750
1950	49,096	30,023	73,565
1960	101,118	64,193	144,470
1970	200,152	129,226	285,937
1980	256,777	164,901	368,630
1990	330,584	236,652	439,257
1995	372,316	272,903	488,664
2000	394,073	297,652	511,334
2005	397,541	295,547	512,798
2006	394,034	291,465	506,680
2007	391,065	292,576	502,541
2008	388,172	290,611	500,258
2009	386,049	293,216	500,944
2010	385,160	292,336	494,330

Lolo National Forest

Description

The Lolo National Forest is located in western Montana and stretches approximately 140 miles from east to west, and 100 miles from north to south with its northern border roughly 70 miles south of the Canada (fig. 55). The forest is bordered to the north by the Kootenai National Forest, the Flathead Reservation of the Confederated Salish and Kootenai Tribes, and the Flathead National Forest. The forest is bordered by the Lewis and Clark National Forest to the northeast, the Helena National Forest to the east, the Beaverhead-Deerlodge National Forest to the southeast, the Bitterroot National Forest and Bitterroot Valley to the south, the Nez Perce-Clearwater National Forest to the southwest, and the Idaho Panhandle National Forest to the west.

The Lolo National Forest was established September 20, 1906. Part of the Missoula National Forest was added December 16, 1931, followed a few years later by the addition of part of the Selway National Forest October 29, 1934. A final addition to Lolo National Forest was made July 1, 1954, when part of the Cabinet National Forest was incorporated (Davis 1983).

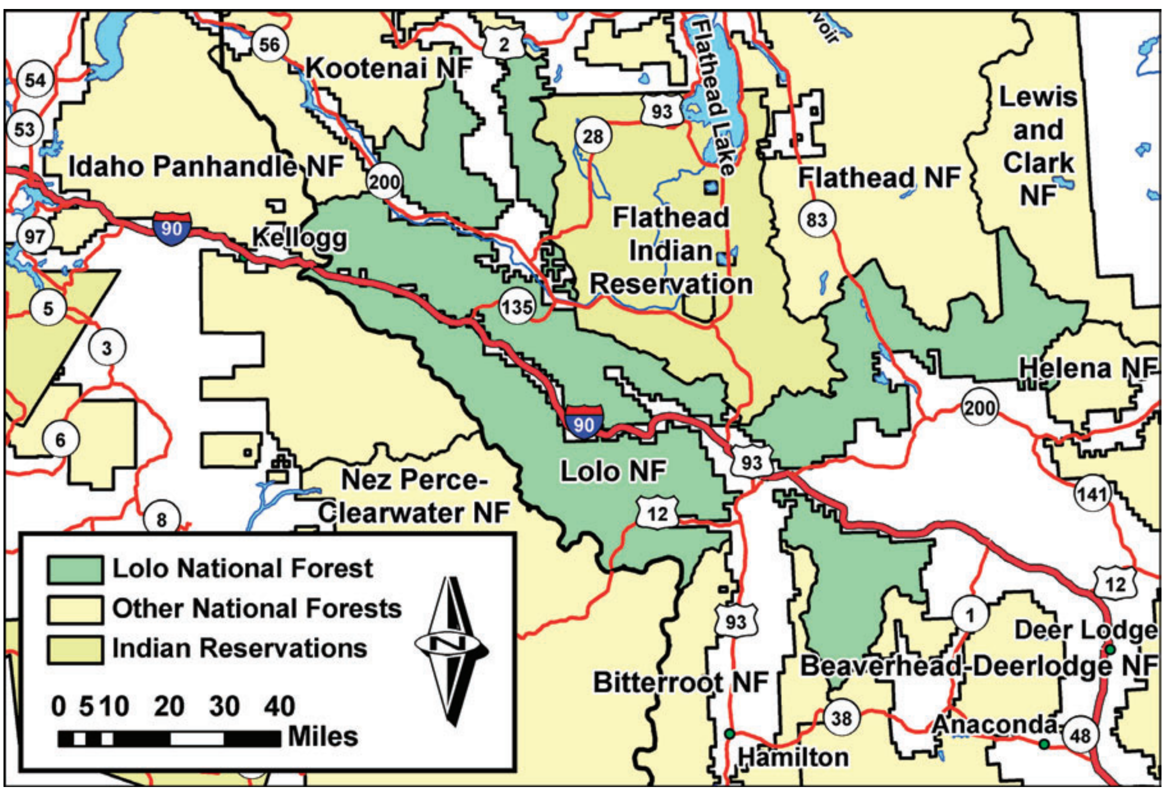

Figure 55—Location map of Lolo National Forest.

The Lolo National Forest is 2,079,327 acres and contains over 80 unique forest habitat types, the most common of which is classified as moderately warm and dry covering 34 percent of the forest (DeBlander 2000). Most of the saw timber is located on steep terrain, resulting in skyline yarding being a popular logging method within the forest (USDA 1986, p VI12). The forest is 95 percent forested, leaving the remaining 5 percent either non-forested or water. Eight percent of the forested lands are protected under reserves including wilderness designation, and 56 percent of non-reserved lands are considered suitable for timber production with a net annual growth of all forested lands estimated to be over 90 million cubic feet (DeBlander 2000). Forest ecosystems range from warm, dry pine-bunchgrass forests with yearly productivity of 20 cubic feet per acre, to warm, moist western hemlock forests with yearly productivity of 164 cubic feet per acre. Forest cover is 41 percent Douglas-fir, 21 percent lodgepole pine, 18 percent spruce-fir, 6 percent larch, 4 percent ponderosa pine, 3 percent western redceder, 2 percent grand fir, 2 percent Engelmann spruce, and 2 percent whitebark pine, as well as traces of mountain hemlock and aspen (DeBlander 2000). Old growth forests are also present, estimated to cover 9.6 percent of the forest (USDA 2007).

Natural disturbances within the Lolo National Forest are insect infestation including significant impacts from the mountain pine beetle, as well as root disease, and forest fires (USDA 1986). Infected timber from the mountain pine beetle has been observed forest-wide in both lodgepole and ponderosa pine with heavy concentrations on the Plains Ranger District and much of the Thompson River drainage. Infected timber on the Plains Ranger District jumped from 5,500 acres in 1979 to more than 16,000 in 1982 (USDA 1986, p VI-26). Forest-wide, the pine beetle killed on average 27 trees per acre in 1980 and up to 53 trees per acre in 1982, representing a 6:1 increase since 1979 (USDA 1986, p VI-26). A partial aerial survey of the forest showed that 306,201 acres were infected with mountain pine beetle in 2009, which went down to 57,673 acres in 2010, and slightly up in 2011 to 62,537 acres, mostly occurring in lodgepole and ponderosa pine for all 3 years (USDA 2012b, p 45).

Other disturbances on the forest include root diseases (primarily armillaric) and forest fires. Root disease is an active pathogen on much of the forest, infecting more than 20,000 acres of forested land in 1986 (USDA 1986, p VI-27). Fire activity is also common on the forest with an average of 180 fires per year between 1955 and 1974 (USDA 1986, p VI-25). Twenty percent of the forest is 85 years to 115 years old, with stand replacing fires in the western half of the forest occurring in 1880 and 1910 (USDA 1986, p VI-13). Within the forest 25 percent of plots show no visible signs of disturbances, 26 percent show signs of disease, 18 percent show evidence of cutting, 13 percent have evidence of fire, 5 percent have signs of weather damage, 5 percent show signs of insect damage, and 8 percent have undergone wind damage, road building, land clearing, or other disturbances (DeBlander 2000).

Harvest Trends

Lolo National Forest is among the top five timber producing National Forests in the Northern Region (fig. 9). From 1906 to 1929, timber production averaged about 20,000 MgC per year before beginning a downward trend (fig. 56). Starting at the global minimum of 5,925 MgC in 1932, annual timber production began to grow exponentially with some inter-annual variability until 1969, when timber production hit its global maximum at 280,613 MgC. Timber production began to fall after 1969 with some isolated inter-annual variability, hitting a local minimum of 66,182 MgC in 1982. Following 1982, production increased with high inter-annual variability until hitting a local maximum of 169,982 MgC in 1990. Production began to fall again after 1990 with moderate inter-annual variability until hitting the local minimum of 17,101 MgC in 2007. After 2007, production began to increase, ending with 38,752 MgC in production in 2009.

Carbon in Harvested Wood Products

Starting in 1907 total carbon storage in HWP grew linearly until flattening out in 1931with 209,096 MgC in use and 46,002 MgC in the SWDS for a total of 255,098 MgC (fig. 57). After 1940, carbon storage began to grow exponentially until 1973 with 1,698,829 MgC in use and 488,720 in the SWDS for a total of 2,187,549 MgC. Carbon storage continued to grow at a steady rate after 1973 until slowing about 1978 with 1,840,924 MgC in use and 600,785 MgC in the SWDS for a total of 2,441,709 MgC. From 1978 to 1987, carbon storage continued to grow but at a slow rate with 1,833,244 MgC in use and 710,887 MgC in the SWDS for a total of 2,544,131 MgC in 1987. After 1987, carbon storage began to grow at an increased rate until hitting the global maximum in

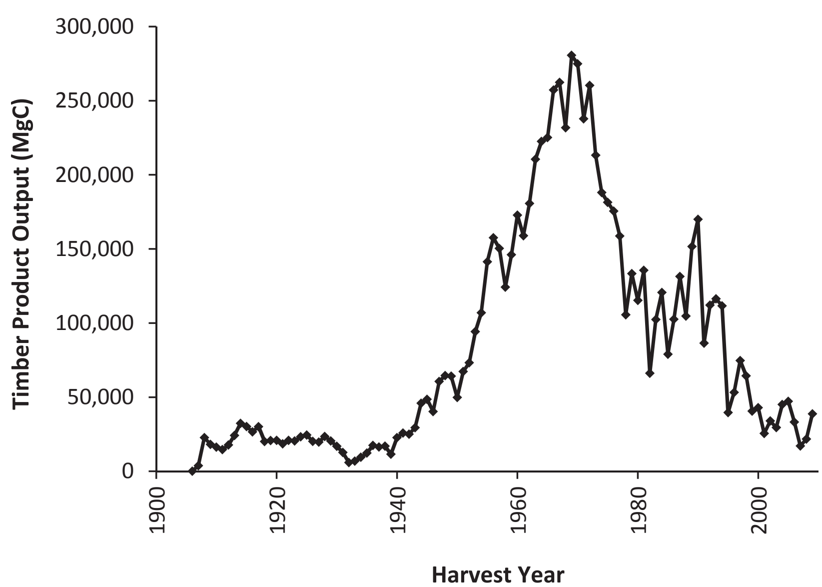

Figure 56—Annual timber product output for Lolo National Forest, 1906 to 2010.

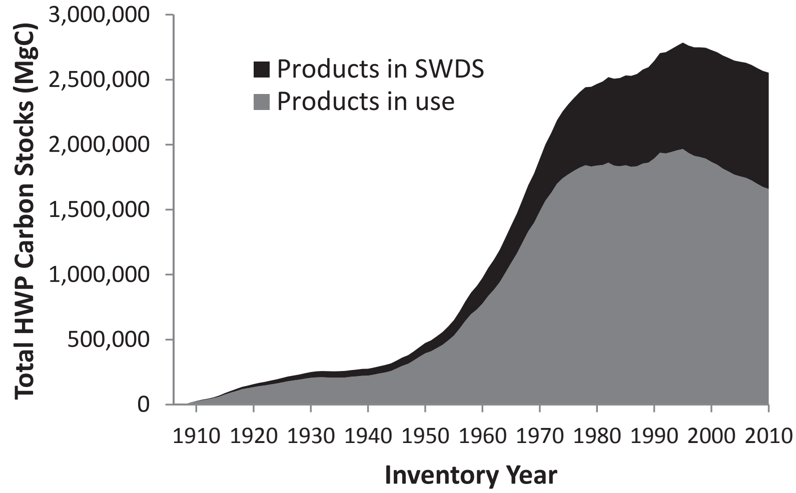

Figure 57—Cumulative total carbon stored in HWP manufactured from Lolo National Forest timber.

1995 with 1,966,652 MgC in use and 818,431 MgC in the SWDS for a total of 2,785,083 MgC. After 1995, carbon storage began to decline at a slow, steady rate ending in 2010 with 1,658,554 MgC in use and 895,375 MgC in the SWDS for a total of 2,553,929 MgC remaining in total carbon storage (table 46).

From 1907 to 1929, net stock change averaged about 10,000 MgC ranging from a low point in 1907 of 49 MgC in use and 4 MgC in the SWDS for a total of 53 MgC, to the high point in 1915 of 16,308 MgC in use and 2,410 MgC in the SWDS for a total of 18,718 MgC (fig. 58). After 1929, net stock change began

Table 46—Lolo National Forest cumulative disposition of HWP carbon for selected years. This table shows the fate of all carbon removed from the ecosystem by harvesting.

Inventory year	Emitted with energy capture	Emitted without energy capture	Products in use	SWDS	Total remaining in HWP pool[a]
	(MgC)				
1910	16,198	1,295	24,757	2,506	27,263
1920	100,547	20,679	133,496	23,090	156,586
1930	177,360	63,121	205,234	44,332	249,566
1940	223,155	117,445	222,226	53,753	275,979
1950	377,749	192,465	394,324	79,186	473,510
1960	793,883	385,596	776,333	198,898	975,231
1970	1,618,872	847,199	1,487,298	403,883	1,891,181
1980	2,341,844	1,476,653	1,838,739	628,899	2,467,639
1990	2,736,156	2,015,001	1,893,645	750,650	2,644,295
1995	2,939,086	2,267,684	1,966,652	818,431	2,785,083
2000	3,040,927	2,496,168	1,867,094	860,254	2,727,349
2005	3,108,705	2,694,683	1,756,083	881,892	2,637,975
2006	3,126,662	2,731,567	1,744,597	885,686	2,630,282
2007	3,140,734	2,767,381	1,724,865	888,749	2,613,614
2008	3,148,028	2,801,867	1,698,010	890,924	2,588,934
2009	3,158,258	2,835,232	1,674,146	892,919	2,567,066
2010	3,177,588	2,867,791	1,658,554	895,375	2,553,929

[a] Sum of products in use and SWDS.

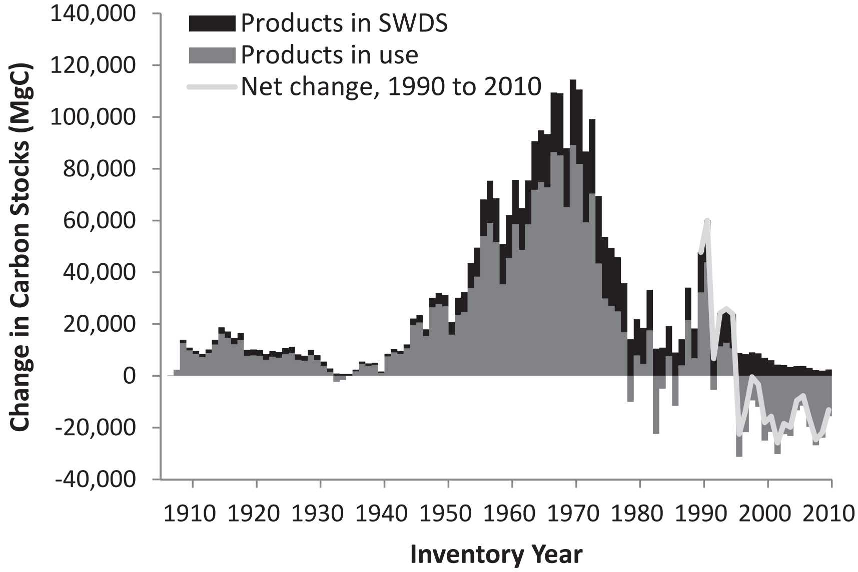

Figure 58—Lolo National Forest net change in carbon stocks in HWP from the previous year.

to decline until hitting a local minimum in 1933 with –2,319 MgC in use and 903 MgC in the SWDS for a net negative change in carbon stocks (emissions) of –1,416 MgC. Following 1933, net stock change experienced positive growth at an exponential rate with a moderate amount of inter-annual variability until hitting the global maximum in 1970 with 89,084 MgC in use and 25,378 MgC in the SWDS for a total of 114,462 MgC. After 1970, net additions rapidly declined until hitting a local minimum in 1983 with –22,453 MgC in use and 10,525 MgC in the SWDS for a total net stock change of –11,928 MgC. This was followed by a period of rapid growth with moderate inter-annual variability until hitting a local maximum in 1991 with 43,789 MgC in use and 16,286 MgC in the SWDS for a total of 60,075 MgC in net stock change. Net stock change experienced a rapid decline after 1991 with moderate inter-annual variability first showing signs of continued net negative growth in 1996 with –31,264 MgC in use and 8,782 MgC in the SWDS for a total of –22,482 MgC. After 1996, net stock change continued to experience high inter-annual variability, averaging about –16,000 MgC per year, ranging from the global minimum in 2002 of –30,227 MgC in use and 4,366 MgC in the SWDS for a total of –25,861 MgC, to a local maximum in 1998 of –9,506 MgC in use and 9,058 MgC in the SWDS for a total of –458 MgC (table 47).

From 1906 to 1929, the 100-year average carbon storage was about 9,500 MgC ranging from a low point in 1906 of 23 MgC in use, and 18 MgC in the SWDS for a total of 41 MgC, to the high point in 1914 of 8,609 MgC in use and 6,650 MgC in the SWDS for a total of 15,259 MgC, before beginning a short downward trend and hitting the global minimum in 1932 with 1,579 MgC in use and 1,220 MgC in the SWDS for a total of 2,799 MgC (fig. 59). After 1932, average carbon storage experienced positive growth at an exponential rate with a

Table 47—Lolo National Forest annual net change in HWP carbon stocks for selected years for harvests beginning in 1906.

Inventory year	Stock change[a] ($MgC\ yr^{-1}$)
1910	10,931
1920	10,186
1930	7,949
1940	1,685
1950	31,291
1960	62,133
1970	114,462
1980	21,848
1990	47,759
1995	23,863
2000	-18,054
2005	-9,538
2006	-7,692
2007	-16,668
2008	-24,680
2009	-21,869
2010	-13,137

[a]Net annual change in carbon in products in use and SWDS.

moderate amount of inter-annual variability until reaching the global maximum in 1969 with 55,699 MgC in use and 51,356 MgC in the SWDS for a total of 107,055 MgC. Following 1969, average carbon storage in HWP fell rapidly with some isolated inter-annual variability until hitting a local minimum in 1982, with 13,833 MgC in use and 12,926 MgC in the SWDS for a total of 26,759 MgC.

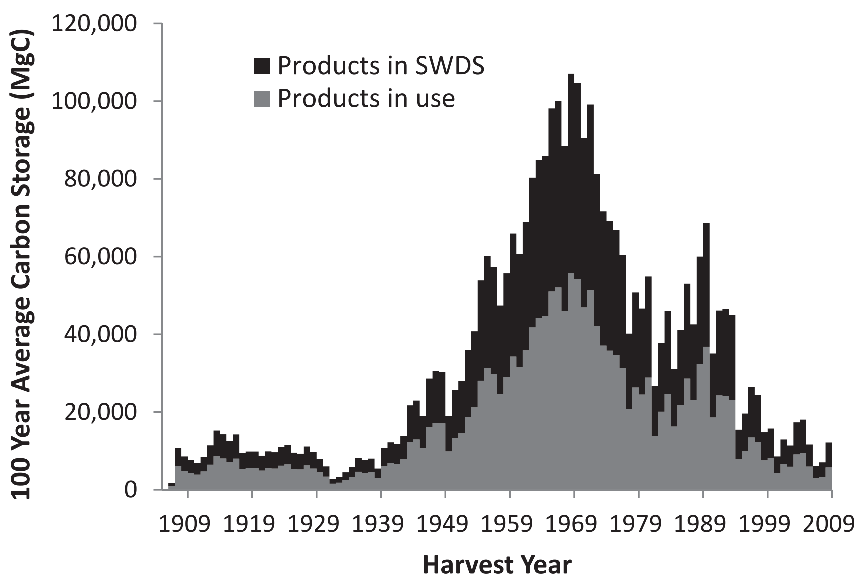

Figure 59—Lolo National Forest harvest 100-year average carbon HWP storage using the California Forest Project Protocol.

After 1982, carbon storage experienced steady growth with high inter-annual variability, hitting a local maximum in 1990 with 36,825 MgC in use and 31,811 MgC in the SWDS for a total of 68,636 MgC. This was followed by a steady decline in carbon storage with moderate inter-annual variability until hitting the most recent local minimum in 2007 with 2,965 MgC in use and 3,124 MgC in the SWDS for a total of 6,089 MgC, and ending in 2009 with 5,760 MgC in use and 6,400 MgC in the SWDS for a total of 12,160 MgC (tables 48, 49).

Table 48—Lolo National Forest 100-year average carbon stored in HWP for selected years.

Harvest year	Products in use[a]	Landfills and dumps[b]	Total
	- - - - - - - - (MgC) - - - - - - - -		
1910	4,357	3,365	7,722
1920	5,550	4,287	9,837
1930	4,491	3,469	7,960
1940	6,065	4,685	10,750
1950	9,883	9,113	18,996
1960	34,302	31,628	65,930
1970	54,251	50,438	104,689
1980	24,487	22,139	46,626
1990	36,825	31,811	68,636
1995	7,842	7,620	15,462
2000	8,189	7,581	15,770
2005	9,505	8,551	18,055
2006	5,984	5,676	11,659
2007	2,965	3,124	6,089
2008	3,256	3,786	7,042
2009	5,760	6,400	12,159

[a] The 100-year average carbon storage in products in use for the harvest year.
[b] The 100-year average carbon storage in SWDS for the harvest year.

Table 49—Lolo National Forest confidence intervals for cumulative carbon in HWP for selected years for harvests beginning in 1906.

Inventory year	Total remaining in HWP pool	90% Confidence interval (% difference from estimate) 5%	95%
	- - - - - - - - (MgC) - - - - - - - -		
1910	27,263	16,009	40,396
1920	156,586	90,351	236,877
1930	249,566	141,442	390,700
1940	275,979	164,066	421,951
1950	473,510	289,560	709,504
1960	975,231	619,107	1,393,343
1970	1,891,181	1,221,024	2,701,739
1980	2,467,639	1,584,707	3,542,548
1990	2,644,295	1,892,949	3,513,557
1995	2,785,083	2,041,434	3,655,414
2000	2,727,349	2,060,023	3,538,907
2005	2,637,975	1,961,167	3,402,792
2006	2,630,282	1,945,608	3,382,222
2007	2,613,614	1,955,383	3,358,641
2008	2,588,934	1,938,244	3,336,499
2009	2,567,066	1,949,762	3,331,068
2010	2,553,929	1,938,431	3,277,817

Nez Perce-Clearwater National Forest

Description

The Nez Perce-Clearwater National Forest is located in the southern portion of the Idaho Panhandle with the Nez Perce Reservation located to its east (fig. 60). The forest stretches approximately 100 miles from east to west and from north to south. The forest is bordered by the Idaho Panhandle National Forest to the north, the Lolo National Forest to the northeast, the Bitterroot National Forest to the east, the Payette National Forest to the south, and the Wallowa-Whitman National Forest as well as privately held lands to the west.

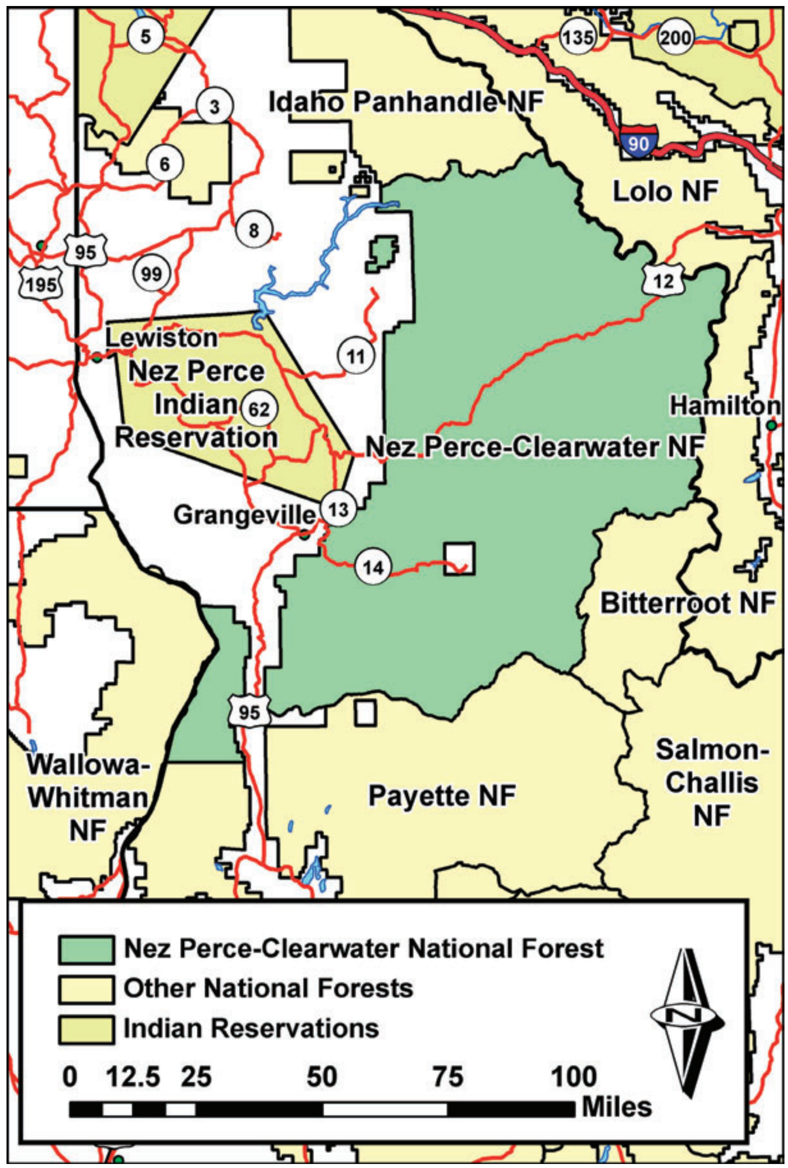

Figure 60—Location map of Nez Perce-Clearwater National Forest.

The Nez Perce and Clearwater National Forests were both established July 1, 1908, from parts of the Bitter Root and Weiser National Forests, and the Bitter Root and Coeur d'Alene National Forests, respectively. Part of the Selway National Forest was added October 29, 1934, to both the Nez Perce and Clearwater National Forests (Davis 1983). In December 2010, the Regional Forester decided to combine the Nez Perce and Clearwater National Forests into one administrative area, a goal that is still in transition (USDA 2012e, f).

The Nez Perce and Clearwater National Forests are 2,111,238 acres and 1,825,422 acres respectively, where both have a high correlation between elevation and forest type. This correlation is due to high elevations (above 6,000 feet) receiving more precipitation and having a lower temperature than low elevations (below 4,000 feet) (Disney 2010; Hughes 2011). Common forest types in the Nez Perce National Forest are subalpine fir and lodgepole pine at high elevations, grand fir at middle elevations (4,000-6,000 feet), and Douglas-fir across all elevations (Disney 2010). Common forest types within the Clearwater National Forest are whitebark pine and subalpine fir at high elevations, grand fir at both middle and low elevations, and Douglas-fir across all elevations (Hughes 2011). The Nez Perce National Forest is 94 percent forested, leaving the remaining 6 percent either non-forested or water, with 38 percent of the forested lands protected under reserves including wilderness designation (Disney 2010). The Clearwater National Forest is 95 percent forested, leaving the remaining 5 percent either non-forested or water, with 13 percent of the forested lands protected under reserves including wilderness designation (Hughes 2011). Net annual growth of all forested lands in the Nez Perce and Clearwater National Forests are estimated to be over 102 million cubic feet and 116 million cubic feet, respectively (Disney 2010; Hughes 2011). The Nez Perce National Forest cover type is 24 percent spruce-fir, 22 percent grand fir, 22 percent Douglas-fir, 15 percent lodgepole pine, 9 percent ponderosa pine, 4 percent western redceder, 2 percent Engelmann spruce, and 2 percent maple woodland (Disney 2010). Stands of old growth forest are also present on the Nez Perce National Forest, estimated to cover 14.4 percent of forested lands (USDA 2007). The Clearwater National Forest cover type is 26 percent spruce-fir, 21 percent Douglas-fir, 19 percent grand fir, 13 percent lodgepole pine, 8 percent western redceder, 4 percent Engelmann spruce, 3 percent mountain hemlock, 3 percent maple woodland, 1 percent paper birch, 1 percent western larch, and 1 percent ponderosa pine, with traces of mountain hemlock and aspen also present (Hughes 2010). The Clearwater also contains some old growth forests, estimated to cover 9.4 percent of the forest (USDA 2009d, p 122).

Natural disturbances within the Nez Perce-Clearwater National Forest are insect infestation including significant impacts from mountain pine beetle, root disease, forest fires, and wind damage. Twenty-two percent of tree mortality on the Nez Perce National Forest in 2000 was caused by root disease, 20 percent by fire, and 12 percent by mountain pine beetle infestations. Twenty-six percent of tree mortality occurred in Douglas-fir, 23 percent in lodgepole pine, 22 percent in grand fir, 19 percent in subalpine fir, and 7 percent in ponderosa pine, while whitebark pine mortality was 63 percent of its gross annual growth (Disney 2010). Forty-nine percent of tree mortality on the Clearwater National Forest in 1999 was caused by disease, 22 percent by weather damage, 20 percent by insects, 5 percent by unknown causes, and 3 percent by fire. Twenty percent of tree mortality occurred in subalpine fir, 18 percent in lodgepole pine, 15 percent in Douglas-fir, 15 percent in mountain hemlock, and 14 percent in grand fir (Hughes 2010). Infected timber from the mountain pine beetle epidemic rapidly increased due to drought conditions from 1998 to 2003, and can be observed forest-wide in lodgepole pine, Douglas-fir, and whitebark pine, as well as the acreage burned in the 1910 fires (USDA 2004, p 19; USDA 2009d, p 109). In 2004, it was also concluded that subalpine fir forests were increasingly in threat of infection from balsam woolly adelgid and the western balsam bark beetle (USDA 2004, p 23; USDA 2009d, p 109).

Harvest Trends

Nez Perce-Clearwater National Forest is one of the top timber producing forests in the Northern Region (fig. 9). From 1906 to 1929, timber production averaged about 50,000 MgC per year before beginning a downward trend (fig. 61). Starting at the global minimum of 13,243 MgC in 1932, annual timber production began to grow exponentially with some inter-annual variability until 1966 when timber production hit its global maximum at 574,897 MgC. After 1969, timber production began to decline with high inter-annual variability until hitting a local minimum of 183,390 MgC in 1982. Production increased sharply after 1982 to 331,659 MgC in 1983. Production experienced a moderate amount of inter-annual

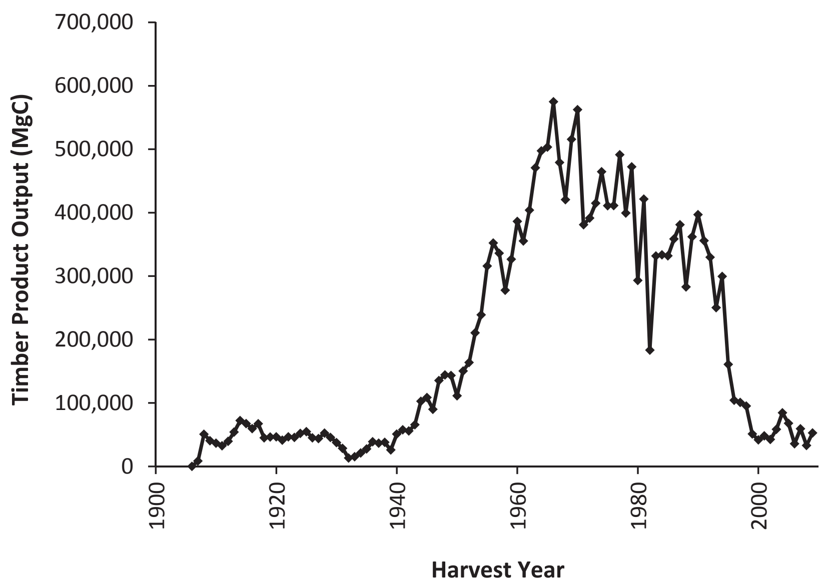

Figure 61—Annual timber product output for Nez Perce-Clearwater National Forest, 1906 to 2010.

variability from 1983 to 1994 averaging about 330,000MgC per year, hitting a local maximum of 396,901 MgC in 1990. Following 1990, production began to steadily decline hitting a local minimum in 2000 with production at 41,818 MgC. From 2000 to 2009 production averaged about 53,000 MgC per year with a local maximum in 2004 of 84,613 MgC, a local minimum in 2008 of 33,076 MgC, and ending with 52,659 MgC in 2009.

Carbon in Harvested Wood Products

Starting in 1907, total carbon storage in HWP grew linearly until flattening out in 1931with 467,394 MgC in use and 102,829 MgC in the SWDS for a total of 570,223 MgC (fig. 62). After 1940, carbon storage began to grow exponentially until 1971 with 3,333,271 MgC in use and 936,131 in the SWDS for a total of 4,269,402 MgC. Carbon storage continued to grow at a steady rate from 1971 until 1982, hitting a local maximum with 4,239,030 MgC in use and 1,451,483 MgC in the SWDS for a total of 5,690,513 MgC. After experiencing a net loss in 1983 of 5,855 MgC, carbon storage began to rise again at a steady rate until hitting the global maximum in 1995 with 4,791,455 MgC in use and 2,001,527 MgC in the SWDS for a total of 6,792,982 MgC. Carbon storage began to decline after 1995 at a slow, steady rate, ending in 2010 with 3,846,378 MgC in use and 2,191,266 MgC in the SWDS for a total of 6,037,644 MgC remaining in total carbon storage (table 50).

From 1907 to 1929, net stock change averaged about 23,000 MgC ranging from a low point in 1907 of 109 MgC in use and 9 MgC in the SWDS for a total of 118 MgC, to the high point in 1915 of 36,453 MgC in use and 5,387 MgC in the SWDS for a total of 41,840 MgC (fig. 63). After 1929, net stock change began to decline until hitting a local minimum in 1933 with –5,183 MgC in use and

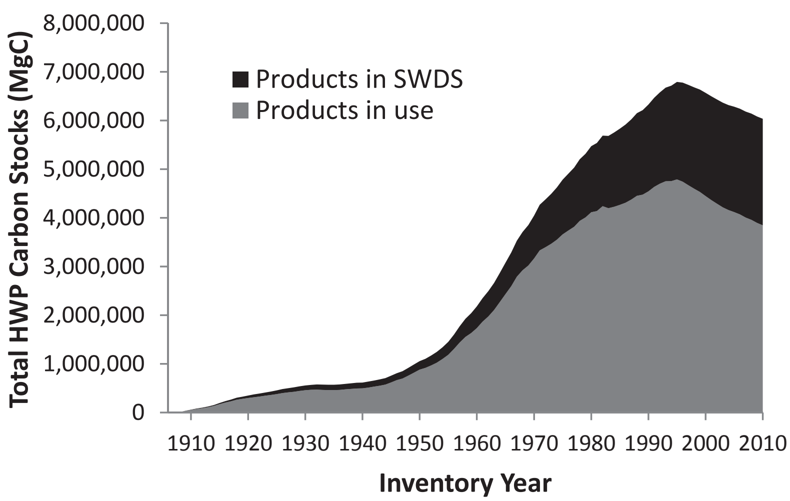

Figure 62—Cumulative total carbon stored in HWP manufactured from Nez Perce-Clearwater National Forest timber.

Table 50—Nez Perce-Clearwater National Forest cumulative disposition of HWP carbon for selected years. This table shows the fate of all carbon removed from the ecosystem by harvesting.

Inventory year	Emitted with energy capture	Emitted without energy capture	Products in use	SWDS	Total remaining in HWP pool[a]
			(MgC)		
1910	36,208	2,894	55,340	5,601	60,941
1920	224,754	46,225	298,404	51,614	350,018
1930	396,455	141,095	458,761	99,096	557,857
1940	498,820	262,526	496,743	120,154	616,897
1950	844,385	430,218	881,435	177,004	1,058,439
1960	1,774,572	861,925	1,735,341	444,599	2,179,940
1970	3,500,196	1,876,121	3,167,429	879,733	4,047,162
1980	5,149,037	3,199,210	4,116,979	1,357,348	5,474,327
1990	6,317,812	4,455,095	4,544,654	1,784,320	6,328,974
1995	6,872,402	5,068,599	4,791,455	2,001,527	6,792,982
2000	7,062,222	5,615,689	4,448,592	2,119,785	6,568,378
2005	7,168,015	6,068,530	4,119,240	2,166,102	6,285,342
2006	7,193,910	6,151,362	4,071,504	2,173,101	6,244,605
2007	7,209,089	6,231,248	4,007,300	2,178,073	6,185,373
2008	7,234,413	6,309,070	3,958,190	2,183,405	6,141,595
2009	7,249,988	6,384,067	3,896,869	2,187,232	6,084,101
2010	7,276,255	6,456,914	3,846,378	2,191,266	6,037,645

[a] Sum of products in use and SWDS.

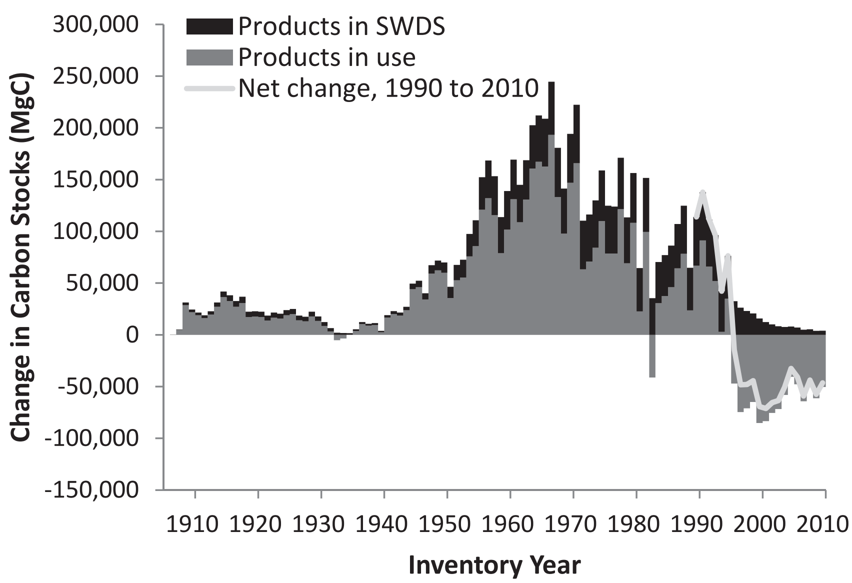

Figure 63—Nez Perce-Clearwater National Forest net change in carbon stocks in HWP from the previous year.

2,020 MgC in the SWDS for a net negative change in carbon stocks (emissions) of –3,163 MgC. Following 1933, net stock change experienced positive growth at an exponential rate with a moderate amount of inter-annual variability until hitting the global maximum in 1967 with 193,157 MgC in use and 51,427 MgC in the SWDS for a total of 244,584 MgC. Net additions steadily declined after 1967 with high inter-annual variability until hitting a local minimum in 1983 with –41,256 MgC in use and 35,401 MgC in the SWDS for a total net stock change of –5,855 MgC. This was followed by a period of rapid growth, hitting a local maximum in 1991 with 91,166 MgC in use and 46,662 MgC in the SWDS for a total of 137,828 MgC in net stock change. After 1991, net stock change experienced a rapid decline, first showing signs of continued net negative growth in 1996 with –47,098 MgC in use and 32,513 MgC in the SWDS for a total of –14,585 MgC. Net stock change continued to fall until hitting the global minimum in 2001 with –83,391 MgC in use and 12,288 MgC in the SWDS for a total of –71,103 MgC. After 2001, net stock change averaged about –52,000 MgC per year, ranging from the low point in 2002 with –75,524 MgC in use and 10,097 MgC in the SWDS for a total of –65,428 MgC, to the high point in 2005 with –40,581 MgC in use and 8,062 MgC in the SWDS for a total of –32,519 MgC, and ending in 2010 with –50,490 MgC in use and 4,034 MgC in the SWDS for a total of –46,456 MgC (table 51).

Table 51—Nez Perce-Clearwater National Forest annual net change in HWP carbon stocks for selected years for harvests beginning in 1906.

Inventory year	Stock change[a] (MgC yr^{-1})
1910	24,435
1920	22,770
1930	17,769
1940	3,767
1950	69,944
1960	138,886
1970	194,216
1980	156,366
1990	113,893
1995	76,325
2000	-69,345
2005	-32,519
2006	-40,736
2007	-59,233
2008	-43,778
2009	-57,494
2010	-46,456

[a] Net annual change in carbon in products in use and SWDS.

From 1906 to 1929, the 100-year average carbon storage was about 22,000 MgC ranging from a low point in 1906 of 51 MgC in use and 39 MgC in the SWDS for a total of 90 MgC, to the high point in 1914 of 19,243 MgC in use and 14,864 MgC in the SWDS for a total of 34,107 MgC, before beginning a short downward trend and hitting the global minimum in 1932 with 3,530 MgC in use and 2,726 MgC in the SWDS for a total of 6,256 MgC (fig. 64). After 1932, average carbon storage experienced positive growth at an exponential rate with a moderate amount of inter-annual variability until reaching the global maximum in 1966 with 114,111 MgC in use and 105,214 MgC in the SWDS for a total of 219,325 MgC. Following 1966, average carbon storage in HWP steadily declined with high inter-annual variability until hitting a local minimum in 1982, with 38,330 MgC in use and 35,818 MgC in the SWDS for a total of 74,148 MgC. Carbon storage rapidly increased in 1983 and continued to grow steadily until hitting a local maximum in 1990 with 85,984 MgC in use and 74,278 MgC in the SWDS for a total of 160,262 MgC. This was followed by a rapid decline in carbon storage, hitting a local minimum in 2000 with 7,987 MgC in use and 7,395 MgC in the SWDS for a total of 15,382 MgC. After 2000, carbon storage averaging around 17,000 MgC per year ranging from a local maximum in 2004 with 17,063 MgC in use and 15,509 MgC in the SWDS for a total of 32,572 MgC, to a local minimum in 2008 with 4,957 MgC in use and 5,764 MgC in the SWDS for a total of 10,721 MgC, and ending in 2009 with 7,827 MgC in use and 8,696 MgC in the SWDS for a total of 16,523 MgC (tables 52, 53).

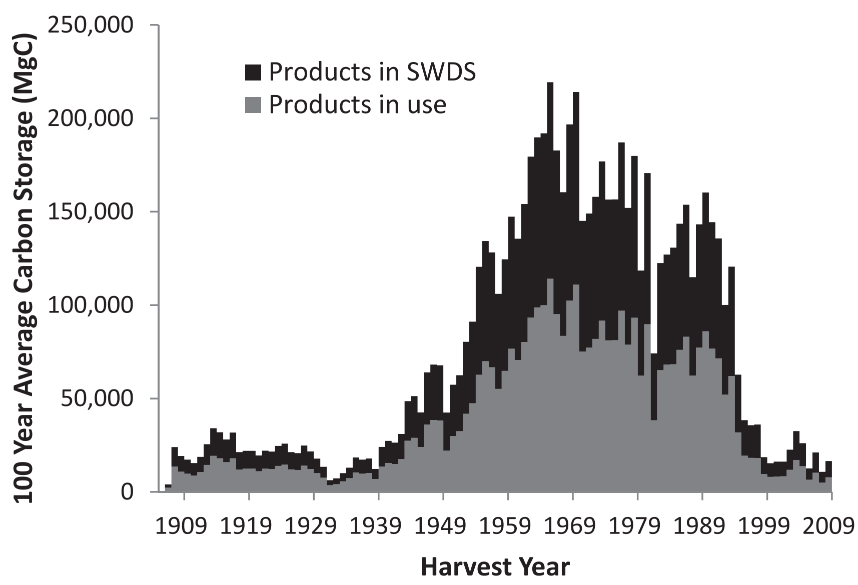

Figure 64—Nez Perce-Clearwater National Forest harvest 100-year average carbon HWP storage using the California Forest Project Protocol

Table 52—Nez Perce-Clearwater National Forest 100-year average carbon stored in HWP for selected years.

Harvest year	Products in use[a]	Landfills and dumps[b]	Total
	(MgC)		
1910	9,739	7,522	17,261
1920	12,406	9,583	21,989
1930	10,039	7,755	17,794
1940	13,558	10,472	24,030
1950	22,092	20,369	42,461
1960	76,675	70,698	147,373
1970	110,960	103,159	214,119
1980	62,249	56,281	118,530
1990	85,984	74,278	160,262
1995	31,840	30,937	62,777
2000	7,987	7,395	15,382
2005	13,707	12,330	26,037
2006	6,455	6,122	12,577
2007	10,292	10,846	21,139
2008	4,957	5,764	10,721
2009	7,827	8,696	16,523

[a] The 100-year average carbon storage in products in use for the harvest year.
[b] The 100-year average carbon storage in SWDS for the harvest year.

Table 53—Nez Perce-Clearwater National Forest confidence intervals for cumulative carbon in HWP for selected years for harvests beginning in 1906.

Inventory year	Total remaining in HWP pool	90% Confidence interval (% difference from estimate) 5%	95%
	(MgC)		
1910	60,941	35,785	90,296
1920	350,018	201,963	529,493
1930	557,857	316,167	873,334
1940	616,897	366,738	943,188
1950	1,058,439	647,255	1,585,958
1960	2,179,940	1,383,894	3,114,547
1970	4,047,162	2,613,015	5,781,770
1980	5,474,327	3,515,590	7,858,956
1990	6,328,974	4,530,669	8,409,504
1995	6,792,982	4,979,178	8,915,771
2000	6,568,378	4,961,232	8,522,883
2005	6,285,342	4,672,753	8,107,624
2006	6,244,605	4,619,107	8,029,800
2007	6,185,373	4,627,606	7,948,553
2008	6,141,595	4,597,996	7,915,006
2009	6,084,101	4,621,054	7,894,833
2010	6,037,645	4,582,570	7,748,961

References

Climate Action Reserve. 2009. Climate Action Reserve 2010: Forest Project Protocol Version 3.2. Los Angeles, CA: Climate Action Reserve. [http://www.climateactionreserve.org/wp-content/uploads/2011/05/Forest_Project_Protocol_Version_3.2.w-Announce.pdf].

Davis, R. C., ed. 1983. Appendix I: The national forests of the United States. In: Encyclopedia of American forest and conservation history. Vol. II, New York: Macmillan Publishing Company: 743-788.

DeBlander, L. T. 2000. Forest resources of the Lolo National Forest. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 13 p.

DeBlander, L. T. 2001a. Forest resources of the Beaverhead-Deerlodge National Forest. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 13 p.

DeBlander, L. T. 2001b. Forest resources of the Custer National Forest. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 13 p.

DeBlander, L. T. 2001c. Forest resources of the Gallatin National Forest. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 13 p.

DeBlander, L. T. 2002. Forest resources of the Lewis and Clark National Forest. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 13 p.

Disney, M. 2010. Forest resources of the Nez Perce National Forest. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 13 p.

Frescino, T. S. 2000. Forest resources of the Bitterroot National Forest. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 13 p.

Galik, C.S.; Jackson, R.B. 2009. Risks to forest carbon offset projects in a changing climate. Forest Ecology and Management. 257(11): 2209-2216.

Galik, C. S.; Mobley, M. L.; Richter, D. 2009. A virtual "field test" of forest management carbon offset protocols: the influence of accounting. Mitigation and Adaptation Strategies for Global Change. 14(7): 677-690.

Hamilton, R.; Megown, K.; DiBenedetto, J.; Bartos, D.; Mikeck, A. 2009. Assessing aspen using remote sensing. RSAC-0110-RPT2. Salt Lake City, UT: U.S. Department of Agriculture Forest Service, Remote Sensing Applications Center. 8 p.

Harkins, K. C.; Morgan, P.; Neuenschwander, L. F.; Chrisman, A.; Jacobson, C.; Grant, M.; Sampson, N. 1999. The Idaho Panhandle National Forests wildfire hazard-risk assessment. Corvallis, OR: Oregon State University. 9 p.

Healey, S. P.; Morgan, T. A.; Songster, J.; Brandt, J. 2009. Determining landscape-level carbon emissions from historically harvested wood products. In: 2008 Forest Inventory and Analysis (FIA) Symposium; October 21-23, 2008: Park City, UT. Edited by: McWilliams, W.; Moisen, G.; Czaplewski, R.: Proc. RMRS-P-56CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 1 CD.

Heath, L. S.; Smith, J. E.; Woodall, C. W.; Azuma, D. L.; Waddell, K. L. 2011. Carbon stocks on forestland of the United States, with emphasis on USDA Forest Service ownership. Ecosphere. 2(1): 21 p.

Hughes, R. P. 2011. Forest resources of the Clearwater National Forest. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 13 p.

Ingerson, A. 2011. Carbon storage potential of harvested wood: summary and policy implications. Mitigation and Adaptation Strategies for Global Change. 16(3): 307-323.

IPCC. 2006. 2006 IPCC guidelines for national greenhouse gas inventories. Prepared by the National Greenhouse Gas Inventories Programme [Institute for Global Environmental Strategies (IGES), Tokyo, Japan, 2006].

Jones J. G.; Loeffler, D.; Calkin, D.; Chung, W. 2010. Forest treatment residues for thermal energy compared with disposal by onsite burning: Emissions and energy return. Biomass and Bioenergy. 34(5): 737-746.

McKeever, D. B. 2009. Estimated annual timber products consumption in major end uses in the United States, 1950-2006. Gen. Tech. Rep. FPL-181. Madison, WI: U.S. Department of Agiriculture, Forest Service, Forest Products Laboratory.. 47 p.

McKinley, D. C.; Ryan, M. G.; Birdsey, R. A.; Giardina, C. P.; Harmon, M. E.; Heath, L. S.; Houghton, R. A.; Jackson, R. B.; Morrison, J. F.; Murray, B. C.; Pataki, D. E.; Skog, K. E. 2011. A synthesis of current knowledge on forests and carbon storage in the United States. Ecological Applications. 21(6): 1902-1924.

Miner, R. 2006. The 100-year method for forecasting carbon sequestration in forest products use. Mitigation and Adaption Strategies for Global Change. 48(7/8): 1-20.

O'Brien, R. A. 1999. Forest resources of the Flathead National Forest. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 13 p.

Palisade Corporation. 2010. @Risk: Advanced risk analysis using Monte Carlo simulation. , Ithaca, NY: Palisade Corporation.

Pan, Y.; Birdsey, R. A.; Fang, J.; Houghton, R.; Kauppi, P. E.; Kurz, W. A.; Phillips O. L.; Shvidenko, A.; Lewis, S. L.; Canadell, J. G.; Ciais, P.; Jackson, R. B.; Pacala, S. W.; McGuire, A. D.; Piao, S.; Rautiainen, A.; Sitch, S.; Hayes, D. 2011. A large and persistent carbon sink in the world's forests. Science. 333(6045): 988-993.

Rebitzer, G.; Ekvall, T.; Frischknecht, R.; Hunkeler, D.; Norris, G.; Rydberg, T.; Schmidt, W. P.; Suh, S.; Weidema, B. P.; Pennington, D. W. 2004. Life cycle assessment part 1: framework, goal and scope definition, inventory analysis, and applications. Environment International. 30(5): 701-20.

Rothermel, R. C. 1993. Mann Gulch Fire: A race that couldn't be won. Gen. Tech. Rep. INT-299. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 12 p.

Ryan, M. G.; Harmon, M. E.; Birdsey, R. A.; Giardina, C. P.; Heath, L. S.; Houghton, R. A.; Jackson, R. B.; McKinley, D. C.; Morrison, J. F.; Murray, B. C.; Pataki, D. E.; Skog, K. E. 2010. A synthesis of the science on forests and carbon for U.S. forests. Issues in Ecology. 13: 6 p.

Skog, K. E. 2008. Sequestration of carbon in harvested wood products for the United States. Forest Products Journal. 58(6): 56-72.

Smith, J. E.; Heath, L. S.; Woodbury, P. B. 2004. How to estimate forest carbon for large areas from inventory data. Journal of Forestry. 102(5): 25-31.

Smith, J. E.; Heath, L. E.; Skog, K. E.; Birdsey, R. A. 2006. Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States. Gen. Tech. Rep. NE-343. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 222 p.

Smith, J. E.; Heath, L. S.; Nichols, M. C. 2007. U.S. Forest carbon calculation tool: Forest-land carbon stocks and net annual stock change. Gen. Tech. Rep. NRS-13. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 36 p.

U.S. Department of Agriculture, Forest Service [USDA]. 1985. Flathead National Forest Plan. Kalispell, MT: U.S. Department of Agriculture, Forest Service, Northern Region.

U.S. Department of Agriculture, Forest Service [USDA]. 1986. Lolo National Forest Plan. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region.

U.S. Department of Agriculture, Forest Service [USDA]. 1987. Idaho Panhandle National Forests Plan. Coeur d'Alene, ID: U.S. Department of Agriculture, Forest Service, Northern Region.

U.S. Department of Agriculture, Forest Service [USDA]. 1994. Fire growth maps for the 1988 greater Yellowstone area fires. Gen. Tech. Rep. INT-304. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 66 p.

U.S. Department of Agriculture, Forest Service [USDA]. 1998. Beaverhead-Deerlodge National Forest Plan: Forest monitoring and evaluation report: Vegetation treatment. Dillon, MT: U.S. Department of Agriculture, Forest Service, Beaverhead-Deerlodge National Forest. 32 p.

U.S. Department of Agriculture, Forest Service [USDA]. 2003. Fire, fuel treatments, and ecological restoration: Conference proceedings. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Proceedings RMRS-P-29. 475 p.

U.S. Department of Agriculture, Forest Service [USDA]. 2004. 16th and 17th Annual monitoring and evaluation report: Executive summary: Fiscal Year 2003 and 2004. Orofino, ID: U.S. Department of Agriculture, Forest Service, Nez Perce National Forest. 45 p.

U.S. Department of Agriculture, Forest Service [USDA]. 2007. Forest plan: Monitoring and evaluation report: Fiscal Year 2006. Libby, MT: U.S. Department of Agriculture, Forest Service, Kootenai National Forest. 28 p.

U.S. Department of Agriculture, Forest Service [USDA]. 2008a. Bitterroot National Forest Plan: Monitoring and evaluation report. Hamilton, MT: U.S. Department of Agriculture, Forest Service, Bitterroot National Forest. 166 p.

U.S. Department of Agriculture, Forest Service [USDA]. 2008b. Insect activity on the Helena National Forest: Assessment and recommendations. Lincoln, MT: U.S. Department of Agriculture, Forest Service, Helena National Forest. 16 p.

U.S. Department of Agriculture, Forest Service [USDA]. 2009a. Web Site: [http://www.fia.fs.fed.us/program-features/tpo/]. Last accessed 2/23/2013.

U.S. Department of Agriculture, Forest Service [USDA]. 2009b. Beaverhead-Deerlodge National Forest Plan: Monitoring and evaluation report. Dillon, MT: U.S. Department of Agriculture, Forest Service, Beaverhead-Deerlodge National Forest. 93 p.

U.S. Department of Agriculture, Forest Service [USDA]. 2009c. Idaho Panhandle National Forest Plan: Monitoring and evaluation reports 2007, 2008, 2009. Coeur d'Alene, ID: U.S. Department of Agriculture, Forest Service, Idaho Panhandle National Forests. 144 p.

U.S. Department of Agriculture, Forest Service [USDA]. 2009d. Clearwater National Forest Annual monitoring and evaluation: Fiscal Year 2009. Grangeville, ID: U.S. Department of Agriculture, Forest Service, Clearwater National Forest. 132 p.

U.S. Department of Agriculture, Forest Service [USDA]. 2010a. Forest management, cut and sold reports. Washington, DC: U.S. Department of Agriculture, Forest Service. [http://www.fs.fed.us/forestmanagement/reports/sold-harvest/cut-sold.shtml]. Last accessed on 2/25/2013.

U.S. Department of Agriculture, Forest Service [USDA]. 2010b. News release: Rocky Mountain District releases benchmark fuels reduction decision. Great Falls, MT: U.S. Department of Agriculture, Forest Service, Lewis and Clark National Forest. 1 p.

U.S. Department of Agriculture, Forest Service [USDA]. 2011a. Helena National Forest: Annual monitoring report: Fiscal year 2008. Helena, MT: U.S. Department of Agriculture, Forest Service, Helena National Forest. 230 p.

U.S. Department of Agriculture, Forest Service [USDA]. 2011b. Draft land management plan: Idaho Panhandle National Forests. Coeur d'Alene, ID: U.S. Department of Agriculture, Forest Service, Idaho Panhandle National Forest. 126 p.

U.S. Department of Agriculture, Forest Service [USDA]. 2011c. Kootenai National Forest Plan: Monitoring and evaluation report. Libby, MT: U.S. Department of Agriculture, Forest Service, Kootenai National Forest. 51 p.

U.S. Department of Agriculture, Forest Service [USDA]. 2011d. Kootenai National Forest Plan: Draft land management. Missoula, MT: U.S. Department of Agriculture, Forest Service, Kootenai National Forest. 428 p.

U.S. Department of Agriculture, Forest Service [USDA]. 2012a. Beaverhead-Deerlodge National Forest home page: About the Forest; [http://www.fs.usda.gov/main/bdnf/about-forest]. Last accessed on 2/25/2013.

U.S. Department of Agriculture, Forest Service [USDA]. 2012b. Montana forest insect and disease conditions and program highlights – 2011. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region. 59 p.

U.S. Department of Agriculture, Forest Service [USDA]. 2012c. Decision memo: Little Belt Mountains hazard tree removal. Great Falls, MT: U.S. Department of Agriculture, Forest Service, Lewis and Clark National Forest. 21 p.

U.S. Department of Agriculture, Forest Service [USDA]. 2012d. News release: Extreme winds bring down trees on numerous snowmobile trails. Great Falls, MT: U.S. Department of Agriculture, Forest Service, Lewis and Clark National Forest. 1 p.

U.S. Department of Agriculture, Forest Service [USDA]. 2012e. Value analysis study summary. Missoula, MT: U.S. Department of Agriculture, Forest Service, Nez Perce-Clearwater National Forest. 16 p.

U.S. Department of Agriculture, Forest Service [USDA]. 2012f. Nez Perce-Clearwater National Forest home page: Nez Perce-Clearwater Forests Supervisor's Office Location Study; [http://www.fs.usda.gov/main/bdnf/about-forest]. Last accessed on 2/26/2013.

U.S. Environmental Protection Agency (EPA) [US EPA]. 2010. Inventory of U.S. greenhouse gas emissions and sinks: 1990–2008. EPA 430-R-10-006. Washington, DC: U.S. Environmental Protection Agency, Office of Atmospheric Programs.; [http://www.epa.gov/climatechange/emissions/usgginv_archive.html]. Last accessed on 2/26/2013.

U.S. Forest Service [USFS]. 2011. Navigating the climate change performance scorecard a guide for national forests and grasslands (Version 2, August 2011). Washington, DC: U.S. Department of Agriculture, Forest Service. 144 p; [http://www.fs.fed.us/climatechange/advisor/scorecard/scorecard-guidance-08-2011.pdf]. Last accessed on 2/26/2013.

Van Deusen, P.; Heath, L. S. 2007. COLE web applications suite. NCASI and Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. [http://www.ncasi2.org/COLE/]. Last accessed on 2/26/2013.

Wilson, A. M.; Miles, P. D. 2000. Forest resources of the Kootenai National Forest. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 13 p.

Wilson, A. M. 2001. Forest resources of the Helena National Forest. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 13p.

Zheng, D.; Heath, L. S.; Ducey, M. J.; Butler, B. 2010. Relationships between major ownerships, forest aboveground biomass distributions, and landscape dynamics in the New England Region of USA. Environmental Management. 45(2): 377-386.

Rocky Mountain Research Station

The Rocky Mountain Research Station develops scientific information and technology to improve management, protection, and use of the forests and rangelands. Research is designed to meet the needs of the National Forest managers, Federal and State agencies, public and private organizations, academic institutions, industry, and individuals. Studies accelerate solutions to problems involving ecosystems, range, forests, water, recreation, fire, resource inventory, land reclamation, community sustainability, forest engineering technology, multiple use economics, wildlife and fish habitat, and forest insects and diseases. Studies are conducted cooperatively, and applications may be found worldwide. For more information, please visit the RMRS web site at: www.fs.fed.us/rmrs.

Station Headquarters
Rocky Mountain Research Station
240 W Prospect Road
Fort Collins, CO 80526
(970) 498-1100

Research Locations

Flagstaff, Arizona	Reno, Nevada
Fort Collins, Colorado	Albuquerque, New Mexico
Boise, Idaho	Rapid City, South Dakota
Moscow, Idaho	Logan, Utah
Bozeman, Montana	Ogden, Utah
Missoula, Montana	Provo, Utah

To learn more about RMRS publications or search our online titles:

www.fs.fed.us/rm/publications

www.treesearch.fs.fed.us