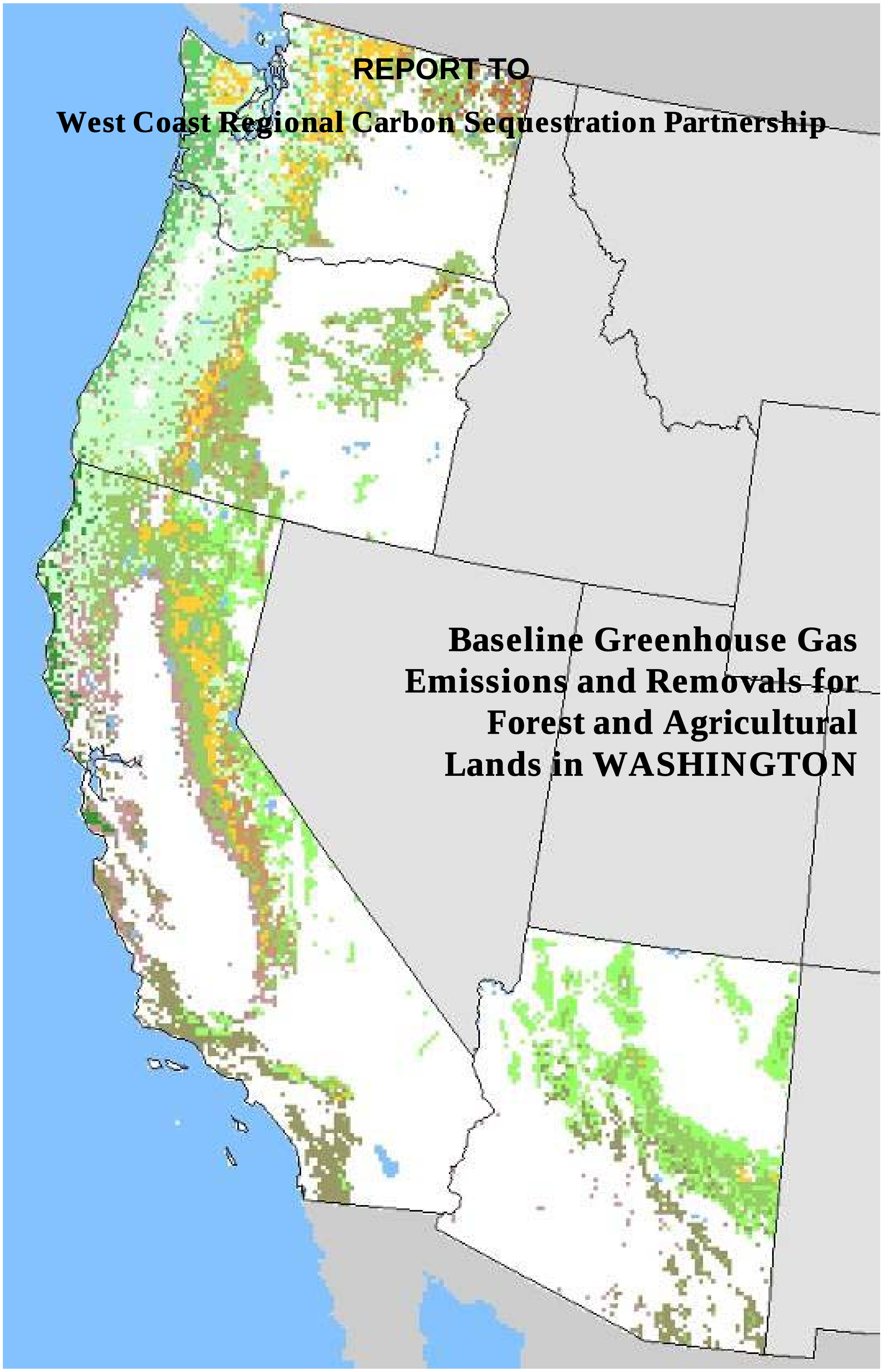
REPORT TO

West Coast Regional Carbon Sequestration Partnership

Baseline Greenhouse Gas Emissions and Removals for Forest and Agricultural Lands in WASHINGTON



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Citations

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EXECUTIVE SUMMARY

The objective of this report is to establish the baseline carbon stocks and changes in stocks for the forest and agricultural sectors in the state of Washington during the most recent 10-year period for which data are available (generally the decade of the 1990s). Such baselines can assist in identifying opportunities where carbon removals (sequestration) in each sector might be increased, or carbon emissions decreased, through changes in the use and management of lands.

Baseline for Forest Lands

The baseline for forests is separated into three components. A general forests baseline is presented at the State level for all forestlands, based on USDA Forest Service data, detailing change in forest area and change in carbon stocks, but with no attribution to the causes for the change. Using additional data bases, the specific cases of emissions associated with development and with fire are further examined. These components form part of the total detailed in the general forest baseline section and should not be considered separately.

General Forestlands Baseline

Forest area and carbon stocks were derived from USFS published data for the period 1987 to 1997. An extrapolation was made for the period 1997 to 2003 using recently completed USFS inventory data.

Between 1987 and 2003 forest area in Washington decreased by 0.9 million acres. Rates of loss between 1987-97 were 62,000 ac per year, and slowed to 49,000 ac/yr between 1997 and 2003 (Table S-1).

This is equivalent to a gross emission of 187 $MMTCO_2e$ or 12.5 $MMTCO_2e$/yr between 1987-97, and 10.1 $MMTCO_2e$/yr between 1997 and 2003.

Table S-1
Gross change in forest area and forest carbon stocks in Washington

	1987	1997	2003	Annual Change 1987-1997	Annual Change 1997-2003
Area (million ac)	22.5	21.9	21.6	-0.062	-0.049
Carbon stock ($MMTCO_2e$)	3,091	2,965	2,904	-12.6	-10.1

The values presented here are gross emissions and will be reduced when consideration of the storage in dead wood and wood products pools are included. However, the emissions from forests are undoubtedly a significant proportion of the total emissions for the State of Washington, estimated to be 101 $MMTCO_2e$ in the year 1995.

Baseline for Development on Forest Lands

The baseline for emissions from development was created using land use data from the National Resources Inventory of the USDA and carbon data derived from the USFS Forest Inventory and Analysis Database (FIA). Due to data availability, the period chosen was 1987 to 1997. The detail of the NRI database made it possible to examine conversion of nonfederal forest lands to other land uses, both at the state and county level of analysis. Due to data limitations the analysis is limited to the gross carbon dioxide emissions from aboveground live tree biomass on conversion of forestland to developed land uses.

Between 1987 and 1997, 246,000 acres of forest were converted to development. Large losses were concentrated in the coastal regions.

For gross carbon emissions, two scenarios were considered. Under Scenario 1 all tree biomass in the converted area was immediately emitted as carbon dioxide. Under Scenario 2 for developed areas of less than 10 acres, it was assumed that 50 % of the carbon was retained in the form of residual trees.

Under Scenario 1, an estimated 70.3 $MMTCO_2e$ were emitted for the 10-year period due to development. Under Scenario 2, 65.4 $MMTCO_2e$ were emitted. Development was concentrated in the Puget Sound region where the major city of Seattle is located (Table S-2). In this region 60 % of the emissions under scenario 1, or 56 % of the emissions under scenario 2 occurred, despite the fact that the region represents only 16 % of the area of the State.

Table S-2
Region-level summary of loss in area and carbon emissions between 1987 and 1997 due to development. Scenario 2 is more conservative assuming that trees are not clearcut during small scale development

	Area lost (thousand ac)	Carbon emissions ($MMTCO_2e$)	
		Scenario 1	Scenario 2
Puget Sound	138.5	42.3	39.4
Olympic	53.8	16.4	15.3
Southwest	30.0	8.2	7.5
Central	20.1	2.9	2.7
Inland Empire	3.3	0.6	0.6
TOTAL	245.7	70.3	65.4

The emissions from development on non-federal lands of 6.5-7.3 $MMTCO_2e$/yr represent between 52 and 55 % of the total gross emissions from the forest sector (12.6 $MMTCO_2e$/yr between 1987 and 1997). Compared to total emissions for the state as a whole, 101 $MMTCO_2e$/yr for the year 1995 (Kerstetter 1999), emissions from deforestation on non-federal land represent more than 5 % of the total in the state.

Baseline Effect of Fire on Forest Lands

Emissions from fire were examined through overlaying the wildfire database for Washington (point data and an estimate of aerial extent) on AVHRR satellite imagery showing change in NDVI. (NDVI measures 'greenness' of landscapes, greenness decreases immediately after fire). This process determined the location, size and estimated intensity (based on degree of change in the NDVI) of fires between 1990 and 1996[1]. Carbon values were applied to these areas burned using data from the USDA FIA and proportional emissions from the detailed baseline fire analysis for California.

Across the six years analyzed, a total area of 70.8 thousand hectares (0.175 million acres) of fire were recorded. This is equivalent to an average 11.8 thousand hectares per year (29.2 thousand ac/yr) for the period studied. Emissions totaling 1.07 $MMTCO_2e$ were estimated to have occurred from fire during the analysis period. On an averaged annual basis this is equal to 0.18 $MMTCO_2e$/yr.

Thirty-three percent of the burned area and 87 % of the emissions were in forest rather than rangeland. No one year dominated fire incidence. Fifty-five percent of area burned and 44 % of the emissions were from private land. Fires covered a greater extent and caused more emissions in the North and Northeast of the State. Incidence was low in the Southeast and Northwest.

Compared to total emissions for the state as a whole, 101 $MMTCO_2e$/yr for the year 1995, the average annual emissions from fire of 0.18 MMTCO2e represented more than 0.2 % of the total in the state.

Baseline for Agricultural lands

A general methodology for determining the agricultural baseline is presented. As with other terrestrial carbon baselines, the areas (acres) of different land uses and changes in land use are combined with carbon densities (tons of carbon per acre) of each land use to yield an estimate of the total emissions and removals of carbon associated with land management and/or conversion of lands over a given time period. Estimates of area and changes in area of agricultural and non-agricultural land use types were derived from the National Resource Inventory (NRI) database for the period 1987 to 1997. The detail of the NRI database made it possible to examine conversion of agricultural lands to other land uses, both at the state and county level of analysis, and for both perennial woody crops (fruit and nut orchards, vineyards, berry crops etc.) and annual non-woody crops.

Agricultural land in Washington amounts to almost 15% of the total land area. The state lost agricultural land area from 1987-97 through conversion to other land uses, in particular to urban development/transportation and the retiring of agricultural land from cultivation. In some counties, the area of woody cropland increased, but these increases were more than offset by decreases in non-woody cropland. Accompanying these losses in area were losses in standing carbon stocks on agricultural land, so that conversion of agricultural land to other uses was responsible for a net annual emission of CO_2 to the atmosphere of 0.05 $MMTCO_2eq$/yr (Table S-3).

Table S-3
Summary of agricultural land area and changes in area, carbon stocks and changes in stocks, for Washington 1987-97

Parameter	Units	Results
Proportion of agricultural land to total land	%	14.6
Change in agricultural land area, 1987-97	Hectares (%)	-234,486 (8%)

[1] 1994 was excluded due to poor image quality.

Change in woody cropland area		+43,828 (37%)
Change in non-woody cropland area		-278,314 (9.9%)
Total carbon stocks in agricultural land, 1997	$MMTCO_2e$	22.9
Change in carbon stocks in agricultural land,	$MMTCO_2e$	-0.5
Estimated net annual source (emissions) from agricultural lands, disregarding non-CO_2 greenhouse gas emissions	$MMTCO_2e$	-0.05
From woody cropland		+0.1
From non-woody cropland		-0.15
Estimated net annual source from non-CO_2 greenhouse gas emissions, 1995	$MMTCO_2e$	-3.54

Emissions of CO_2 from agricultural land conversion, while the primary focus of this report, represent only a portion of the total greenhouse gas emissions attributable to the agricultural sector. The primary non-CO_2 greenhouse gas associated with agricultural activities, emitted from agricultural soils especially after fertilizer application, is nitrous oxide (N_2O), with approximately 296 times the global warming potential of CO_2. Examination of data from Washington indicated that greenhouse gas emissions from N_2O dwarf the annual CO_2 source from agricultural land conversion: CO_2 emissions from land conversion represented about 1.4% of the total CO_2 and non-CO_2 greenhouse gas emissions attributable to the agricultural sector.

Chapter 1 – Introduction and Background Information

1.1 General Approach

The purpose of this baseline document is to examine changes in land use and the associated emissions or sequestration of carbon for forest and agricultural lands in the State of Washington.

Separate baseline analyses are included here for forestlands and agricultural lands. The agricultural land study follows the same principles as the California baseline study (Brown et al. 2004). For forestlands, the California baseline study was based on CA-specific interpreted satellite imagery that detailed the scale of change, vegetation type and cause of change. Because no comparable data is available for Washington, we instead rely predominantly on two national datasets (see Section 1.2). The consequence of using generalized broad-scale datasets is that the outcome is less certain than we were able to achieve in California.

The forest baseline includes a state-level analysis on the change in area and carbon stocks in all forestland, plus a county-level analysis of changes on non-Federal forestland. Also included are specific case studies on emissions due to development and fire.

1.2 Datasets used in the Analysis

Two datasets are used repeatedly through the baseline analyses:

1.2.1 The National Resources Inventory

The National Resources Inventory (NRI) is conducted by the US Department of Agriculture - National Resources Conservation Service (NRCS). The NRI is a scientifically-designed survey of the nation's soil, water, and other related resources with the purpose of assessing conditions and trends. The NRI contains data only on non-Federal lands and water bodies. As noted in the Users' Manual (NRCS 2000), the NRI data are useful in developing estimates of natural resource conditions and in conducting geospatial and temporal analyses of these conditions (however, the location of the survey plots is not given in the data base). In these baseline analyses, NRI data were used for estimates of area because NRI data is available across the WESTCARB States, wide in coverage, and available for multiple points in time and multiple classes of land use.

Because NRI data come from a sample survey, it is important to have a sufficient sample size for a reliable estimate. The NRI Users' Manual does not recommend that the data be used for county-level analysis because of sample size issues. However, we argue that NRI data is statistically appropriate for county-level analysis for the West Coast states. The nationwide average number of sampling points is about 270 per county, while the average for Washington is 449 points per county, almost twice the national average.

To be conservative, here analyses are reported at the State level. County level results are given for illustrative purposes only.

NRI analyses are for the time period 1987 to 1997. More recently the NRI has switched to annual reporting, but this data is not yet publicly available.

1.2.2 The Forest Inventory and Analysis Database

Forest biomass was estimated using the US Forest Service Forest Inventory and Analysis (FIA) database. Following Acts of Congress in 1928 and 1974, the USFS has been systematically collecting data via the FIA on US forests.

The FIA data is composed of a hierarchy of the following nine tables: SURVEY, COUNTY, PLOT, SUBPLOT, CONDITION, TREE, SEEDLING, SITETREE and BOUNDARY. Examples of plot-level records include: State, County, Plot number, Owner, Forest type, Stand age, Site productivity, and Slope. Examples of tree-level records include: State, County, Plot number, Tree number, Diameter at breast height (DBH), Crown class, Volume, Growth, and Expansion Factors (which allow extension from values per plot to per acre). Diameters are included in the database for all trees with DBH > 1". Creating links between the different hierarchies of the database and utilizing the expansion factors allows the user to explore a variety of topics related to biomass stocks in trees.

In this baseline study, data were downloaded from the FIA website on the scale of individual trees within plots within each county within each state. Using the biomass regressions of Jenkins et al. (2003), diameter at breast height (DBH) was converted to biomass for each tree. Area expansion factors (plot to acre), metric conversions and summation were used to calculate biomass in metric tons per hectare. In the fire baseline, forests are consolidated by forest type which is a plot-level characteristic.

1.3 Geographical Subdivision of the State

In the forest baseline, the State is subdivided into regions. These regions are based on FIA 'units' but are convenient due to climatic, topographic and vegetation similarities within units (Table 1-1). Both the forest and agricultural baselines include county-level analysis; counties in Washington are shown in Figure 1-1.

Table 1-1
Five Washington regions with the component counties detailed

Region	Counties
Puget Sound	Island, King, Kitsap, Pierce, San Juan, Skagit, Snohomish, Whatcom
Olympic Peninsula	Clallam, Grays Harbor, Jefferson, Mason, Thurston
Southwest	Clark, Cowlitz, Lewis, Pacific, Skamania, Wahkiakum
Central	Adams, Asotin, Benton, Columbia, Ferry, Franklin, Garfield, Grant, Lincoln, Pend Oreille, Spokane, Stevens, Walla Walla,
Inland Empire	Chelan, Douglas, Kittitas, Klickitat, Okanogan, Yakima

Figure 1-1
Washington counties. Source: Digital Map Store, *http://county-map.digital-topo-maps.com/washington.shtml*.

Chapter 2 – Baselines for Forests in Washington

2.1 Introduction

This chapter presents a baseline for emissions and sequestration in the forests of Washington. Forest is defined here as land with a greater than 10 % stocking of trees (as in the FIA and NRI).

The forest baseline chapter is presented in three sections.

In Section 2.2 a general forest baseline is presented detailing changes forest area and in stocks in the forests of Washington with an estimate of annual sequestration / emissions. A State level total is presented for all forests with county level detail only for non-Federal Lands.

The remaining sections present case studies of individual causes of emissions from forests. These case studies should not be considered on top of the general baseline (section 2.2) but as a subset of it. Emissions from fire or development will have formed part of the total emissions from forests that are presented or alternatively will have decreased the total estimated sequestration presented from forests.

In Section 2.3 the case study of emissions caused by development on forestland is presented.

In Section 2.4 the case study of emissions caused by fire on forestland is presented.

2.2 General Forests Baseline

2.2.1 State Level Analysis for all Forestlands

1987-1997

The USDA Forest Service published a baseline for forests in Washington between 1987 and 1997 (Birdsey and Lewis 2003). Estimates are based on forest inventory data collected by the Forest Service's Forest Inventory and Analysis Unit. Determination of the location of tree measurement plots and changes in land area were assessed using high altitude photography. Where forest inventory was not available estimates of land use change were derived from the National Resources Inventory.

Between 1987 and 1997 Birdsey and Lewis (2003) estimated a change in forest area for Washington from 9.1 million hectares in 1987 to 8.9 million hectares in 1997. This is a loss of 245,148 hectares of 24,515 hectares per year.

Across the state Birdsey and Lewis calculated a mean forest carbon stock density of 92.5 t C/ha in 1987 and 91.3 t C/ha in 1997, this is a loss of 1.2 t C/ha over the ten years.

Combining the area data with the carbon stock density data gives a total stock on forestland in WA in 1987 and 1997 and a change in stock between the two dates.

The stock in 1987 was estimated as 843 million t C and this fell to 808.6 million t C in 1997. This is equal to a loss of 34.5 million tons of carbon or 3.4 million tons of carbon per year.

Beyond 1997

Using the Forest Inventory Mapmaker (version 2.1, http://www.ncrs2.fs.fed.us/4801/fiadb/fim21/wcfim21.asp), a total estimated area of forestland was attained for the year 2003. This area was 8.7 million ha which is equal to a loss of 117,533 ha from the total in 1997 or a loss of 19,589 ha per year. The rate of loss in forest area has therefore decreased by 20 % between 1997 and 2003 in comparison with the rate between 1987 and 1997.

To attain carbon stock densities to apply to the areas an extrapolation was made from the change in stock density between 1987 and 1997.

	1987	1997	2003
t C/ha	92.5	91.3	90.6

This results in a 2003 carbon stock of 791.9 million tons of carbon or a loss of 16.8 million t C from the total in 1997, which equals a loss of 2.8 million t C per year. The rate of carbon loss due to loss in forest area decreased by 19 % between 1997 and 2003 in comparison with 1987-1997.

2.2.2 Changes in Forest Area on Private Land

This section provides a detailed baseline at the county level for the change in area in privately owned forests in Washington. Changes are only examined on private land. It is not expected that widespread deforestation is occurring on public lands though some afforestation may be overlooked.

The change in land use associated with forests on private lands in OR was analyzed from the National Resources Inventory (NRI). Two dates were used that reported data at the county scale of resolution: the most recent publicly available data for 1997 and for 1987. At the State level all land in forest was estimated in 1987 and 1997 plus the broad destination or origin of land that changed from or to forest in the same time period (Table 2-2-1).

Table 2-2-1
Change in area (ha) between 1987 and 1997 for private forestland in Washington

Category	Unchanged	Lost to	Gained from
Unchanged	5,139,730		
Development		99,435	1,336
Pasture/Rangeland		21,530	40,106
Farmland/Agriculture		3,278	5,868
Other		6,435	7,082
1987 Total			**5,270,408**
1997 Total			**5,194,122**

In Washington forest area decreased by 76,286 hectares in the ten years, or 7,628 ha/yr. Of the total area of forest in 1987, 97.5 % of remained unchanged. There was a loss of 130,678 hectares principally to development and a gain of 54,392 hectares of which 74 % was from pasture/rangeland.

County-Level Changes in Forest Area

Across the State net losses in forest area occurred in 51 % of counties, with gains in forest area in 28 % of the counties. Losses of more than 7,000 hectares occurred in King, Pierce, Snohomish, Thurston and Kitsap Counties, which are all located in the Coastal region. Gains of > 2,500 ha occurred in Steven, Ferry, Pend Oreille and Okanogan Counties, which are all located East of the Cascades (Table 2-2-2).

Table 2-2-2
Area (ha) of nonfederal forestland in Washington in 1987 and 1997 and change between the two dates

County	Population	County Area	Forest 1987	Forest 1997	Change
Adams	16,428	498,563	-	-	-
Asotin	20,551	164,553	12,141	13,638	1,497
Benton	142,475	441,099	-	-	-
Chelan	66,616	756,631	44,881	46,581	1,700
Clallan	64,525	450,516	211,496	209,716	(1,781)
Clark	345,238	162,709	88,386	81,628	(6,758)
Columbia	4,064	225,022	23,473	25,091	1,619
Cowlitz	92,948	294,907	249,498	244,439	(5,059)
Douglas	32,603	471,514	-	-	-
Ferry	7,260	570,829	304,253	307,248	2,995
Franklin	49,347	321,781	-	-	-
Garfield	2,397	184,031	9,308	9,308	-
Grant	74,698	694,392	-	-	-
Grays Harbor	67,194	496,471	393,652	388,795	(4,856)
Island	71,558	53,984	34,319	31,607	(2,711)
Jefferson	25,953	469,883	169,367	166,372	(2,995)
King	1,737,034	550,643	265,726	251,521	(14,205)
Kitsap	231,969	102,557	72,482	65,238	(7,244)

Kittitas	33,362	594,969	171,229	170,662	(567)
Klickitat	19,161	484,943	195,470	195,430	(40)
Lewis	68,600	623,575	352,008	351,401	(607)
Lincoln	10,184	598,599	43,343	43,343	-
Mason	49,405	248,913	152,491	149,779	(2,711)
Okanogan	39,564	1,364,423	294,824	297,333	2,509
Pacific	20,984	241,638	211,011	210,727	(283)
Pend Oreille	11,732	362,668	125,781	129,221	3,440
Pierce	700,820	434,837	216,676	201,298	(15,379)
San Juan	14,077	45,305	32,012	31,405	(607)
Skagit	102,979	449,399	174,385	170,743	(3,642)
Skamania	9,872	429,015	82,923	82,276	(648)
Snohomish	606,024	541,065	178,999	167,263	(11,736)
Spokane	417,939	456,780	141,321	142,454	1,133
Stevens	40,066	641,877	402,231	408,949	6,718
Thurston	207,355	188,298	123,231	108,095	(15,136)
Wahkiakum	3,824	68,438	59,248	59,289	40
Walla Walla	55,180	329,059	11,777	13,274	1,497
Whatcom	166,814	548,957	141,564	137,477	(4,087)
Whitman	40,740	559,275	9,146	10,765	1,619
Yakima	222,581	1,112,718	271,756	271,756	-
TOTAL			**5,270,408**	**5,194,122**	**(76,286)**

Losses in forest area over the study period occurred in the three coastal regions, with gains in forest area in the Central and Inland Empire regions (Table 2-2-3)(for definitions of regions see Chapter 1).

Table 2-2-3
Area of nonfederal forestland in 1987 and 1997 and change between two dates

	Area (ha)		**Change**
	1987	**1997**	**Area**
Puget Sound	1,116,163	1,056,550	**(59,612)**
Olympic Peninsula	1,050,237	1,022,758	**(27,479)**
Southwest	1,043,074	1,029,759	**(13,315)**
Central	1,082,775	1,103,293	**20,518**
Inland	978,160	981,762	**3,602**

2.2.3 Conclusions

An estimated 245 thousand hectares of forest were lost in Washington State between 1987 and 1997 at a rate of 24,515 ha/yr. Between 1997 and 2003 an estimated 117.5 thousand additional hectares were lost at a rate of 19,589 ha/yr. These losses are equivalent to 0.27 % of the forest area per year between 1987 and 1997 and 0.22 % of the forest area per year between 1997 and 2003.

A gross emission of an estimated 126.5 MMTCO_2e would have occurred between 1987 and 1997 (12.6 MMTCO_2e/yr) and 61.6 MMTCO2e (10.3 MMTCO_2e/yr) between 1997 and 2003.

These emissions are gross and would be lowered through, for example, consideration of use of harvested timber and the lifetime of these wood products. However, the gross emission between 1997 and 2003 of 10 $MMTCO_2e$ represented approximately 10 % of the total estimated emission from the State of Washington in 1995 of 101 $MMTCO_2e$ (Kerstetter 1999). *(Note, however, emissions / sequestration from forests were not considered by Kerstetter (1999)).*

For just non-federal lands the net loss is 76 thousand ha primarily in the coastal regions and dominantly in the Puget Sound.

2.3 Development Baseline

2.3.1 General Approach

This section provides a baseline for the emissions of carbon attributable to development of forest lands in Washington. This analysis should be considered a subset of the general forest baseline: the emissions due to development will form part of wider changes in carbon stocks in the State. If this analysis is added to the analysis of the general forest baseline then double counting will occur.

Forest land development is examined only for private lands; it is not expected that widespread development is occurring on public land. Changes in stocks are only changes in aboveground tree biomass, due to uncertainties surrounding both the absolute level of carbon in other carbon pools and whether or not development will cause emissions from these pools.

As in the general forest baseline, changes in forest area due to development were based on NRI data for changes in land use. Carbon stocks and changes in stocks were derived from FIA data. For the purposes of this study, development includes three NRI categories:

- Urban / 10 acres or larger
- Urban / small built-up. The category 'Urban/small built-up' will be referred to as small-scale development.
- Transportation

Statistical confidence can only be maintained in results given at the State level, due to the design of the NRI database. Results are given here at the County level merely for illustrative purposes.

2.3.2 Changes in Area at the State and County Level

Between 1987 and 1997 almost 99,435 hectares of forest were lost in Washington State to development, or 9,944 ha per year. The loss over ten years is equivalent to 1.9 % of the total forest area present in the State in 1987. Just over one thousand hectares reverted from developed land to forest. Of the total area lost to development, 14 % could be considered as small-scale development (Table 2-3-1).

Table 2-3-1
Nonfederal forest area between 1987 and 1997 in Washington. Area in hectares

	Unchanged	Lost to	Gained from
Unchanged	5,139,730		
Development		**99,435**	**1,336**
% small scale		***14%***	
Pasture/Rangeland		21,530	40,106
Farmland/Agriculture		3,278	5,868
Other		6,435	7,082
1987 Total			**5,270,408**
1997 Total			**5,194,122**

Major losses in forest area to development occurred in Clark, King, Pierce, Snohomish and Thurston Counties, all of which are in the coastal region and all of which surround the major cities of Portland, Oregon (Clark) and Seattle, Washington (King, Pierce, Snohomish, Thurston)(Figure 2-3-1, Table 2-3-2). These five counties represent 16 % of the forest area in Washington in 1997, but 58 % of the total area lost to development over the ten-year study period.

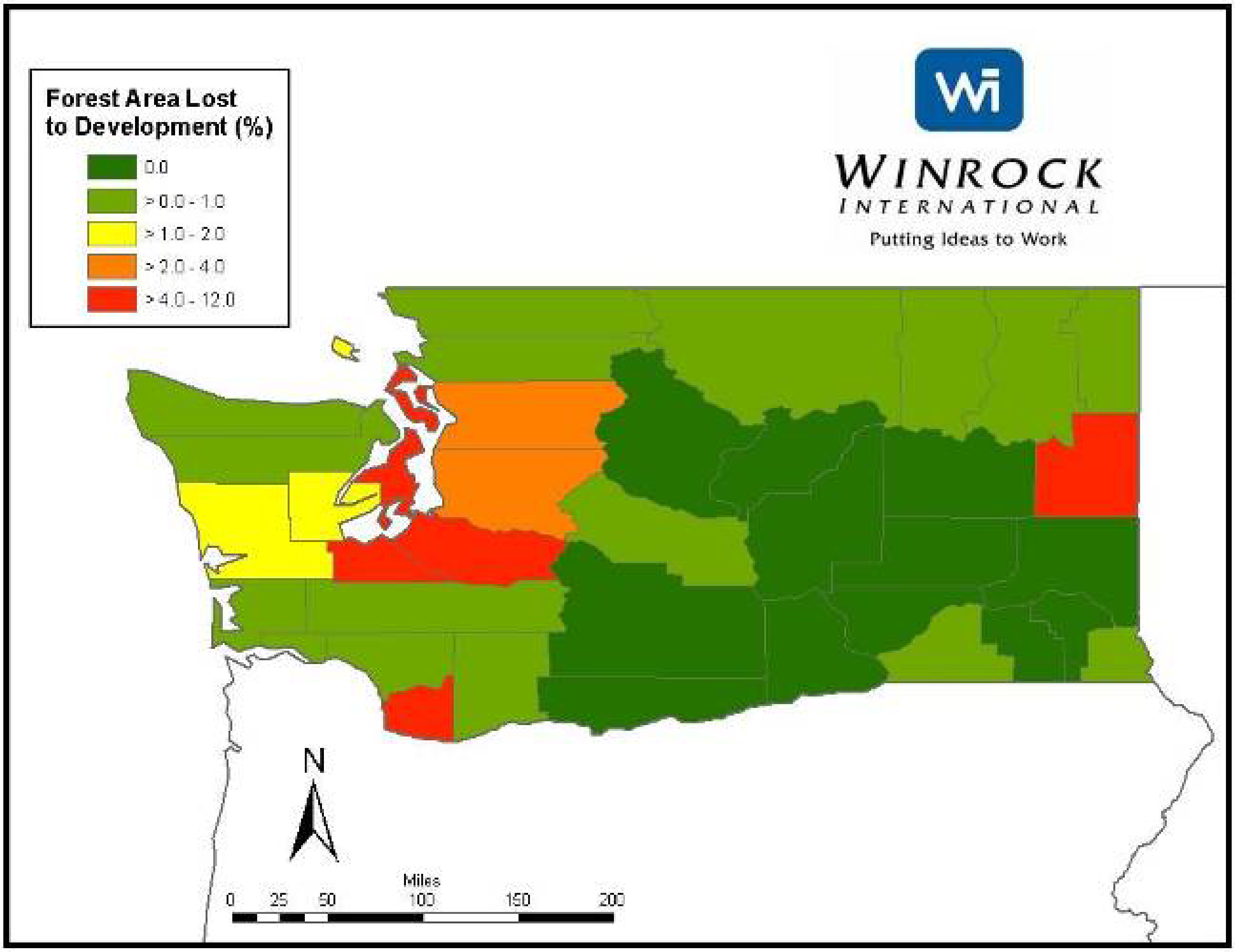

Figure 2-3-1
Loss in forest area between 1987 and 1997 as a percentage of total forest area in the county

Table 2-3-2
County level data on area of nonfederal forest in 1997, area of forest lost to development between 1987 and 1997 and % of losses that were small-scale

	Population	County Area (ha)	Non-Federal Forest Area in 1997 (ha)	Area Lost to Development (ha)	*% small scale*
Adams	16,428	498,563		0	
Asotin	20,551	164,553	13,638	81	*50%*
Benton	142,475	441,099		0	
Chelan	66,616	756,631	46,581	0	
Clallan	64,525	450,516	209,716	1,619	*20%*
Clark	345,238	162,709	81,628	6,192	*16%*
Columbia	4,064	225,022	25,091	0	
Cowlitz	92,948	294,907	244,439	1,740	*35%*
Douglas	32,603	471,514		0	
Ferry	7,260	570,829	307,248	324	*25%*
Franklin	49,347	321,781		0	
Garfield	2,397	184,031	9,308	0	
Grant	74,698	694,392		0	
Grays Harbor	67,194	496,471	388,795	4,775	*3%*
Island	71,558	53,984	31,607	2,388	*27%*
Jefferson	25,953	469,883	166,372	2,833	*16%*
King	1,737,034	550,643	251,521	13,355	*6%*
Kitsap	231,969	102,557	65,238	7,244	*33%*
Kittitas	33,362	594,969	170,662	688	*0%*
Klickitat	19,161	484,943	195,430	0	
Lewis	68,600	623,575	351,401	3,480	*8%*
Lincoln	10,184	598,599	43,343	0	
Mason	49,405	248,913	149,779	2,469	*23%*
Okanogan	39,564	1,364,423	297,333	648	*0%*
Pacific	20,984	241,638	210,727	202	*40%*
Pend Oreille	11,732	362,668	129,221	445	*55%*
Pierce	700,820	434,837	201,298	14,448	*10%*
San Juan	14,077	45,305	31,405	688	*24%*
Skagit	102,979	449,399	170,743	1,416	*23%*
Skamania	9,872	429,015	82,276	405	*10%*
Snohomish	606,024	541,065	167,263	13,760	*12%*
Spokane	417,939	456,780	142,454	5,666	*2%*
Stevens	40,066	641,877	408,949	1,578	*15%*
Thurston	207,355	188,298	108,095	10,077	*15%*
Wahkiakum	3,824	68,438	59,289	121	*67%*
Walla Walla	55,180	329,059	13,274	40	*100%*
Whatcom	166,814	548,957	137,477	2,752	*10%*
Whitman	40,740	559,275	10,765	0	
Yakima	222,581	1,112,718	271,756	0	

2.3.3 Carbon stocks

Estimates of the carbon stocks in live tree biomass are derived from the FIA data base. The FIA databases for 1992/1991 were used as these dates represent a midpoint between 1987 and 1997. FIA data were consolidated at the FIA Unit Level. Biomass carbon estimates were derived from the measurements of tree diameter at breast height for all trees in inventory plots using the allometric equations of Jenkins et al. (2003), scaled up to a per-ha basis using the plot-area expansion factors (Table 2-3-3).

Table 2-3-3
Mean carbon stock (from FIA data) for each region of Washington with the number of plots and the confidence interval around the stock estimate

t C/ha	**Mean**	***95 % CI***	**# plots**	**Counties**
Puget Sound	205.8	*9.9*	676	Island, King, Kitsap, Pierce, San Juan, Skagit, Snohomish, Whatcom
Olympic Peninsula	205.9	*11.8*	656	Clallam, Grays Harbor, Jefferson, Mason, Thurston
Southwest	183.6	*10.6*	657	Clark, Cowlitz, Lewis, Pacific, Skamania, Wahkiakum
Central	96.4	*15.0*	307	Adams, Asotin, Benton, Columbia, Ferry, Franklin, Garfield, Grant, Lincoln, Pend Oreille, Spokane, Stevens, Walla Walla,
Inland Empire	113.5	*6.5*	362	Chelan, Douglas, Kittitas, Klickitat, Okanogan, Yakima

2.3.4 Carbon emissions from development

Two carbon emission scenarios are considered here.

- Scenario 1 assumes that all carbon present on the land in aboveground tree biomass is lost when development occurs.
- Scenario 2 assumes that when small scale development occurs, a significant proportion of the trees remain during and after the process of development. As examples, these may be trees surrounding residential properties or trees on golf courses. Therefore, in this scenario we assume that for Transportation and Urban/10 acres or larger, all carbon is lost, but for Urban/small built-up, only 50 % of the carbon stocks are emitted.

Total emissions from development over the ten-year period were estimated as 19.2 million t C under Scenario 1 and 17.8 million t C under Scenario 2. This is equivalent to 1,918,228 and 1,784,005 t C per year. Emissions by county are summarized below (Figure 2-3-2, Table 2-3-4).

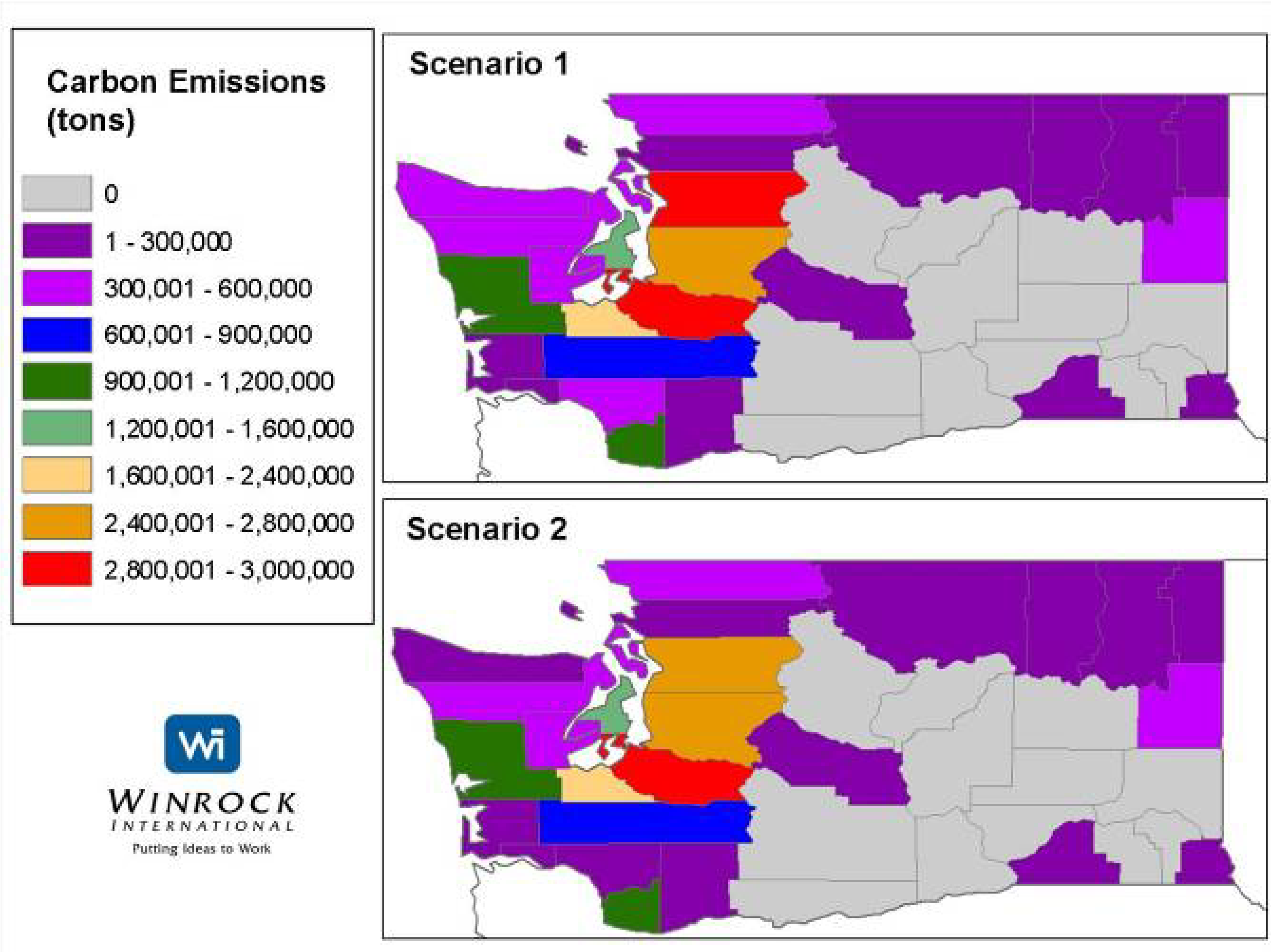

Figure 2-3-2
Carbon emissions under the two scenarios at the county level across the state

Table 2-3-4

County-level estimates on the emissions between 1987 and 1997 due to development. Scenario 2 is more conservative assuming that trees are not clearcut during small scale development

	Population	County Area (ha)	Non-Federal Forest Area in 1997 (ha)	Carbon emissions (t C) Scenario 1	Scenario 2
Adams	16,428	498,563		-	-
Asotin	20,551	164,553	13,638	7,806	5,855
Benton	142,475	441,099		-	-
Chelan	66,616	756,631	46,581	-	-
Clallan	64,525	450,516	209,716	333,246	299,921
Clark	345,238	162,709	81,628	1,136,998	1,044,106
Columbia	4,064	225,022	25,091	-	-
Cowlitz	92,948	294,907	244,439	319,549	263,813
Douglas	32,603	471,514		-	-
Ferry	7,260	570,829	307,248	31,225	27,322
Franklin	49,347	321,781		-	-
Garfield	2,397	184,031	9,308	-	-
Grant	74,698	694,392		-	-
Grays	67,194	496,471	388,795	983,074	966,412
Island	71,558	53,984	31,607	491,368	424,741
Jefferson	25,953	469,883	166,372	583,180	537,358
King	1,737,034	550,643	251,521	2,748,327	2,665,045
Kitsap	231,969	102,557	65,238	1,490,759	1,245,075
Kittitas	33,362	594,969	170,662	78,066	78,066
Klickitat	19,161	484,943	195,430	-	-
Lewis	68,600	623,575	351,401	639,097	613,087
Lincoln	10,184	598,599	43,343	-	-
Mason	49,405	248,913	149,779	508,199	449,881
Okanogan	39,564	1,364,423	297,333	73,474	73,474
Pacific	20,984	241,638	210,727	37,157	29,725
Pend Oreille	11,732	362,668	129,221	42,935	31,225
Pierce	700,820	434,837	201,298	2,973,190	2,823,282
San Juan	14,077	45,305	31,405	141,580	124,924
Skagit	102,979	449,399	170,743	291,489	258,176
Skamania	9,872	429,015	82,276	74,314	70,598
Snohomish	606,024	541,065	167,263	2,831,610	2,656,716
Spokane	417,939	456,780	142,454	546,439	540,585
Stevens	40,066	641,877	408,949	152,222	140,513
Thurston	207,355	188,298	108,095	2,074,454	1,916,162
Wahkiakum	3,824	68,438	59,289	22,294	14,863
Walla Walla	55,180	329,059	13,274	3,903	1,952
Whatcom	166,814	548,957	137,477	566,322	537,173
Whitman	40,740	559,275	10,765	-	-
Yakima	222,581	1,112,718	271,756	-	-

The highest loss in area due to development (56 % of total loss) and the highest emissions (60 % of total under scenario 1, 56 % under scenario 2) occurred in the Puget Sound region (Table 2-3-5) even though these counties only account for 16 % of the area of the state.

The small difference between Scenario 1 and 2 reflects the fact that the majority of development across the state is large scale (> 10 acres).

Table 2-3-5
Region-level summary of loss in area and carbon emissions between 1987 and 1997 due to development. Scenario 2 is more conservative assuming that trees are not clearcut during small scale development

	Area lost (ha)	Carbon emissions (t C) Scenario 1	Scenario 2
Puget Sound	56,051	11,534,646	10,735,133
Olympic	21,773	4,482,153	4,169,735
Southwest	12,141	2,229,409	2,036,193
Central	8,134	784,531	747,451
Inland Empire	1,336	151,541	151,541

This is equal to an annual loss in area across the state of almost 10 thousand hectares with annual carbon dioxide equivalent emissions of between 6.5 and 7 million metric tons of CO_2e (Table 2-3-6).

Table 2-3-6
Region-level summary of annual loss in area and carbon dioxide equivalent emissions between 1987 and 1997 due to development. Scenario 2 is more conservative assuming that trees are not clearcut during small scale development

	Area lost per yr (ha/yr)	Annual carbon emissions ($MMTCO_2e$) Scenario 1	Scenario 2
Puget Sound	5,605	4.23	3.94
Olympic	2,177	1.64	1.53
Southwest	1,214	0.82	0.75
Central	813	0.29	0.27
Inland Empire	134	0.06	0.06
TOTAL	9,944	7.03	6.54

2.3.5 Additional Considerations

Emissions discussed presented above for conversion of forestland to development are gross emissions from aboveground tree biomass only.

Gross vs Net Emissions

The analysis here represents gross changes. The only consideration was of emissions from losses of forest to development.

Where gains of forest were made from development, this was not considered.

The destination of biomass upon development is also not considered. The assumption is made that all carbon is immediately emitted. In reality this is unlikely to be the case. Some of the wood is likely to ultimately become fire wood, some will be left to decompose and some may be used as timber and will have a longer existence as wood products. Regardless, all trees cut for development will ultimately be emitted to the atmosphere as carbon dioxide or carbon dioxide equivalents. Instead of including any delay here the assumption is made of immediate emission.

Other Carbon Pools

Aboveground tree biomass was the only carbon pool considered in this analysis. The reason behind this decision was the uncertainty involved in other pools generally, and specifically in the case of development.

Soil carbon is particularly uncertain. If the land is capped by concrete it is unlikely that soil carbon will be affected at all. If grasses are planted there is even the possibility that development could lead to an increase in soil carbon.

For similar reasons roots are also uncertain. The rate at which roots decompose is very poorly known and even less is known about the diminished rate if the roots are buried beneath concrete or tarmac.

Dead wood and litter are likely to be emitted either immediately upon development or through time as decomposition occurs. However, there is no clear relationship between aboveground tree biomass and these pools and the uncertainty involved with any assumption would be very large.

Non-carbon dioxide greenhouse gas emissions are also unknown. If site preparation occurs through burning, there will be emissions of methane and nitrous oxide. If site preparation involves drainage there will be emissions of methane. Without specific site-by-site information it is not possible to make these estimations.

2.3.6 Conclusions

An estimated 99 thousand hectares were lost to development in Washington State between 1987 and 1997 at a rate of 9,943 hectares per year. This forest loss is equivalent to a gross emission of between 65 and 70 million metric tons of carbon dioxide equivalent or 6.5 to 7.0 $MMTCO_2e$ per year.

The emissions are concentrated in the coastal region and in particular in the Puget Sound (the region in which Seattle is located).

These emissions compare with the estimated gross emission from forests in Washington of 12.6 $MMTCO_2e$/yr between 1987 and 1997 (Section 2.2) and gross emissions for the state of 101 $MMTCO_2e$/yr for the year 1995 (Kerstetter 1999). Emissions from deforestation on non-federal land therefore represent between 52 and 55 % of the total gross emissions from the forest sector and more than 5 % of the total emissions in the state. However, Kerstetter (1999) considered neither emissions nor sequestration from forests and so the emissions calculated here would be in addition to the reported annual 101 MMTCO_2e.

2.4 Fire Baseline

In this fire analysis the emissions caused by fire between 1990 and 1996 are estimated. These emissions are part of the general forest baseline (section 2.2), without emissions from fire the general forest baseline would be raised by an amount equal to these emissions.

This baseline, unlike the general forest baseline and the development emissions baseline contains an analysis of rangelands as well as forests.

There are two components to a fire analysis. It is necessary to know both the area that is burnt and the amount of biomass that is volatilized into greenhouse gases per area. Knowledge of these components permits an estimation of total fire-derived emissions.

The period 1990 to 1996 was chosen for this analysis, for (although a partial dataset exists for 1997-2003) these study dates represent the most recent, consistent complete coverage. Complete coverage is essential in order to be able to make State level conclusions on the impact of fire.

2.4.1 Methods for Assessing Biomass Volatilized

2.4.1.1 Background

The effects of fire on carbon stocks are dependent on the intensity of the fire. An intense fire will destroy biomass and release a great proportion of the carbon to the atmosphere, while a less intense fire will even fail to kill the majority of the trees. Here fires are divided into three potential intensities: high, medium and low.

Pre-fire carbon has five potential destinations during and after a fire (Fig. 2-4-1). The first proportion will survive the fire to continue as live vegetation, a second proportion will be volatilized during the fire and immediately released to the atmosphere and the remainder will be divided between the pools of dead wood, soot and charcoal. Soot and charcoal are stable forms of carbon and can remain unchanged for very many years; in contrast dead wood decomposes over time.

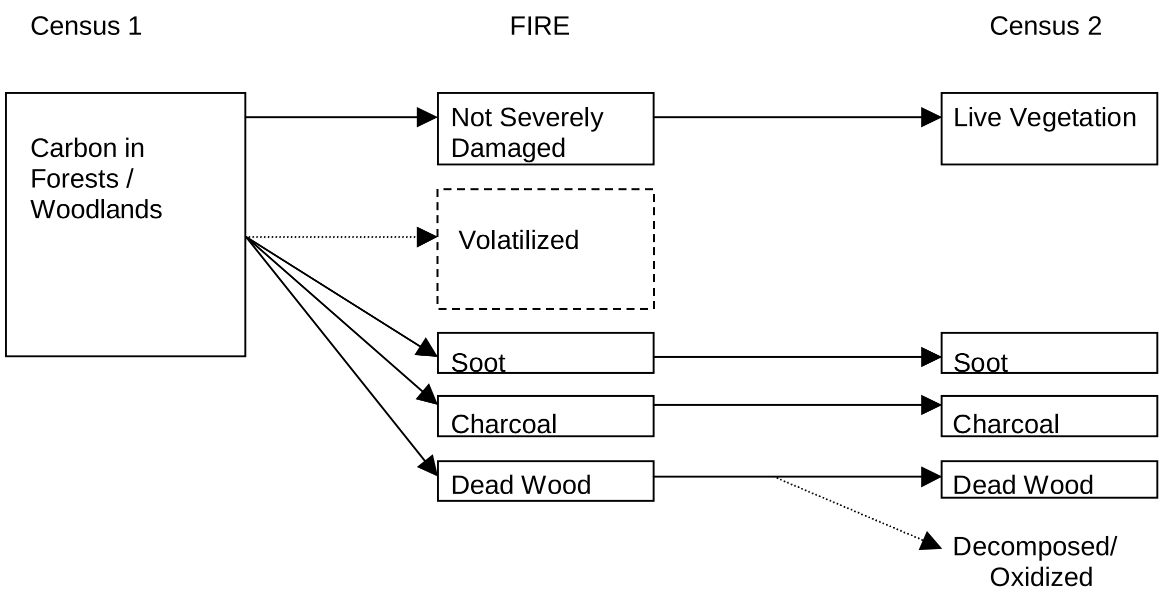

Figure 2-4-1
Flow Diagram Illustrating the Various Destinations of Pre-burn Carbon after a Fire

The basis for this baseline analysis was the detailed study conducted for California (Brown et al. 2004). Under the California baseline analysis changes in canopy coverage (measured from satellite imagery) were recorded through time for forest types and causes including fire were assigned. We assumed (based on expert opinion) that the three intensities are associated with the magnitude of change in crown cover, so that a large decrease in crown cover would be due to a high intensity fire or a small decrease is caused by a low intensity fire.

The midpoint of each decrease in canopy coverage class was assumed to be the proportion of the vegetation killed by the fire. The proportion volatilized is dependent on fire intensity (60 % high intensity fire, 40 % mid-intensity, 20 % low intensity; McNaughton et al. 1998; Carvalho et al. 2001). If the volatilized proportion is subtracted from the midpoint of the decrease then the remaining fraction is the dead wood, soot and charcoal pool. This fraction was divided using the following proportions: 22 % charcoal, 44 % soot, 32 % dead wood (Comery 1981, Raison et al. 1985, Fearnside et al. 1993, Neary et al. 1996).

2.4.1.2 Approach for Calculations

The aim of this study is to determine the loss in biomass as a result of fire in Washington. In California we had data on the area affected by fire in classes of initial and post fire crown cover and forest type. The degree of reduction in crown cover was used to indicate the intensity of the fire. We also had the biomass associated with each crown cover class and so a change between two cover classes could be represented as a loss in carbon. In contrast, in Washington available data included only forest type and an indication of fire intensity from fire extent and change in spectral reflectance.

The approach for this study is therefore to use the California data to determine the percentage loss in biomass that occurs as a result of a high, a medium or a low intensity fire in each of the forest types. The percentage loss is then applied to Washington-specific biomass numbers.

The source of biomass values is the Washington 2004 inventory of the FIADB (forest inventory and analysis database). These were split between forest types. In all cases, Washington FIA data were divided by the four forest / woodland types (Douglas Fir, Fir-Spruce, Other Conifer, Hardwood Forest; Table 2-4-1) at the county level. The division by forest / woodland type occurred to align the Oregon analysis with the original California study (Brown et al. 2004).

Table 2-4-1
Forest types for fire baseline analysis cross-walked with FIA forest type

California-analysis forest type	FIA forest type
Douglas-fir	Douglas-fir
Fir Spruce	White fir, Red fir, Noble fir, Pacific silver fir, Engelmann spruce, Engelmann spruce / Subalpine fir, Grand fir, Subalpine fir, Blue spruce, Sitka spruce
Other Conifer	Port-Orford cedar, Ponderosa pine, Western white pine, Jeffrey pine / Coulter pine / big cone Douglas-fir, Mountain hemlock, Lodgepole pine, Western hemlock, Western redcedar, Alaska yellow cedar, Western larch, Misc. western softwoods
Hardwoods - forest	Cottonwood, Willow, Oregon Ash, Aspen, Red alder, Bigleaf maple, Tanoak, Giant chinkapin, Pacific Madrone

The FIA data was further split into regions – Eastern, Central and Coastal with the assumption that the climatic variation will lead to variation in biomass that will refine our estimates. The split of counties between regions is listed in Chapter 1, with the exception that Puget Sound, the Olympic Peninsula and the Southwest are combined into a single Coastal region.

The mean biomass stocks were calculated from WA FIA data by region and forest type (Table 2-4-2).

Table 2-4-2
Mean biomass stock by forest type and region

	Mean biomass		
t biomass/ha	Coastal	Central	Eastern
Douglas Fir	293.4	147.9	201.7
Fir Spruce	369.3	219.5	261.8
Other Conifer	466.8	127.8	145.8
Hardwood	207.2		

2.4.1.3 Biomass Loss through Fire

To calculate the emissions through fire, results from the California analysis (Brown et al. 2004) were used. From the California analysis, the estimated stocks for each forest type at each of the 4 canopy density classes was taken, plus the net emissions for each forest type/canopy density class/fire intensity class. Finally the emissions were calculated as a proportion of the original biomass and the results expressed as a percentage.

As no canopy cover class data exists for Washington, a mean emission percentage is required excluding canopy cover. This was achieved by weighting the emission percentages by the proportion of forest in each canopy class in the most representative region of California (North Coast for Coastal regions and Cascades Northeast for Central and Eastern regions).

The proportions by forest type by region by fire intensity were then multiplied by the biomass by forest type by region to give estimated biomass lost through emissions from fire (Tables 2-4-3, 2-4-4, 2-4-5).

Table 2-4-3
Mean emissions from a high, mid and low intensity fire in the Coastal Region of Washington

t biomass/ha	High	Mid	Low
Douglas Fir	127.5	54.8	22.1
Fir Spruce	194.1	85.0	34.2
Other Conifer	184.3	122.1	60.8
Hardwood	98.7	42.6	17.2

Table 2-4-4
Mean emissions from a high, mid and low intensity fire in the Central Region of Washington

t biomass/ha	High	Mid	Low
Douglas Fir	62.1	26.7	10.7
Fir Spruce	114.4	50.4	20.3
Other Conifer	48.1	31.9	15.9
Hardwood			

Table 2-4-5
Mean emissions from a high, mid and low intensity fire in the Eastern Region of Washington

t biomass/ha	High	Mid	Low
Douglas Fir	84.6	36.4	14.6
Fir Spruce	136.4	60.2	24.2
Other Conifer	54.8	36.3	18.1
Hardwood			

2.4.1.4 Non-Tree Vegetation

Biomass numbers for non-tree vegetation (primarily shrubs and grasses in rangelands) are taken from the literature and Winrock International experience (Table 2-4-5).

Table 2-4-5
Estimates of pre-fire biomass stocks in non-tree vegetation

Vegetation type	Biomass carbon (t C/ha)	Source
Wet Grasslands	5.9	Prichard et al
Mesic Grasslands	2.4	Brown and Archer
Xeric Grasslands	0.6	Winrock unpublished data
Shrublands	5.1	Martin et al
Desert scrub	2.6	Winrock unpublished data

Here the conservative assumption is made that 50 % of the pre-fire biomass in non-tree vegetation is volatilized to be emitted as carbon dioxide.

2.4.2 Methods for Assessing Area Impacted by Fire and Fire Intensity

Satellite-based analysis is a practical method of quantifying area burned primarily due to the dangerous nature and the wide geographic extent of wildfires. The State reports the location and size of recorded fires but with no measure of fire intensity, nor with the location of the boundaries of the fire. It is necessary to know fire intensity to estimate emissions and the precise location is necessary for a correlation with a database of vegetation species. The approach for this analysis was to estimate the extent of fires at known fire locations, through delineating areas with a change in reflectance on multiple satellite images.

A common measurement of vegetation from satellite imagery is the Normalized Difference Vegetation Index (NDVI). Very low values of NDVI (0.1 and below) correspond to barren areas of soil without vegetation or of sand, rock or snow. Moderate values represent shrub and grassland (0.2 to 0.3), while high values indicate forests (0.6 to 0.8).

2.4.2.1 Databases

NDVI was calculated from 1.1 km pixel resolution NOAA Advanced Very High Resolution Radiometer (AVHRR) 10 day composite images. The temporal frameset covered the month of September and spanned 1990 – 2003 (except 1994). This encompassed the NOAA 11, 14, 16 satellites. September was chosen for the analysis time frame because it is towards the end of the fire season and the burned areas are not yet affected by regrowth. Only one September 1994 composite was produced for 1994 due to the failure of the AVHRR sensor aboard NOAA-11. As a result, the imagery for 1994 along with fire data were dropped from the analysis due to data inconsistencies in image values and incomplete temporal coverage from sensor failures.

The wildfire database for Washington encompassed a total of 15,994 occurrences that vary from less than 1 acre to many thousand acres. Fires for the study period with a final size greater than 2,000 acres were identified for NDVI postfire burn detection analysis to quantify area burned. Each fire record included a unique ID with a GPS point location, date, and final extent in acres. There was no GIS polygon representing the extent of the fire in the original database so it was not possible to precisely locate the extent of the fire.

2.4.2.2 Mapping Methods

Fire Identification

This analysis used a postfire burn detection method to quantify area burned by wildfires. NDVI was calculated from the water vapor corrected bands 10, visible (0.58 - 0.68 µm) and band 11, near infrared (0.725 – 1.10 µm).

NDVI = (ch 11 – ch 10) / (ch 11 + ch 10).

In order to obtain a single September NDVI for each year of the study period, three or in some years four, 10 day composites were averaged into a single image ($NDVI_y$). These September images were then averaged into a 13 year historical NDVI reference image ($NDVI_m$).

NDVI reflectance values are bi-modal, ranging from -1.0 to 1.0. Positive values reflect vegetation or 'greenness', and negative values are indicative of soil or non-vegetated areas. Values close to 1 are 'greener' than values close to 0 and values close to -1 are more non-vegetative than values close to 0. When vegetation is burned, a rise in channel 10 reflectance and a decrease in channel 11 reflectance occurs. The degree of change ($NDVI_d$) was measured by subtracting $NDVI_y$ from $NDVI_m$

$NDVI_y - NDVI_m = NDVI_d$

From the reference image each individual annual September image was subtracted and potential fire locations identified. In NDVI difference imagery, positive values indicate an increase in 'greenness' from $NDVI_m$ and negative values a decrease. For burned area-identification purposes, all positive values were removed along with negative values greater than -0.05. The result was an image containing areas of concentrated vegetation decrease. The fire location data was then overlaid to confirm the changes as potential fires.

Fire Extent

The extent of fires listed as having over 2,000 acres in final size were mapped by visual interpretation from the changes seen in $NDVI_d$ with assistance from the fire's GPS location and extent information (Figure 2-4-2).

The wildfire mapping process consisted of creating polygons that represent the extent of the burn area. Fires were first divided into big and small based on final extent. Fires with a final extent of < 2,000 acres or 8 pixels were labeled as small fires. For AVHRR imagery, 1 pixel = 100 hectares = 247.5 acres. Areas of vegetation decrease in $NDVI_d$ greater than 8 pixels and with a corresponding fire greater than 2,000 acres were digitized using the 'heads up method'[2]. The area digitized was then compared with the reported final extent.

[2] Heads up digitizing refers to on screen digitizing. It is referred to as 'heads up' because the analyst focuses on the screen as opposed to on a digitizing tablet.

All fires with less than 2,000 acres burned were classified too small to display a change in the AVHRR imagery. For these fires, a buffer was calculated and added to the fire point based on the GPS point, which was considered the center of the fire, and the radius; that was derived from the size reported in the original record.

Additionally, if a fire that was larger than 2,000 acres could not be mapped by visual interpretation, it was mapped by the buffering method.

Fire Severity

For the fires that occurred in forested lands, three classes of burn severity were identified: low, medium, and high (Figure 2-4-2). Again, the intensity was evaluated separately depending on the fire mapping method. For the fires that were identified using the imagery, the value of burn severity corresponded with the value of the difference in NDVI. The rationale is that the more negative the difference between the actual NDVI and the mean NDVI, the more severe is the fire. As a result, one fire can include areas with different burn severities. Small fires (< 2,000 acres) were arbitrarily considered to experience a low burn fire severity, since there was no image data to consistently support the estimation.

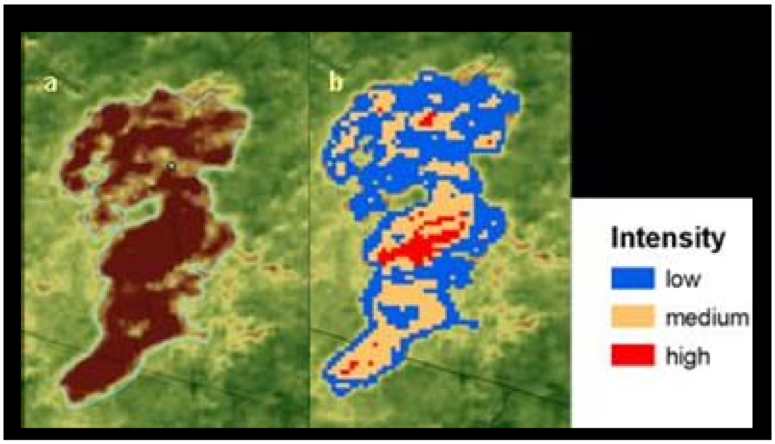

Figure 2-4-2
Illustration of the mapping methodology. In (a) the point location from the State or Federal database is established, a fire boundary is then created and compared to the fire area reported with the point location; in (b) the fire intensity through the burn area is calculated using NDVI values.

Land Cover Affected by Fire

Finally, the fires map were crossed with the land cover maps, making possible to estimate the amount of land cover type / forest type that was affected by fires.

2.4.3 Results

Across the six years analyzed, fires with a total area of 70.8 thousand hectares (0.175 million acres) were recorded (illustrated in Figure 2-4-3). This is equivalent to an average 11.8 thousand hectares per year (29.2 thousand ac/yr) for the period studied.

Emissions totaling 0.29 million tons of carbon or 1.07 $MMTCO_2e$ were estimated to have occurred from fire during the analysis period. On an averaged annual basis this is equal to 48.6 thousand tons of carbon per year (0.18 $MMTCO_2e$/yr).

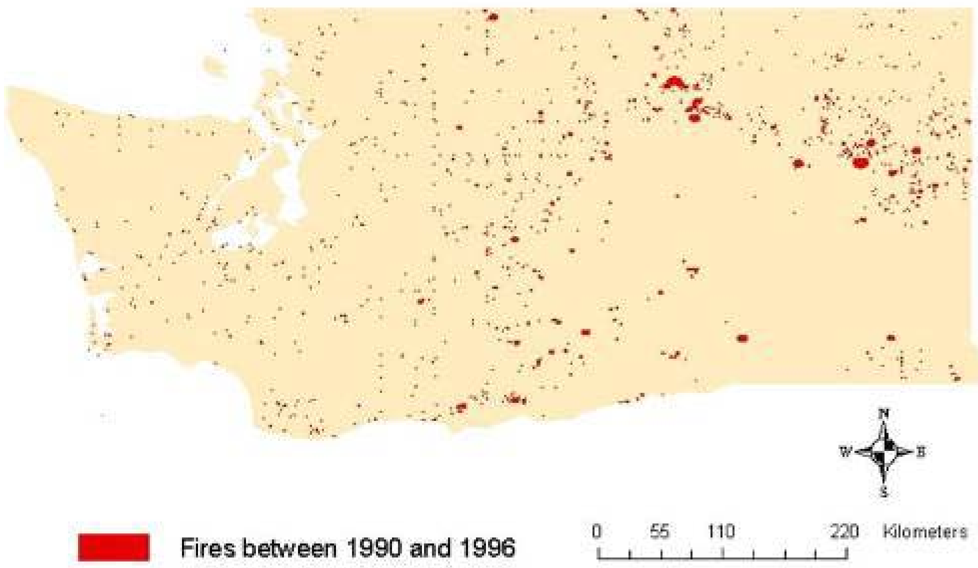

Figure 2-4-3
The location and extent of fires in Arizona between 1990 and 1996

Thirty-three percent of the fires occurred in forests and 47 % in rangeland during the study period (Table 2-4-6)[3]. Due to the higher biomass loss from forests during fire more than 87 % of the total emissions from fire originated in the 33 % of fire area that was in forest.

Table 2-4-6
Area burned and carbon emissions in forests and in rangeland across the analysis period

	Area burned (ha)	Emissions (t C)
Forest	23.665	254.594
Rangeland	33,002	37,290

Emissions from fire happened each year of the analysis (Table 2-4-7, Figure 2-4-4). (1994 was not examined due to poor image quality). The largest areas of fire occurred in 1991, 1992 and 1996. In each of the remaining years less than 10 thousand hectares were burned and less than 50,000 tons of carbon

[3] The remaining fire area was on developed, agricultural or barren land

emitted. The lowest burn year was 1995 when 2.4 thousand hectares burned. The lowest emissions occurred in 1993 with 12 thousand tons of carbon released through fire.

Table 2-4-7
Area burned and carbon emissions per year across the analysis period

YEAR	Area burned (ha)	Emissions (t C)
1990	8.144	44.440
1991	20,382	92,703
1992	16,612	63,643
1993	3,191	12,184
1994		
1995	2,371	20,506
1996	20,141	58,415

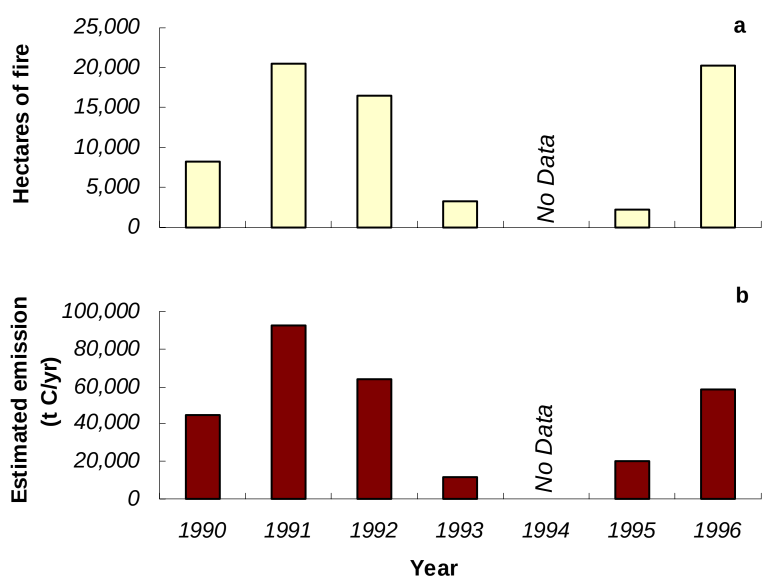

Figure 2-4-4
Area impacted by fire and estimated emissions from fire across the study period

Fifty-five percent of the area burned and 44 % of the emissions from fire occurred on private land (Table 2-4-8).

Table 2-4-8
Area burned and carbon emissions by ownership across the analysis period

OWNERSHIP	Area burned (ha)	Emissions (t C)
City or Municipal Government	3	16
County Government	4	26
Private	31,712	128,700
State Government	5,731	27,748
Tribal	22,035	67,772
US Federal Government	11,356	67,629

Emissions from fire occurred throughout Washington State. However the areas burned were lowest in the developed Northwest and non-forested Southeast (Figure 2-4-5, Table 2-4-9). The largest areas burned and the greatest quantity of emissions were in the North and Northeast, for example Okanogan had 17 thousand hectares of fire during the study period, which caused an estimated emission of 35.6 thousand tons of carbon (Figure 2-4-6, Table 2-4-9).

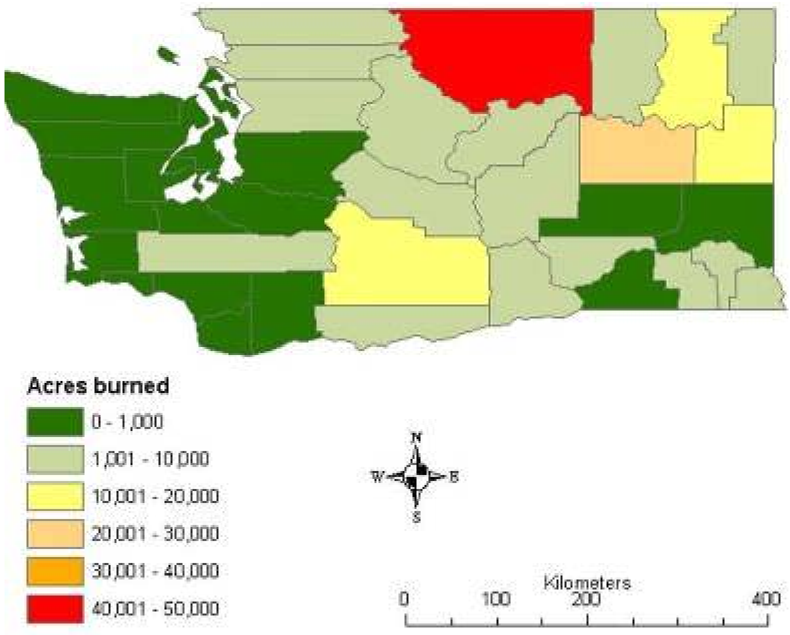

Figure 2-4-5
Area burned (in acres), at the county level, between 1990 and 1996 (excluding 1994)

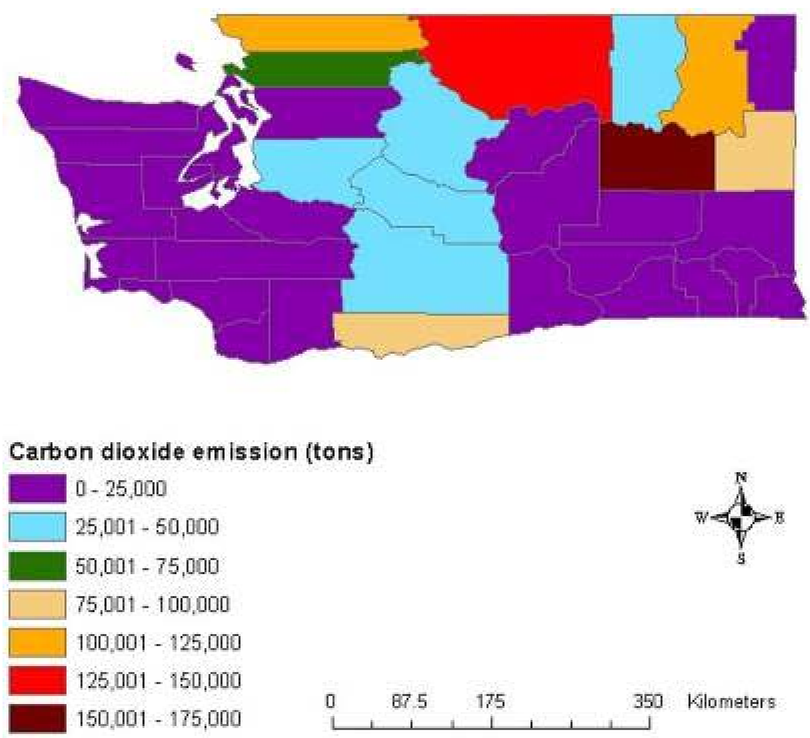

Figure 2-4-6
Metric tons of carbon dioxide emitted, at the county level, between 1990 and 1996 (excluding 1994)

Table 2-4-9
Area burned and carbon emissions per county across the analysis period

COUNTY	County Area (ha)	Area burned (ha)	Emissions (t C)
Adams	498.563	275	239
Asotin	164,553	584	1,102
Benton	441,099	1,542	1,924
Chelan	756,631	3,829	10,976
Clallam	450,516	190	4,454
Clark	162,709	71	536
Columbia	225,022	794	1,480
Cowlitz	294,907	91	635
Douglas	471,514	686	1,245
Ferry	570,829	1,426	10,877
Franklin	321,781	2,714	821
Garfield	184,031	596	306
Grant	694,392	1,141	1,439
Grays Harbor	496,471	169	2,331
Island	53,984	30	237
Jefferson	469,883	50	1,226
King	550,643	296	7,016
Kitsap	102,557	20	556
Kittitas	594,969	2,695	7,049
Klickitat	484,943	3,846	24,584
Lewis	623,575	513	4,502
Lincoln	598,599	9,320	42,460
Mason	248,913	207	4,387
Okanogan	1,364,423	16,981	35,610
Pacific	241,638	236	1,802
Pend Oreille	362,668	554	3,110
Pierce	434,837	48	744
San Juan	45,305	1	15
Skagit	449,399	641	17,435
Skamania	429,015	199	1,463
Snohomish	541,065	539	4,978
Spokane	456,780	6,924	25,134
Stevens	641,877	4,832	31,175
Thurston	188,298	141	1,804
Wahkiakum	68,438	1	4
Walla Walla	329,059	12	96
Whatcom	548,957	1,758	29,309
Whitman	559,275	1	0
Yakima	1,112,718	6,886	8,829

2.4.4 Uncertainties

The carbon stocks to which percentage emission factors are applied are averaged values across all FIA plots in a forest type / region combination. Consequently, the same average value is used to represent forests with very high carbon stocks or very low carbon stocks. Fires will occur in forests regardless of starting carbon stock, yet it is possible that the forests with the very lowest carbon stocks (for example in the year immediately after clear cut logging) may not have enough biomass to sustain a fire. The emissions reported here may therefore be a small *overestimate* for if the very lowest biomass plots are excluded from the FIA analysis the mean will be raised and consequently the estimated emissions.

The calculated emissions presented here are conservatively limited to just aboveground tree biomass and therefore represent an *underestimation* of total emissions. Carbon stored in other pools will combust and be emitted through fire. However, we have no detailed source that will link the region and forest type-specific FIA data on aboveground tree biomass with similar data on other carbon pools.

Fire will directly impact dead wood, litter, shrubs and herbs (though even these pools may not be completely volatilized in low severity fires (e.g. Skinner 2002)). The influence of fire on soil carbon or the carbon stored in roots is less clear. When a tree is killed, the roots will not be burned but will become dead material that will decompose at a rate that is not well understood. A very intense fire will impact soil carbon though it is not fully understood what proportion of soil carbon is volatilized nor what depth the impact penetrates to.

To give an indication of the scale of potential additional emissions for pools not included here, the literature was consulted. Smithwick et al. (2002) took measurements of all carbon pools across 43 stands at seven sites in Washington and Oregon. The authors divided their measurements into three regions – Coastal, Cascades and Eastern. No measurements were taken in Eastern Washington so the results from Eastern Oregon are presented here. Values for roots were not taken from Smithwick et al. (2002), roots were estimated more directly by using the temperate forest allometric equation of Cairns et al. (1997), which calculates belowground biomass from aboveground biomass. The amount of additional biomass carbon as a percentage of aboveground live tree biomass carbon stocks is given in Table 2-4-X.

Table 2-4-10
Relative increase in stocks that would result from adding each of the additional carbon pools to live aboveground trees

	Litter	Dead Wood	Shrubs	Herbs	Roots	Soil Carbon
Coastal	6 %	26 %	0.12 %	0.12 %	23-25 %	54 %
Cascades	8 %	26 %	0.25 %	0.07 %	25-26 %	31 %
Eastern	22 %	23 %	0.38 %	0.09 %	24-26 %	43 %

The measurements of Smithwick et al (2002) were in old growth forests. In younger forests lower absolute amounts of dead wood might be expected together with similar quantities of litter, shrubs and herbs. Therefore a lower proportion of dead wood and a higher proportion of litter, shrubs and herbs might be expected in younger forests.

Here, as an indication of potential additions, the values of Smithwick et al. (2002) are used. Adding just litter, dead wood, shrubs and herbs, and assuming that the same proportion of these pools are volatilized as for live aboveground trees, gives an additional emission over the study period equal to 41,253 tons of carbon or an additional 7.4 %.

2.4.5 Conclusions

Across the six years analyzed[4], fires with a total area of 70.8 thousand hectares (0.175 million acres) were recorded. This is equivalent to an average 11.8 thousand hectares per year (29.2 thousand ac/yr) for the period studied. Emissions totaling 0.29 million tons of carbon or 1.07 $MMTCO_2e$ were estimated to have occurred from fire during the analysis period. On an averaged annual basis this is equal to 48.6 thousand tons of carbon per year (0.18 $MMTCO_2e$/yr).

Thirty-three percent of the burnt area and 87 % of the emissions were in forest as opposed to rangeland. No one year dominated fire incidence. Fifty-five percent of area burned and 44 % of the emissions were from private land. Fires covered a greater extent and caused more emissions in the North and Northeast of the State. Incidence was low in the Southeast and Northwest.

Compared to total emissions for the state as a whole, 101 $MMTCO_2e$/yr for the year 1995, the average annual emissions from fire of 0.18 MMTCO2e represented more than 0.2 % of the total in the state.

[4] 1994 was excluded due to poor image quality.

Chapter 3 – Baselines for Agricultural Lands in Washington

3.1 General Approach

The goal of this report is to quantify the baseline of changes in carbon stocks in the Washington agricultural sector for the decade of the 1990s. Baselines provide an estimate of the emissions and removals of greenhouse gases caused by changes in the use and management of land. The focus of this report is on emissions and removals of carbon dioxide and not on non-CO_2 greenhouse gases. Baselines are useful for identifying where, within the landscape of a state, opportunities exist for enhancing carbon stocks and/or reducing carbon sources to mitigate greenhouse gas emissions.

The baseline for the agricultural sector depends on two types of data: (1) the total area of agricultural land, and area of each of the major agricultural land-use types, through time; (2) the carbon stocks in each land-use type. Areas and changes in area of agricultural lands are based primarily on the National Resource Inventory (NRI) database for the period 1987-1997. Carbon stock estimates for various agricultural land-use types were derived from consultation with experts in local universities and from the literature in combination with standard methods. The analysis is conducted for the entirety of the state of Washington at the county scale of resolution.

3.1.1 Classification of Agricultural Land

In this study, NRI data were used for estimates of area because of the NRI's relative strength in agricultural surveys compared with other sources of data. The coverage of NRI data is wider and is available across the states for multiple points in time and for multiple classes of agriculture.

In this analysis, agricultural land is equated to cropland as defined in the NRI (NRCS 2000). The NRI recognizes two categories of cropland: cultivated and non-cultivated. Cultivated cropland includes small grains and row crops, hay and pasture with cropping history, and horticulture with double cropping (meaning horticulture with crops planted under the trees). Non-cultivated cropland includes horticulture without double cropping, and hay without cropping history.

The distinction between cultivated and non-cultivated crops is not useful for the purpose of carbon analysis, which depends instead on biomass models based on the growth form of the vegetation. Therefore, the specific land-use categories from NRI were regrouped for this analysis into categories related to the growth form of the crop. All horticulture lands, with or without double cropping, were reclassified as woody cropland. The rest of the croplands, including hay, row crops and small grains, were considered to be non-woody crops (Table 3-1).

Table 3-1
NRI Categories and Subcategories in Washington

Broad classification	Detailed classification	NRI classification	Broad classification	Detailed classification	NRI classification
Perennial woody crops	Fruit orchards		Pasture / rangeland	Pasture / rangeland	Pasture / Grass
	Nut orchards				Pasture / Legume
	Vineyards				Pasture / Grass-forbs-legumes
	Bush crops				Rangeland
	Berry crops		Forest	Forest	Forestland / Grazed
	Other horticulture				Forestland / Not grazed
Annual non-woody crops	Row / close crops	Row / Corn	Urban / transportation	Urban / transportation	Urban / 10 acres or larger
		Row / Sorghum			Urban / Small built-up
		Row / Soybeans			Transportation
		Row / Cotton	Other	Other	Other farmland / Farmsteads
		Row / Peanuts			Other farmland / Other land
		Row / Tobacco			Other farmland / CRP land
		Row / Sugar beets			Barren / Salt flats
		Row / Potatoes			Barren / Bare exposed rock
		Row / Other veg / truck			Barren / Strip mines
		Row / All other row crops			Barren / Beaches
		Row / Sunflower			Barren / Sand dunes
		Close / Wheat			Barren / Mixed barren lands
		Close / Oats			Barren / Mud flats
		Close / Rice			Barren / River wash
		Close / Barley			Barren / Oil wasteland
		Close / All other close			Barren / Other barren land
		Hay / Grass			Other rural / Permanent snow-
		Hay / Legume			Other rural / Marshland
		Hay / Legume-grass			All other land
		Other crop / Summer fallow			Water / Body 2-40 acres
		Other crop / Aquaculture			Water / Body less than 2 acres
		Other crop / Other-set-aside			Water / Streams per. < 66 ft.
					Water / Streams per. 66-660 ft.
					Water / Large

3.1.2 Limitations of the NRI Database

Despite the general acceptance of NRI for agricultural resource analysis, it is important to note its limitations. First, the samples were taken from non-federal lands only, while in the West Coast states, federal lands occupy half or more of the total land area. Second, the data are not from a complete census, but rather from a statistically sound sampling design. Finally, the NRI's classification of land cover/land use types may not be consistent with other classification schemes commonly used in land cover/land use analysis, e.g. the classification in USGS National Land Cover Classification system.

For the purposes of this report, however, these limitations have virtually no effect on the analysis as the data are only being used for the agricultural sector, where lands are privately owned, easy to classify, and statistically well reported.

The NRI reports a margin of error for the 1997 reporting (equivalent to a 95% confidence interval) of ±9% for its sampling of areas of cropland.

3.1.3 Area and Change in Area of Agricultural Land

The NRI data for each state were reclassified into the broad classes shown in Table 3-1. The areas for each class in each state for 1987 and 1997 were then calculated. Although data for 1992 were available, a similar analysis for California where the change over two 5-year periods was included (1987-1992 and 1992-1997) indicated that using two periods did not appear to add any further insights into the dynamics of land-use and carbon stock change. Thus for the three states in this report, we only examine the change over the 10-year period 1987 to 1997.

3.1.4 Carbon Density of Agricultural Land

The baseline analysis for the agricultural sector focuses on carbon in vegetation only, including above- and belowground (roots) components. Carbon in vegetation is estimated as 50% of the biomass of the vegetation.

Carbon Stocks for Non-Woody and Woody Crops

A difficulty in estimating the biomass of non-woody annual crops is caused by the seasonal change of the vegetation. During the non-growing season, there is little biomass in annual crops, while at the peak of the growing season just before harvest, biomass can be high. Considering that litter production is usually low in these crops, peak biomass is assumed to be equivalent to the annual primary production of the crops on the land. In many cases the majority of the biomass (or production) is removed from the field at harvest. An approximate temporal average of the biomass was used to derive the carbon stock. The biomass in cultivated non-woody crops was estimated based on three sources of data: crop biomass from the U.S. Department of Agriculture – National Agriculture Statistics Service (USDA NASS, see http://www.usda.gov/nass/sso-rpts.htm), length and timing of harvest cycles, and the relative abundance of each crop type.

Carbon stocks of horticultural crops have less seasonal variation, but data on carbon stocks for these crops are scarce. Yield data from the USDA NASS represents only the biomass of the harvest – a useful estimate of peak biomass for non-woody crops, but only a small portion of the standing biomass for woody crops. Thus estimates were instead derived from consultation with extension agents, university researchers and government officials in combination with literature searches, principally to determine typical stocking densities (number of trees per unit area), tree diameters and tree heights. Biomass can then be estimated from tree diameter and height using a regression equation (Winrock unpublished).

The stocking densities were combined with estimates of biomass per plant to arrive at an estimate of biomass carbon density in metric t C / ha. For fruit orchards and bush fruits, multiple crop types were included and the relative abundance of each crop type in the state, derived from USDA NASS, determined the area-weighted mean carbon stock that was used in this analysis (Table 3-2).

Table 3-2
Estimates of the average carbon stock (t C/ha) for each of the crop types in WA

Crop type	Average C stock (t C/ha)
Fruit orchards	24.3
Nut orchards	36.1
Vineyards	4.3
Bush fruits	3.4
Berry fruits	1.8
Other horticulture	4.5
Non-woody crops	1.5

Soil carbon stocks are not included in this report because we assume that most agricultural land has been under cultivation long enough that changes in soil carbon would be minimal to non-existent under current practices. The stability of soil carbon on cultivated land was confirmed by the study of DeClerck and Singer (2003), who showed that the percent change in soil carbon under row crops in CA remained constant over an approximate period of 50 years. Interestingly, DeClerck and Singer also found the same trend for tree crops, but an increase in soil carbon over the past 50 years for soils under viticulture (about a 1.7-fold increase) and pasture (about a 1.6-fold increase). These results are difficult to apply in baseline determination because the results were reported as an increase in percent carbon with no indication of changes in soil bulk density; calculating changes in carbon stocks requires not only the change in percent carbon but also the change in soil bulk density.

Estimates of the carbon stocks in non-agricultural lands (e.g., urban / transportation, and all the other class) are assumed to be zero. This assumption is probably reasonable for “other” as this contains mostly barren lands, but for urban / transportation there is likely to more carbon than in non-woody croplands. Urban development often contains significantly more (but unknown) amount of biomass in trees and shrubs that homeowners and local municipalities plant than in the agricultural lands that they replace. This is an area of further research—estimating the amount of carbon in biomass of urban areas as a function of density, etc.

Change in Stocks

When a change in agricultural land use occurred it was assumed in this analysis that the entire carbon stocks in vegetation present before the change would be emitted into the atmosphere as carbon dioxide. This is a reasonable assumption given the necessity to clear the land in order to plant alternative crops or initiate urban development.

For changes in land use to agricultural crops it is assumed that the change occurred at the midpoint of the period under analysis (in 1992), five years before 1997 and five years after 1987. For non-woody crops such as vineyards, bush and berry crops, and other horticulture crops, it is reasonable to assume that in five years, these crop types will have reached their predicted steady-state biomass. The same assumption cannot be applied to orchards, which will take longer than five years to attain their maximal biomass. Instead, the biomass accumulation that might have occurred in five years of growth for fruit and nut orchards respectively was estimated (Table 3-3).

Table 3-3
The estimated average biomass carbon accumulation after five years of growth for fruit and nut orchards in WA (t C/ha)

	Average biomass carbon accumulation
Fruit orchards	1.6
Nut orchards	1.8

In addition, it can be expected that fruit orchards and nut orchards will continue to accumulate biomass for very many years. We therefore applied an average biomass accumulation to areas of orchards that remained constant over the ten years of the analysis. The rate of biomass accumulation was determined by estimating the stocks at years 40 and 60 and dividing the difference by 20 to get an annual accumulation. The annual accumulation was multiplied by 10 to give an accumulation for the ten years 1987 to 1997 (Table 3-4).

Table 3-4
The estimated average biomass carbon accumulation over 10 years of growth for fruit and nut orchards in WA (t C/ha). This growth rate is for existing orchards, i.e. for areas unaffected by land-use change

	Average biomass carbon accumulation
Fruit orchards	3.4
Nut orchards	5.6

3.1.5 Uncertainty

Uncertainty in NRI Data

The estimated margin of error (95 % confidence interval) for the area of cultivated cropland in 1997 is 6.5 % for Washington (NRCS 2000). For areas presented at finer scales (county level, specific crop) or for changes in area, the margin of error will be significantly higher.

Uncertainty in Carbon Stock Data

To evaluate the confidence in the estimated carbon stocks, ranges were determined based on the ranges in diameter, height, biomass and planting density provided by the sources consulted (Table 3-5).

Table 3-5
Estimated ranges in average carbon stocks for each crop type WA (t C/ha)

Crop type	Range in C stocks
Fruit orchards	9.5-35.8
Nut orchards	17.8-69.
Vineyards	2.4-6.7
Bush fruits	2.7-4.1
Berry fruits	1.4-2.2
Other horticulture	3.4-5.7
Non-woody crops	1.0-2.0

Weighting the deviations from the mean by area and carbon stock gave a mean deviation value for carbon stocks of 42 %.

3.2 Results

3.2.1 Statewide Land Use and Land Use Change 1987-1997

The total area of Washington is 18.47 million ha, of which 70% is covered by the NRI and the remainder is federal land falling outside the scope of the NRI.

In 1997 agricultural land in Washington, including both perennial woody and annual non-woody lands, was estimated as 2,690,564 ha or 14.6 % of the total land area of the state. The area of woody cropland was 6.1 % of the total area under agricultural cultivation (Figure 3-1).

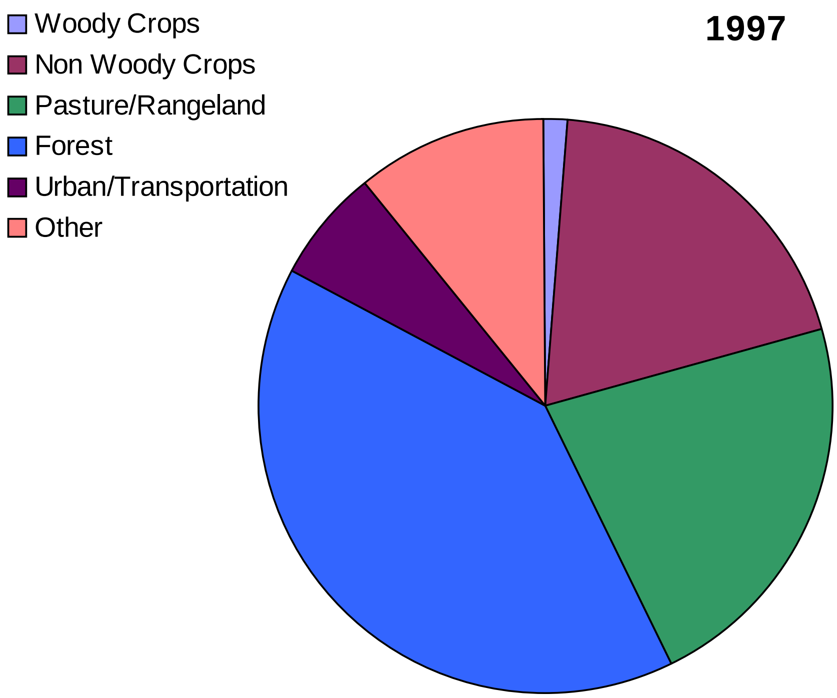

Figure 3-1
Proportional area for land-uses in Washington in 1997, based on NRI data (non-federal lands only)

Table 3-6
Areas (ha) and changes in areas (ha) for land use types in Washington from the NRI dataset

	1987	1997	Change
Woody crops			
Fruit orchards	82,356	97,371	15,015
Nut orchards	728	728	0
Vineyards	14,084	33,266	19,182
Bush crops	850	1,942	1,092
Berry crops	2,347	2,144	-203
Other horticulture	19,506	28,248	8,742
Total woody crops	119,871	163,699	43,828
Non-woody crops			
Row / Close crops	2,805,179	2,526,865	-278,314
Other land uses			
Pasture/Rangeland	2,978,066	2,856,332	-121,734
Forest	5,270,408	5,194,122	-76,286
Urban/Transportation	653,064	835,705	182,641
Other	1,169,097	1,418,959	249,862
TOTAL	12,995,685	12,995,685	

Overall, agricultural land in Washington experienced a 8.0 %(234,486 ha) loss in area during the 10-year period from 1987-1997. However, this loss included a 9.9 % loss in area of non-woody crops and a 36.6

% increase in area of woody crops. Over the same period there were small decreases in the area of pasture/rangeland (4.1%) and forest (1.4%) and increases in the area of urban/transportation (28 %) and the Other category (21.4 %) (Table 3-6, Figure 3-2).

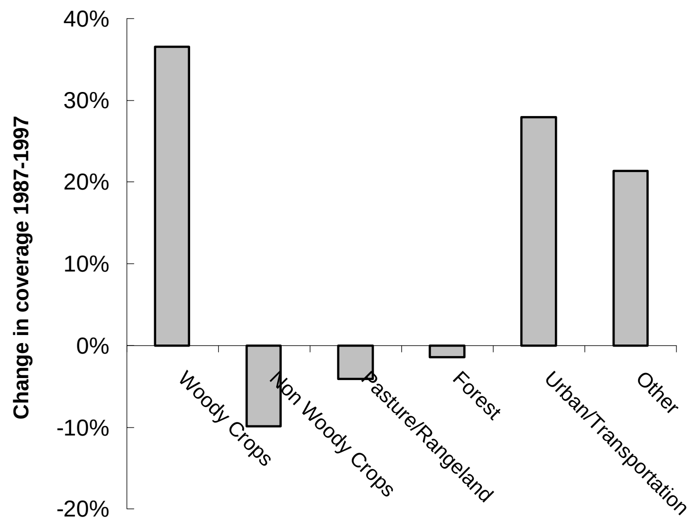

Figure 3-2
Proportional change in area between 1987 and 1997 for broad land uses in Washington

3.2.2 Changes in Specific Land-use Type

Agricultural area in Washington is dominated by non-woody crop types (94 %; Figure 3-3). Among the woody crops fruit orchards make up 60 %, nut orchards < 1 %, vineyards 20 %, bush crops 1 %, berry crops 1 % and other 17%.

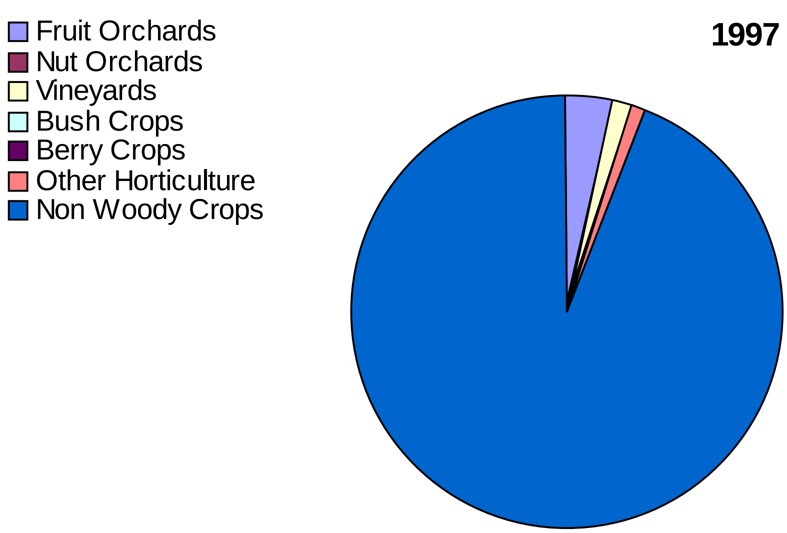

Figure 3-3
Proportional coverage of each agricultural land-use in Washington in 1997

The 36.6 % gain in area of woody crops between 1987 and 1997 was composed of an 18 % increase in fruit orchards (15,015 ha), a 136 % increase in vineyards (19,182 ha), a 129 % increase in berry crops (1,092 ha) and a 45% increase in other horticulture (8,742 ha). A small portion of this gain was offset by a 9 % loss in bush crops (203 ha) (Table 3-7, Figure 3-4).

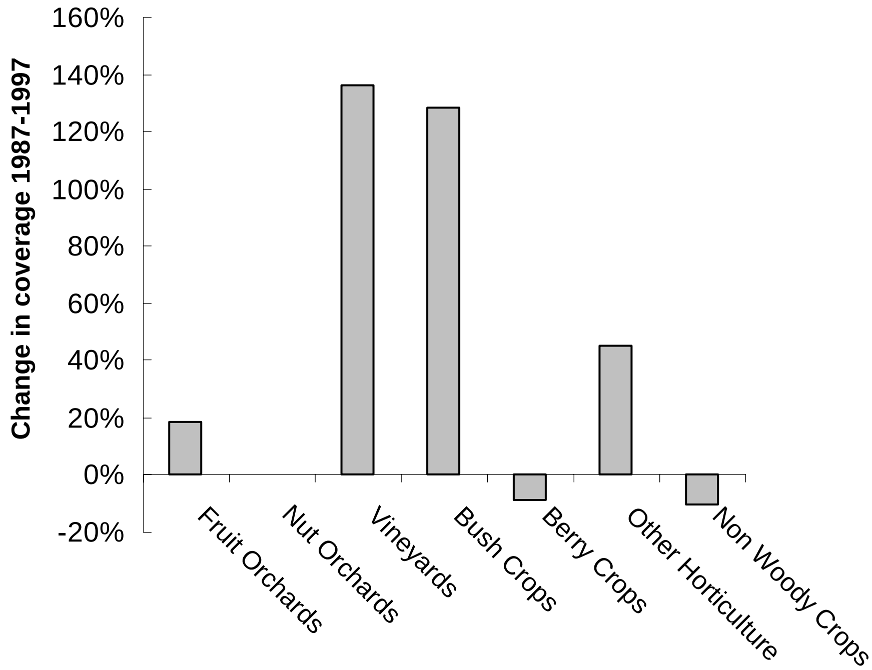

Figure 3-4
Proportional change in area between 1987 and 1997 for agricultural land uses in Washington

Between 1987 and 1997 large net losses to development occurred including 26,750 ha from non-woody crops, 47,350 ha from pasture/rangeland and 98,099 ha from forest. Forest regrowth occurred on 18,576 ha of pasture/rangeland. A large area, almost 248 thousand ha, was converted from non-woody crops to the Other category, including water, marshland, barren land and non-cultivated farmland. It is probable that most of this loss in area simply represents agricultural land taken out of cultivation.

The large gains in vineyards were at the expense of non-woody crops (11,412 ha), other horticulture (3,319 ha), fruit orchards (1,012 ha) and pasture/rangeland (1,538 ha). The gains in fruit orchards were predominantly at the expense of non-woody crops (11,898 ha) and pasture/rangeland (5,140 ha). (Table 4-2).

Table 3-7

Land-use change transition matrix, showing the source and direction of changes in Washington 1987-1997. The area unchanged between the time periods is listed at left, then the net gain and loss from the land uses listed in the rows to the land uses listed in the columns. A negative sign indicates a net loss of area from the land use in the row to the land use in the column

		Change to (-) / Change from (+)											
	Unchanged	Fruit Orchards	Nut Orchards	Vineyards	Bush Crops	Berry Crops	Other Horticulture	Non-Woody Crops	Rangeland	Forest	Urban / Transport-ation	Other	TOTAL CHANGE
Fruit Orchards	76,367			-1,012			445	11,898	5,140		-2,307	850	15,014
Nut Orchards	728												0
Vineyards	11,858	1,012					3,319	11,412	1,538		40	1,862	19,183
Bush Crops	850							1,093					1,093
Berry Crops	1,336							242	-445				-203
Other Horticulture	11,655	-445		-3,319				10,198	971		-81	1,416	8,740
Non-Woody Crops	2,393,517	-11,898		-11,412	-1,093	-242	-10,198		34,561	-3,440	-26,750	-247,838	-278,310
Rangeland	2,741,155	-5,140		-1,538		445	-971	-34,561		-18,576	-47,350	-14,043	-121,734
Forest	5,139,730							3,440	18,576		-98,099	-202	-76,285

3.2.3 County Level Estimate of Agricultural Land Area

Figure 3-5 shows the counties of Washington. Although woody cropland is broadly distributed across counties, only one county (Yakima) has more than 2% of its total land area in this land use type (Figure 3-5a). The greatest areas of non-woody cropland are concentrated in Washington's southeastern counties, with 14 counties in which non-woody cropland exceeds 5% of the total land area and 9 in which it exceeds 30% (Douglas, Grant, Lincoln, Adams, Franklin, Whitman, Walla Walla, Columbia and Garfield) (Figure 3-5b).

Multiple counties recorded slight increases in area of woody cropland between 1987 and 1997, but only three counties more than 500 ha increase and only one (Yakima) more than 1,000 ha increase (Figure 3-6a). Most of these increases were due to installation of vineyards and other horticulture (Table 3-8). Four counties lost woody cropland over the period (Challam, Skamania, Chelan and Pierce).

Six counties experienced slight gains in area on non-woody crops. Most counties experienced slight losses; six lost more than 4,000 ha and four (Yakima, Benton, Franklin and Adams) lost more than 15,000 ha of non-woody cropland (Figure 3-6b).

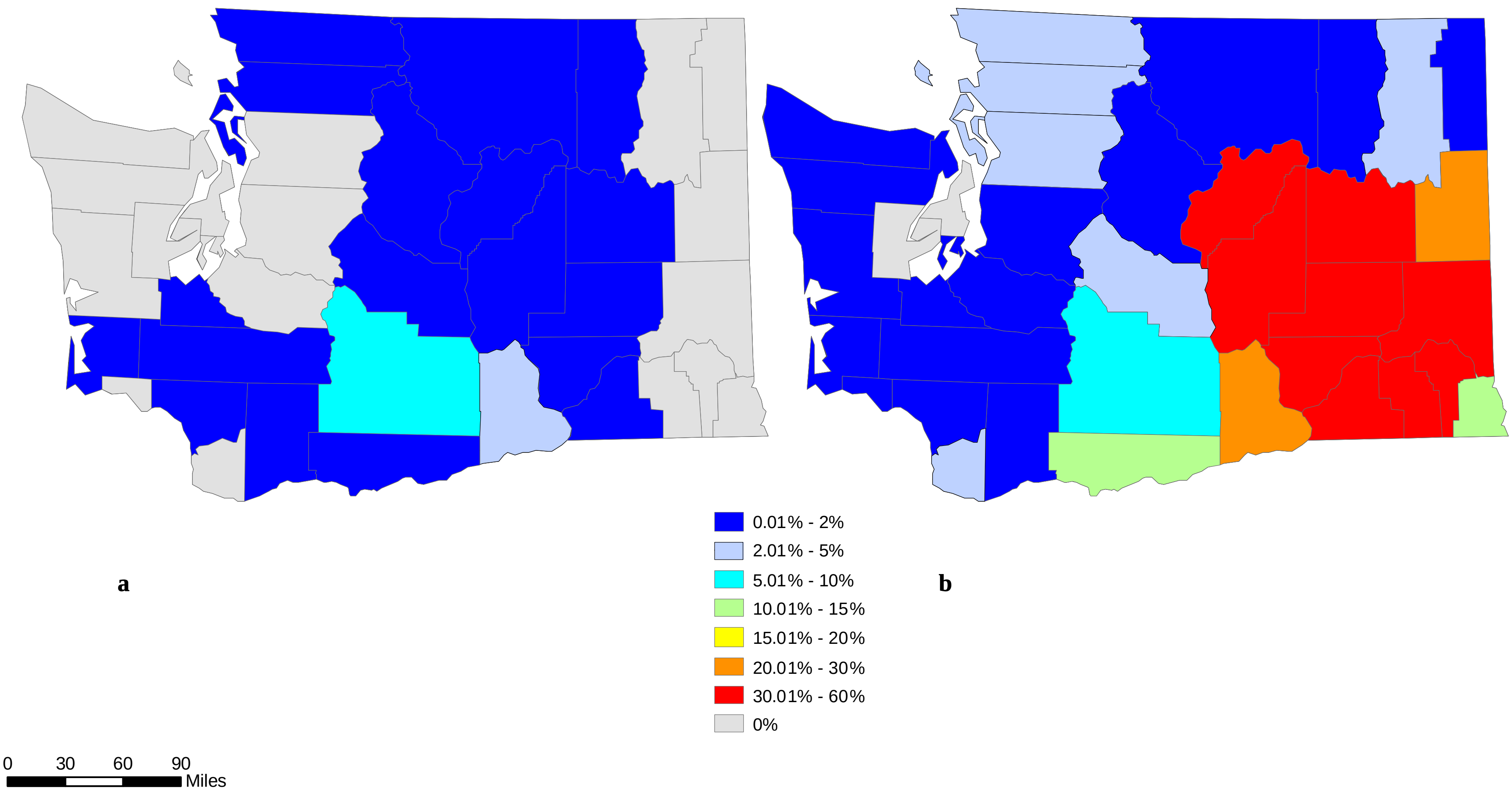

Figure 3-5
Distribution of woody (a) and non-woody (b) cropland by county in Washington in 1997. Values indicate the percentage of total land area in each county occupied by agricultural land

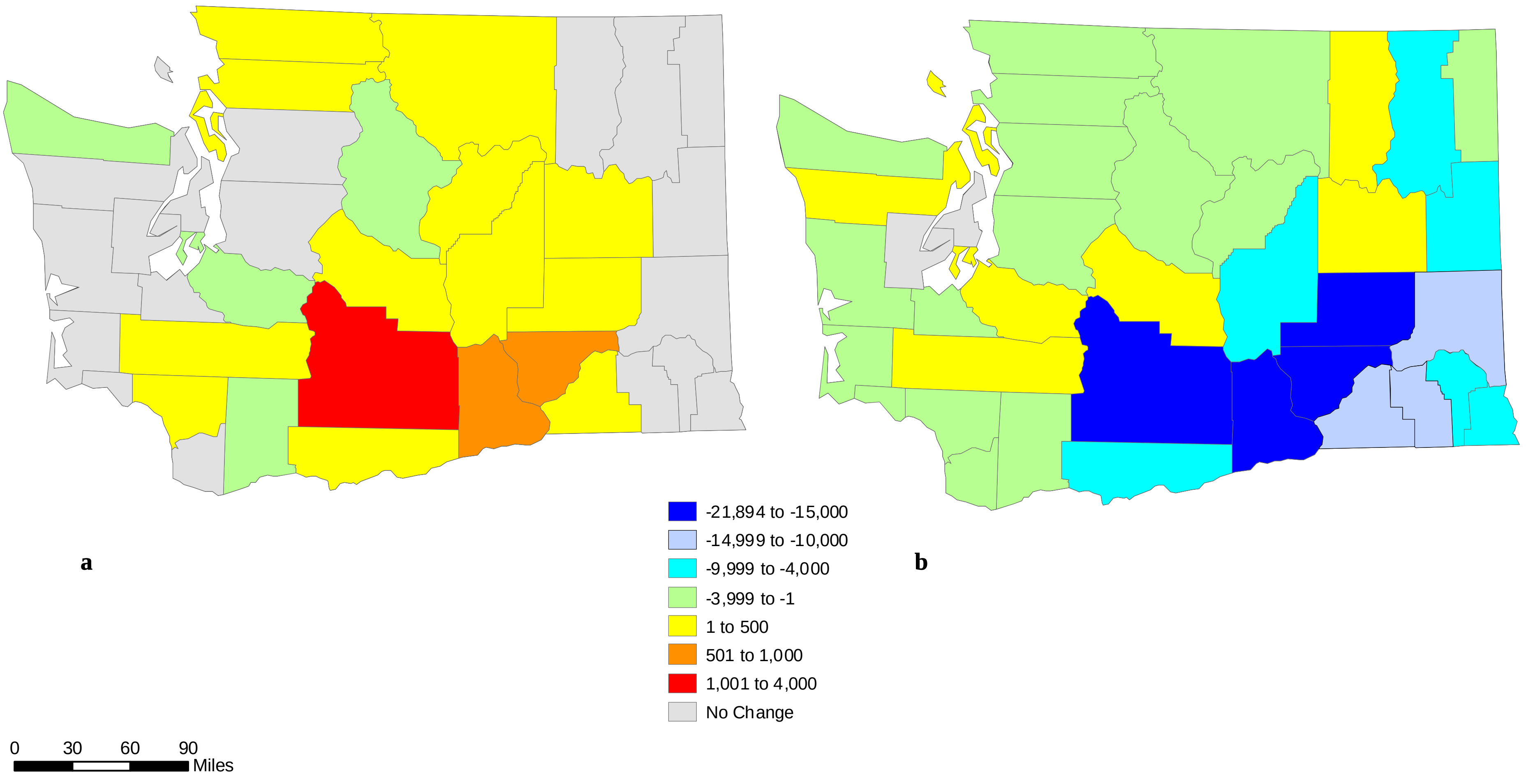

Figure 3-6

Distribution of change in area in woody (a) and non-woody (b) cropland in Washington by county. Values indicate change in hectares; minus sign indicates a loss in area from 1987 to 1997 and plus sign indicates a gain in area in the same period

Table 3-8
The county level coverage (ha) for specific agricultural land uses and the change in coverage in Washington 1987 to 1997

	High Carbon Crops												Low Carbon Crops			
	Fruit Orchards		Nut Orchards		Vineyards		Bush Crops		Berry Crops		Other Horticulture		Row / Close crops		TOTAL	
	1987	1997	1987	1997	1987	1997	1987	1997	1987	1997	1987	1997	1987	1997	1987	1997
Adams	0	648											315,868	262,043	315,868	262,691
Asotin													27,762	21,287	27,762	21,287
Benton	4,249	5,544			6,435	14,286					809	1,497	168,396	133,713	179,889	155,040
Chelan	8,458	7,608											971	890	9,429	8,498
Clallan											283	0	2,833	2,185	3,116	2,185
Clark													13,557	8,742	13,557	8,742
Columbia													90,774	74,748	90,774	74,748
Cowlitz											0	81	3,845	2,833	3,845	2,914
Douglas	8,661	10,118			162	0					445	0	172,078	170,419	181,346	180,537
Ferry	162	162											8,094	9,106	8,256	9,268
Franklin	1,457	5,909			0	809							169,367	137,153	170,824	143,871
Garfield													73,777	64,266	73,777	64,266
Grant	4,007	6,718											300,894	291,101	304,901	297,819
Grays Harbor													7,568	7,123	7,568	7,123
Island							0	121					1,781	2,792	1,781	2,913

	High Carbon Crops												Low Carbon Crops			
	Fruit Orchards		Nut Orchards		Vineyards		Bush Crops		Berry Crops		Other Horticulture		Row / Close crops		TOTAL	
	1987	1997	1987	1997	1987	1997	1987	1997	1987	1997	1987	1997	1987	1997	1987	1997
Jefferson													0	324	0	324
King													4,978	2,792	4,978	2,792
Kitsap															0	0
Kittitas	3,197	3,440											26,751	29,462	29,948	32,902
Klickitat	1,376	2,104											80,940	75,557	82,316	77,661
Lewis											0	890	9,349	10,563	9,349	11,453
Lincoln											1,902	3,602	306,803	307,936	308,705	311,538
Mason															0	0
Okanogan	10,198	14,367											17,483	17,443	27,681	31,810
Pacific									445	445			202	162	647	607
Pend Oreille													6,435	5,990	6,435	5,990
Pierce									243	0			2,550	5,261	2,793	5,261
San Juan													0	445	0	445
Skagit									890	890	405	850	23,230	22,056	24,525	23,796
Skamania	364	81											648	607	1,012	688
Snohomish													17,524	14,650	17,524	14,650
Spokane													158,400	145,975	158,400	145,975
Stevens													25,010	17,078	25,010	17,078

	High Carbon Crops												Low Carbon Crops			
	Fruit Orchards		Nut Orchards		Vineyards		Bush Crops		Berry Crops		Other Horticulture		Row / Close crops		TOTAL	
	1987	**1997**	**1987**	**1997**	**1987**	**1997**	**1987**	**1997**	**1987**	**1997**	**1987**	**1997**	**1987**	**1997**	**1987**	**1997**
Thurston							526	526					4,775	3,804	5,301	4,330
Wahkiakum													648	162	648	162
Walla Walla	0	1,376			1,821	1,821							222,018	197,089	223,839	200,286
Whatcom			728	728			324	1,295	769	809			20,802	16,350	22,623	19,182
Whitman													383,210	366,011	383,210	366,011
Yakima	40,227	39,296			5,666	16,350					15,662	21,328	135,858	98,747	197,413	175,721
TOTAL	82,356	97,371	728	728	14,084	33,266	850	1,942	2,347	2,144	19,506	28,248	2,805,179	2,526,865	2,925,050	2,690,564

3.2.4 Change in Carbon Stock of Agricultural Land During 1987-1997

Conversion of agricultural lands to other land uses was responsible for a net loss of carbon equal to 140.5 thousand t C over the ten years 1987-97. This net loss included a loss in area and consequently of carbon in non-woody cropland of 417.5 thousand t C, partially counterbalanced by a gain from woody crops equal to 277 thousand t C (Table 3-9). These carbon stock changes equate to a decrease in non-woody cropland of 9.9 %, a gain in woody cropland of 12.7 %, and a net loss for all agricultural land of 2.2 %.

Table 3-9
Carbon stocks (t C) and changes in carbon stocks (t C) for land use types in Washington

	1987	1997	Change
Woody crops			
Fruit orchards	2,001,262	2,148,970	147,708
Nut orchards	23,893	27,972	4,079
Vineyards	60,561	143,044	82,483
Bush crops	2,890	6,603	3,713
Berry crops	4,225	3,859	-365
Other horticulture	87,777	127,116	39,339
Total woody crops	2,180,608	2,457,564	276,956
Non-woody crops			
Row / Close crops	4,207,769	3,790,298	-417,471
TOTAL	6,388,376	6,247,861	-140,515

The gains in carbon stocks in woody crops come largely from fruit orchards (147.7 thousand t C), vineyards (82 thousand t C) and other horticulture (largely Christmas trees – 39 thousand t C). A smaller gain was recorded from nut orchards and bush crops, and a small loss from berry crops (Figure 3-7).

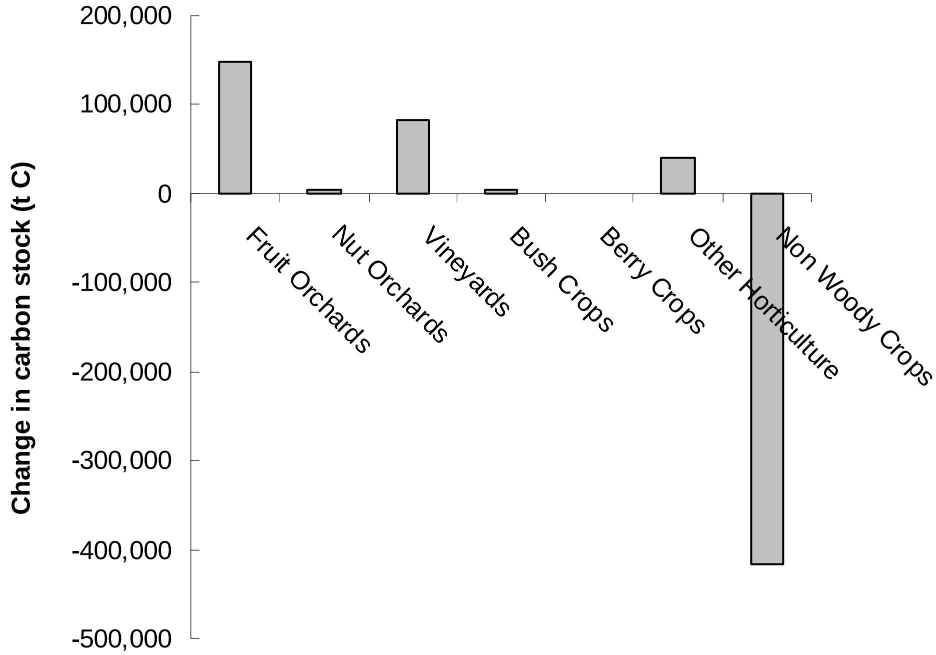

Figure 3-7
Changes in carbon stock (t C) across crop types in Washington between 1987 and 1997

The largest single loss of carbon was from non-woody crops to the Other category (Table 3-10). The Other category includes non-cultivated farmland, so it is likely that this loss of carbon simply represents agricultural land temporarily or permanently taken out of cultivation. Additional large losses occurred between 1987 and 1997 from both woody and non-woody crops to urban development/transportation (98.2 thousand t C). There was a substantial loss from fruit orchards to rangeland, but this was more than balanced by conversion of rangeland to row/close crops. Substantial carbon stocks moved from fruit orchards, vineyards and other horticulture to non-woody crops – a total of 114,000 tons (Table 3-10).

The gross gains in carbon (excluding losses) are dominated by the continued growth of existing stands (88.5 % for fruit orchards, 100 % for nut orchards), as opposed to carbon gained through the planting and initial growth of new orchards. It is assumed that beyond the initial years of growth there is no additional carbon accumulation in the other crop types.

Table 3-10

The land use origins and destinations of changes in carbon stocks in agriculture in WA between 1987 and 1997. The growth of existing stands is listed at left, then the net gain and loss in carbon stocks from the land uses listed in the rows to the land uses listed in the columns. A negative sign indicates a net loss of carbon stocks from the land use in the row to the land use in the column

		Change to (-) / Change from (+)											
	Growth of existing stands	Fruit Orchards	Nut Orchards	Vineyards	Bush Crops	Berry Crops	Other Horticulture	Non-woody Crops	Rangeland	Forest	Urban / Transport-ation	Other	TOTAL CHANGE
Fruit Orchards	259,648			-28,260			712	19,037	-36,792		-57,892	-8,746	147,707
Nut Orchards	4,079												4,079
Vineyards		4,352					14,272	49,072	6,613		172	8,007	82,487
Bush Crops								3,716					3,716
Berry Crops								436	-801				-365
Other Horticulture		-2,003		-14,936				45,891	4,370		-365	6,372	39,330
Non-Woody Crops		-17,847		-17,118	-1,640	-363	-15,297		51,842	-5,160	-40,125	-371,757	-417,465

When converted to carbon dioxide equivalents the total stocks in 1997 on agricultural land in Washington are estimated at 22.9 MMtCO_2eq (Table 3-11). There was a net loss of 0.5 MMtCO_2eq between 1987 and 1997. This is equal to an annual source of 0.05 MMtCO_2eq. Sixty-one percent of the stocks are estimated to be in non-woody vegetation. Non-woody vegetation represented an annual source of 0.15 MMtCO_2eq and woody vegetation represented an annual sink of 0.1 MMtCO_2eq.

Table 3-11
Carbon stocks on agricultural land in Washington and their change (million tons of carbon dioxide equivalent (MMTCO_2e)

	Agricultural Land	Woody	Non-woody
1987	23.4	8.0	15.4
1997	22.9	9.0	13.9
1987-1997	-0.5	1.0	-1.5

3.2.5 Carbon Stocks of Agricultural Land by County

Seventy-four percent of the counties in Washington had a loss in carbon stocks due to conversion of non-woody cropland between 1987 and 1997 (Table 3-12). For three counties the losses exceed 50 thousand t C (Adams, Yakima and Benton). Two counties had no agricultural land at all at either date and eight counties increased their carbon stocks in non-woody crops through land conversion to these crop types.

As for change in carbon stocks on woody cropland, four counties experienced a loss in fruit orchards while 9 counties increased carbon stocks in fruit orchards; the gains greatly exceeded the losses. Changes in vineyards were restricted to three counties with gains in particular in Yakima and Benton counties (46 and 34 thousand t C respectively). The gain in other horticulture (Christmas trees) of 39 thousand t C is dominated by an estimated gain of 25.5 thousand t C in Yakima county.

Figure 3-8a illustrates that the gain in carbon stocks in woody cropland was broadly distributed across counties, with the greatest gains in Okanagan, Douglas, Grant, Benton, Franklin, and Yakima. The greatest loss in carbon from woody crops was in Skamania county. The greatest loss in carbon from conversion of non-woody cropland to other uses came in five counties that lost more than 15,000 t C each (Yakima, Benton, Franklin, Adams and Walla Walla) (Figure 3-8b).

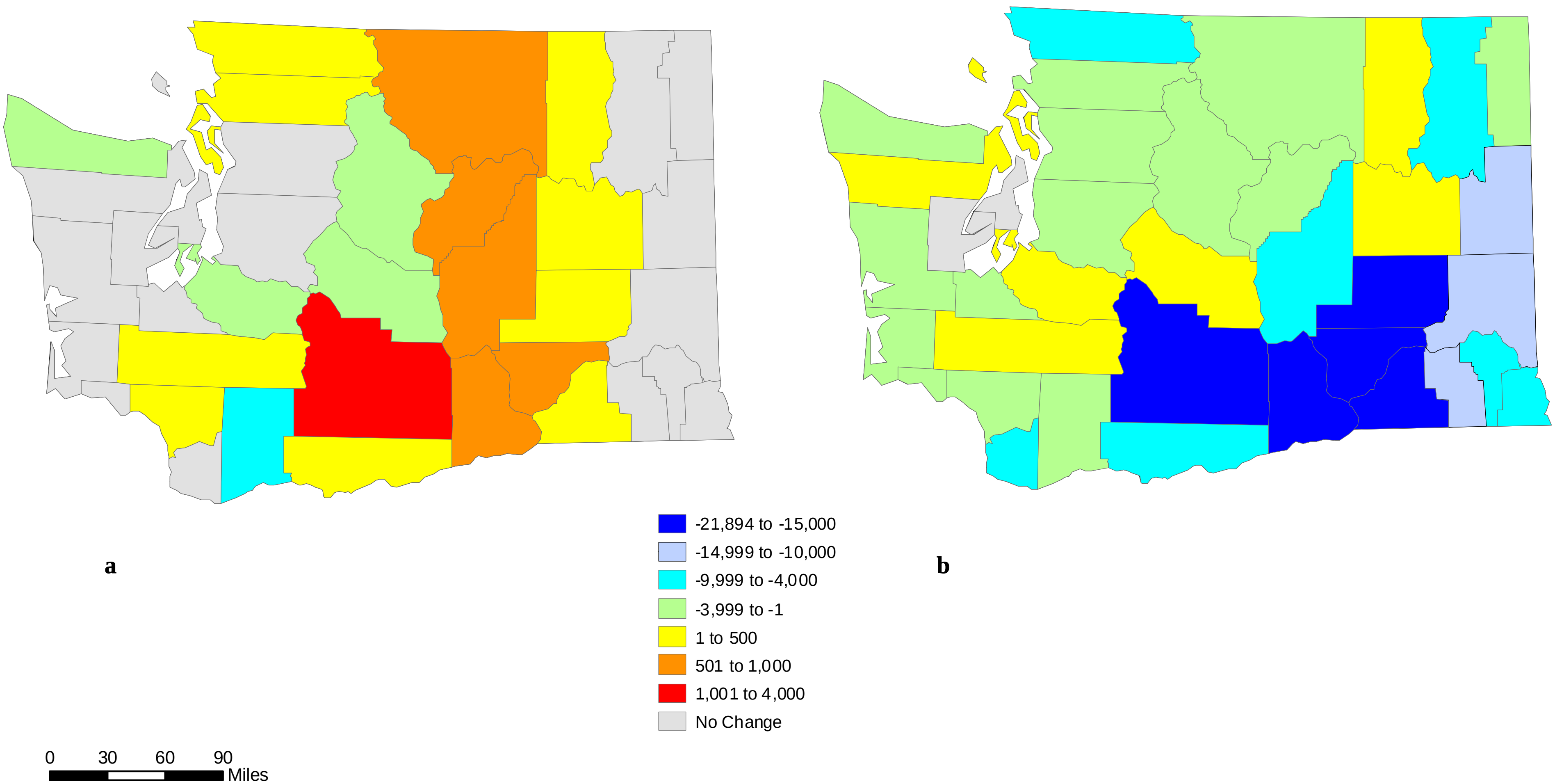

Figure 3-8
county-scale change in carbon stocks, 1987 to 1997, in high-carbon crops (orchards and vineyards, (a)) and in low-carbon crops (non-woody crops, (b)) in Washington. Values in tons of carbon

Table 3-12
Change in carbon stocks (t C) between 1987 and 1997 across crop types in Washington

County	Woody crops						Non-woody	TOTAL
	Fruit Orchards	Nut Orchards	Vineyards	Bush Crops	Berry Crops	Other Horticulture	Row / Close Crops	
Adams	1,036	0	0	0	0	0	-80,738	-79,702
Asotin	0	0	0	0	0	0	-9,713	-9,713
Benton	-14,112	0	33,759	0	0	3,096	-52,025	-29,281
Chelan	-1,120	0	0	0	0	0	-122	-1,242
Clallan	0	0	0	0	0	-1,274	-972	-2,246
Clark	0	0	0	0	0	0	-7,223	-7,223
Columbia	0	0	0	0	0	0	-24,039	-24,039
Cowlitz	0	0	0	0	0	365	-1,518	-1,154
Douglas	20,157	0	-697	0	0	-2,003	-2,489	14,969
Ferry	550	0	0	0	0	0	1,518	2,068
Franklin	12,077	0	3,479	0	0	0	-48,321	-32,765
Garfield	0	0	0	0	0	0	-14,267	-14,267
Grant	17,960	0	0	0	0	0	-14,690	3,271
Grays Harbor	0	0	0	0	0	0	-668	-668
Island	0	0	0	411	0	0	1,517	1,928
Jefferson	0	0	0	0	0	0	486	486
King	0	0	0	0	0	0	-3,279	-3,279
Kitsap	0	0	0	0	0	0	0	0
Kittitas	-4,585	0	0	0	0	0	4,067	-519
Klickitat	5,844	0	0	0	0	0	-8,075	-2,231
Lewis	0	0	0	0	0	4,005	1,821	5,826
Lincoln	0	0	0	0	0	7,650	1,700	9,350
Mason	0	0	0	0	0	0	0	0
Okanogan	40,288	0	0	0	0	0	-60	40,228
Pacific	0	0	0	0	0	0	-60	-60
Pend Oreille	0	0	0	0	0	0	-668	-668

County	Woody crops						Non-woody	TOTAL
	Fruit Orchards	Nut Orchards	Vineyards	Bush Crops	Berry Crops	Other Horticulture	Row / Close Crops	
Pierce	0	0	0	0	-437	0	4,067	3,629
San Juan	0	0	0	0	0	0	668	668
Skagit	0	0	0	0	0	2,003	-1,761	242
Skamania	-6,609	0	0	0	0	0	-62	-6,671
Snohomish	0	0	0	0	0	0	-4,311	-4,311
Spokane	0	0	0	0	0	0	-18,638	-18,638
Stevens	0	0	0	0	0	0	-11,898	-11,898
Thurston	0	0	0	0	0	0	-1,457	-1,457
Wahkiakum	0	0	0	0	0	0	-729	-729
Walla Walla	2,202	0	0	0	0	0	-37,394	-35,192
Whatcom	0	4,079	0	3,301	72	0	-6,678	774
Whitman	0	0	0	0	0	0	-25,799	-25,799
Yakima	74,020	0	45,941	0	0	25,497	-55,667	89,792
TOTAL	147,708	4,079	82,483	3,713	-365	39,339	-417,471	-140,515

3.3 Non-CO_2 Greenhouse Gas Emissions

The primary non-CO_2 greenhouse gas emitted from croplands is nitrous oxide, with approximately 296 times the global warming potential of CO_2. Nitrous oxide (N_2O) is emitted from agricultural soils especially after fertilizer application.

Kerstetter (2004), writing for the Department of Community, Trade and Economic Development of the State of Washington, reported an N_2O emission for the year 1990 of 4.00 $MMTCO_2eq$ and for the year 1995 of 4.54 $MMTCO_2eq$. This however represents N_2O emissions from all sources, including agriculture, industry, manure and waste. The proportion of the total N_2O emission that would have been attributable to agricultural soil management was estimated from data for Oregon (Governor's Advisory Group 2004). This data showed that in 1990, 77 % of N_2O emissions were from agricultural soil management and in 1995 the proportion was 78 %. This predicts an N_2O emission from agriculture in WA of 3.08 $MMTCO_2eq$ in 1990 and 3.54 $MMTCO_2eq$ in 1995, or an average of 3.3 $MMTCO_2eq$ over a five-year period overlapping with this study. This is about 66 times the estimated CO_2 emissions from agricultural land conversion of 0.05 $MMTCO_2eq$ per year. Stated differently, emissions from N_2O from soil management make up 99 % of the total CO_2eq emissions from agriculture of 3.35 $MMTCO_2eq$ per year.

3.4 Conclusions

Agricultural land in Washington in 1997 represented 14.6% of the total land area. Non-woody crops were about 94% of all agricultural land; fruit orchards constituted 60% of all woody cropland. The greatest areas of non-woody cropland are in the southeastern counties. Although the overall area of woody cropland increased by 37% between 1987 and 1997, due to the greater loss of non-woody cropland to other uses there was an overall loss in agricultural land area of about 234,000 hectares over the period. Most agricultural land area was lost to urban / transportation and the Other category, which gained by 28% and 21% respectively. The 37% increase in woody cropland area was attributable to increases in fruit orchards, vineyards, berry crops, and other horticulture (primarily Christmas trees). The largest losses of non-woody cropland were in Yakima, Benton, Franklin and Adams counties.

Total carbon stocks in all agricultural land in Washington were estimated at 6.2 million tons. Between 1987 and 1997, there was a total loss of about 140,000 tons of carbon, or 2.2% of the carbon stored in agricultural lands in 1987. However, this included an overall increase in carbon stocks in woody croplands of 277,000 tons of carbon (12.7% increase over 1987), exceeded by a decrease in carbon stocks in non-woody croplands of 417,000 tons (9.9% decrease over 1987). In CO_2 equivalent terms, total agricultural carbon stocks in 1997 were 22.9 $MMTCO_2eq$, and the net loss 1987-97 disregarding non-CO_2 greenhouse gas emissions was 0.5 $MMTCO_2eq$, equivalent to an annual source of 0.05 $MMTCO_2eq$. However, because woody croplands increased in area while non-woody croplands decreased, woody croplands represented a net annual carbon sink of 0.1 $MMTCO_2eq$, offset by non-woody croplands as a net annual carbon source of 0.15 $MMTCO_2eq$. At the county level of analysis, 74% of Washington's counties lost carbon stocks between 1987 and 1997 due to conversion of non-woody cropland, with Yakima, Adams and Benton counties losing the greatest number of hectares. The greatest gains in carbon on woody cropland were in Okanagan, Douglas, Grant, Benton, Franklin and Yakima counties, while the greatest losses in carbon on non-woody croplands were in Yakima, Benton, Franklin, Adams and Walla Walla counties.

Non-CO_2 greenhouse gas emissions from N_2O (emitted from agricultural soils after fertilizer application) dwarf the annual CO_2 source from agricultural land conversion in Washington.

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