Assessment of the Influence of Disturbance, Management Activities, and Environmental Factors on Carbon Stocks of U.S. National Forests

General Technical Report
RMRS-GTR-402

Appendix 8: Pacific Northwest Region, Individual Forests

Office of Sustainability and Climate
National Forest System

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Abstract: This report assesses how carbon stocks at regional scales and in individual national forests are affected by factors such as timber harvesting, natural disturbances, climate variability, increasing atmospheric carbon dioxide concentrations, and nitrogen deposition. Previous baseline assessments of carbon stocks (https://www.fs.fed.us/managing-land/sc/carbon) evaluated observed trends based on forest inventory data but were limited in ability to reveal detailed causes of these trends. The expanded assessments reported here are based on an extensive disturbance and climate history for each national forest, and two forest carbon models, to estimate the relative impacts of disturbance (e.g., fires, harvests, insect outbreaks, disease) and nondisturbance factors (climate, carbon dioxide concentrations, nitrogen deposition). Results are summarized for each region of the National Forest System in the main document. A set of appendixes (available online) provides more detailed information about individual national forests within each region. Results are highly variable across the United States. Generally, carbon stocks are increasing in forests of the eastern United States as these forests continue to recover and grow older after higher historical harvesting rates and periods of nonforest land use. In contrast, carbon stocks in forests of the western United States may be either increasing or decreasing, depending on recent effects of natural disturbances and climate change. The information supports national forest units in assessing carbon stocks, quantifying carbon outcomes of broad forest management strategies and planning, and meeting carbon assessment requirements of the 2012 Planning Rule and directives. Results of these expanded assessments will provide context for project-level decisions, separated from the effects of factors that are beyond land managers' control.

Keywords: forest carbon stock, national forest, land management, natural disturbance, climate change

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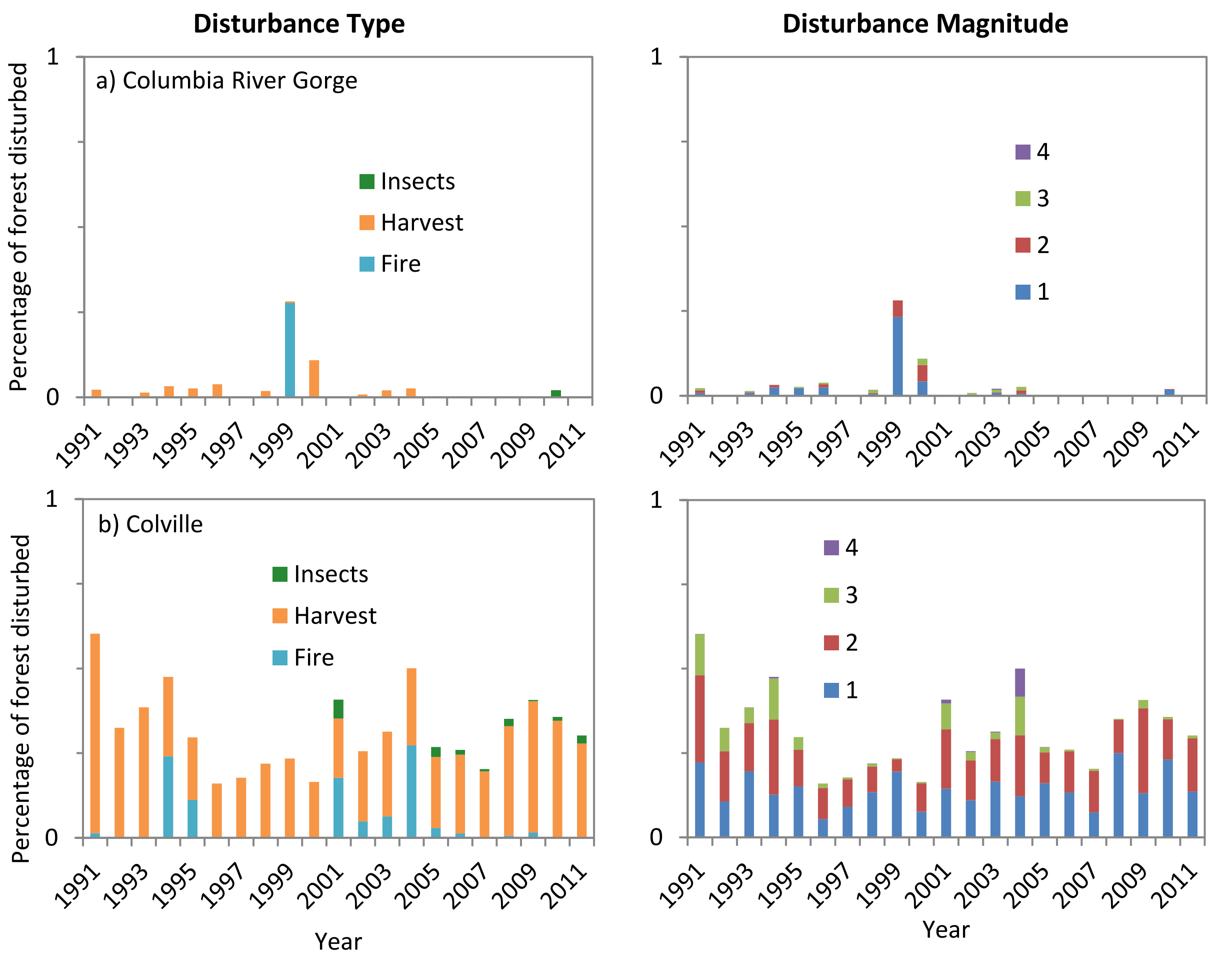
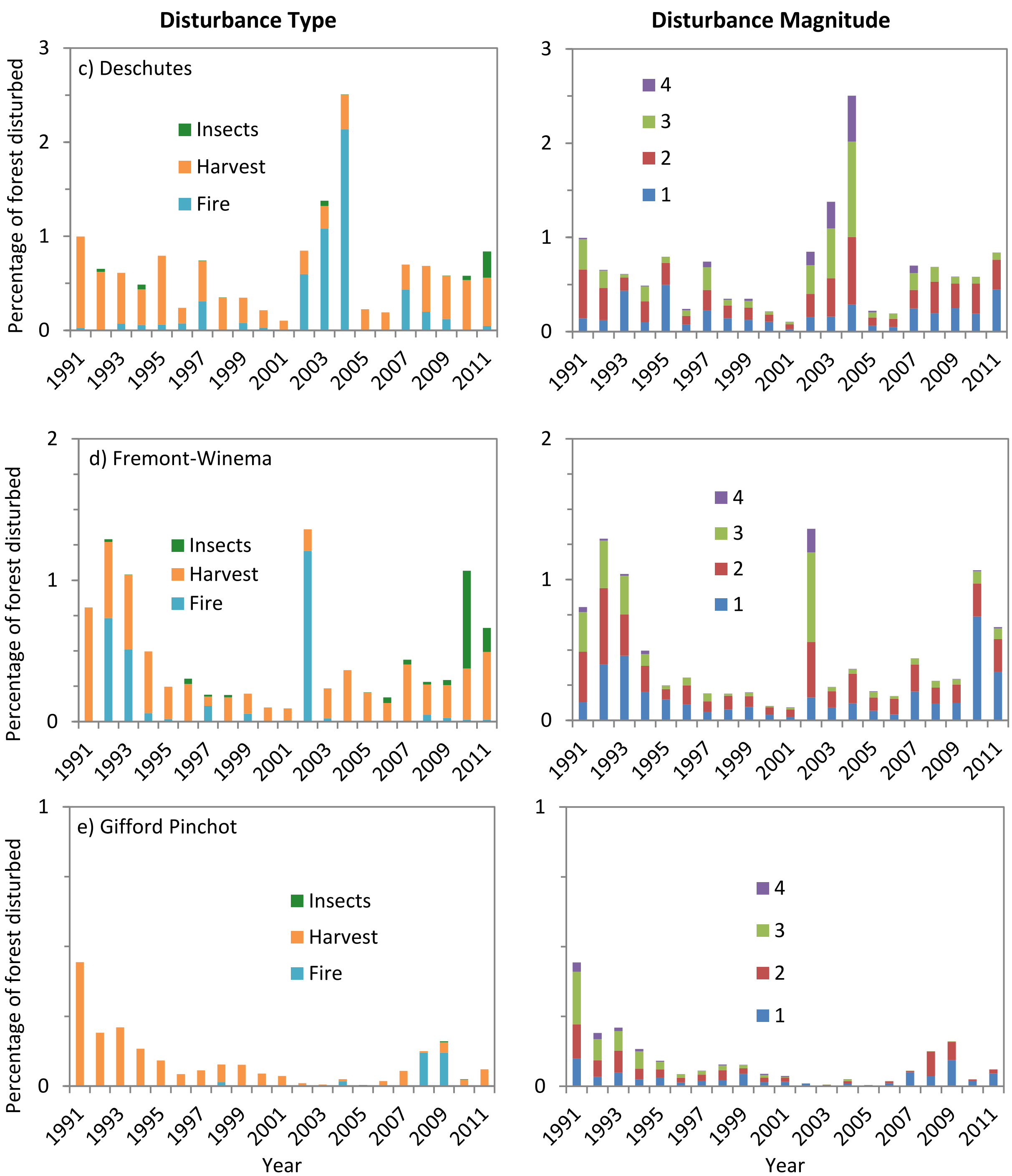
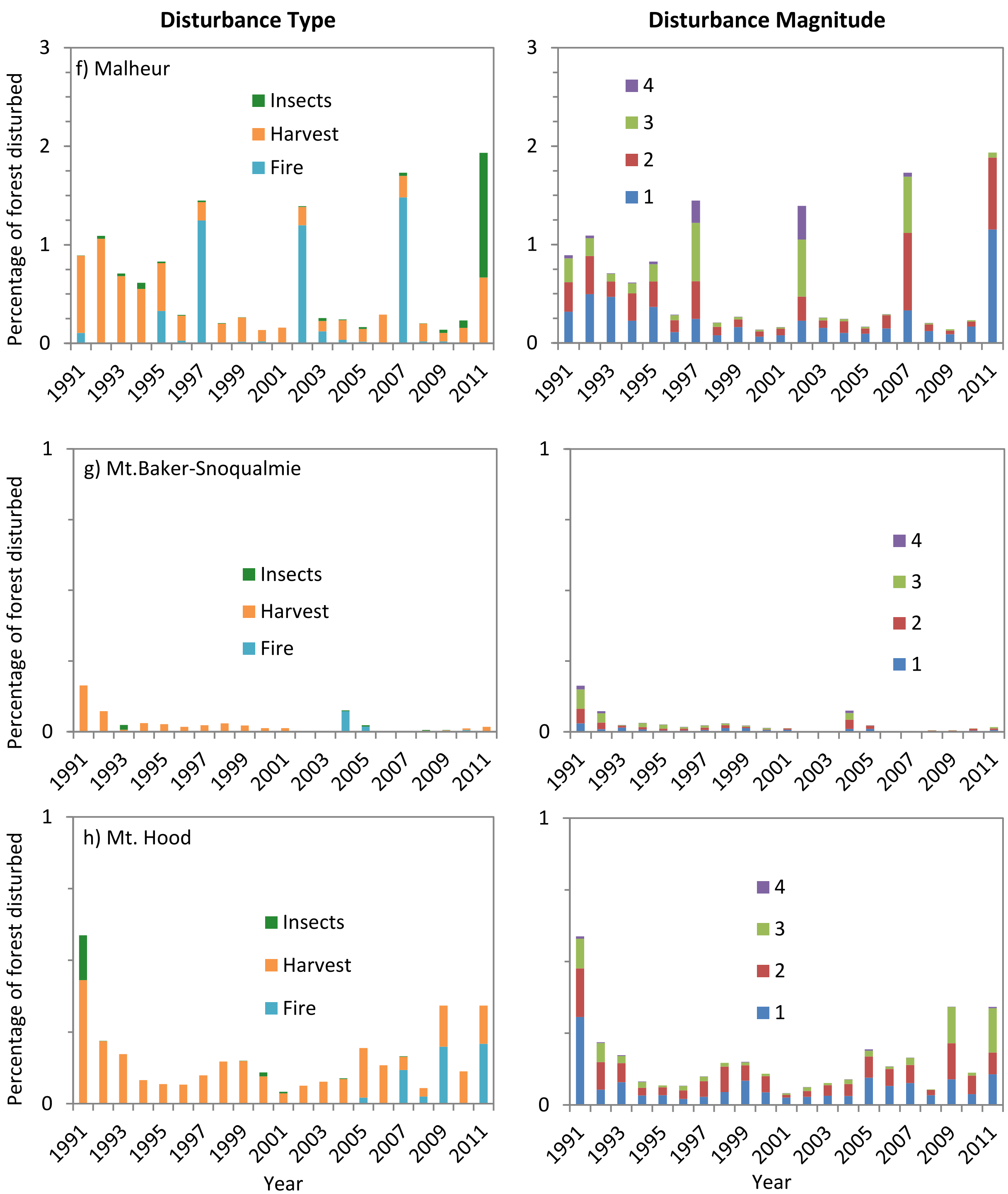
Contents

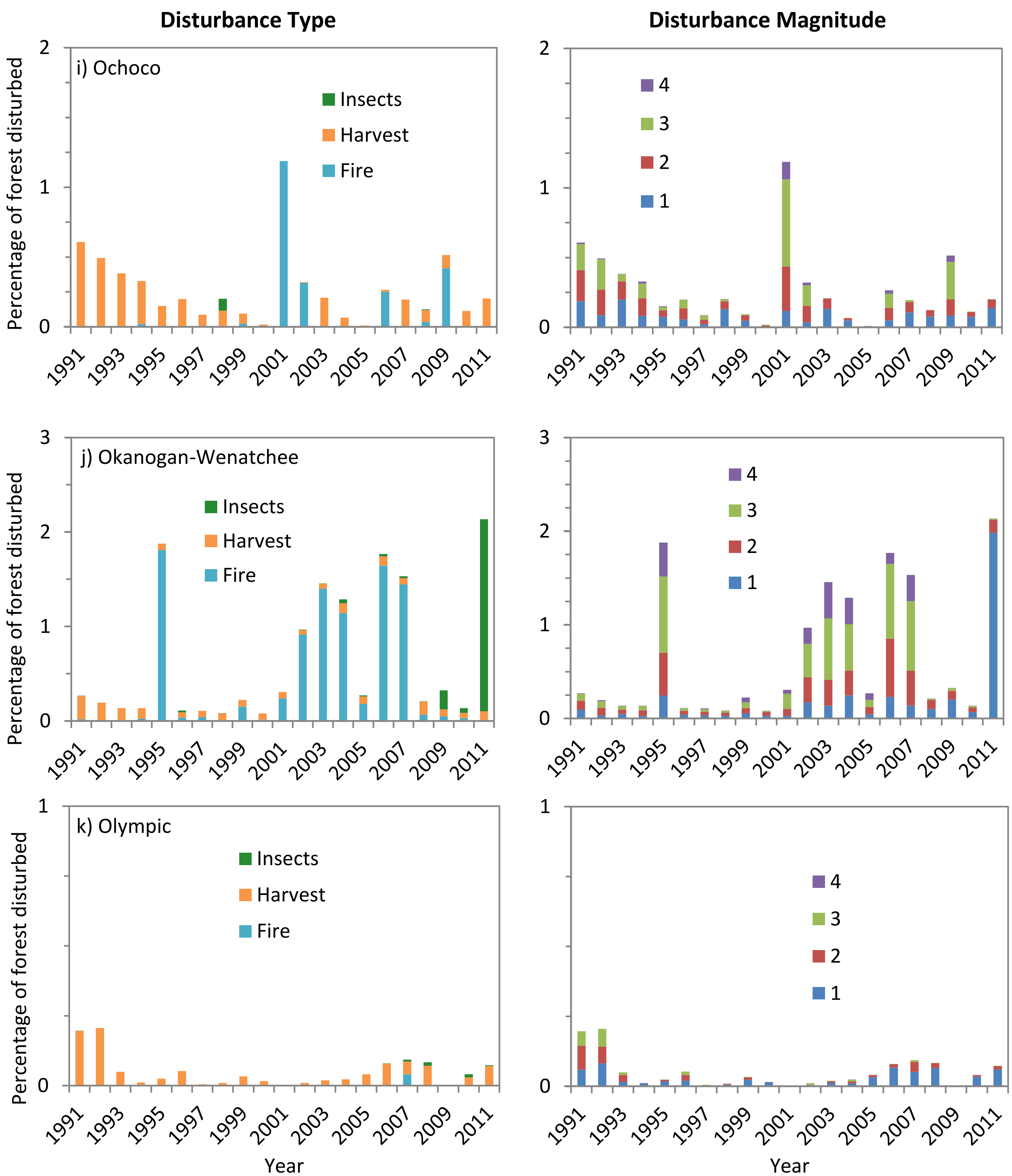
1. Disturbance trends

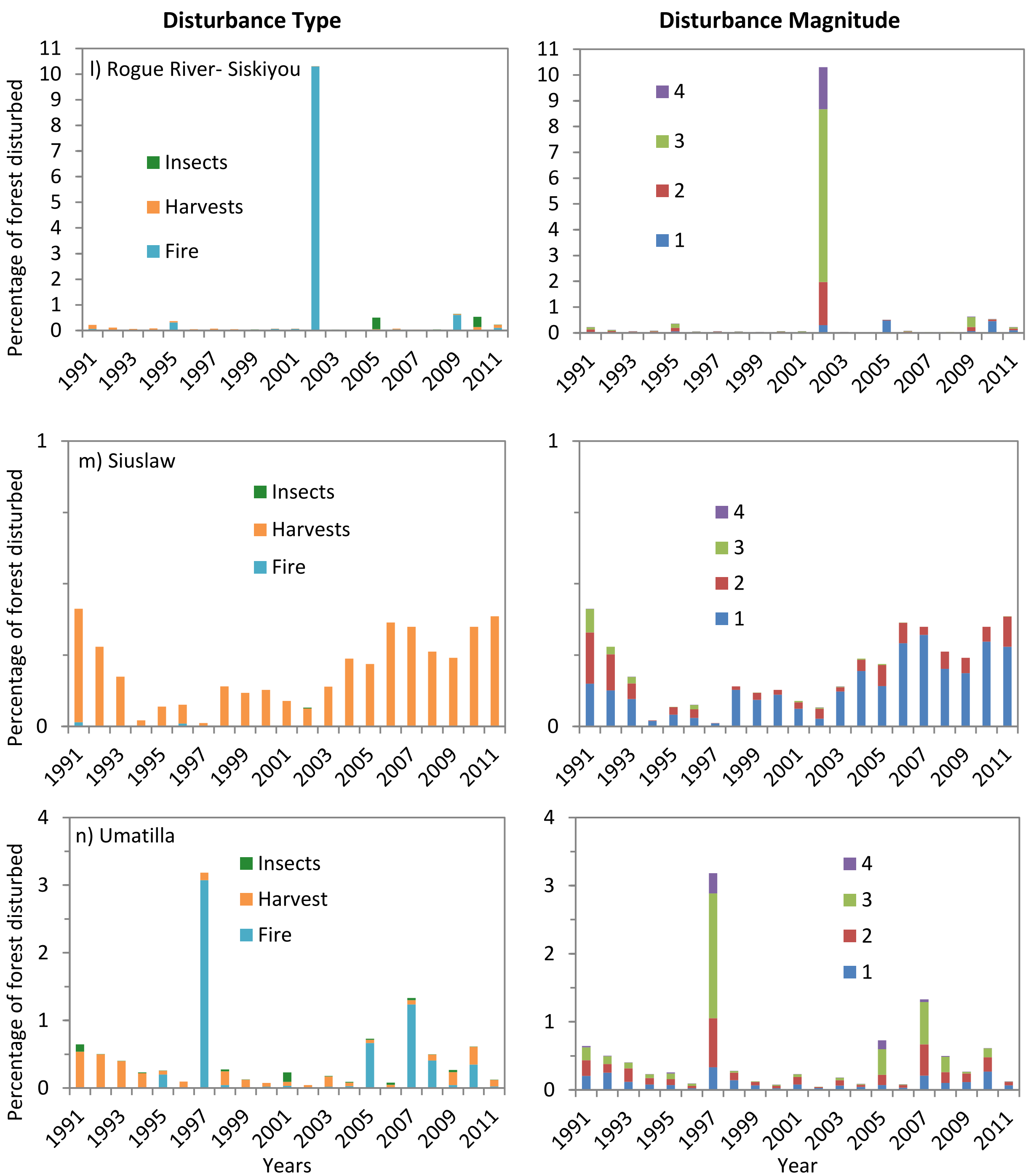
Disturbance records were summarized by type (fire, harvest, and insects) and by magnitude in Figure 1.1 (a-q). Harvest was mapped in each unit in at least one year between 1990 and 2011, and fire was detected in each national forest except the Siuslaw. Insect activity was noted in several Forests, although the temporal distribution mortality due to insects varied. For example, events were apparent in several years in the Colville, while those events were concentrated at the end of the period in the Fremont-Winema. Note the different scaling among forests in Figure 1.1, necessitated by locally extreme disturbance rates (e.g. the Biscuit Fire in 2002 in the Rogue River - Siskiyou).




Disturbance Type
Disturbance Magnitude
Percentage of forest disturbed
c) Deschutes
d) Fremont-Winema
e) Gifford Pinchot
Insects
Harvest
Fire
4
3
2
1
Year
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011


Disturbance Type
Disturbance Magnitude
f) Malheur
g) Mt.Baker-Snoqualmie
h) Mt. Hood
Insects
Harvest
Fire
4
3
2
1
Percentage of forest disturbed
Year
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011


Disturbance Type
Disturbance Magnitude
i) Ochoco
j) Okanogan-Wenatchee
k) Olympic
Insects
Harvest
Fire
4
3
2
1
Percentage of forest disturbed
Year
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011


Disturbance Type
Disturbance Magnitude
l) Rogue River- Siskiyou
m) Siuslaw
n) Umatilla
Insects
Harvests
Harvest
Fire
4
3
2
1
Percentage of forest disturbed
Years
Year
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011

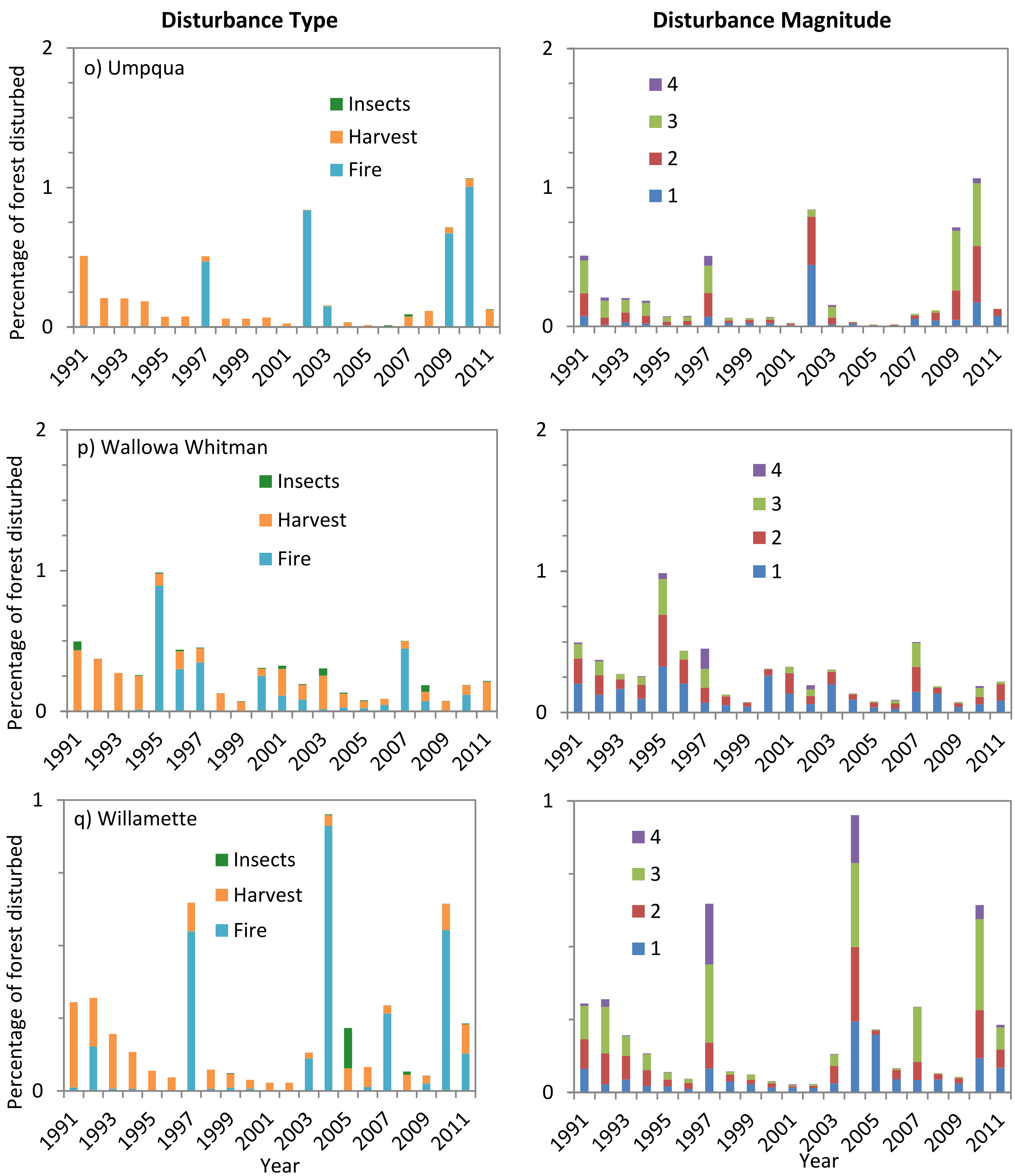


Figure 1.1. Annual rates of disturbance in the Pacific Northwest Region, mapped using visual interpretation of several independent datasets and summarized as the percentage of the forested area disturbed from 1991 through 2011 by (a) disturbance types including fire, harvests, insects, and abiotic; and b) magnitude classes, characterized by percentage change in canopy cover (CC) and categorized as follows: (1) 0 to 25 percent CC, (2) 25 to 50 percent CC, (3) 50 to 75 percent CC, and (4) 75 to 100 percent CC.

2. Effects of disturbance and management activities (ForCaMF)

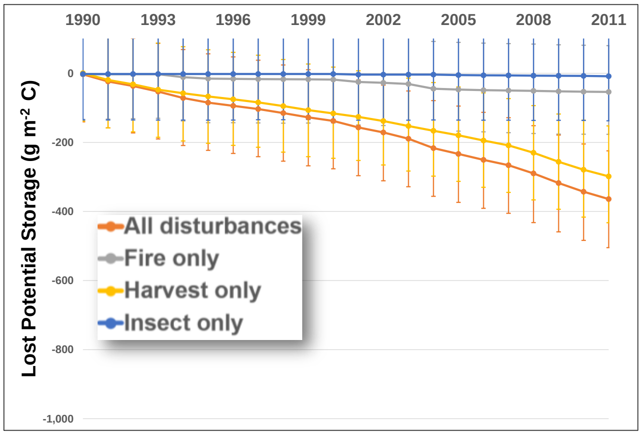
ForCaMF uses C dynamics derived from the combination of FIA plot data and FVS to interpret the consequences of recorded harvests and natural disturbances. This appendix contains ForCaMF results for each national forest in the Pacific Northwest Region from 1990 to 2011. Figure 2.1 shows the evolution of C impacts resulting from the disturbance patterns shown in Figure 1.1. Units in Figure 2.1 represent reduced C storage on a per square meter basis. Error bars around the impact of each type of disturbance represent 95% confidence intervals derived from 500 simulations of all recognized constituent uncertainties, as described earlier. Figure 2.2 summarizes the ForCaMF output shown in Figure 2.1: the pie chart represents the proportional importance of each type of disturbance as measured in 2011 (the last date in Figure 2.1). While disturbance information was obtained for the Columbia River Gorge (Figure 2.1a)*, not enough FIA plots were available for that management unit to calibrate ForCaMF, and it is therefore omitted from Figures 2.2 and 3.1.*

The 2002 Biscuit Fire in the Rogue River-Siskiyou was the Region's most significant single-year disturbance event, and Figure 2.1 shows a consequent dramatic shift in that Forest's C stocks. It must be emphasized that there is a residual effect for almost every disturbance because impact is being compared to what would happen to C storage if the stand had remained undisturbed. For fires, ForCaMF accounts for gradual decay of fire-killed material, so net C storage will likely continue to diverge from the undisturbed scenario for several years. This explains the fact that the effects of fire can increase even in years when those events do not occur.

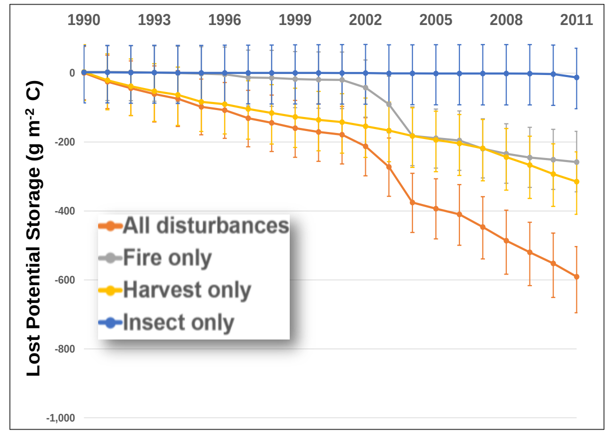
Disturbance effects of some forests (e.g., the Colville and Mt. Hood NFs) were dominated by harvest, while others were fire-dominated (Okanogan-Wenatchee and Rogue River-Siskiyou, Figures 2.1 and 2.2). Several units showed fairly equal impacts of fire and harvest (e.g., the Ochoco and Willamette), with harvest effects evident from the beginning of the 1990-2011 period, and fire effects emerging only when fires occurred. The C impacts of insects grew in affected forests according to the timelines recorded in Figure 1. The magnitude of disturbance effects varied significantly, with units like the Olympic and Mt. Baker-Snoqualmie showing very low D_F values (below 100g/m^2) and some showing much higher impacts.

Some of the harvest addressed across forests in this analysis was probably designed to salvage timber following fire or insect activity. Given the mapping methods used here, it is likely that both the original disturbance and the subsequent harvest were detected and mapped. For purposes of this assessment, losses of C storage potential (Figure 2.1) occurring between the two events (e.g., losses in a fire due to combustion and immediate emission) were assessed to the first process. Salvage operations and subsequent C dynamics were associated with harvests. For managers wishing to assign salvage impacts solely to the original disturbance, this decision within ForCaMF over-stated the impact of harvest.

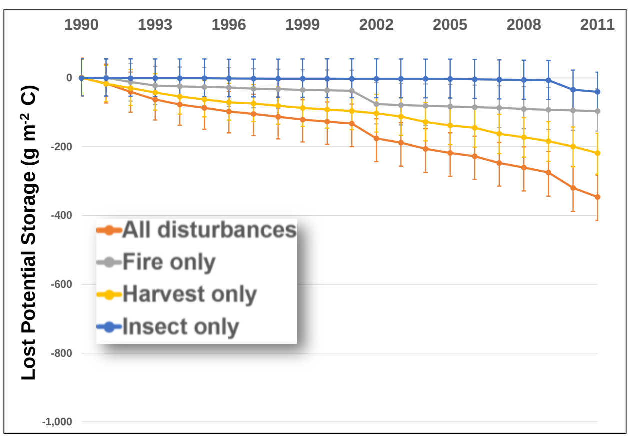
2.1a) Colville National Forest



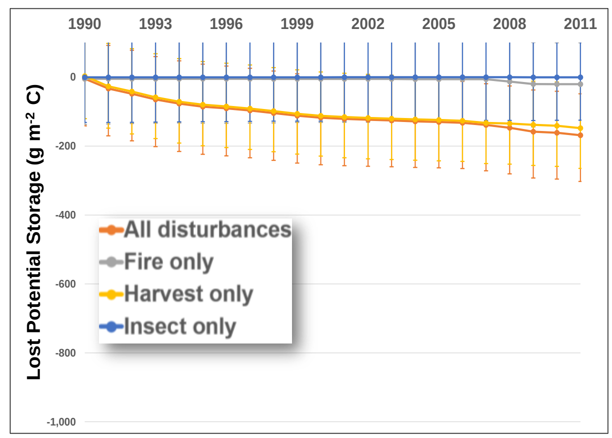
2.1b) Deschutes National Forest



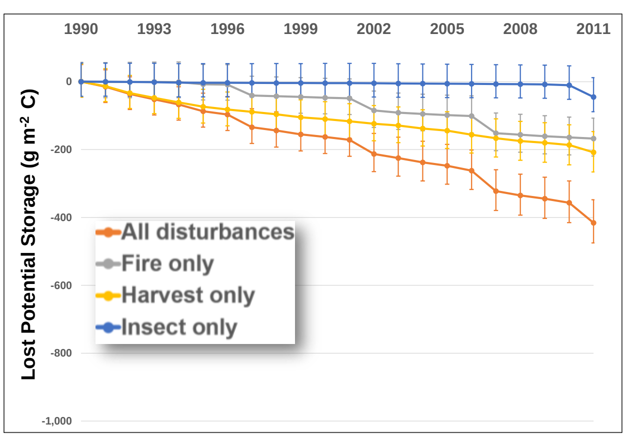
2.1c) Fremont – Winema National Forest



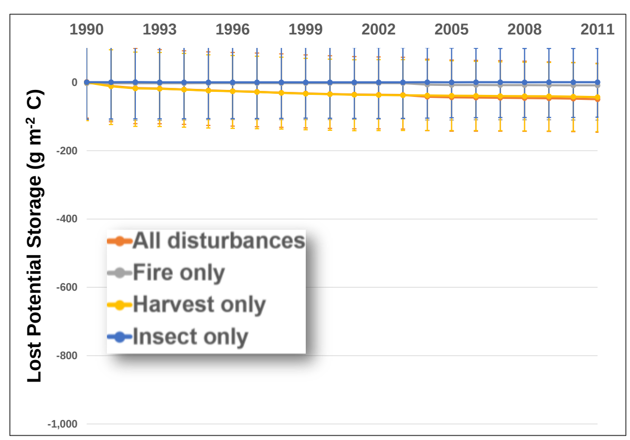
2.1d) Gifford Pinchot National Forest



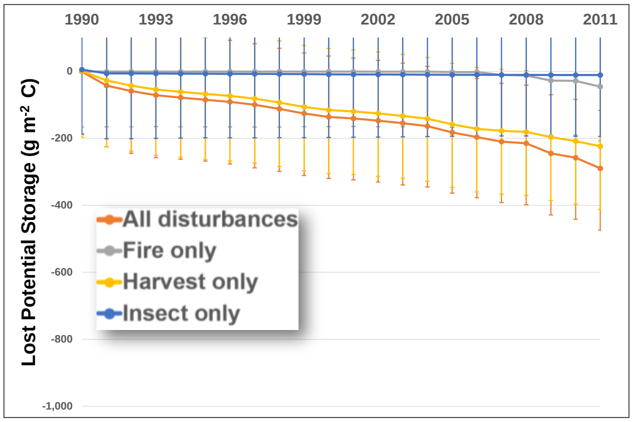
2.1e) Malheur National Forest



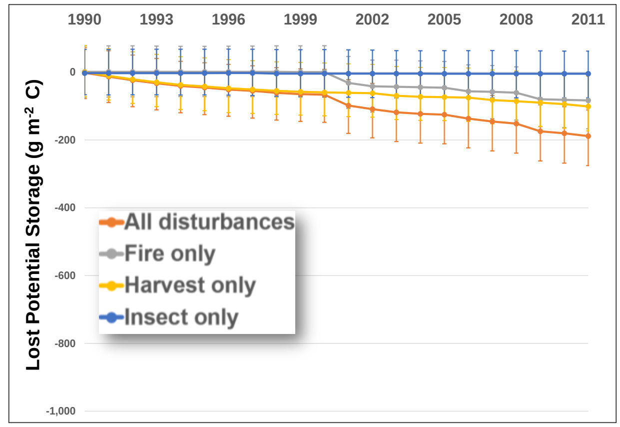
2.1f) Mt. Baker – Snoqualmie National



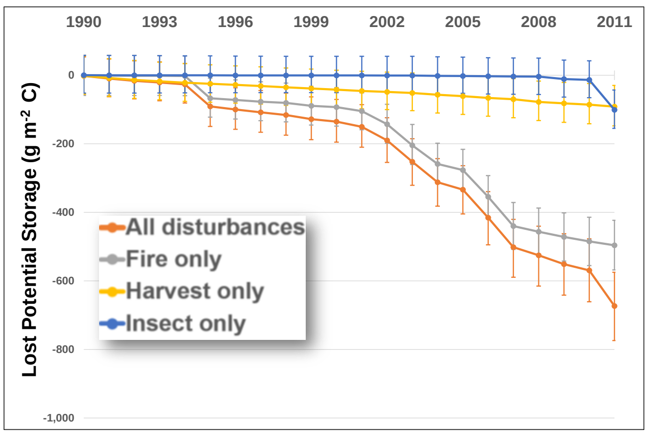
2.1g) Mt. Hood National Forest



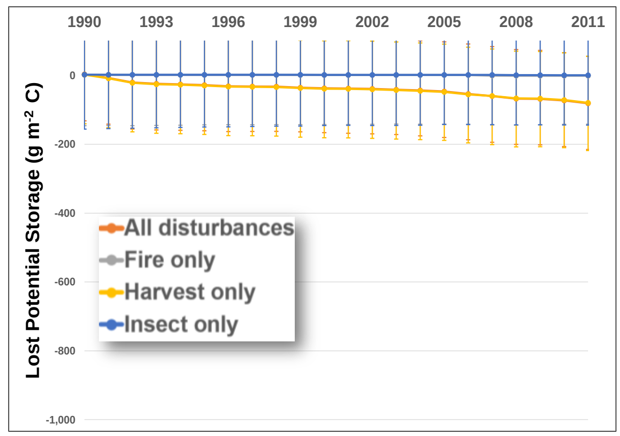
2.1h) Ochoco National Forest



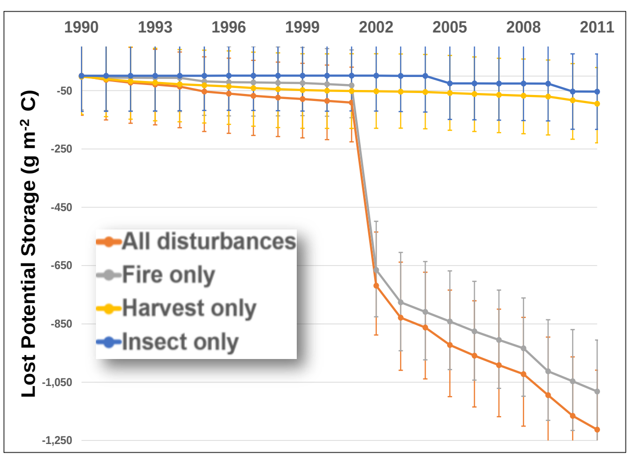
2.1i) Okanogan Wenatchee National Forest



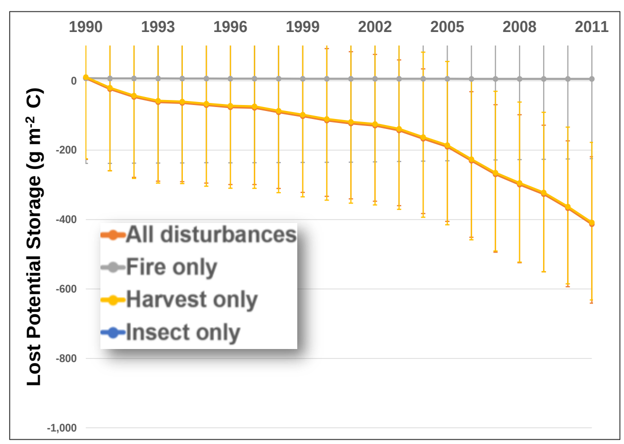
2.1j) Olympic National Forest



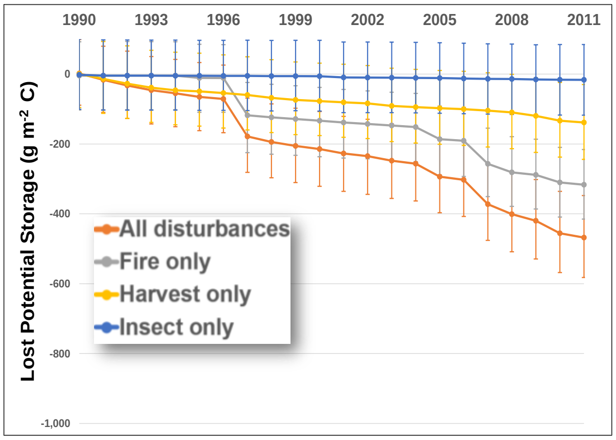
2.1k) Rogue River - Siskiyou National Forest



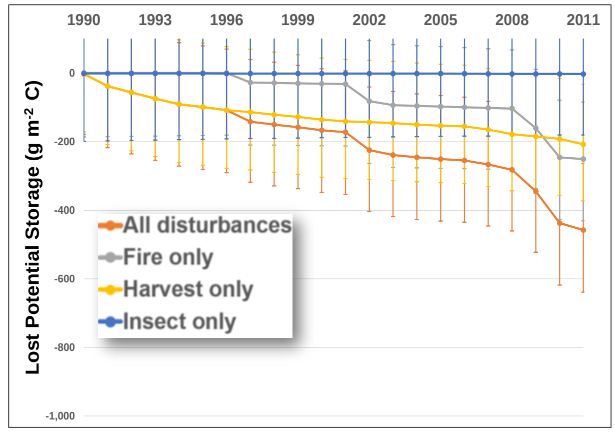
2.1l) Siuslaw National Forest



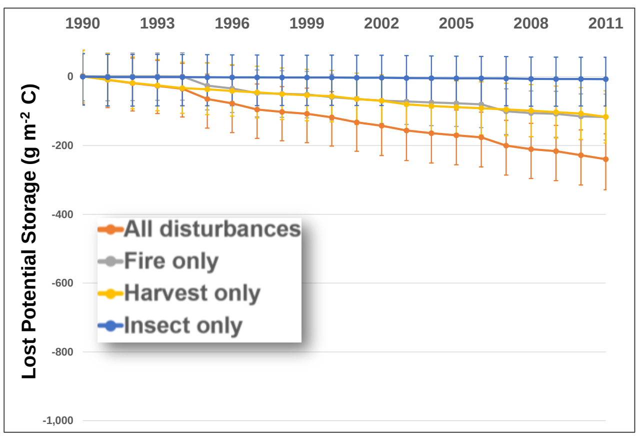
2.1m) Umatilla National Forest



2.1n) Umpqua National Forest



2.1o) Wallowa Whitman National Forest



2.1p) Willamette National Forest

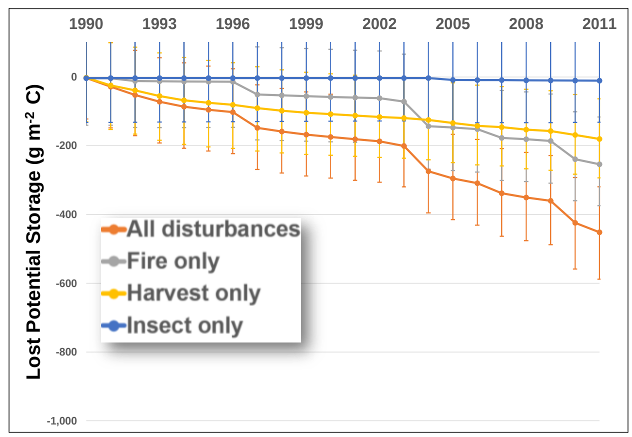
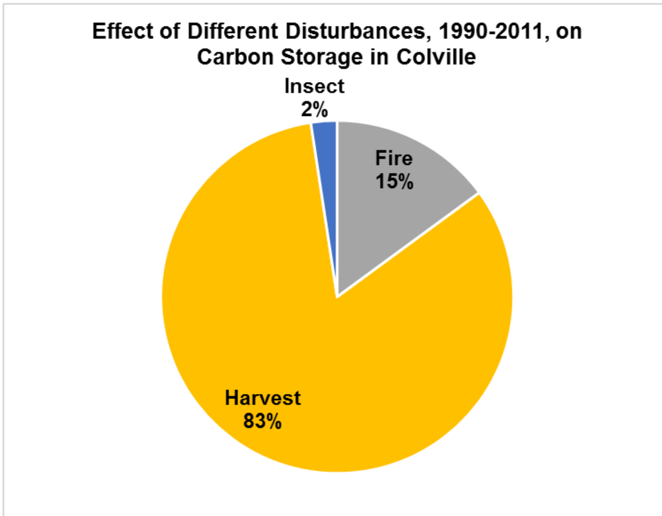
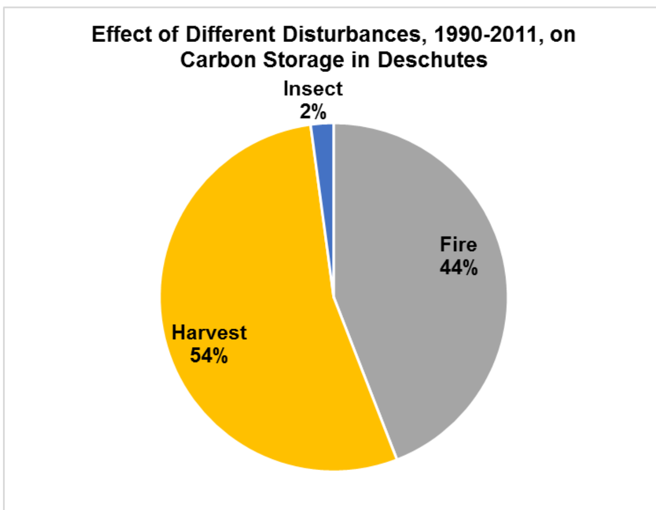
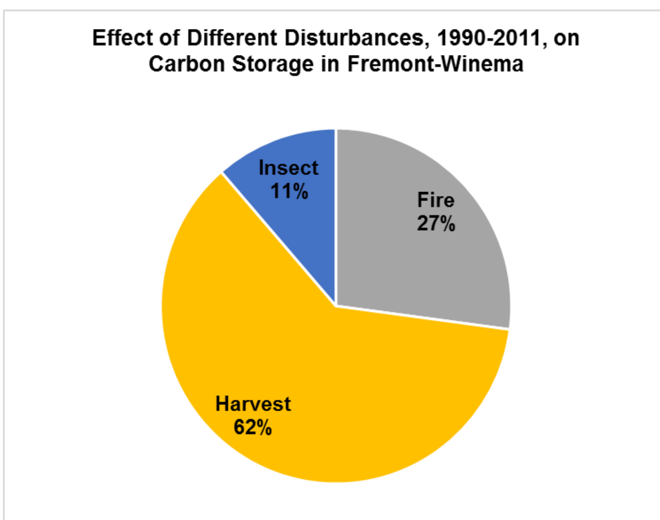
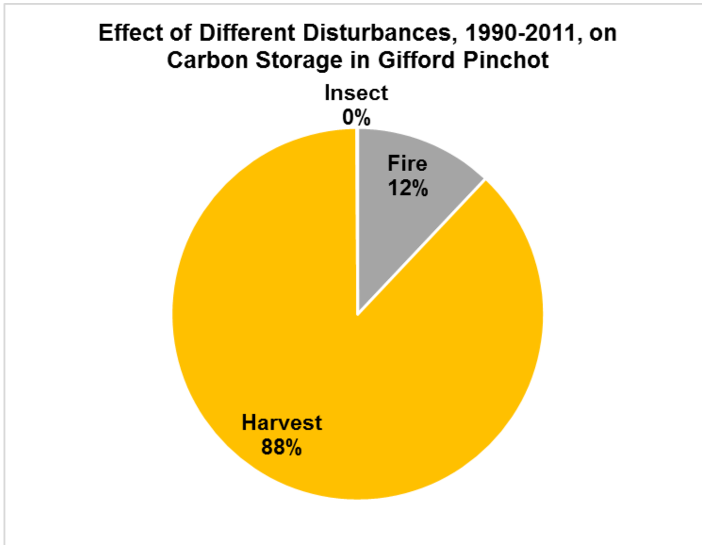


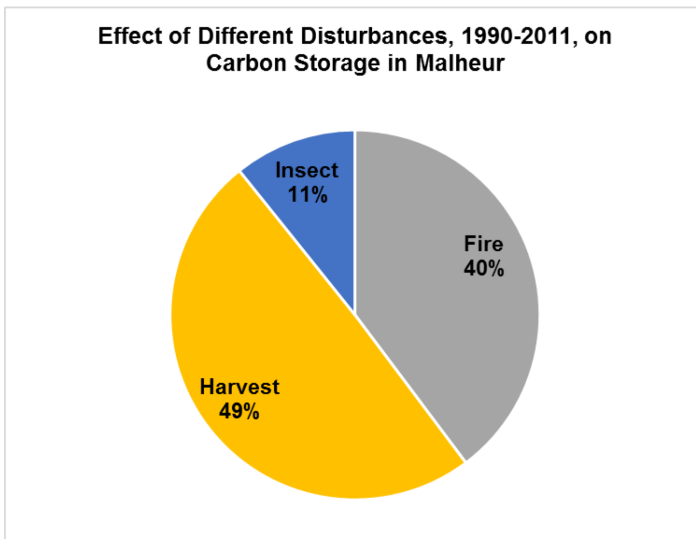
Figure 2.1. The impact of different kinds of disturbance, occurring from 1990 through 2011, on carbon (C) stores in the Pacific Northwest Region. The difference in storage for each year is shown between an "undisturbed" scenario and a scenario that includes only observed amounts of the specified type of disturbance. Error bars represent a 95-percent confidence interval; 100 g/m2 equals 1 metric tonne (or Mg)/ha.

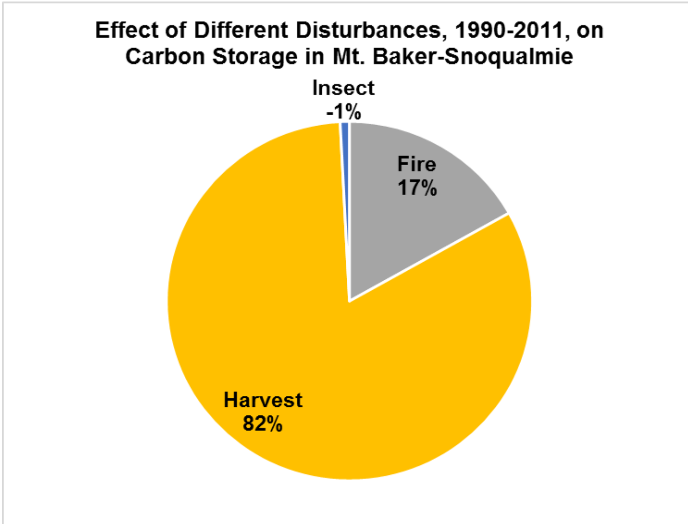

Effect of Different Disturbances, 1990-2011, on
Carbon Storage in Colville
Insect
2%
Fire
15%
Harvest
83%

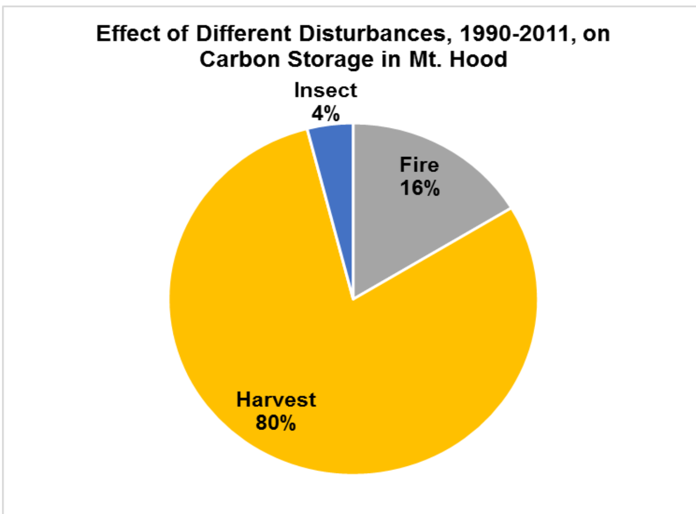

Effect of Different Disturbances, 1990-2011, on
Carbon Storage in Deschutes
Insect
2%
Fire
44%
Harvest
54%

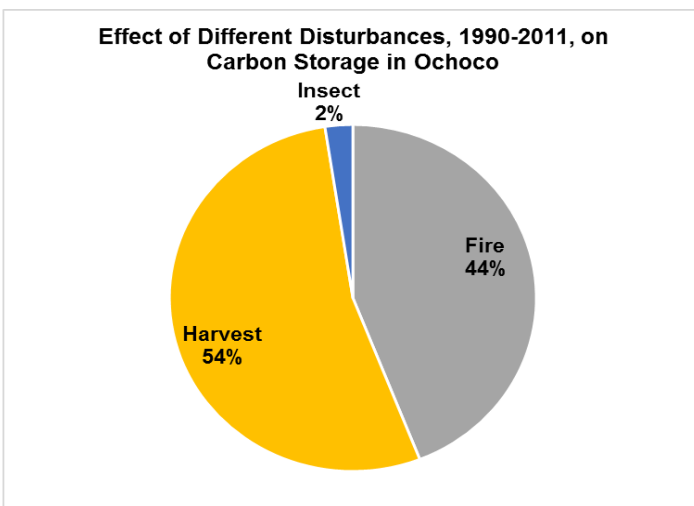

Effect of Different Disturbances, 1990-2011, on
Carbon Storage in Fremont-Winema
Insect
11%
Fire
27%
Harvest
62%

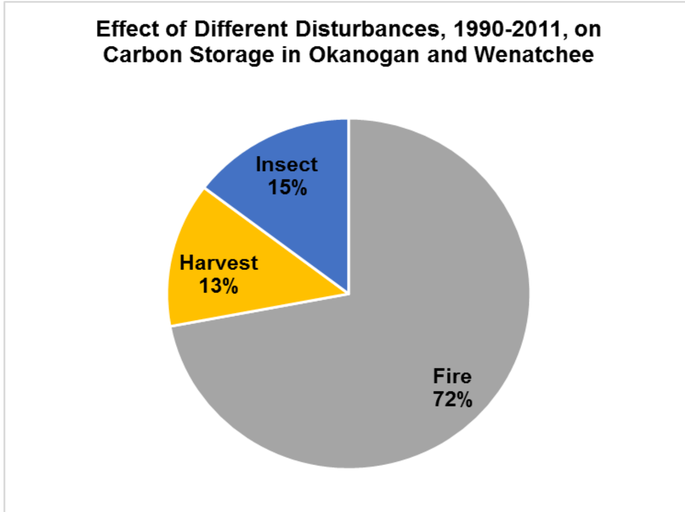

Effect of Different Disturbances, 1990-2011, on Carbon Storage in Gifford Pinchot
Insect 0%
Fire 12%
Harvest 88%

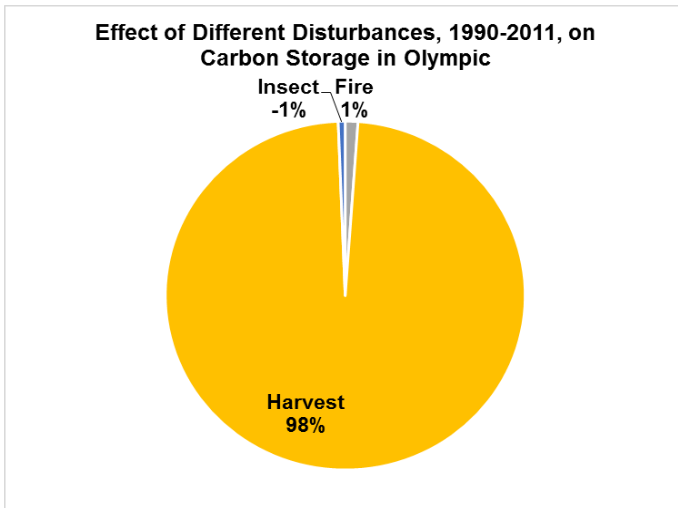

Effect of Different Disturbances, 1990-2011, on Carbon Storage in Malheur
Insect 11%
Fire 40%
Harvest 49%

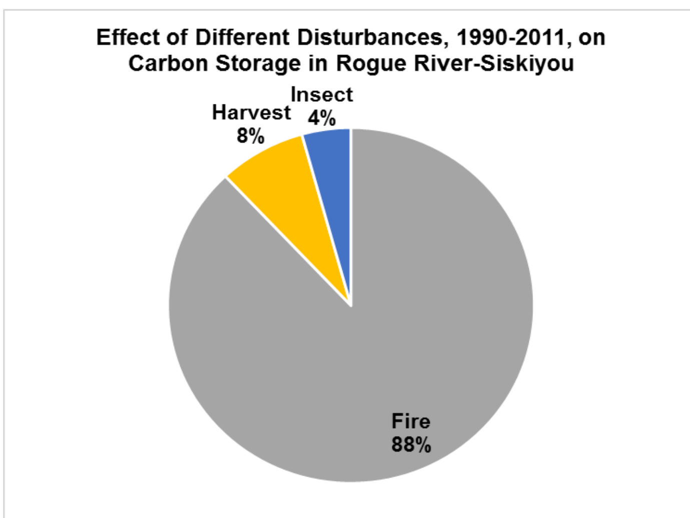

Effect of Different Disturbances, 1990-2011, on Carbon Storage in Mt. Baker-Snoqualmie
Insect -1%
Fire 17%
Harvest 82%

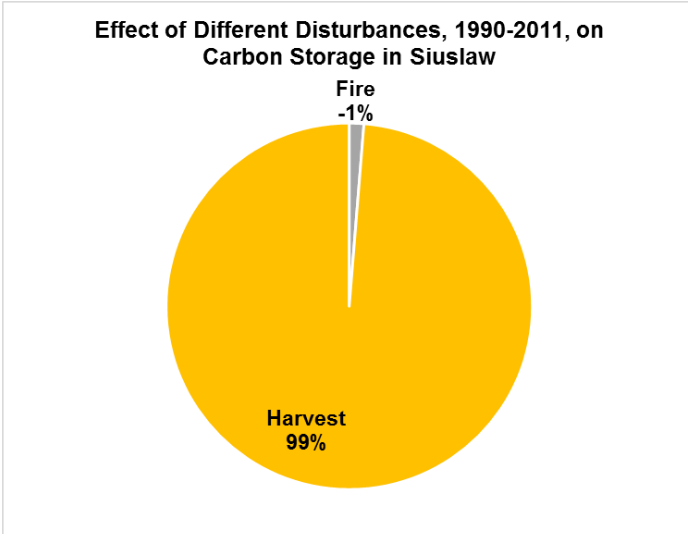

Effect of Different Disturbances, 1990-2011, on Carbon Storage in Mt. Hood
Insect 4%
Fire 16%
Harvest 80%

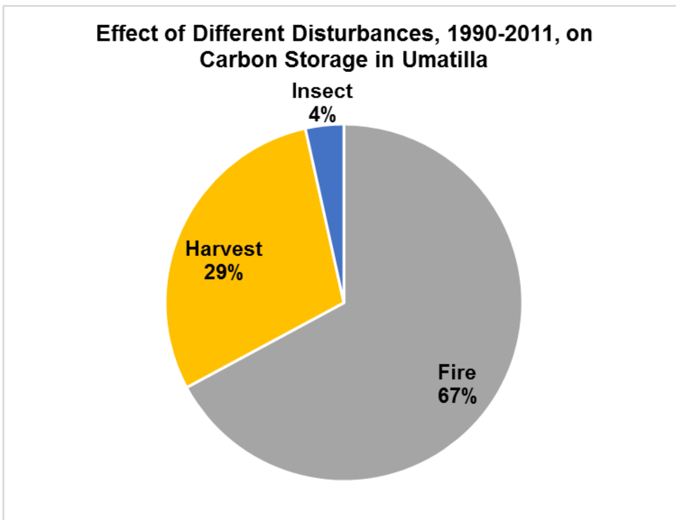

Effect of Different Disturbances, 1990-2011, on Carbon Storage in Ochoco
Insect 2%
Fire 44%
Harvest 54%

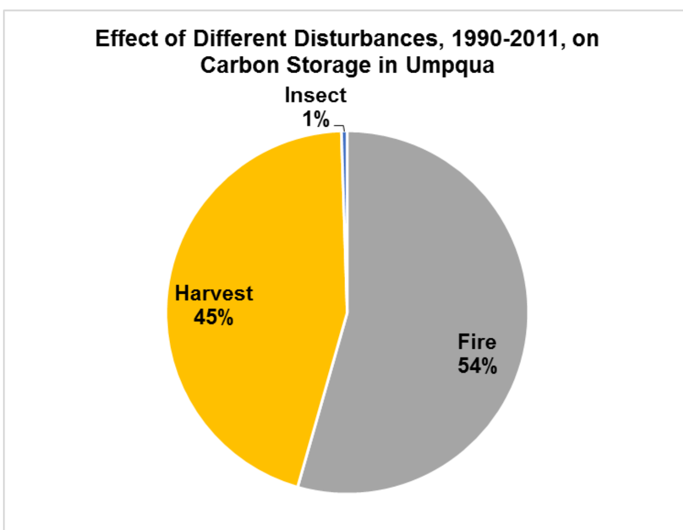

Effect of Different Disturbances, 1990-2011, on Carbon Storage in Okanogan and Wenatchee
Insect 15%
Harvest 13%
Fire 72%

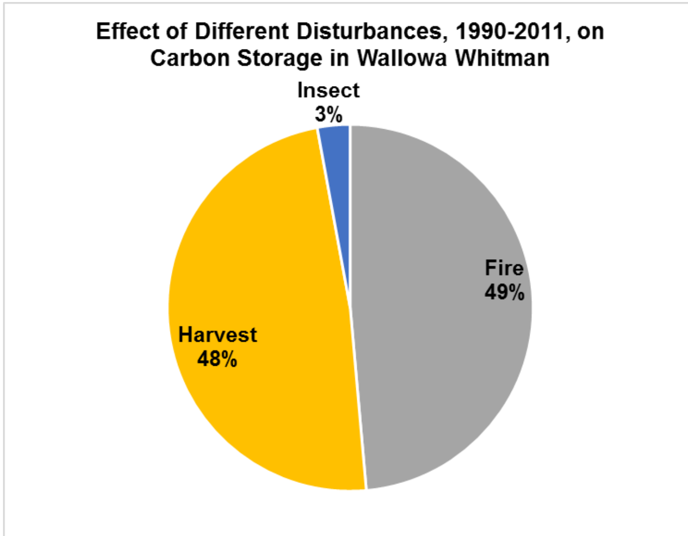

Effect of Different Disturbances, 1990-2011, on Carbon Storage in Olympic
Insect -1%
Fire 1%
Harvest 98%


Effect of Different Disturbances, 1990-2011, on Carbon Storage in Rogue River-Siskiyou
Insect 4%
Harvest 8%
Fire 88%


Effect of Different Disturbances, 1990-2011, on
Carbon Storage in Siuslaw
Fire
-1%
Harvest
99%


Effect of Different Disturbances, 1990-2011, on
Carbon Storage in Umatilla
Insect
4%
Harvest
29%
Fire
67%


Effect of Different Disturbances, 1990-2011, on
Carbon Storage in Umpqua
Insect
1%
Harvest
45%
Fire
54%



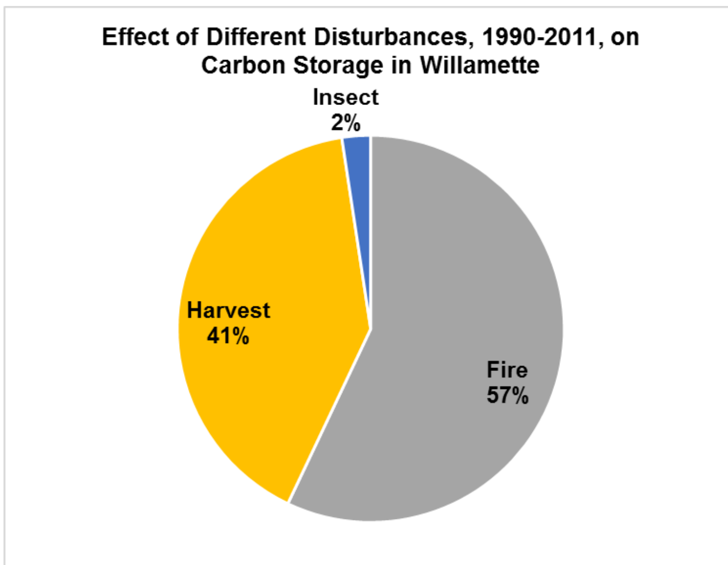


Figure 2.2. Proportional effect of different kinds of disturbance on carbon storage in each national forest in the Pacific Northwest Region for the period 1990 through 2011.

3. Management implications of ForCaMF results

Earlier baseline assessments (http://www.fs.fed.us/climatechange/advisor/products.html) presented inventory-derived estimates of how much carbon is stored in the forests and in the harvested wood product pools of each national forest. The ForCaMF analyses here focused on how different types and intensities of disturbance have influenced those stocks in recent decades. Specifically, results given in Section 6.6 of the main report and previous sections of this appendix provide details about: 1) patterns of disturbance; 2) how disturbance impacts on C storage evolved in each forest from 1990 to 2011, and; 3) the level of uncertainty associated with assessments of each forest. In this section, we bring this information together to answer the simple questions of: "How much do disturbances really disrupt C storage?" and "which disturbance processes in each forest are the most important?"

In highlighting what information managers and planners can gain from these analyses, it is useful to remember that C storage is simply one ecological service, among many, that forests provide. That service mitigates the climate impacts of greenhouse gases emitted through the use of fossil fuels by removing carbon dioxide (CO_2) from the atmosphere. Figure 3.1 shows how much less C (by percentage) was stored in each forest in 2011 because of different types of disturbance since 1990. Disturbance patterns continue to change, but this assessment of the recent past represents the best available insight into how sensitive National Forest C storage is to fire, harvest, insects, disease, and weather events. Residual disturbance effects (*e.g.,* decaying dead C) of monitored events will depress C storage for many years after 2011, just as many pre-1990 disturbances continue to affect current stocks. In most cases, forests re-grow after disturbance and become C sinks for many decades or centuries after a relatively short period of reduced C stocks. In some regions where C stocks have reached elevated levels because of disturbance suppression, a lower level of C stock may be more sustainable compared with the recent past.

The period of this snapshot was somewhat arbitrary; however, every analysis needs sideboards, and the period used here coincides with our best monitoring data (satellite imagery, Agency activity records, FIA data). The percentages recorded in Figure 3.1 may seem relatively small, but they often represent very large amounts of climate mitigation benefit. For instance, if a National Forest has half a million hectares of forestland that FIA tells us is storing 50 Mg of C per hectare, and ForCaMF tells us that there would be 2% more C without insect activity from 1990-2011, that is a difference of half a million metric tonnes (Mg) of C, or 1.835 million tonnes of CO_2 (using a 3.67 conversion ratio for C to CO_2). For perspective, this is approximately the amount of CO_2 released by burning around 200 million gallons of gasoline (US Energy Information Administration), and its offset value (amount it would be worth if its continued storage were sold on an open market at a conservative price of $10/tonne) would be almost $20 million.

There are certain ways that Figure 3.1 does not tell the complete story. The FVS model, which supplies stand dynamics within ForCaMF, does not cover soil organic C, and Figure 3.1's calculations exclude soils. Fortunately, the InTEC model presented in this assessment do provide insight into soil C dynamics. More importantly, there are some types of disturbance known to be important that were excluded. For instance, root diseases are known to be prevalent in many parts of the country, but they can be difficult to detect with satellite or aerial imagery because their effects in most years can be limited to reduced growth and suppression of regeneration. ForCaMF was used to assess the impacts of root disease in only 6 national forests, all in the Northern Region. That analysis, which was only possible because of a specialized "regional add-on" variable to core FIA measurements, showed significant root disease impacts that equaled the impacts of fire despite several large fire events in the Region (Healey et al., 2016). We know that we are missing similar processes across the country that are not well addressed by available monitoring data.

Disturbances due to climate variability were assessed with the InTEC model which includes precipitation and temperature as major factors affecting forest processes. The effects of climate variability may be positive or negative, and are often highly variable from year to year, depending on the region and how the climate variables interact to affect photosynthesis and respiration. The effects of climate also interact with other atmospheric changes particularly increasing atmospheric CO_2 concentration and nitrogen deposition, both of which typically enhance growth rates of forests.

Lastly, this assessment does not consider storage of harvested C in product pools. Conversion of forest material to durable wood products defers emissions of the associated C until decay or combustion occurs following disposal. Earlier baseline assessments and assessments by Stockmann et al. (2012) quantified C stocks in wood products that remain in use or landfills, and work is ongoing to combine ForCaMF and product C dynamics models. In the present assessment, however, harvest effects (like the effects of all disturbances) are restricted to ecosystem stocks, a limitation that overstates the emissions of CO_2 from harvest from an atmospheric point of view. The effect of substituting wood products for other materials such as concrete and aluminum are not considered in any of the assessments but are potentially significant and will be assessed in future work.

It is outside the scope of this assessment to suggest the importance of ecosystem services associated with C relative to other values such as water yield or habitat conservation. What we do provide is tangible information about how management and disturbance prevention/suppression can impact (and has impacted) the climate change mitigation a national forest generates. To the degree planners value C storage as a service, the disturbance rates published here, along with resultant C storage differences, can frame management goals moving forward.

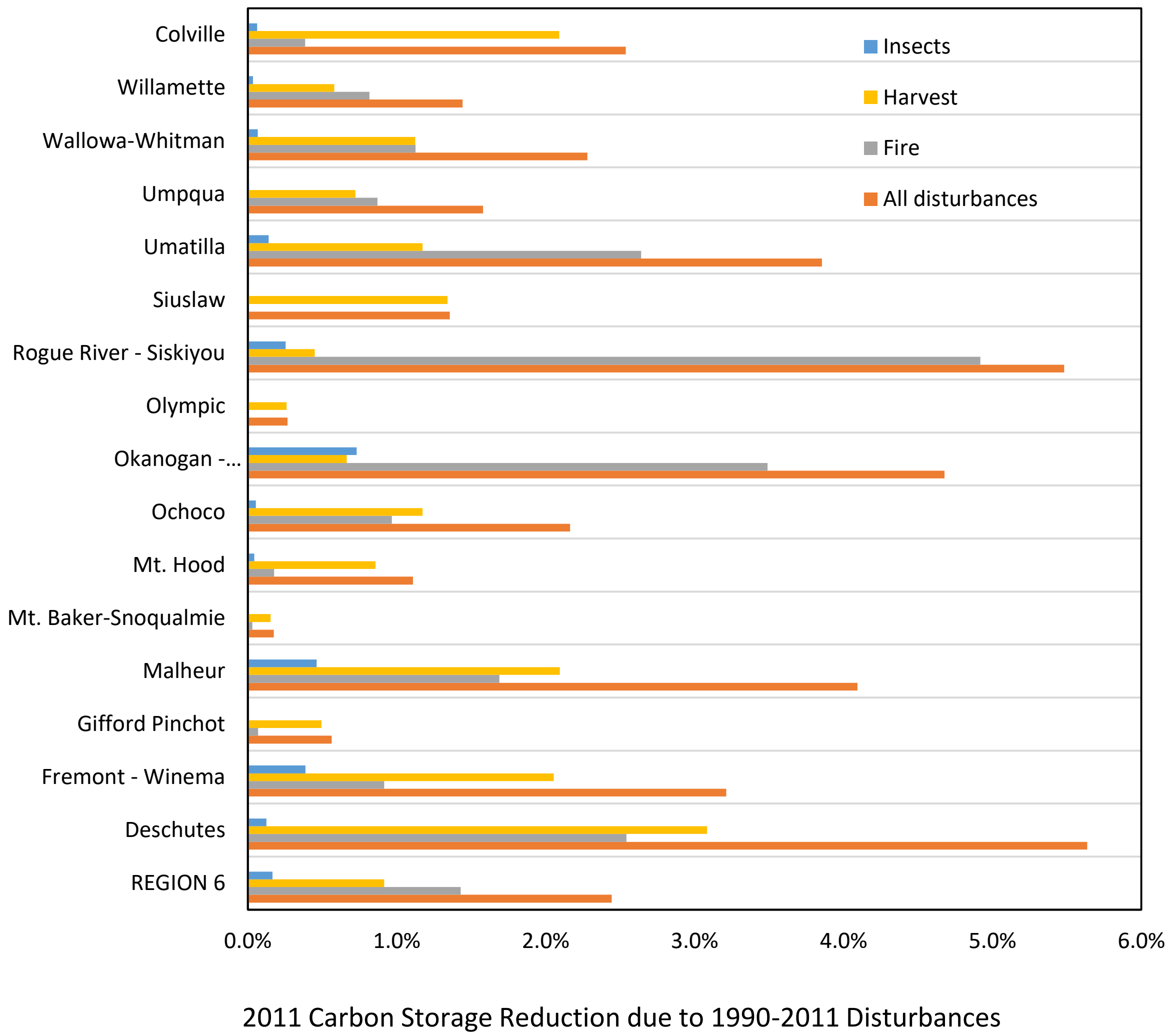


Figure 3.1. Carbon stock reduction in 2011 due to disturbances occurring from 1990 through 2011, by each national forest and for all national forests combined in the Pacific Northwest Region. Percent reduction represents how much nonsoil carbon was lost from the baseline forest inventory carbon stock estimates.

4. Effects of disturbance, management, and environmental factors (InTEC)

The set of figures for each of 17 National Forests units in the Pacific Northwest Region were generated from both input datasets and outputs from the InTEC model. Note that the numbering sequence of figures in this section is repeated for each National Forest. The input dataset figures presented here include stand age-forest type distributions (Figure 4.1), net primary productivity and stand age relationships (Figure 4.2), total annual precipitation (Figure 4.3a), mean annual temperature (Figure 4.3b), and total annual nitrogen (N) deposition (Figure 4.3c) from 1950-2010. A single atmospheric CO_2 dataset indicating an increasing trend from 280 ppm in 1901 to 390 ppm 2010 (Keeling et al. 2009) was used for all National Forest units across the U.S. The disturbance type and magnitude figures (Figure 1.1) are also referenced as they are useful for understanding model results. Summary figures of the input datasets have been included in these reports because they provide useful context for interpreting the model outputs.

Model outputs presented here include C stock changes and C accumulation due to disturbance and non-disturbance factors, and C emissions due to disturbances alone from 1950-2011. C stock change outputs show the change in C stocks over the course of a year, thus the value in a given year is the difference between total C stocks in that year and total C stocks in the previous year. C stock change is equivalent to Net Biome Production, which is the total photosynthetic uptake of C by the forest minus the loss of C due to autotrophic and heterotrophic respiration and disturbances. The change in C stocks have been attributed to the following effects: (1) individual non-disturbance factors (climate, N deposition, CO_2 concentrations) (Figure 4.4a), (2) combined disturbances factors (fire, harvests, insects, aging and regrowth) (Figure 4.4b), (3) combined non-disturbance factors (Figure 4.4b), and (4) all factors which is the sum of all non-disturbance and disturbance effects (Figure 4.4c). A positive C stock change value in a given year signifies that the factor(s) caused the forest to absorb more C from the atmosphere than it emitted, thus acting as a C sink. A negative C stock change value indicates that the factor(s) caused the forest to release more C to the atmosphere than it absorbed, thus acting as a C source.

Consecutively summing the annual C stock changes (Figure 4.4a-4.4c) yields the total accumulated ecosystem C since 1950 (Figure 4.4d). Positive values indicate accumulated effects that enhanced the total C stock, and negative values represent accumulated effects that reduced the total C stock. The total C emissions due to disturbances alone are also included (Figure 4.4e) and when added to the C stock change (NBP), yields the Net Ecosystem Productivity. The results of the InTEC model runs are numerous and include mapped outputs, C densities, and the effects of both non-disturbance and disturbance factors on individual component pools (e.g. aboveground live C, soil C), thus only summary results are presented here.

For further examples of how to interpret the figures in this section, see Section 6.6 of the main report which provides explanation of the regional InTEC results.

Columbia River Gorge National Scenic Area

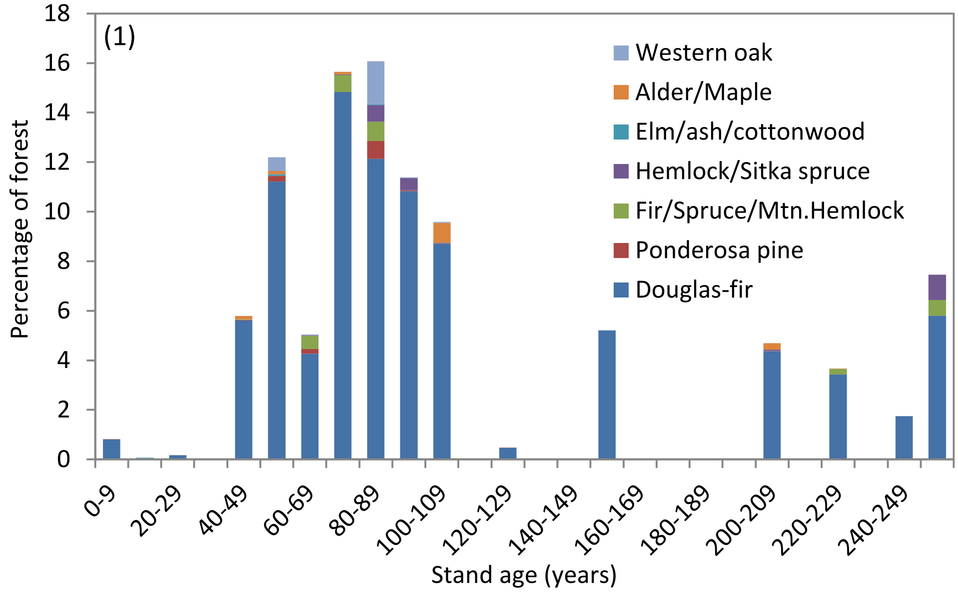


Figure 4.1. Age class distribution in 2011 in the Columbia River Gorge National Scenic Area displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

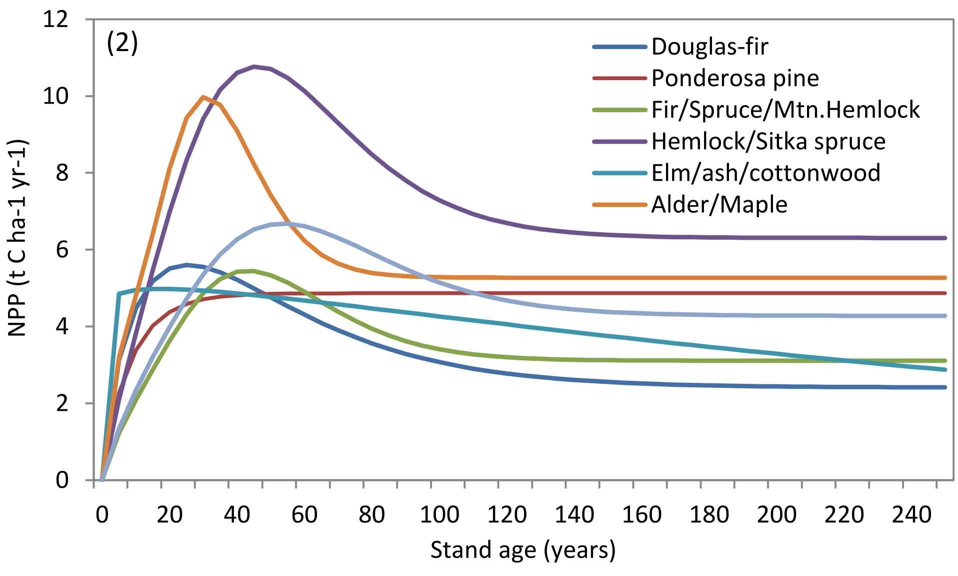


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Columbia River Gorge National Scenic Area. Curves were developed by He et al. 2012. The Evergreen Needleleaf curve was applied to Douglas-fir forest type.

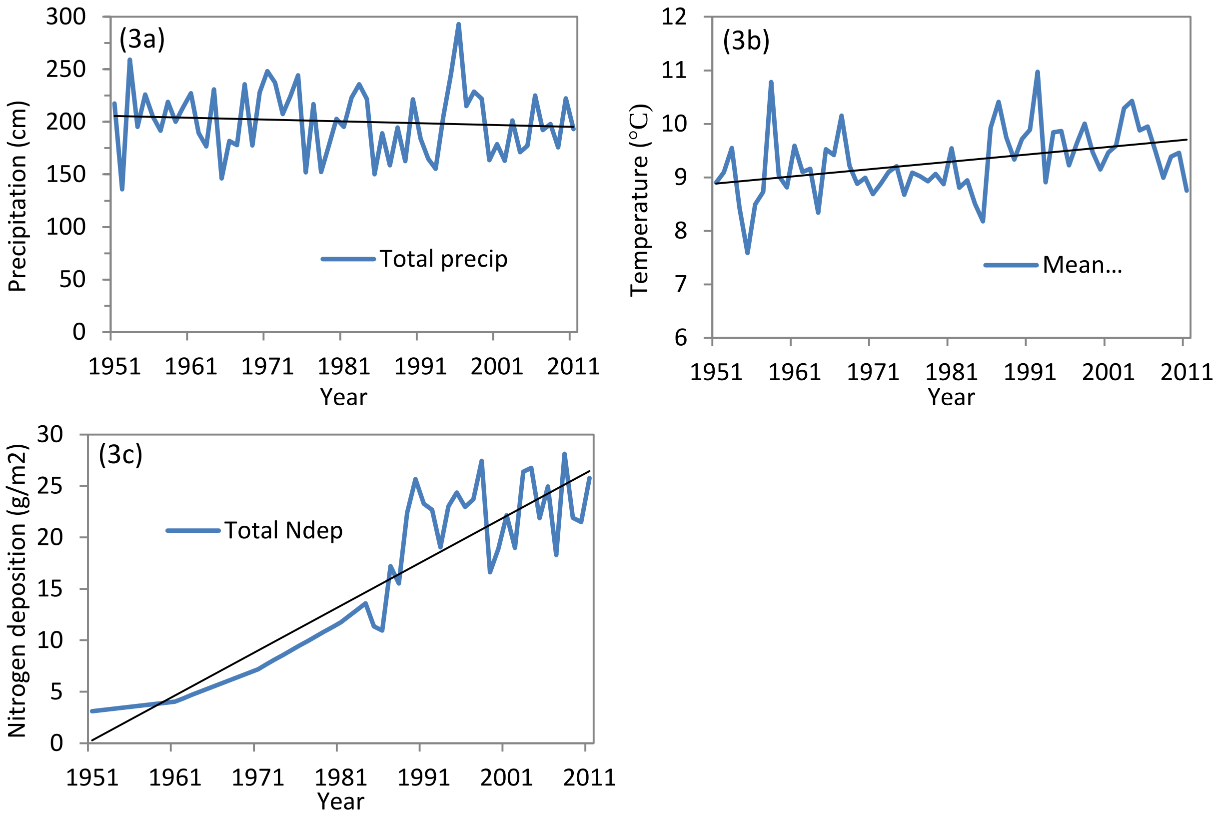


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Columbia River Gorge National Scenic Area. Linear trend lines shown in black.

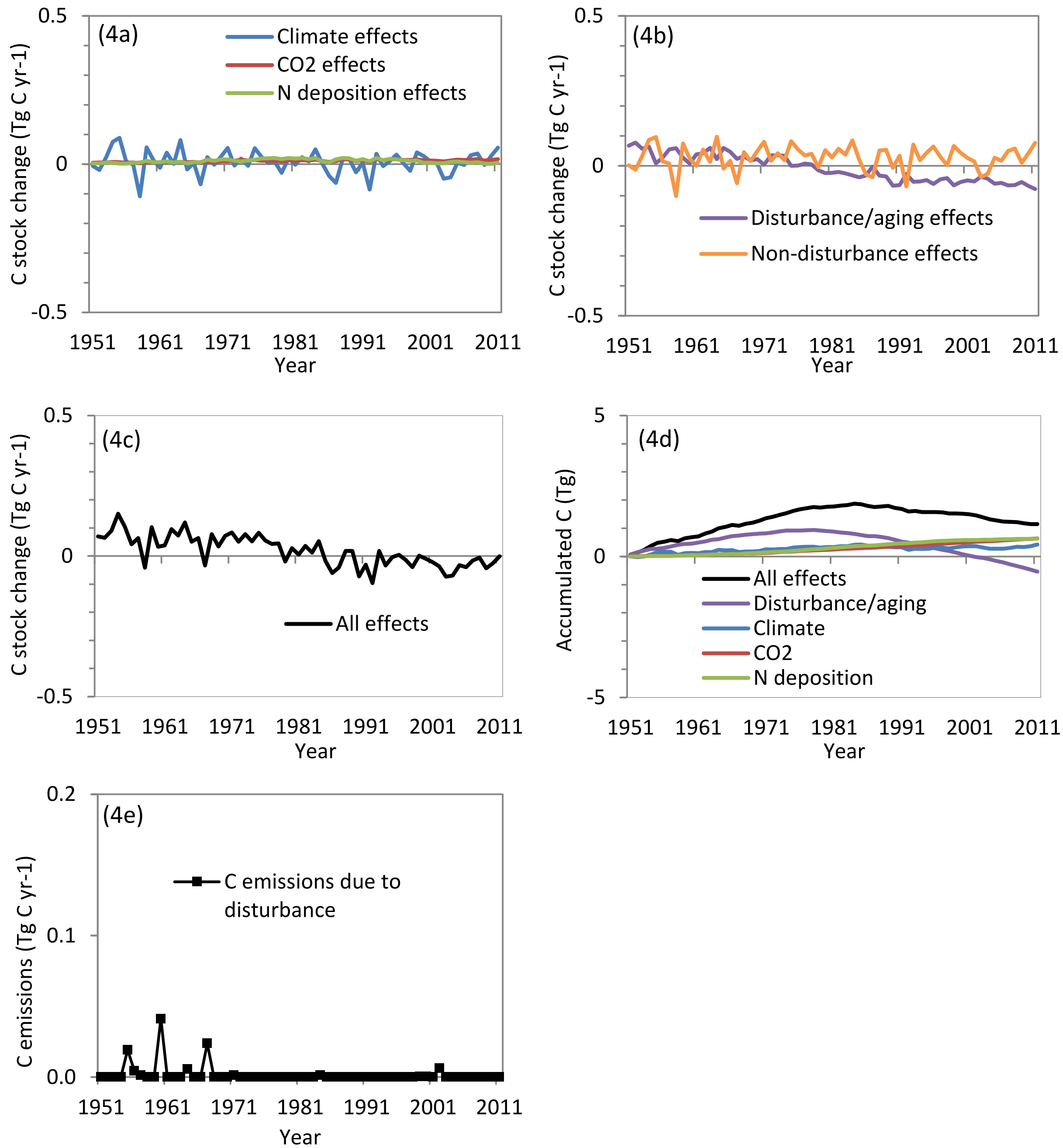


Figure 4.4. Changes in carbon stocks in the Columbia River Gorge National Scenic Area due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and aging and the sum of all non-disturbance factors combined; and (c) all factors combined which is the sum of disturbance\aging and non-disturbance effects; (d) Accumulated C due to individual disturbance\aging and non-disturbance factors and all factors combined from 1950-2011 excluding C accumulated pre-1950; and (e) C emissions due to disturbance events only. Positive values in Figures 4.4 a-c represent C sinks from the atmosphere or enhancement effects, whereas negative values represent C sources to the atmosphere, or detraction effects.

Colville National Forest

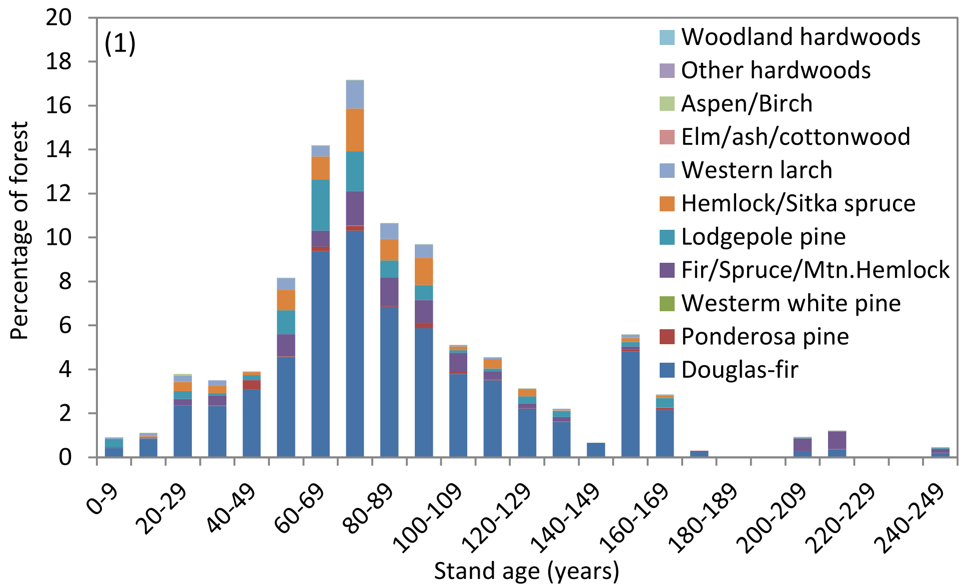


Figure 4.1. Age class distribution in 2011 in the Colville National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

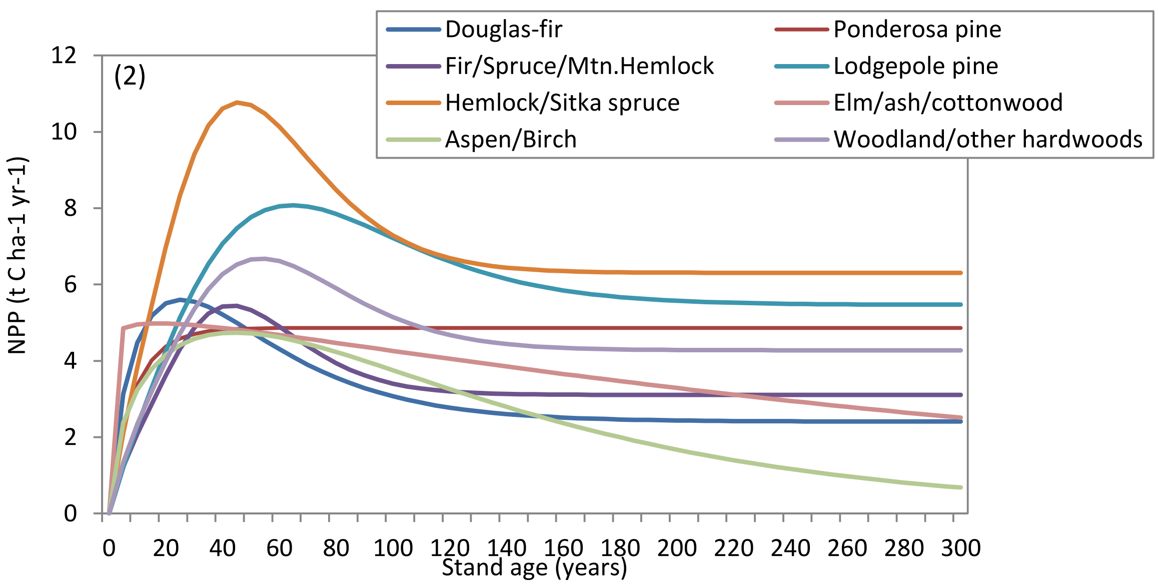


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Colville National Forest. Curves were developed by [He et al. 2012](). The Ponderosa pine curve was applied to the Western White Pine forest type. The Evergreen Needleleaf curve was applied to Douglas-fir forest type and the Western oak curve was applied to the Woodland/Other hardwoods for types.

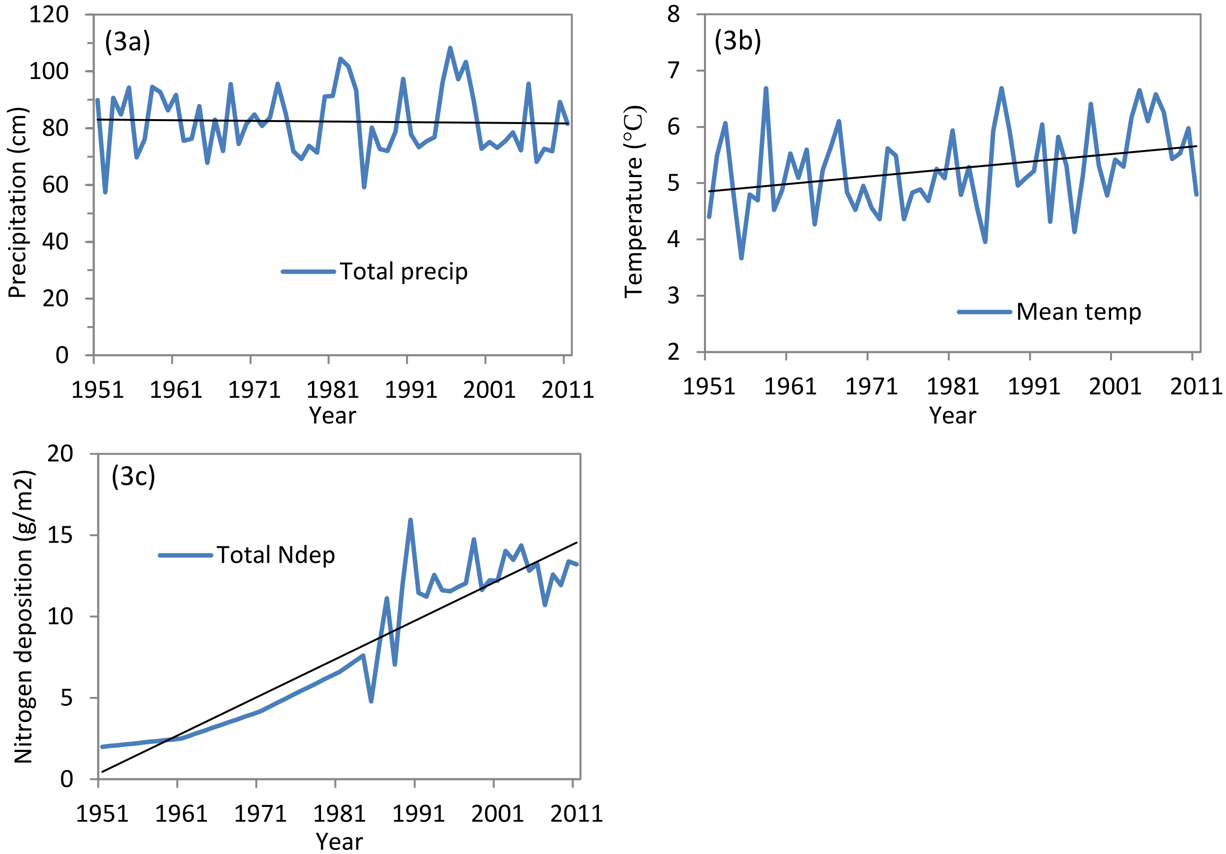


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Colville National Forest. Linear trend lines shown in black.

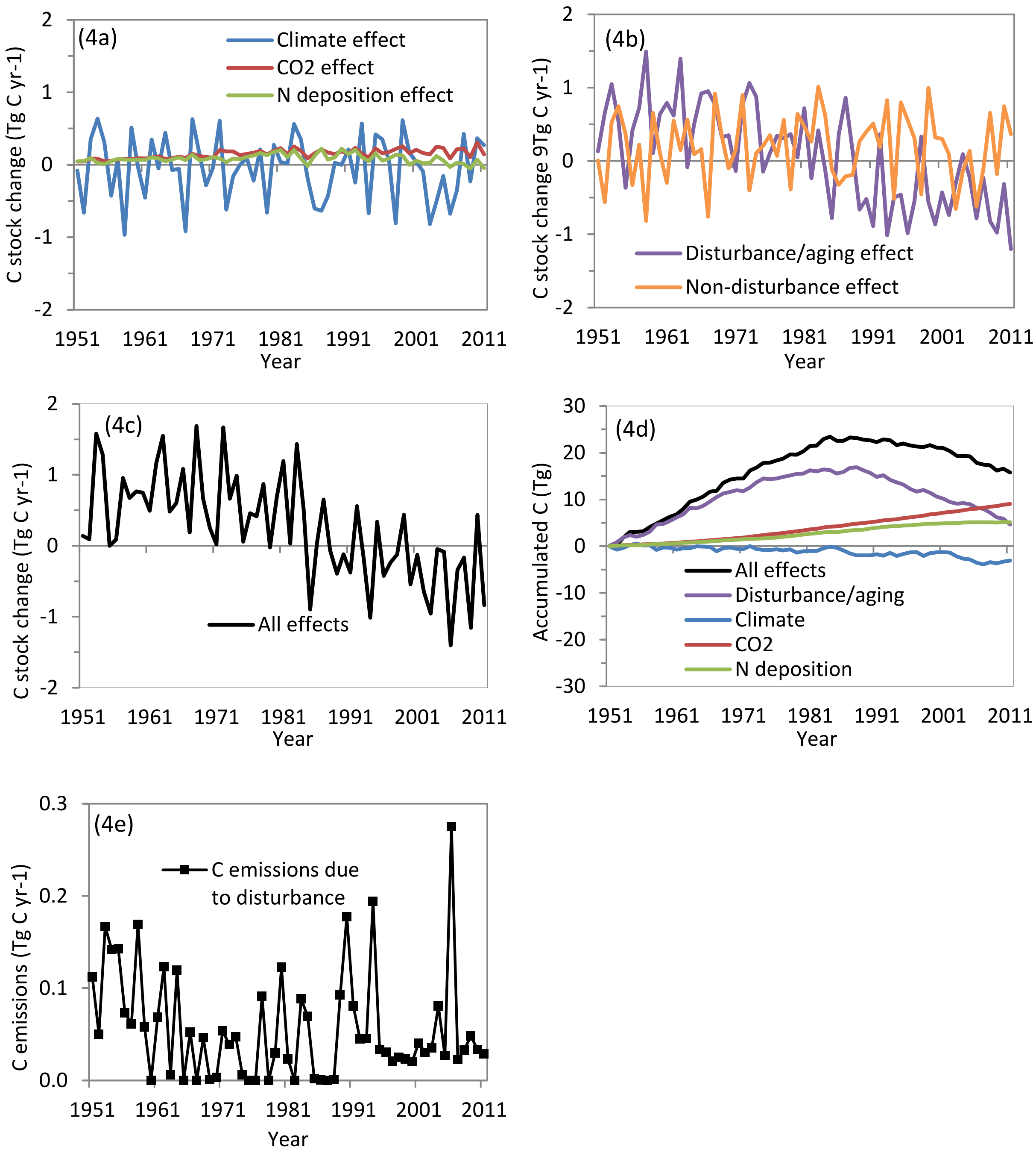


Figure 4.4. Changes in carbon stocks in the Colville National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and aging and the sum of all non-disturbance factors combined; and (c) all factors combined which is the sum of disturbance\aging and non-disturbance effects; (d) Accumulated C due to individual disturbance\aging and non-disturbance factors and all factors combined from 1950-2011 excluding C accumulated pre-1950; and (e) C emissions due to disturbance events only. Positive values in Figures 4.4 a-c represent C sinks from the atmosphere or enhancement effects, whereas negative values represent C sources to the atmosphere, or detraction effects.

Deschutes National Forest

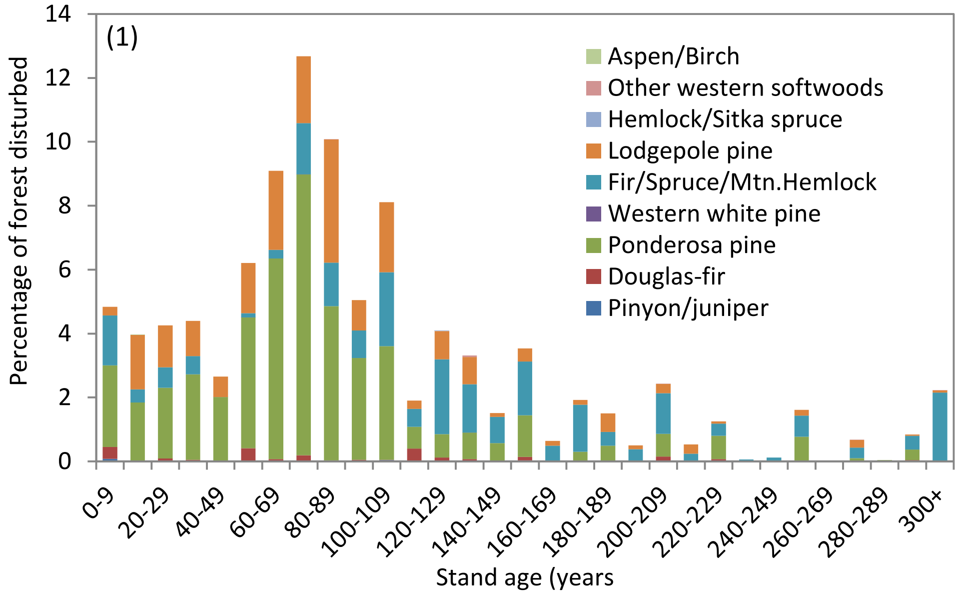


Figure 4.1. Age class distribution in 2011 in the Deschutes National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

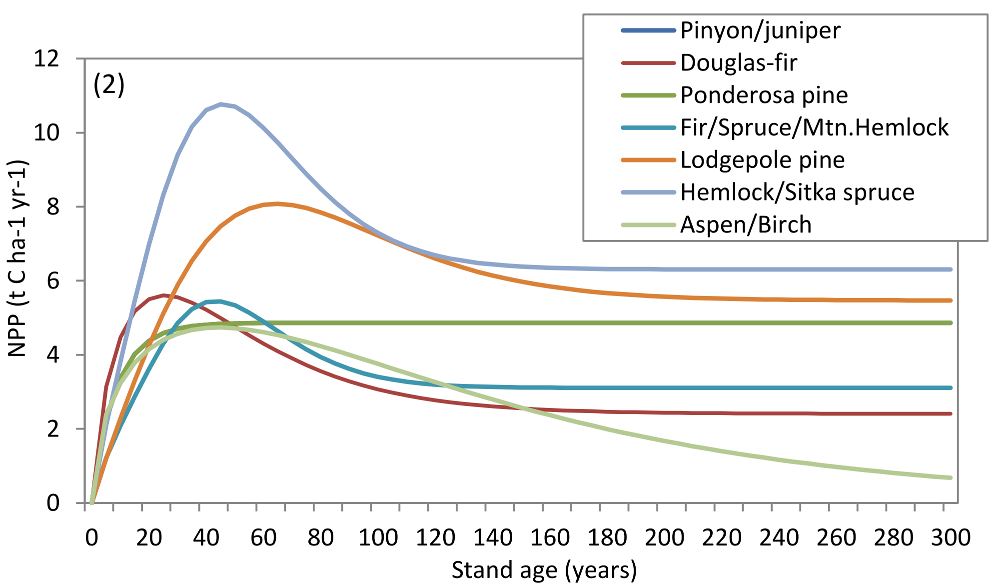


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Deschutes National Forest. Curves were developed by He et al. 2012. The Evergreen Needleleaf curve was applied to Douglas-fir forest type. The Ponderosa pine curve was applied to the Pinyon/juniper, Other Western Softwoods, and Western White pine forest types.

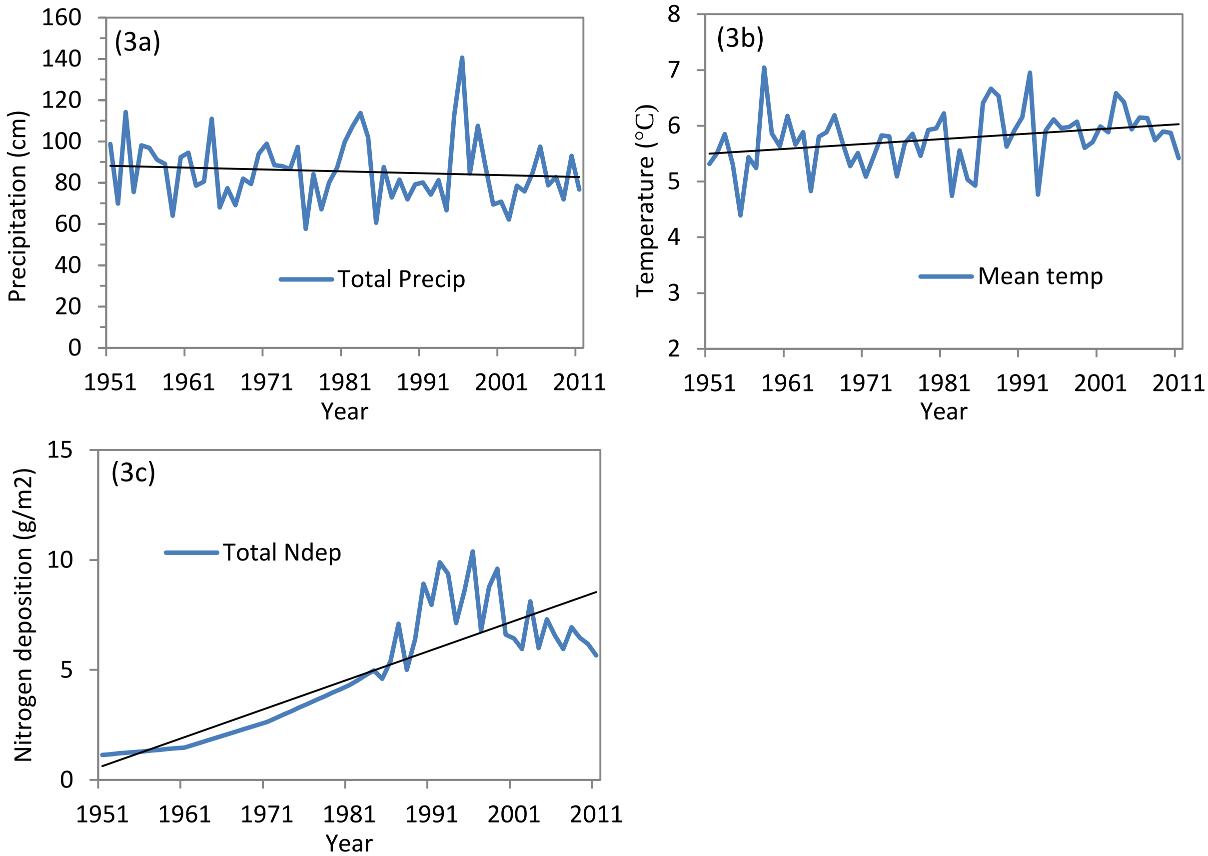


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Deschutes National Forest. Linear trend lines shown in black.

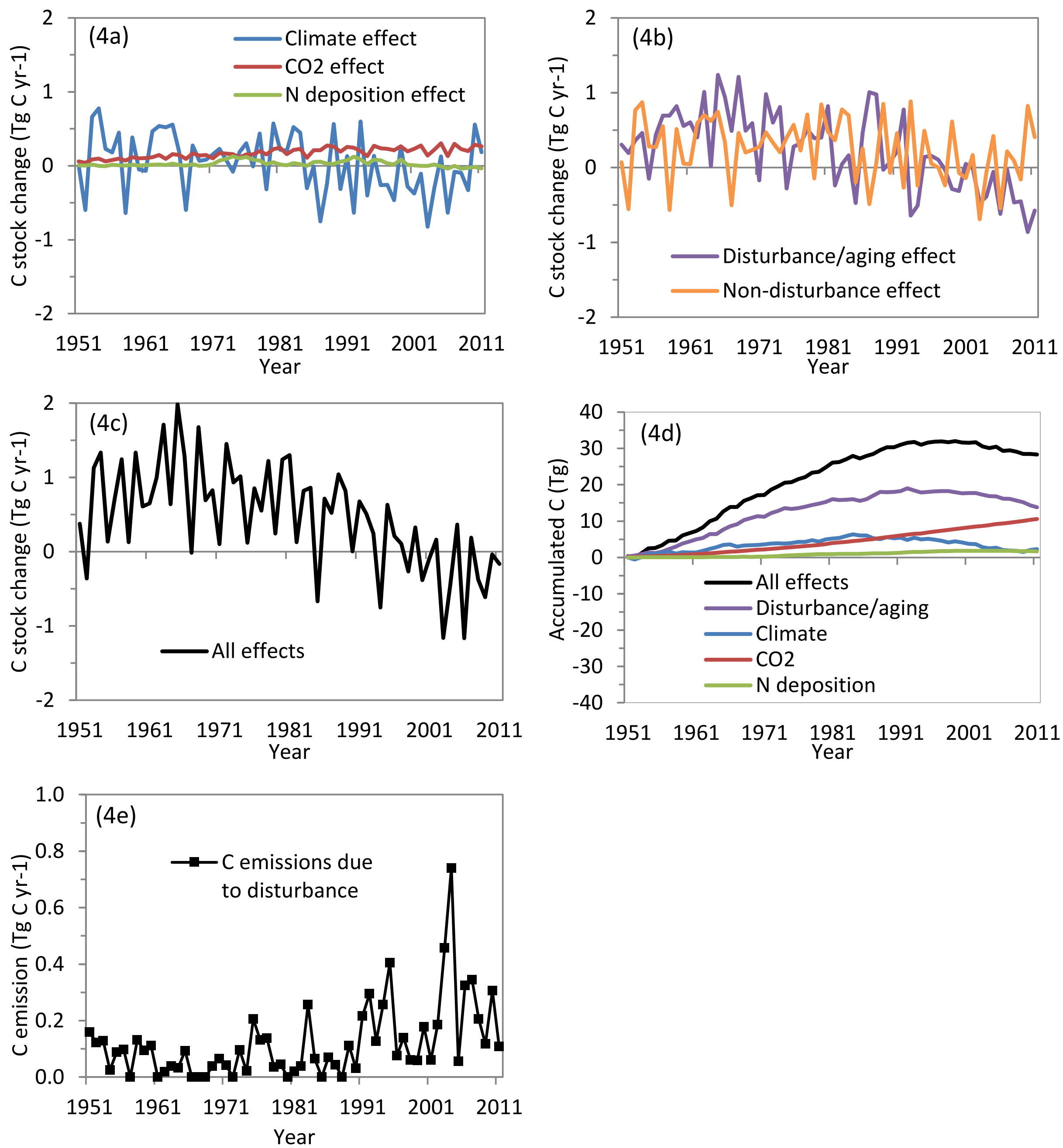


Figure 4.4. Changes in carbon stocks in the Deschutes National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and aging and the sum of all non-disturbance factors combined; and (c) all factors combined which is the sum of disturbance\aging and non-disturbance effects; (d) Accumulated C due to individual disturbance\aging and non-disturbance factors and all factors combined from 1950-2011 excluding C accumulated pre-1950; and (e) C emissions due to disturbance events only. Positive values in Figures 4.4 a-c represent C sinks from the atmosphere or enhancement effects, whereas negative values represent C sources to the atmosphere, or detraction effects.

Fremont-Winema National Forest

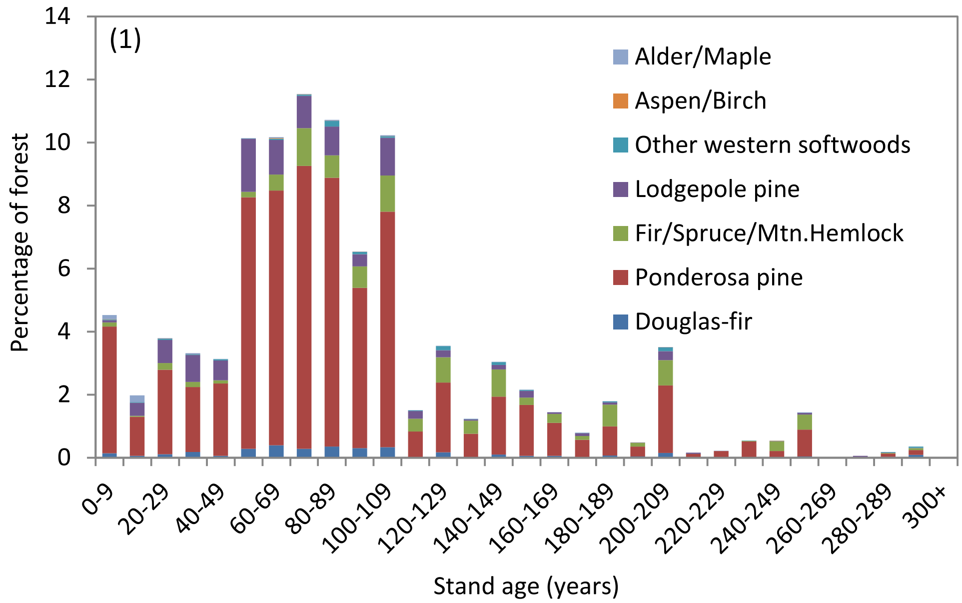


Figure 4.1. Age class distribution in 2011 in the Fremont-Winema National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

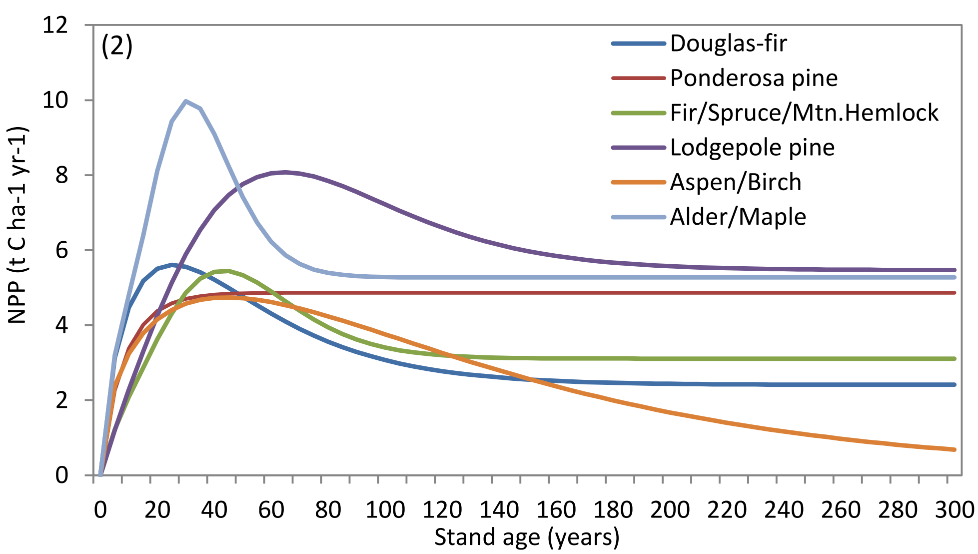


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Fremont-Winema National Forest. Curves were developed by He et al. 2012. The Evergreen Needleleaf curve was applied to Douglas-fir forest type.

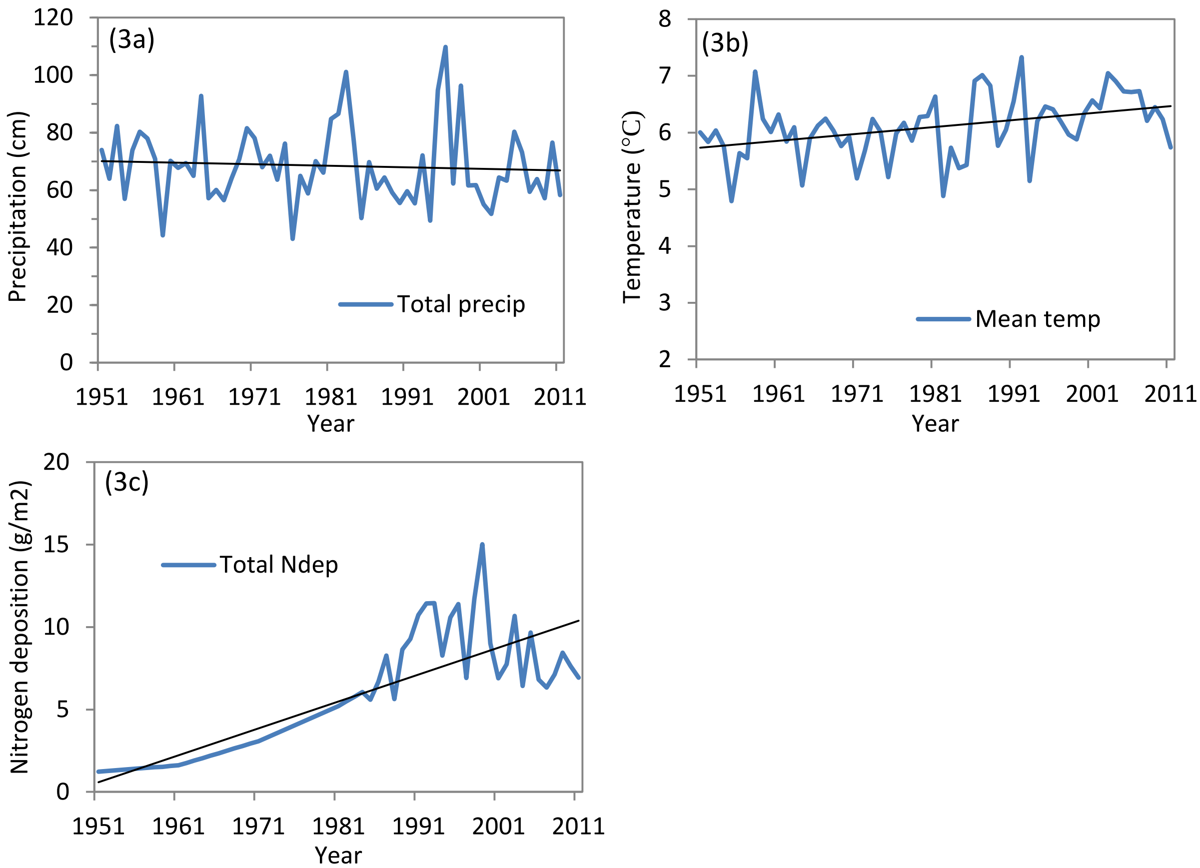


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Fremont-Winema National Forest. Linear trend lines shown in black.

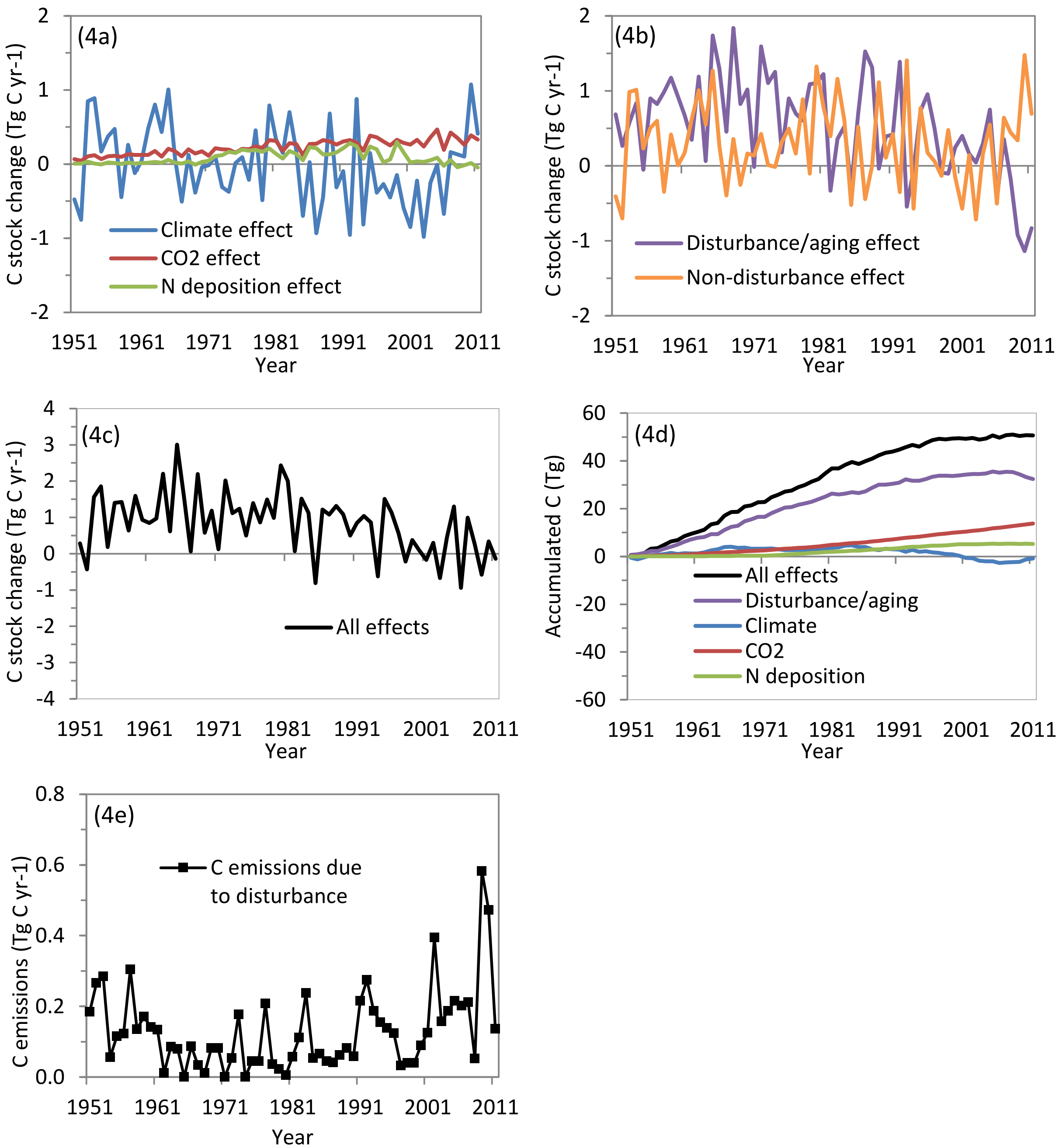


Figure 4,4. Changes in carbon stocks in the Fremont-Winema National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and aging and the sum of all non-disturbance factors combined; and (c) all factors combined which is the sum of disturbance\aging and non-disturbance effects; (d) Accumulated C due to individual disturbance\aging and non-disturbance factors and all factors combined from 1950-2011 excluding C accumulated pre-1950; and (e) C emissions due to disturbance events only. Positive values in Figures 4.4 a-c represent C sinks from the atmosphere or enhancement effects, whereas negative values represent C sources to the atmosphere, or detraction effects.

Gifford Pinchot National Forest

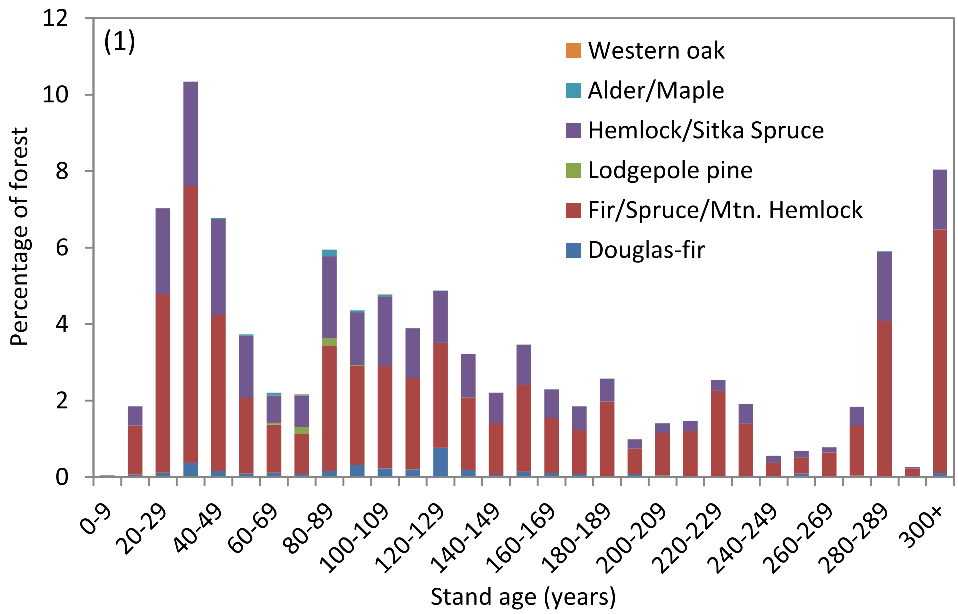


Figure 4.1. Age class distribution in 2011 in the Gifford Pinchot National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

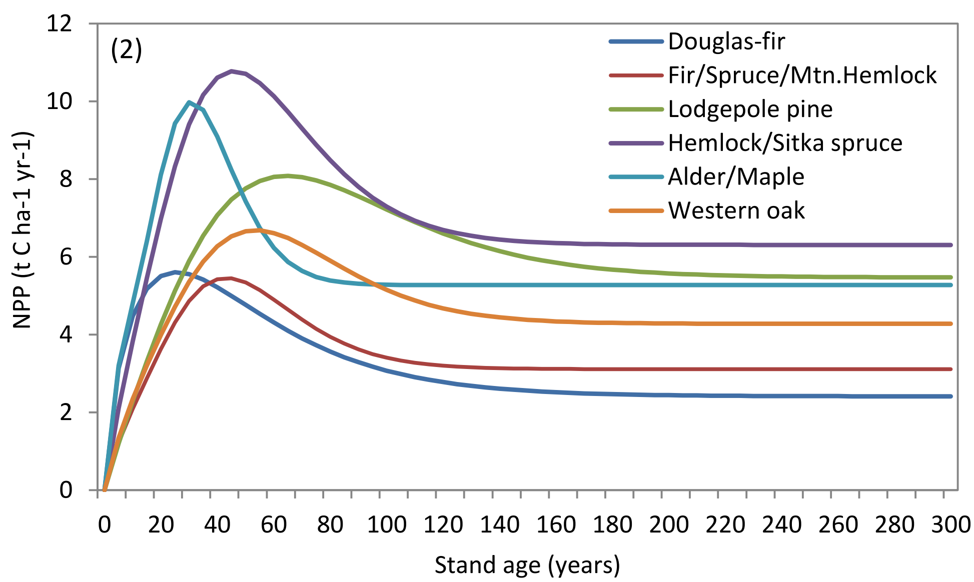


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Gifford Pinchot National Forest. Curves were developed by He et al. 2012. The Evergreen Needleleaf curve was applied to Douglas-fir forest type.

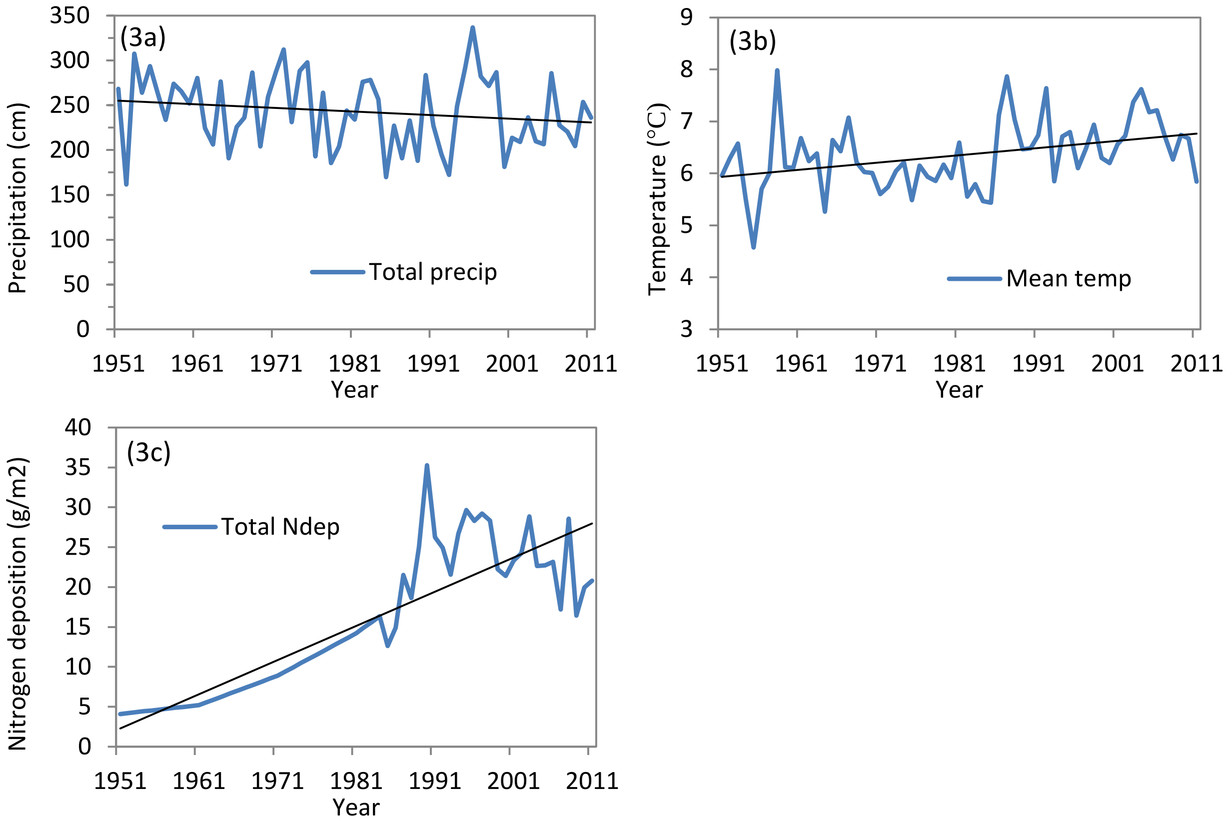


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Gifford Pinchot National Forest. Linear trend lines shown in black.

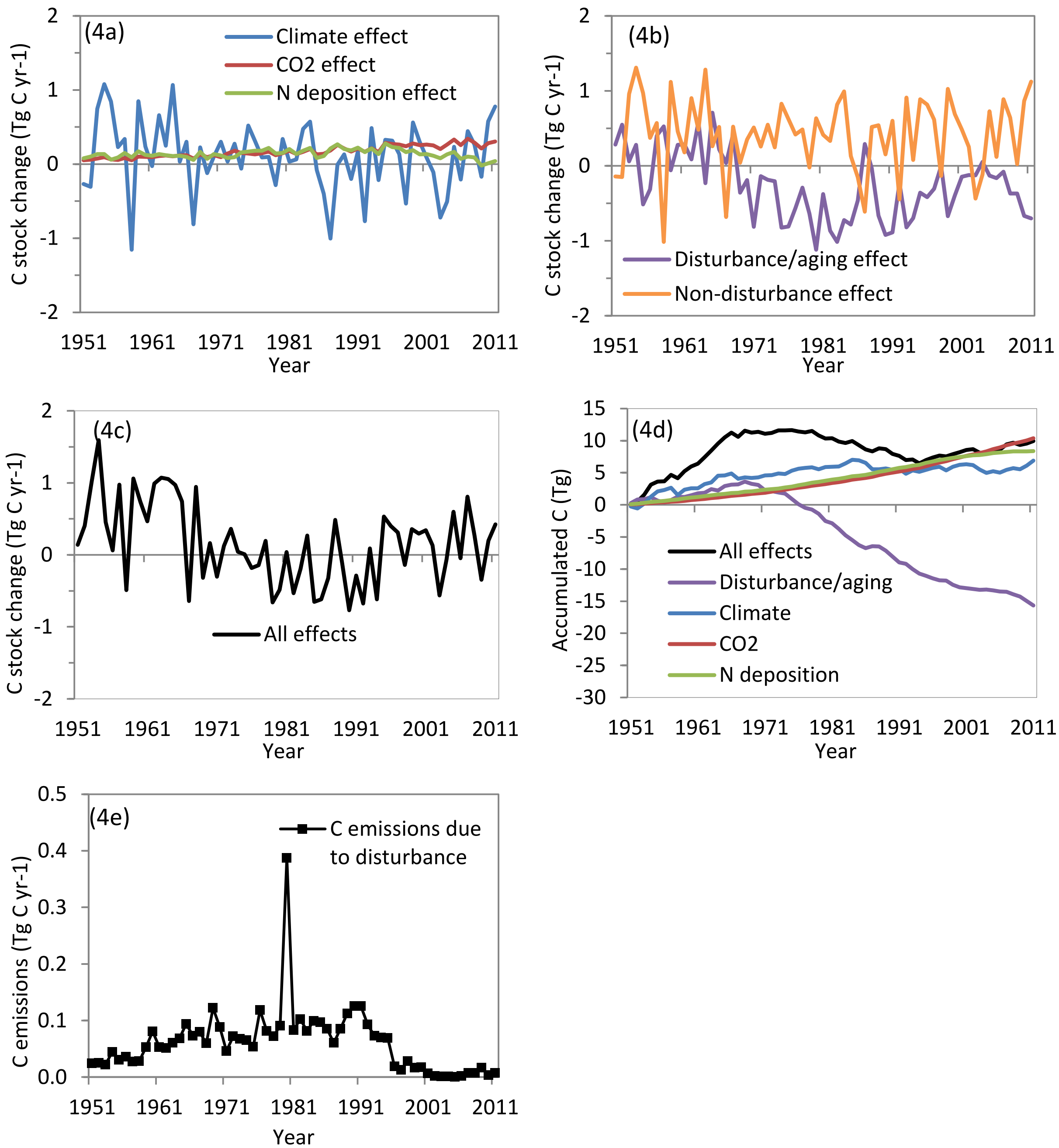


Figure 4.4. Changes in carbon stocks in the Gifford Pinchot National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and aging and the sum of all non-disturbance factors combined; and (c) all factors combined which is the sum of disturbance\aging and non-disturbance effects; (d) Accumulated C due to individual disturbance\aging and non-disturbance factors and all factors combined from 1950-2011 excluding C accumulated pre-1950; and (e) C emissions due to disturbance events only. Positive values in Figures 4.4 a-c represent C sinks from the atmosphere or enhancement effects, whereas negative values represent C sources to the atmosphere, or detraction effects.

C.6 Malheur National Forest

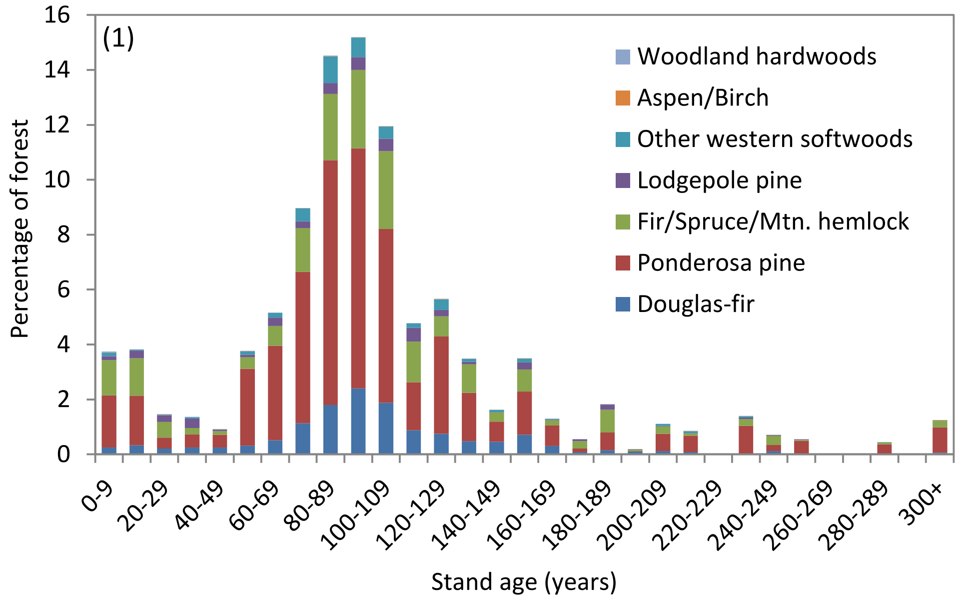


Figure 4.1. Age class distribution in 2011 in the Malheur National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

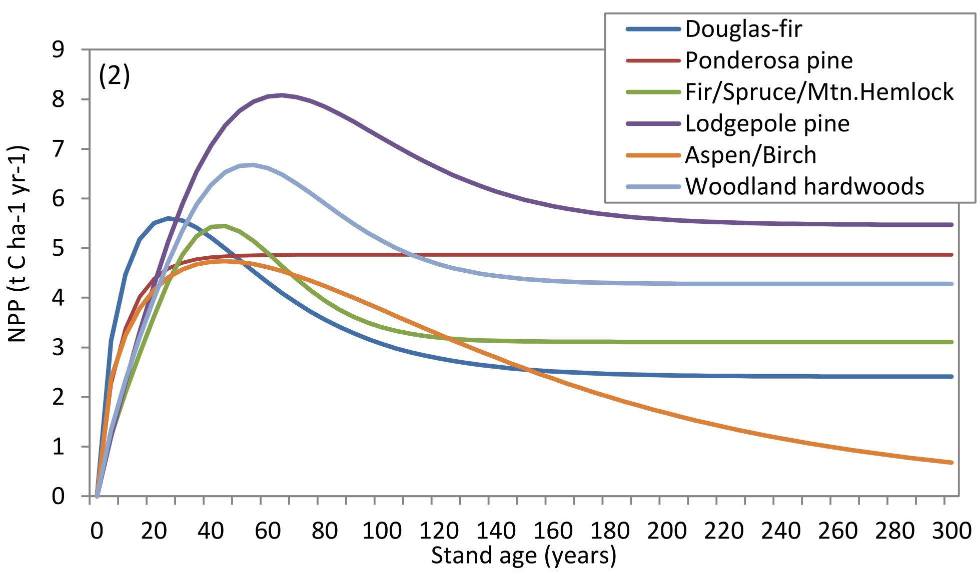


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Malheur National Forest. Curves were developed by He et al. 2012. The Evergreen Needleleaf curve was applied to Douglas-fir forest type. The Ponderosa pine curve was applied to the Other Western Softwoods forest type.

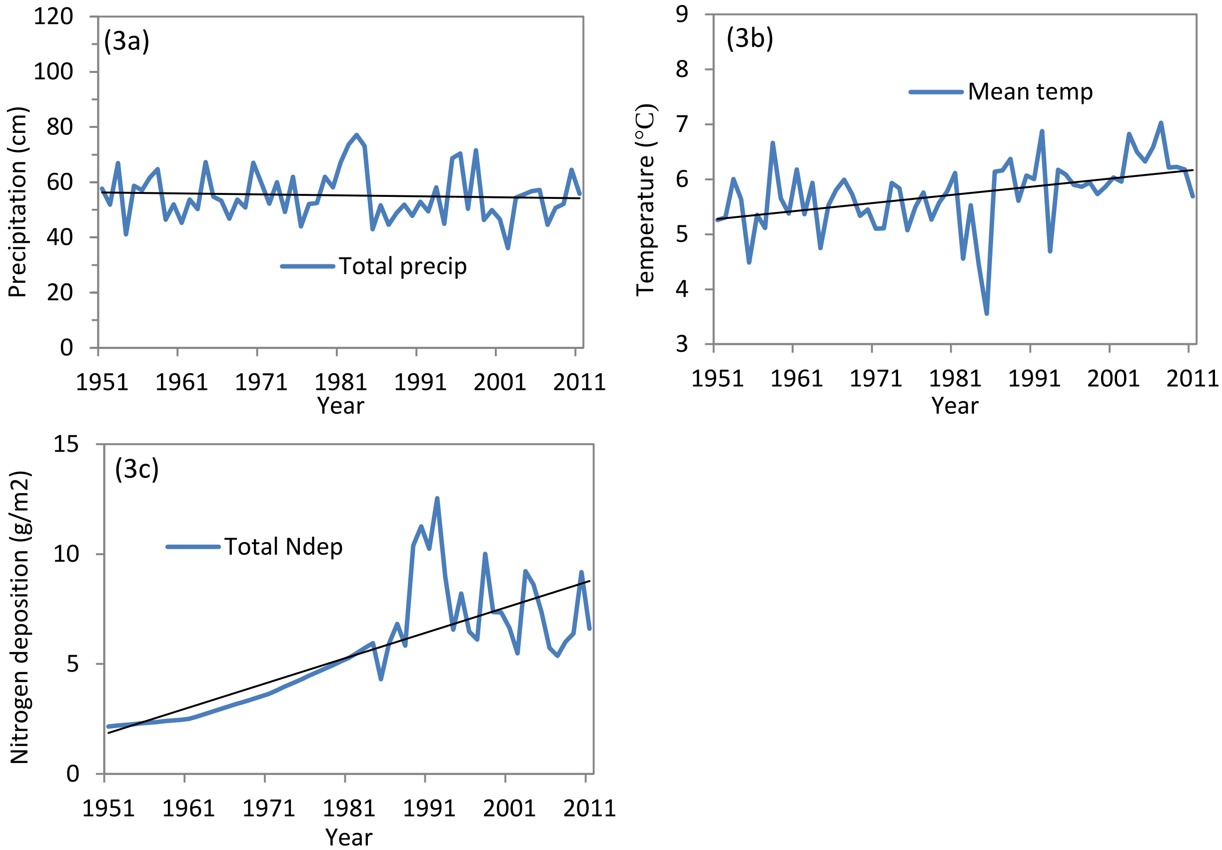


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Malheur National Forest. Linear trend lines shown in black.

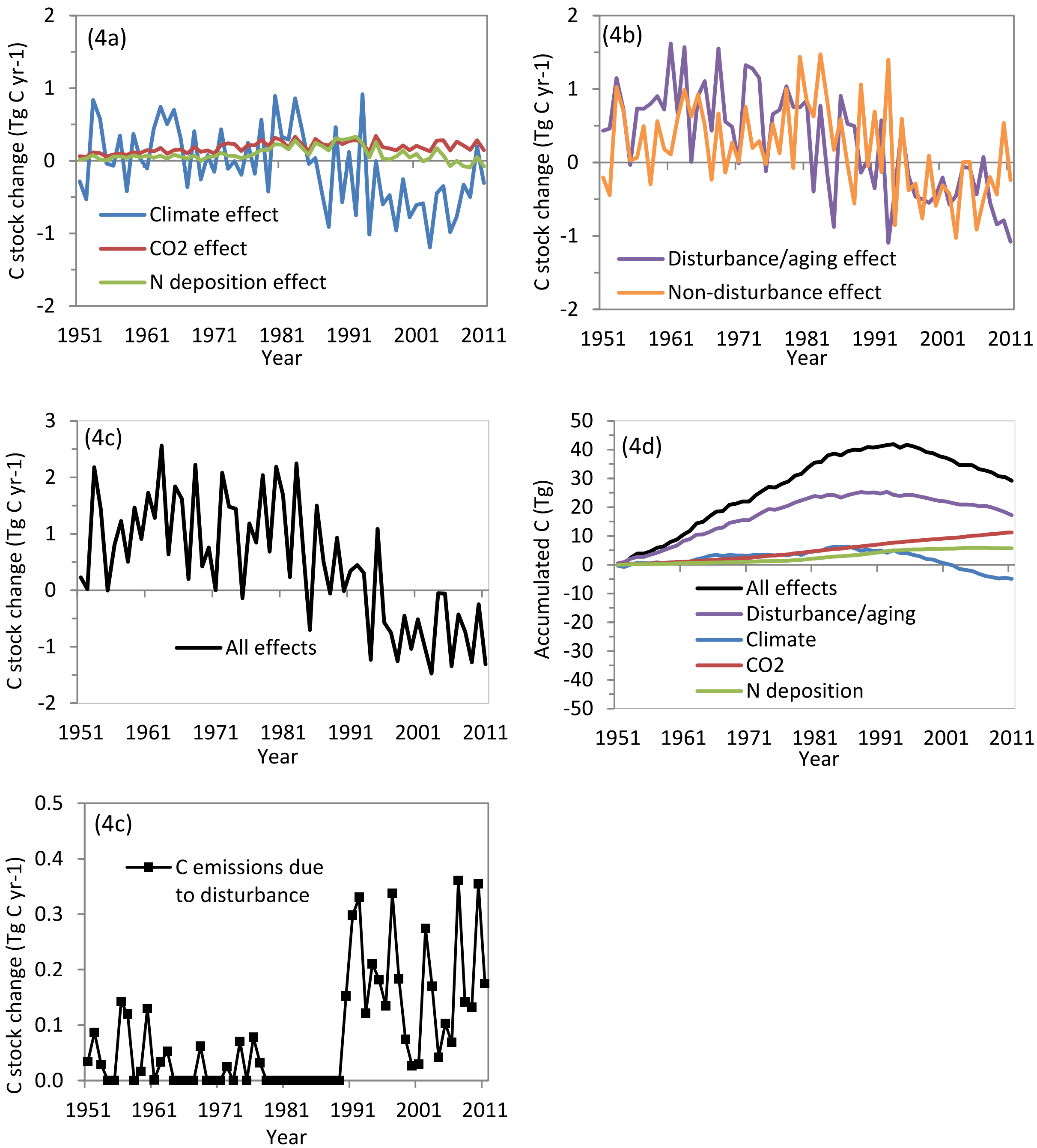


Figure 4.4. Changes in carbon stocks in the Malheur National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and aging and the sum of all non-disturbance factors combined; and (c) all factors combined which is the sum of disturbance\aging and non-disturbance effects; (d) Accumulated C due to individual disturbance\aging and non-disturbance factors and all factors combined from 1950-2011 excluding C accumulated pre-1950; and (e) C emissions due to disturbance events only. Positive values in Figures 4.4 a-c represent C sinks from the atmosphere or enhancement effects, whereas negative values represent C sources to the atmosphere, or detraction effects.

Mt. Baker – Snoqualmie National Forest

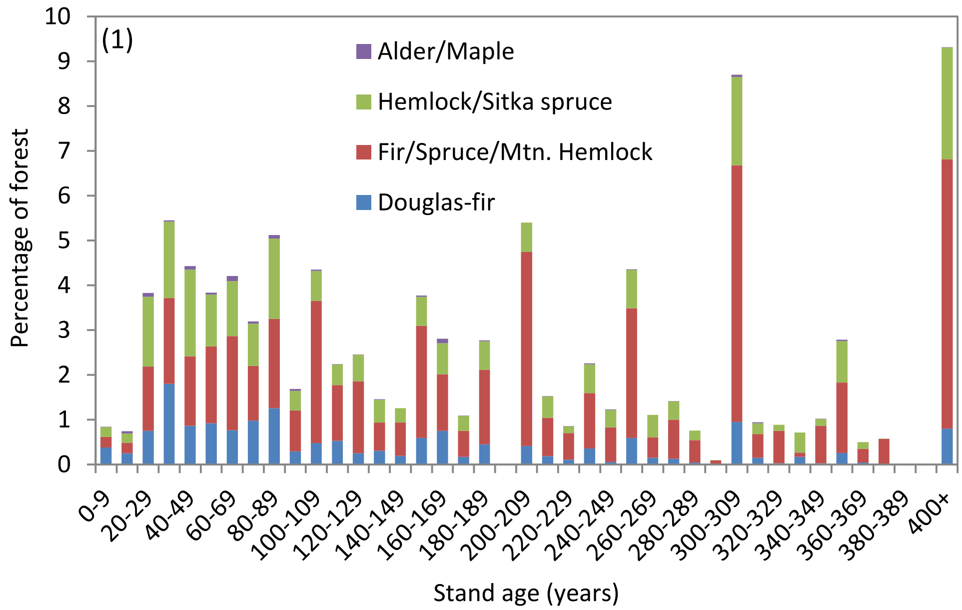


Figure 4.1. Age class distribution in 2011 in the Mt. Baker-Snoqualmie National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

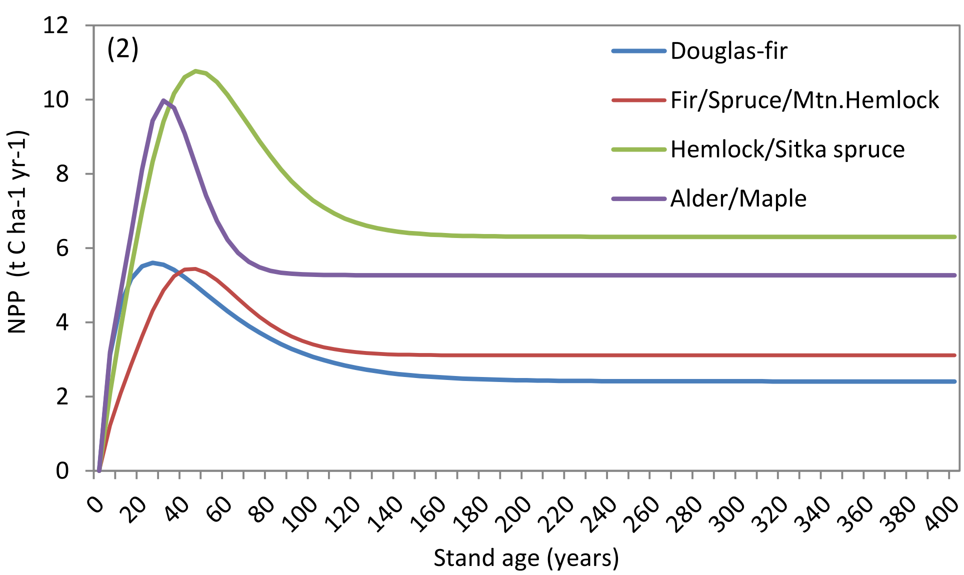


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Mt. Baker-Snoqualmie National Forest. Curves were developed by He et al. 2012. The Evergreen Needleleaf curve was applied to Douglas-fir forest type.

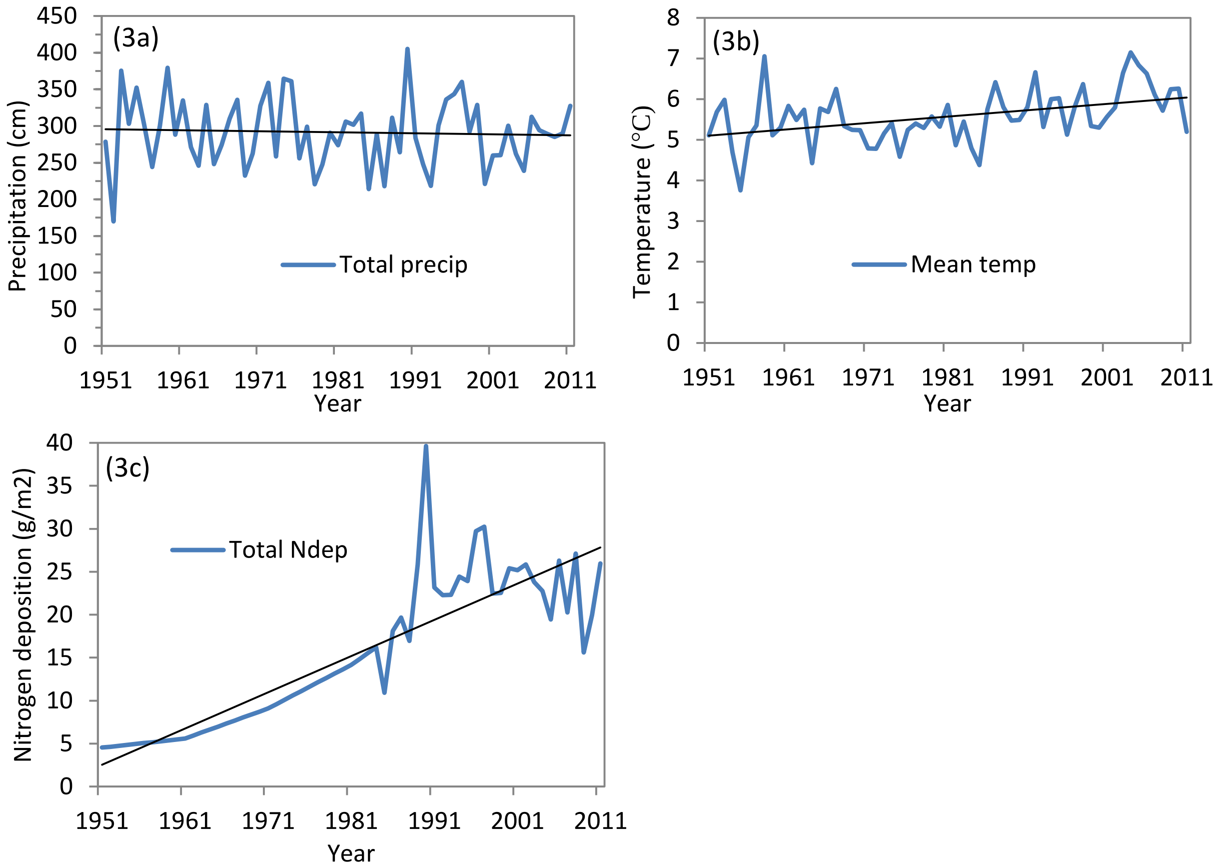


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Mt. Baker-Snoqualmie National Forest. Linear trend lines shown in black.

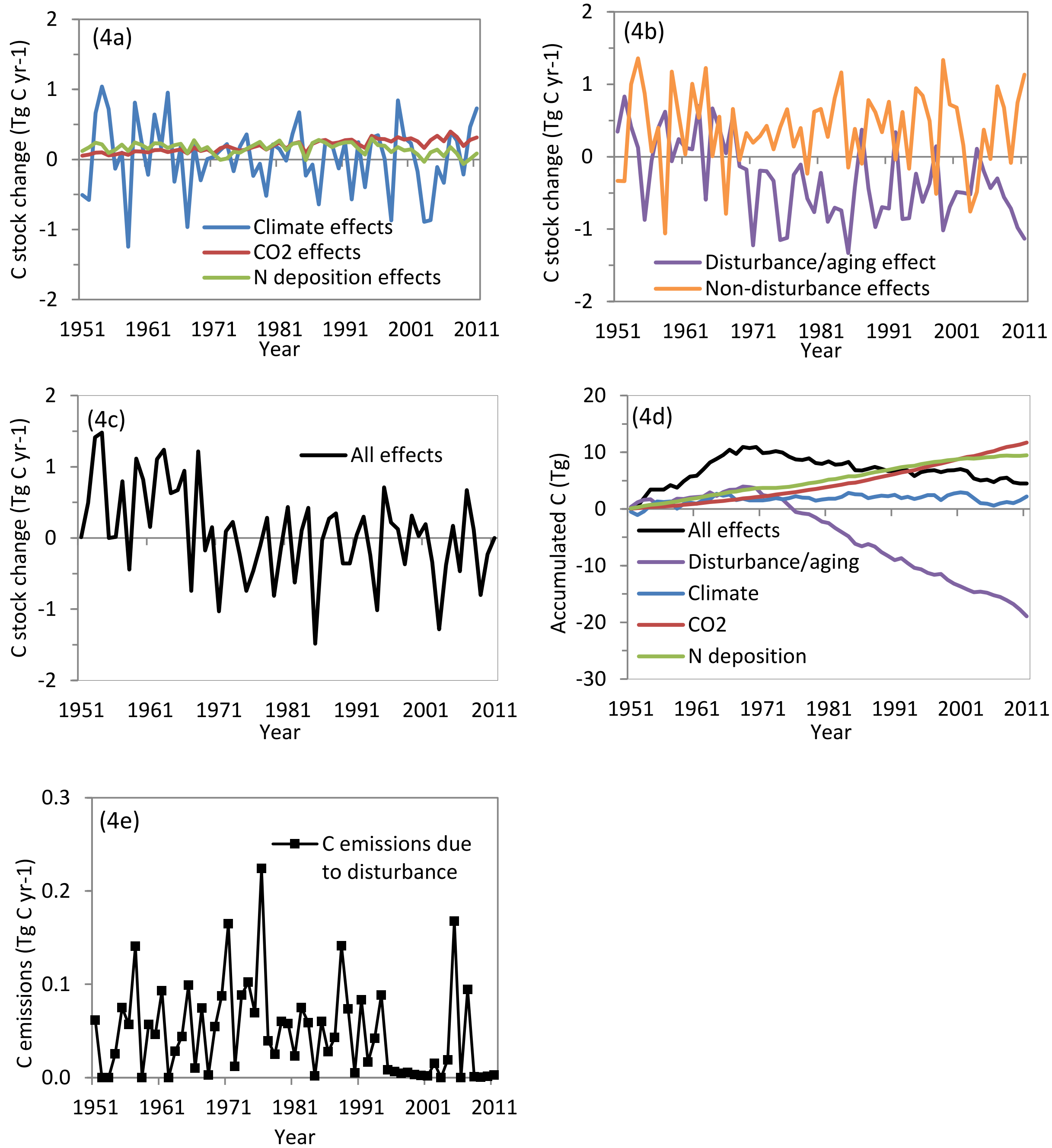


Figure 4.4. Changes in carbon stocks in the Mt. Baker-Snoqualmie National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and aging and the sum of all non-disturbance factors combined; and (c) all factors combined which is the sum of disturbance\aging and non-disturbance effects; (d) Accumulated C due to individual disturbance\aging and non-disturbance factors and all factors combined from 1950-2011 excluding C accumulated pre-1950; and (e) C emissions due to disturbance events only. Positive values in Figures 4.4 a-c represent C sinks from the atmosphere or enhancement effects, whereas negative values represent C sources to the atmosphere, or detraction effects.

Mt. Hood National Forest

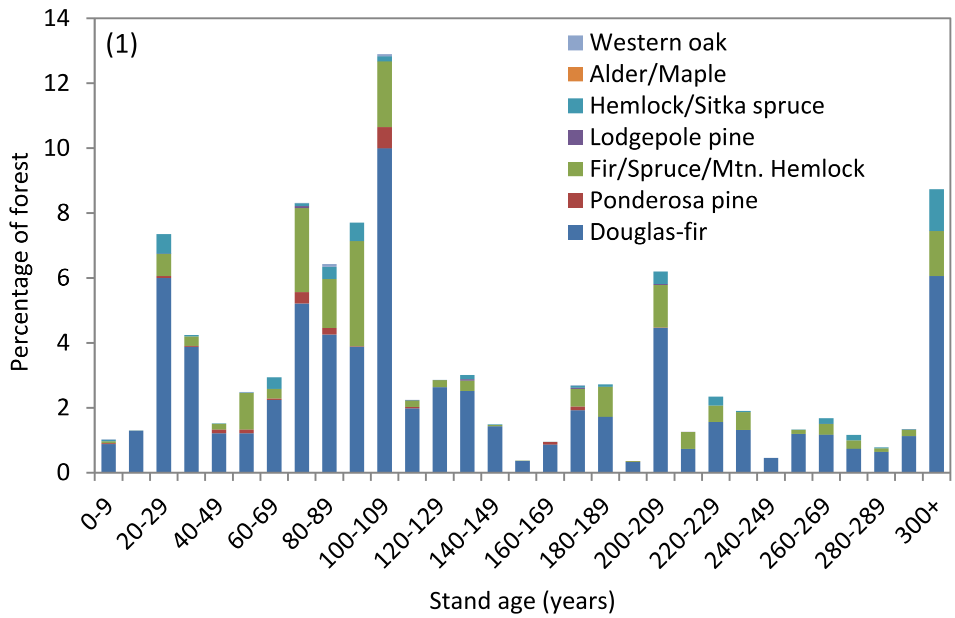


Figure 4.1. Age class distribution in 2011 in the Mt. Hood National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

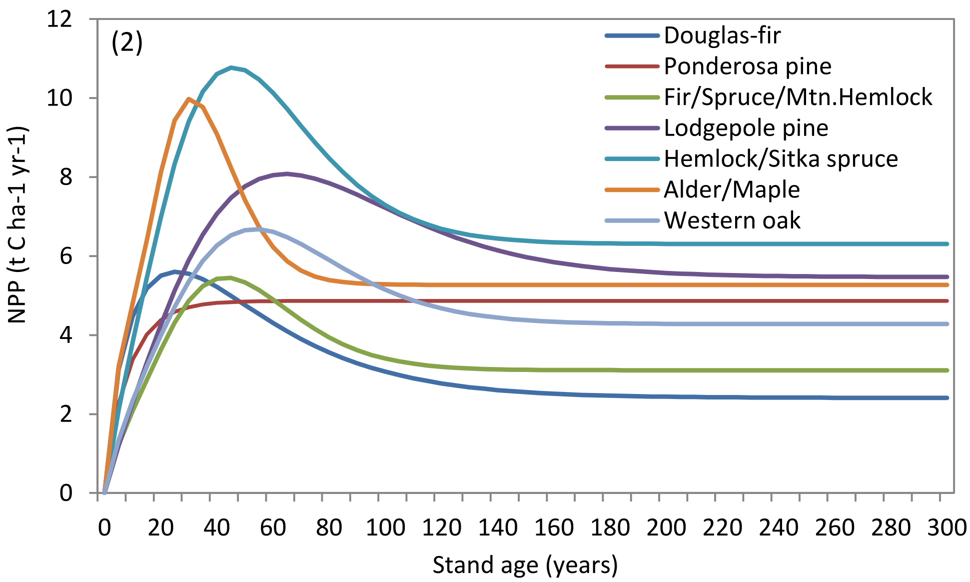


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Mt. Hood National Forest. Curves were developed by He et al. 2012. The Evergreen Needleleaf curve was applied to Douglas-fir forest type.

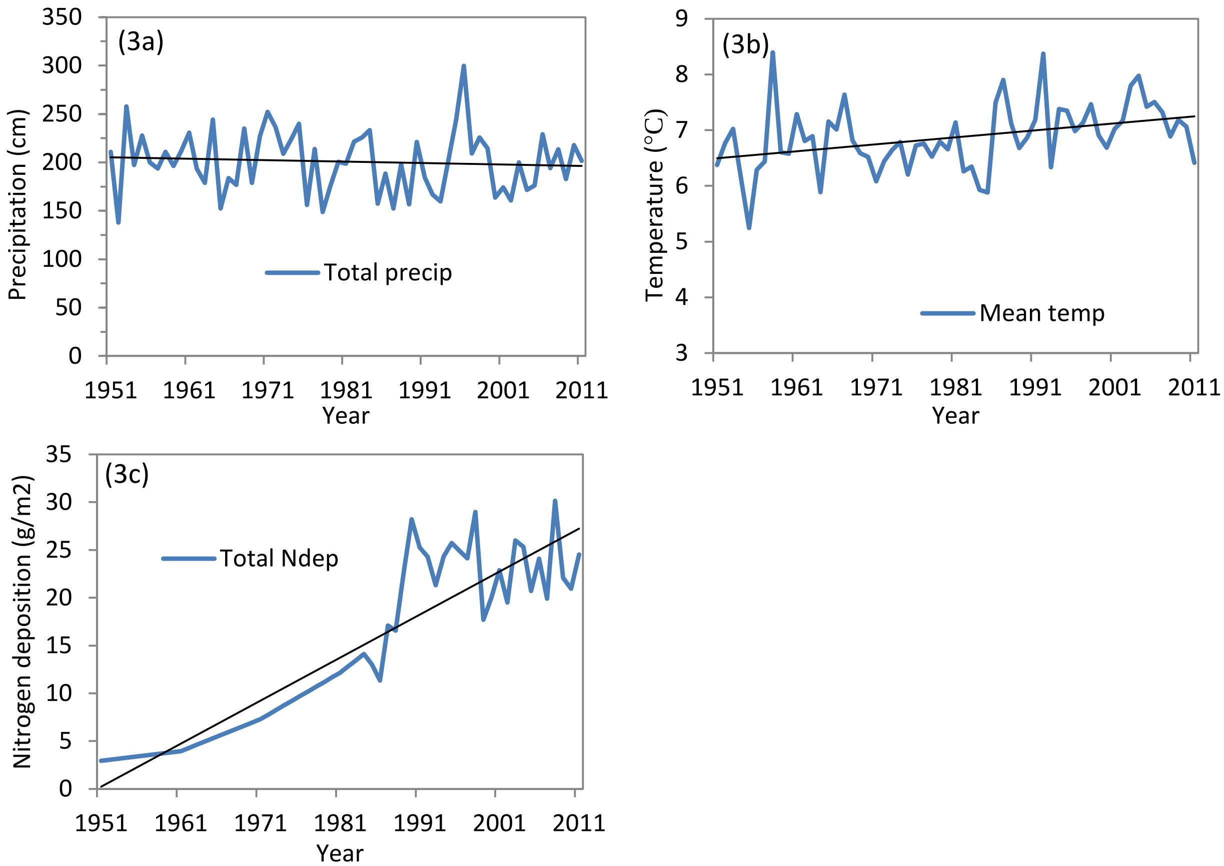


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Mt. Hood National Forest. Linear trend lines shown in black.

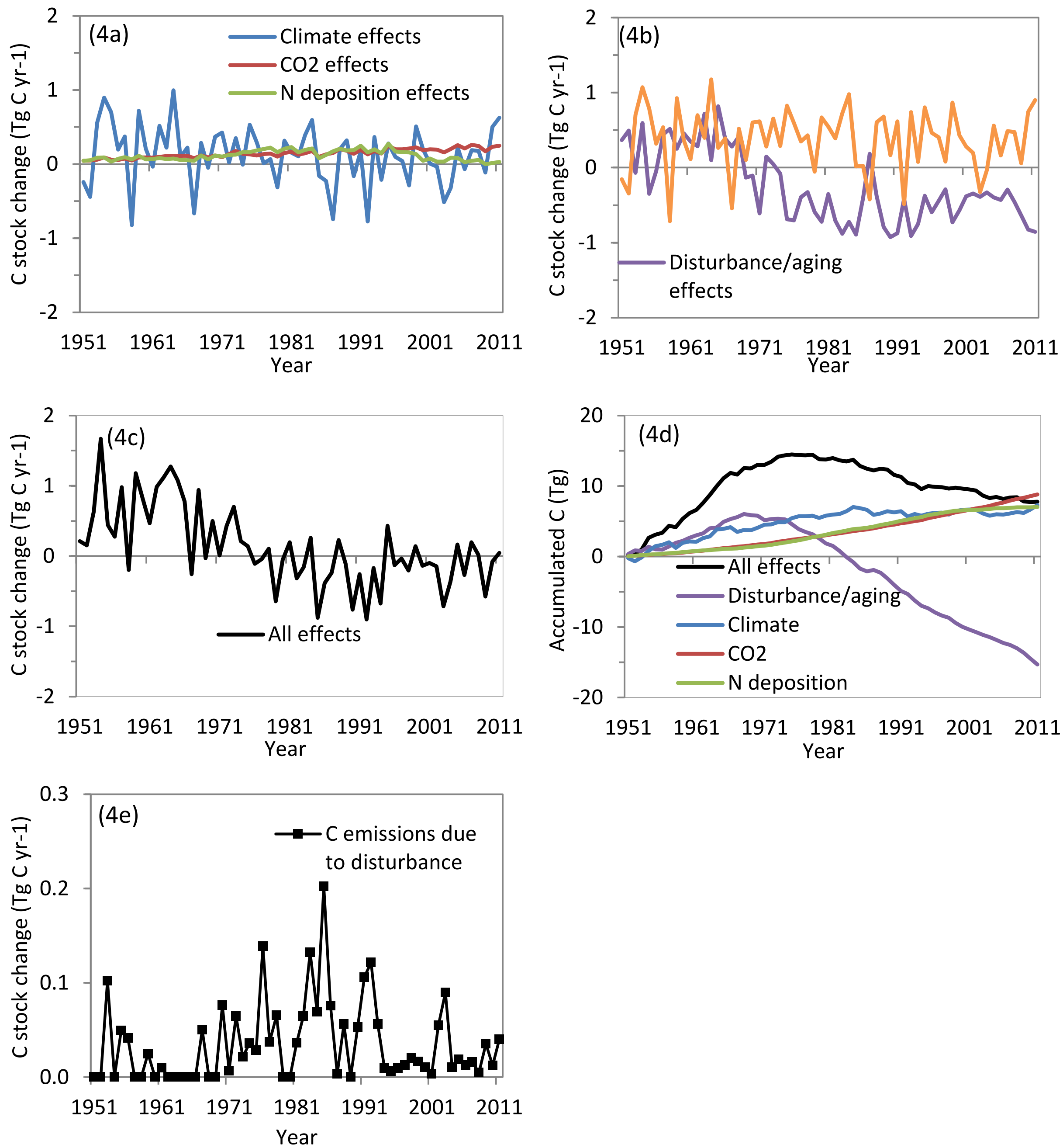


Figure 4.4. Changes in carbon stocks in the Mt. Hood National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and aging and the sum of all non-disturbance factors combined; and (c) all factors combined which is the sum of disturbance\aging and non-disturbance effects; (d) Accumulated C due to individual disturbance\aging and non-disturbance factors and all factors combined from 1950-2011 excluding C accumulated pre-1950; and (e) C emissions due to disturbance events only. Positive values in Figures 4.4 a-c represent C sinks from the atmosphere or enhancement effects, whereas negative values represent C sources to the atmosphere, or detraction effects.

Ochoco National Forest

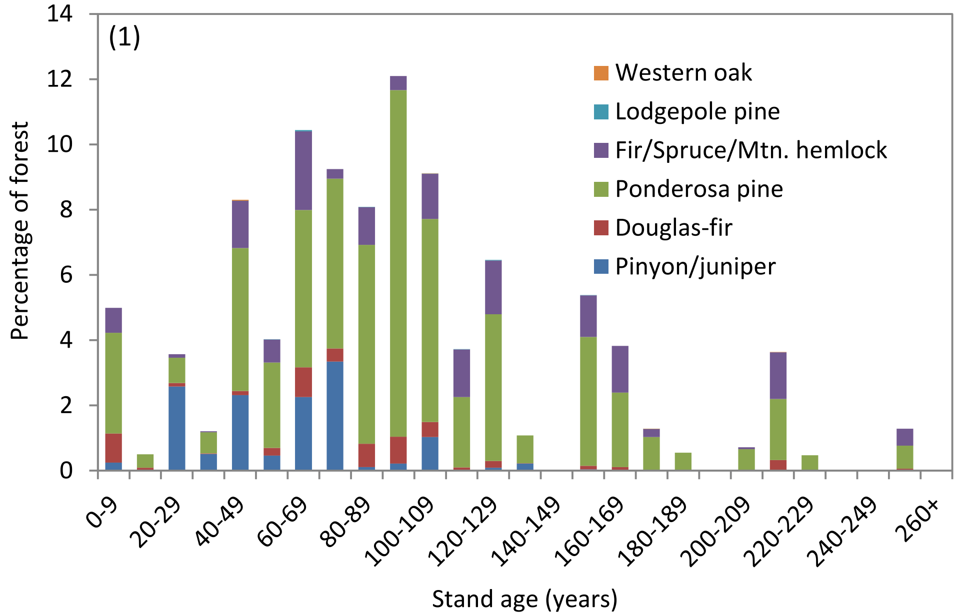


Figure 4.1. Age class distribution in 2011 in the Ochoco National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

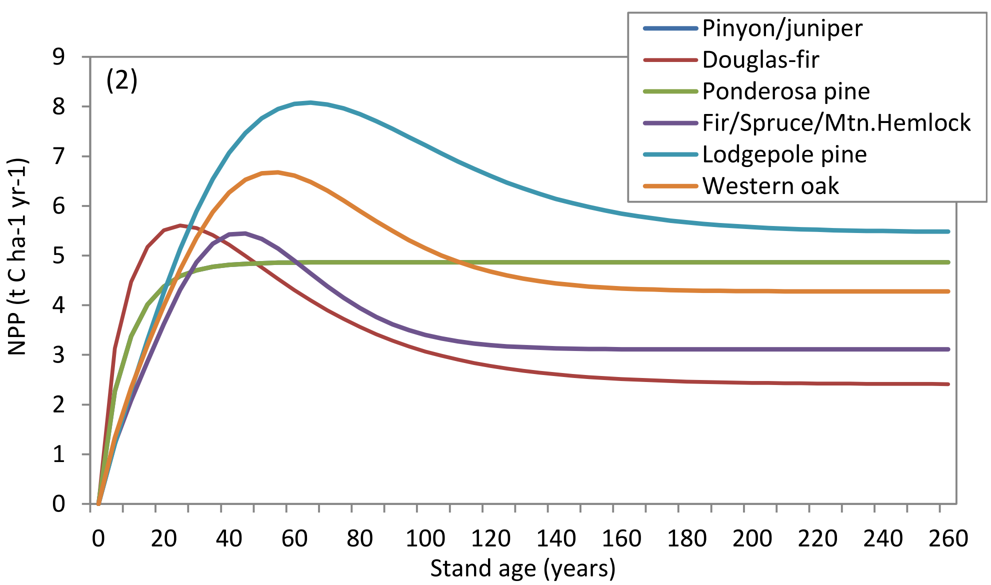


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Ochoco National Forest. Curves were developed by He et al. 2012. The Evergreen Needleleaf curve was applied to Douglas-fir forest type. The Ponderosa pine curve was applied to the Pinyon/Juniper forest type.

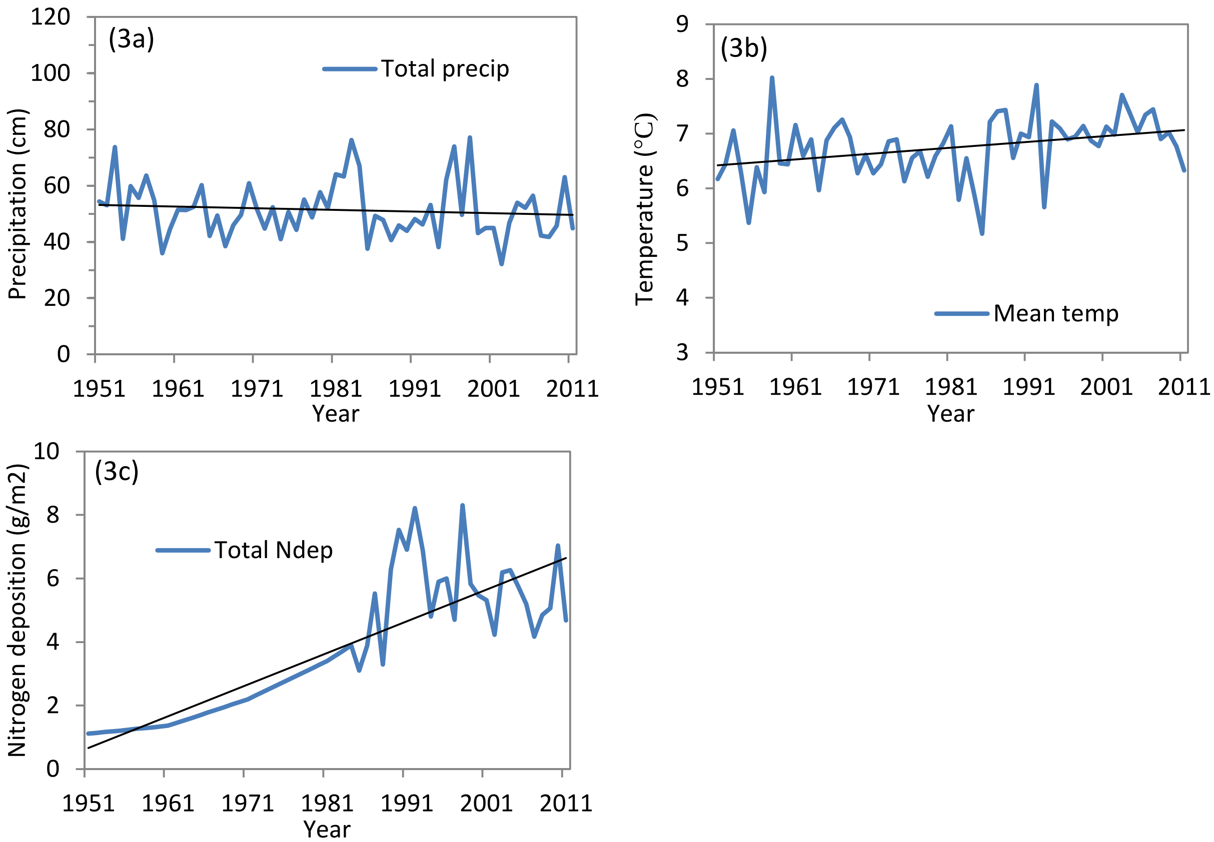


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Ochoco National Forest. Linear trend lines shown in black.

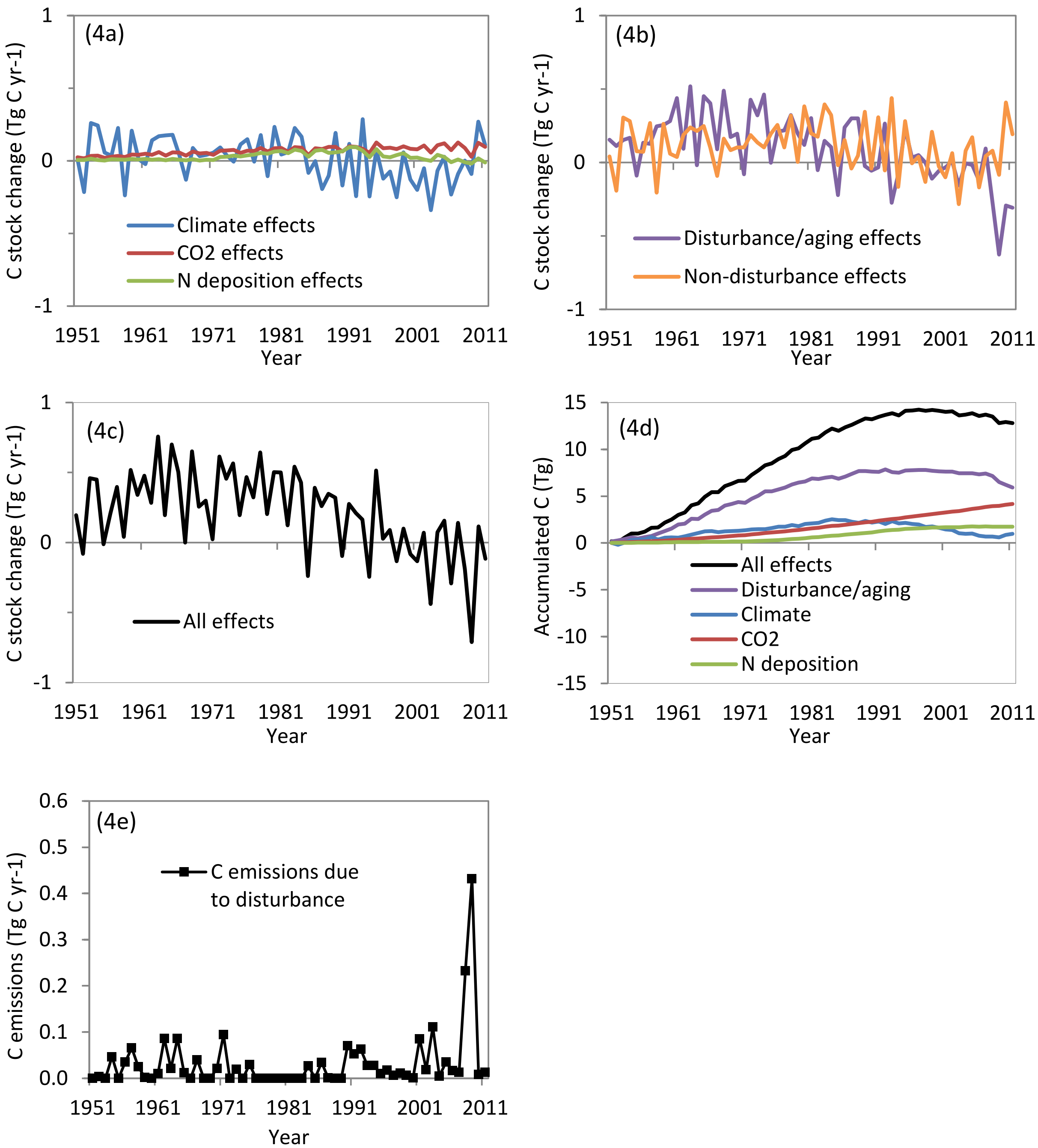


Figure 4.4. Changes in carbon stocks in the Ochoco National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and aging and the sum of all non-disturbance factors combined; and (c) all factors combined which is the sum of disturbance\aging and non-disturbance effects; (d) Accumulated C due to individual disturbance\aging and non-disturbance factors and all factors combined from 1951-2011 excluding C accumulated pre-1950; and (e) C emissions due to disturbance events only. Positive values in Figures 4.4 a-c represent C sinks from the atmosphere or enhancement effects, whereas negative values represent C sources to the atmosphere, or detraction effects.

C.10 Okanogan-Wenatchee National Forests

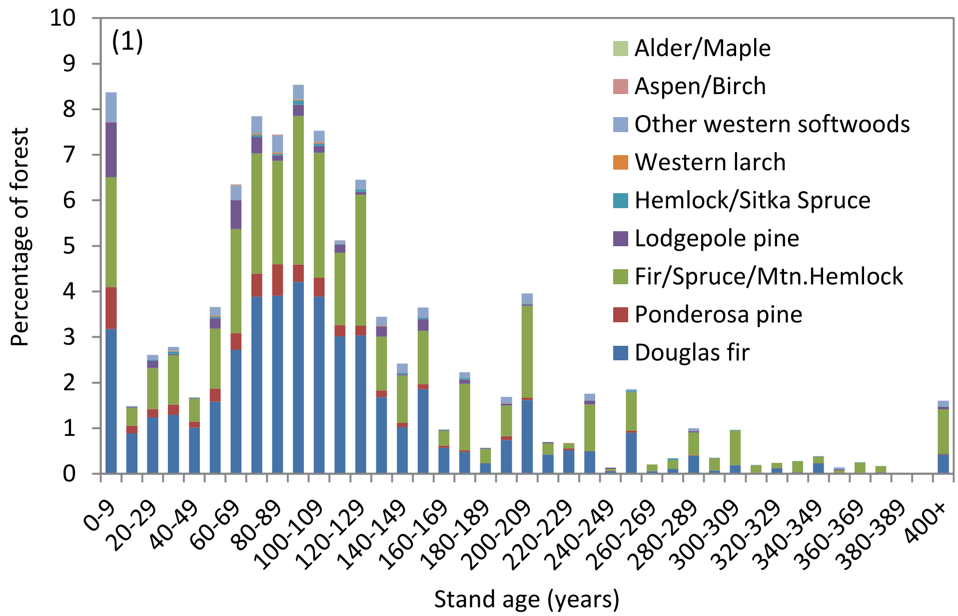


Figure 4.1. Age class distribution in 2011 in the Ochoco National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

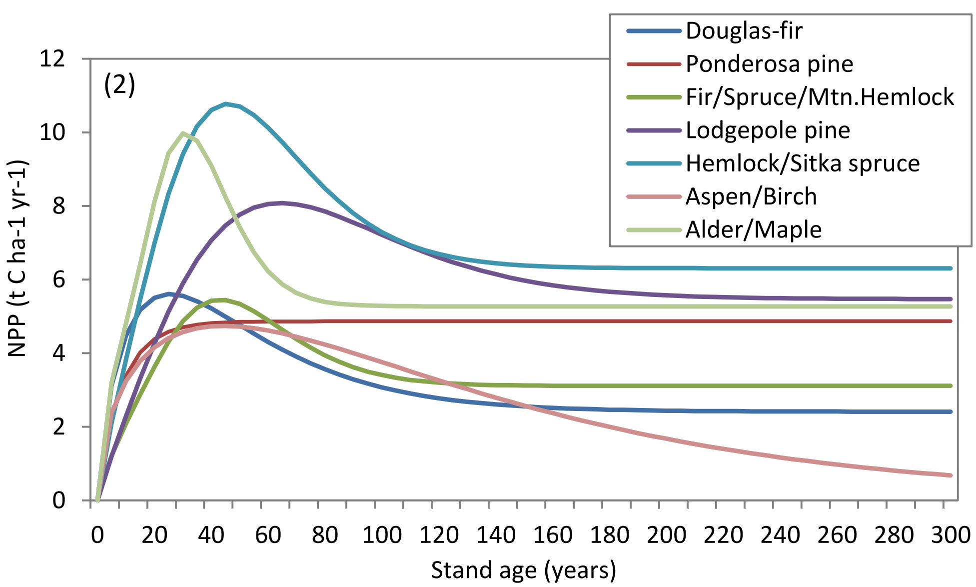


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Ochoco National Forest. Curves were developed by He et al. 2012. The Evergreen Needleleaf curve was applied to Douglas-fir and Western Larch forest types.

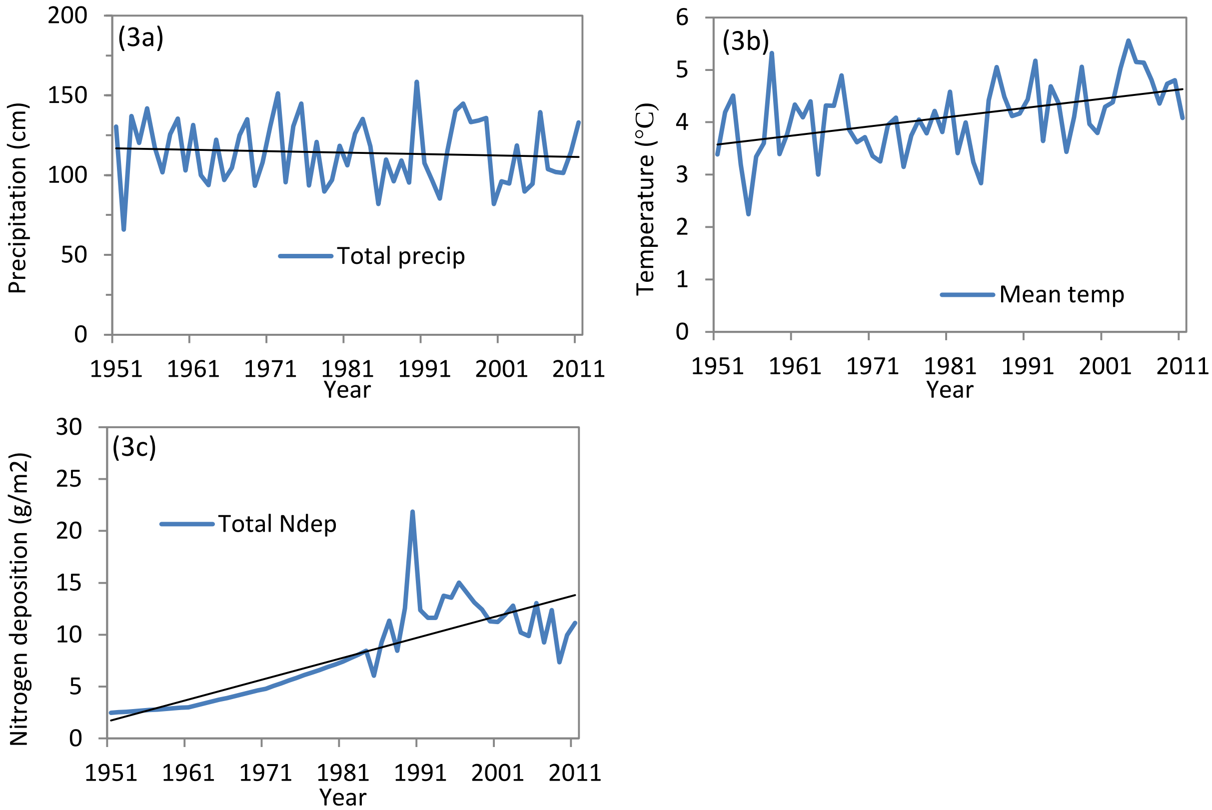


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Ochoco National Forest. Linear trend lines shown in black.

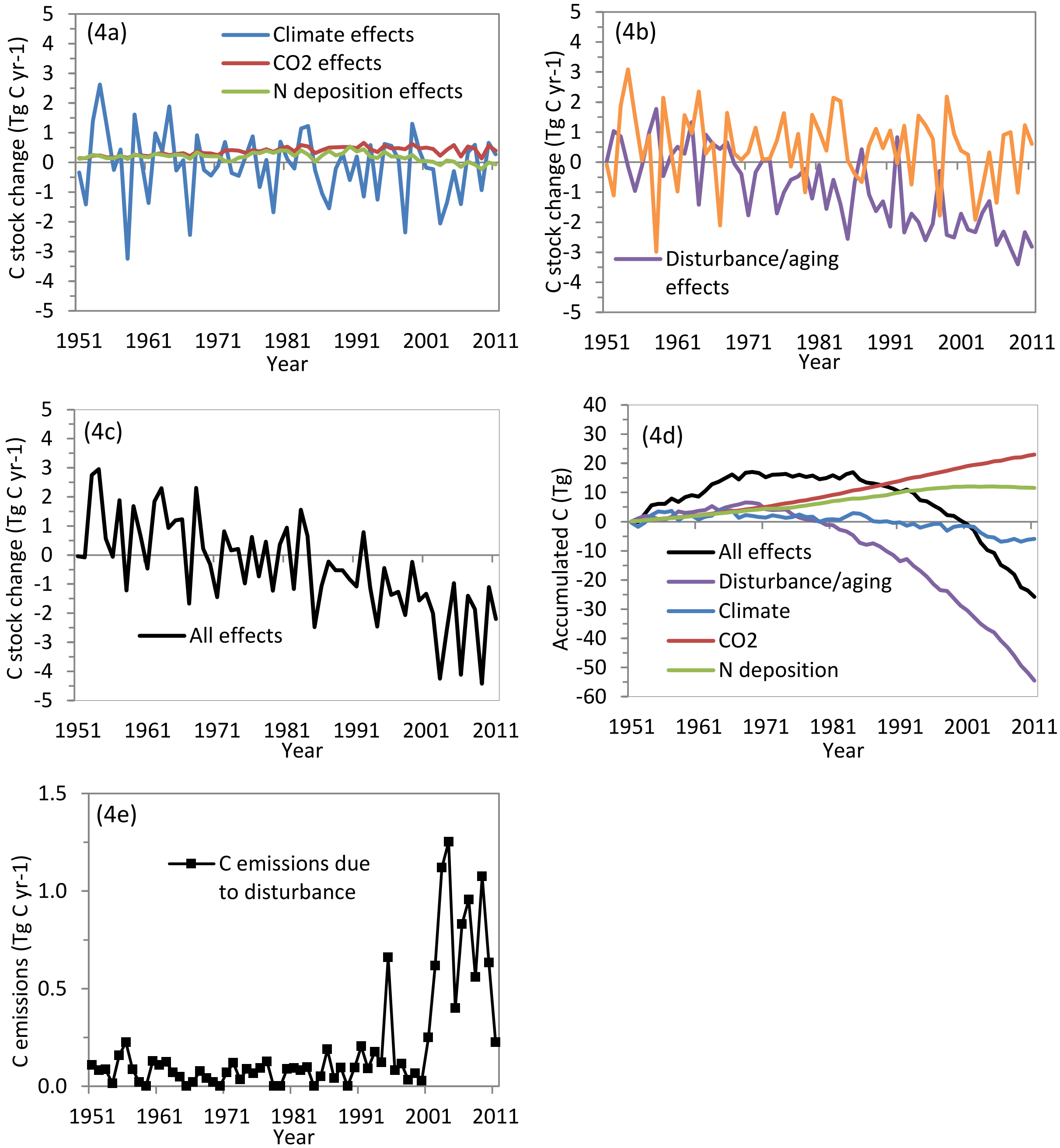


Figure 4.4. Changes in carbon stocks in the Ochoco National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and aging and the sum of all non-disturbance factors combined; and (c) all factors combined which is the sum of disturbance\aging and non-disturbance effects; (d) Accumulated C due to individual disturbance\aging and non-disturbance factors and all factors combined from 1950-2011 excluding C accumulated pre-1950; and (e) C emissions due to disturbance events only. Positive values in Figures 4.4 a-c represent C sinks from the atmosphere or enhancement effects, whereas negative values represent C sources to the atmosphere, or detraction effects.

Olympic National Forest

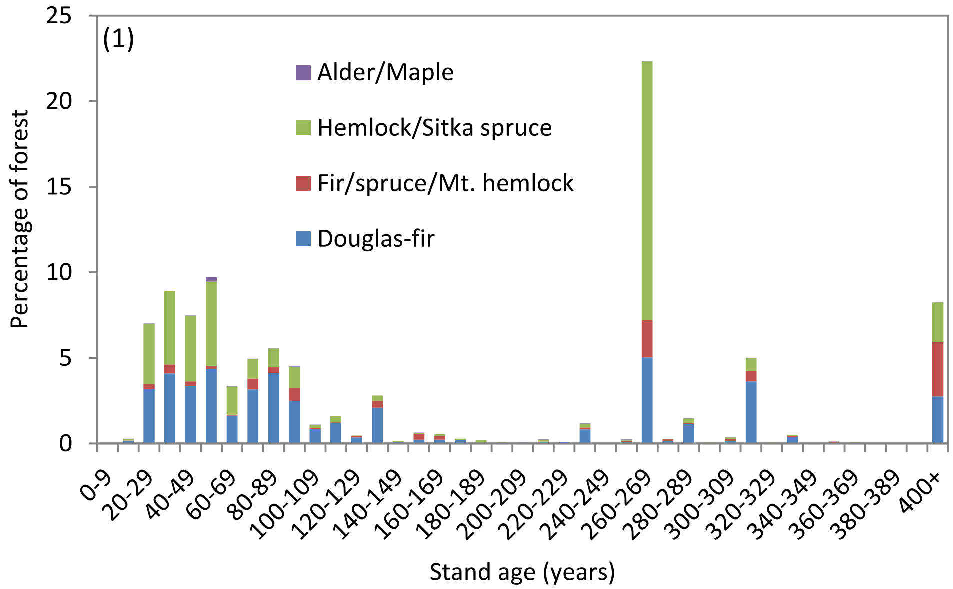


Figure 4.1. Age class distribution in 2011 in the Olympic National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

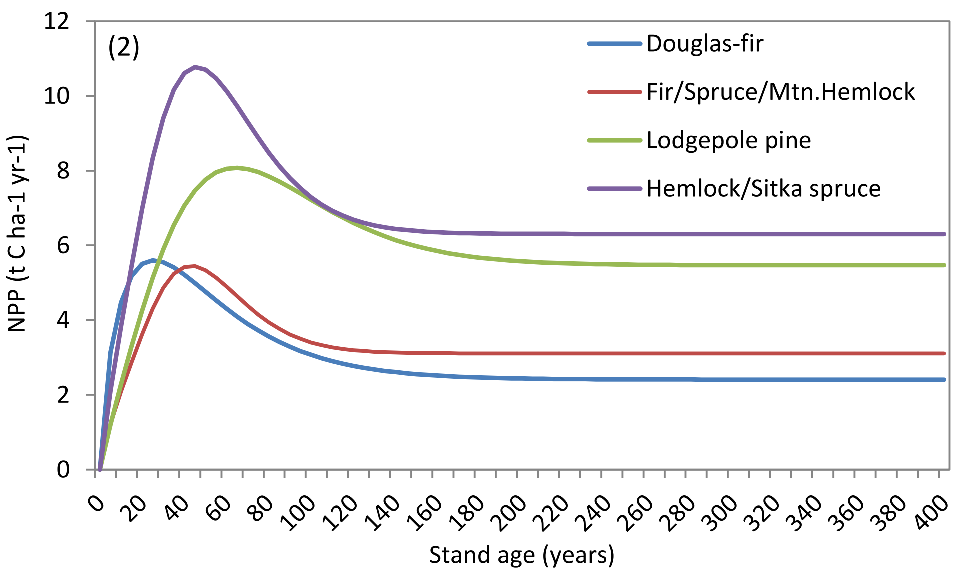


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Olympic National Forest. Curves were developed by He et al. 2012. The Evergreen Needleleaf curve was applied to Douglas-fir forest type.

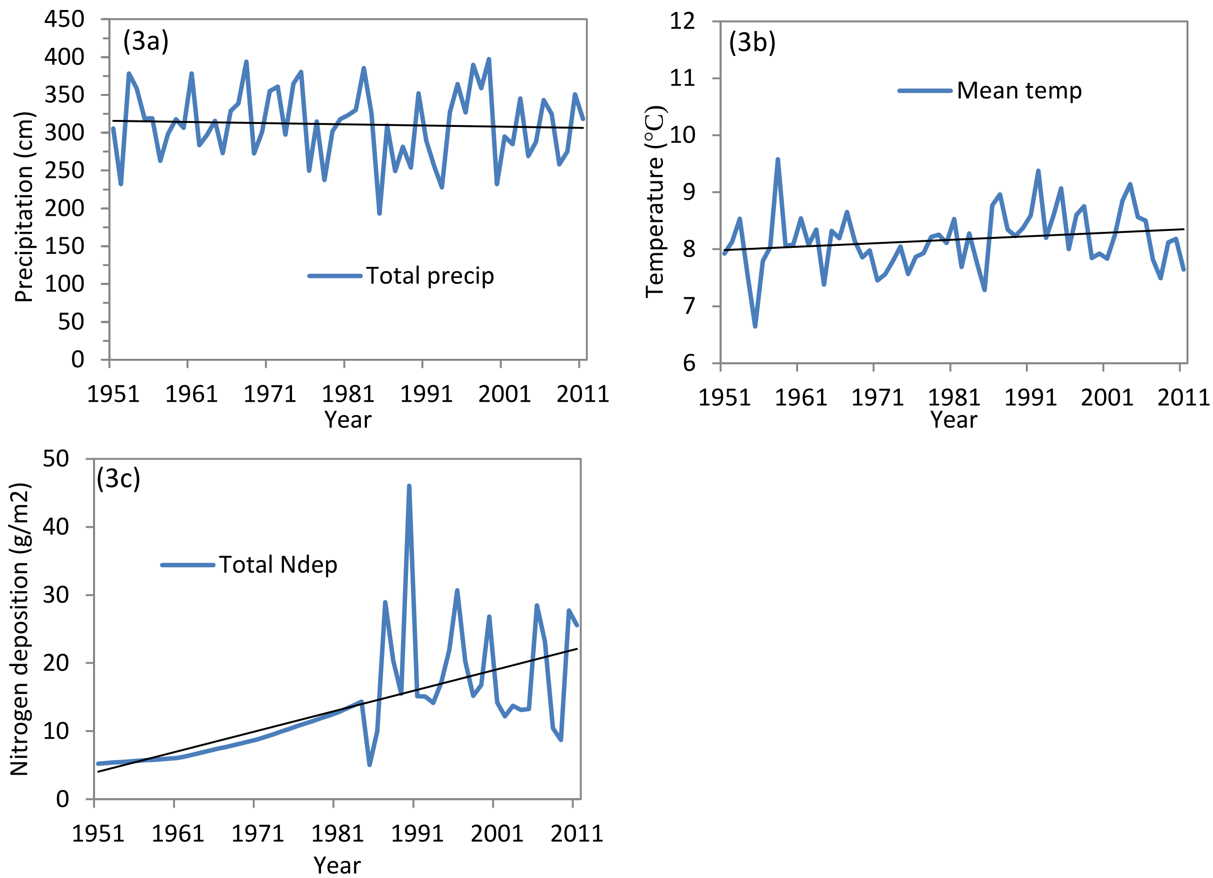


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Olympic National Forest. Linear trend lines shown in black.

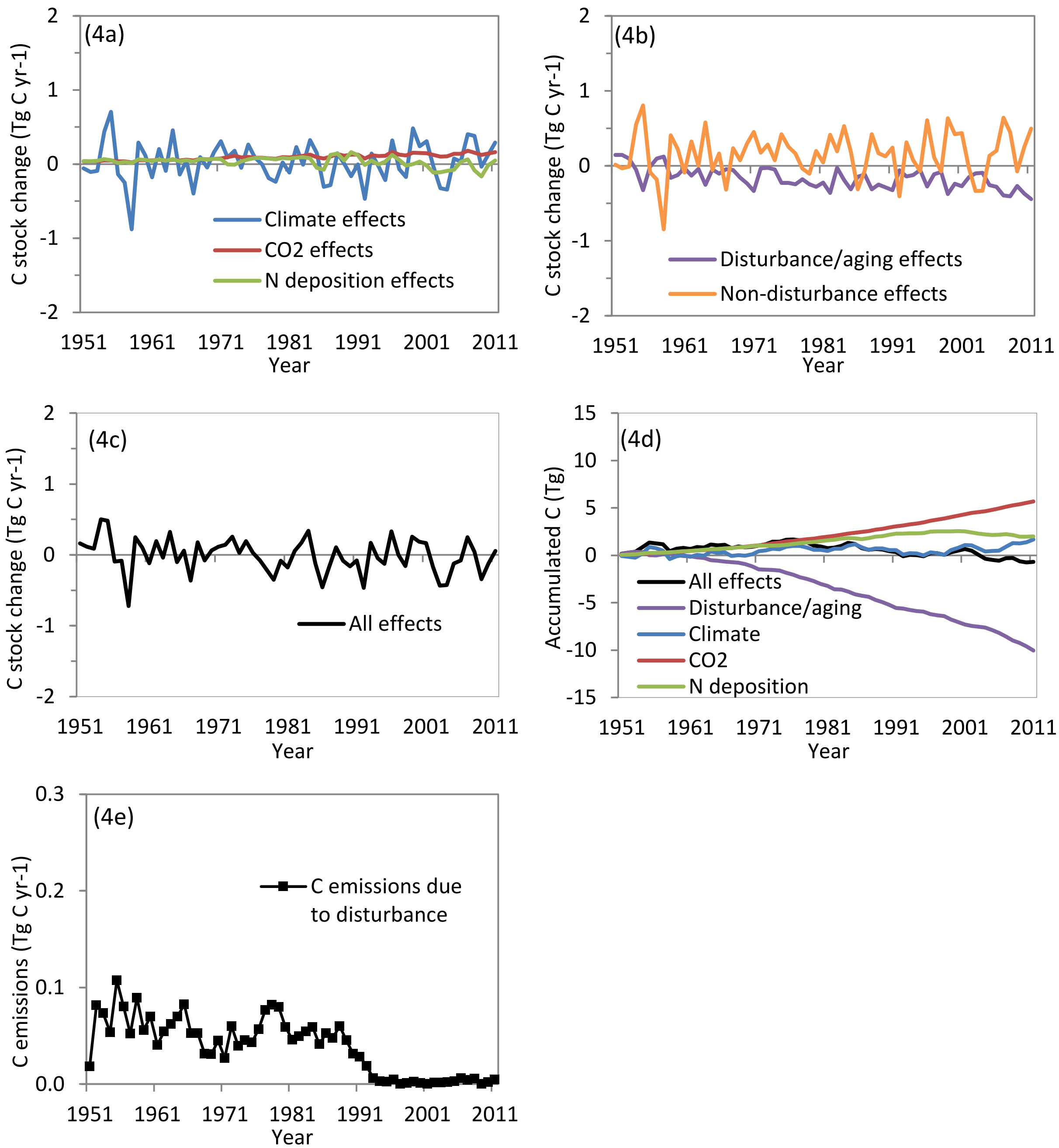


Figure 4.4. Changes in carbon stocks in the Olympic National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and aging and the sum of all non-disturbance factors combined; and (c) all factors combined which is the sum of disturbance\aging and non-disturbance effects; (d) Accumulated C due to individual disturbance\aging and non-disturbance factors and all factors combined from 1950-2011 excluding C accumulated pre-1950; and (e) C emissions due to disturbance events only. Positive values in Figures 4.4 a-c represent C sinks from the atmosphere or enhancement effects, whereas negative values represent C sources to the atmosphere, or detraction effects.

C.12 Rogue River-Siskiyou National Forest

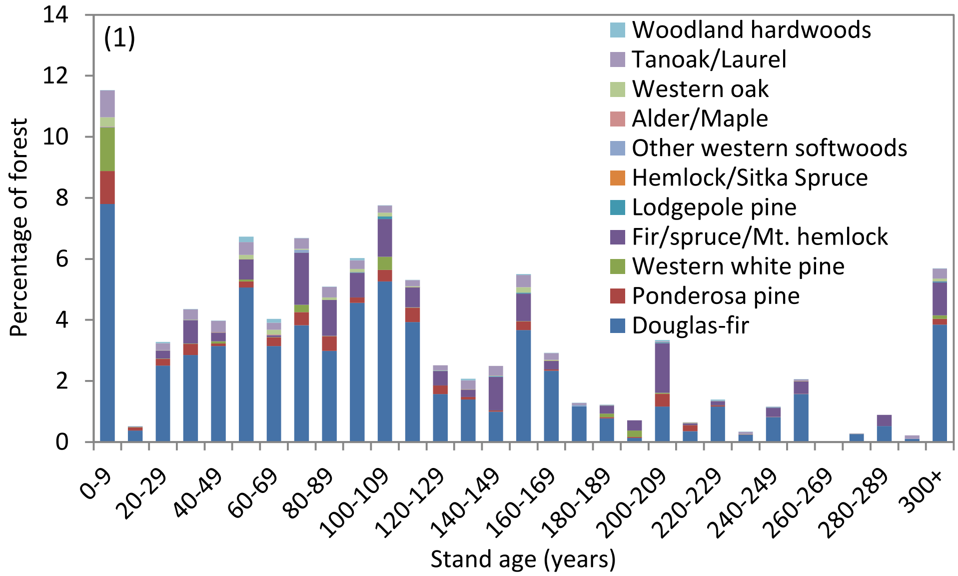


Figure 4.1. Age class distribution in 2011 in the Rogue River-Siskiyou National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

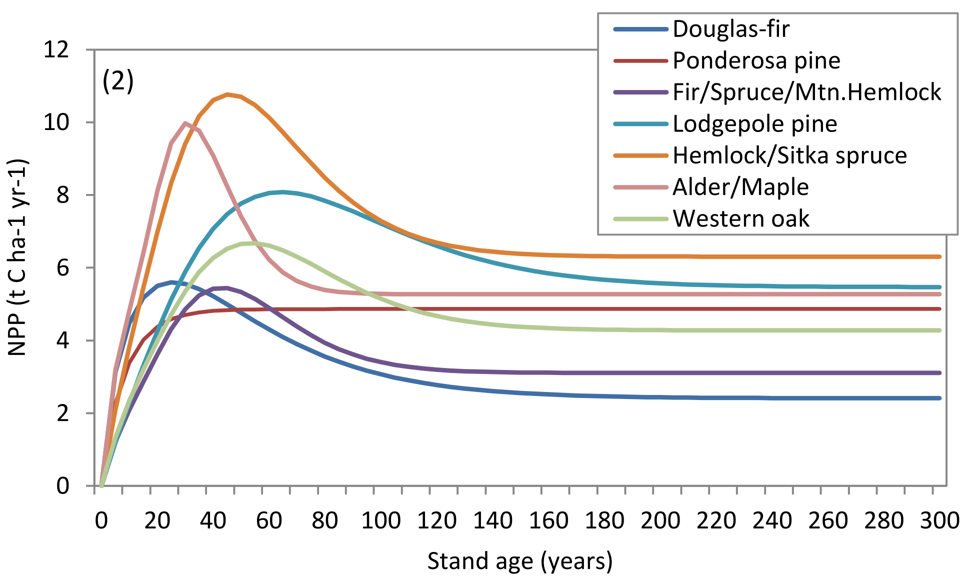


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Rogue River-Siskiyou National Forest. Curves were developed by He et al. 2012. The Evergreen Needleleaf curve was applied to Douglas-fir forest type. The Western oak curve was applied to Tanoak/Laurel and Woodland hardwoods forest types. The Ponderosa pine curve was applied to the Other western softwoods and Western white pine forest types.

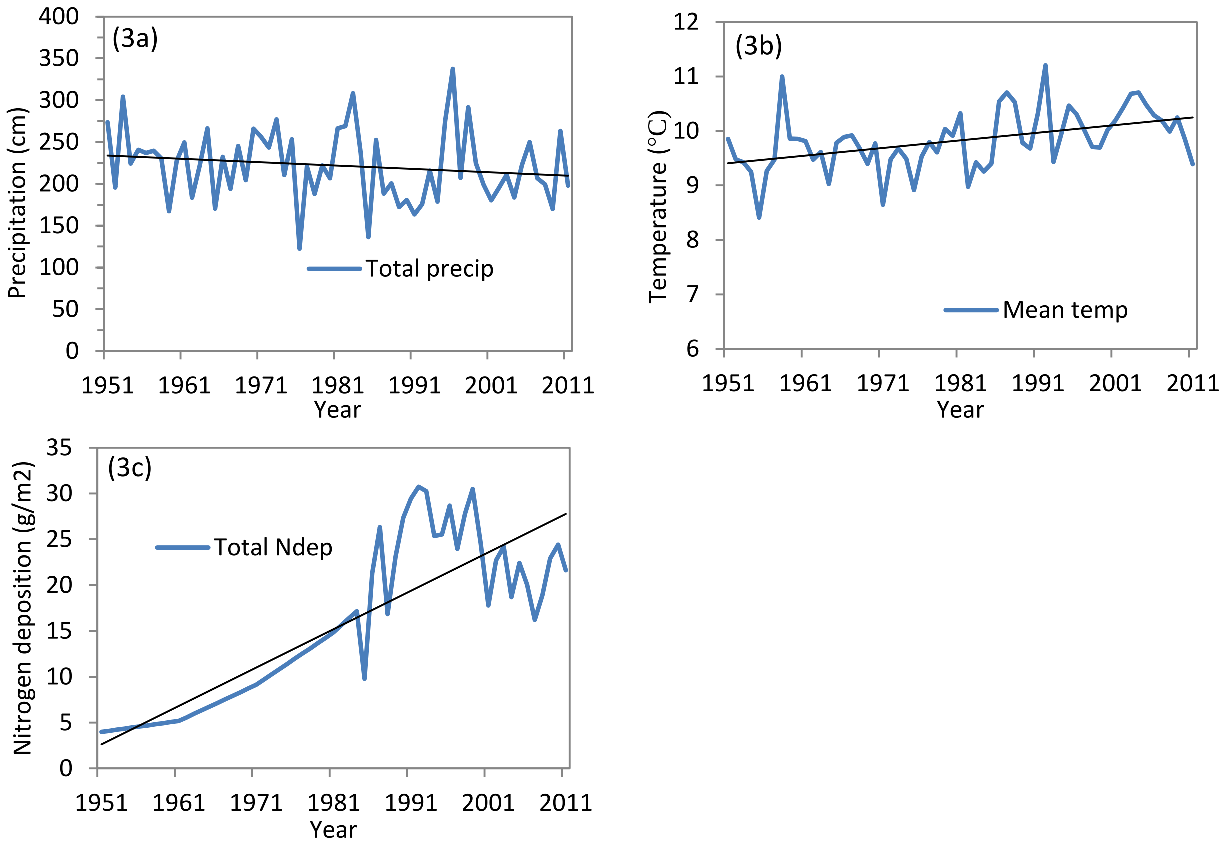


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Rogue River-Siskiyou National Forest. Linear trend lines shown in black.

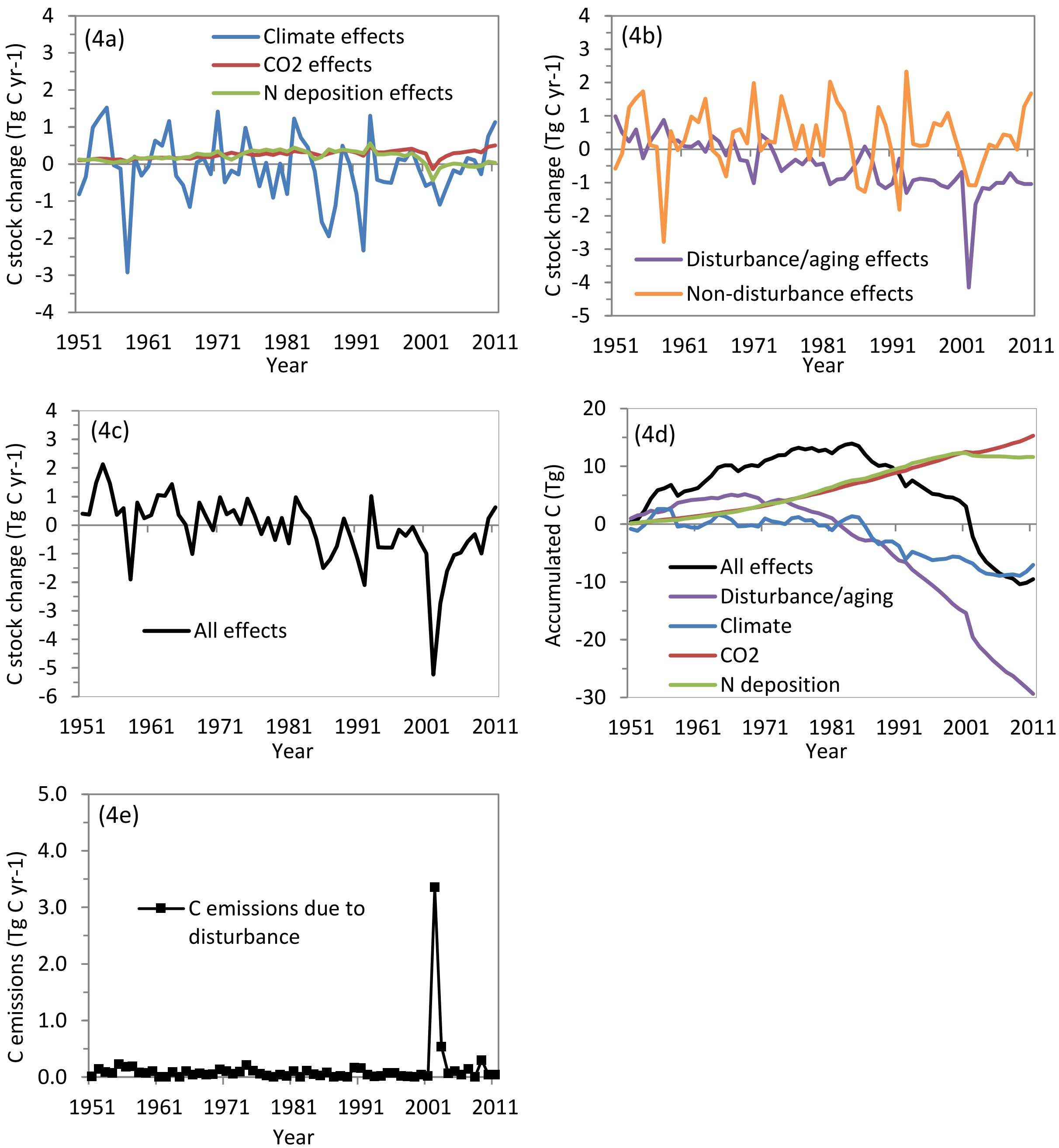


Figure 4.4. Changes in carbon stocks in the Rogue River-Siskiyou National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and aging and the sum of all non-disturbance factors combined; and (c) all factors combined which is the sum of disturbance\aging and non-disturbance effects; (d) Accumulated C due to individual disturbance\aging and non-disturbance factors and all factors combined from 1950-2011 excluding C accumulated pre-1950; and (e) C emissions due to disturbance events only. Positive values in Figures 4.4 a-c represent C sinks from the atmosphere or enhancement effects, whereas negative values represent C sources to the atmosphere, or detraction effects.

Siuslaw National Forest

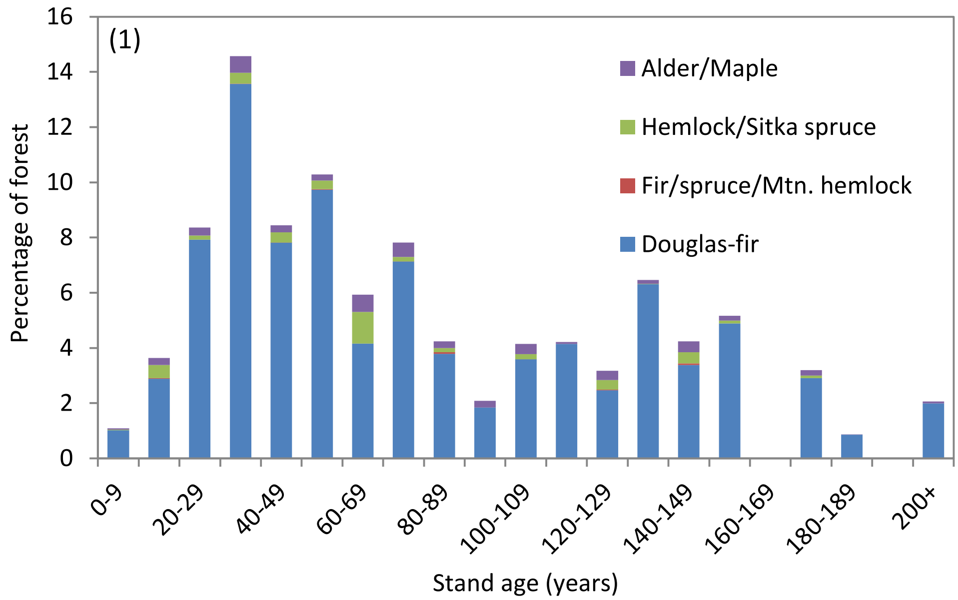


Figure 4.1. Age class distribution in 2011 in the Siuslaw National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

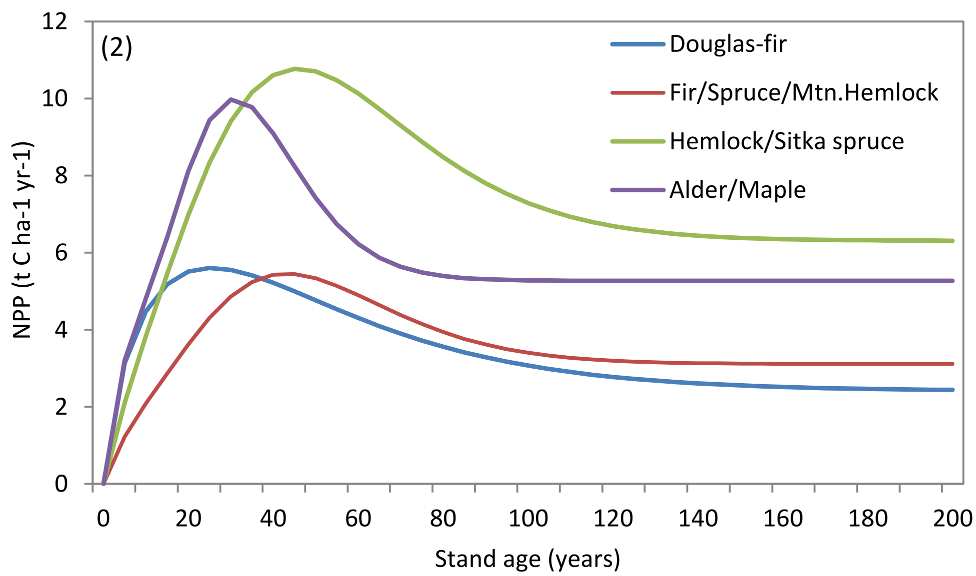


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Siuslaw National Forest. Curves were developed by He et al. 2012. The Evergreen Needleleaf curve was applied to Douglas-fir forest type.

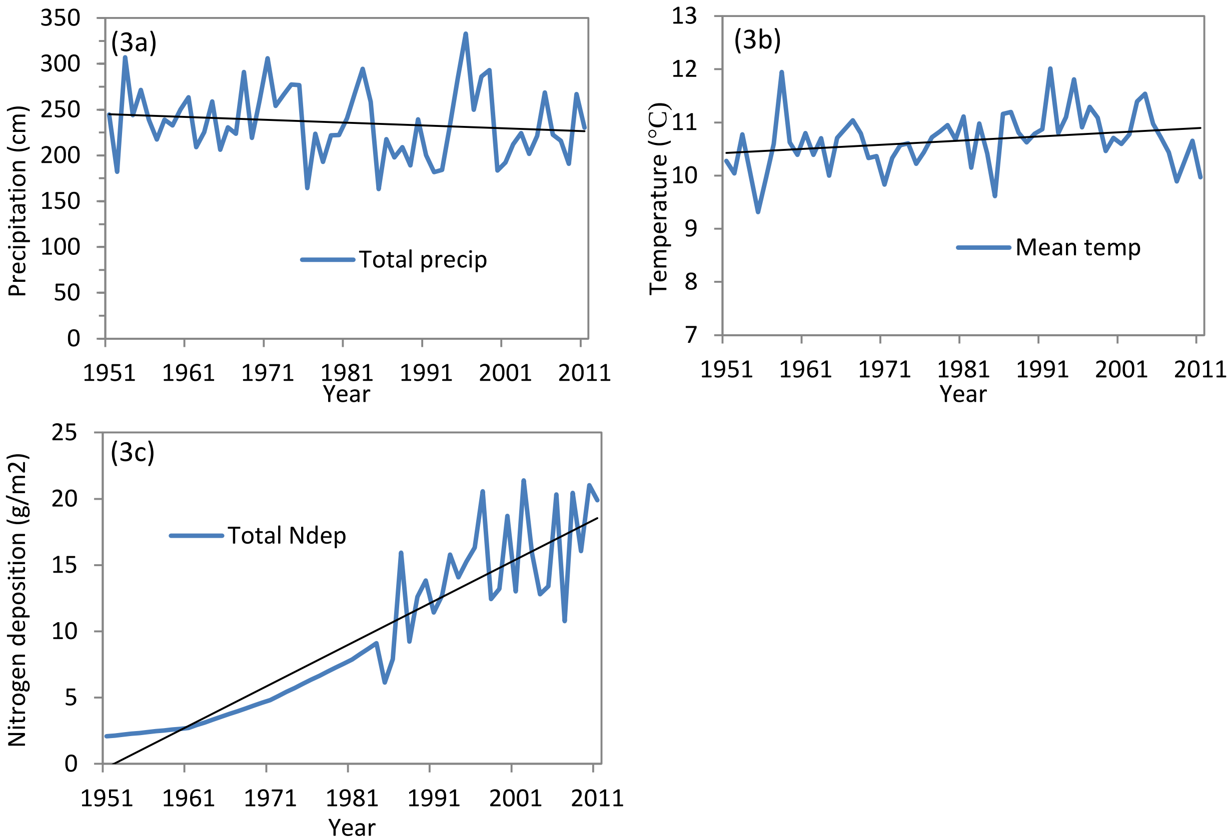


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Siuslaw National Forest. Linear trend lines shown in black.

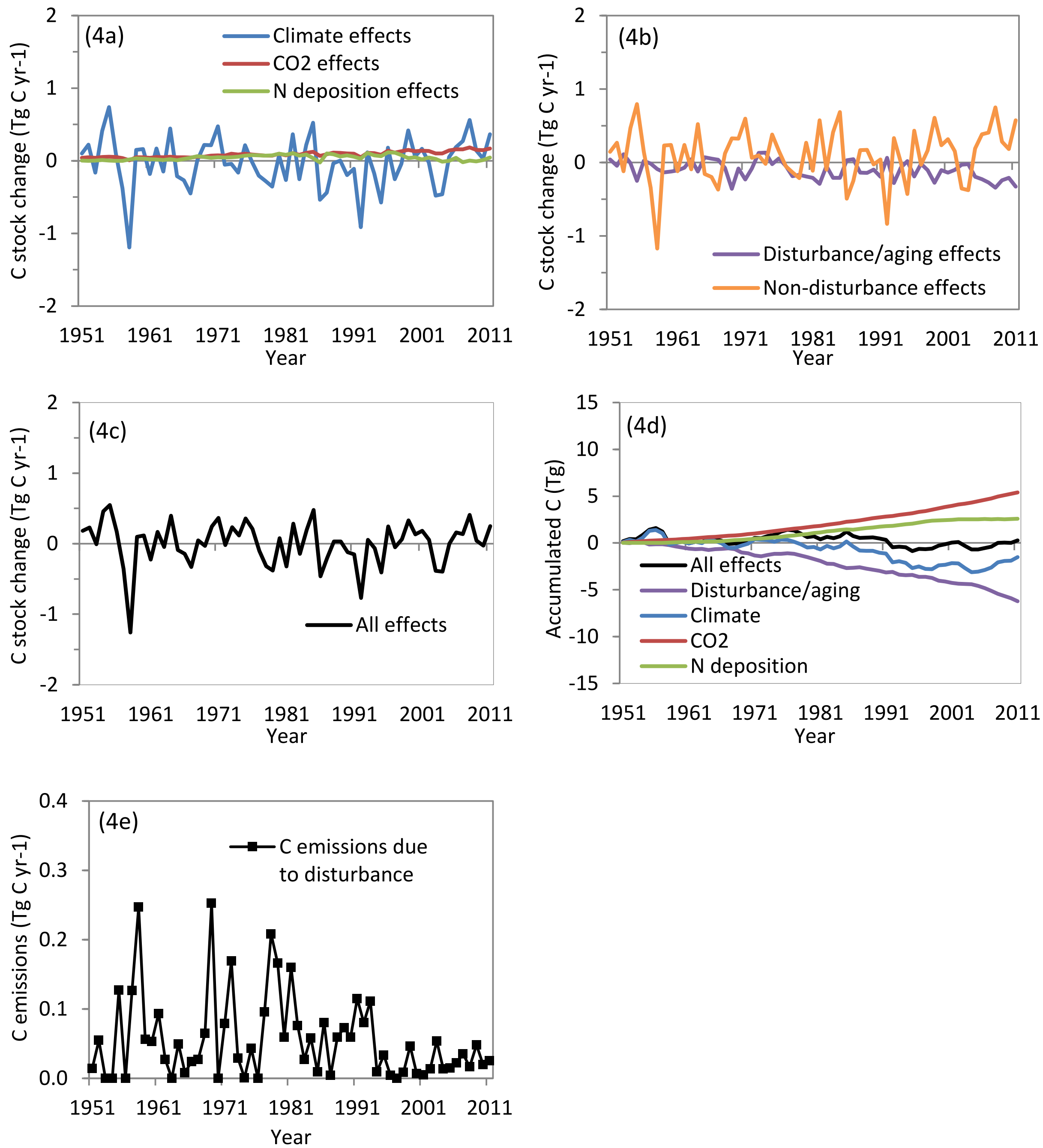


Figure 4.4. Changes in carbon stocks in the Siuslaw National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and aging and the sum of all non-disturbance factors combined; and (c) all factors combined which is the sum of disturbance\aging and non-disturbance effects; (d) Accumulated C due to individual disturbance\aging and non-disturbance factors and all factors combined from 1950-2011 excluding C accumulated pre-1950; and (e) C emissions due to disturbance events only. Positive values in Figures 4.4 a-c represent C sinks from the atmosphere or enhancement effects, whereas negative values represent C sources to the atmosphere, or detraction effects.

Umatilla National Forest

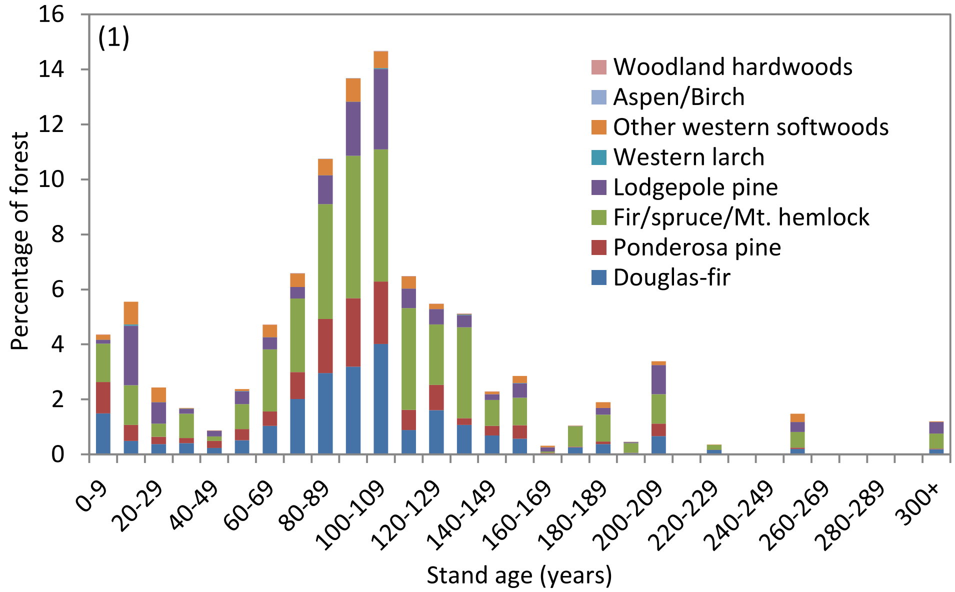


Figure 4.1. Age class distribution in 2011 in the Umatilla National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

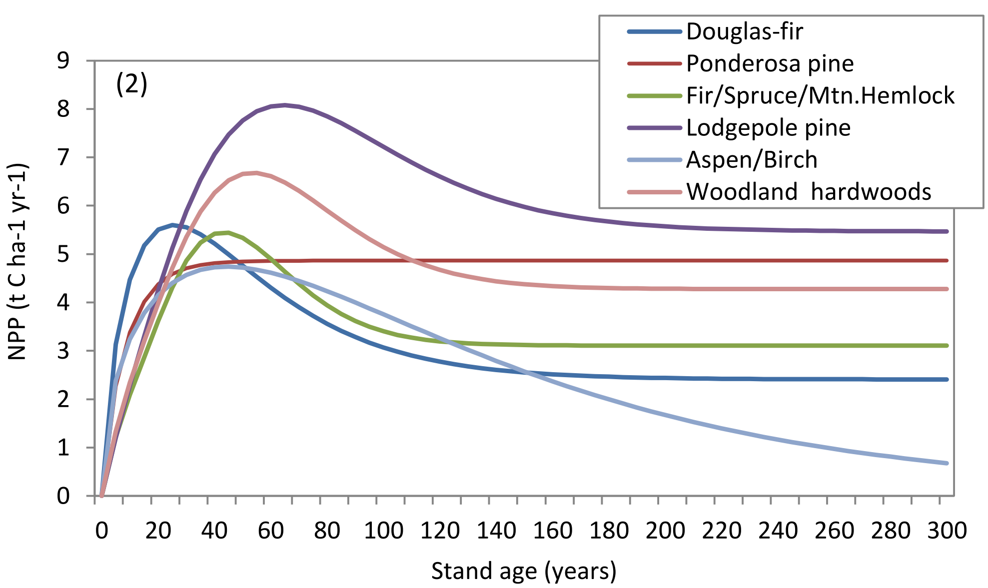


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Umatilla National Forest. Curves were developed by He et al. 2012. The Evergreen Needleleaf curve was applied to Douglas-fir and Western Larch forest type. The Ponderosa pine curve was applied to the Other Western Softwoods forest type.

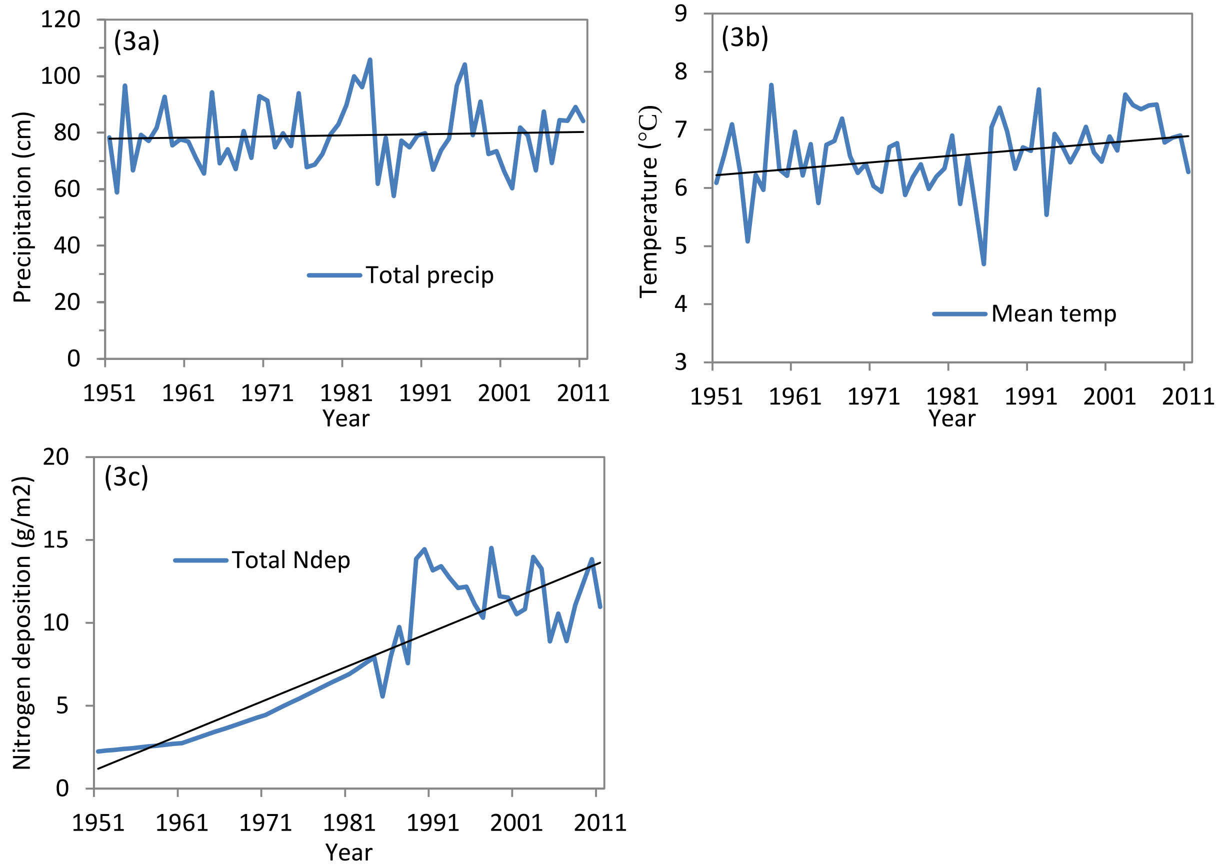


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Umatilla National Forest. Linear trend lines shown in black.

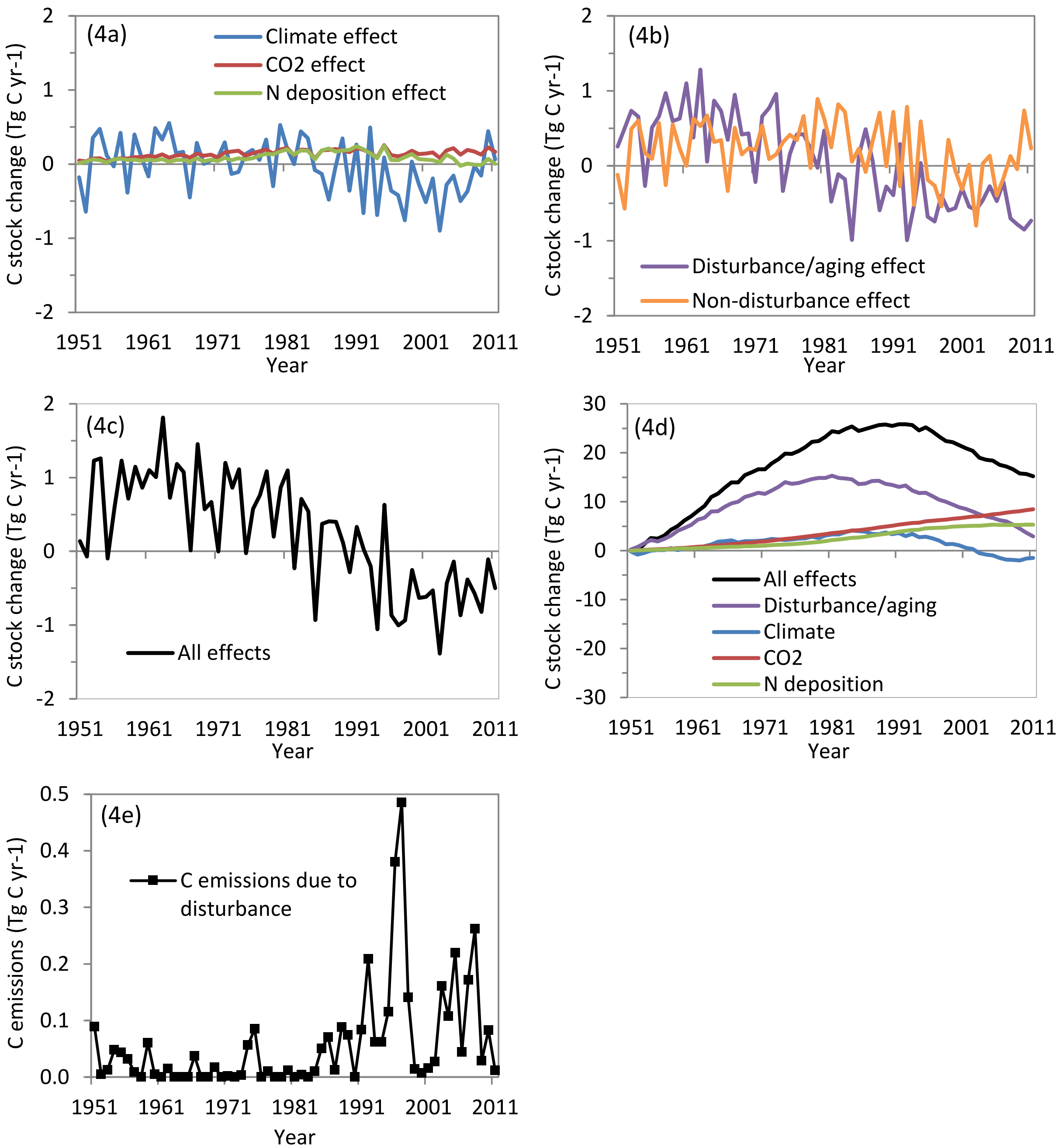


Figure 4.4. Changes in carbon stocks in the Umatilla National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and aging and the sum of all non-disturbance factors combined; and (c) all factors combined which is the sum of disturbance\aging and non-disturbance effects; (d) Accumulated C due to individual disturbance\aging and non-disturbance factors and all factors combined from 1950-2011 excluding C accumulated pre-1950; and (e) C emissions due to disturbance events only. Positive values in Figures 4.4 a-c represent C sinks from the atmosphere or enhancement effects, whereas negative values represent C sources to the atmosphere, or detraction effects.

C.15 Umpqua National Forest

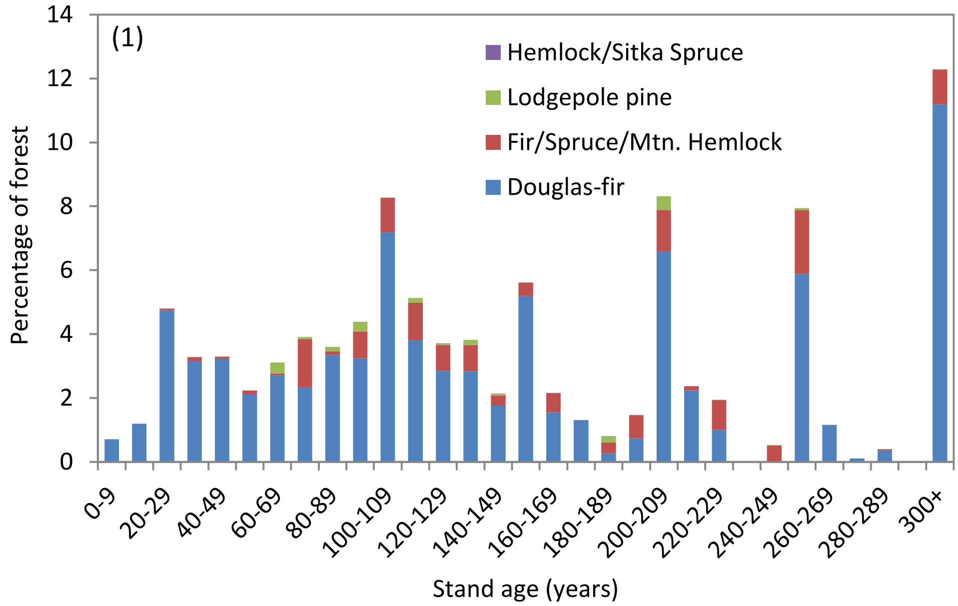


Figure 4.1. Age class distribution in 2011 in the Umpqua National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

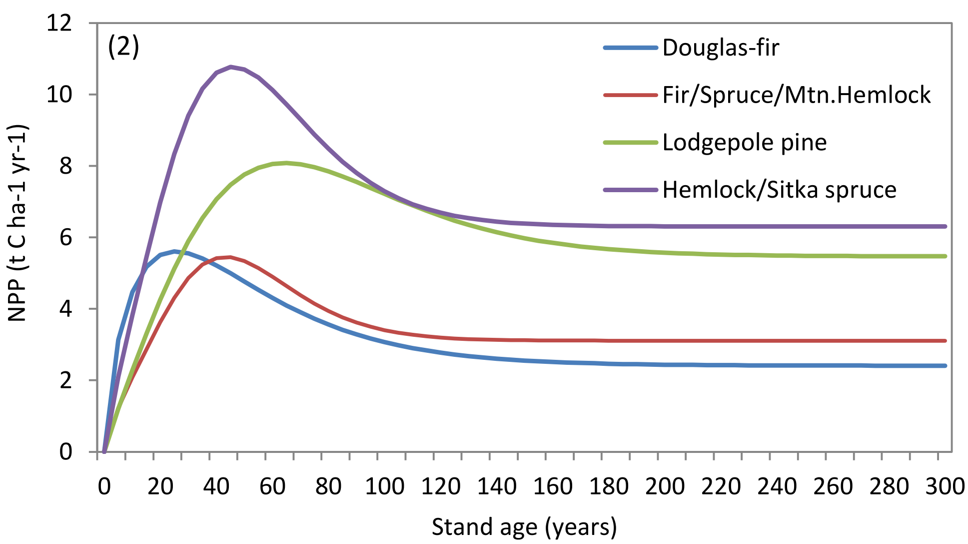


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Umpqua National Forest. Curves were developed by He et al. 2012. The Evergreen Needleleaf curve was applied to Douglas-fir forest type.

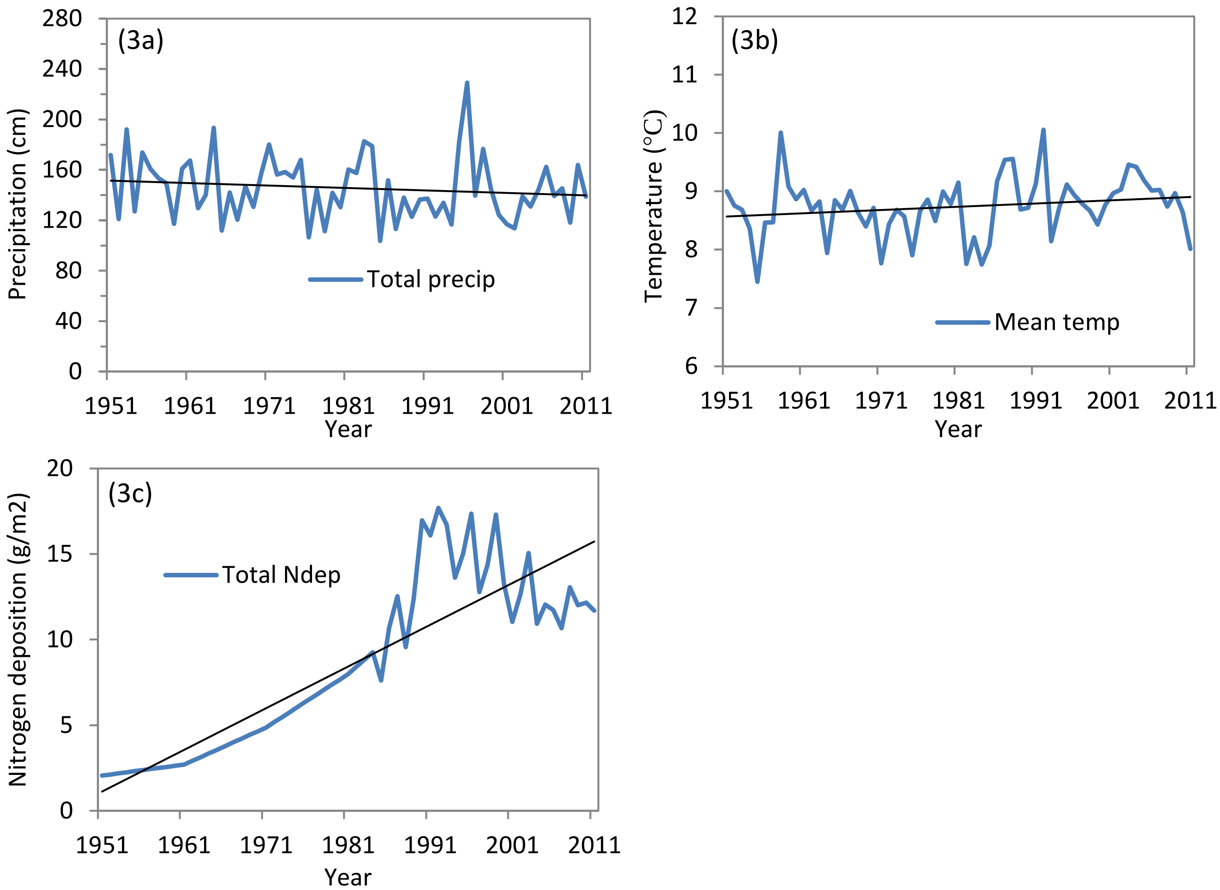


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Umpqua National Forest. Linear trend lines shown in black.

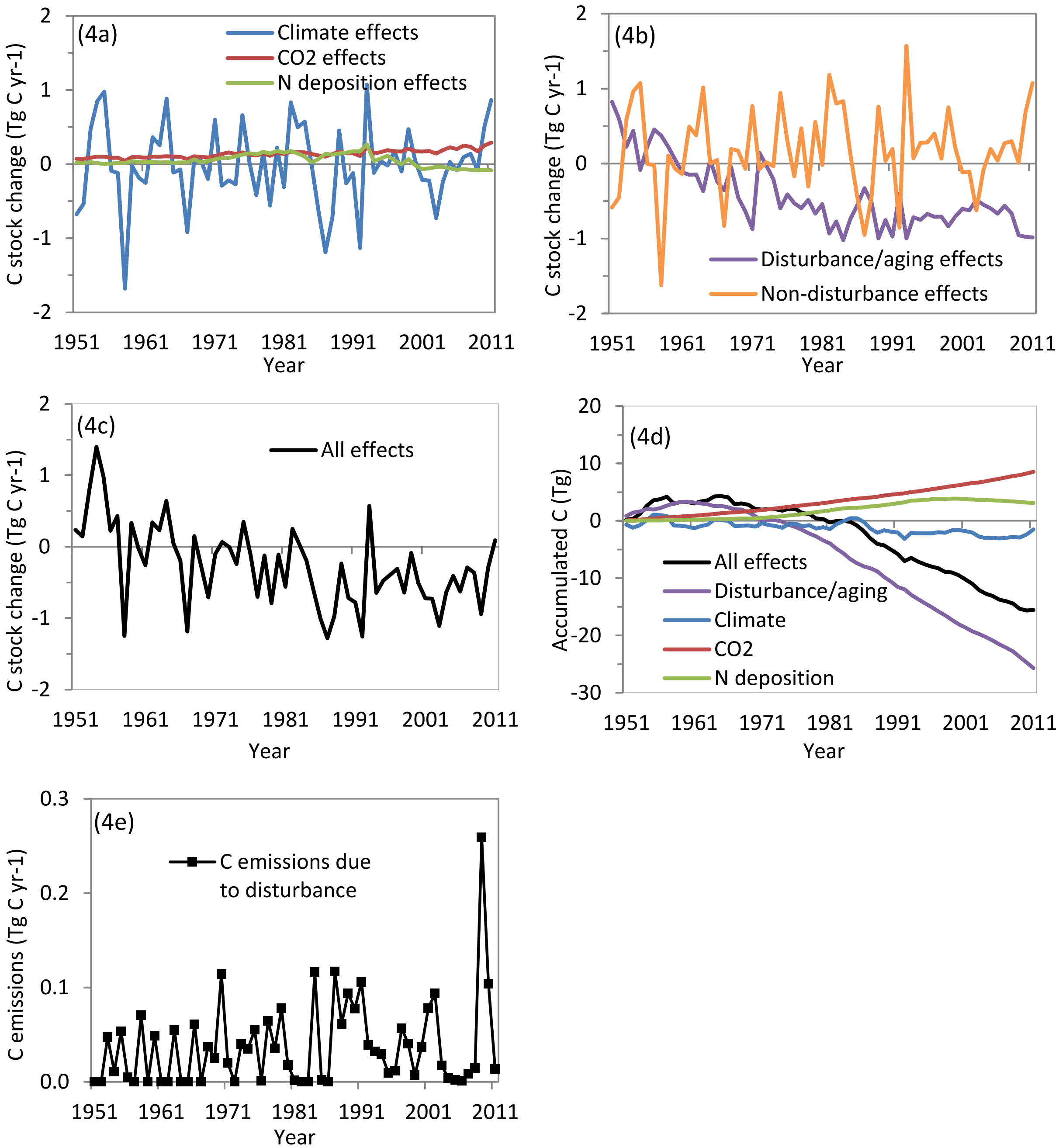


Figure 4.4. Changes in carbon stocks in the Umpqua National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and aging and the sum of all non-disturbance factors combined; and (c) all factors combined which is the sum of disturbance\aging and non-disturbance effects; (d) Accumulated C due to individual disturbance\aging and non-disturbance factors and all factors combined from 1950-2011 excluding C accumulated pre-1950; and (e) C emissions due to disturbance events only. Positive values in Figures 4.4 a-c represent C sinks from the atmosphere or enhancement effects, whereas negative values represent C sources to the atmosphere, or detraction effects.

Wallowa-Whitman National Forest

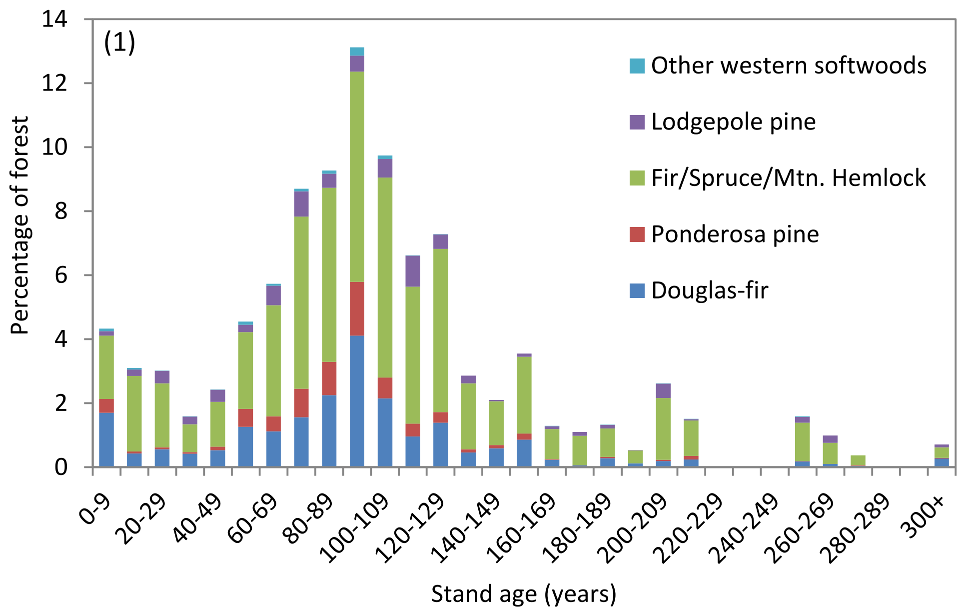


Figure 4.1. Age class distribution in 2011 in the Wallowa-Whitman National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

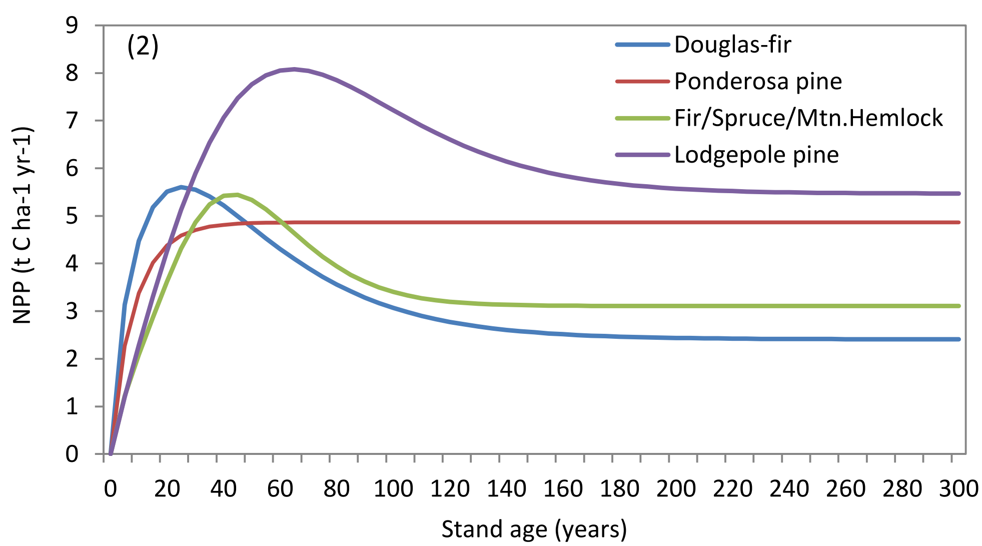


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Wallowa-Whitman National Forest. Curves were developed by He et al. 2012. The Evergreen Needleleaf curve was applied to Douglas-fir forest type. The Ponderosa pine curve was applied to the Other western softwoods forest type.

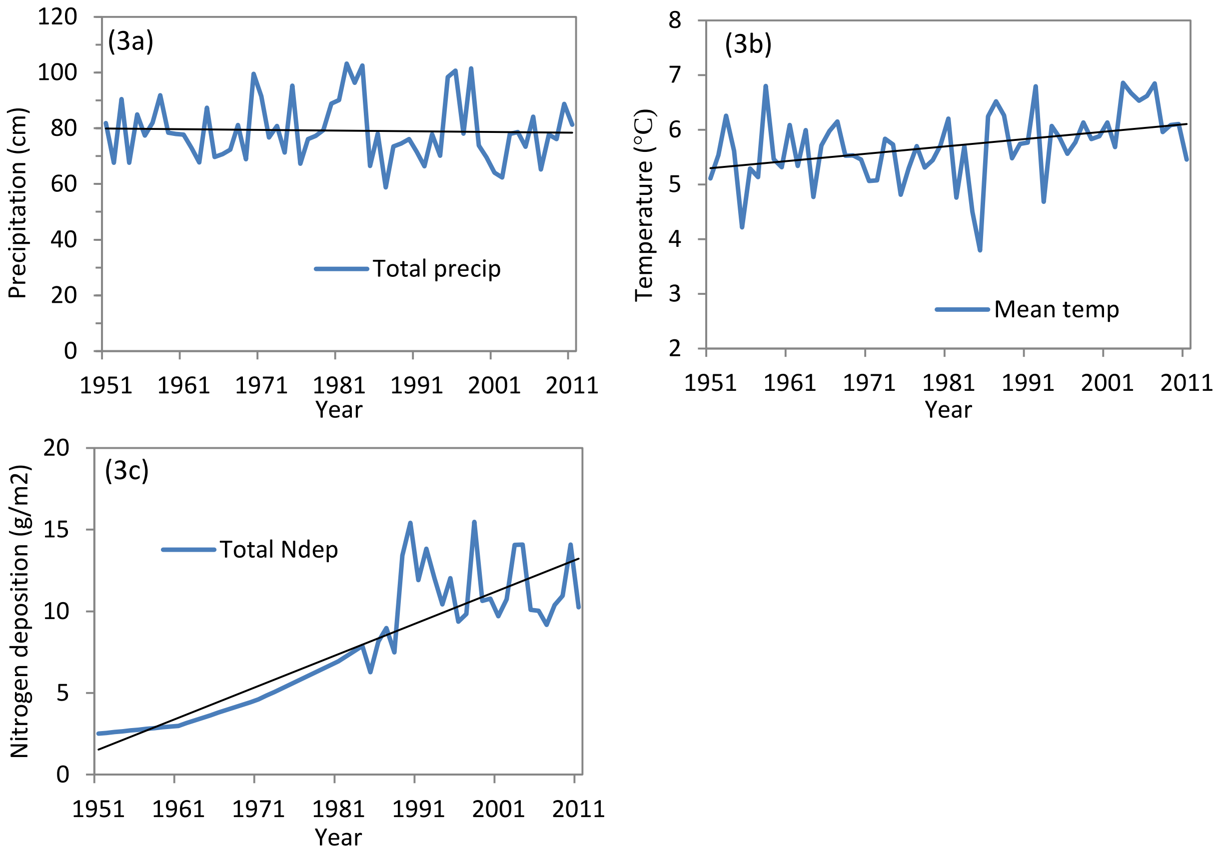


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Wallowa-Whitman National Forest. Linear trend lines shown in black.

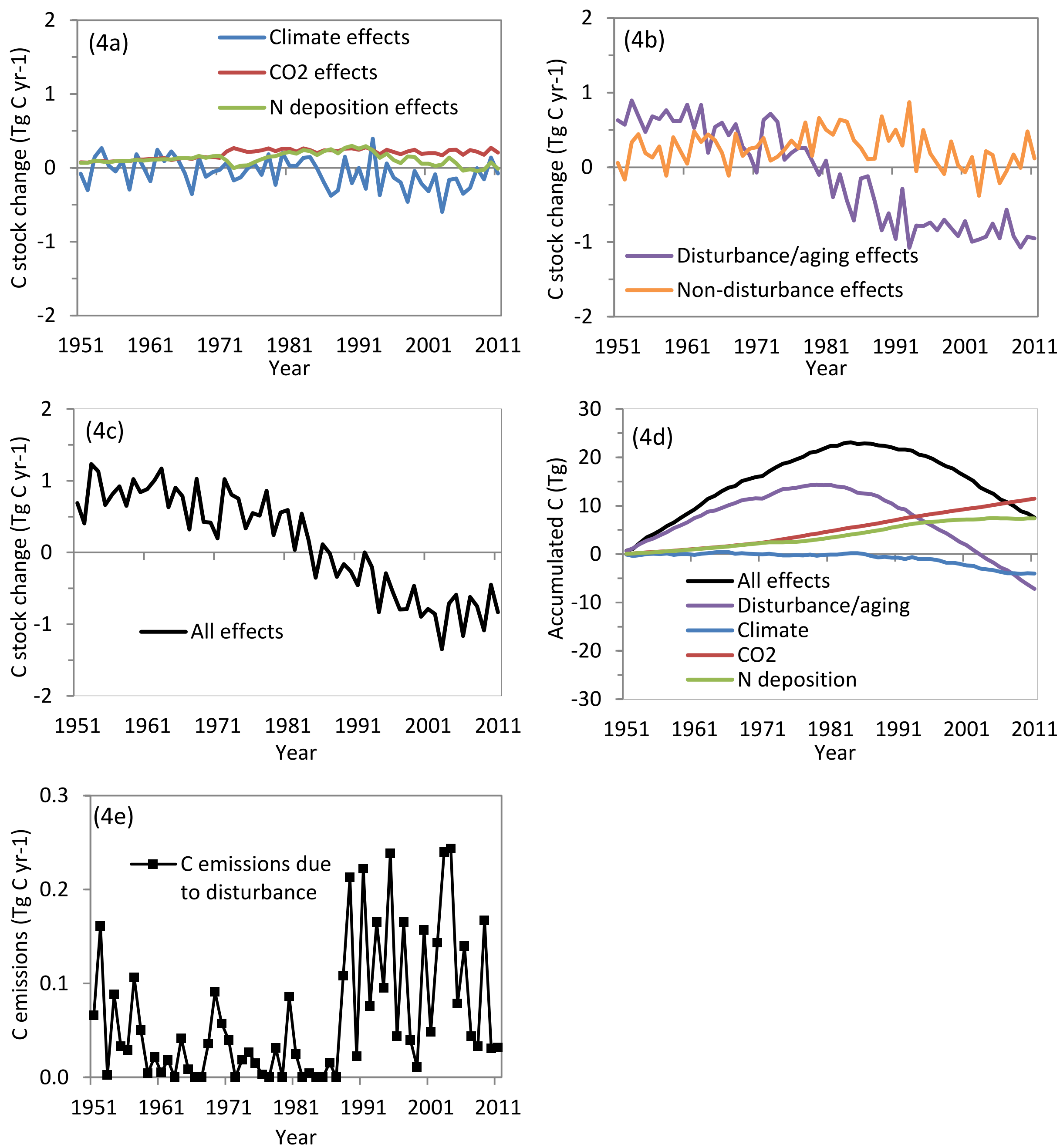


Figure 4.4. Changes in carbon stocks in the Wallowa-Whitman National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and aging and the sum of all non-disturbance factors combined; and (c) all factors combined which is the sum of disturbance\aging and non-disturbance effects; (d) Accumulated C due to individual disturbance\aging and non-disturbance factors and all factors combined from 1950-2011 excluding C accumulated pre-1950; and (e) C emissions due to disturbance events only. Positive values in Figures 4.4 a-c represent C sinks from the atmosphere or enhancement effects, whereas negative values represent C sources to the atmosphere, or detraction effects.

C.17 Willamette National Forest

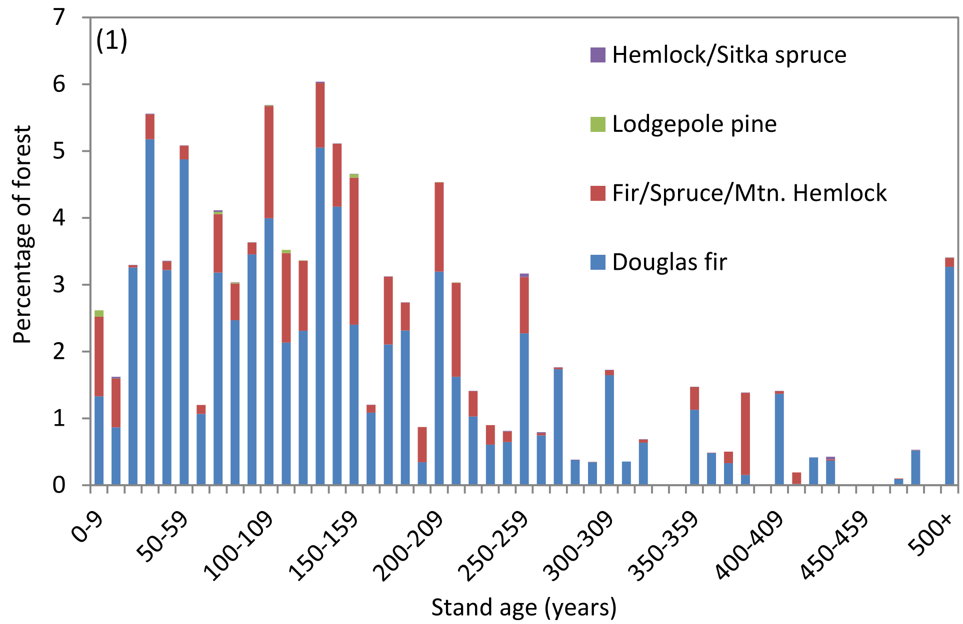


Figure 4.1. Age class distribution in 2011 in the Willamette National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

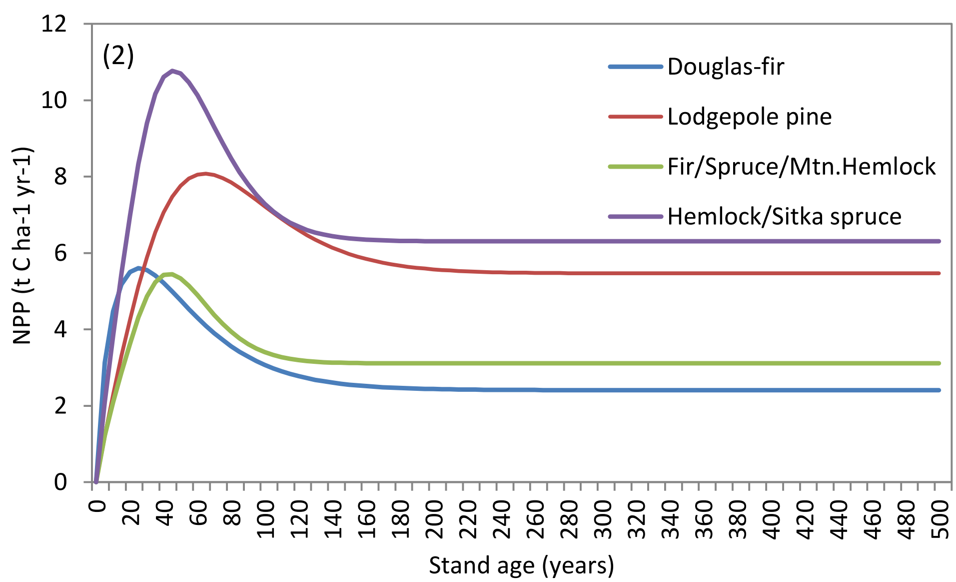


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Willamette National Forest. Curves were developed by He et al. 2012. The Evergreen Needleleaf curve was applied to Douglas-fir forest type.

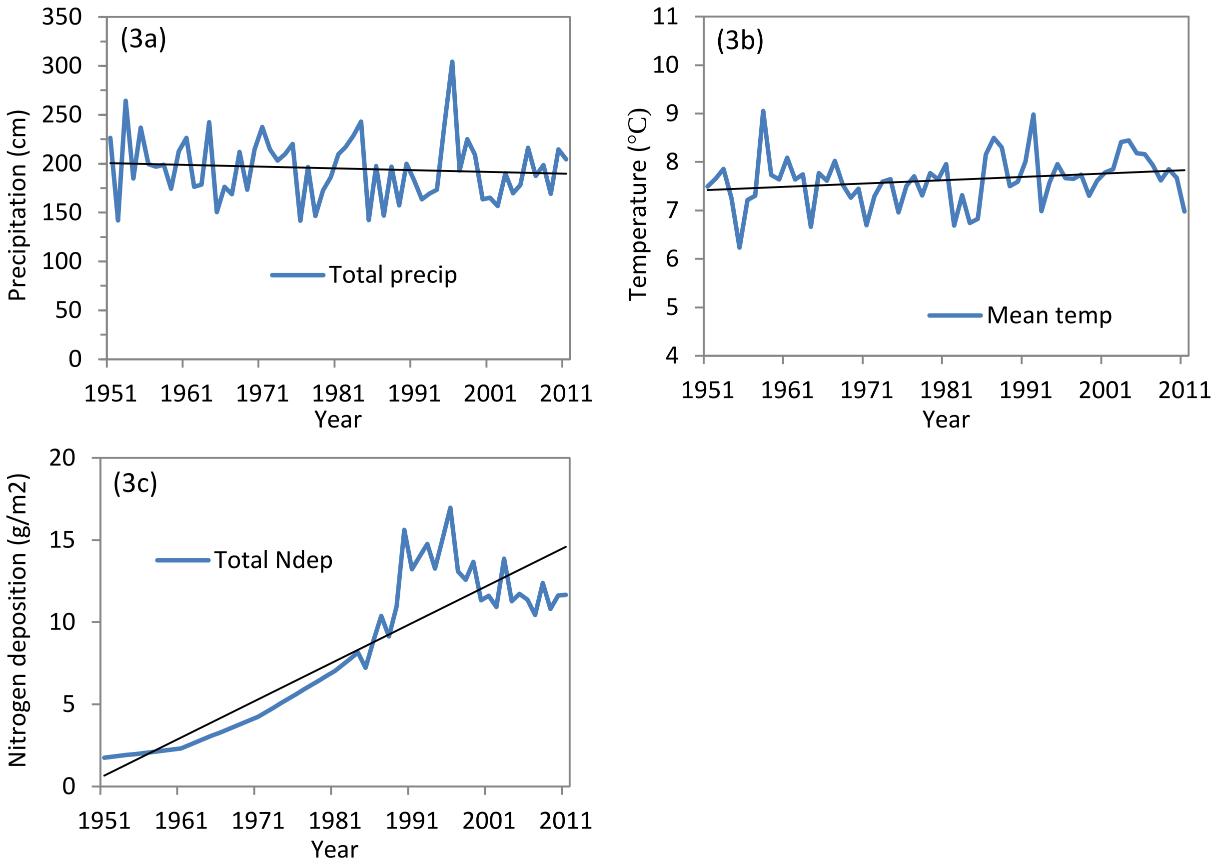


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Willamette National Forest. Linear trend lines shown in black.

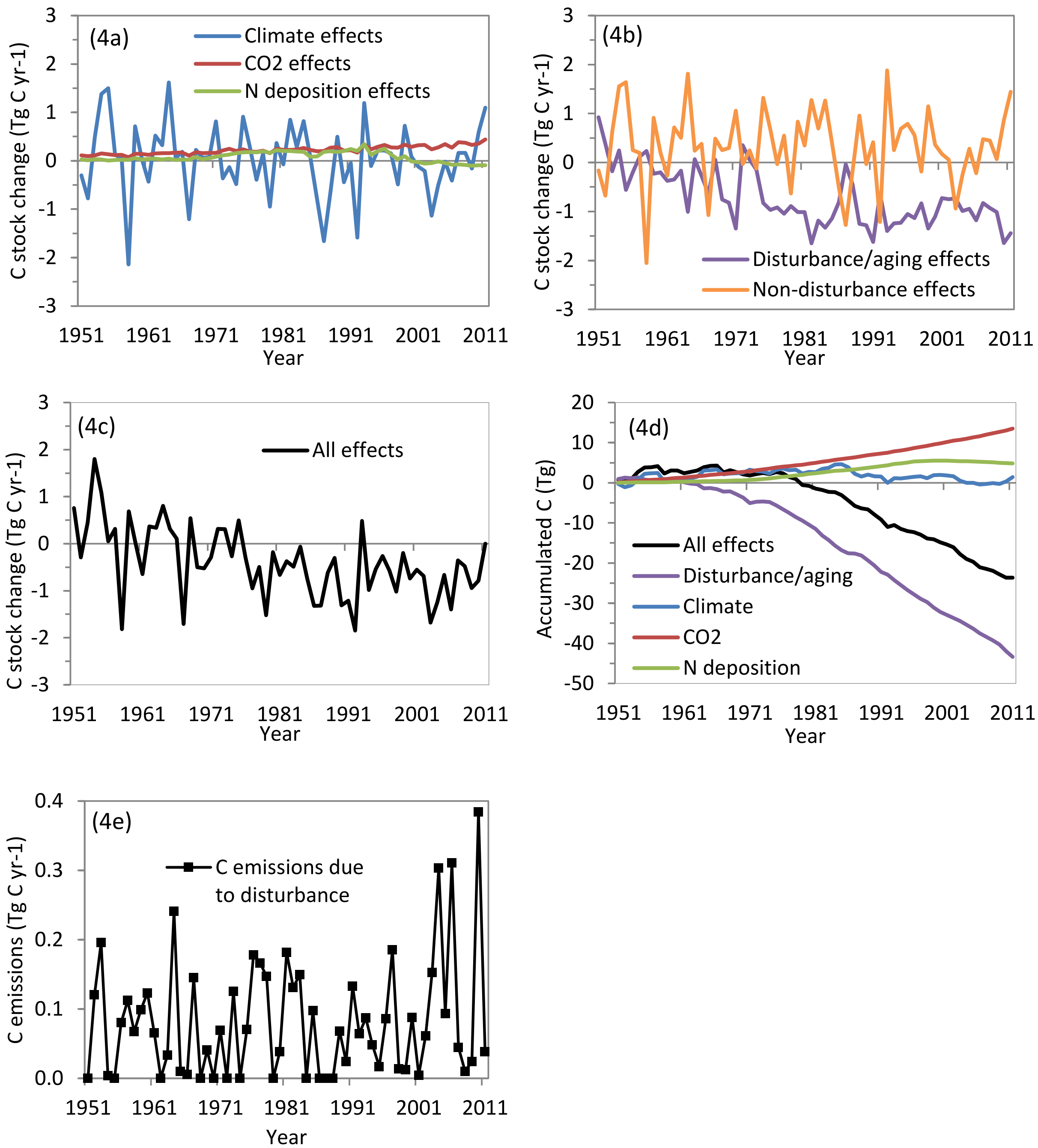


Figure 4.4. Changes in carbon stocks in the Willamette National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and aging and the sum of all non-disturbance factors combined; and (c) all factors combined which is the sum of disturbance\aging and non-disturbance effects; (d) Accumulated C due to individual disturbance\aging and non-disturbance factors and all factors combined from 1950-2011 excluding C accumulated pre-1950; and (e) C emissions due to disturbance events only. Positive values in Figures 4.4 a-c represent C sinks from the atmosphere or enhancement effects, whereas negative values represent C sources to the atmosphere, or detraction effects.