Oregon Forest Ecosystem Carbon Inventory

United States Forest Service
Forest Inventory and Analysis
2021 Monitoring Coda

Metric Unit Conversions

1 Megagram (**Mg**)= 1 metric ton (MT)

1,000,000 **Mg** = 1 **Teragram (Tg)**

1 **Tg** = 1 Million Metric Tons (MMT)

1000 **Tg** = 1 **Petagram (Pg)**
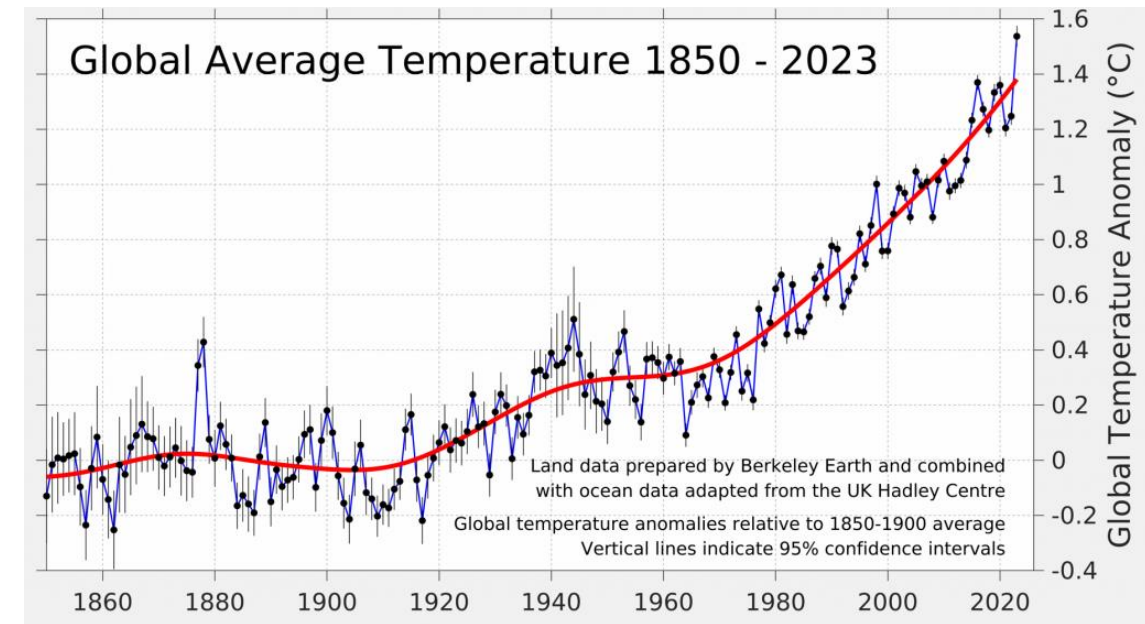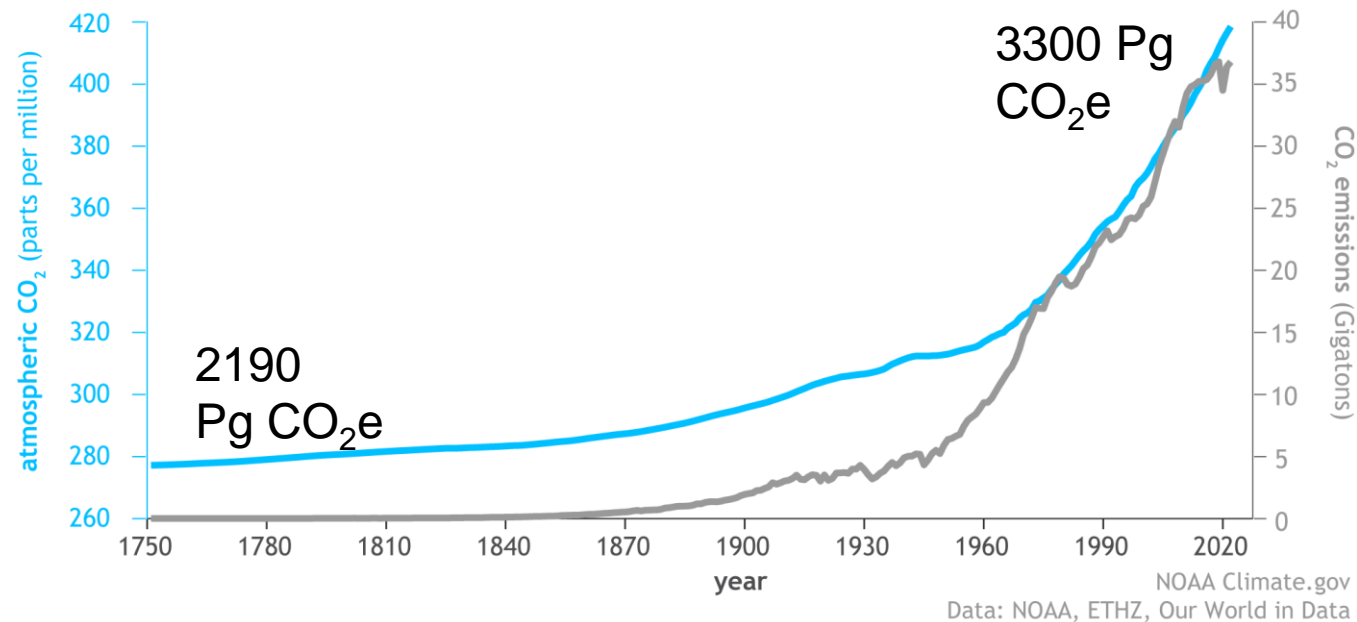
1 **Pg** = 1 Gigatonne

Carbon Unit Conversion

$1 CO_2e = 3.6667 * C$
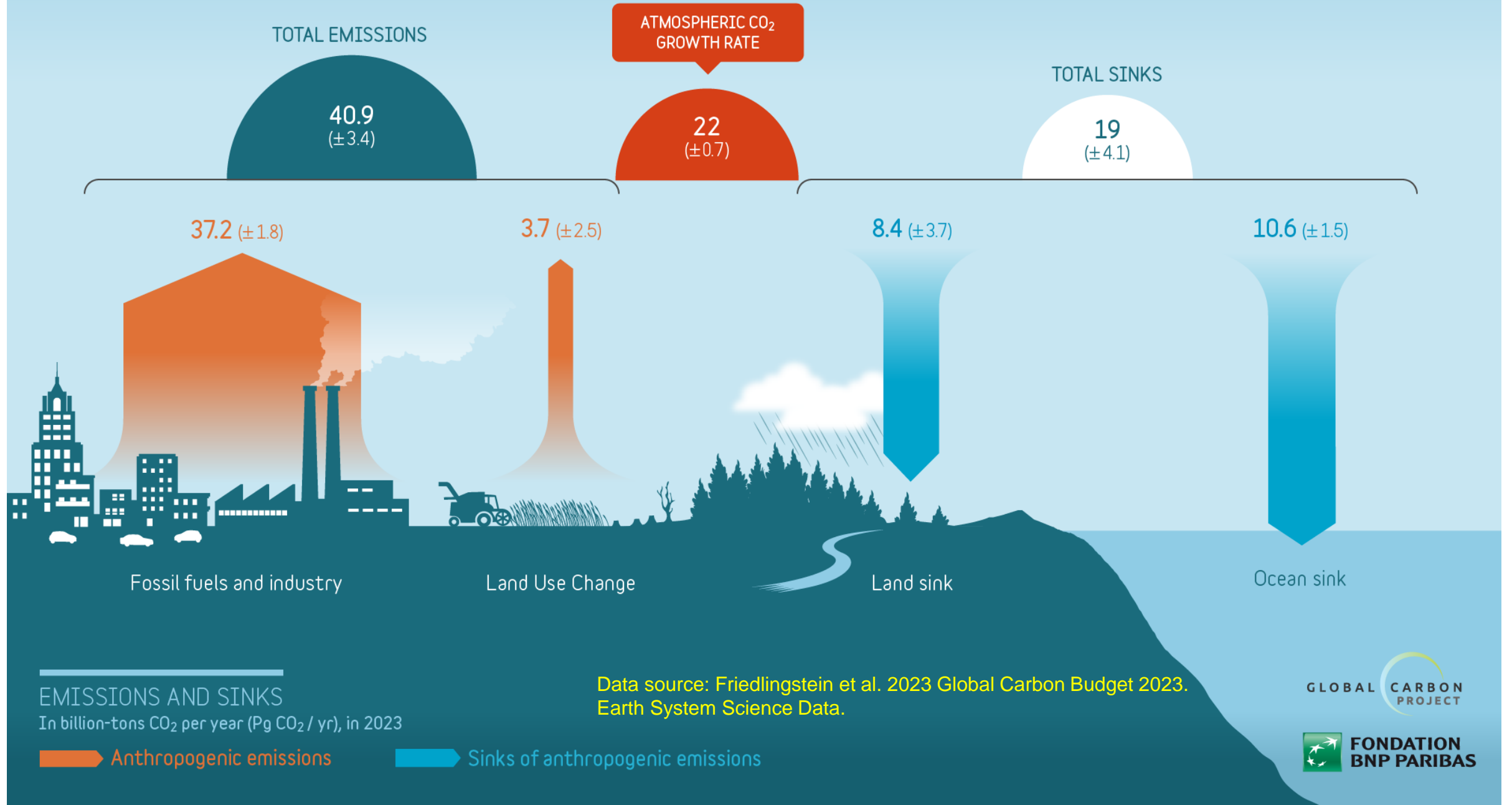
1 ppm of CO2 = 7.82 Pg of CO_2e
or 2.13 Pg of C

We are we concerned with forest carbon dynamics because

1) There is a thermodynamic relationship between increasing concentration of carbon dioxide gas and subsequent increase in temperature.
2) Forests pull carbon dioxide from the atmosphere and store it in woody tissue
3) Forests might be used to offset/mitigate human CO_2 emissions

- Monitoring Oregon's forests is fundamental for determining when they are a source or sink of carbon with the atmosphere

Global atmospheric carbon dioxide compared to annual emissions (1751-2022)

3300 Pg CO_2e

2190 Pg CO_2e

NOAA Climate.gov
Data: NOAA, ETHZ, Our World in Data

Global Average Temperature 1850 - 2023

Land data prepared by Berkeley Earth and combined with ocean data adapted from the UK Hadley Centre
Global temperature anomalies relative to 1850-1900 average
Vertical lines indicate 95% confidence intervals

GLOBAL CARBON BUDGET 2023

Global Carbon Project

TOTAL EMISSIONS

40.9
(±3.4)

ATMOSPHERIC CO_2 GROWTH RATE

22
(±0.7)

TOTAL SINKS

19
(±4.1)

37.2 (±1.8)

3.7 (±2.5)

8.4 (±3.7)

10.6 (±1.5)

Fossil fuels and industry

Land Use Change

Land sink

Ocean sink

EMISSIONS AND SINKS
In billion-tons CO_2 per year (Pg CO_2 / yr), in 2023

Anthropogenic emissions

Sinks of anthropogenic emissions

Data source: Friedlingstein et al. 2023 Global Carbon Budget 2023. Earth System Science Data.

GLOBAL CARBON PROJECT

FONDATION BNP PARIBAS

Board of Forestry

- **Forest Carbon Indicator** – Strategy G of the **2003 Forestry Program for Oregon**
- One of 19 Indicators of Sustainable Forest Management for Oregon-motivated by the Montreal Process Criteria and Indicators.
- Analysis for the indicator was completed with Dr. Mark Harmon's LandCarb modeling system.
- Agreed to collaborate with the Global Warming Commission on forest carbon accounting

Climate Action Commission (aka Global Warming Commission)

- Forest Carbon taskforce 2010 and 2016 with the overall Goal of delivering a report to the State of Oregon that provides:

1) a baseline estimate of carbon in Oregon's forests
2) a quantitative description of carbon flows among forest pools
3) projections of how these quantities and flows may be affected by climate change
4) quantify the carbon flows into and out of the forest from natural and human actions.

OREGON FOREST CARBON ACCOUNTING FRAMEWORK

Based on Monitoring of Historical and Current Processes

Based on Simulations of Future Conditions

Forest Ecosystem Carbon Stocks and Flux

- Live and dead trees
- Live and dead roots
- Understory vegetation
- Fallen logs & branches
- Forest Floor
- Soil

Harvested Wood Products Carbon Stocks and Flux

- IPCC Production Accounting
- Harvests from 1906 to 2017
- Ownership from 1962-2017
- Products in Use, Landfills
- Emissions from fuelwood & decay
- Total Forest and HWP Carbon

Forest Industry Emissions & Energy Production

- Accounted for in industrial sector-DEQ
- Oregon Sawmill Energy Report
- Non-road diesel
- Transportation
- Life Cycle Analysis

Forest Management Scenarios for Carbon Mitigation

- Forest growth and management simulation
- Collaborating with American Forests
- Carbon Budget Model
- Stakeholder process
- Collaborating with MOU partners & PNW RS

Carbon Storage and Flux in Oregon's Forest Ecosystems
Based on 20 years (2001-2020) of Forest Monitoring Conducted by USFS, Forest Inventory and Analysis

Special thanks to Glenn Christensen, Andy Gray, and especially Olaf Kuegler

https://research.fs.usda.gov/inventory/carbonmonitoring/forestcarbonscience

Estimating the Dynamics of Carbon in Oregon's Forests with USFS Forest Inventory and Analysis Data

- Estimates based on tree measurements on 9847 accessible, forested plots across Oregon's forests

- 20 years of data collection with 10% of plots measured each year—
    - One remeasurement of all plots and trees
    - Can be used to estimate growth, removals, and mortality

- Density of *measured*, *forested* plots is greater on National Forests (1 Plot / 1816 acres) and State and local forests (1 Plot / 2768 acres) than privately-owned forests (1 Plot / 6476 acres).

- Nationally-consistent framework of equations for estimating volume and biomass (NSVB) of trees and other pools of forest carbon*

* Westfall, James A et. Al. 2024. A national-scale tree volume, biomass, and carbon modeling system for the United States. Gen. Tech. Rep. WO-104. Washington, DC: U.S. Department of Agriculture, Forest Service. 37 p. https://doi.org/10.2737/WO-GTR-104.

Forest Inventory and Analysis Plots across Oregon

Subplot:
24.0 feet radius

Macroplot:
58.9 feet radius

Azimuth 1 - 2 = 360°
Azimuth 1 - 3 = 120°
Azimuth 1 - 4 = 240°

Distance between
subplot centers is
120 feet horizontal

Micoplot:
6.8 feet radius center
is 12 feet horizontal
@ 90° azimuth from
the subplot center
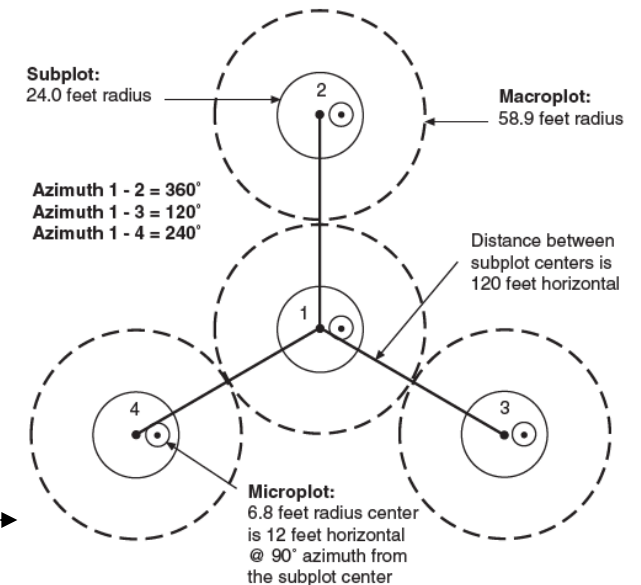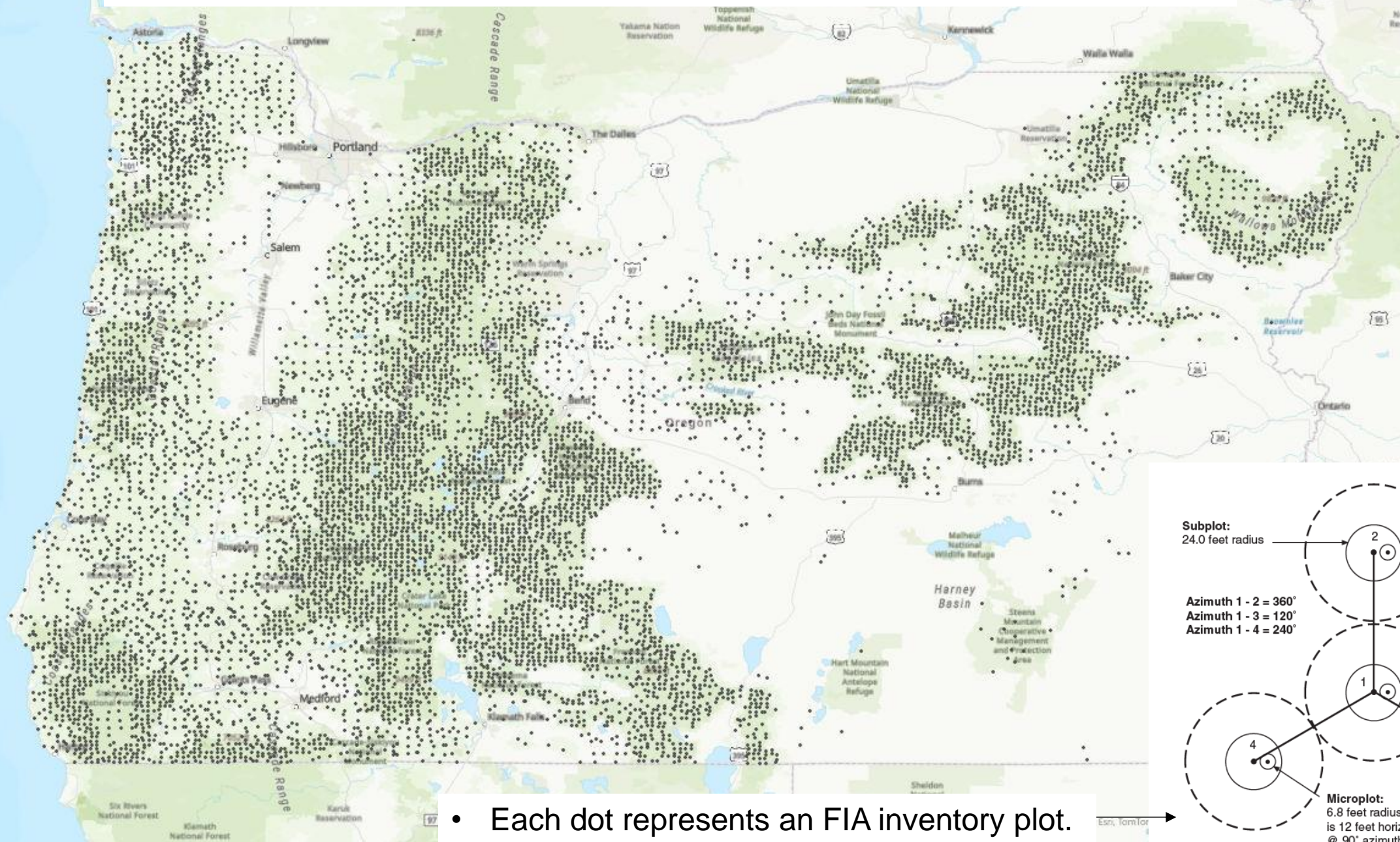
- Each dot represents an FIA inventory plot.

Ecoregions
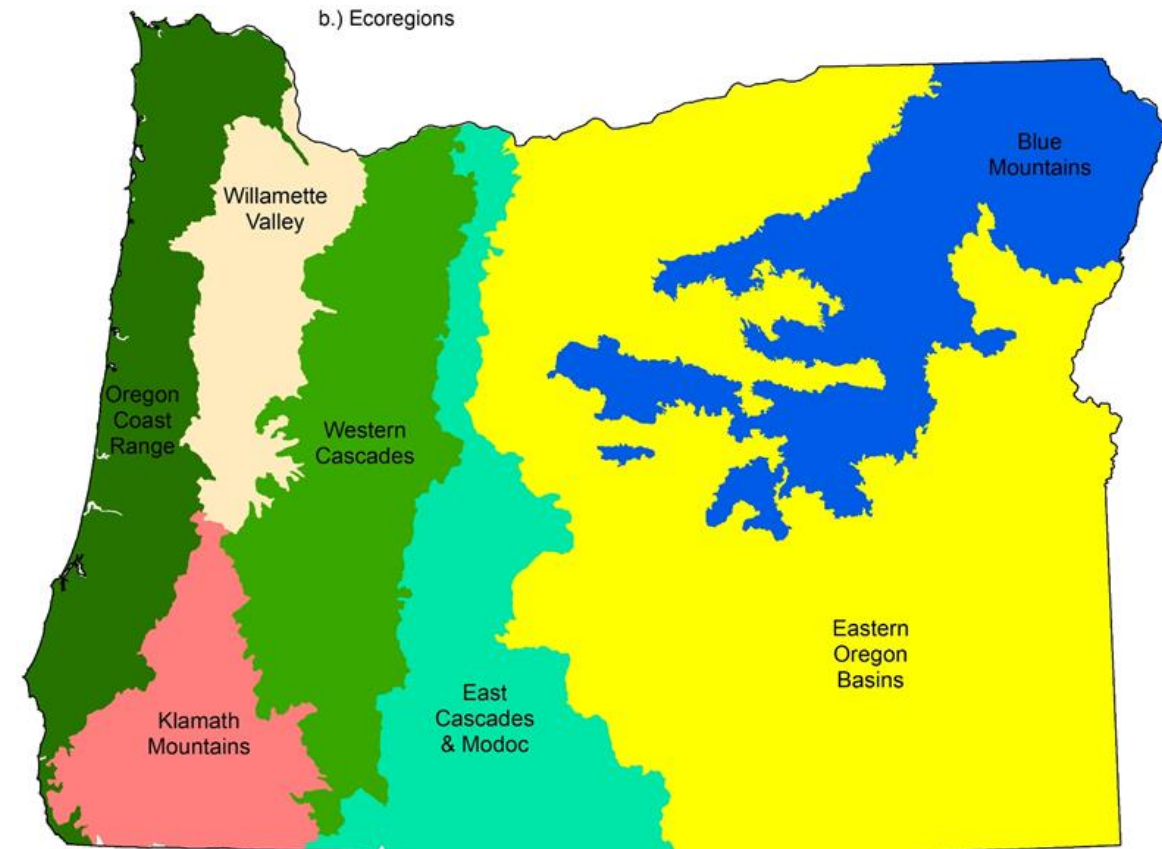
Forest Owners
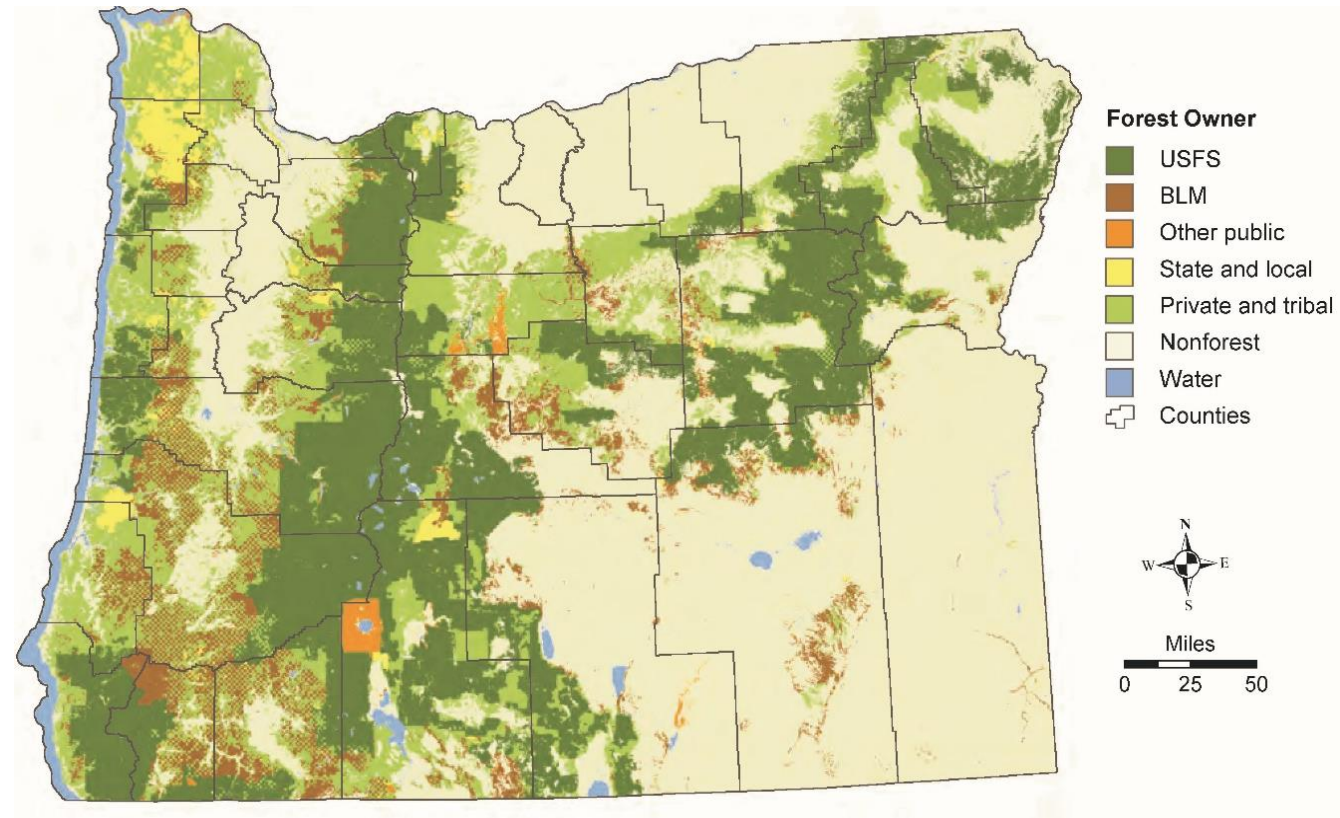
Forest Carbon Pools

- **Live trees**: Biomass is estimated with allometric models for total stem, branch, bark, and foliage

- **Standing dead trees**: Same as live trees, includes reductions for five levels of decay.

- **Understory vegetation**: As modeled and populated in FIA DataBase

- **Dead woody debris**: Use collected measurements and National FIA estimation protocol, piles not included

- **Forest floor**: Uses the national estimation protocol based on modeled relationships.

- **Roots** on live and standing dead trees: Uses National FIA protocol

- **Soils**: As modeled and populated in FIA Database using methods from Domke et al. (2017)**

**Domke, G.M.; Perry, C.H.; Walters, B.F.; Nave, L.E.; Woodall, C.W.; Swanston, C.W. 2017. Towards inventory-based estimates of soil organic carbon in forests of the United States. Ecological Restoration 27(4): 1223-1235. DOI: 10.1002/eap.1516. (accessed: November 2, 2017).

Forest Carbon Stocks

Oregon Forest Carbon Stocks by Forest Pools, 2011-2020

Forest Carbon Pools	Tg CO$_2$e	SE	Tg C	SE
Live Trees	3948.6	34.6	1,076.9	9.4
Standing Dead	316.0	7.8	86.2	2.1
Understory Veg	134.8	0.8	36.8	0.2
Dead Woody Debris	120.9	1.4	33.0	0.4
Forest Floor	475.2	2.1	129.6	0.6
Roots	900.3	8.3	245.5	2.3
Soil Organic C	5779.5	25.6	1,576.2	7.0
All Pools	11,675.0	56.8	3,184.1	15.5

Carbon Stocks in Oregon's Forests by Forest Type and Pool
For the 2012-2021 Inventory Period

Carbon
by Forest Type
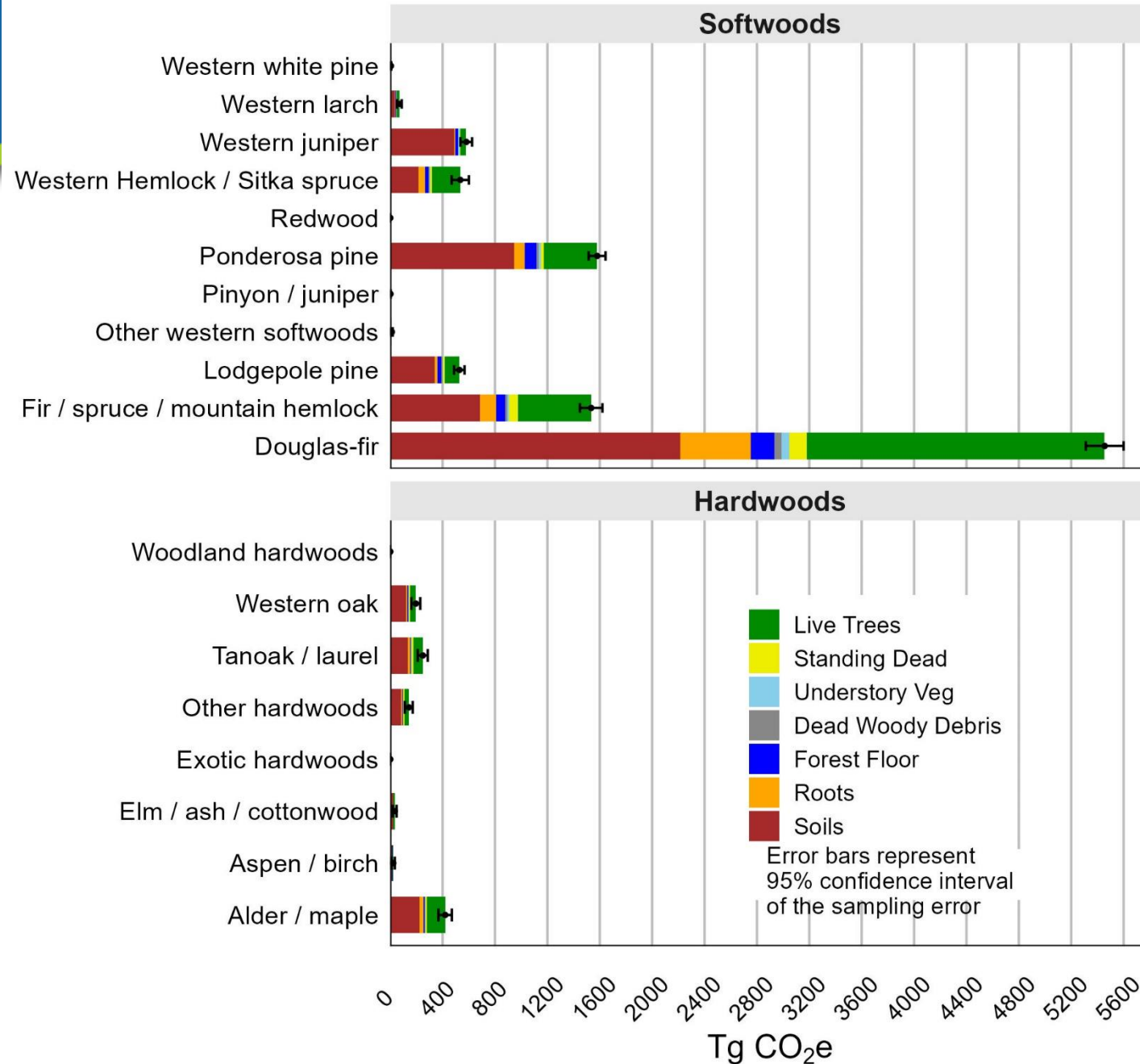
Carbon unit conversion

Owner	Tg CO$_2$e	SE	Tg Carbon	SE C
USFS	6032.9	33.2	1645.3	9.1
Corp	2154.2	39.3	587.5	10.7
Other Fed	1631.3	30.9	444.9	8.4
Non Corp	1273.1	38.5	347.2	10.5
State Local	583.9	21.1	159.2	5.8

Total Carbon Stocks in Oregon's Forests by Pool and Owner For the 2021 Inventory Period
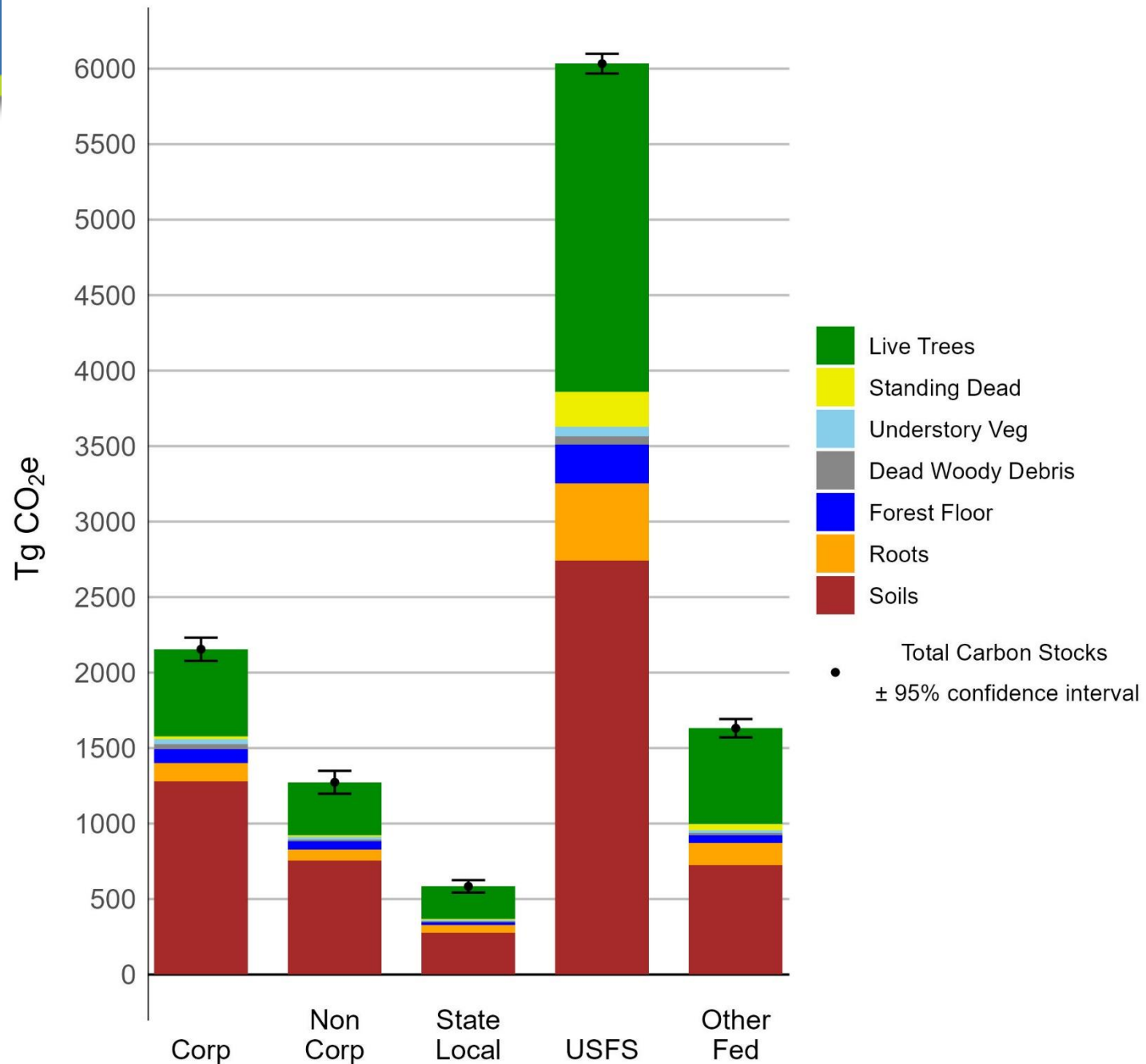
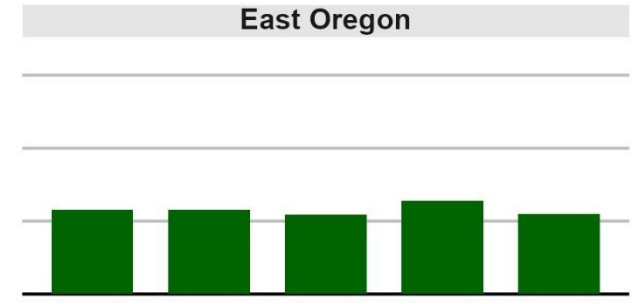| Owner	Mg CO2e Per Acre	Mg C per Acre
USFS	429.1	117.0
Other Fed	426.7	116.4
State Local	443.0	120.8
Corp	330.3	90.1
Non Corp	315.0	85.9

Density of Forest Carbon by Owner for the 2012-2021 Inventory Period
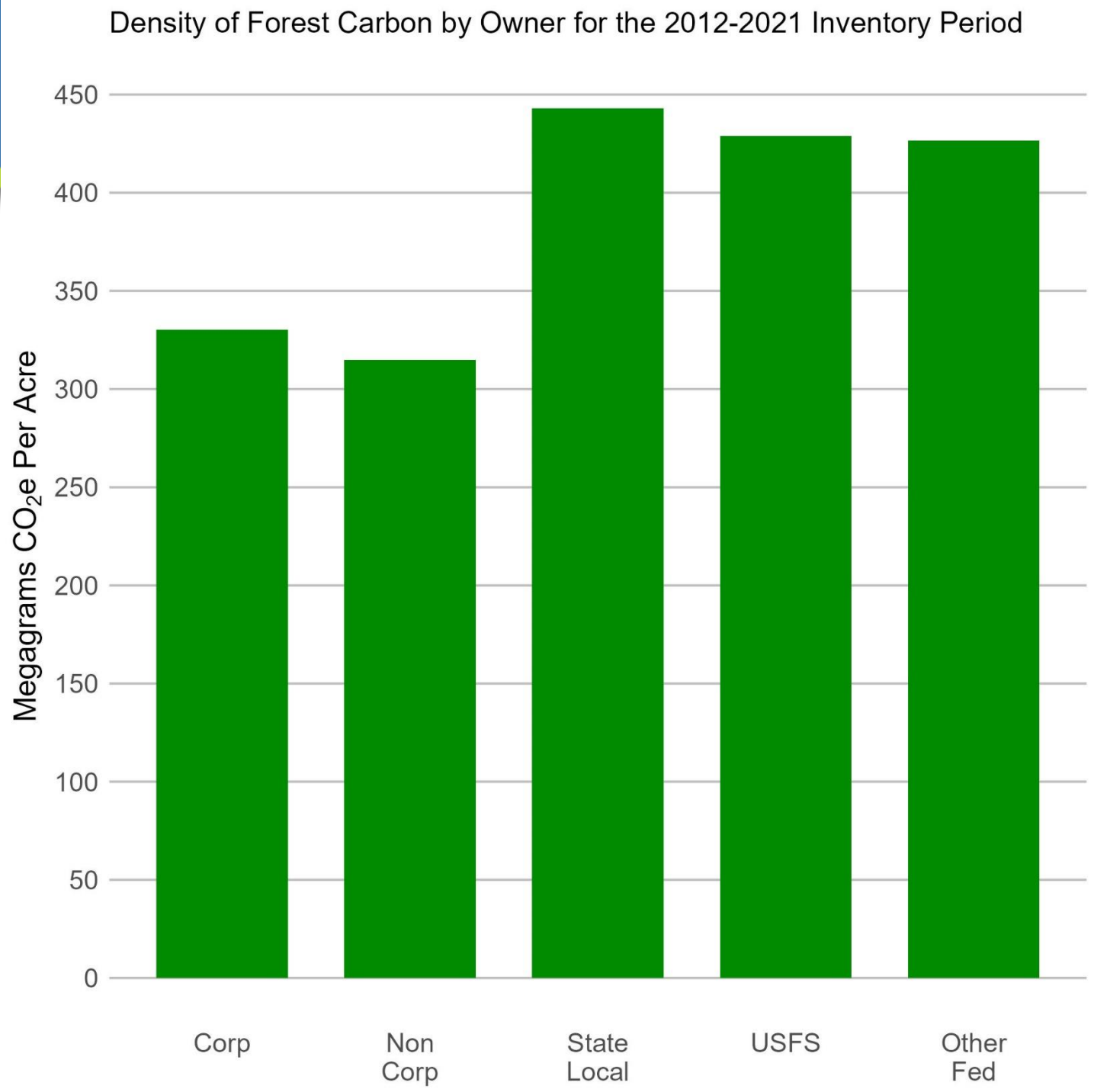
Area of Forestland in Oregon by Ownership

Owner	Million Acres	SE	Percent of Total
USFS	14.1	46	47
Corporate	6.5	109	22
Non Corporate	4.0	117	14
Other Fed	3.8	72	13
State Local	1.3	47	4

Proportion of Forest Carbon Relative to Proportion of Ownership Area
For the 2012-2021 Inventory Period
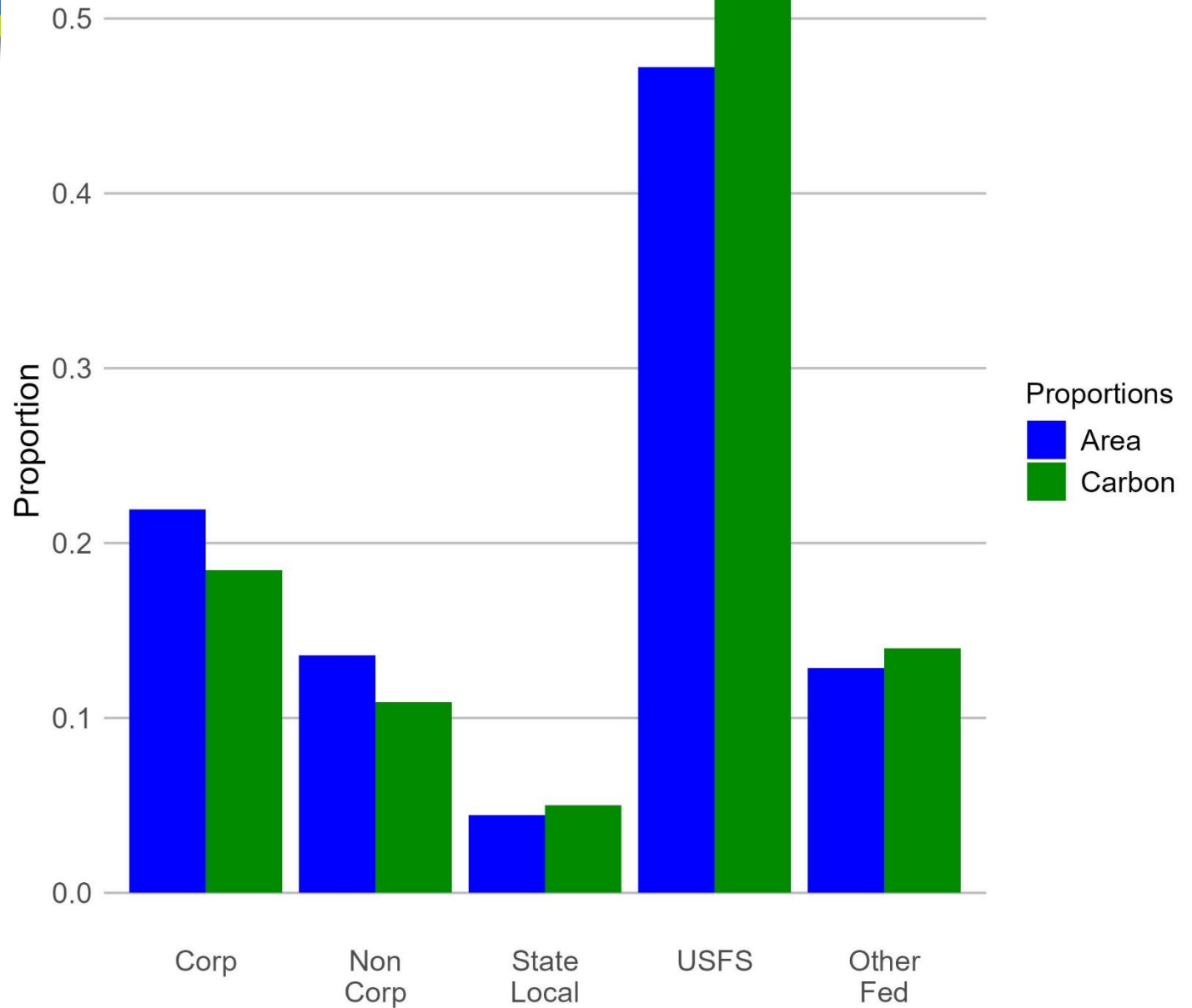
Carbon unit conversion

Ecoregion	Tg CO$_2$ e	SE	Tg Carbon	SE
West Cascades	3418.9	54.9	932.4	14.9
Coast Range	2548.8	63.3	695.1	17.3
Blue Mtns	1936.8	27.3	528.2	7.5
East Cascades	1524.0	30.6	415.6	8.3
Klamath	1285.7	44.8	350.6	12.2
East Oregon	568.10	23.3	154.9	6.4
Willamette Valley	392.9	27.9	107.2	7.6
Total	11,675.3	56.8	3,184.2	15.5

Total Carbon Stocks in Oregon's Forests by Pool and Ecoregion For the 2021 Inventory Period

Tg CO$_2$e

Legend:
- Live Trees
- Standing Dead
- Understory Veg
- Dead Woody Debris
- Forest Floor
- Roots
- Soils
- Total Carbon Stocks ± 95% conf interval

Ecoregions: Blue Mtns, Coast, East Cascades, East Oregon, Klamath, West Cascades, Willamette Valley

Density of Carbon by Ecoregion for the 2012-2021 Inventory Period
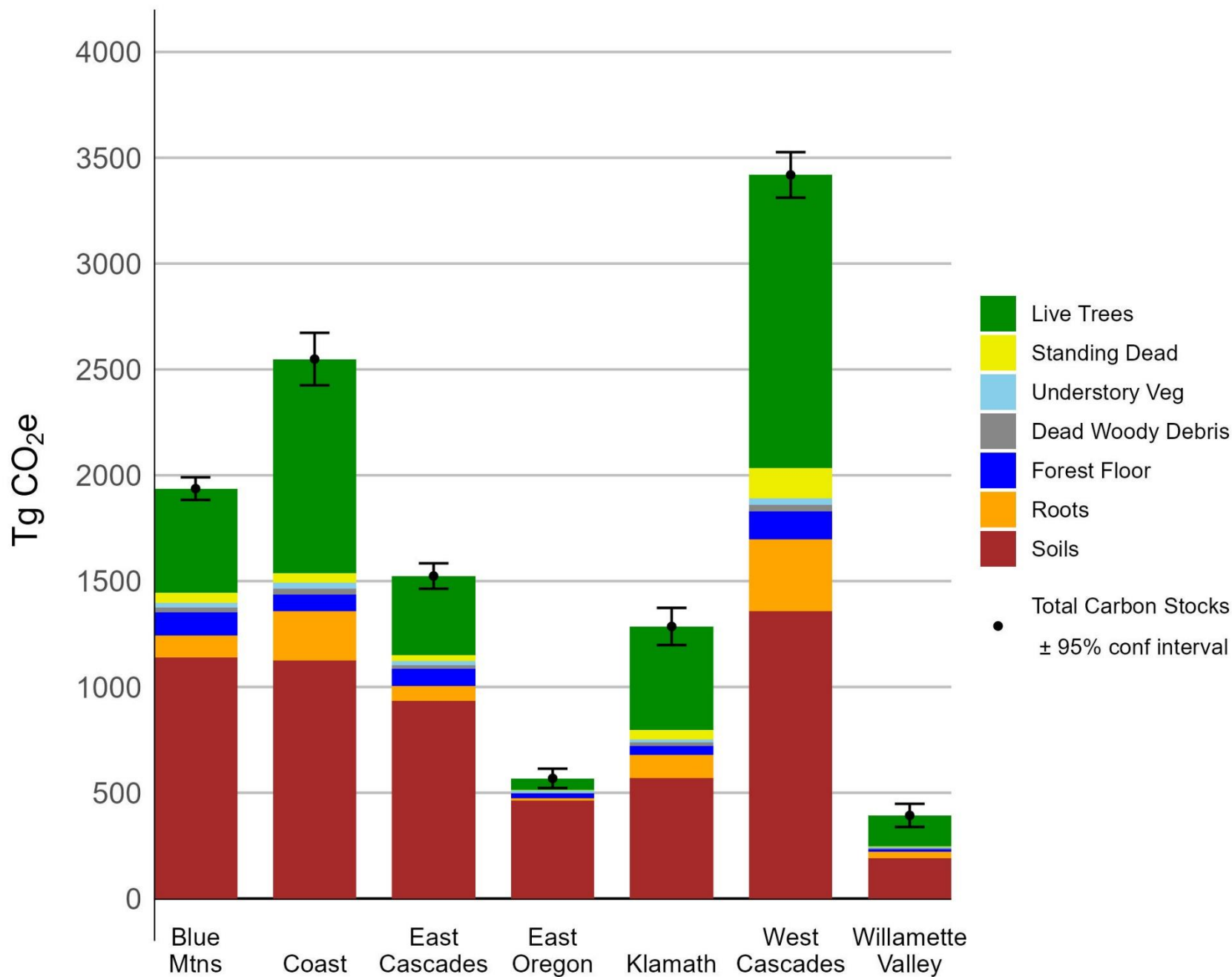
Ecoregion	Mg C per Acre	Mg CO2e per Acre
Blue Mtns	87.0	319.1
East Cascades	79.7	292.3
East Oregon	62.3	228.3
Klamath	117.7	431.5
Coast	132.0	483.9
West Cascades	139.3	510.9
Willamette Valley	101.6	372.6

Carbon stocks in Oregon's Forested Ecoregions by Pool and Owner for the 2012-2021 Inventory Period
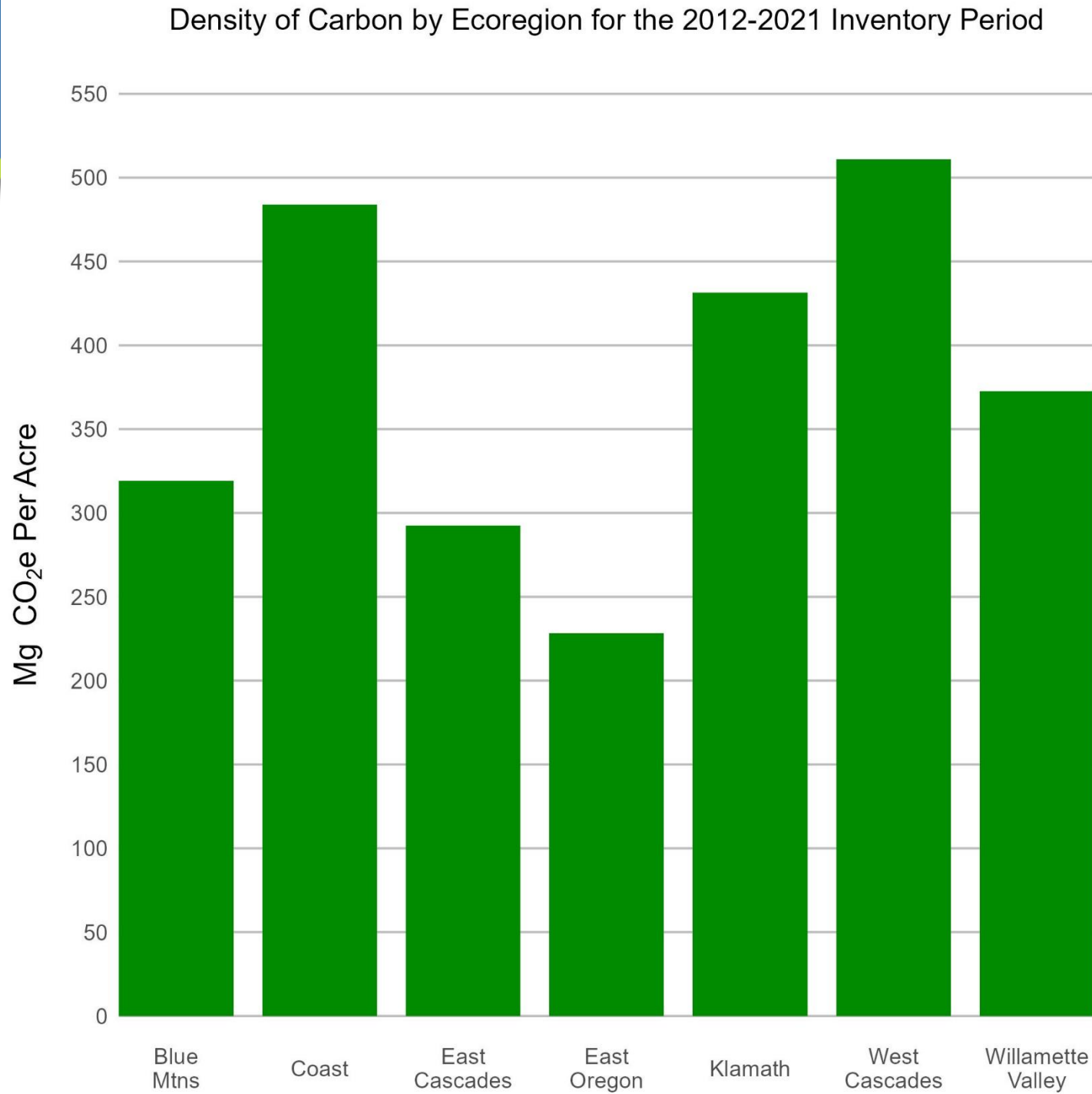
Y axis
the same across ecoregions

Carbon stocks in Oregon's Forested Ecoregions by Pool and Owner for the 2012-2021 Inventory Period

Y axis varies across ecoregions

Density of Carbon stocks in Oregon's Forested Ecoregions by Owner for the 2011-2021 Inventory Period
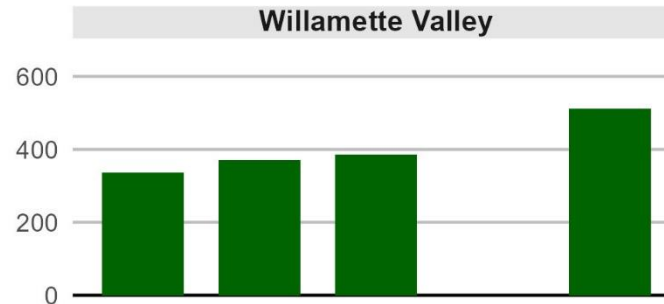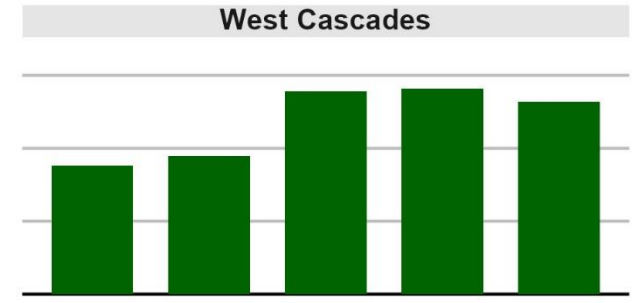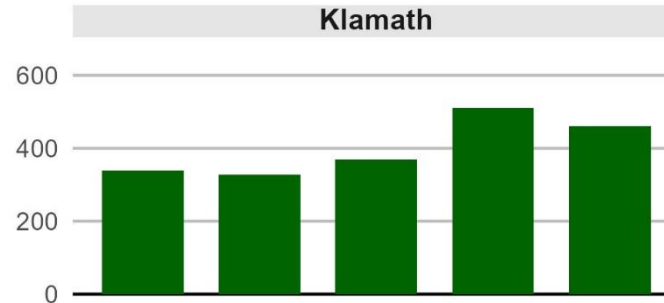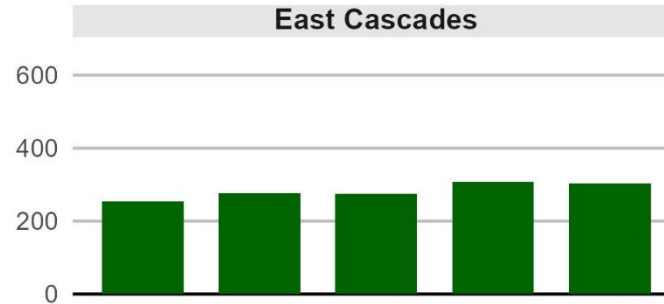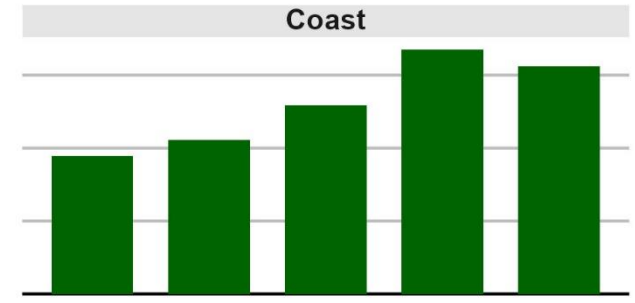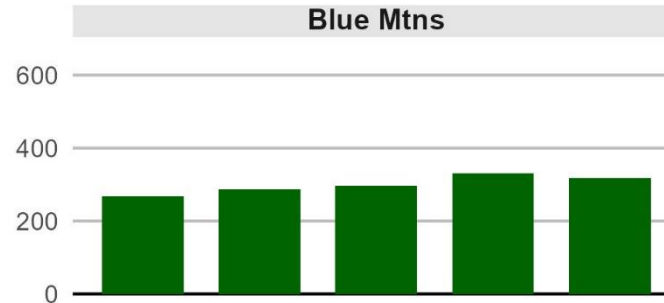
Forest Carbon Flux

- Annual forest carbon flux is estimated from actual measurements of growth-diameter increment, removals-cut, and mortality

- Current estimates of forest carbon flux are based <u>two</u> measurements of each tree on all forested plots in Oregon.

- Every pool of forest carbon has a rate of carbon input and rate of carbon output.

- Flux values represent the net change or the amount of CO_2e going into a pool minus the amount going out

Forest Carbon Flux

Annual Net CO2e Flux From Forest Pools in Forest Land Remaining Forest Land, 2001-2010 to 2011-2020

Forest Carbon Pools	Net flux	
	Total	SE
	$Tg\ CO_2e\ /yr$	
Live Trees	22.22	2.31
Standing Dead	2.18	0.72
Understory Veg	0.02	0.03
Dead Woody Debris	-2.12	0.67
Forest Floor	0.49	0.10
Roots	5.68	0.51
Soil Organic C	-0.10	0.14
Net flux All Pools	28.37	2.71

Average Annual Carbon Flux in Oregon's Forests by Pool and Owner For the 2021 Inventory Period
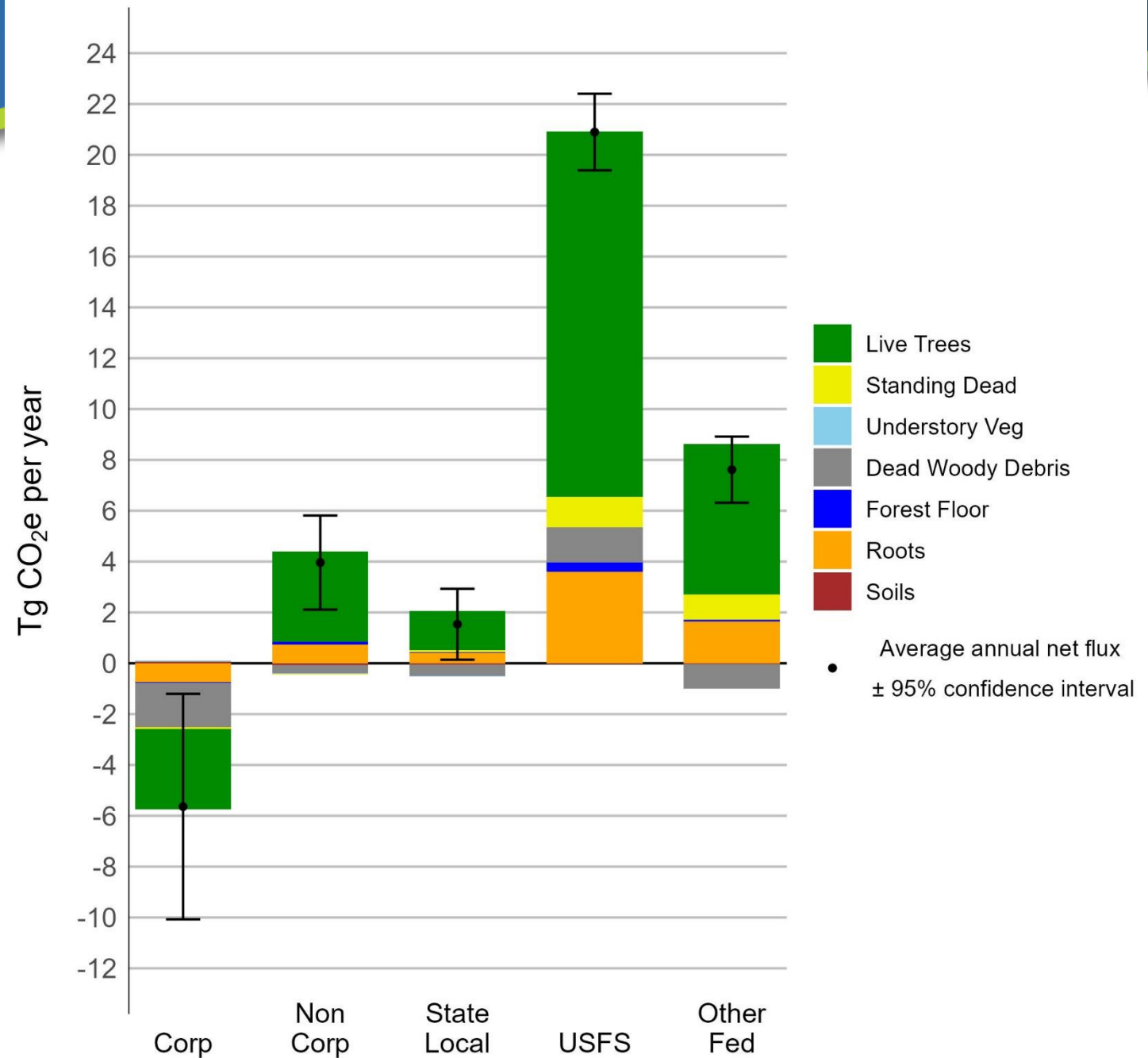
Average Carbon Flux per Acre per Year in Oregon's Forests by Owner For the 2021 Inventory Period
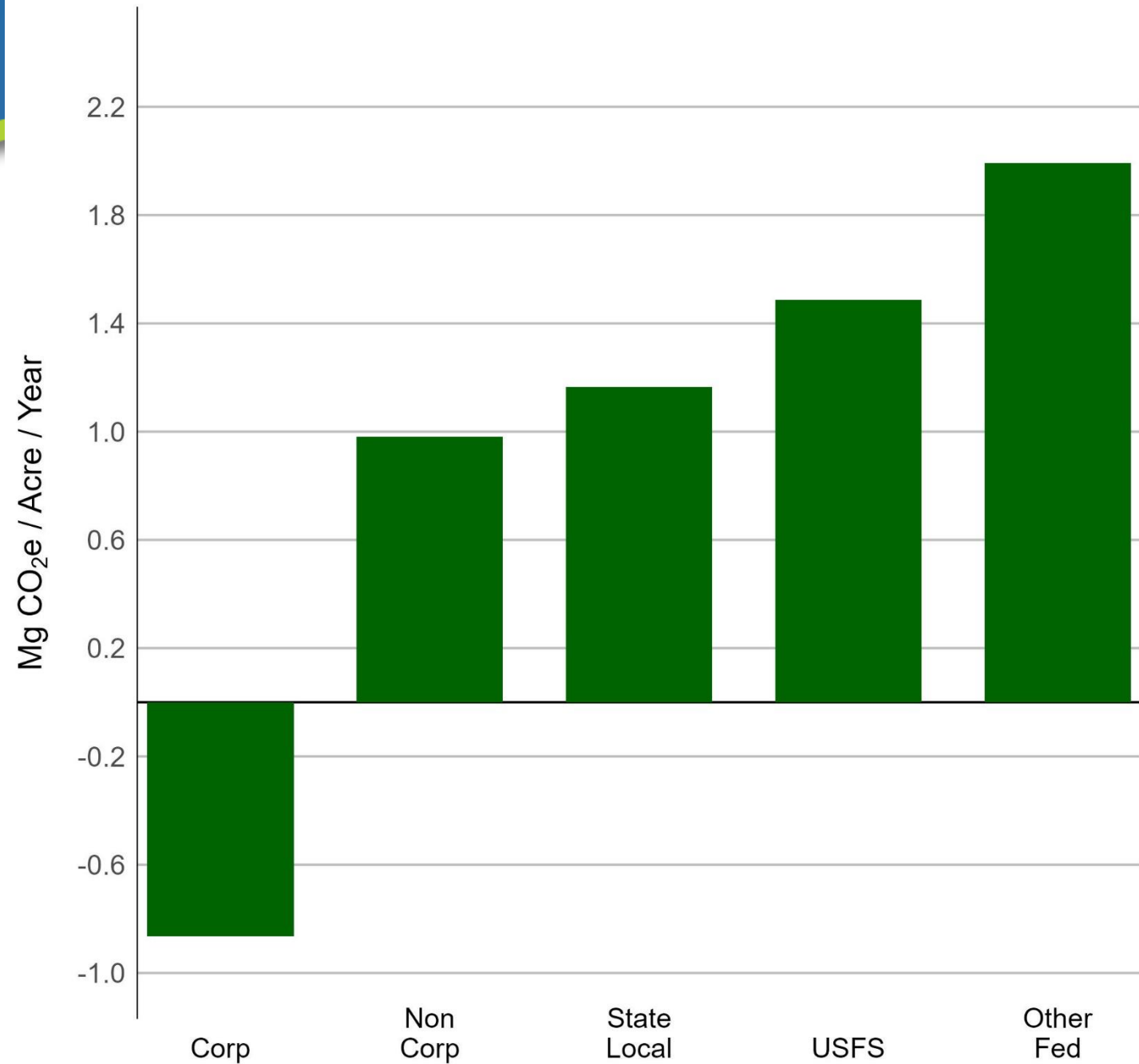
Annual Carbon Flux in Oregon's Forested Ecoregions by Pool For the 2021 Inventory Period
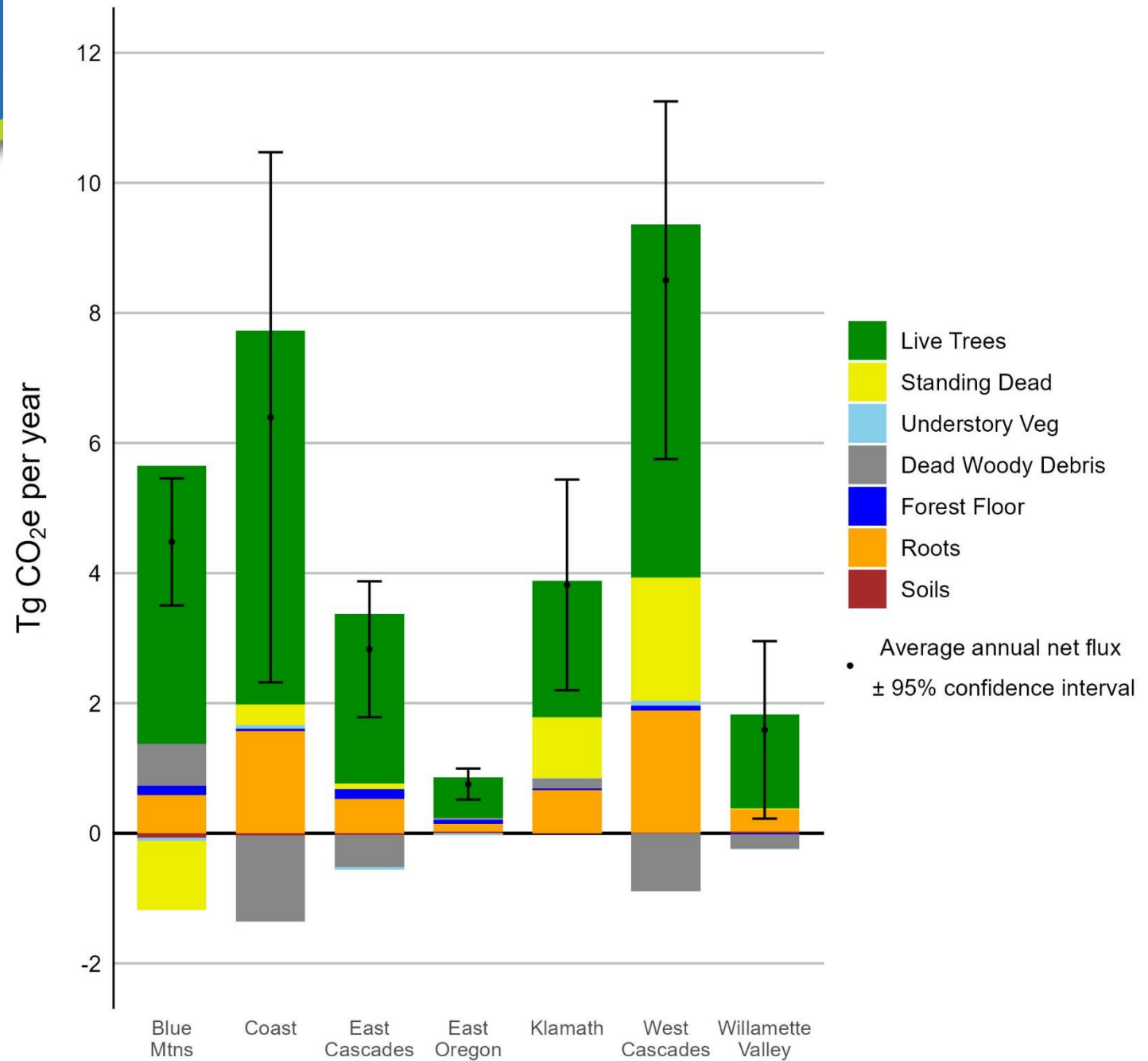
Average Carbon Flux per Acre per Year in Oregon's Forests by Ecoregion For the 2021 Inventory Period
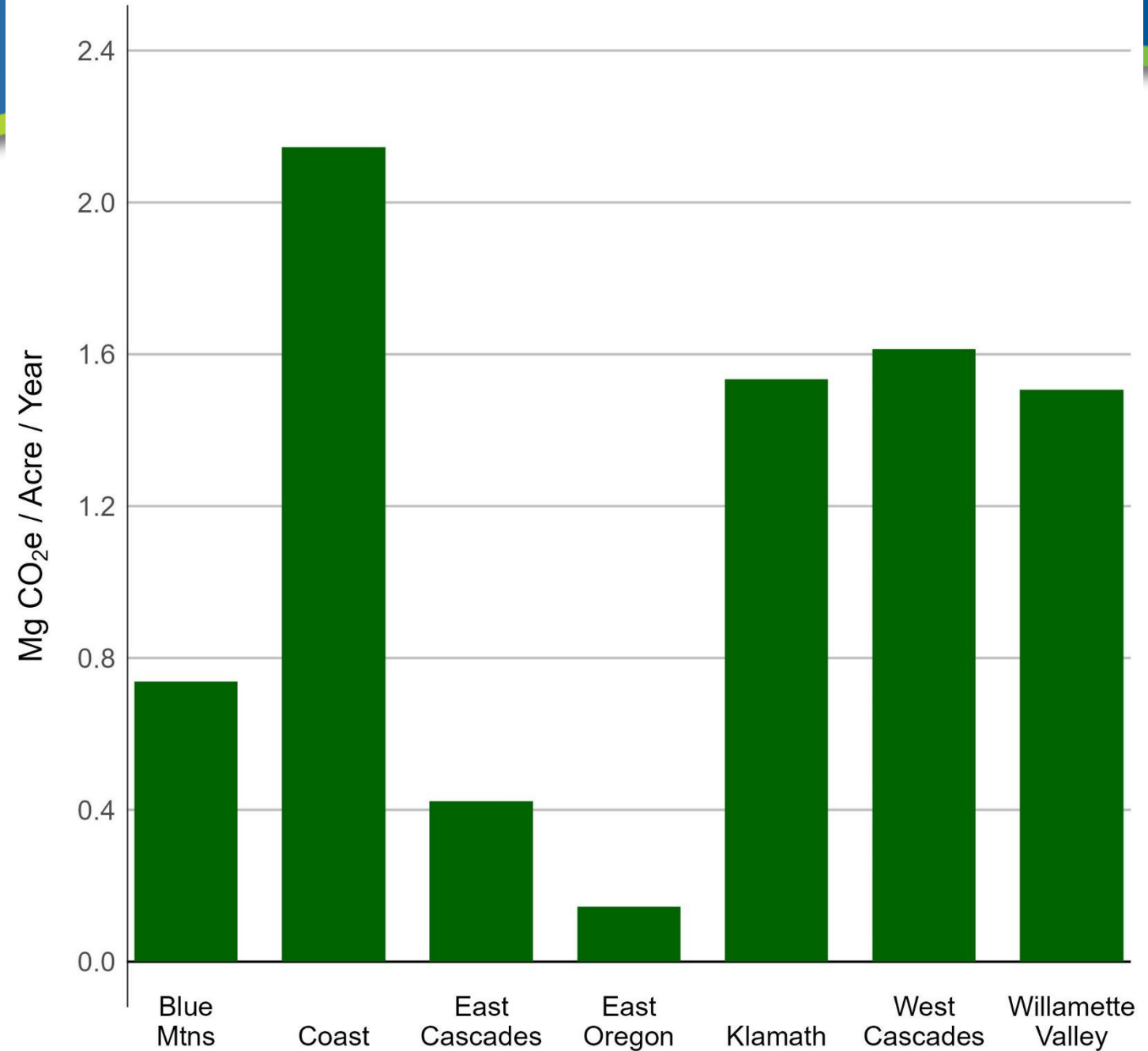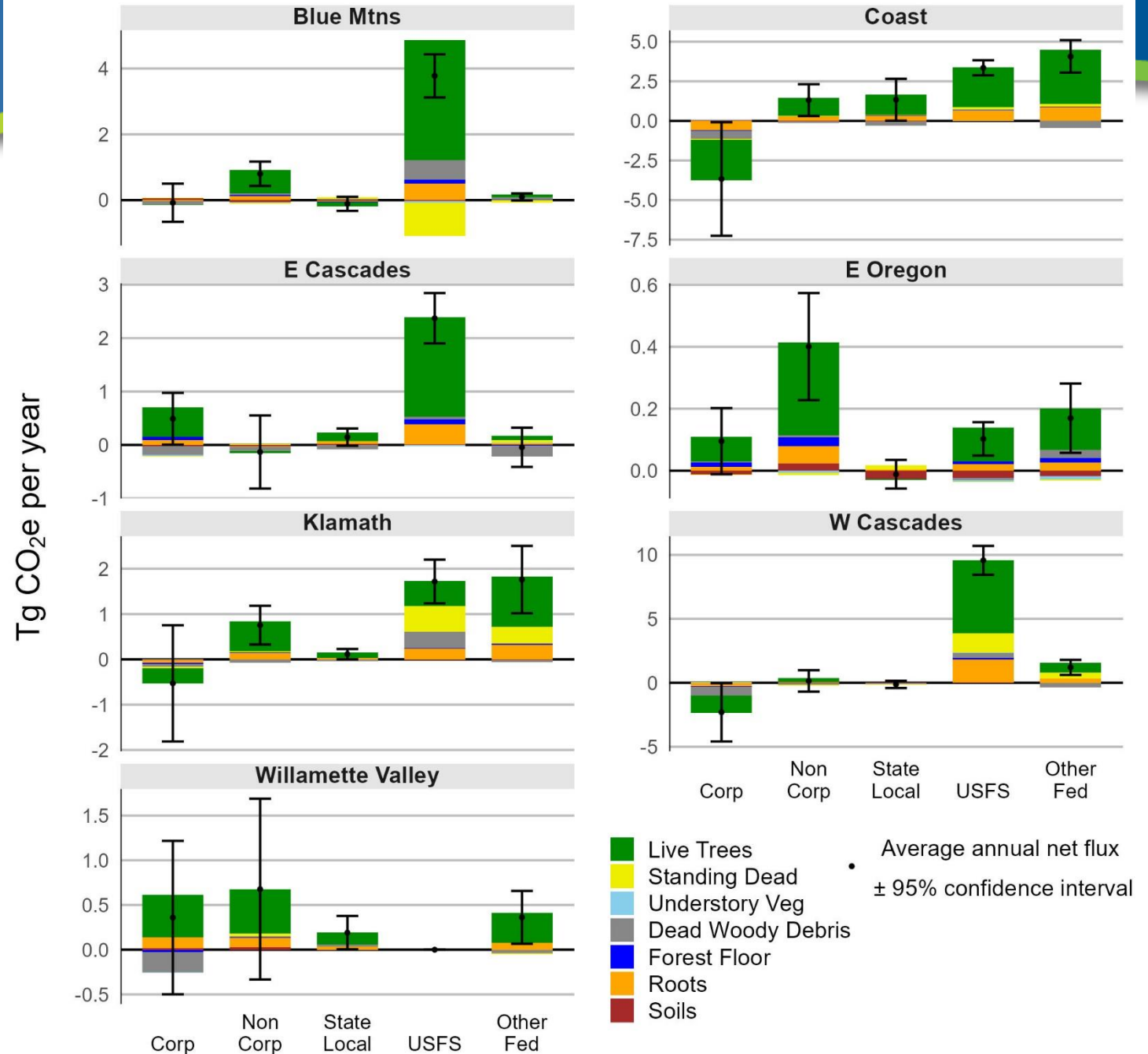
Average Annual Carbon Flux in Oregon's Forested Ecoregions by Pool and Owner For the 2021 Inventory Period

Y axis the same across ecoregions

Average Annual Carbon Flux in Oregon's Forested Ecoregions by Pool and Owner For the 2021 Inventory Period

Y axis varies across ecoregions

Legend:
- Live Trees
- Standing Dead
- Understory Veg
- Dead Woody Debris
- Forest Floor
- Roots
- Soils

Average annual net flux
± 95% confidence interval

Live Tree Flux All Oregon

	TgCO2e	SE
Gross Growth	91.63	0.80
Mortality	-30.86	0.95
Cut	-38.56	2.03

Average Annual Carbon Flux in Live Trees per Acre Per Year by Growth Removals and Mortality for the 2021 Inventory Period

Live Tree Flux / Acre / Year All Oregon

	MgCO2e/ Acre/Year
Gross Growth	3.08
Mortality	-1.04
Cut	-1.30
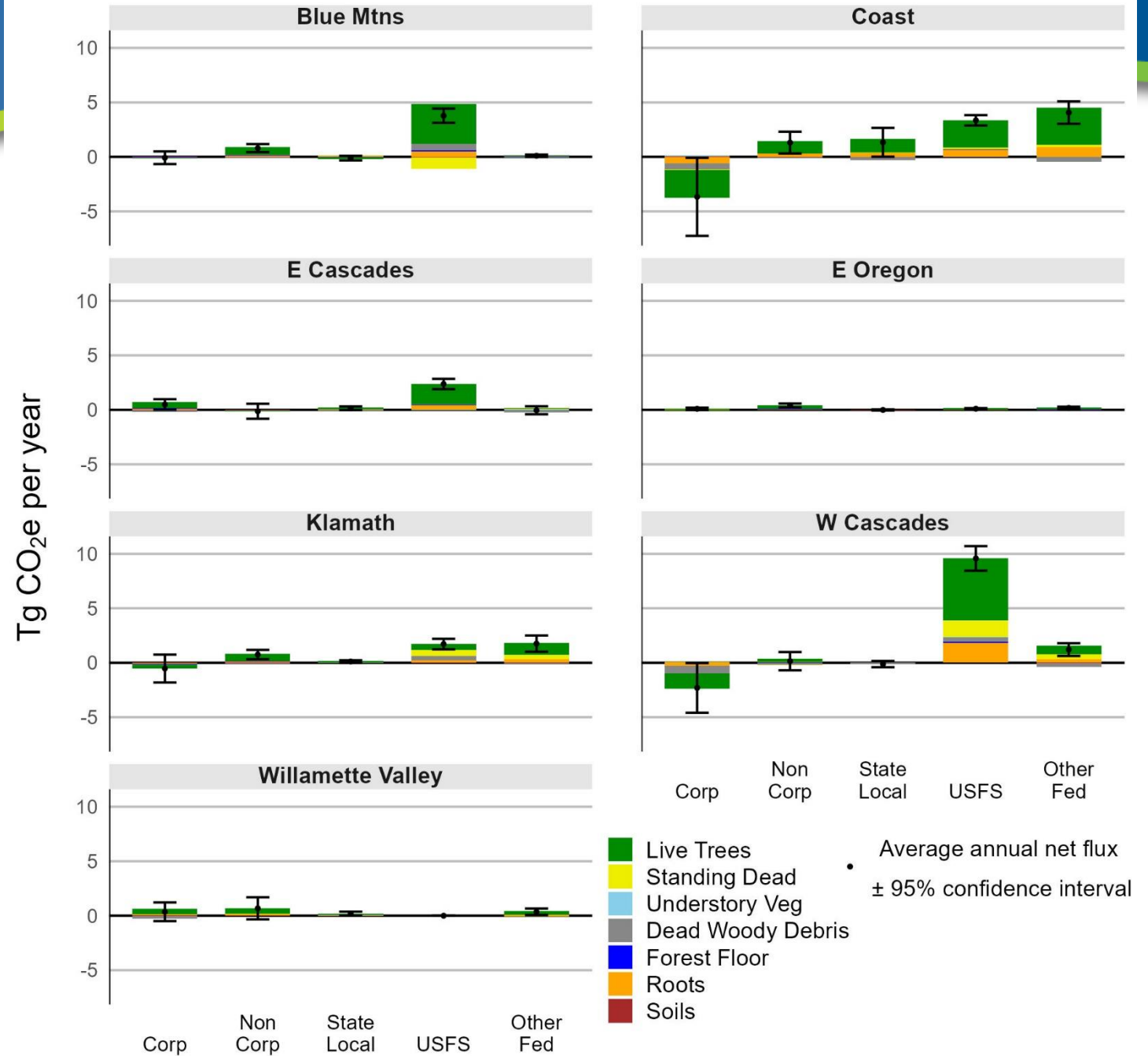
Live Tree Flux All Oregon

	TgCO2e	SE
Gross Growth	91.63	0.80
Mortality	-30.86	0.95
Cut	-38.56	2.03

Average Annual Carbon Flux in Live Trees per Year for the 2021 Inventory Period

Legend:
- Gross Growth
- Harvest
- Mortality
- Average annual net flux ± 95% confidence interval

Y-axis: Tg CO$_2$e per Year

X-axis categories: Blue Mtns, Coast, East Cascades, East Oregon, Klamath, West Cascades, Willamette Valley
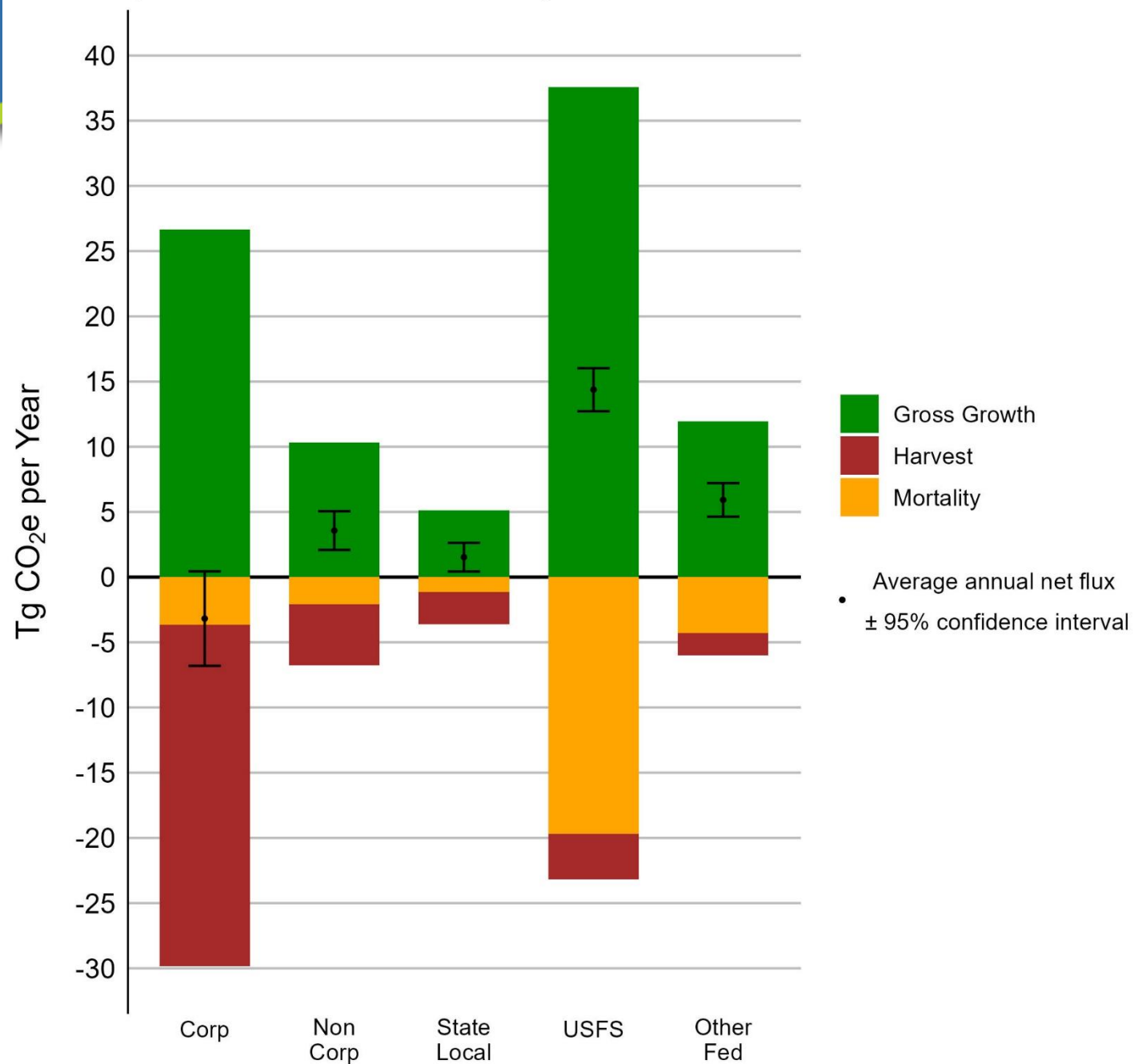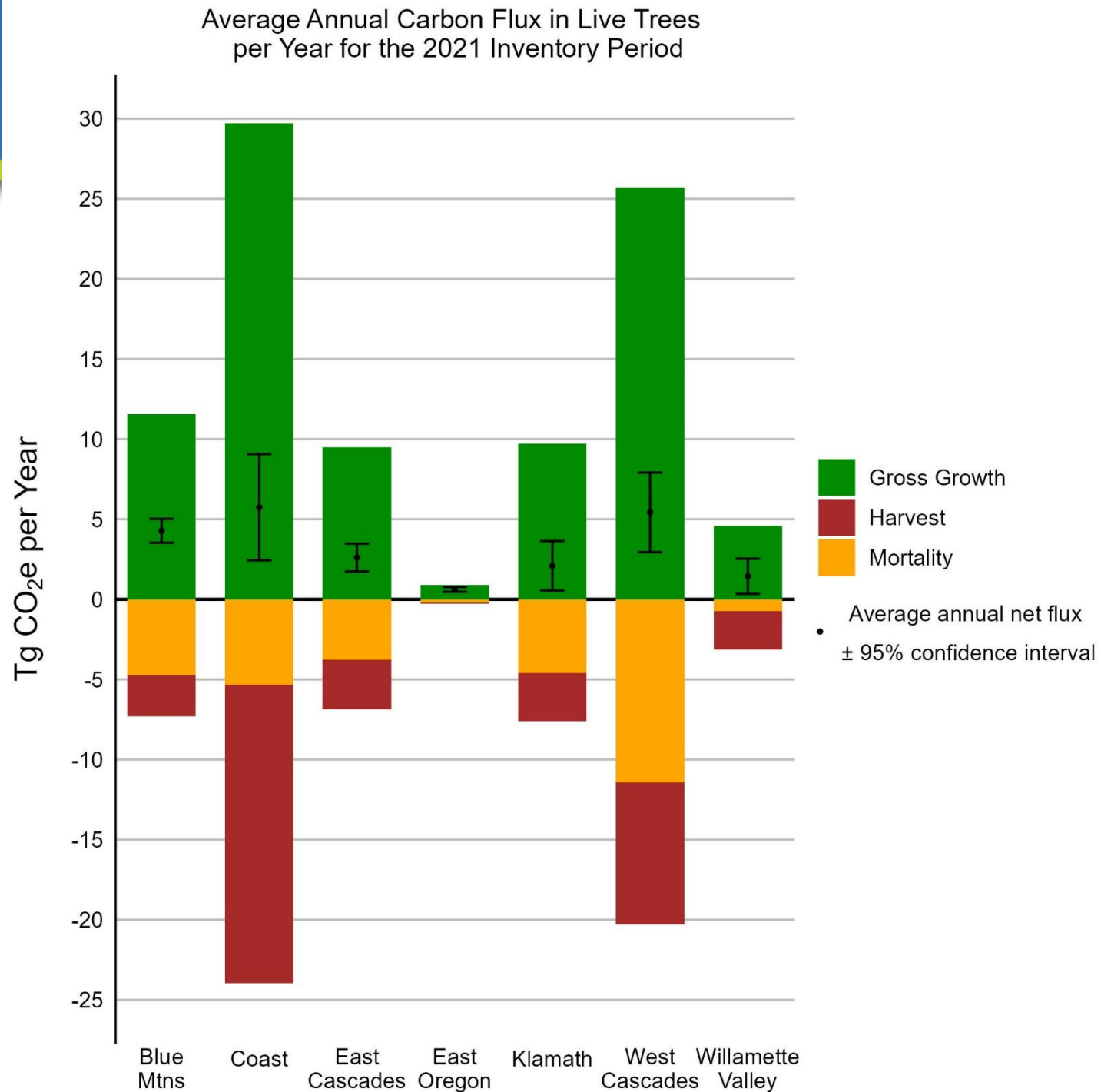
Live Tree Flux / Acre / Year All Oregon

	MgCO2e/ Acre/Year
Gross Growth	3.08
Mortality	-1.04
Cut	-1.30

Average Annual Carbon Flux in Live Trees / Acre / Year by Ecoregion for the 2021 Inventory Period

Stacked bar chart titled "Average Annual Carbon Flux in Live Trees / Acre / Year by Ecoregion for the 2021 Inventory Period." Y-axis: Mg CO_2e / Acre / Year, ranging from -5 to 6. X-axis categories: Blue Mtns, Coast, East Cascades, East Oregon, Klamath, West Cascades, Willamette Valley. Legend: Gross Growth (green), Harvest (dark red), Mortality (orange).
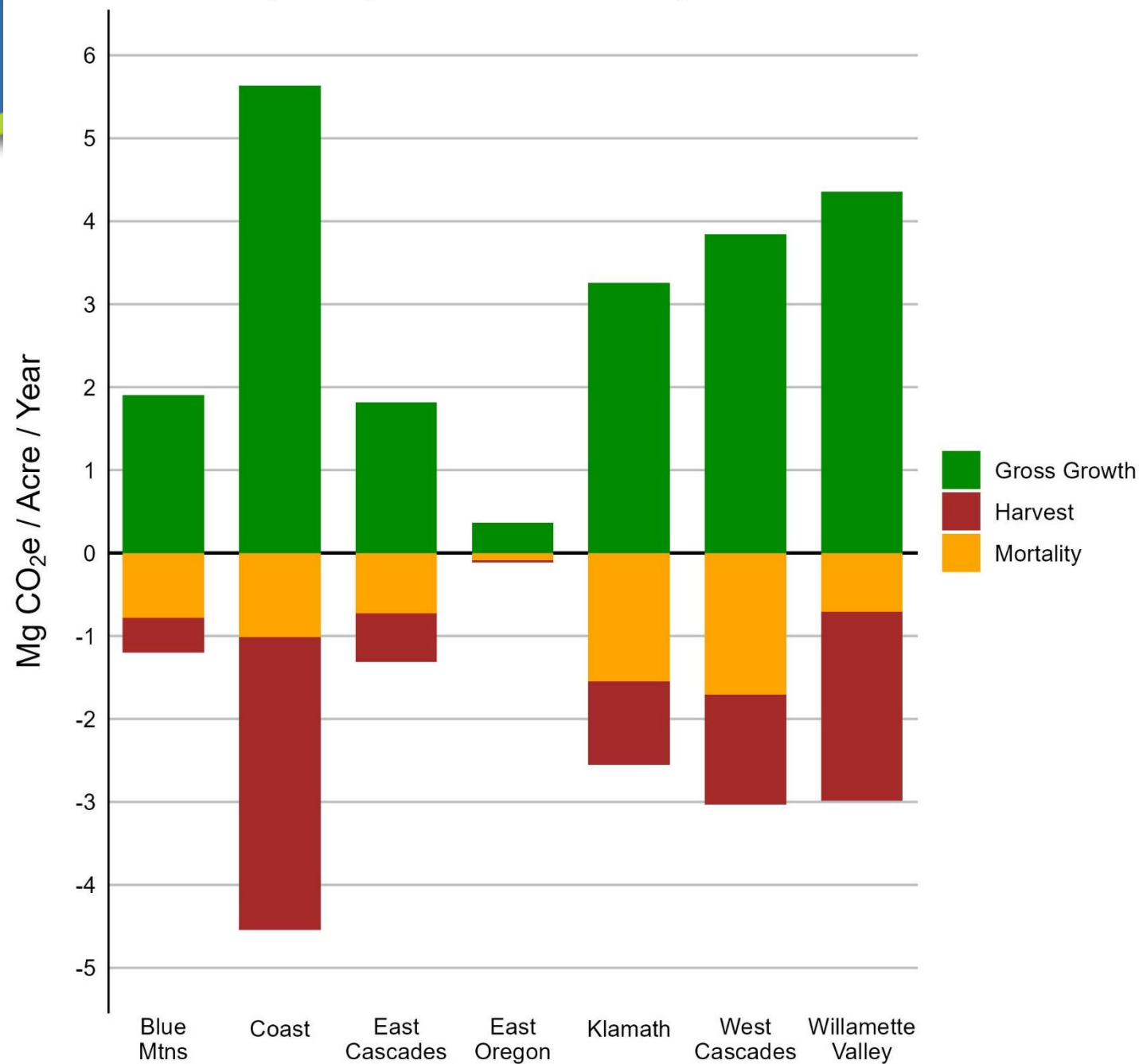
Average Annual Emissions from Fire in Oregon's Forests by Greenhouse Gas and Owner For the 2021 Inventory Period
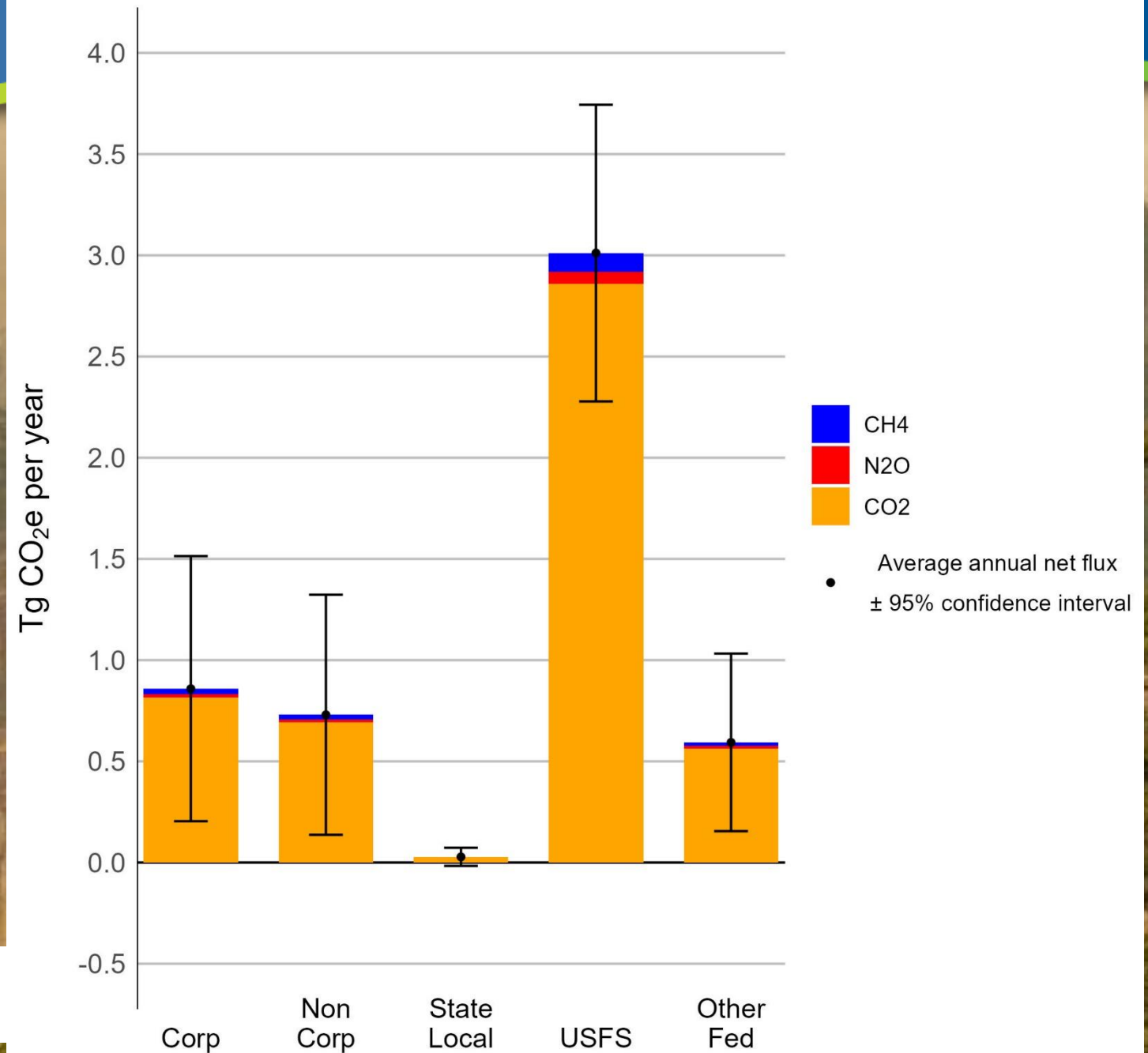
Busby et al. 2023. Inventory analysis of fire effects wrought by wind-driven megafires in relation to weather and pre-fire forest structure in the western Cascades. Fire Ecology 19:58 https://doi.org/10.1186/s42408-023-00219-x

Harvested Wood Product Carbon Storage and flux for Oregon
1906 - 2023

Harvested Wood Product Modeling Framework

Stockmann et al. 2012, Carbon Balance and Management

Web application: https://groomanalyticsllc.shinyapps.io/HWP-C-vR/

The HWP Modeling Framework

– Harvested timber
  - Conversion of Board feet to cubic foot volume
  - Conversion factors decline by decade with tree diameters.

– 40 Timber products
  - sawtimber, poles, small roundwood, etc.

– 64 Primary products
  - lumber, plywood, mill residue pulp, fuel, non-structural panel, etc.
  - Conversion from ccf to Mg C occurs.

– 224 End uses
  - New residential construction (single, multi family, mobile homes), new non-residential construction, manufacturing (household furniture, other furniture, other products), shipping, etc.
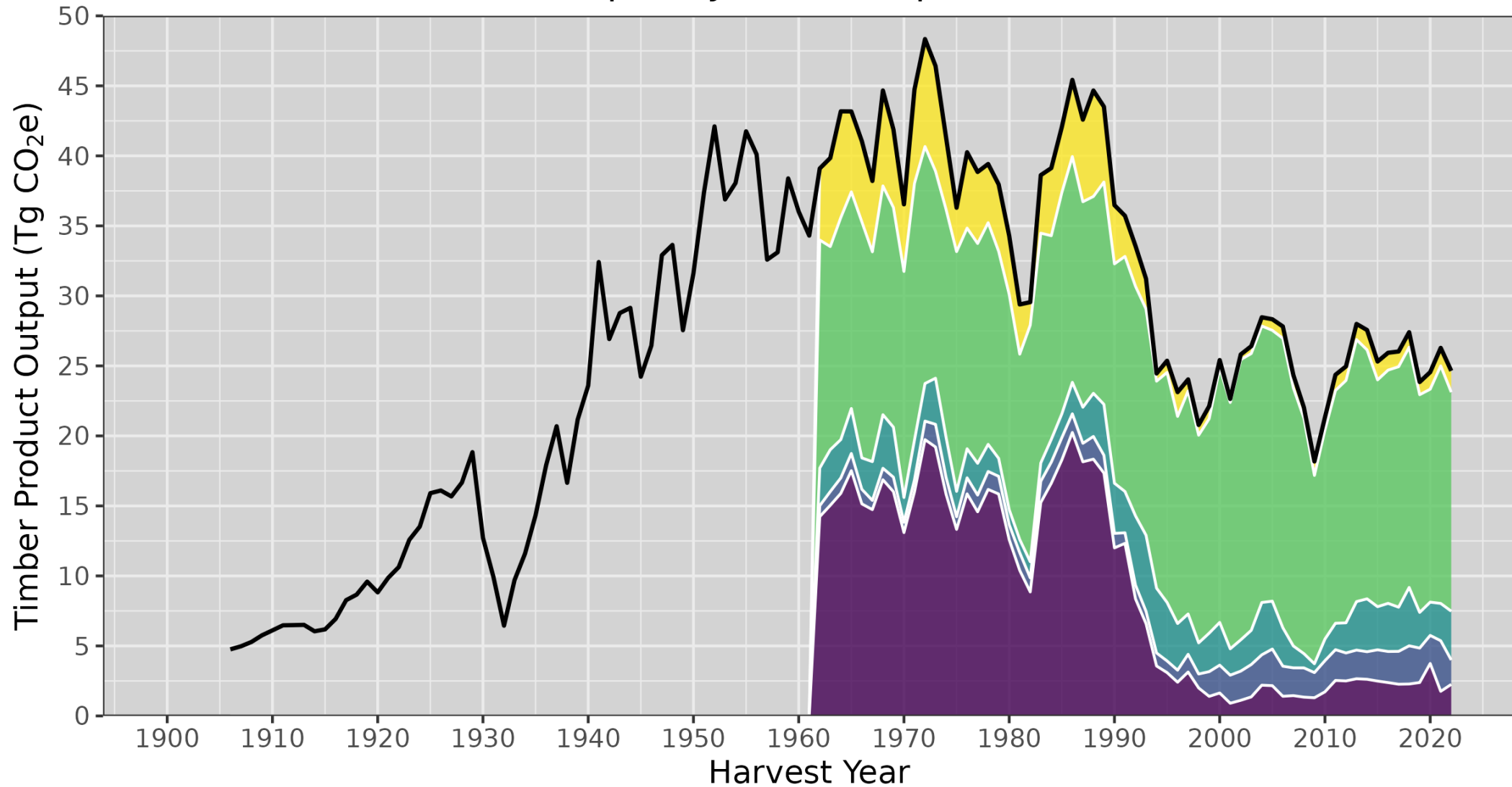
The HWP Carbon Model framework
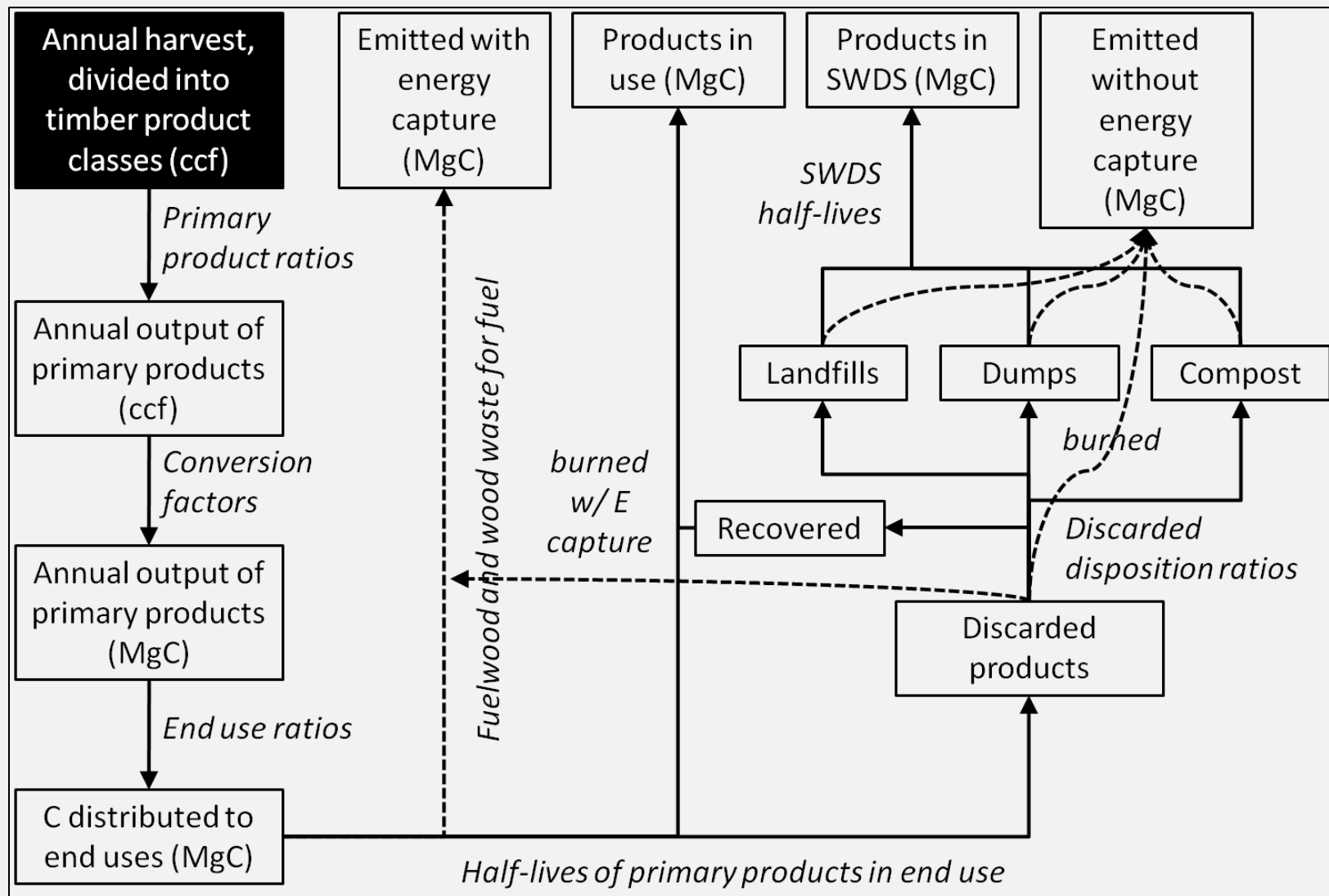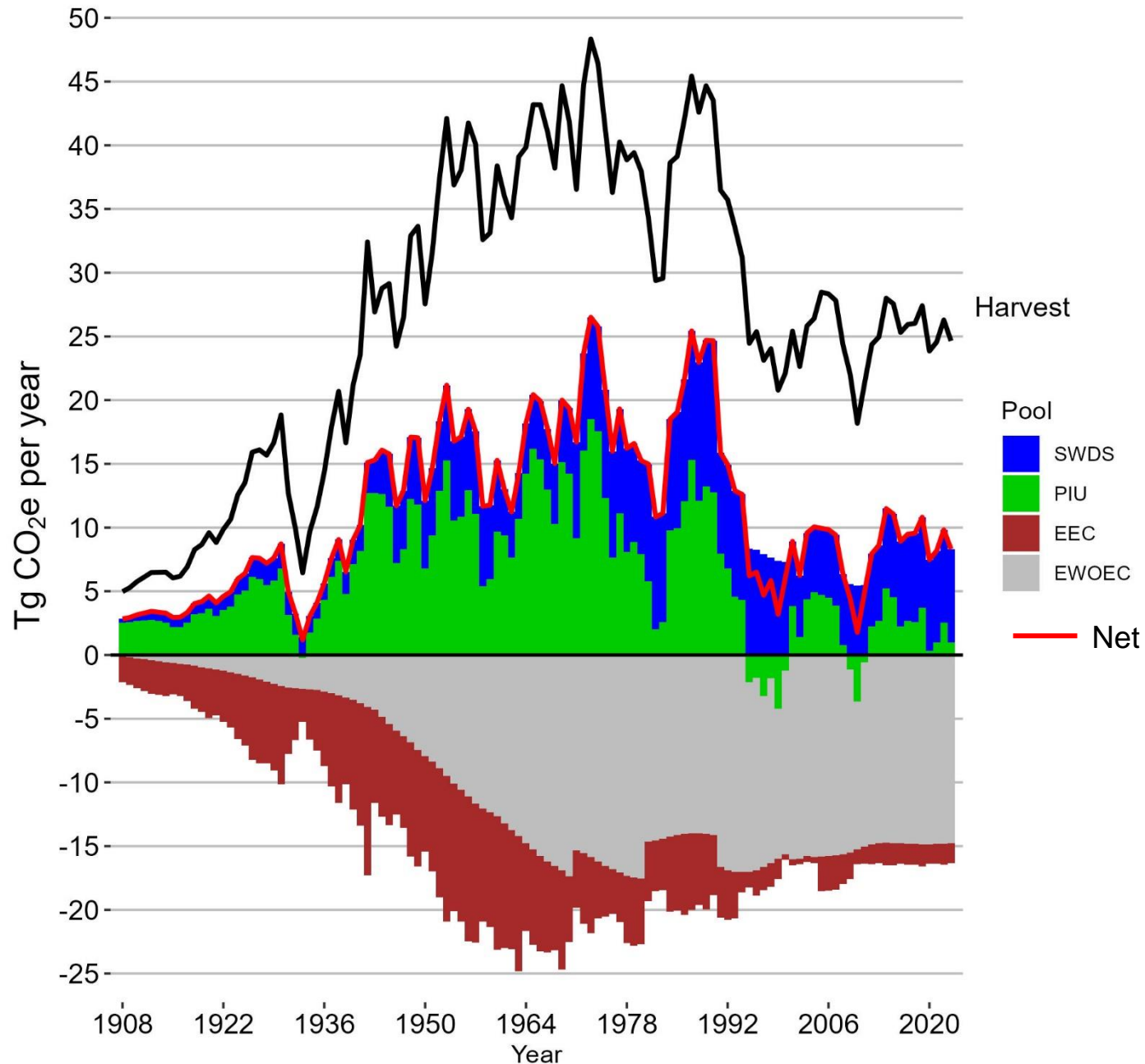

SWDS = Solid Waste Disposal Sites

ccf = 100 cubic feet

Annual timber harvest output by ownership

Annual Change in Timber Harvest, Wood Products, and Emissions Pools

- Harvest in Oregon as annual timber product output, converted to Teragrams of CO_2e, 1906 to 2023.

- SWDS = Solid Waste Disposal Sites

- PIU = Products in use

- EEC = Emissions with energy capture (fuelwood)

- EWOEC = Emissions without energy capture

Stock of CO_2e in Products Pools and Emissions Categories
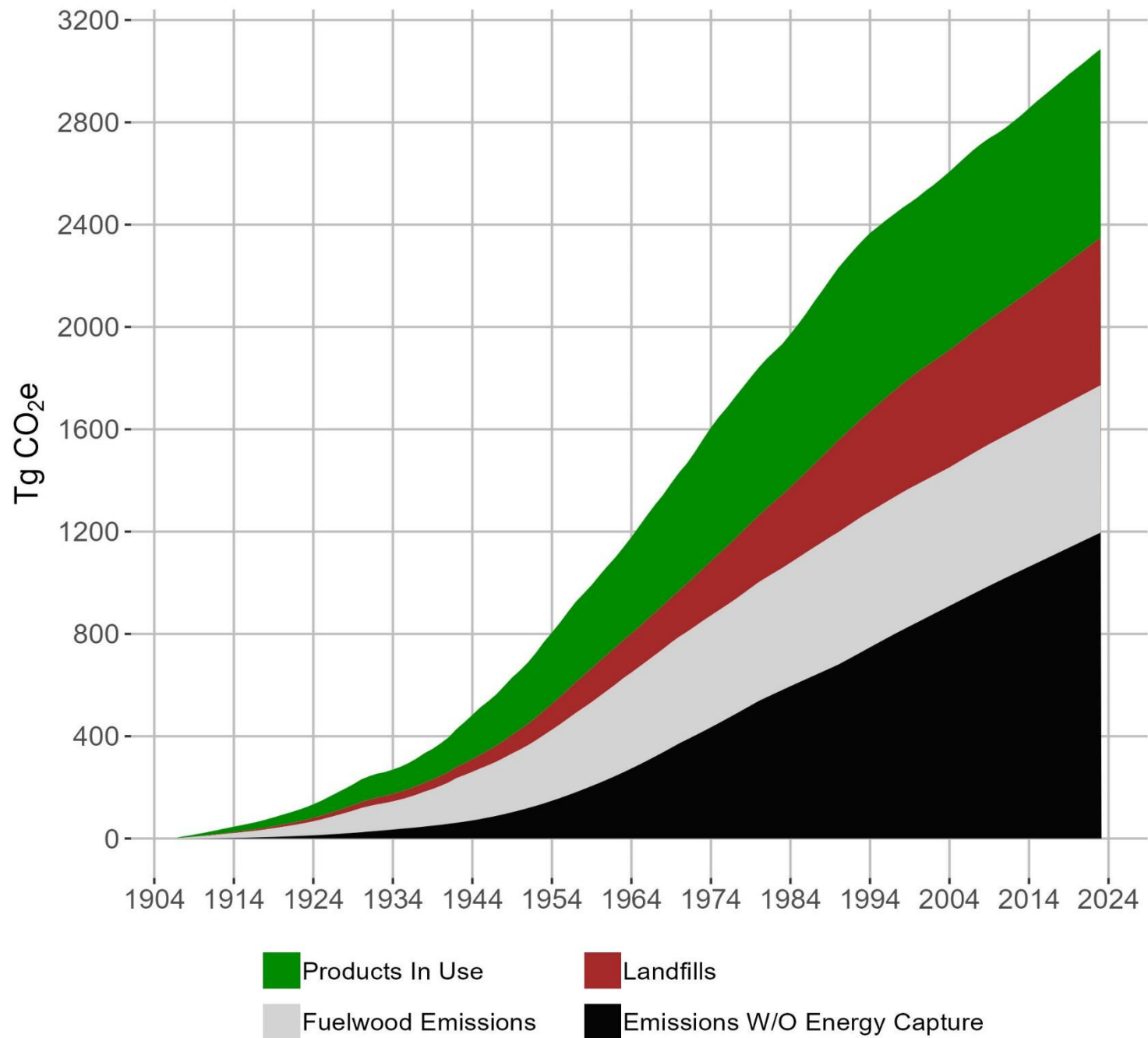
Products in use = 737 Tg CO_2e
+ Landfills = 578 Tg CO_2e
Total = 1315 Tg CO_2e
(358 Tg C)

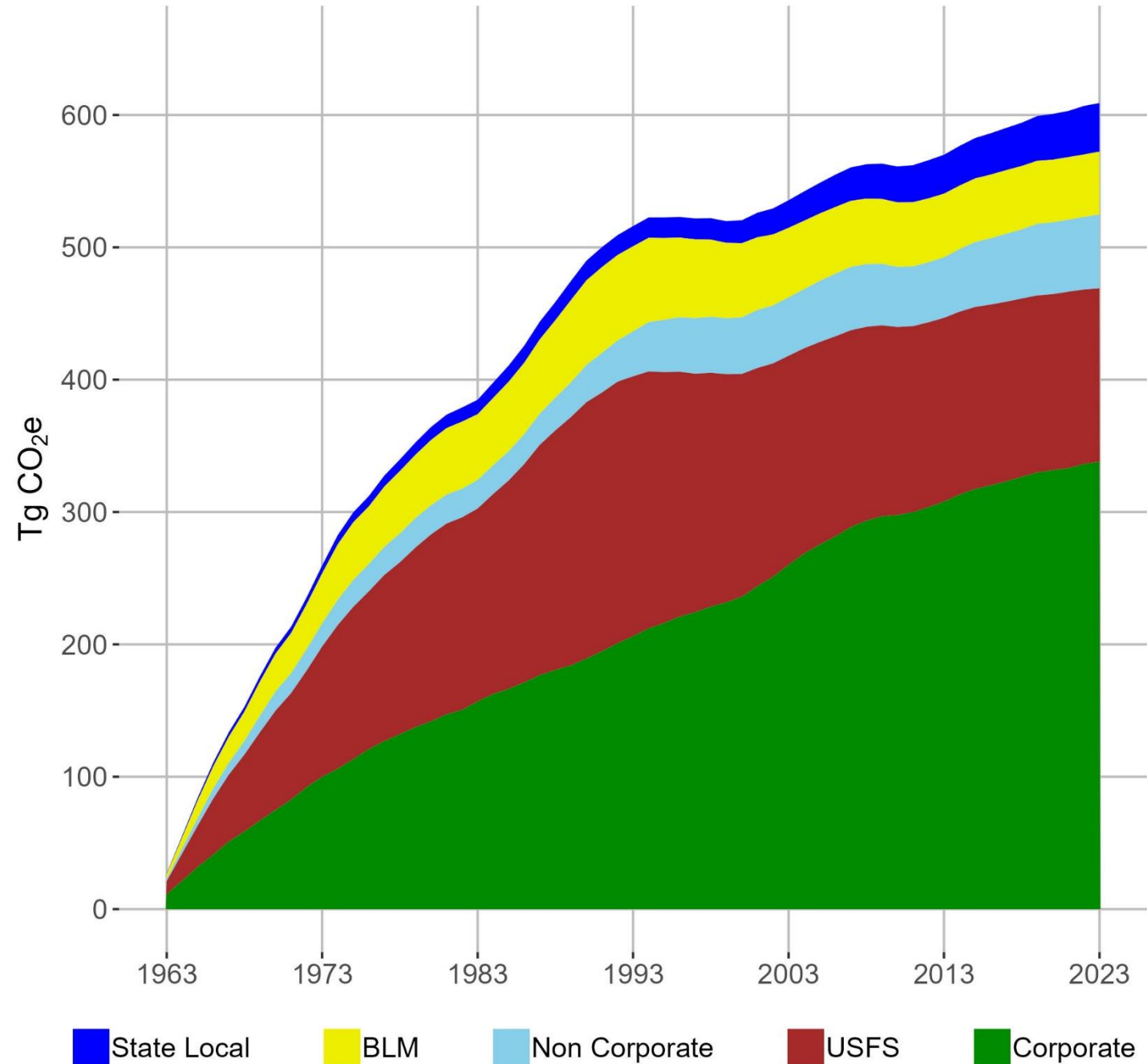Fuelwood emissions = 576 Tg CO_2e
+ no energy capture = 1196 Tg CO_2e
Total = 1772 Tg CO_2e
(483 Tg C)

Total harvested = 3086 Tg CO_2e
(840 Tg C)

Legend: Products In Use, Landfills, Fuelwood Emissions, Emissions W/O Energy Capture

Carbon Storage, Products In Use

Stock of CO$_2$e in Products in Use by Ownership

Tg CO$_2$e

State Local | BLM | Non Corporate | USFS | Corporate

Carbon Storage in Solid Waste Disposal Sites
(Landfills and Dumps)

Stock of CO$_2$e in Solid Waste Disposal sites by Ownership

State Local — BLM — Non Corporate — USFS — Corporate
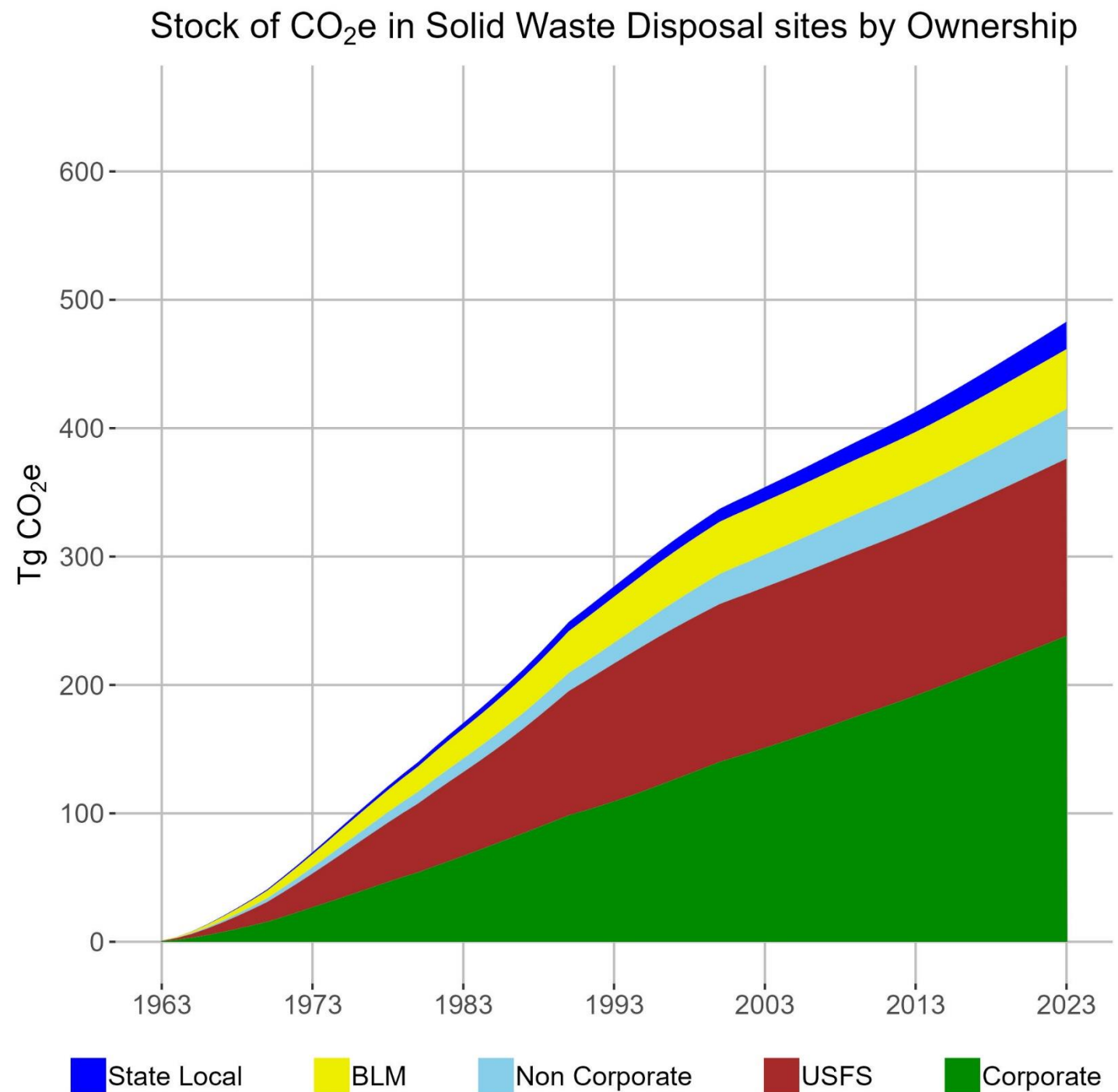
Monte Carlo mean (yellow line) and 90% confidence intervals (black shading) for carbon in storage and emission pools
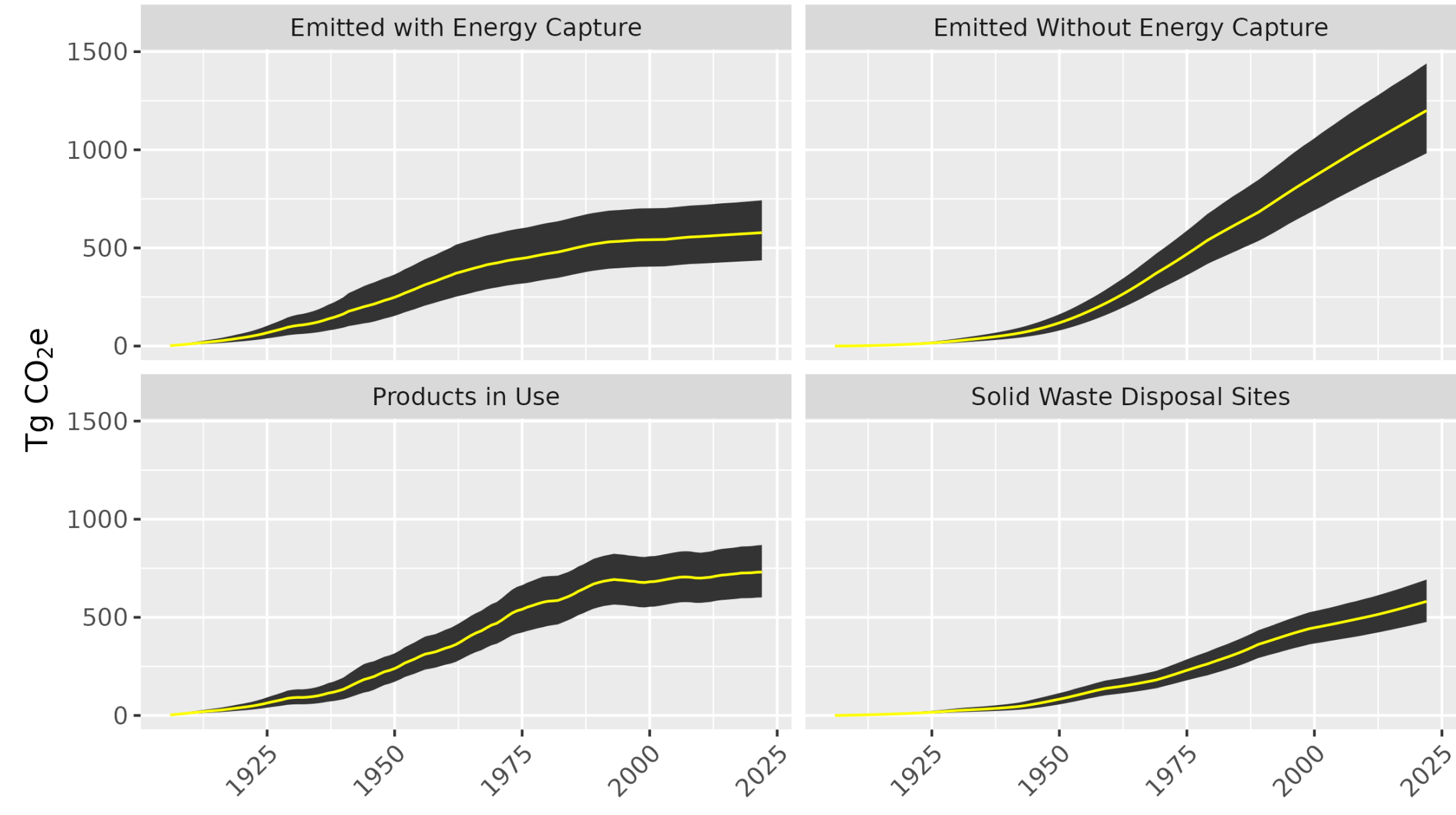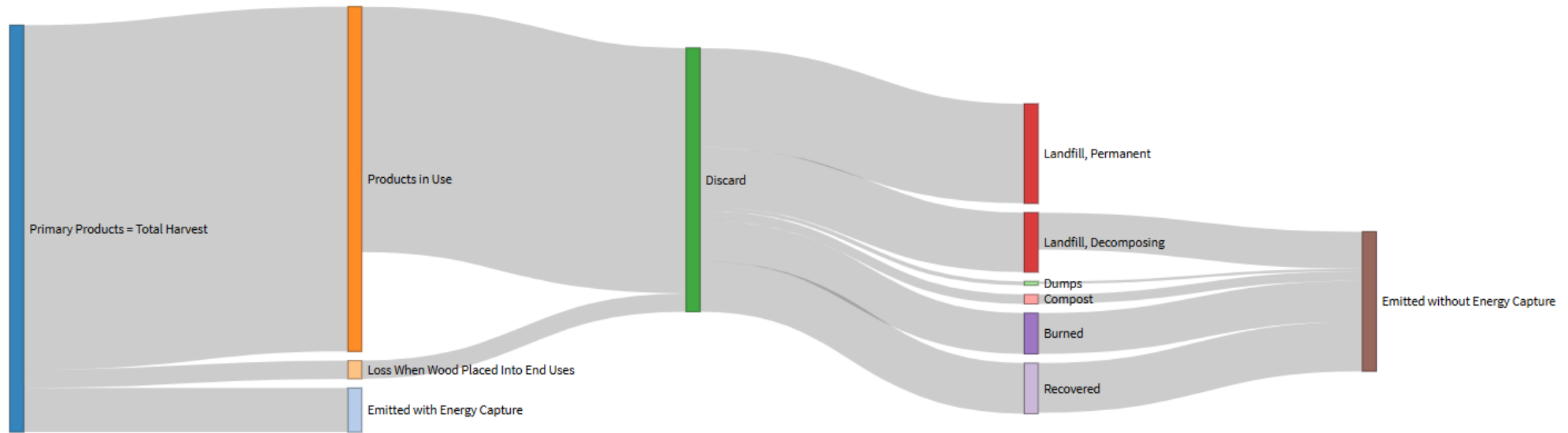
https://groomanalyticsllc.shinyapps.io/HWP-C-vR/
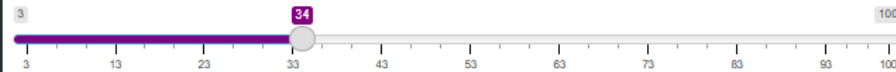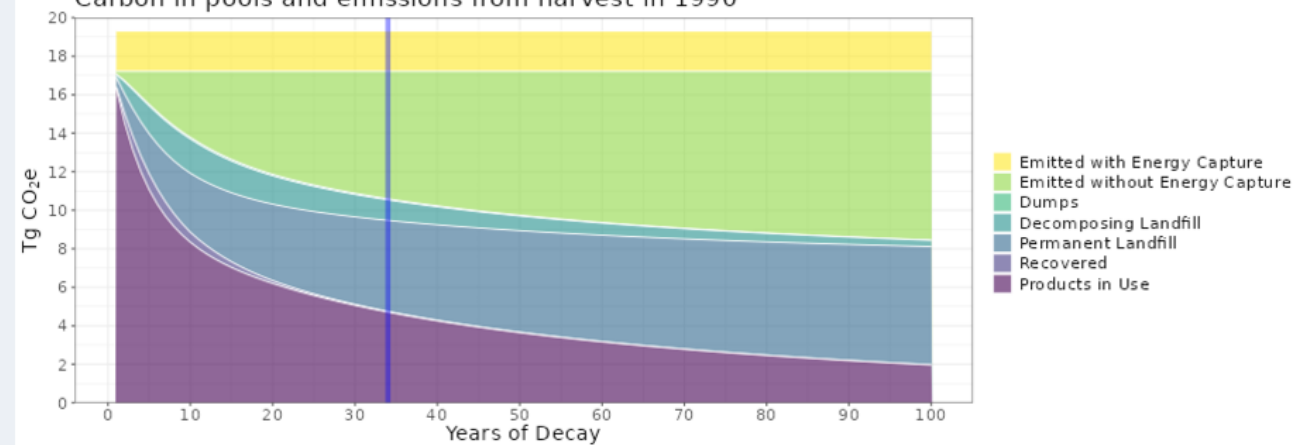
Conclusions – Carbon Stocks

- The amount of carbon in wood products, made from timber harvested in Oregon (1906-2023), is about 6.3% of the total stock of forest carbon.

- The carbon in the pool of products-in-use combined with landfill pool is about 11% of the pool of forest carbon

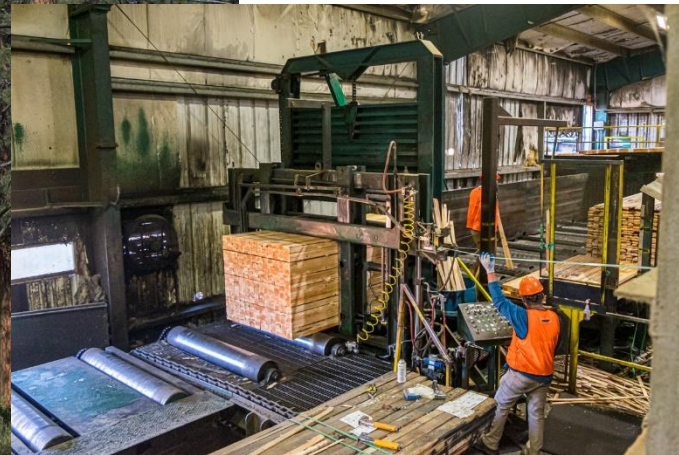| Total Carbon Stocks	Tg CO_2e	(Tg C)
Forest Pools	11,675.34	(3,184.1)
Pool of Wood Products in-use	737.19	(201.05)
Landfills	577.98	(157.63)
Total Carbon	12,990	(3542.86)

Conclusions – Carbon Flux

- Over the 20-year forest monitoring period (2001-2021) Oregon's forests have been a net sink of carbon

- The average increase in the pool of wood products each year has been about 8% of the average positive flux in Oregon's forests.

- The average annual increase in the landfills was more than twice the pool of products in use.

- The average annual carbon flux in forests and wood products combined was 36.7 Tg CO_2e

Annual Flux of Carbon, 2001-2021 average	Tg CO_2e
Forest pools	+ 28.37
Pool of Wood Products in-use	+ 2.39
Pool of Landfills	+ 5.94
Total Forest Sector Carbon Flux	+ 36.70

The End