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 7: Intermountain Region, Individual Forests

Office of Sustainability and Climate
National Forest System

November, 2019

United States Department of Agriculture
Forest Service

Citation: Birdsey, Richard A.; Dugan, Alexa J.; Healey, Sean P.; Dante-Wood, Karen; Zhang, Fangmin; Mo, Gang; Chen, Jing M.; Hernandez, Alexander J.; Raymond, Crystal L.; McCarter, James. 2019. Assessment of the influence of disturbance, management activities, and environmental factors on carbon stocks of U.S. national forests. Gen. Tech. Rep. RMRS-GTR-402. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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

Acknowledgements: Individuals from the USDA Forest Service Washington Office provided valuable guidance and support for this research, particularly Duncan McKinley and Cindi West. The research could not have been done without substantial participation by technicians at Utah State University. The authors wish to acknowledge contributions from the staff of the Forest Service's Northern Research Station and Rocky Mountain Research Station for providing technical support and data used in this report, particularly Chris Woodall, Grant Domke, and Jim Smith. Throughout development of this report, the authors received significant input and feedback from individual national forests which helped us compile the material in a useful and understandable way. We also thank technical reviewers Grant Domke, Bill Connelly, Nadia Tase, Jim Alegria, Dave L. Peterson, Barry Bollenbacher, Elizabeth Wood, Marilyn Buford, and Leslie Brandt.

Contents

1. Disturbance trends

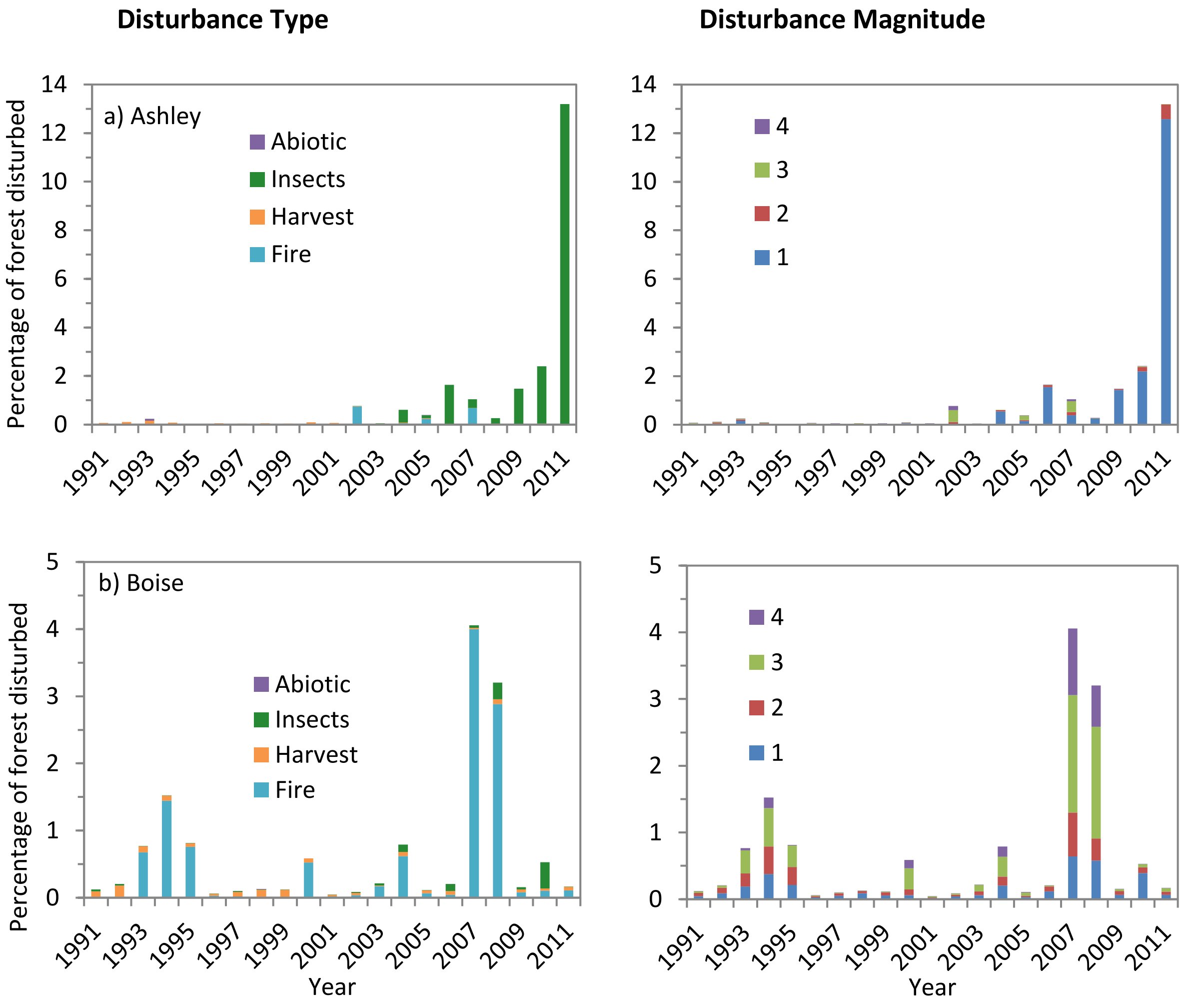
2. Effects of disturbance and management activities (ForCaMF)

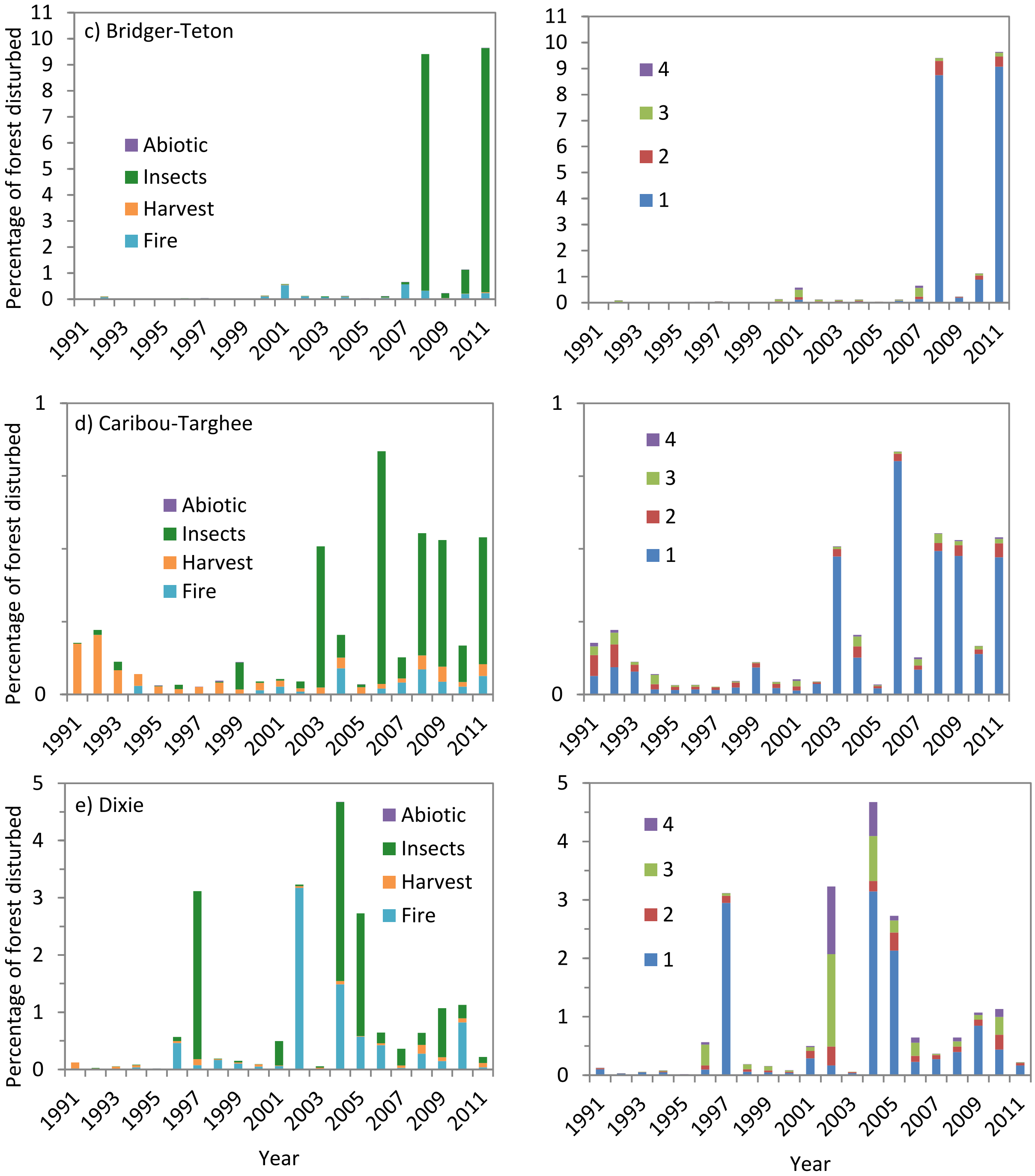
3. Management implications of ForCaMF results

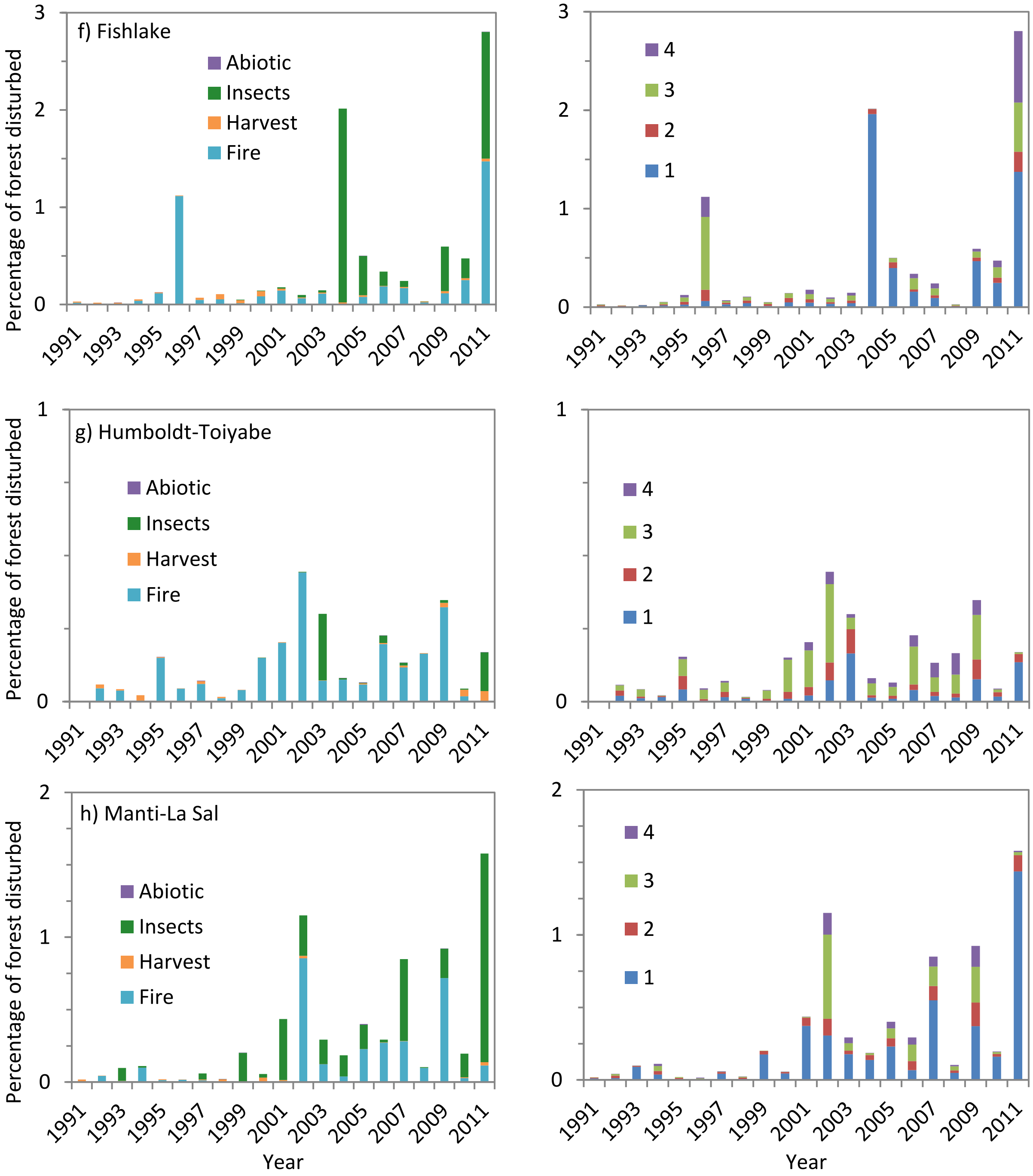
4. Effects of disturbance, management, and environmental factors (InTEC)

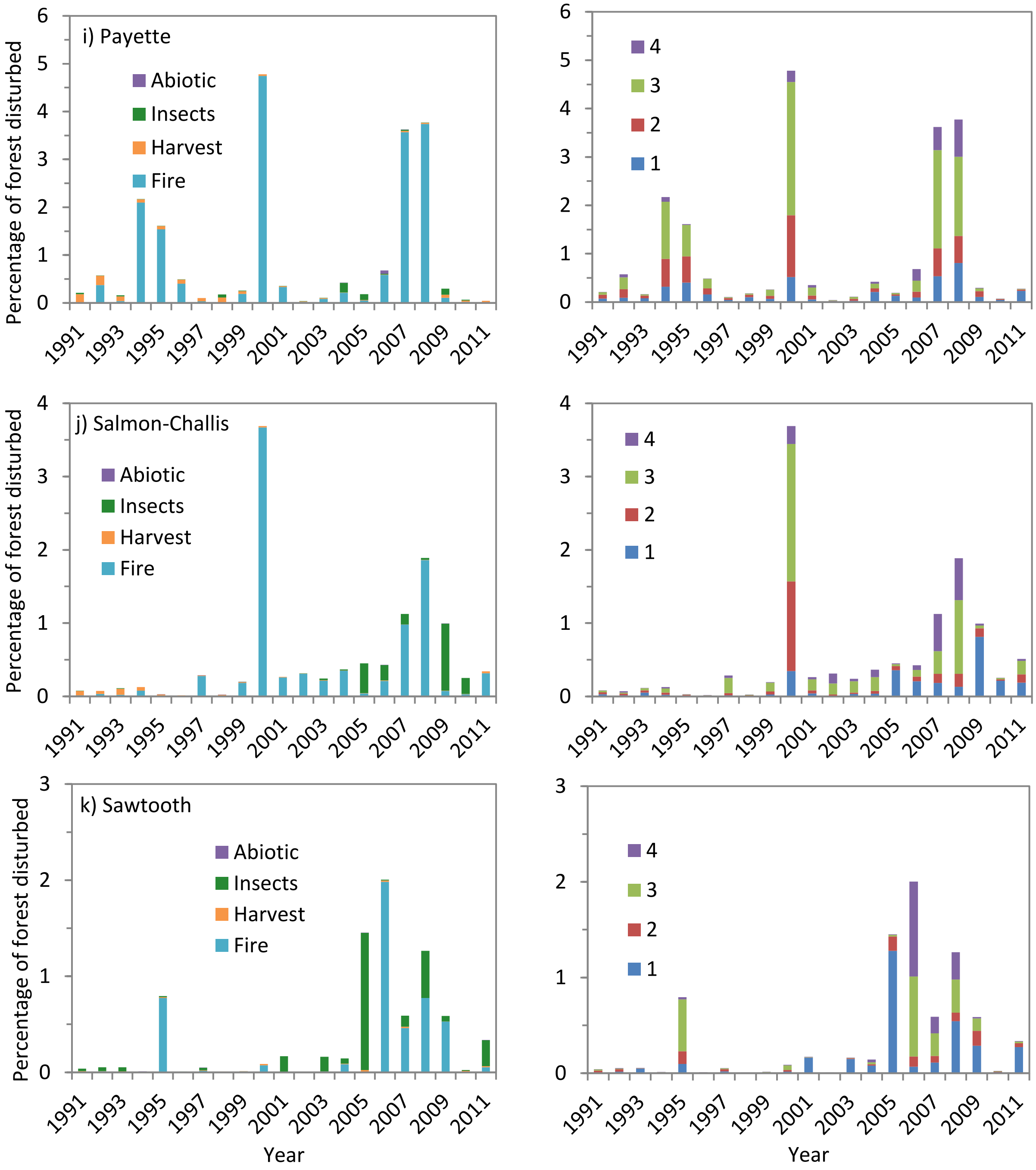
1. Disturbance trends

Disturbance records were summarized by type (fire, harvest, and insects) and by magnitude in Figure 1.1 a-l. For example, extremely high levels of insect disturbance were observed in the Ashley National Forest in 2011, while lower levels of insect activity and occasional fires were observed in the preceding years (Figure 1.1a). Note the different scaling among forests in Figure 1.1, necessitated by locally extreme rates of insects and fire in some national forests.




c) Bridger-Teton
d) Caribou-Targhee
e) Dixie
Percentage of forest disturbed
Abiotic
Insects
Harvest
Fire
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
Year


f) Fishlake
g) Humboldt-Toiyabe
h) Manti-La Sal
Abiotic
Insects
Harvest
Fire
4
3
2
1
Percentage of forest disturbed
Year
0
1
2
3
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011



i) Payette
j) Salmon-Challis
k) Sawtooth
Percentage of forest disturbed
Abiotic
Insects
Harvest
Fire
4
3
2
1
0
1
2
3
4
5
6
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
Year

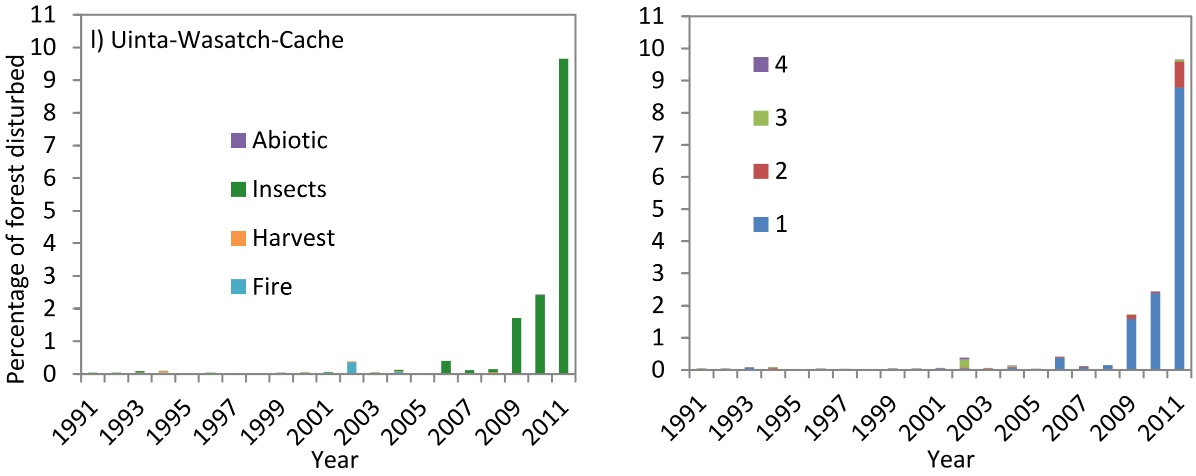


Figure 1.1. Annual rates of disturbance in the Intermountain Region, mapped using visual interpretation of several independent datasets and summarized as the percentage of the forested area disturbed from 1991 through 2011 by (a) disturbance types including fire, harvests, insects, and abiotic; and b) 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)

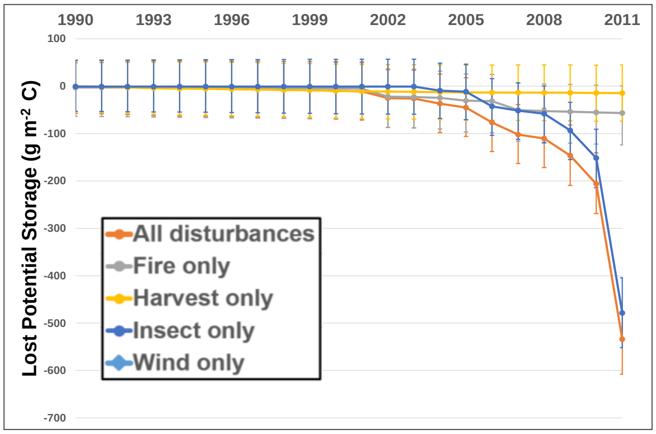
ForCaMF uses C dynamics derived from the combination of FIA plot data and FVS to interpret the consequences of recorded harvests and natural disturbances. This appendix contains ForCaMF results for each national forest in the Intermountain Region from 1990 to 2011. Figure 2.1 shows insect-related jumps after approximately 2005 in the difference of sequestered vs. potentially sequestered C in many forests, including the Ashley mentioned above. 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. ForCaMF accounts for gradual decay of fire- or insect-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.

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). In the Ashley, for example, insect damage occurring between 1990 and 2011 had the dominant impact on carbon storage (87%), although fire (10%) and harvest (3%) also had a significant impacts.

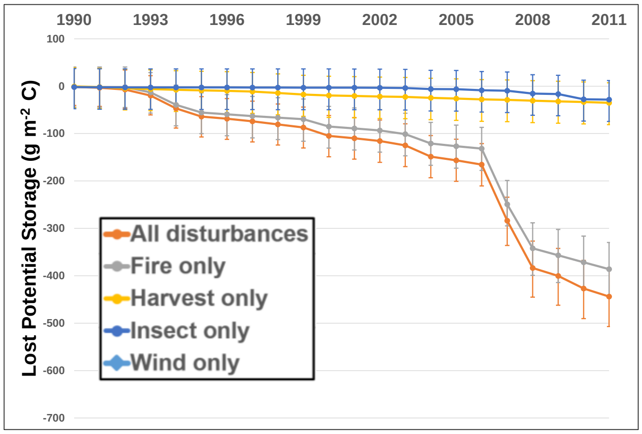
Despite low levels of detected insect activity through the 1990s, insects impacted the carbon storage of every forest in the Region. While some forests experienced impacts of fire and insects that were approximately equal (the Fishlake, Dixie, and Manti-La Sal NFs), recent insect activity dominated disturbance impact on C storage in others (e.g., the Uinta Wasatch-Cache, Caribou Targhee, Bridger-Teton, and Ashley National Forests). On the forests most affected by insects, the biggest losses of potential carbon storage came in 2011, with absolute losses approaching 500 g/m^2 (or, 5 Mg/ha) in some cases.

Several large fire years in the Payette NF (Figure 1.1) produced a significant impact in 2011 C storage (almost 600 g/m^2). The Payette, along with the Boise, also had the largest carbon storage impacts of harvest (Figure 2.2), although harvests in both Forests resulted in a loss of less than 50 g/m^{2}potential C storage. This is significantly lower than harvest impacts in actively managed forests in other regions. Some of the harvest addressed across forests in this analysis may have been 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 2.2) 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 harvests.

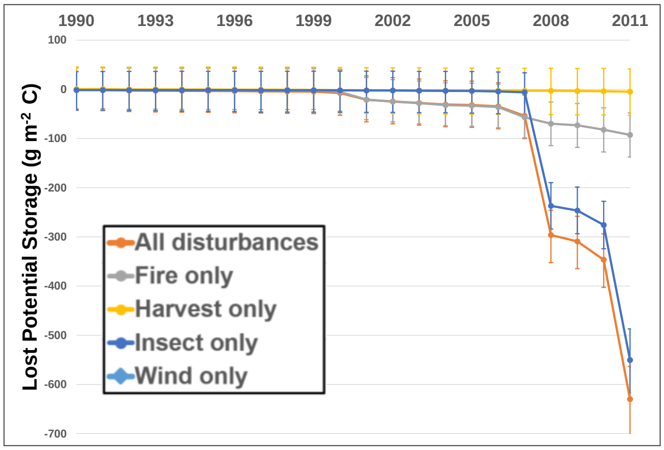
2a) Ashley National Forest



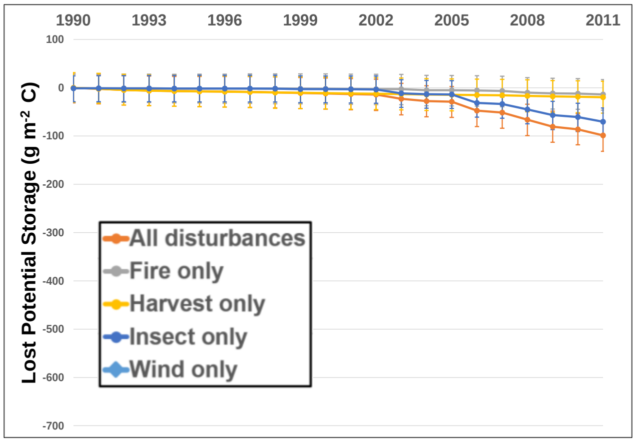
2b) Boise National Forest



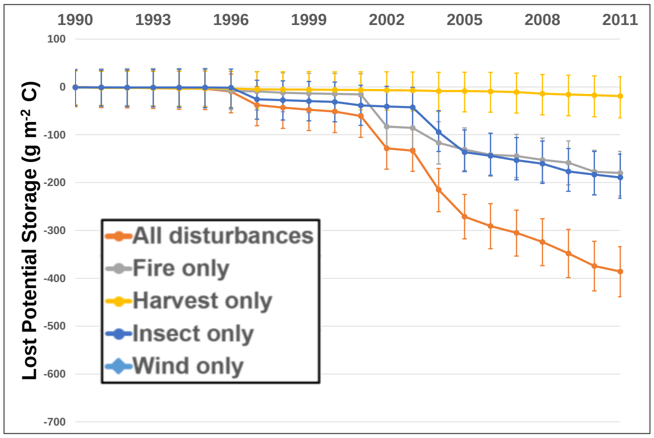
2c) Bridger – Teton National Forest



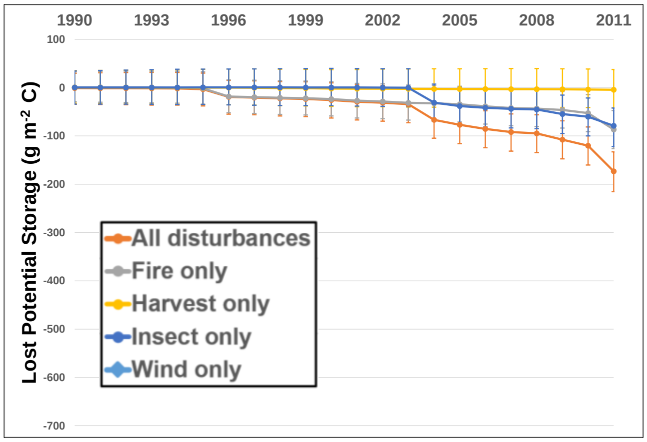
2d) Caribou - Targhee National Forest



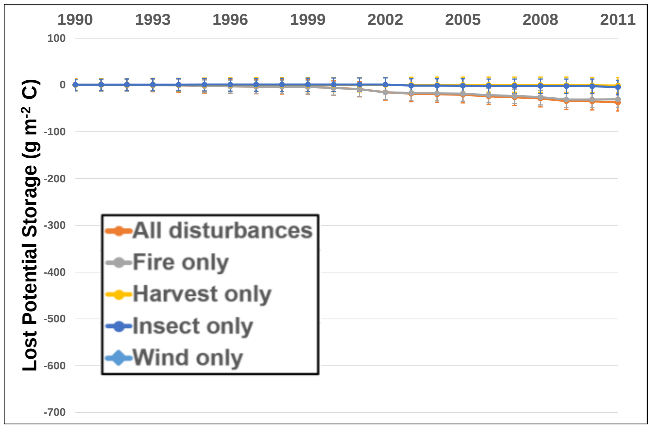
2e) Dixie National Forest



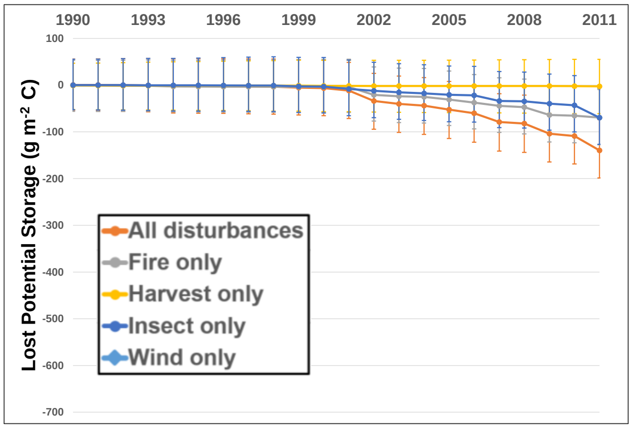
2f) Fishlake National Forest



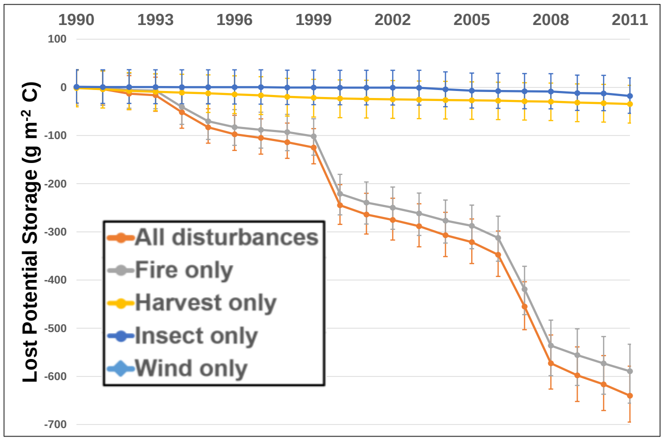
2g) Humboldt - Toiyabe National Forest



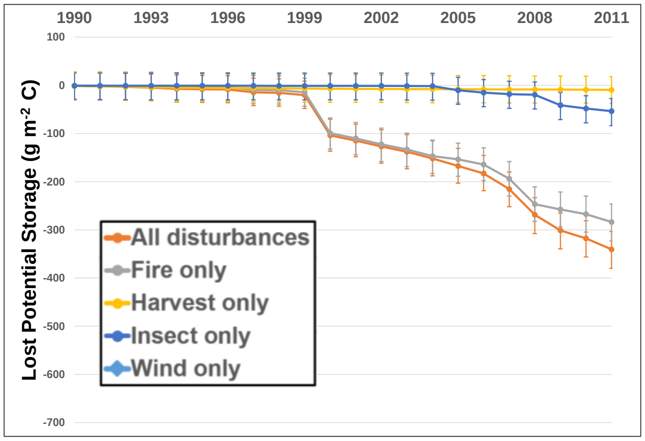
2h) Manti-La Sal National Forest

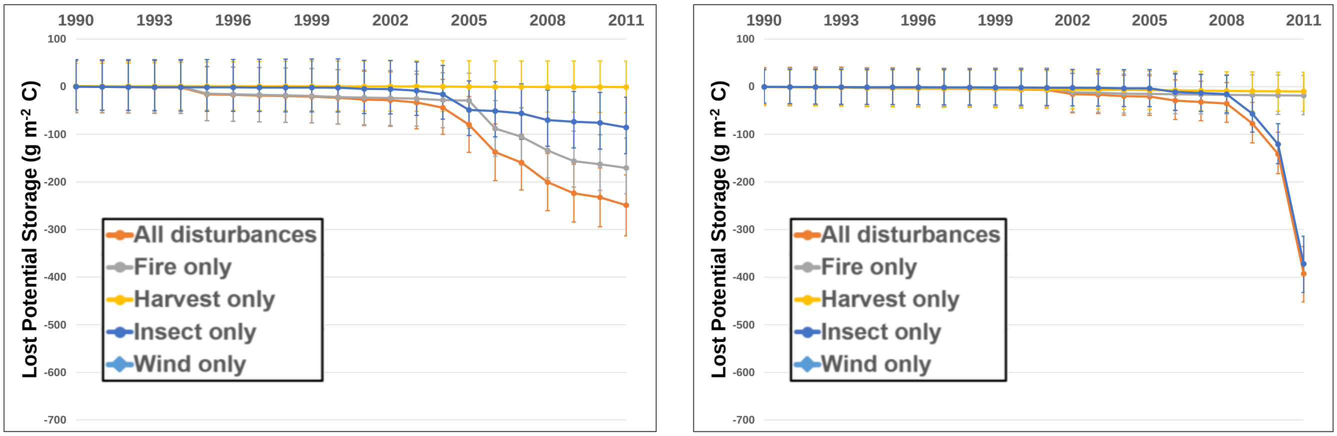


2i) Payette National Forest



2j) Salmon - Challis National Forest

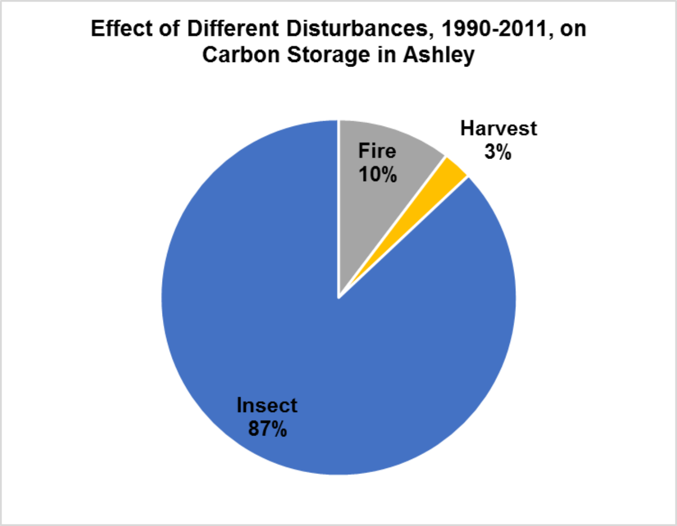


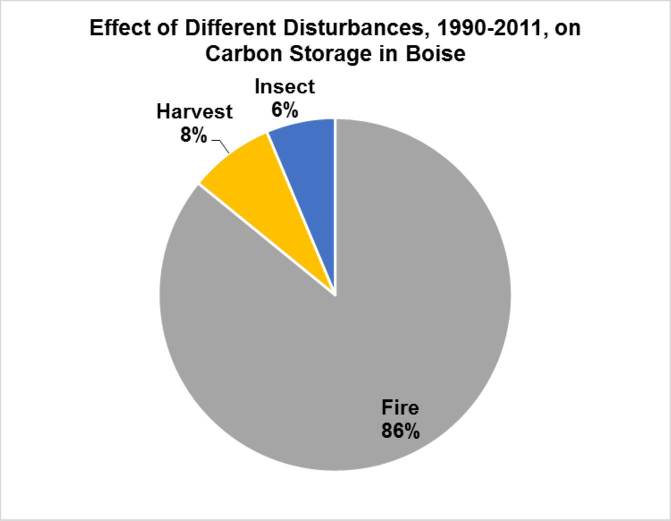


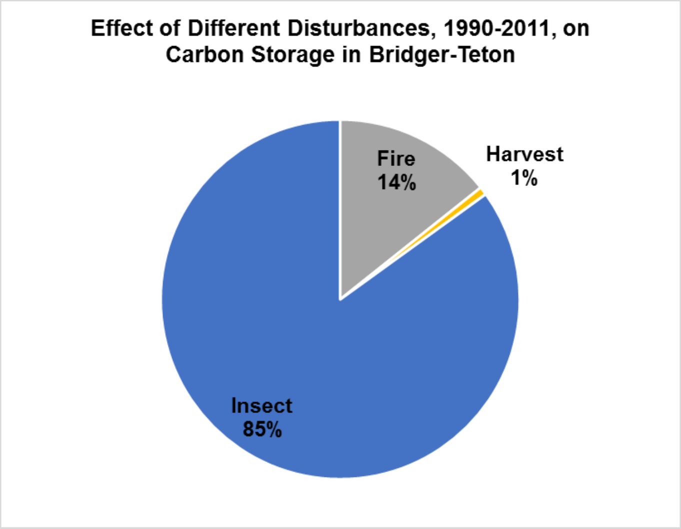
2k) Sawtooth National Forest

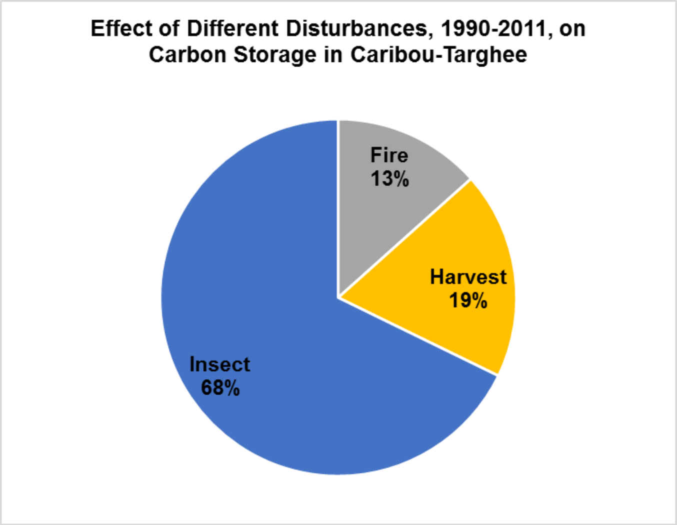
2l) Uinta-Wasatch-Cache National Forest

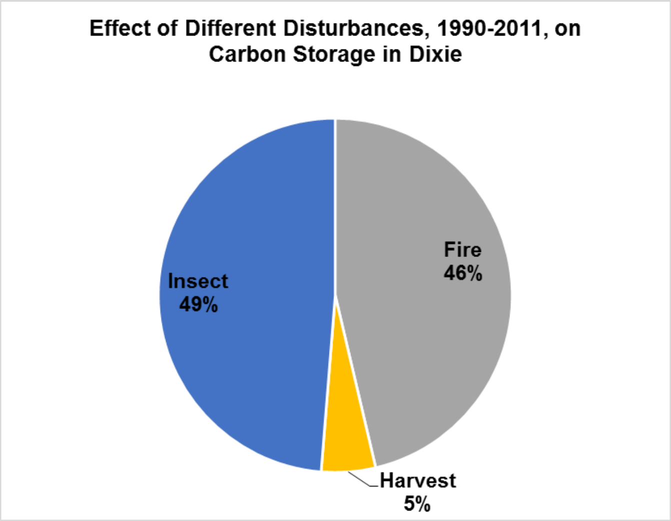
Figure 2.1 The impact of different kinds of disturbance, occurring from 1990 through 2011, on carbon (C) stores in the Intermountain Region. The difference in storage for each year is shown between an “undisturbed” scenario and a scenario that includes only observed amounts of the specified type of disturbance.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

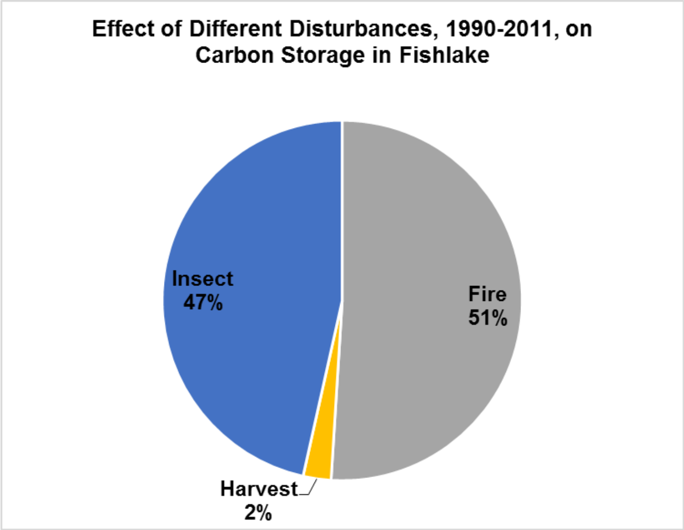

Effect of Different Disturbances, 1990-2011, on Carbon Storage in Ashley
Fire 10%
Harvest 3%
Insect 87%

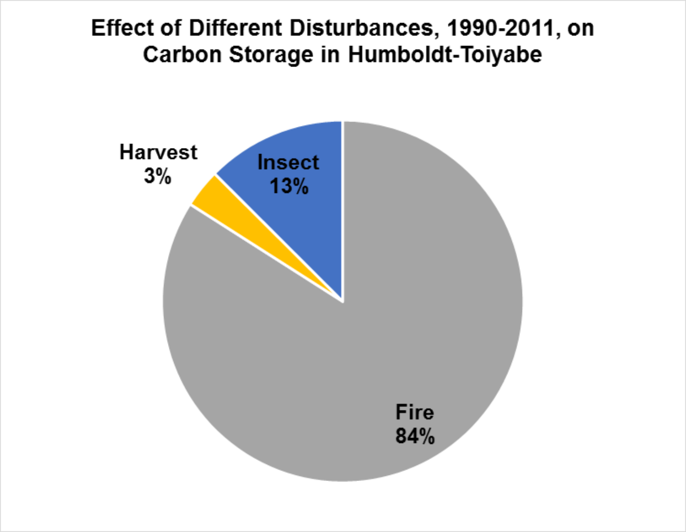

Effect of Different Disturbances, 1990-2011, on Carbon Storage in Boise
Insect 6%
Harvest 8%
Fire 86%

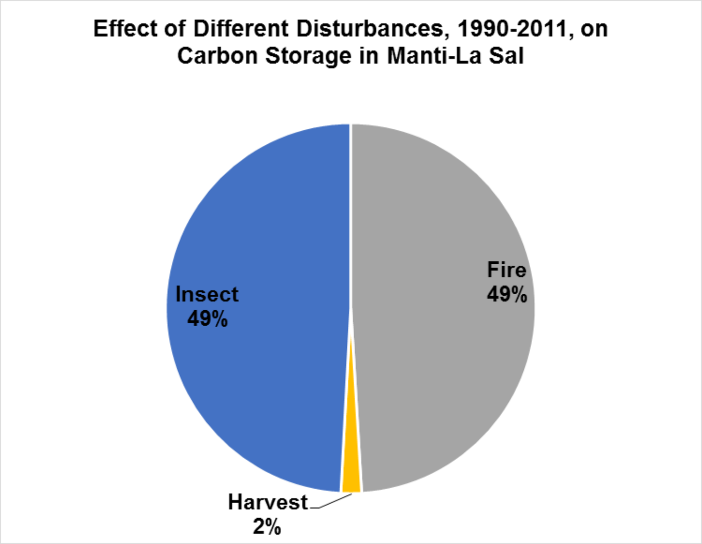

Effect of Different Disturbances, 1990-2011, on Carbon Storage in Bridger-Teton
Fire 14%
Harvest 1%
Insect 85%

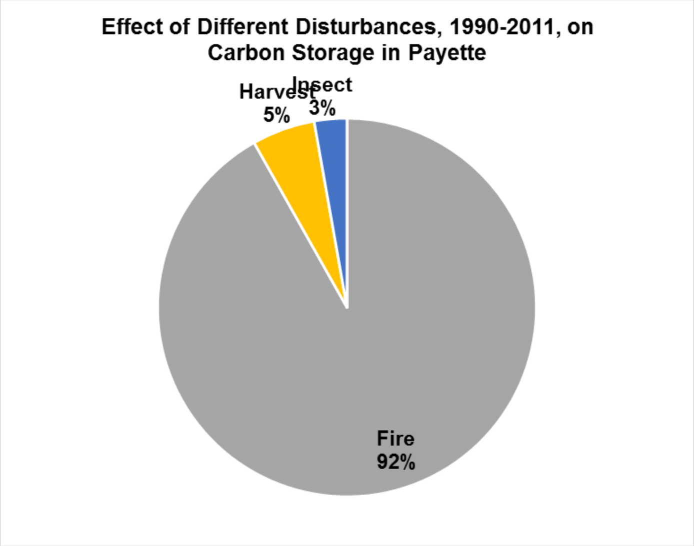

Effect of Different Disturbances, 1990-2011, on Carbon Storage in Caribou-Targhee

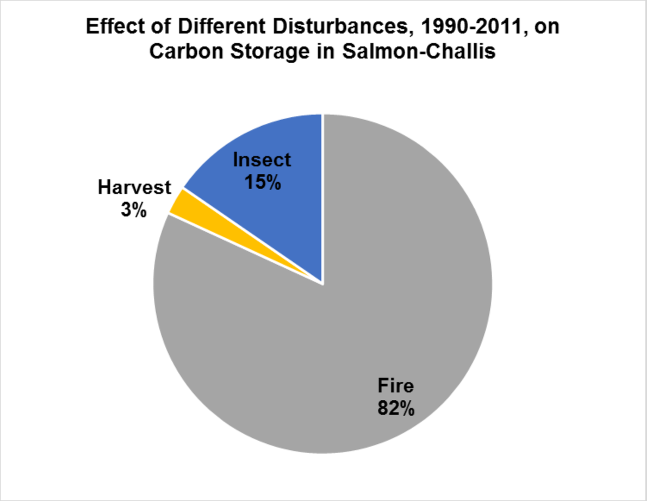

Effect of Different Disturbances, 1990-2011, on Carbon Storage in Dixie

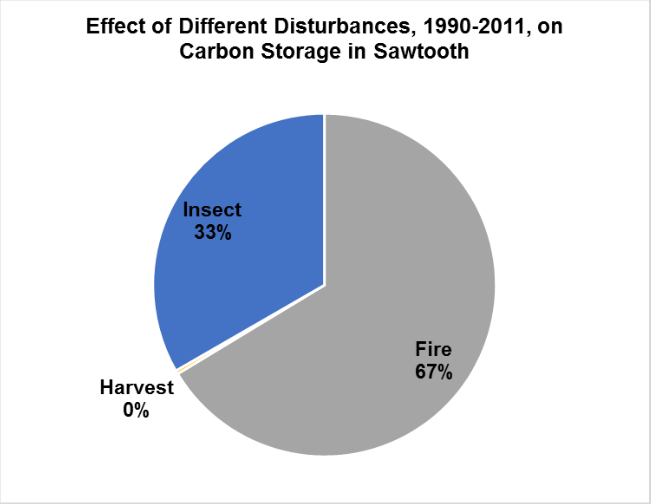

Effect of Different Disturbances, 1990-2011, on Carbon Storage in Fishlake


Effect of Different Disturbances, 1990-2011, on Carbon Storage in Humboldt-Toiyabe
Harvest 3%
Insect 13%
Fire 84%


Effect of Different Disturbances, 1990-2011, on Carbon Storage in Manti-La Sal
Fire 49%
Insect 49%
Harvest 2%


Effect of Different Disturbances, 1990-2011, on Carbon Storage in Payette
Harvest 5%
Insect 3%
Fire 92%





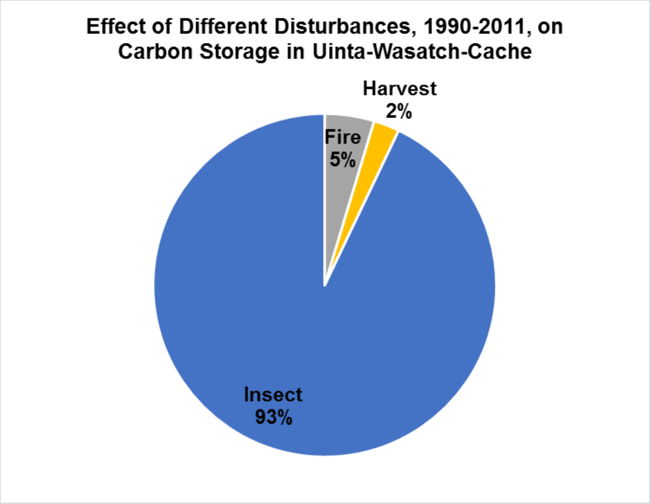


Figure 2.2. Proportional effect of different kinds of disturbance on carbon storage in each national forest in the Intermountain Region for the period 1990 through 2011.

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 6.5 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.

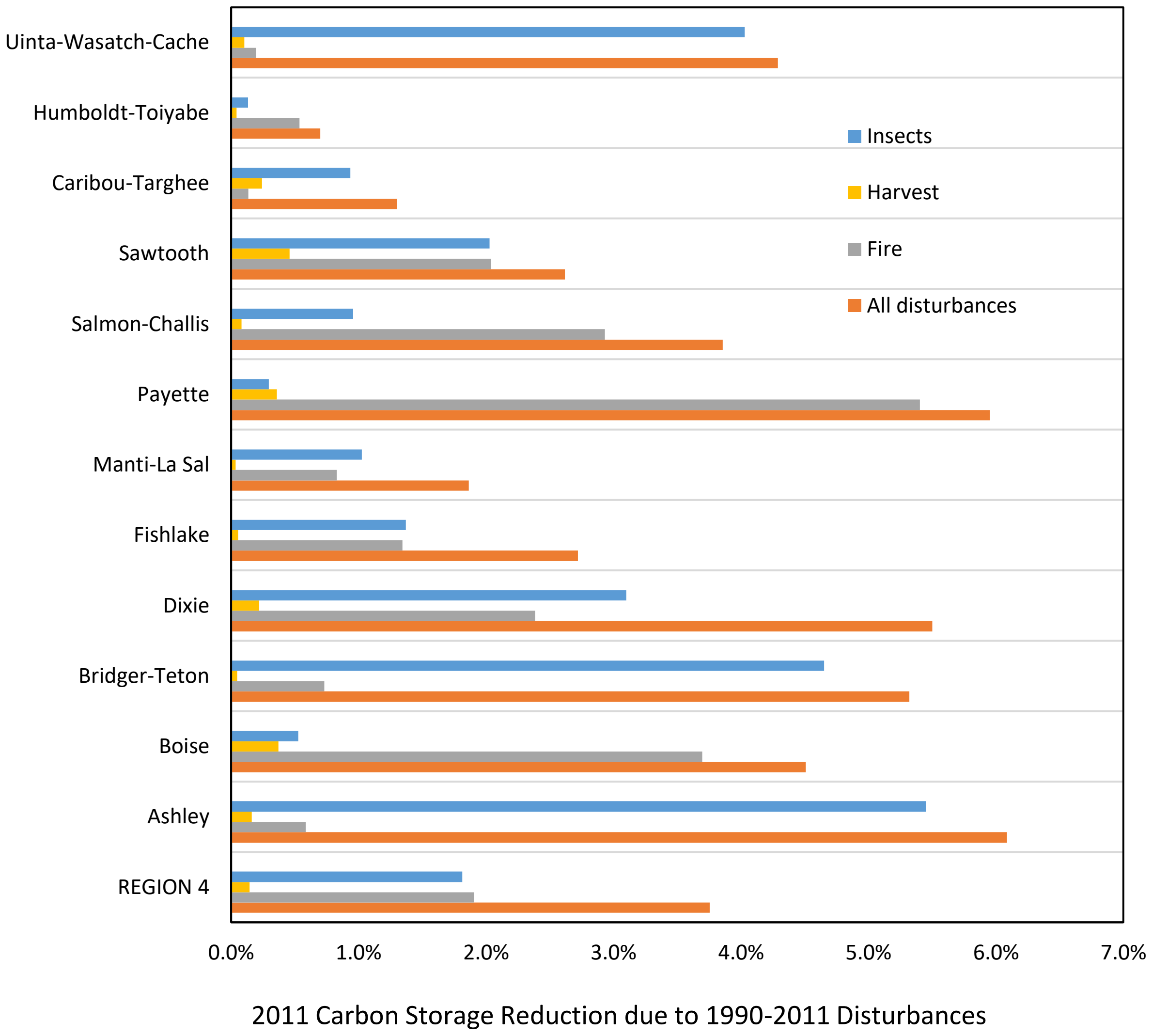


Figure 3.1. Carbon stock reduction in 2011 due to disturbances occurring from 1990 through 2011, by each national forest and for all national forests combined in the Intermountain Region. Percent reduction represents how much nonsoil carbon was lost from the baseline forest inventory carbon stock estimates.

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

The set of figures for each of 12 National Forests units in the Intermountain 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 6.5 of the main report which provides explanation of the regional InTEC results.

Ashley National Forest

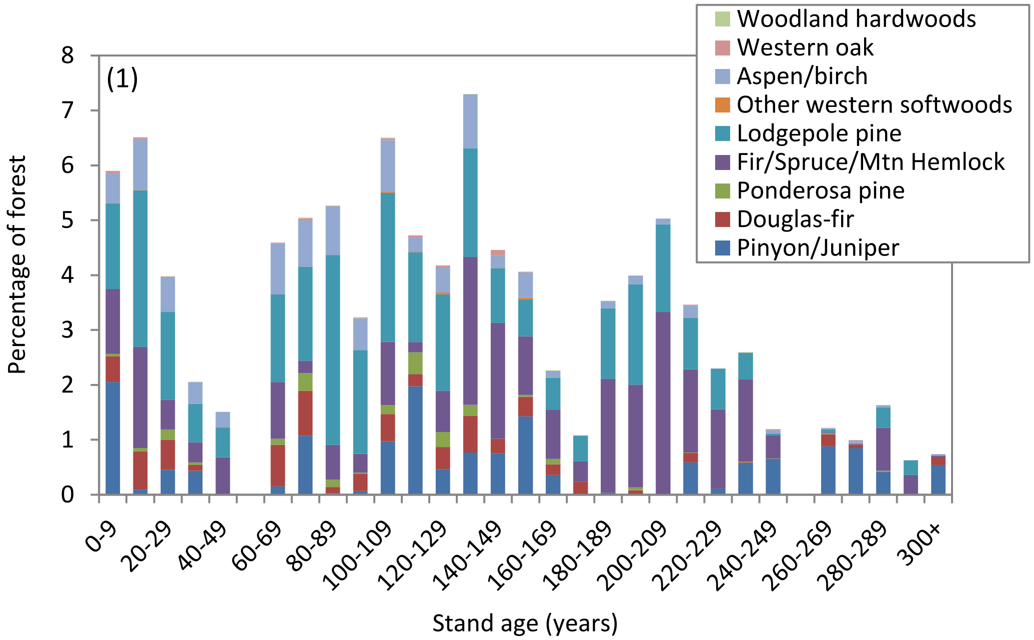


Figure 4.1. Age class distribution in 2011 in the Ashley National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

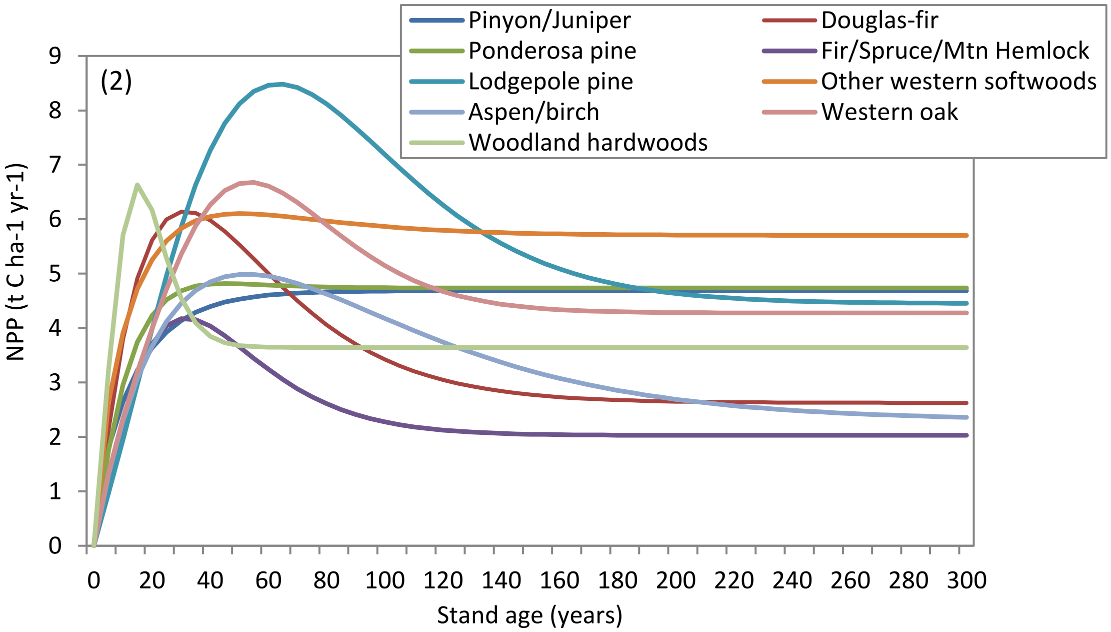


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Ashley National Forest.

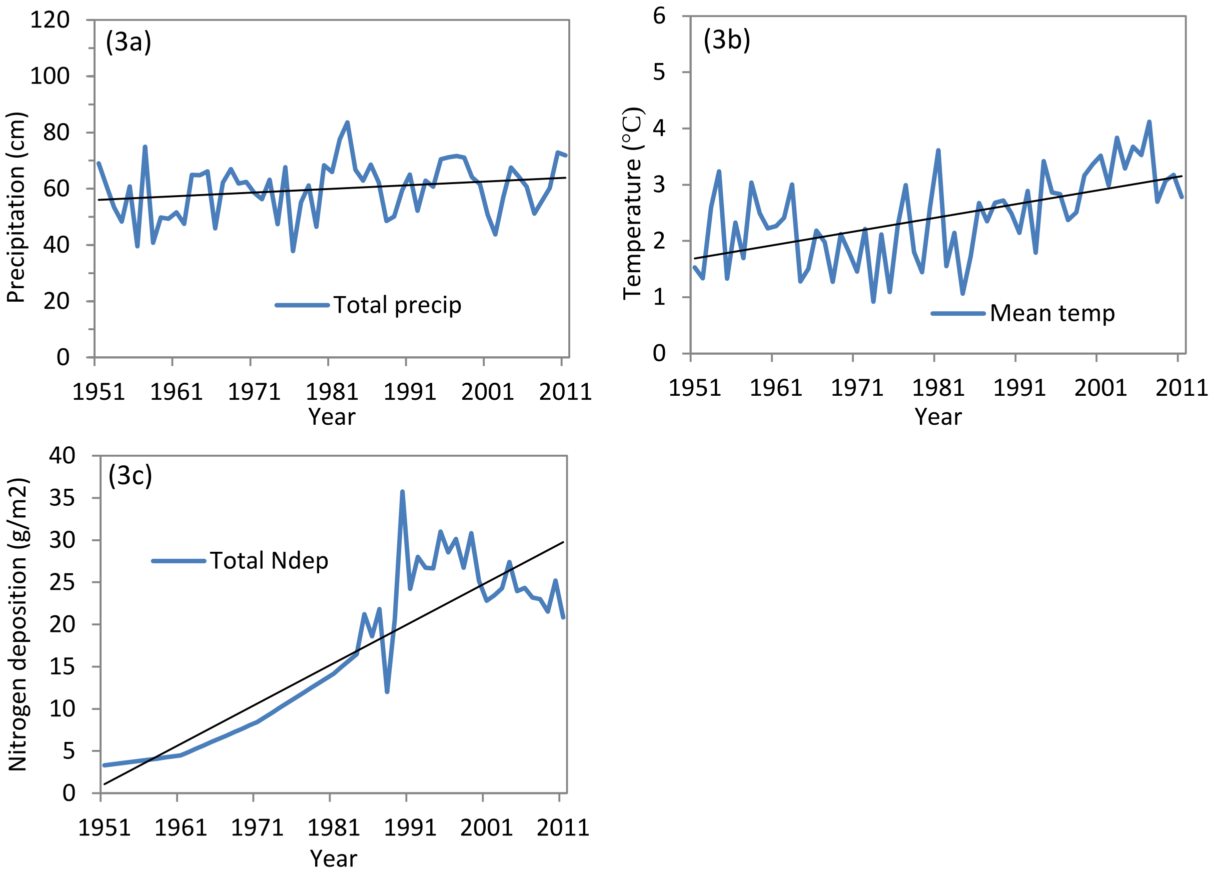


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Ashley National Forest. Linear trend lines shown in black.

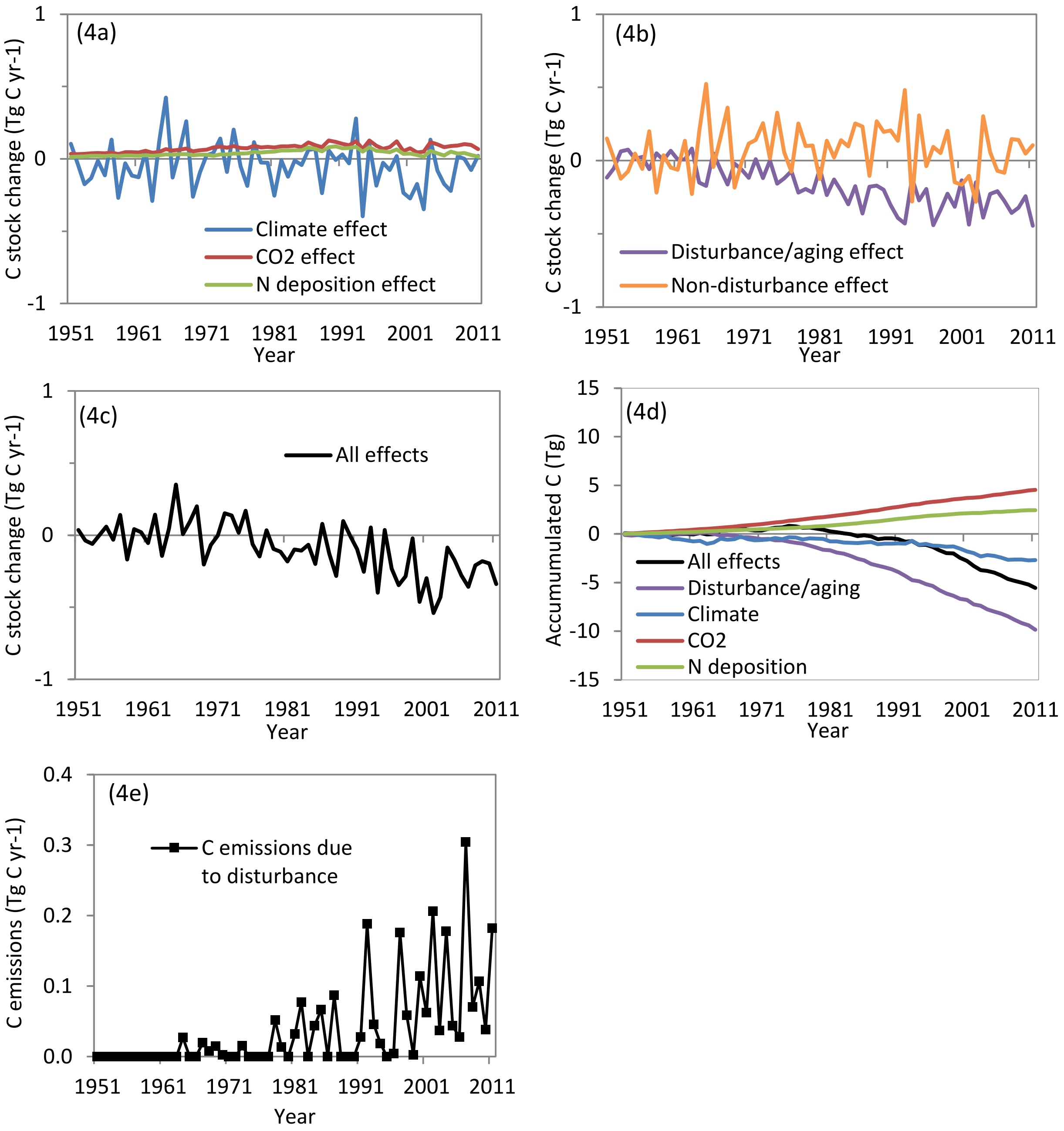


Figure 4.4. Changes in carbon stocks in the Ashley National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and aging 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.

Boise National Forest

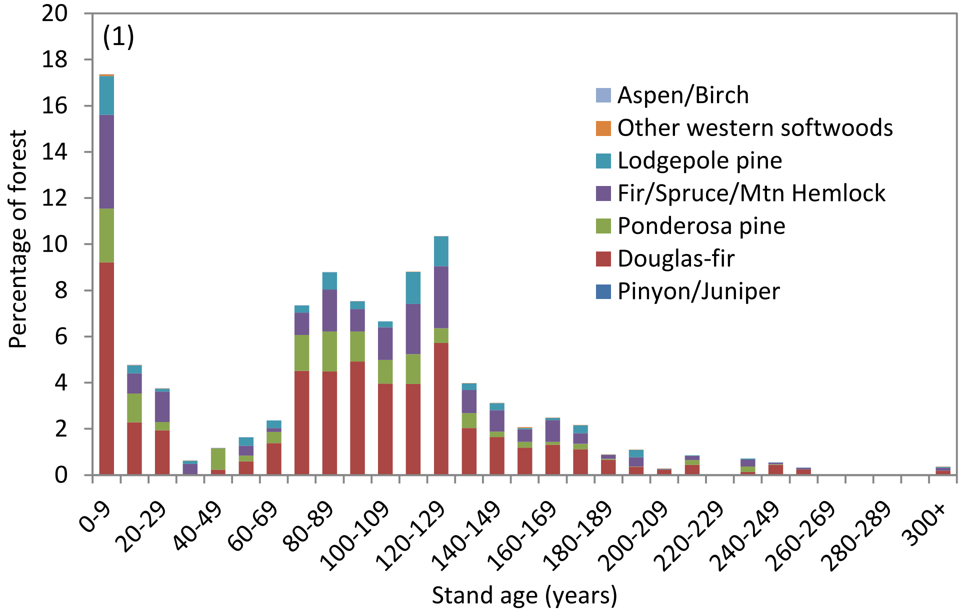


Figure 4.1. Age class distribution in 2011 in the Boise National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

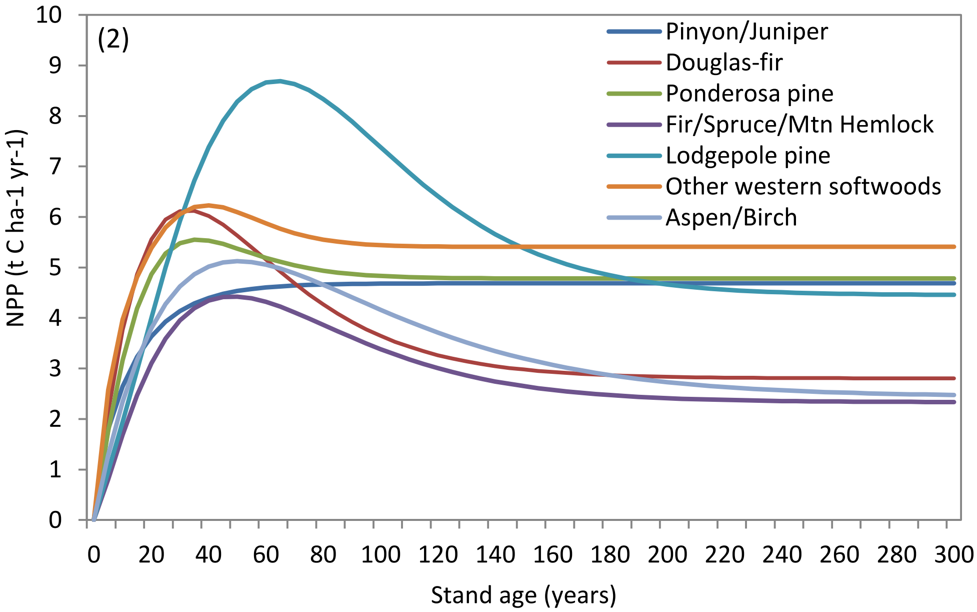


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Boise National Forest.

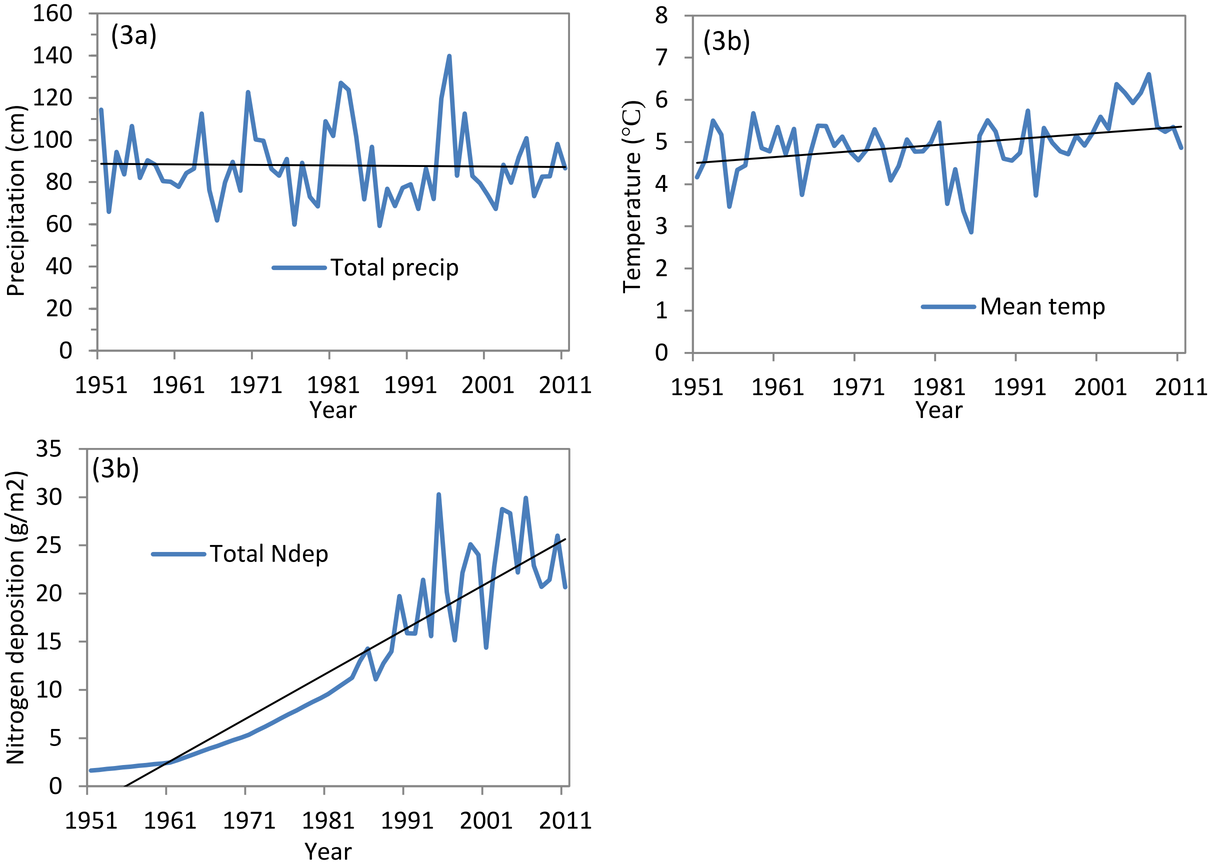


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Boise National Forest. Linear trend lines shown in black.

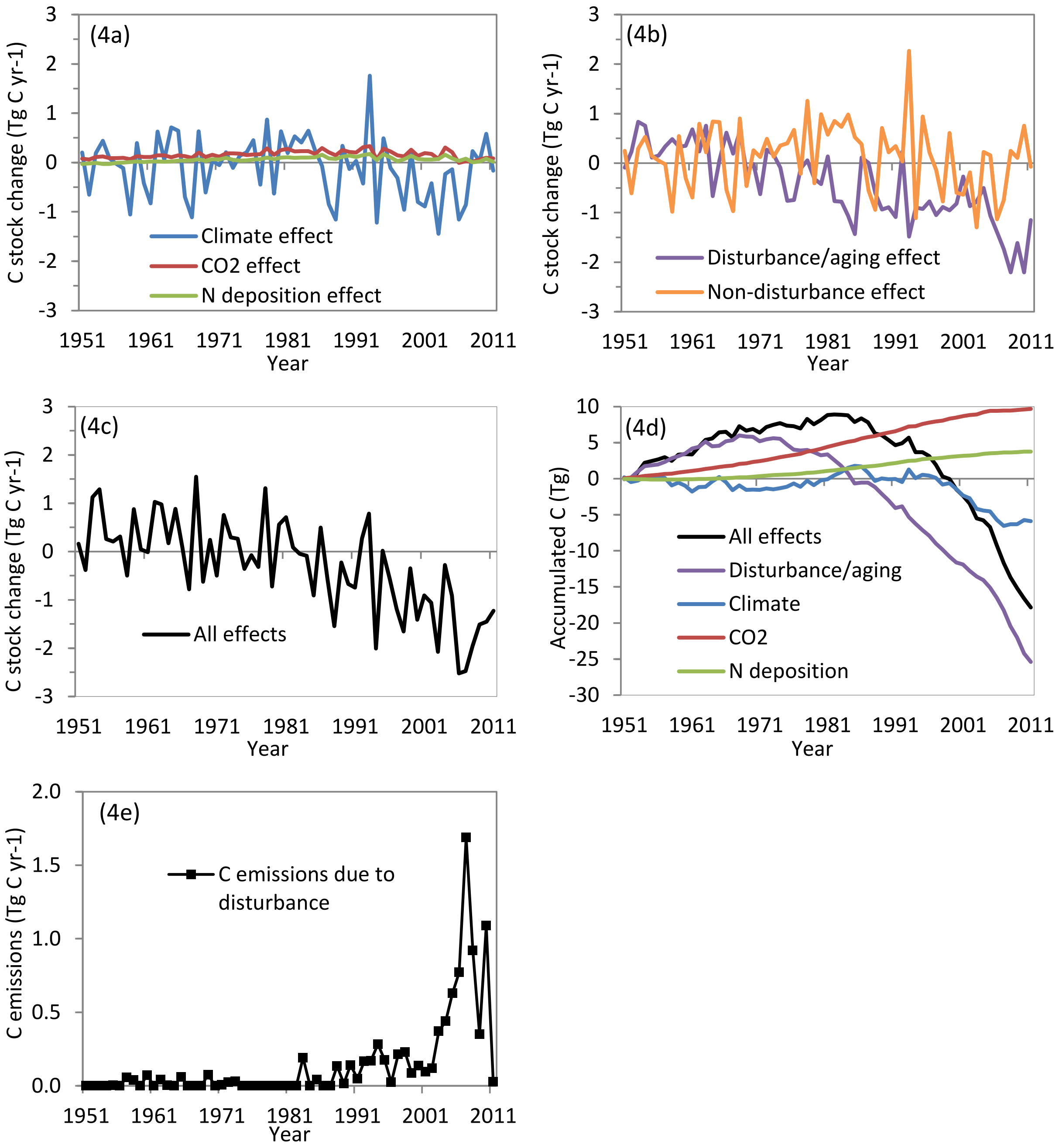


Figure 4.4. Changes in carbon stocks in the Boise National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and aging 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.

Bridger-Teton National Forest

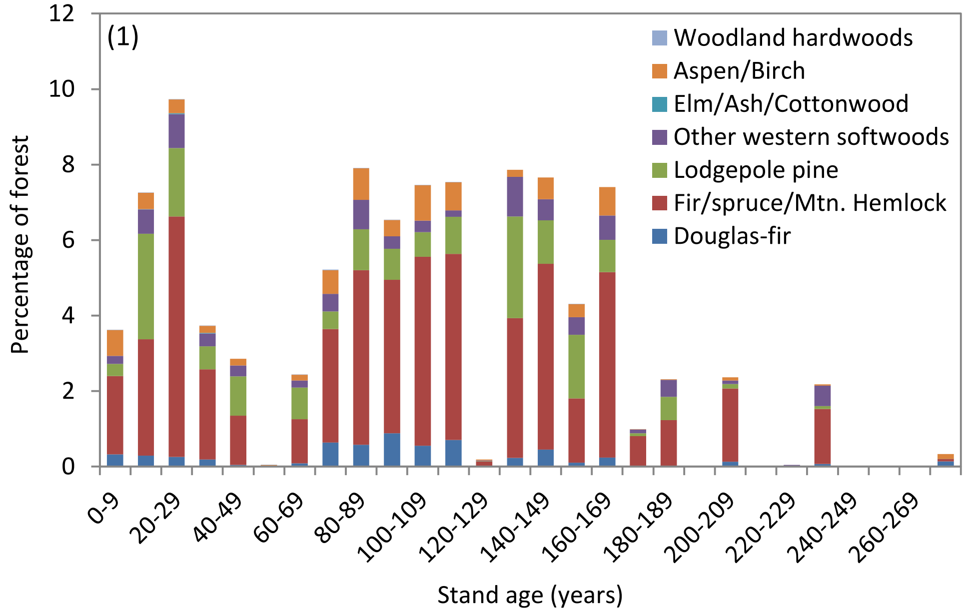


Figure 4.1. Age class distribution in 2011 in the Bridger-Teton National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

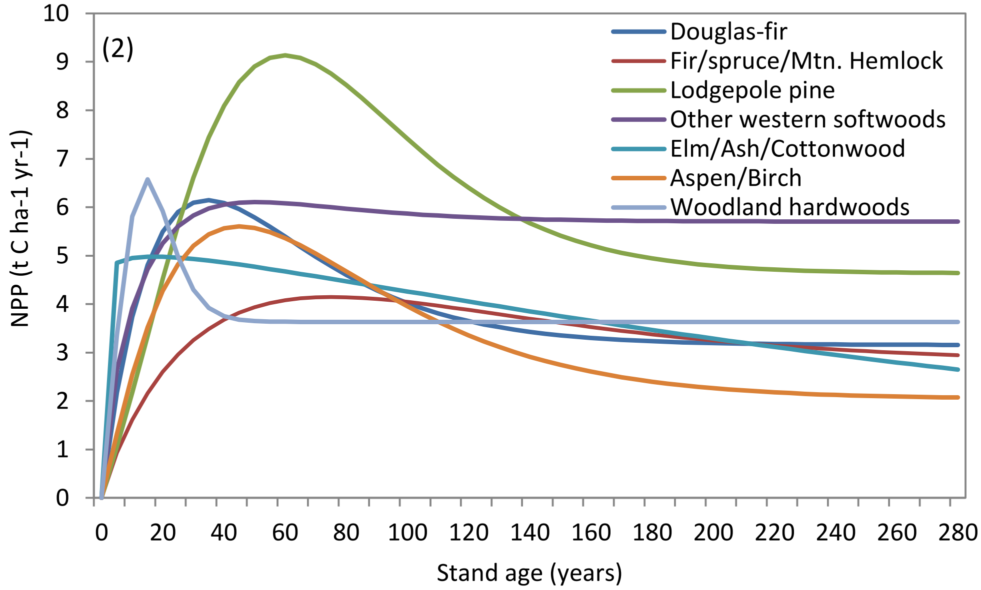


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Bridger-Teton National Forest.

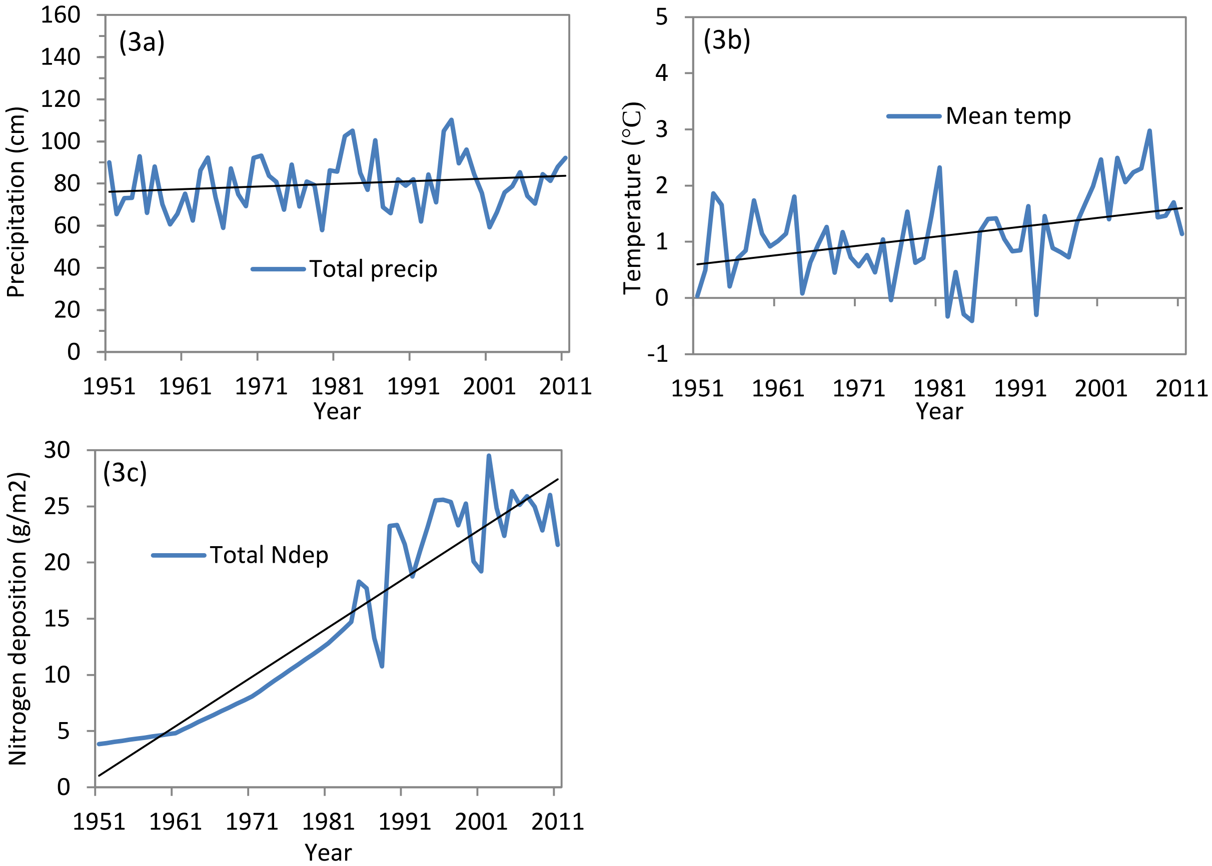


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Bridger-Teton National Forest. Linear trend lines shown in black.

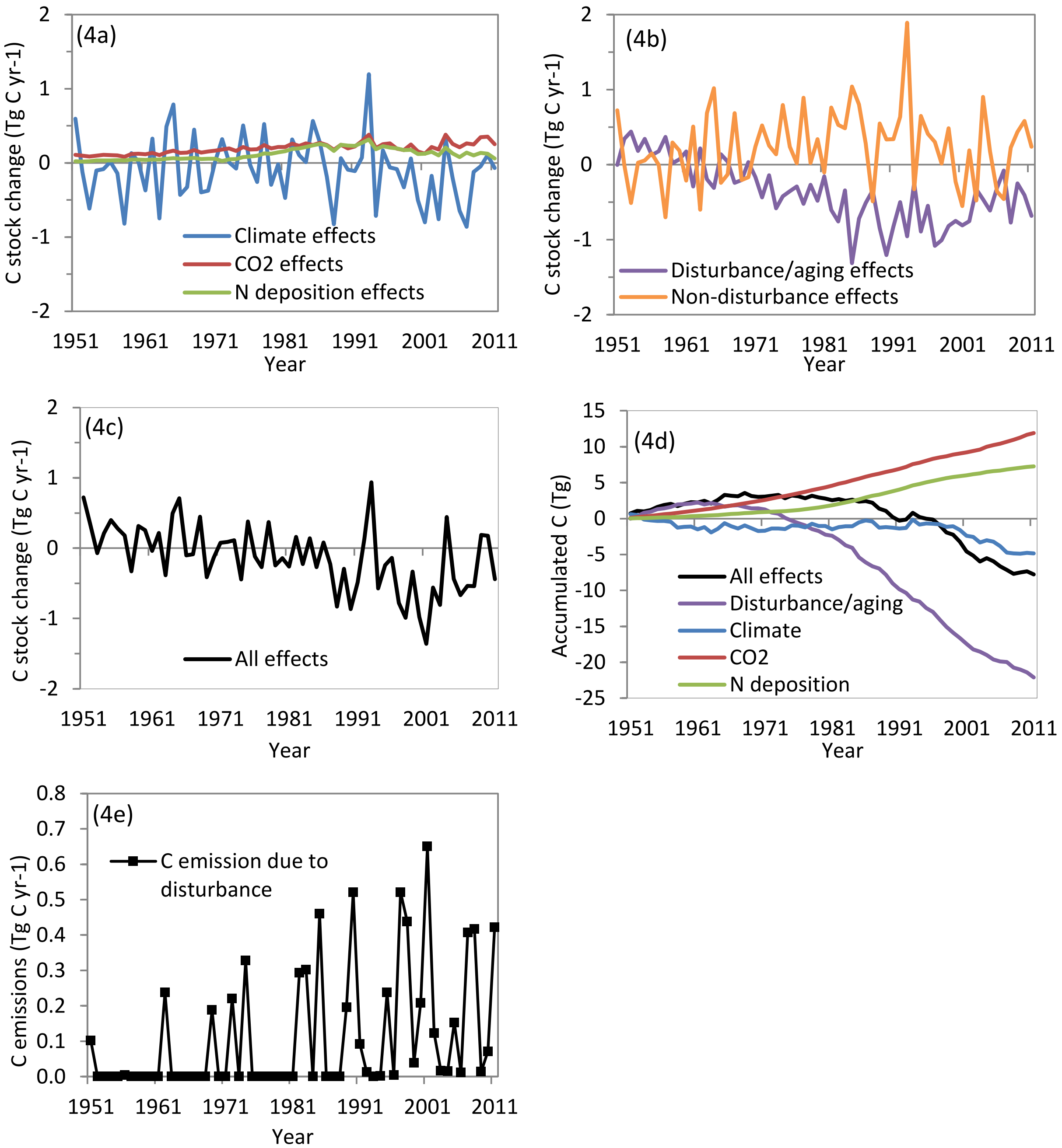


Figure 4.4. Changes in carbon stocks in the Bridger-Teton National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and 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.

Caribou-Targhee National Forest

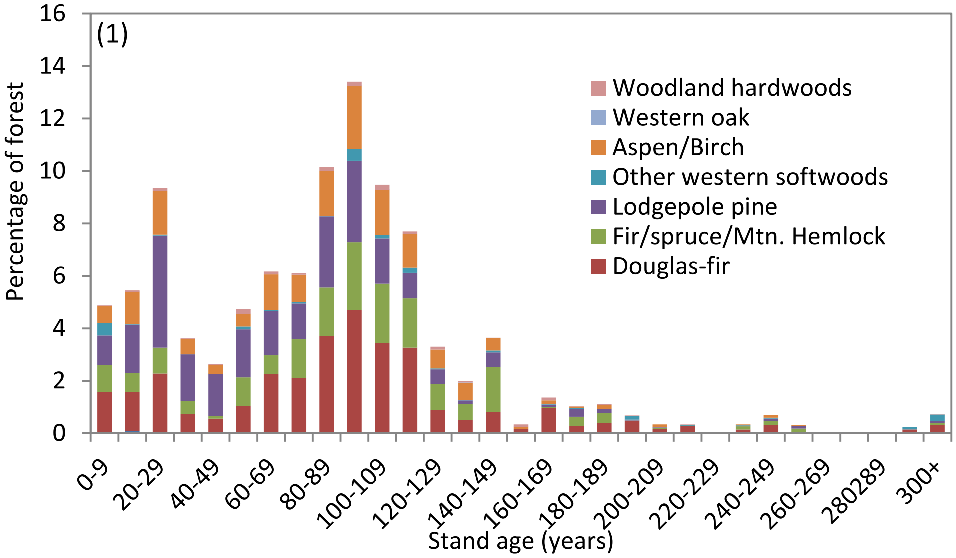


Figure 4.1. Age class distribution in 2011 in the Caribou-Targhee National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

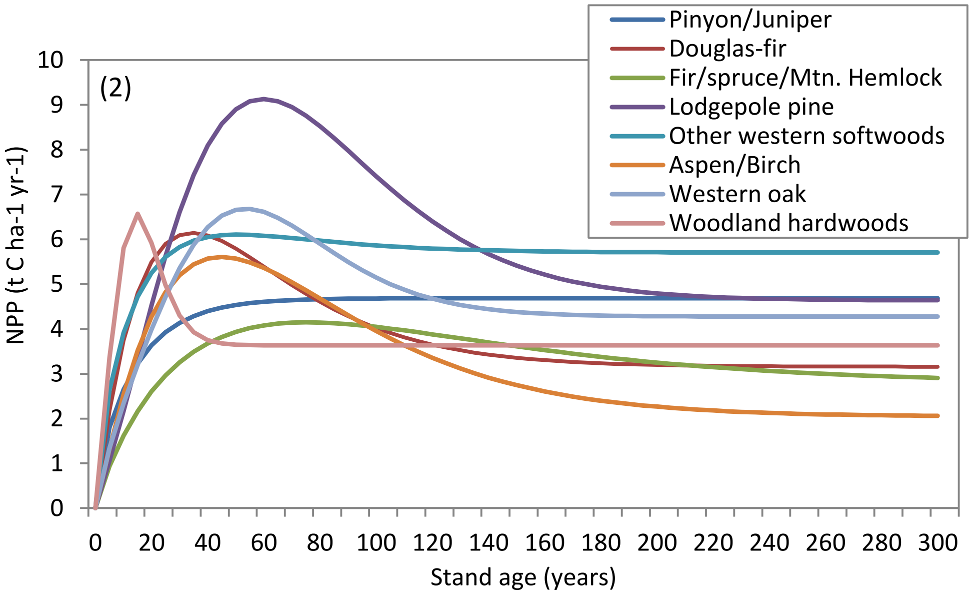


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Caribou-Targhee National Forest.

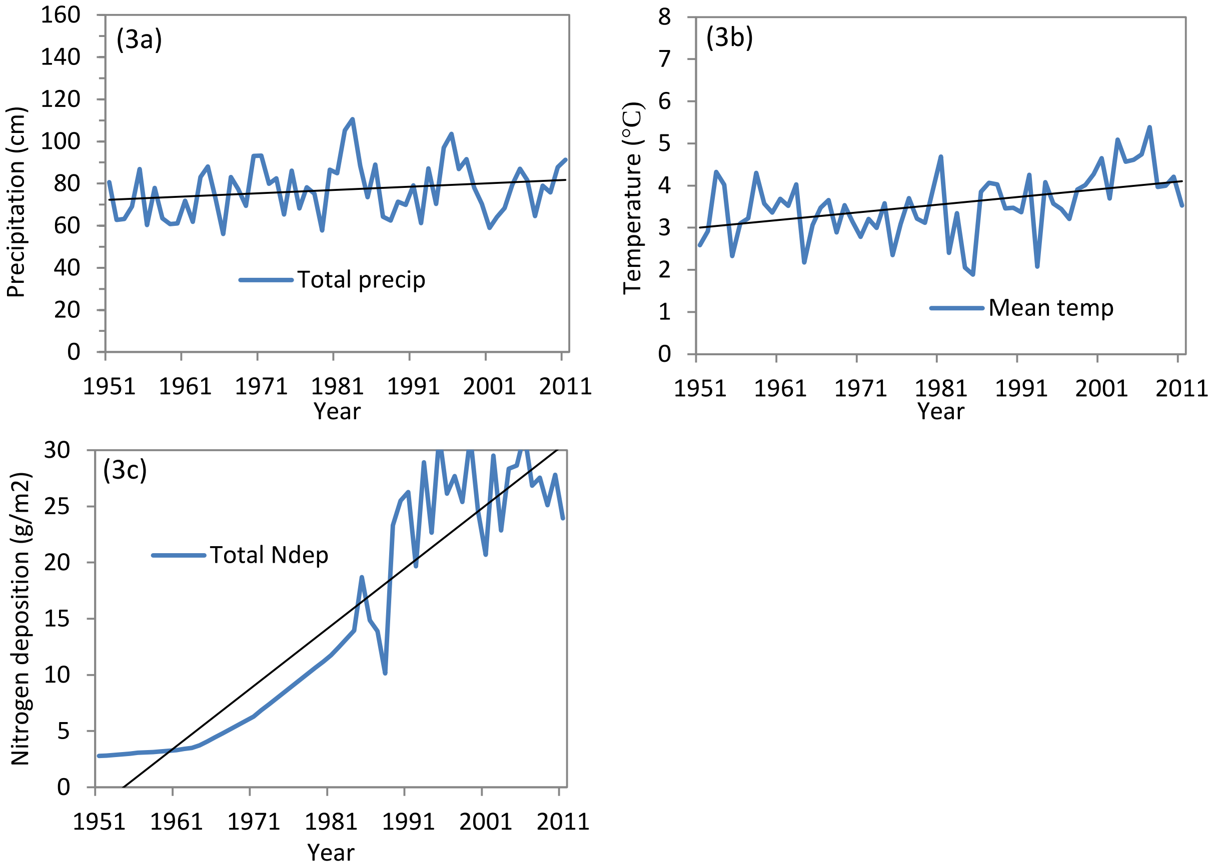


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Caribou-Targhee National Forest. Linear trend lines shown in black.

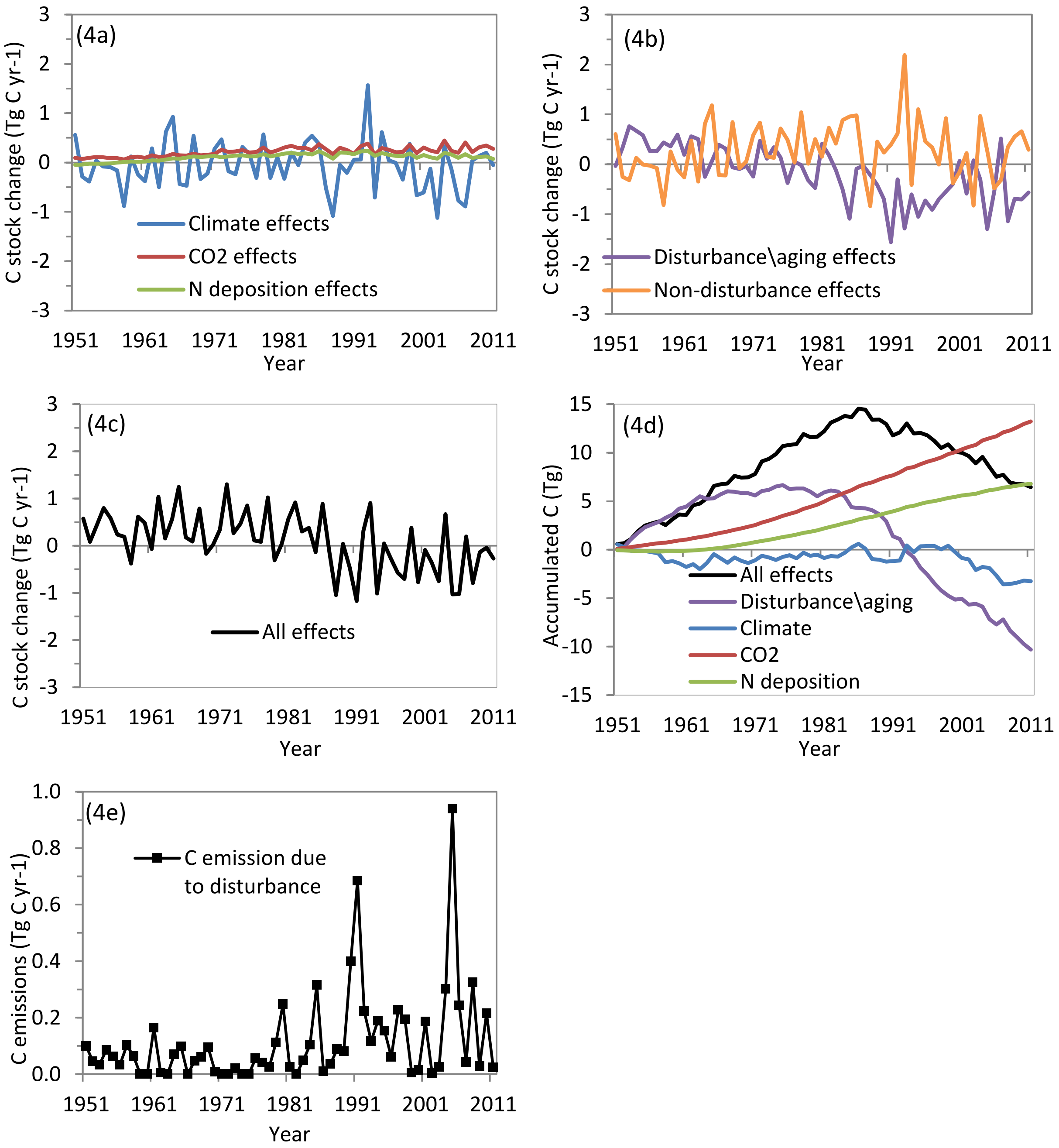


Figure 4.4. Changes in carbon stocks in the Caribou-Targhee National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth 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.

Dixie National Forest

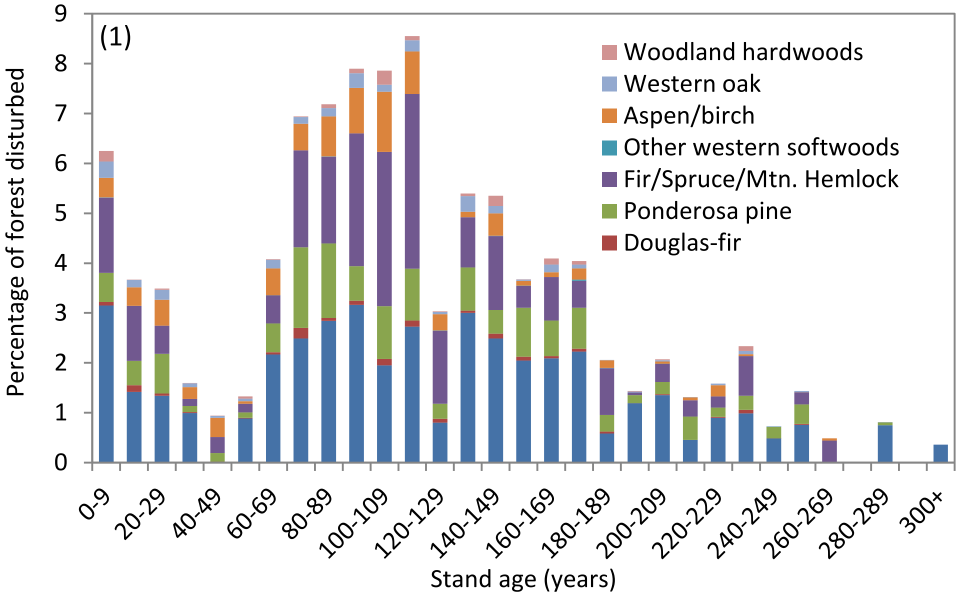


Figure 4.1. Age class distribution in 2011 in the Dixie National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

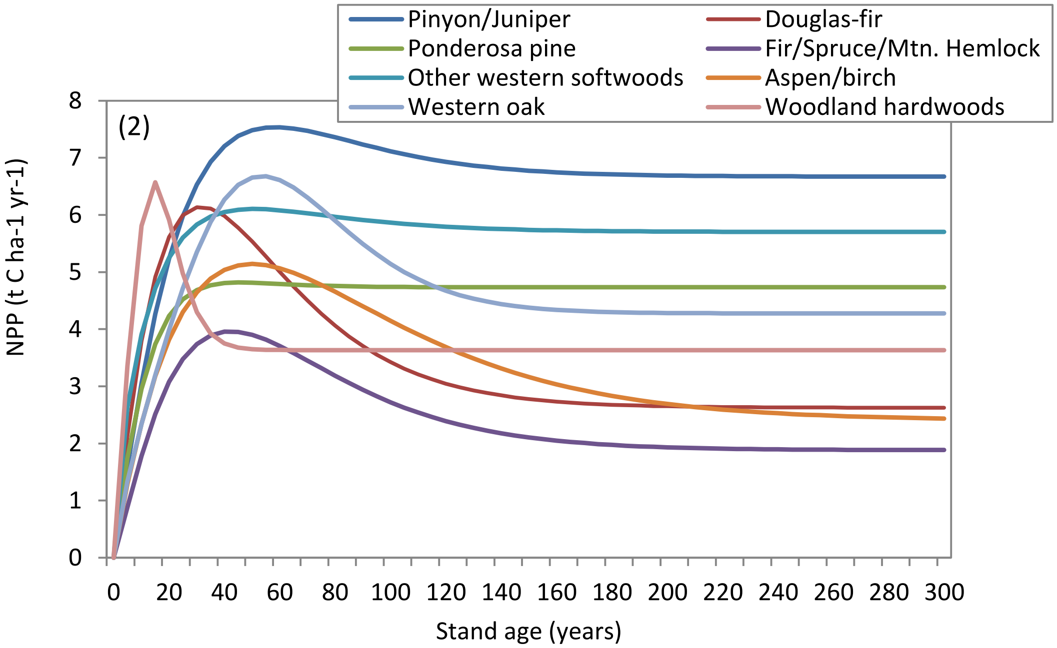


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Dixie National Forest.

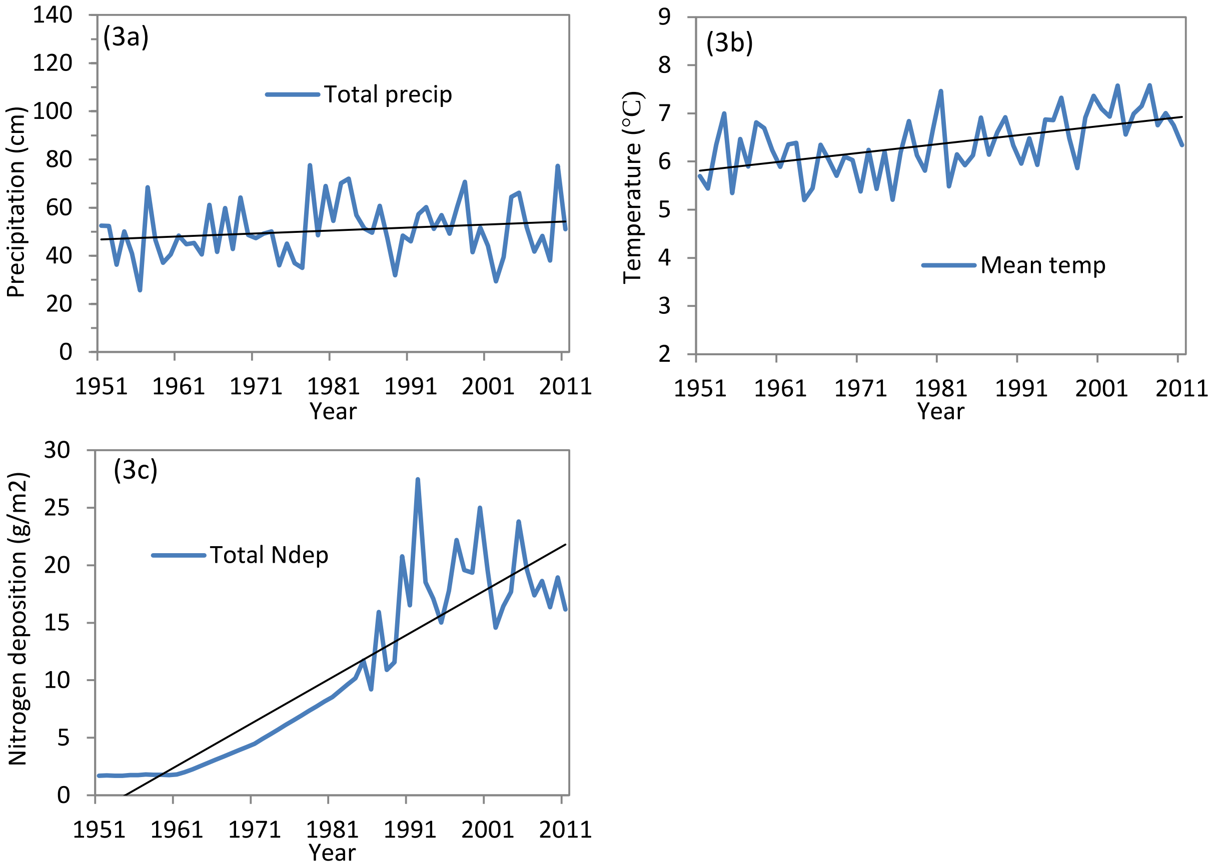


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Dixie National Forest. Linear trend lines shown in black.

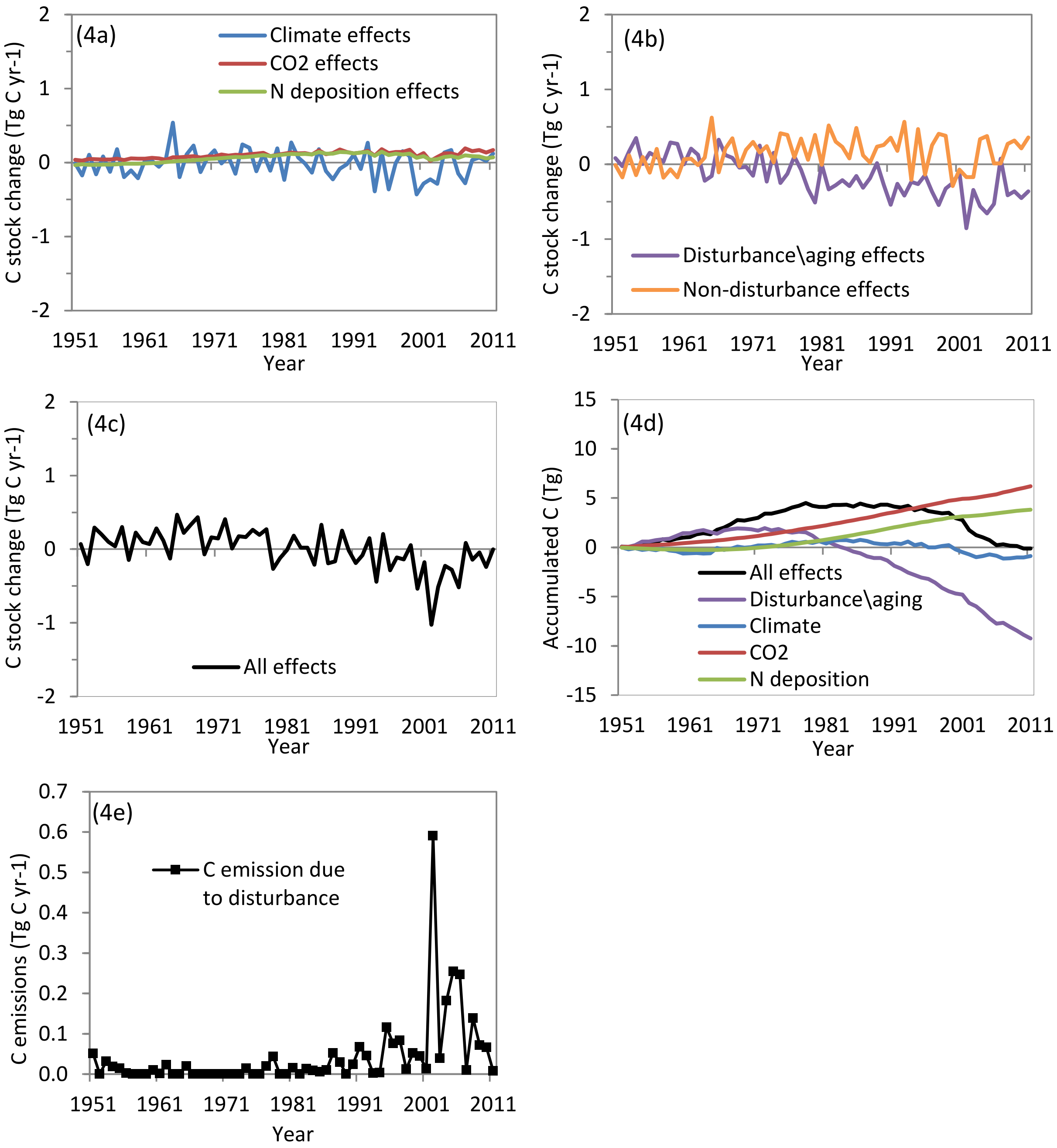


Figure 4.4. Changes in carbon stocks in the Dixie National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and aging 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.

Fishlake National Forest

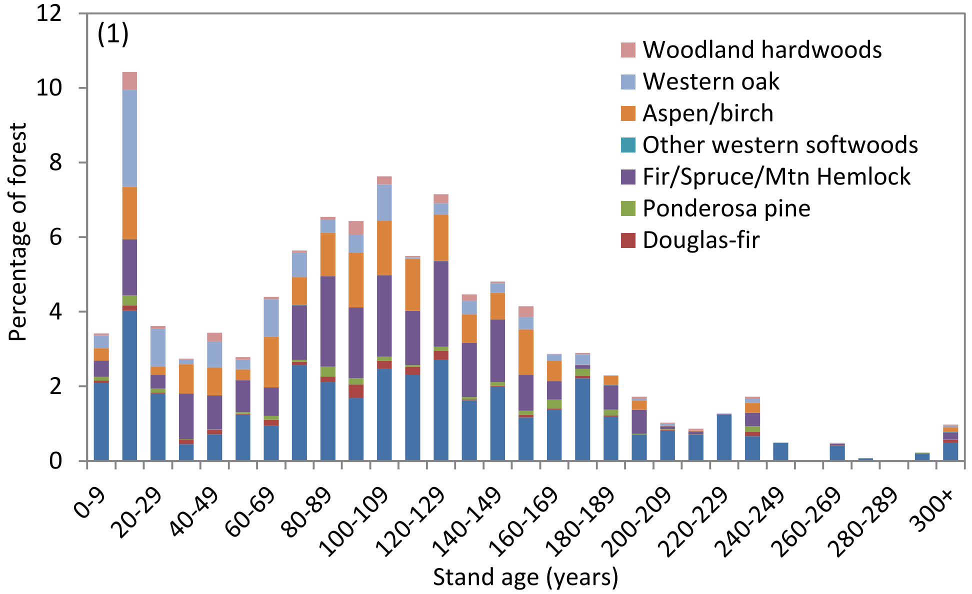


Figure 4.1. Age class distribution in 2011 in the Fishlake National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

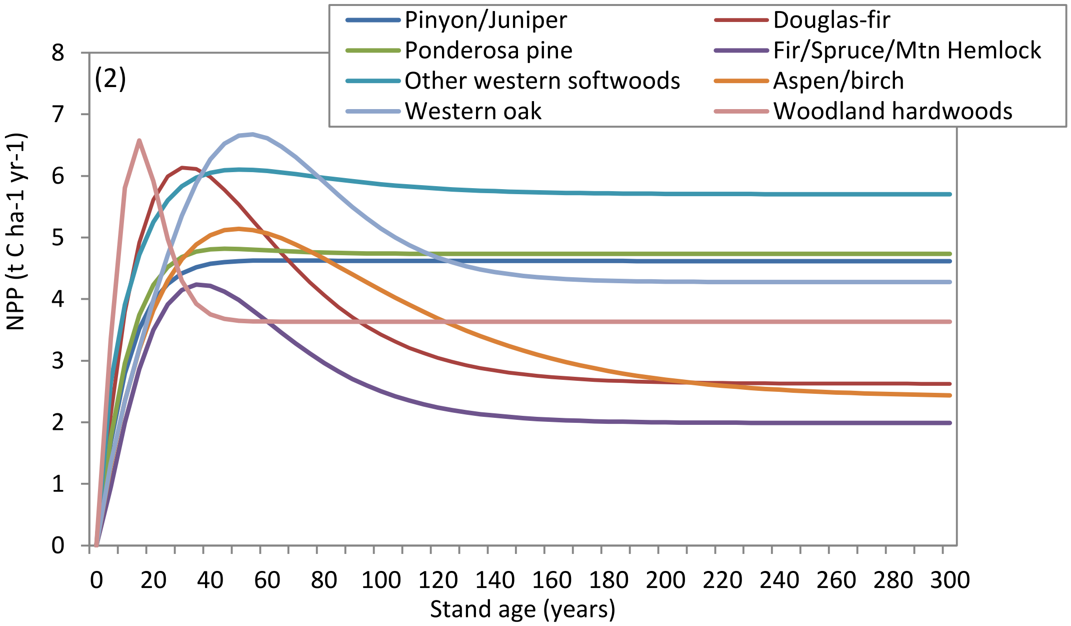


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Fishlake National Forest.

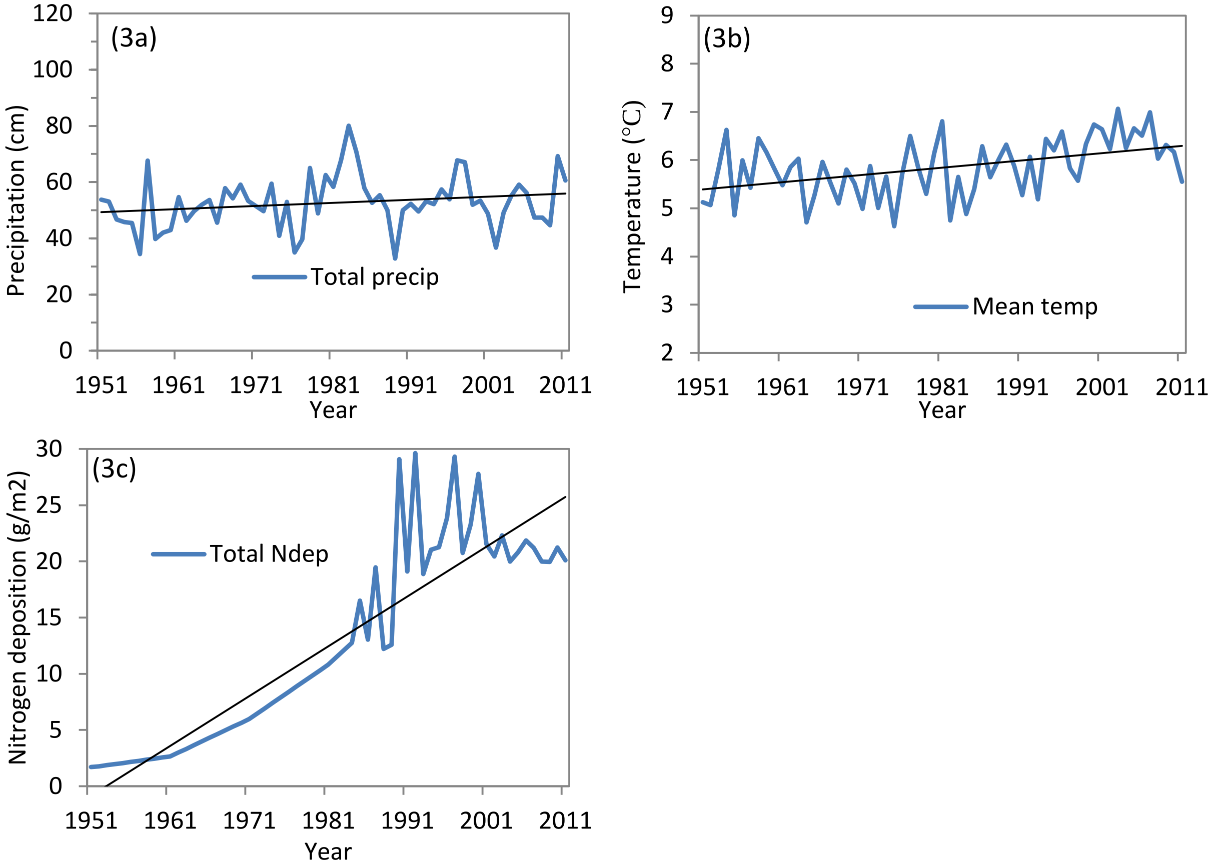


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Fishlake National Forest. Linear trend lines shown in black.

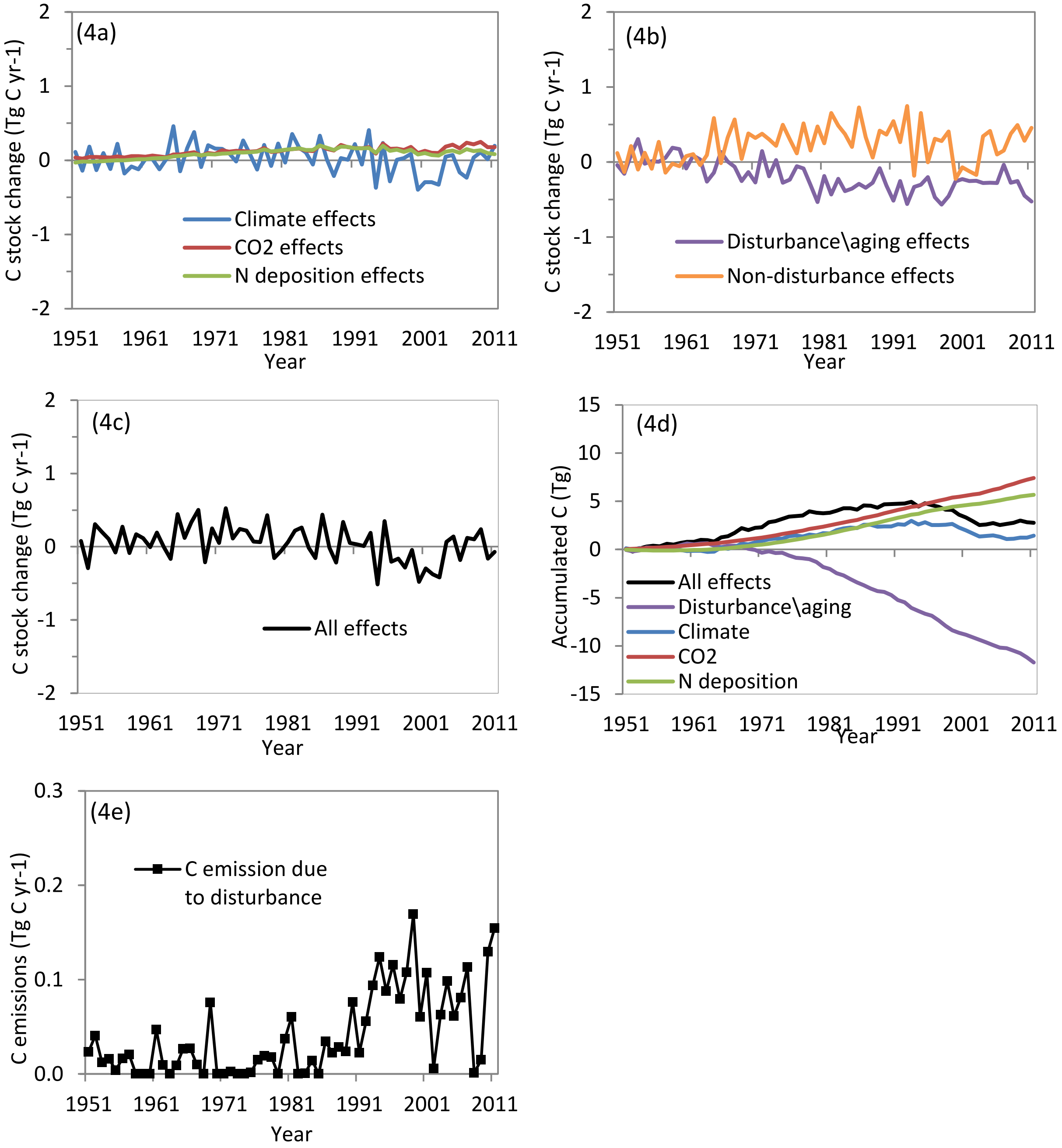


Figure 4.4. Changes in carbon stocks in the Fishlake National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and aging 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.

Humboldt-Toiyabe National Forest

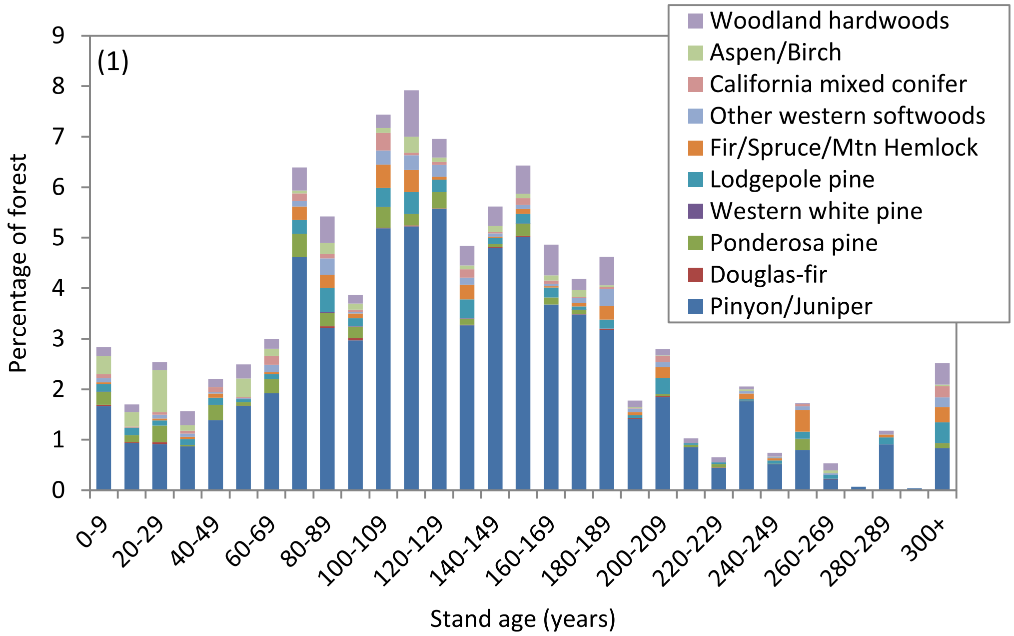


Figure 4.1. Age class distribution in 2011 in the Humboldt-Toiyabe National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

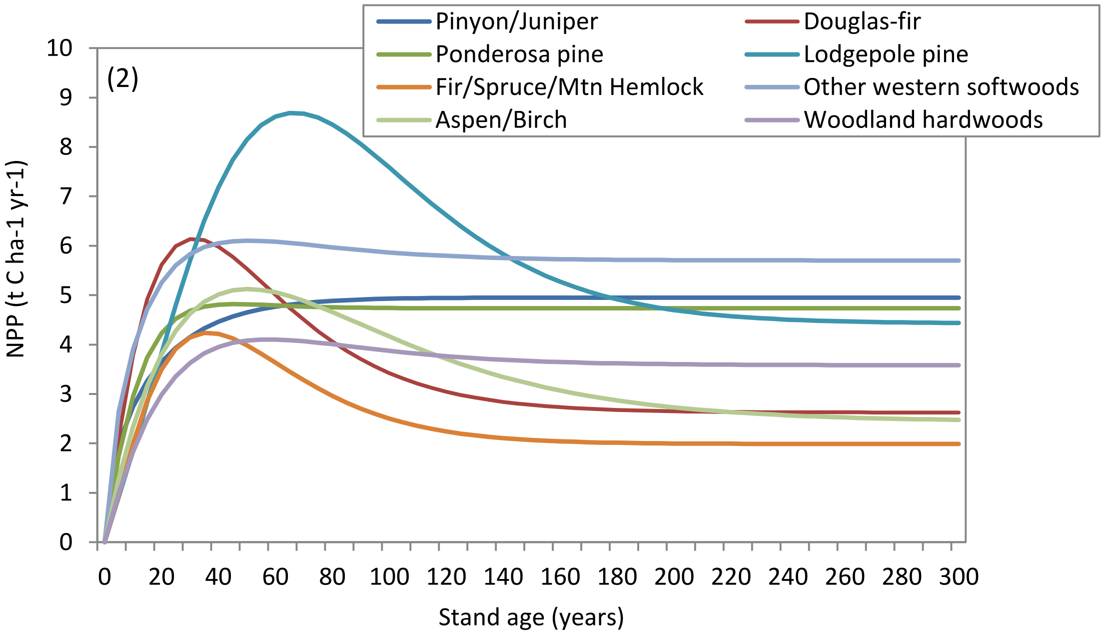


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Humboldt-Toiyabe National Forest. Due to small sample sizes, the Ponderosa pine curve was applied to the Western White pine and the Other Western Softwoods curve was used for the California mixed conifer forest type.

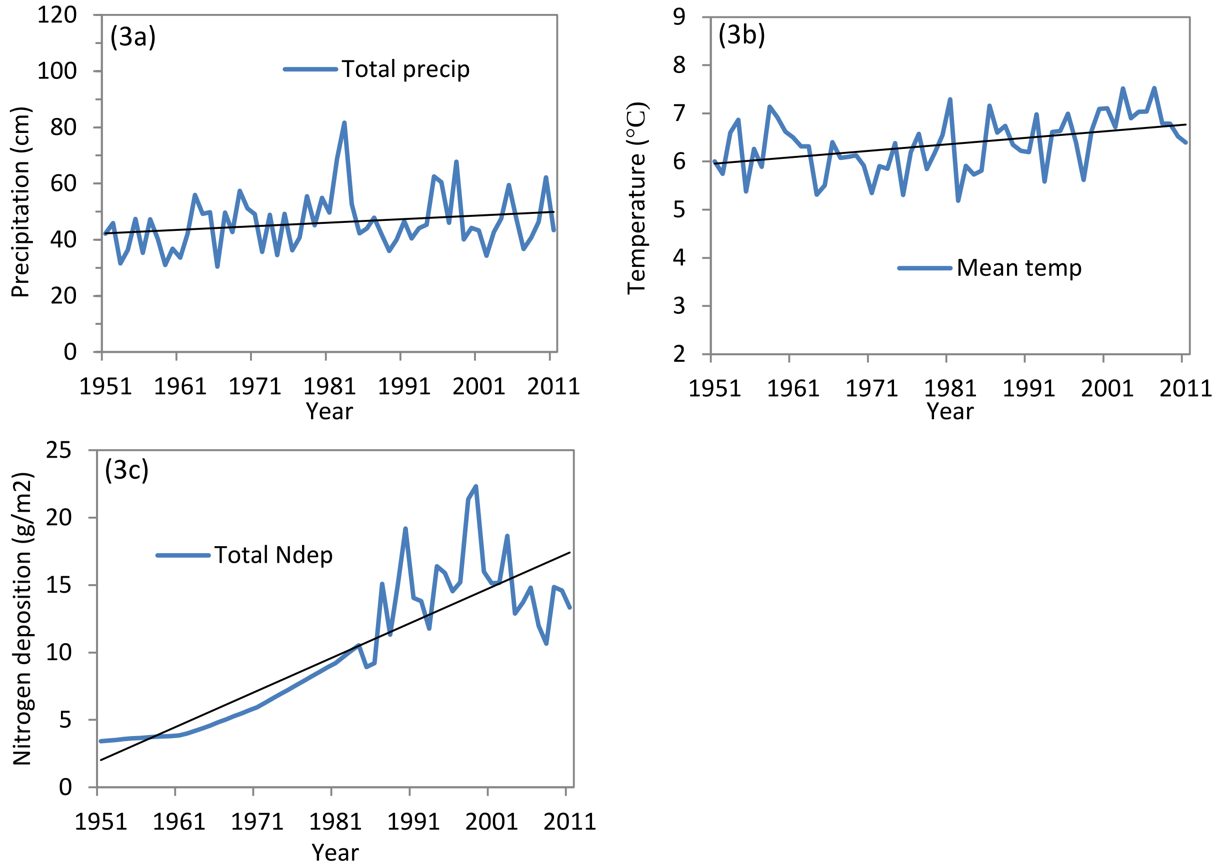


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Humboldt-Toiyabe National Forest. Linear trend lines shown in black.

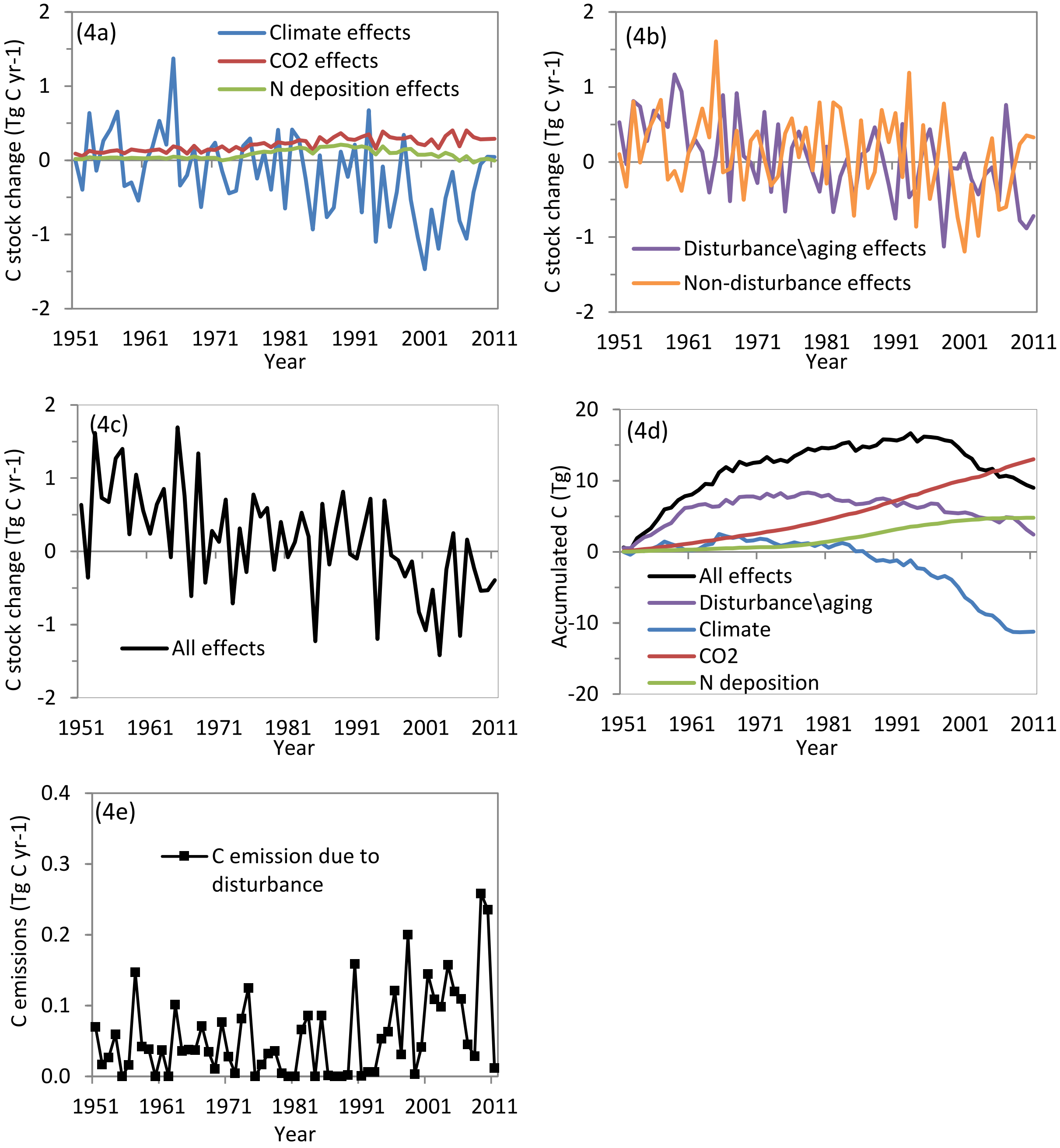


Figure 4.4. Changes in carbon stocks in the Humboldt-Toiyabe National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth 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.

Manti-La Sal National Forest

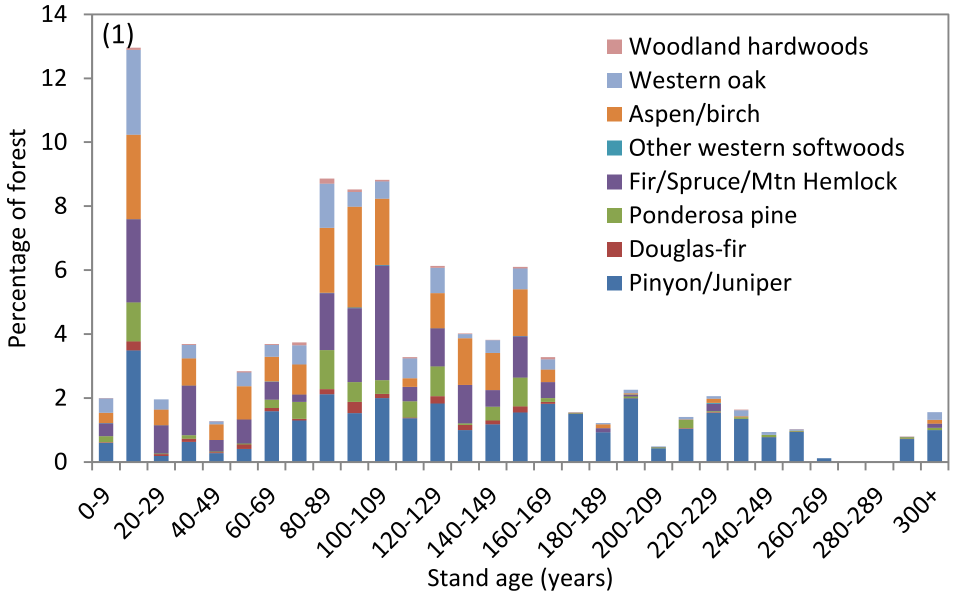


Figure 4.1. Age class distribution in 2011 in the Manti-La Sal National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

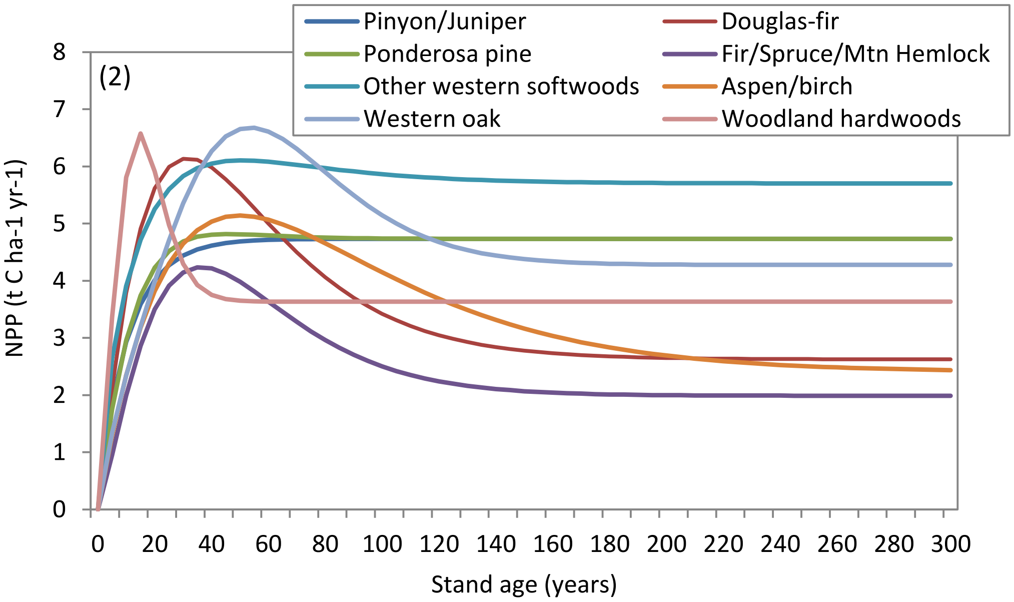


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest in the Manti-La Sal National Forest.

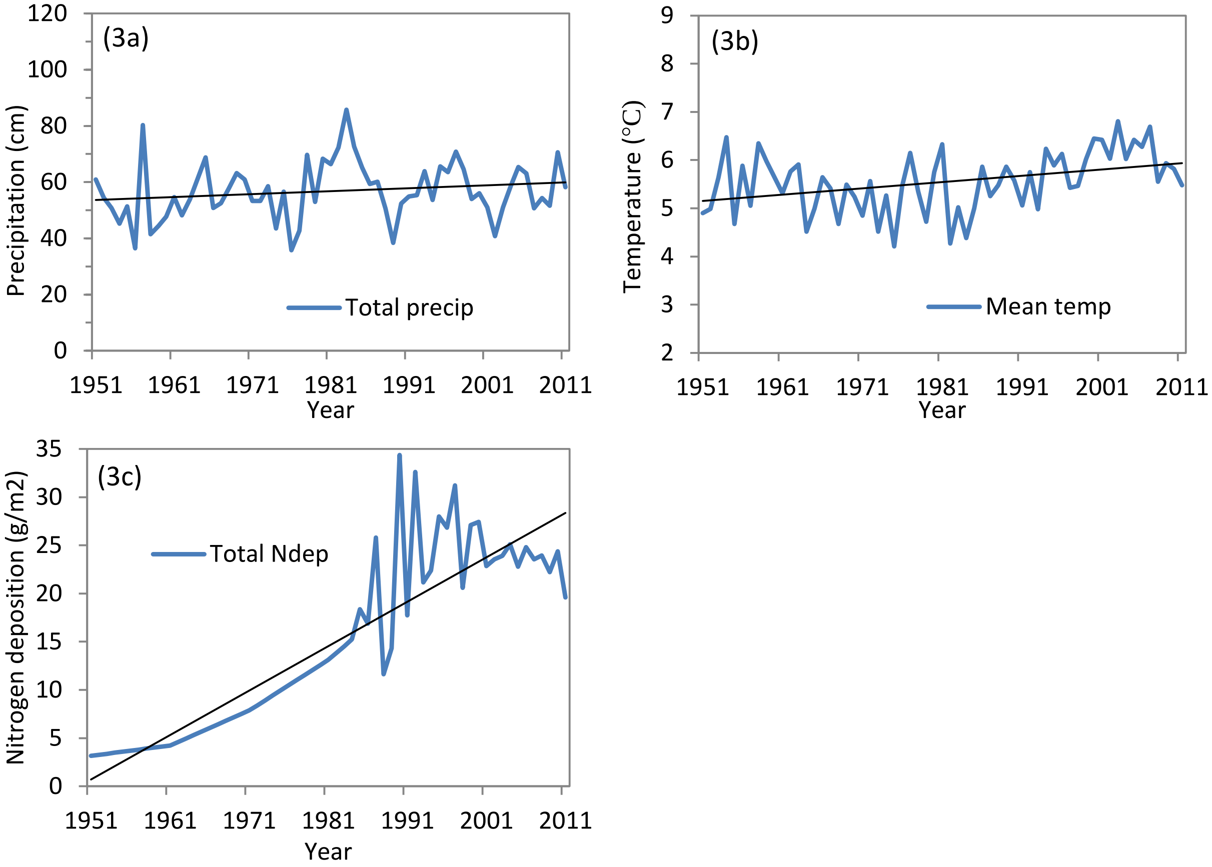


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Manti-La Sal National Forest. Linear trend lines shown in black.

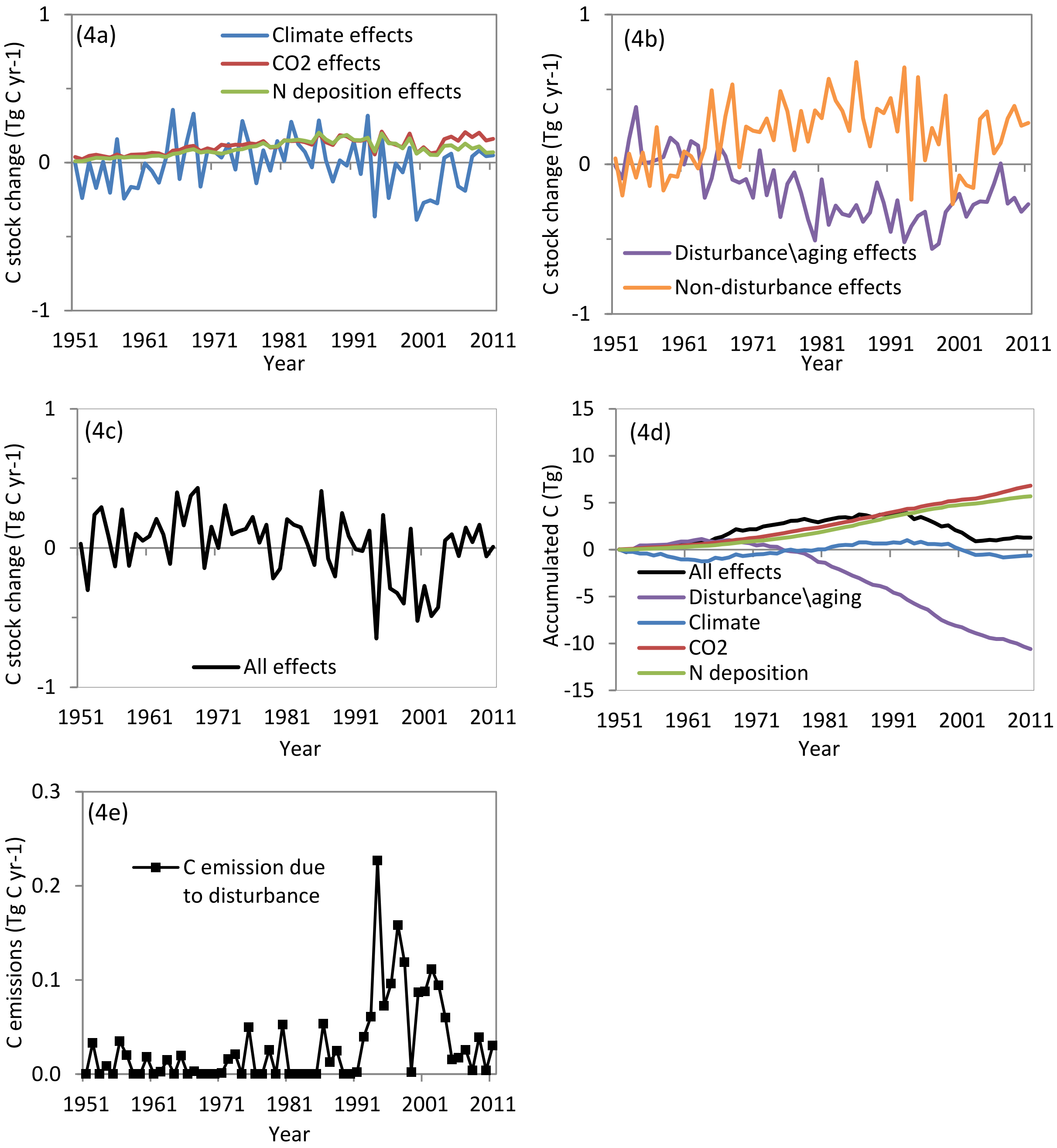


Figure 4.4. Changes in carbon stocks due in the Manti-La Sal National Forest to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and 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.

Payette National Forest

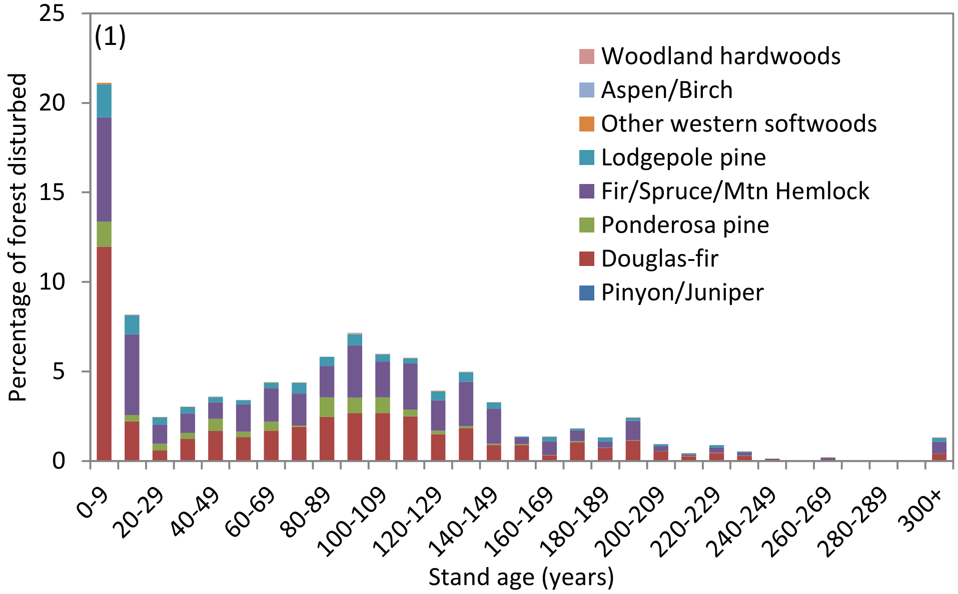


Figure 4.1. Age class distribution in 2011 in the Payette National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

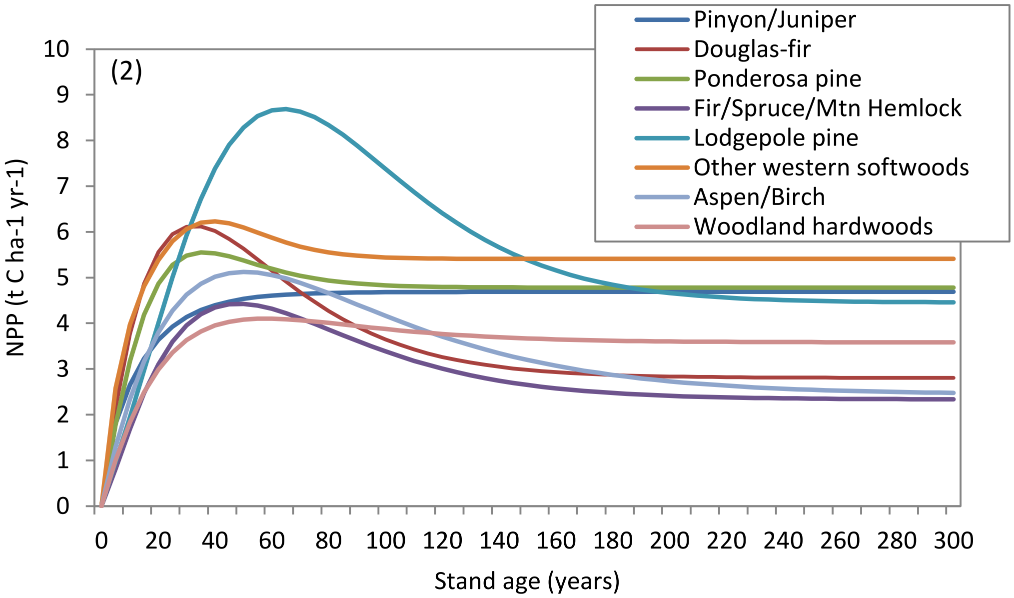


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Payette National Forest.

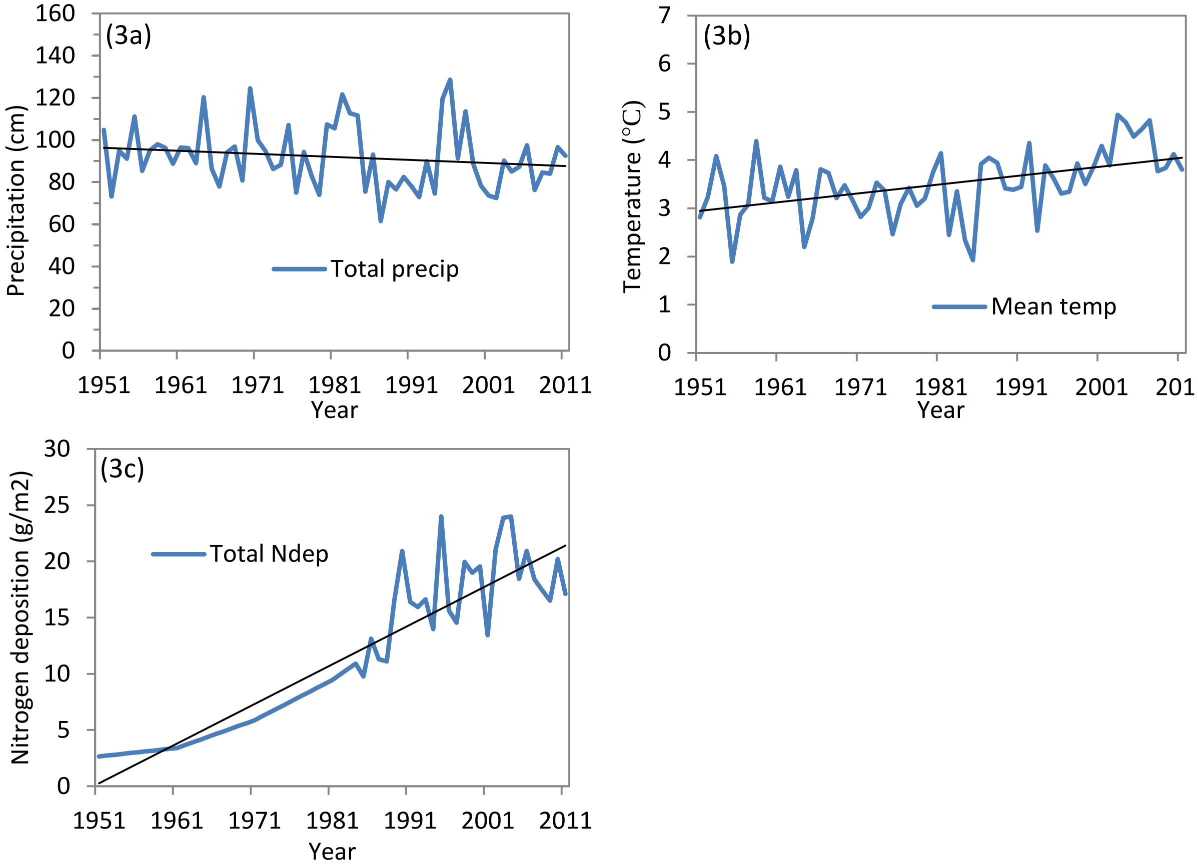


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Payette National Forest. Linear trend lines shown in black.

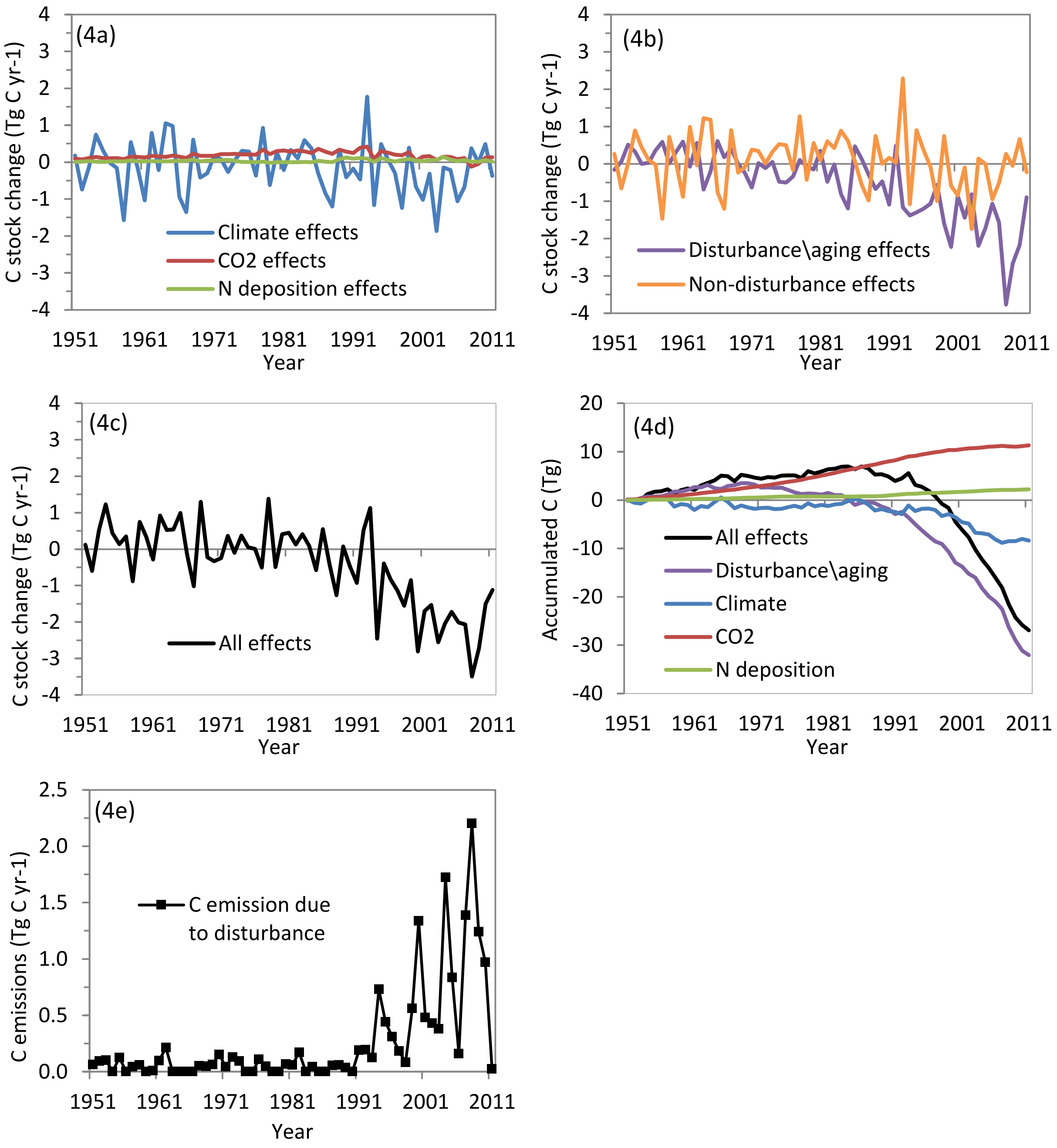


Figure 4.4. Changes in carbon stocks due in the Payette National Forest to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and aging 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.

Salmon-Challis National Forest

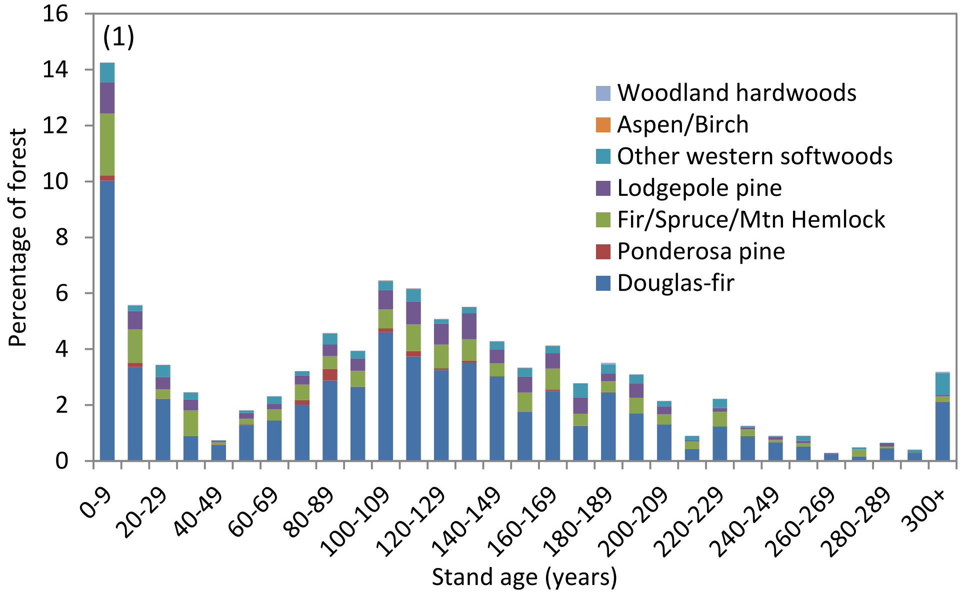


Figure 4.1. Age class distribution in 2011 in the Salmon-Challis National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

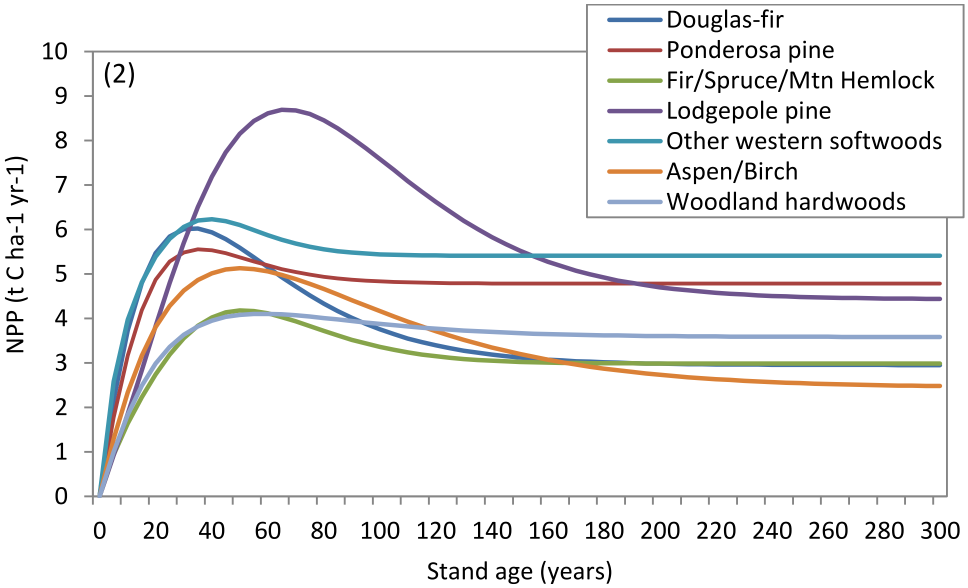


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Salmon-Challis National Forest.

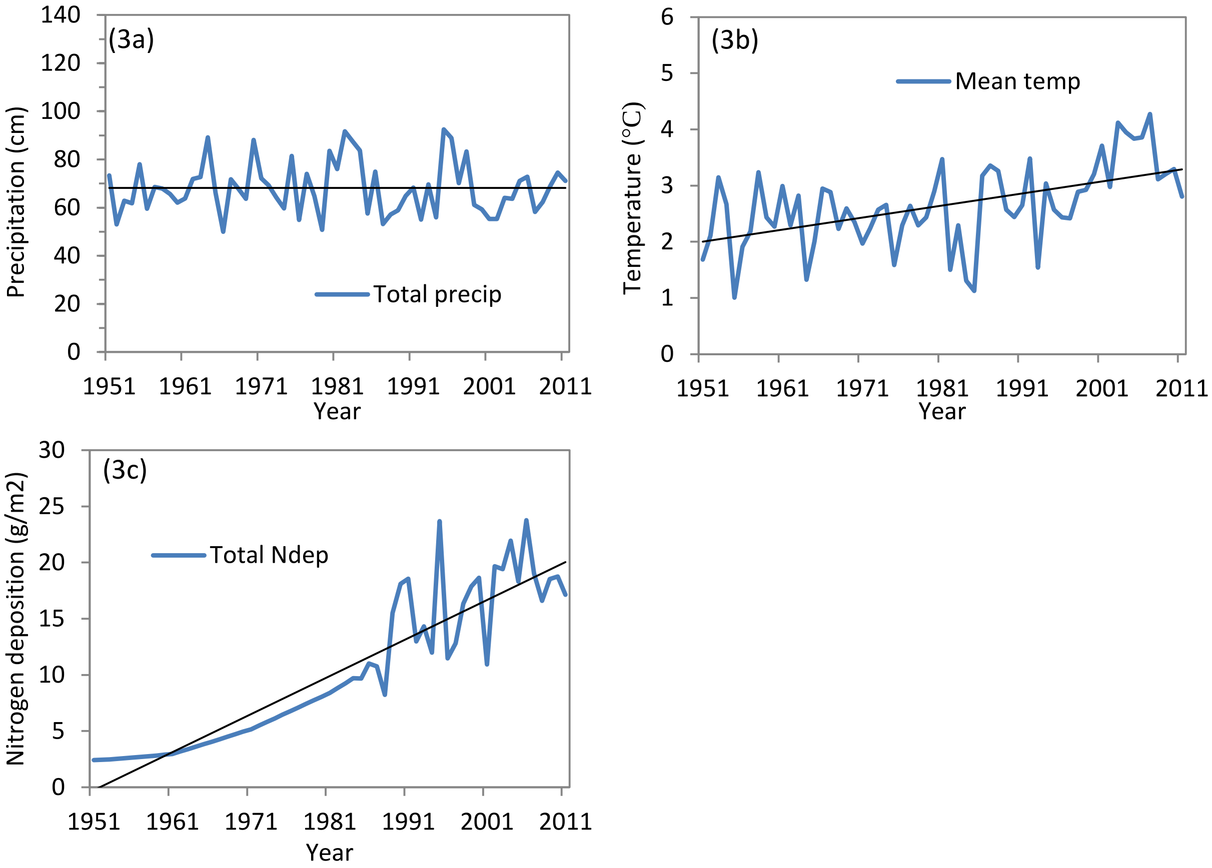


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Salmon-Challis National Forest. Linear trend lines shown in black.

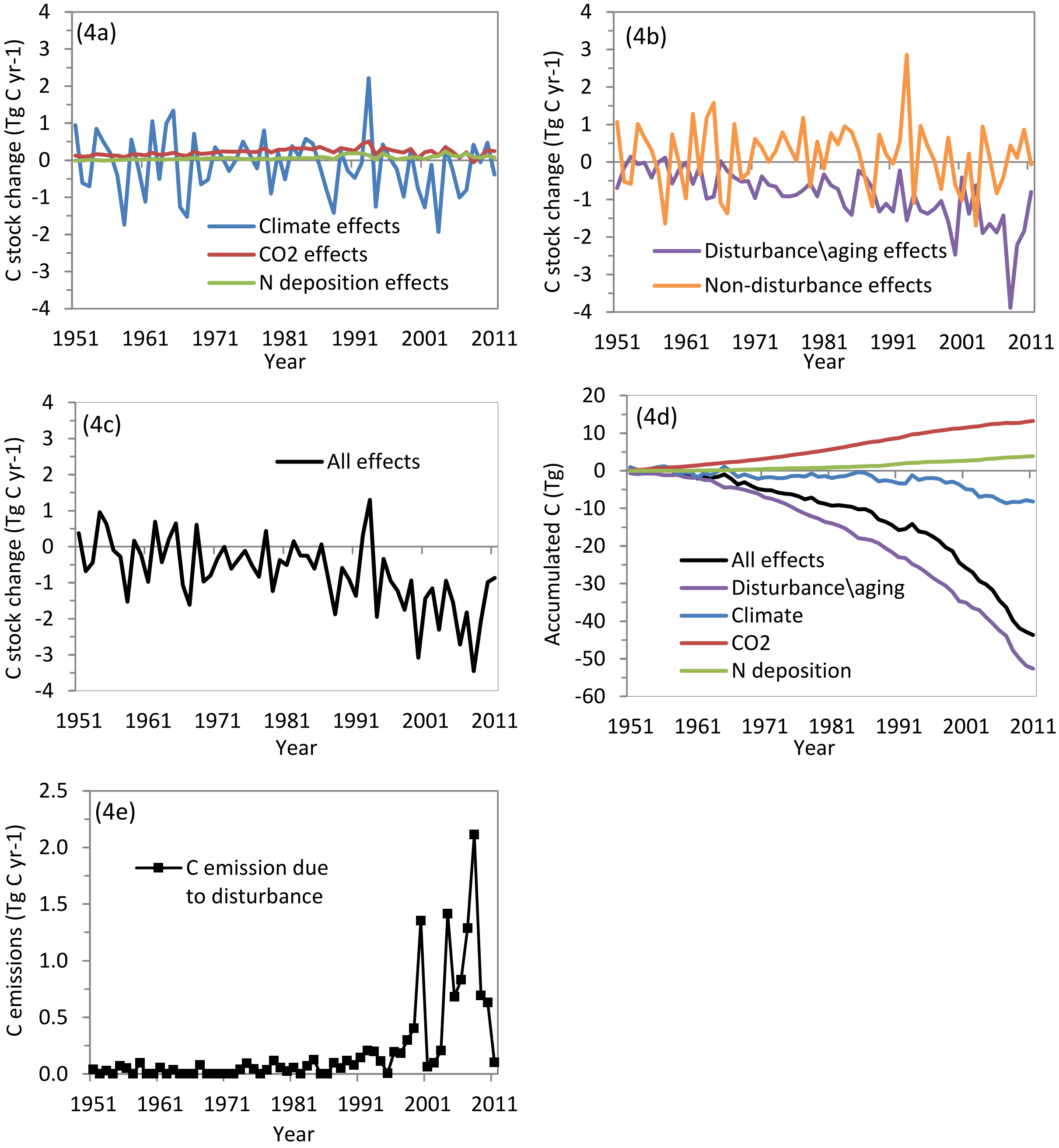


Figure 4.4. Changes in carbon stocks in the Salmon-Challis National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and 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.

Sawtooth National Forest

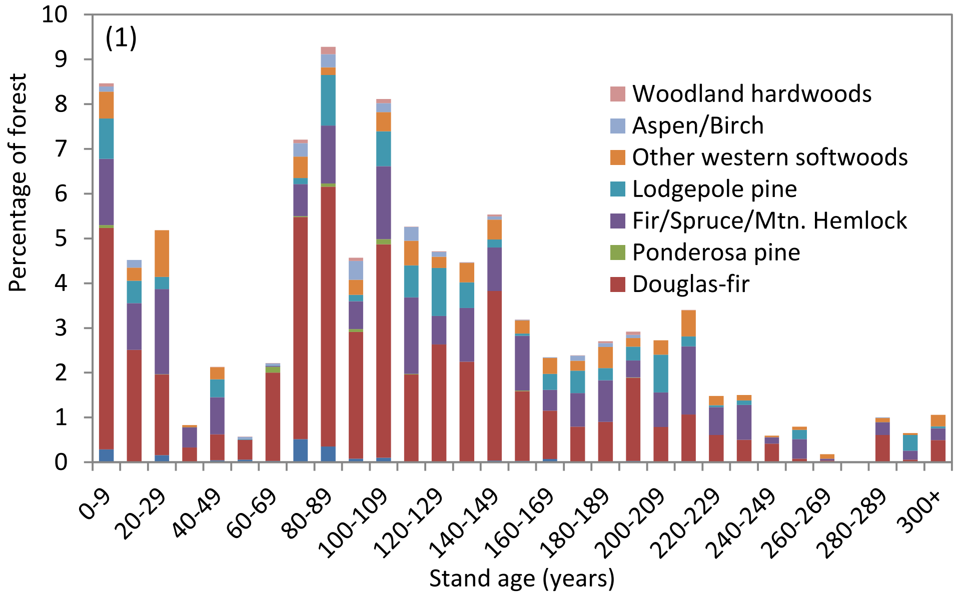


Figure 4.1. Age class distribution in 2011 in the Sawtooth National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

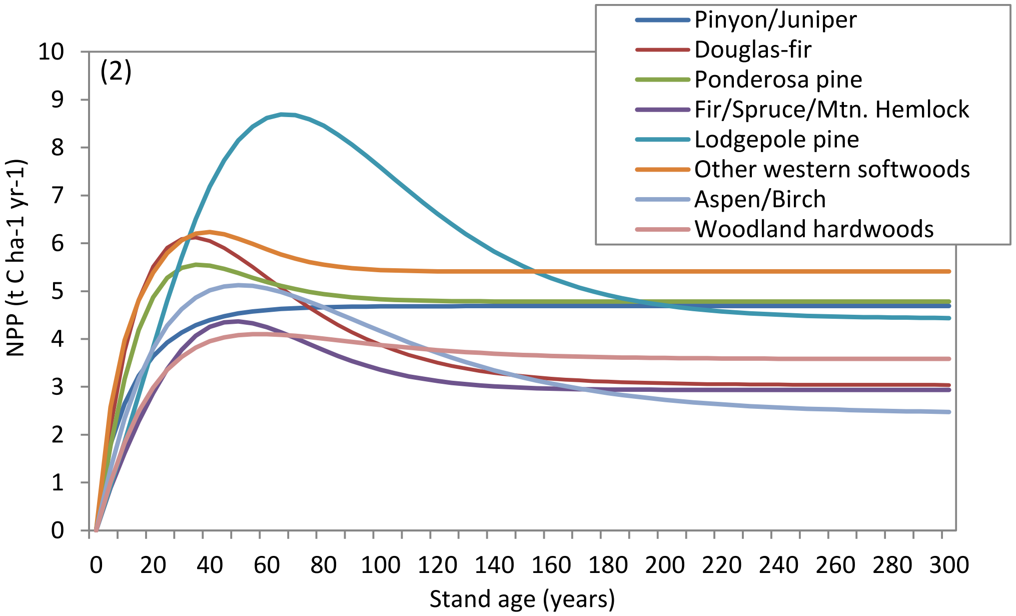


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Sawtooth National Forest.

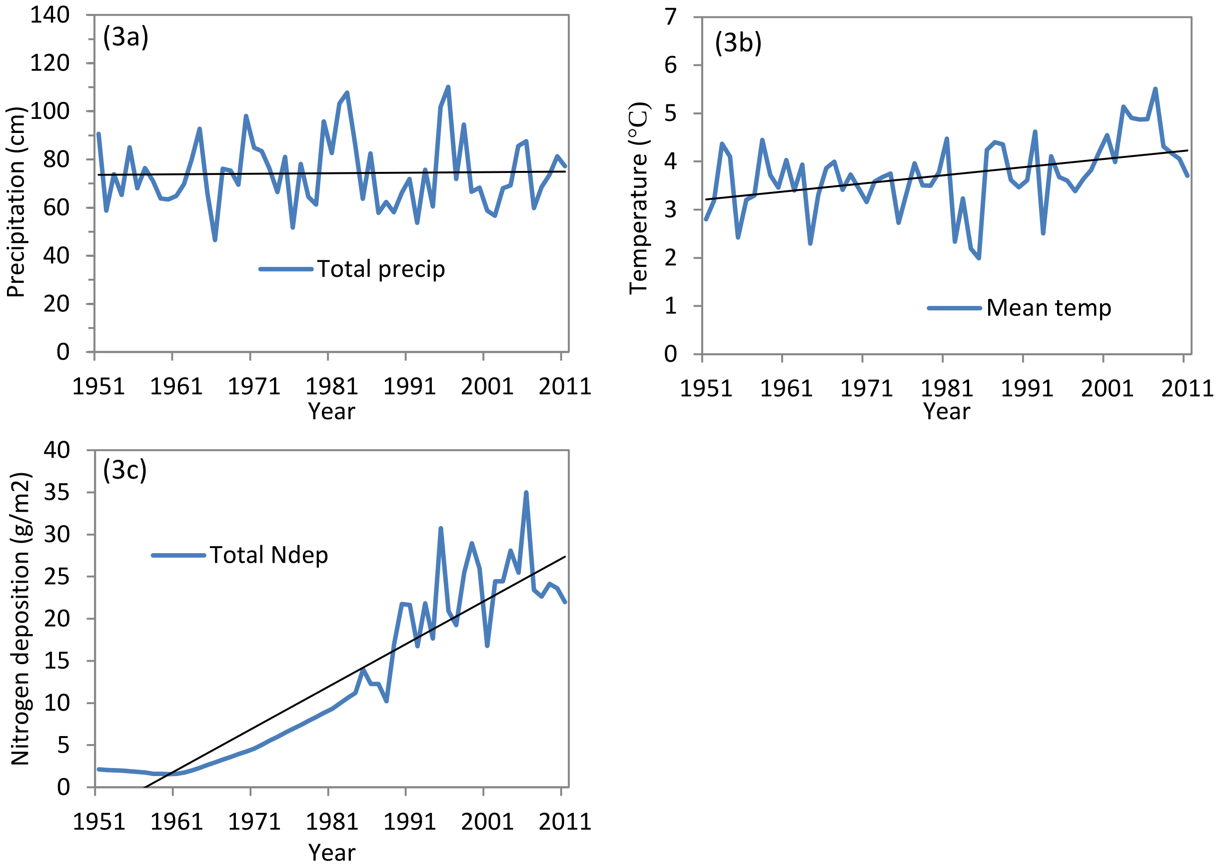


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Sawtooth National Forest. Linear trend lines shown in black.

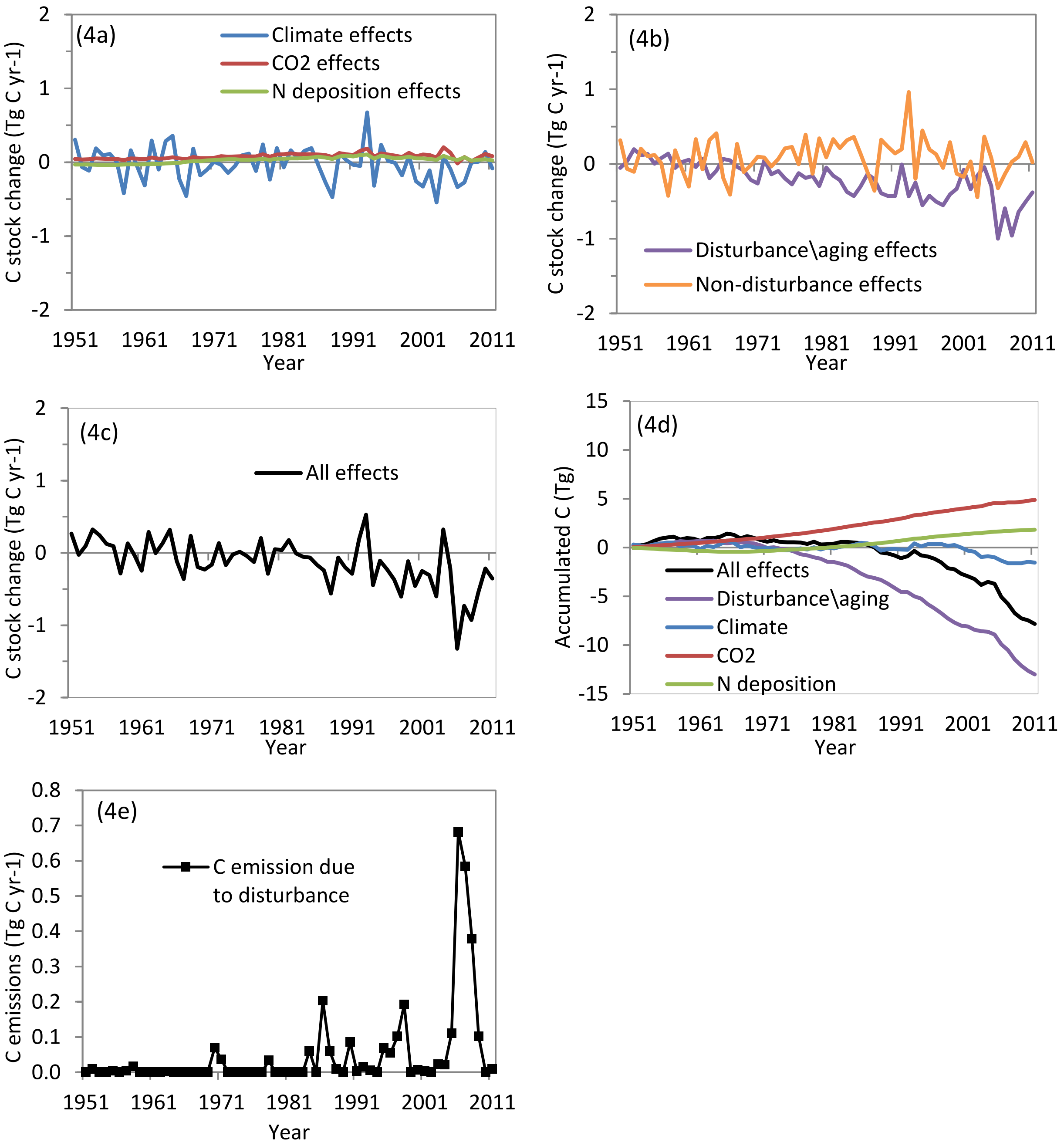


Figure 4.4. Changes in carbon stocks in the Sawtooth National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth and aging 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.

Uinta-Wasatch-Cache National Forest

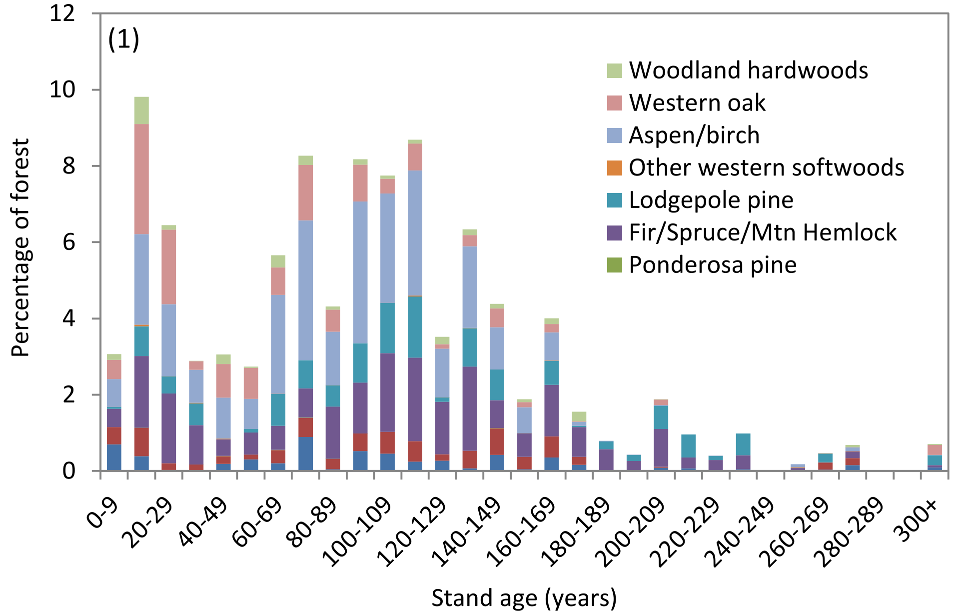


Figure 4.1. Age class distribution in 2011 in the Uinta-Wasatch-Cache National Forest displaying the percentage of forested area of each forest type in 10-year age classes. Forest types are symbolized by stacked, colored bars that also correspond to the forest types in Figure 2 below.

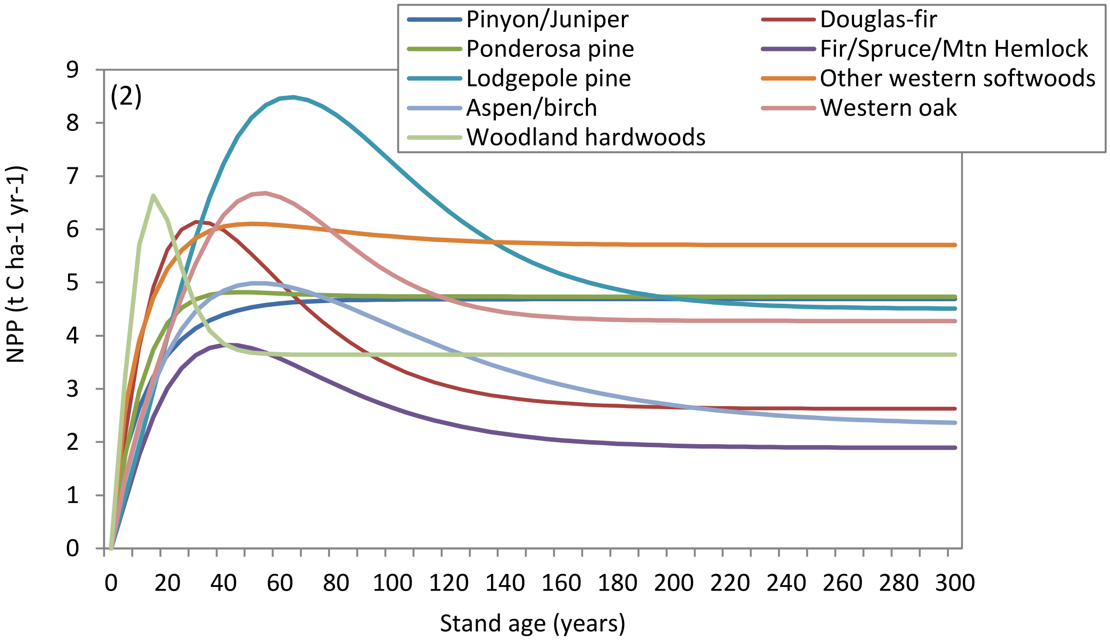


Figure 4.2. Relationship between net primary productivity (NPP) and stand age for each forest type in the Uinta-Wasatch-Cache National Forest.

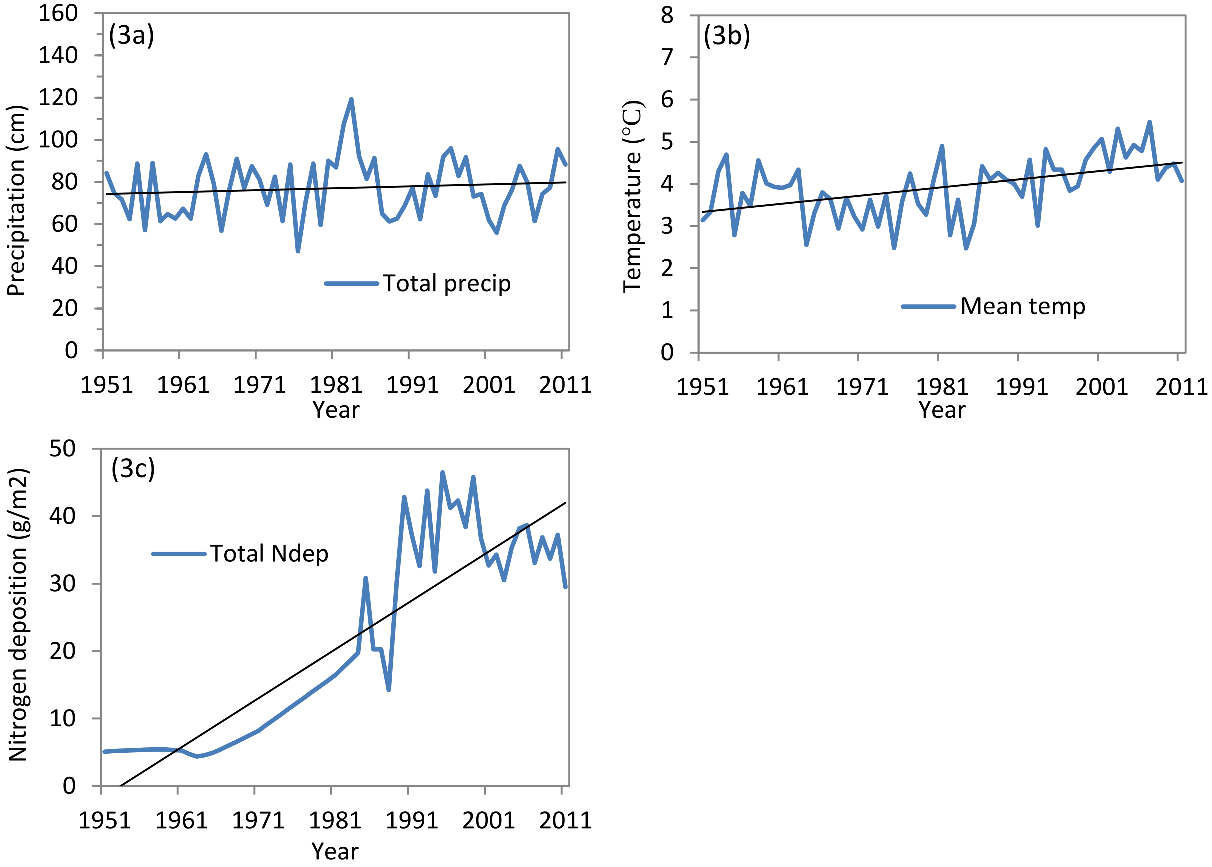


Figure 4.3. (a) Total annual precipitation (cm), (b) average annual temperature (°C), and (c) total annual nitrogen deposition from 1951-2011 in the Uinta-Wasatch-Cache National Forest. Linear trend lines shown in black.

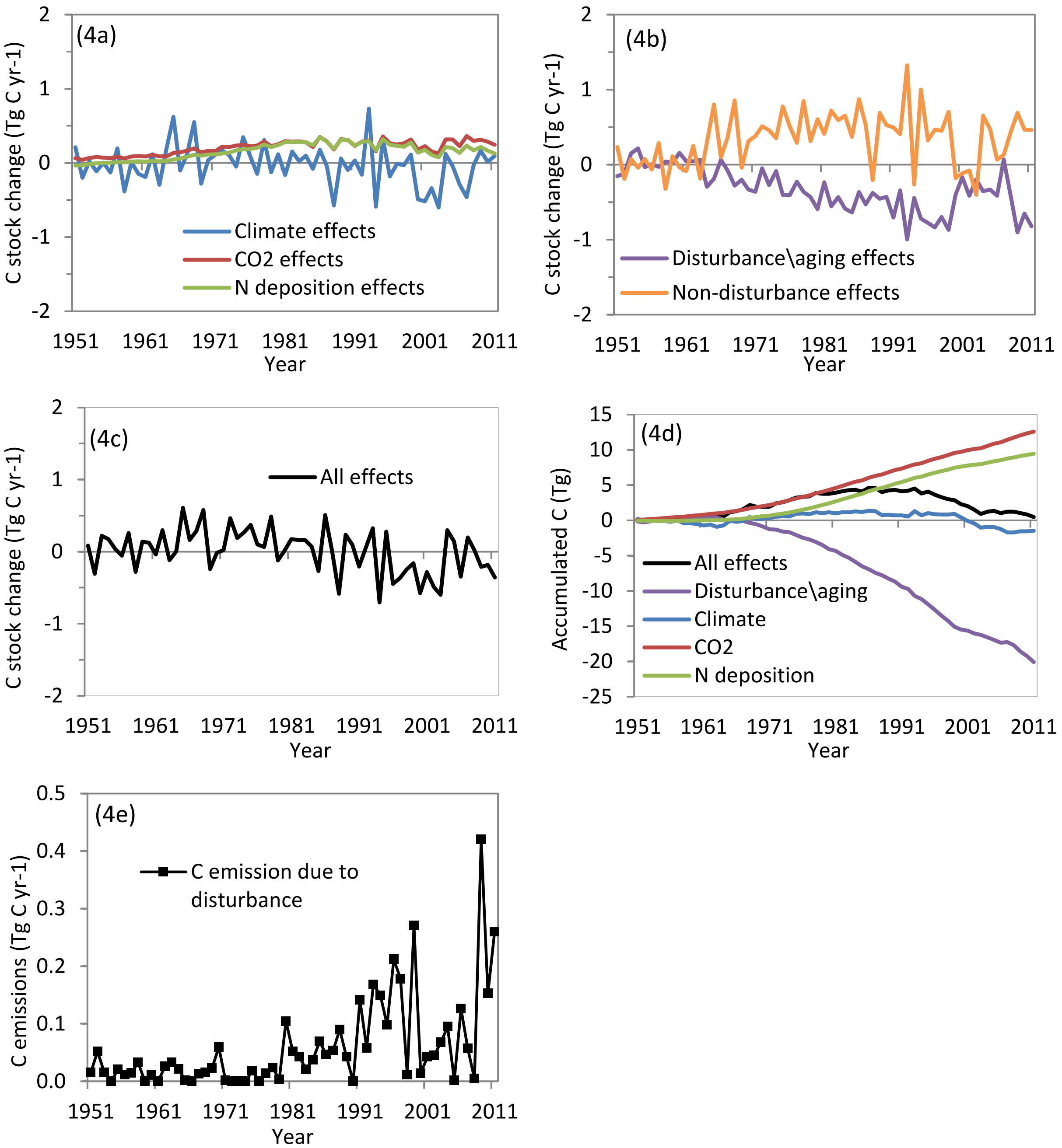


Figure 4.4. Changes in carbon stocks in the Uinta-Wasatch-Cache National Forest due to: (a) individual non-disturbance factors alone including climate variability, atmospheric CO_2 concentration, and nitrogen deposition; (b) all disturbance factors such as fire, harvest, and insects, as well as regrowth 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.