Washington's Forest Carbon Inventory

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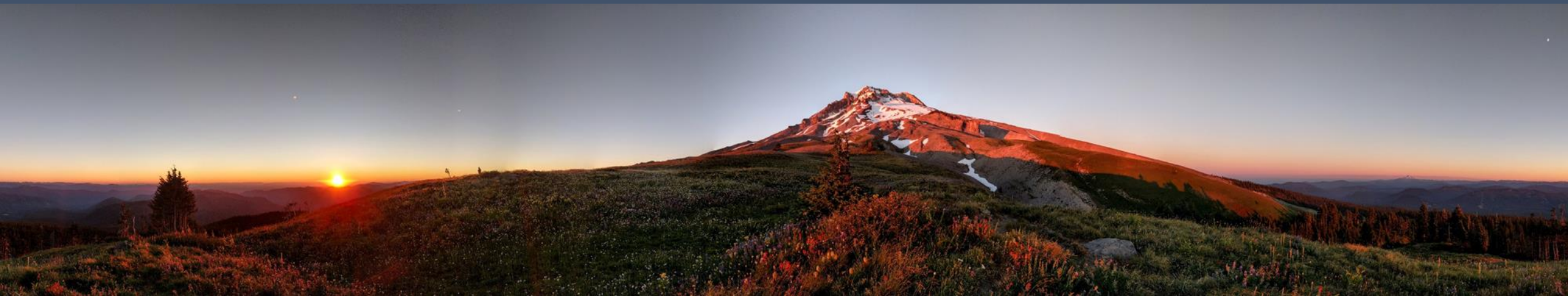
Pacific Northwest Research Station

Overview

- FIA forest carbon inventory methodology
- Washington forest carbon inventory results
- Next steps

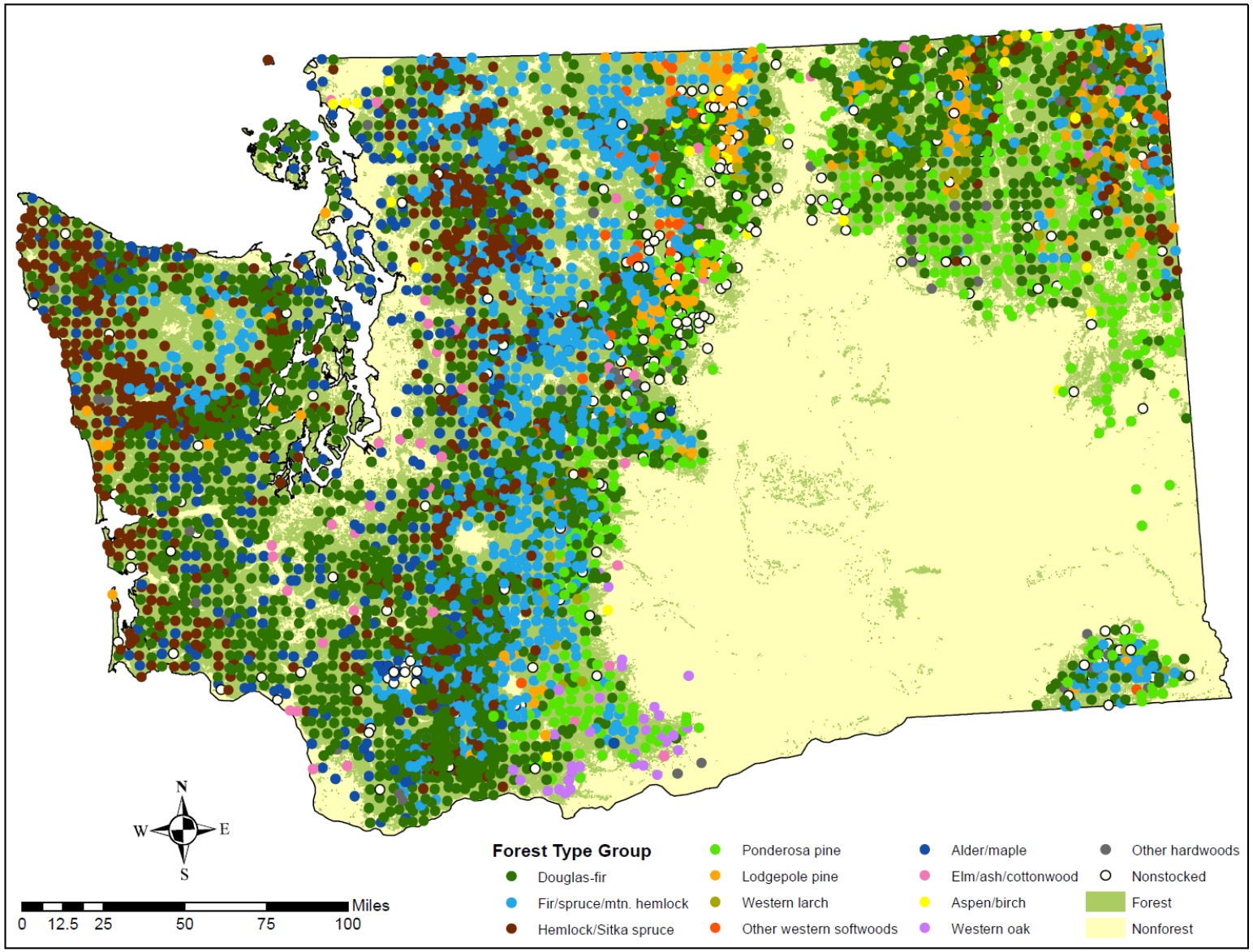


FIA Forest Carbon Pools

- Forest carbon pools include:
  - Live trees
    - Foliage
    - Roots
  - Standing dead trees
    - Roots
  - Downed woody debris
  - Understory vegetation
    - Roots
  - Forest floor – duff and litter
  - Soils
- Carbon stored as harvested wood products is not included

Forest Carbon Stocks – CA, OR, WA

- Carbon stocks reported in units of carbon, metric tons (MT)
- Above-ground live trees: Uses PNW regional biomass equations, added foliage weight
- Above-ground dead trees: Same as live trees, reduction for decay and tendency for bark and branches to shed faster than bole biomass
- Below-ground live and standing dead trees (roots): National FIA protocol
- Downed woody debris: National FIA protocol, piles not included
- Understory vegetation: As modeled and populated in FIADB
- Forest floor: As modeled and populated in U.S. National Greenhouse Gas Inventory
- Organic soils: As modeled and populated in U.S. National Greenhouse Gas Inventory

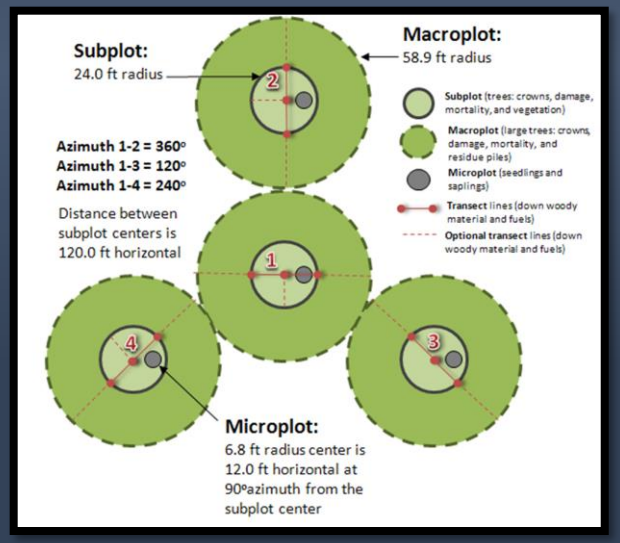


FIA in Washington

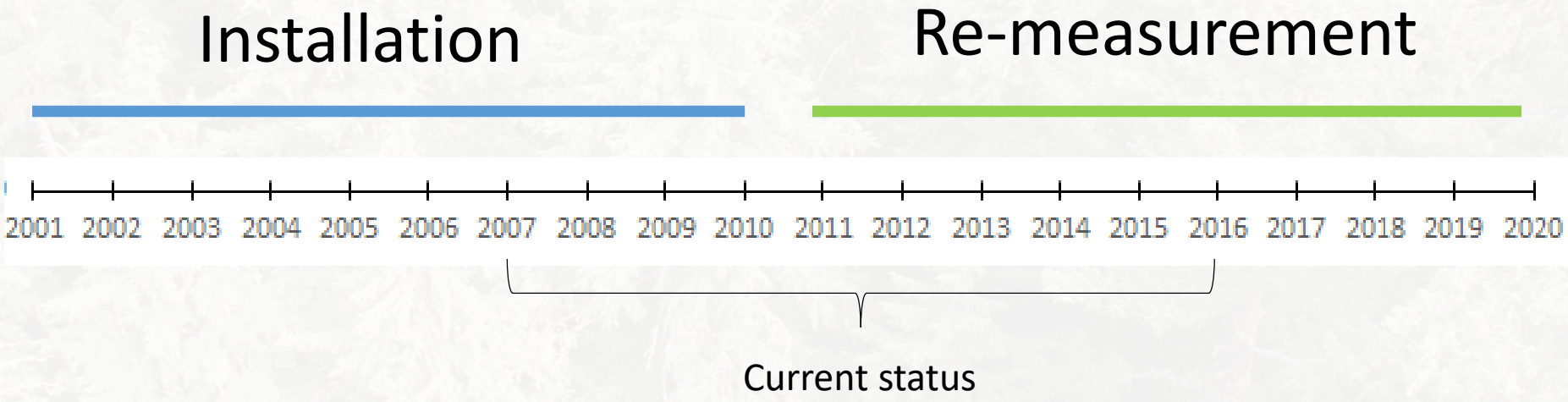
Annual field measurements began 2002

Current 10-year period, 2007-2016:

- 6,112 field plots measured
- 22.1 million ac of forest land
- 9.3 billion trees ≥ 1-inch DBH
- 46% True fir/Douglas-fir



Carbon Stocks, estimate of current status: 10-yr cycle

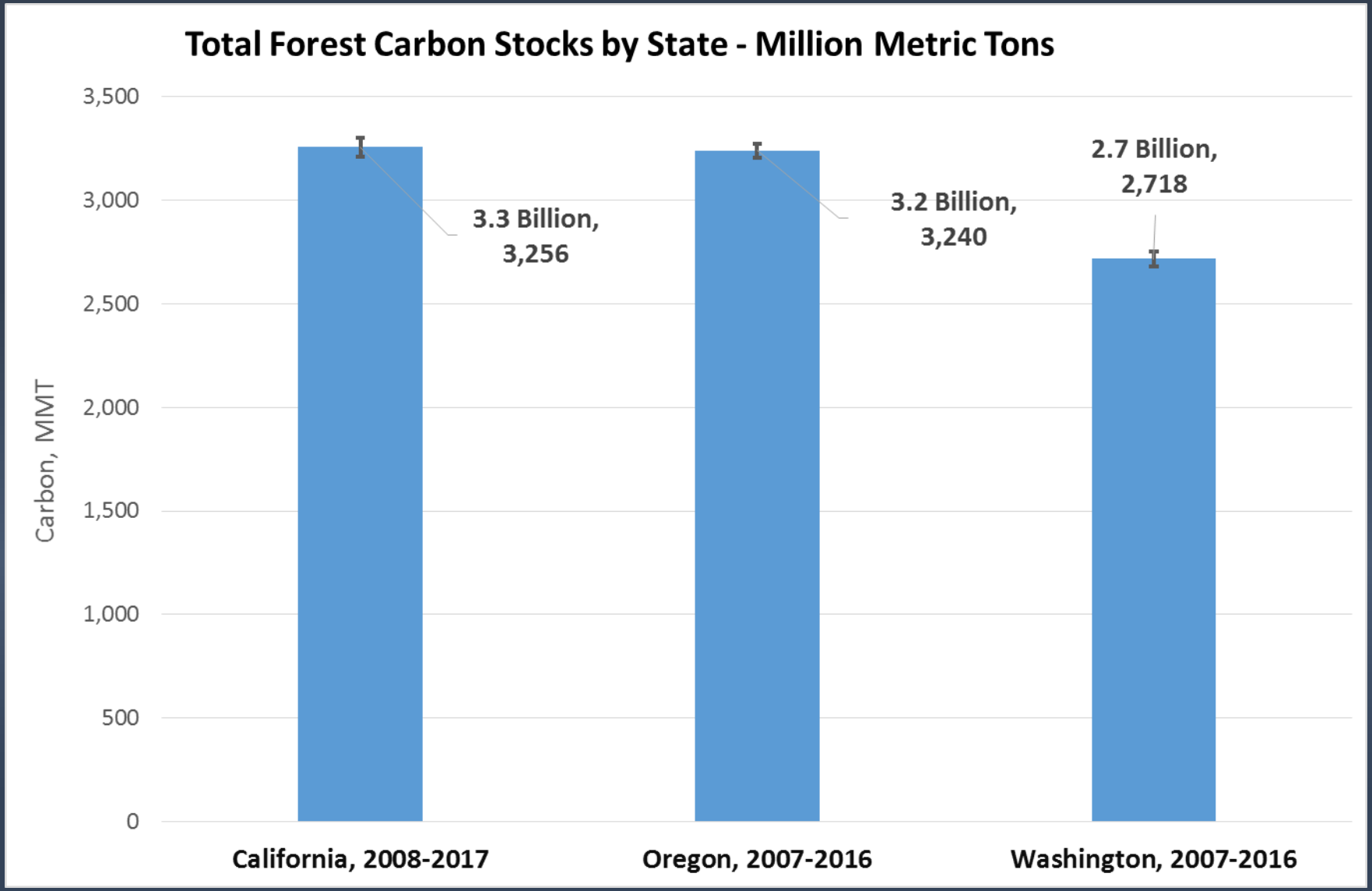


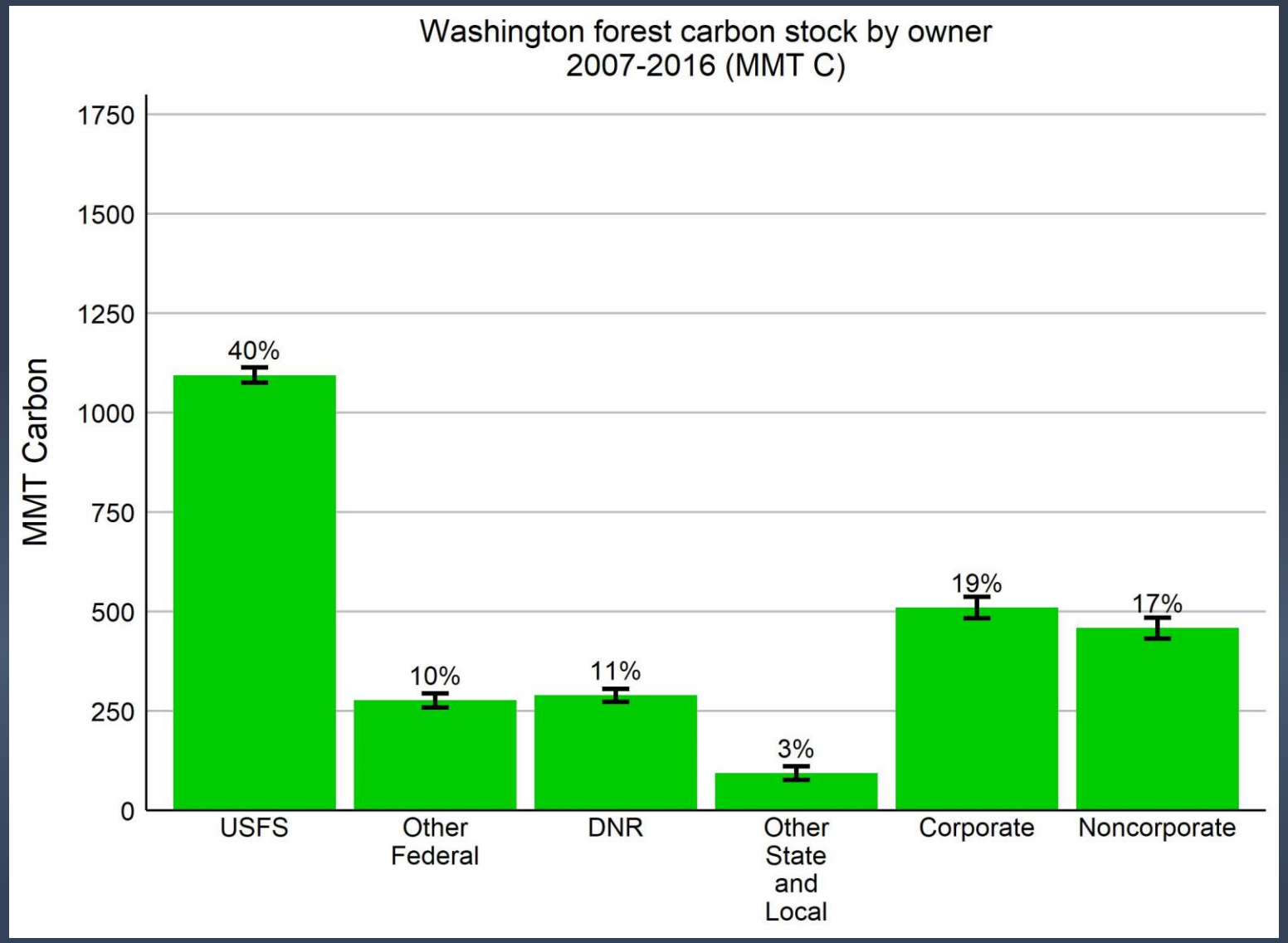
Estimates of carbon stocks based on current 10-year moving average, ex. Washington 2007-2016

Washington Total Carbon Stocks on Forest Land by Pool, All Ownerships: 2007-2016

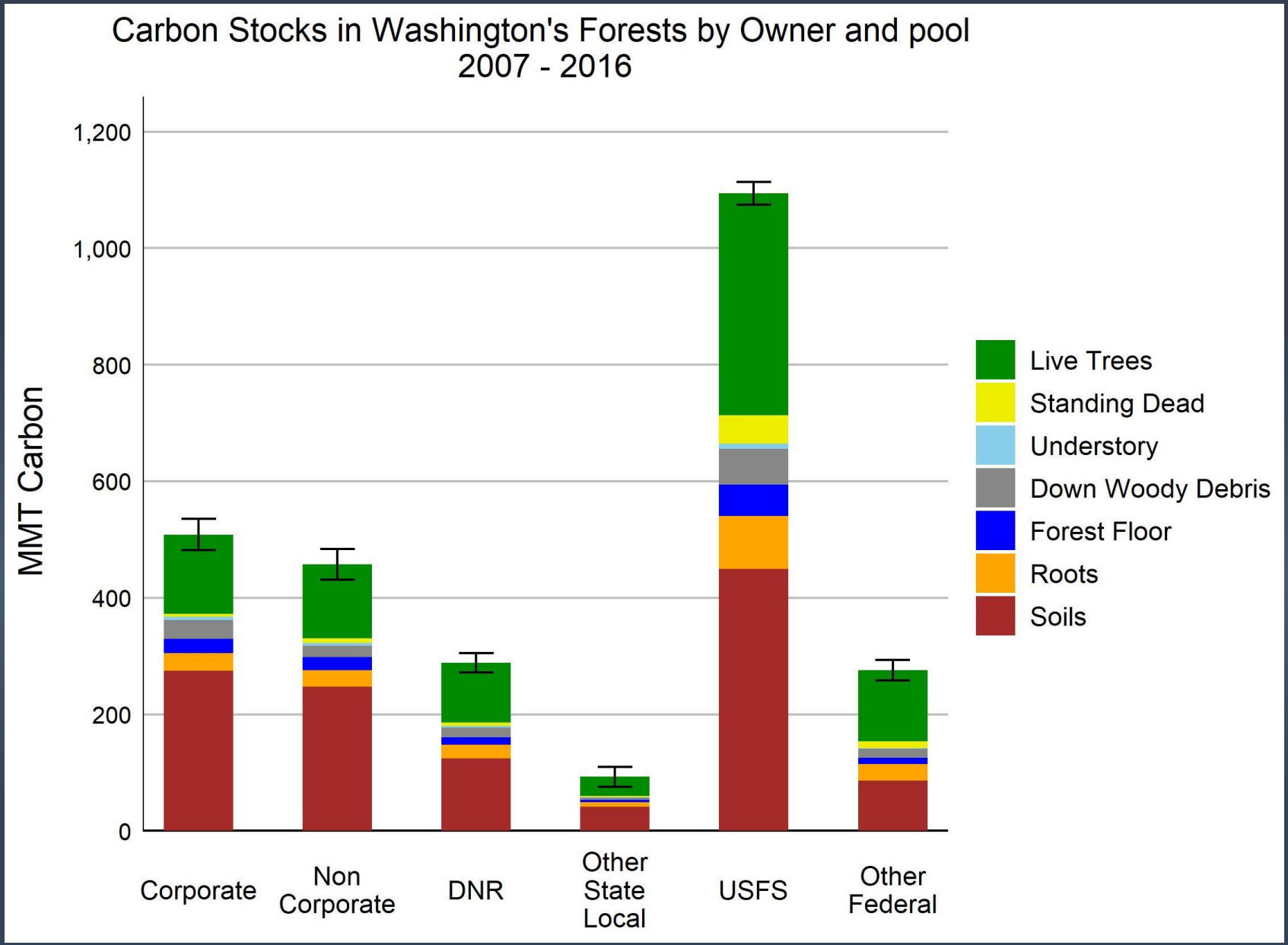
	Statewide Forest Carbon Stocks			
	Total	**SE**	**Total**	**SE**
CARBON POOL	*million metric tons C*		*metric tons C per acre*	
Live trees				
Aboveground live[1]	901.6	10.5	40.8	0.5
Belowground live	182.0	2.2	8.2	0.1
Dead trees				
Aboveground dead	80.5	2.0	3.6	0.1
Belowground dead	22.1	0.5	1.0	<0.1
Understory vegetation				
Aboveground	25.4	0.2	1.1	<0.1
Belowground	2.8	<0.1	0.1	<0.1
Downed wood	149.8	2.3	6.8	0.1
Forest Floor	129.0	0.8	5.8	<0.1
Soil Organic C	1,224.8	6.9	55.4	0.1
TOTAL FOREST STOCKS	***2,718.2***	***18.5***	***122.9***	***0.7***

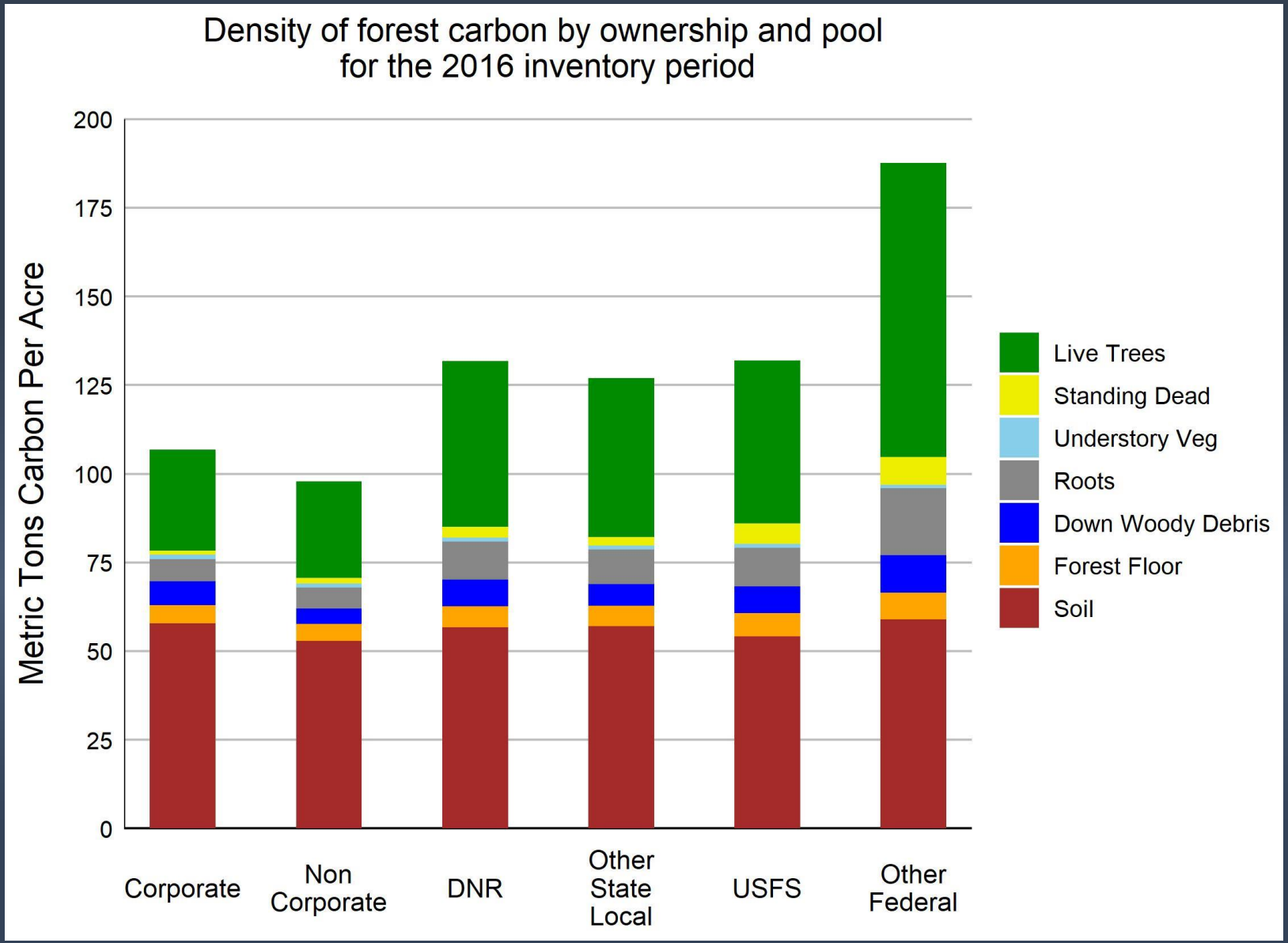
[1]includes live tree foliage


Total Forest Carbon Stocks by State - Million Metric Tons
Carbon, MMT
3,500
3,000
2,500
2,000
1,500
1,000
500
0
3.3 Billion, 3,256
3.2 Billion, 3,240
2.7 Billion, 2,718
California, 2008-2017
Oregon, 2007-2016
Washington, 2007-2016



MMT C = Million metric tons of carbon

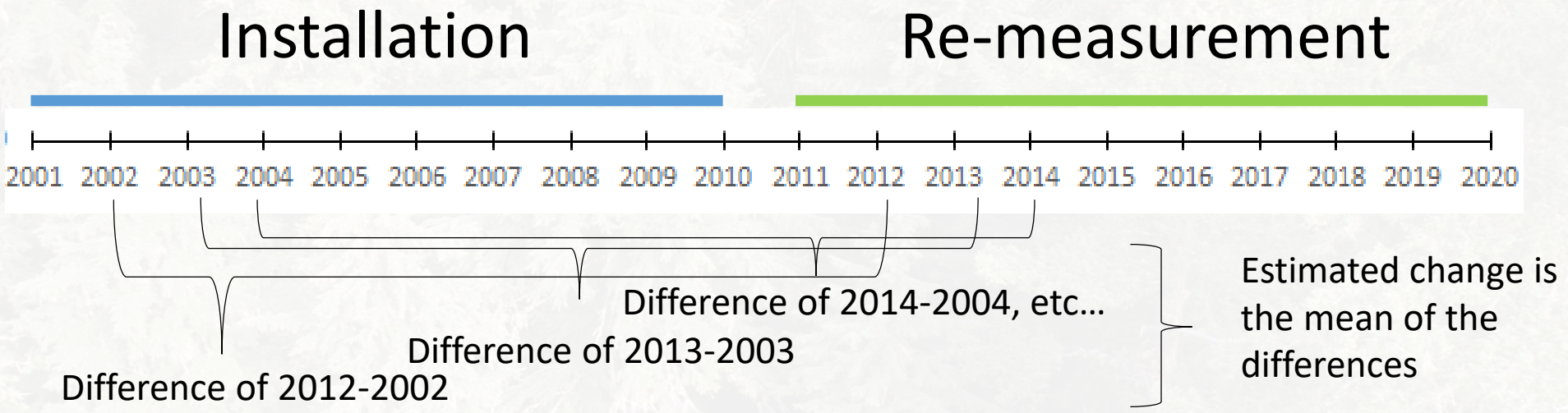

Carbon Stocks in Washington's Forests by Owner and pool
2007 - 2016
MMT Carbon
1,200
1,000
800
600
400
200
0
Corporate
Non Corporate
DNR
Other State Local
USFS
Other Federal
Live Trees
Standing Dead
Understory
Down Woody Debris
Forest Floor
Roots
Soils


Density of forest carbon by ownership and pool
for the 2016 inventory period
Metric Tons Carbon Per Acre
200
175
150
125
100
75
50
25
0
Corporate
Non Corporate
DNR
Other State Local
USFS
Other Federal
Live Trees
Standing Dead
Understory Veg
Roots
Down Woody Debris
Forest Floor
Soil

Forest Carbon Flux: Estimates of change

- Flux is reported in units of CO_2 equivalents (CO_2e)
  - 1 MT Carbon = 3.667 MT CO_2e
- Unlike carbon stocks, estimates of change represent 50% remeasurement of all FIA plots in Washington
  - FIA plot remeasurement will be 100% complete in 2021
- Every pool of forest carbon has a rate of carbon input and rate of carbon output
- Flux represents the amount of carbon going into a pool minus the amount going out

Carbon Flux: estimate of change on remeasured plots



Change (flux) is based on the measured growth on the same set of plots and trees 10 years apart. Estimated carbon flux is the average change of the 10-year periods.
Ex. Average annual carbon flux (CO2e) in Washington is based on 10-year time periods starting in 2002 through 2006, compared to 10 years later in 2012 through 2016. As of 2016 50% of all FIA plots have been remeasured.

Forest Carbon Flux: Estimates of change

- Current estimates of forest carbon flux are based on one repeat plot measurement
- Annual forest carbon flux is estimated from actual measurements of growth, removals, and mortality
- Uses FIA protocol to calculate live tree growth, removals, and mortality (GRM)
  - Growth = Measured growth between time 1 and time 2
  - Removals = Harvested trees or trees cut in conjunction with a silvicultural operation
  - Mortality = Any live tree at time 1 that died before remeasurement at time 2
- Accounting for carbon in harvested wood products to be added later

FIA Estimates of Change on Forest Land:

- Gross tree growth = tree growth at Time 2 – Time 1 + ingrowth + other accretion
  - Other Accretion accounts for growth on mortality, removals, reversion, diversion
- Net flux (net change) on live trees = Gross tree growth – tree mortality since time 1 – removals (harvested) trees since time 1
- Net flux other pools = Estimate at Time 2 – Estimate at Time 1, “stock change”

See GTR-SRS-80 (Bechtold & Patterson 2005) for more info.

FIA Estimates of Change by Pool

- Based on FIA plots and trees measured 10 years apart
- Used condition classification at the initial measurement
- By carbon pool
  - Trees: live and dead use FIA growth, removals, and mortality (GRM) estimation protocol
  - Down wood: Flux based on measured stock change for the plot, i.e. pieces of wood are not tracked
  - Below-ground: Stock change, based on plot-level modeled estimates in FIADB
  - Understory: Stock change, based on plot-level modeled estimates using FIADB
  - Forest floor: Stock change, based on plot-level modeled estimates as populated in U.S. National Greenhouse Gas Inventory
  - Soil: Stock change, based on plot-level modeled estimates as populated in U.S. National Greenhouse Gas Inventory
- Land use change – forest land conversions

Washington Annual Carbon Flux (CO_2e) on Forest Land by Pool, All Ownerships: 2002-2006 to 2012-2016

	Statewide Forest CO_2e Net Flux			
	Total	**SE**	**Total**	**SE**
	million metric tons CO_2e per year		*metric tons CO_2e per year per acre*	
CARBON POOL				
Live trees				
Aboveground live[1]	15.14	3.29	0.65	0.15
Belowground live	3.11	0.75	0.14	0.03
Dead trees				
Aboveground dead	4.08	0.91	0.18	0.04
Belowground dead	0.64	0.23	0.03	0.01
Understory vegetation				
Aboveground	-0.06	0.04	<-0.01	<0.01
Belowground	-0.01	<0.01	<-0.01	<0.01
Downed wood	-6.85	1.19	-0.31	0.05
NET VEGETATION FLUX	***16.06***	***4.27***	***0.73***	***0.20***
Forest Floor	0.25	0.21	0.01	<0.01
N-fertilization[2]	-0.13	0.10	<0.01	<0.01
Soil Organic C	-0.17	0.30	-0.01	0.01
TOTAL FOREST NET FLUX	***16.00***	***4.40***	***0.73***	***0.20***

[1]includes live tree foliage
[2]estimated CO_2e emission associated with nitrogen fertilization on commercial timberland in western Washington

Live Tree Annual Carbon Flux (CO_2e), All Ownerships: 2002-2006 to 2012-2016

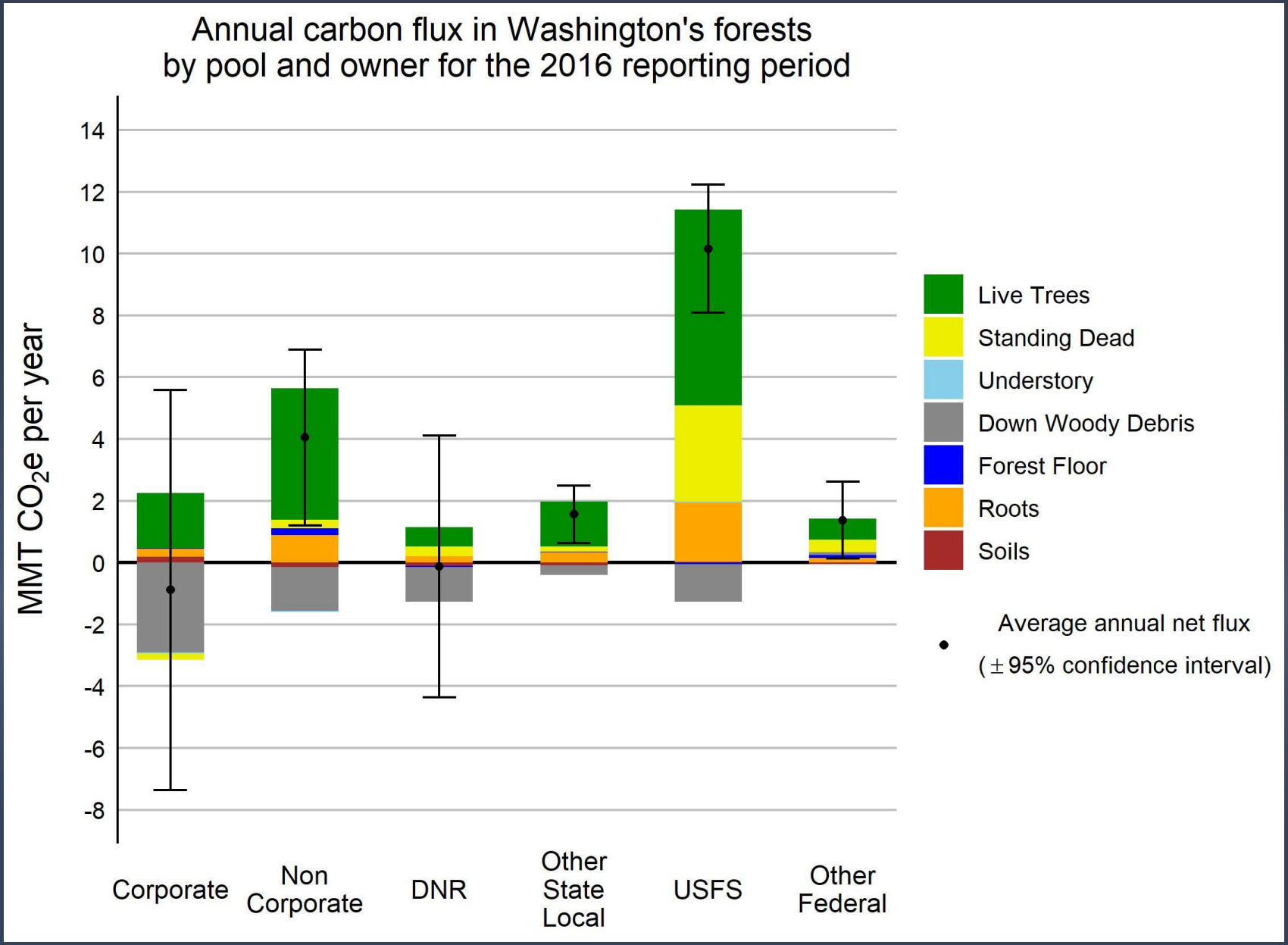
	Statewide Forest CO_2e Flux			
	Total	**SE**	**Total**	**SE**
CARBON POOL	*million metric tons CO_2e per year*		*metric tons CO_2e per acre per year*	
Standing live trees[1]				
Mortality	-32.9	1.2	-1.49	0.06
Removals	-31.2	2.7	-1.42	0.12
Gross growth	78.4	1.2	3.56	0.05
Net Live Tree Flux	***14.3***	***3.3***	***0.65***	***0.15***

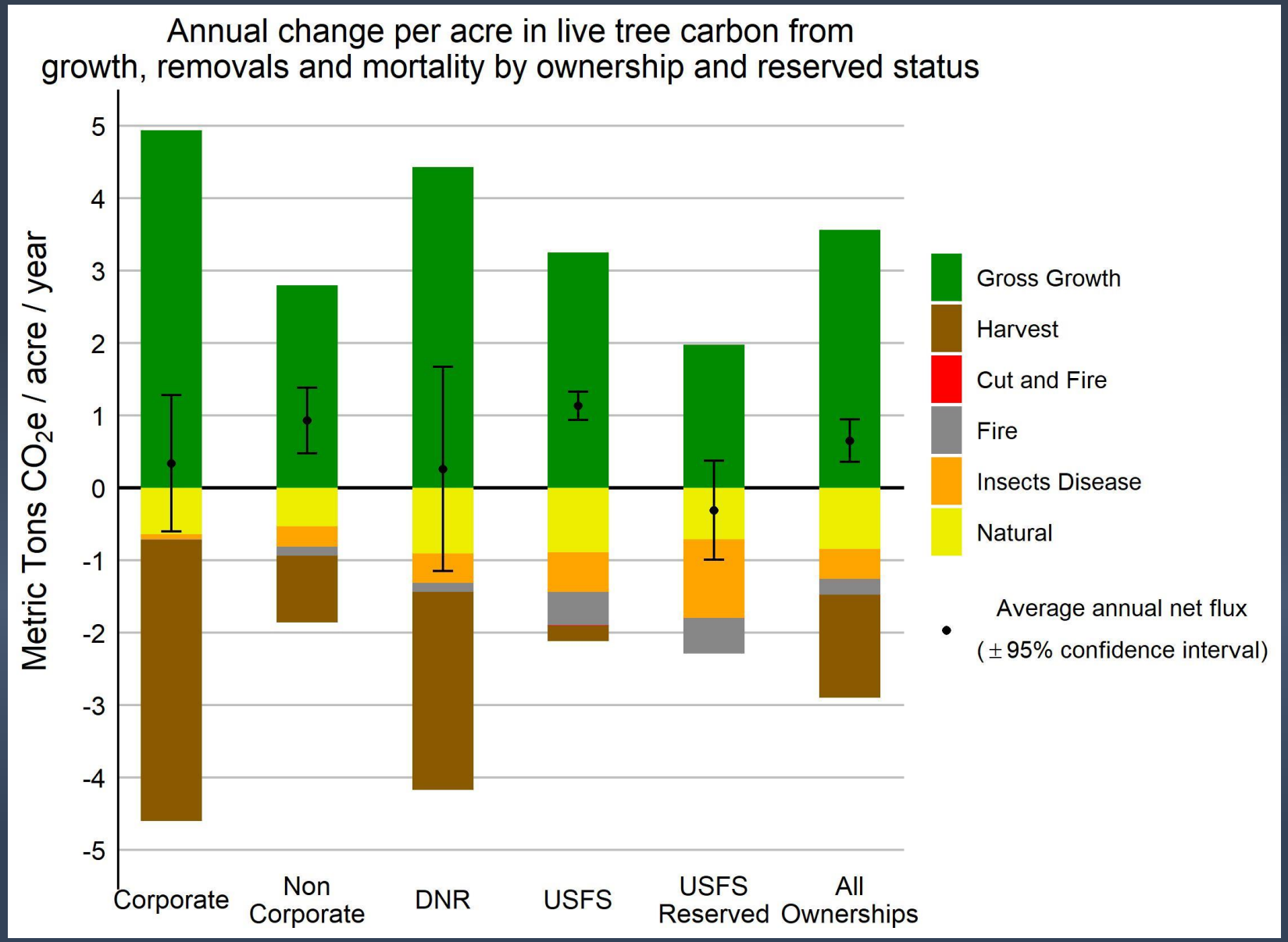
[1]excluding live tree foliage

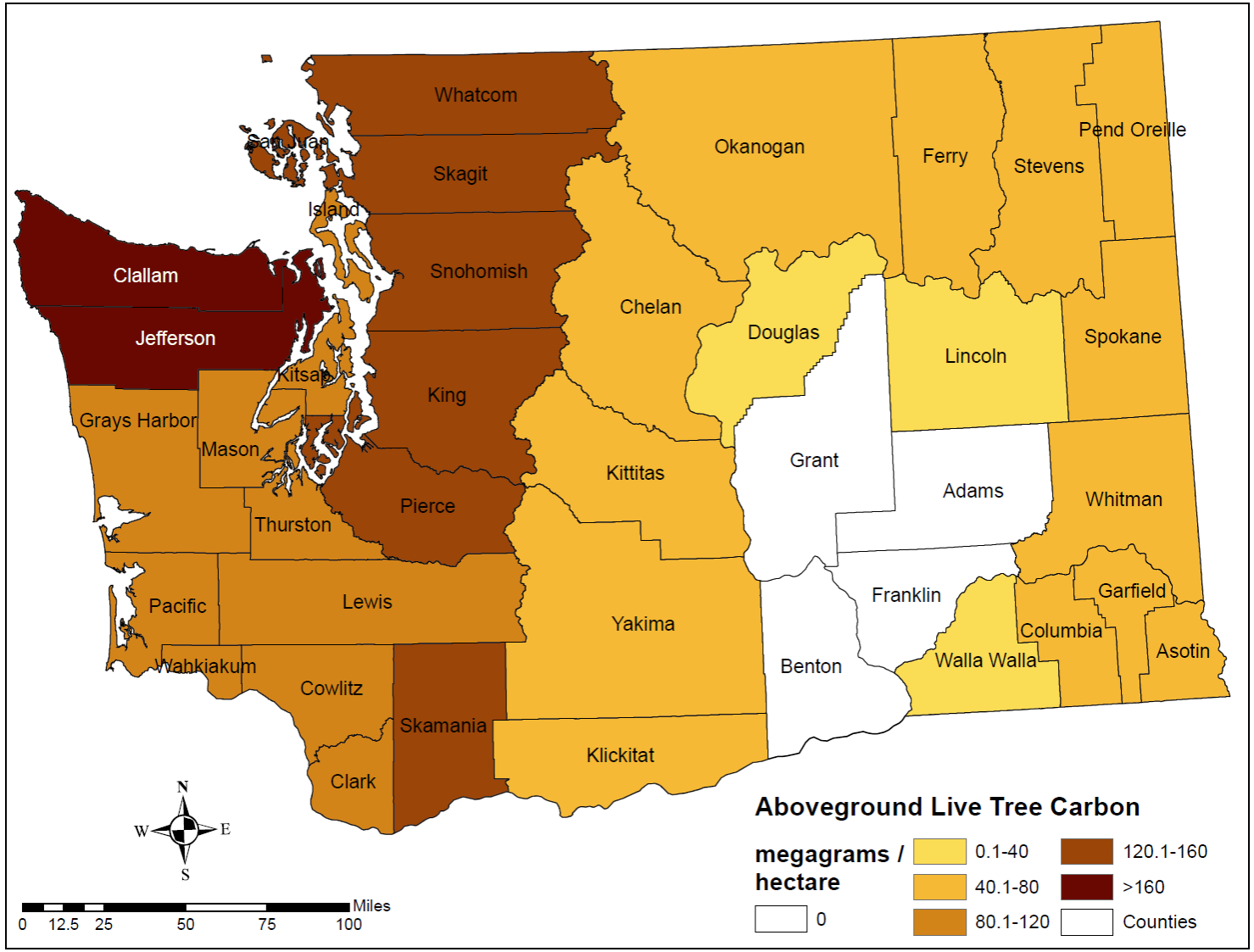
Live Tree Mortality Carbon Flux (CO_2e) by Cause, All Ownerships: 2002-2006 to 2012-2016

	Statewide Live Tree Mortality CO_2e Flux			
	Total	**SE**	**Total**	**SE**
LIVE TREE MORTALITY ATTRIBUTION	*million metric tons CO_2e per year*		*metric tons CO_2e per acre per year*	
Fire killed	-4.9	0.7	-0.22	0.03
Cut and fire[1]	-0.1	<0.1	-0.00	0.00
Insects and disease	-9.3	0.9	-0.42	0.04
Natural and other causes	-18.5	0.8	0.84	0.04
Net Mortality Change	***-32.9***	***1.2***	***-1.49***	***0.06***

[1]plots where mortality has occurred due to both harvest and fire


Annual carbon flux in Washington's forests
by pool and owner for the 2016 reporting period
MMT CO_2e per year
14
12
10
8
6
4
2
0
-2
-4
-6
-8
Corporate
Non Corporate
DNR
Other State Local
USFS
Other Federal
Live Trees
Standing Dead
Understory
Down Woody Debris
Forest Floor
Roots
Soils
Average annual net flux
(±95% confidence interval)


Annual change per acre in live tree carbon from growth, removals and mortality by ownership and reserved status
Metric Tons CO_2e / acre / year
5
4
3
2
1
0
-1
-2
-3
-4
-5
Corporate
Non Corporate
DNR
USFS
USFS Reserved
All Ownerships
Gross Growth
Harvest
Cut and Fire
Fire
Insects Disease
Natural
Average annual net flux
(±95% confidence interval)



Carbon Stocks and Flux on Forest Land by Western/Eastern Region

Western Region

Total stocks: 1,763 MMT (SE: 20.6 MMT)
C Stocks/ac: 146.2 MMT

CO_2e Flux: 15.0 MMT/yr (SE: 4.2 MMT/yr)
Flux/ac: 1.26 MT/yr

Eastern Region

Total stocks: 955 MMT (SE: 13.9 MMT)
C Stocks/ac: 94.4 MMT

CO_2e Flux: 1.1 MMT/yr (SE: 1.3 MMT/yr)
Flux/ac: 0.11 MT/yr

Forest Carbon Stocks by Region and Pool: 2007-2016

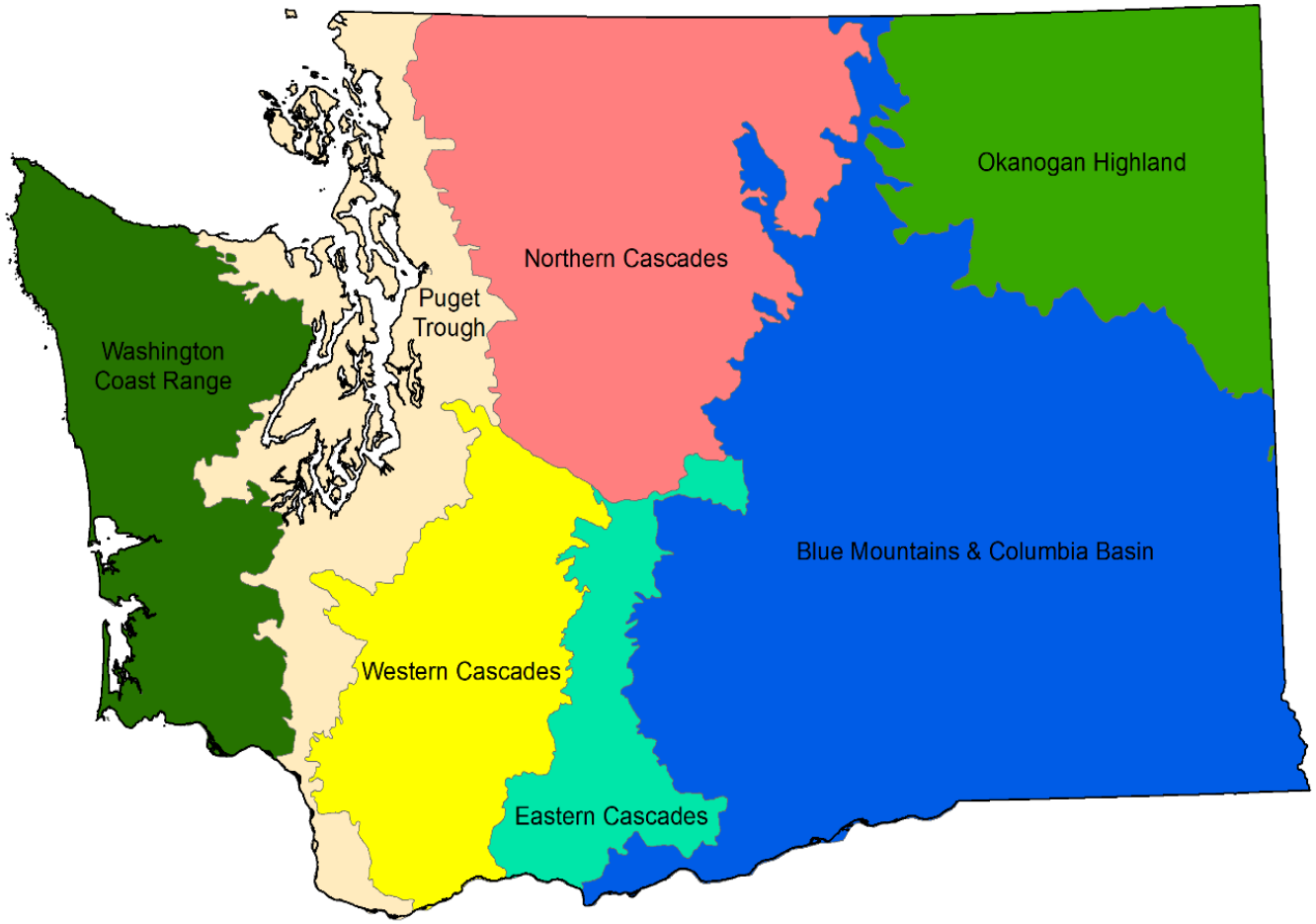
Western Washington		
Forest Carbon Pools	Total Carbon *(MMT)*	Per Ac *(MT)*
Live Trees	792.7	65.7
Standing Dead	55.8	4.6
Understory Veg	15.3	1.3
Down Woody Debris	101.7	8.4
Forest Floor	75.8	6.3
Soil Organic C	721.9	59.9
All Pools	1,763.3	146.2

Eastern Washington		
Forest Carbon Pools	Total Carbon *(MMT)*	Per Ac *(MT)*
Live Trees	290.9	28.9
Standing Dead	46.8	4.6
Understory Veg	12.9	1.3
Down Woody Debris	48.1	4.8
Forest Floor	53.1	5.3
Soil Organic C	502.9	50.0
All Pools	954.8	94.4

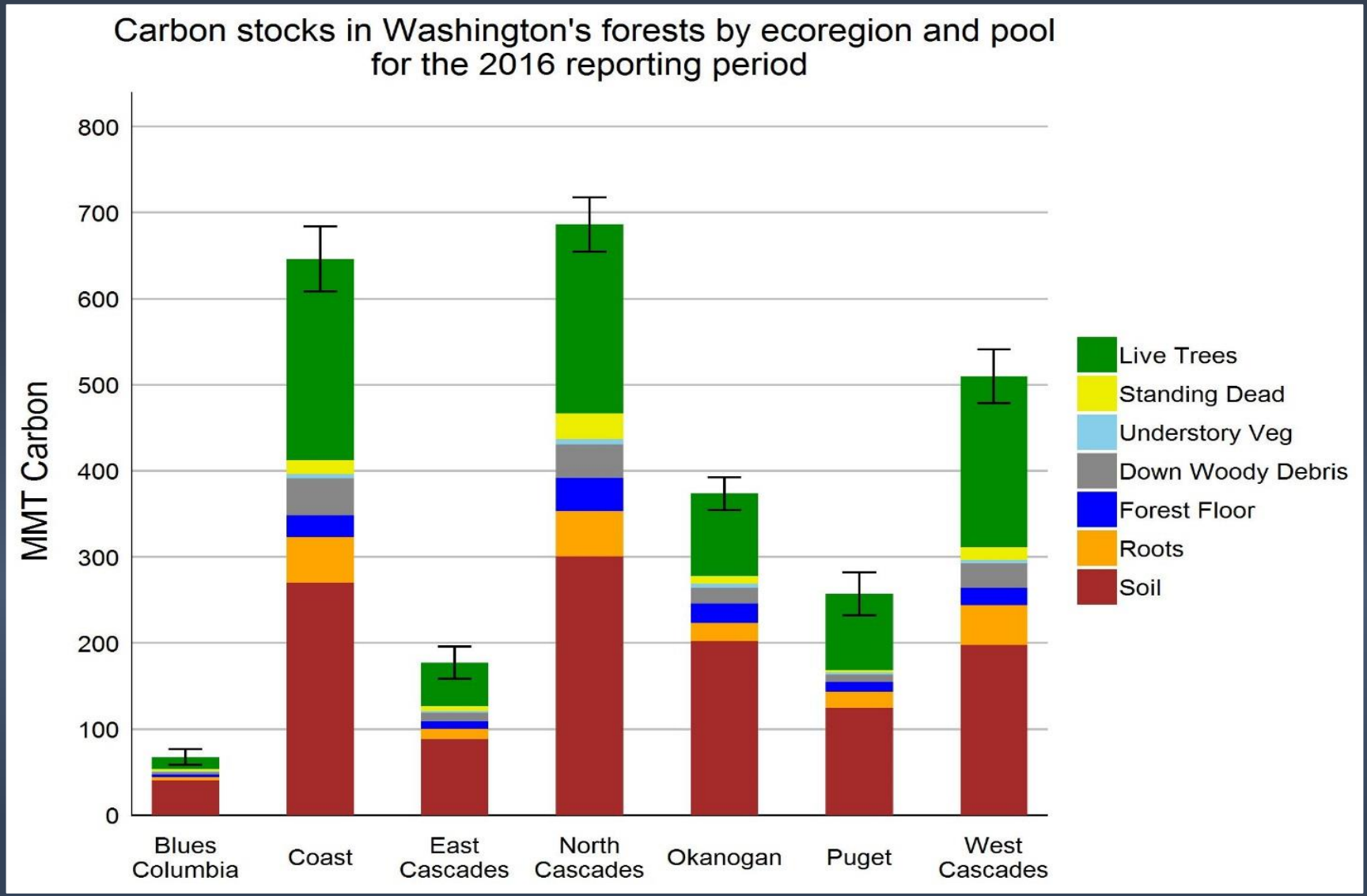
Annual Carbon Flux (CO_2e) by Region and Pool: 2002-2006 to 2012-2016

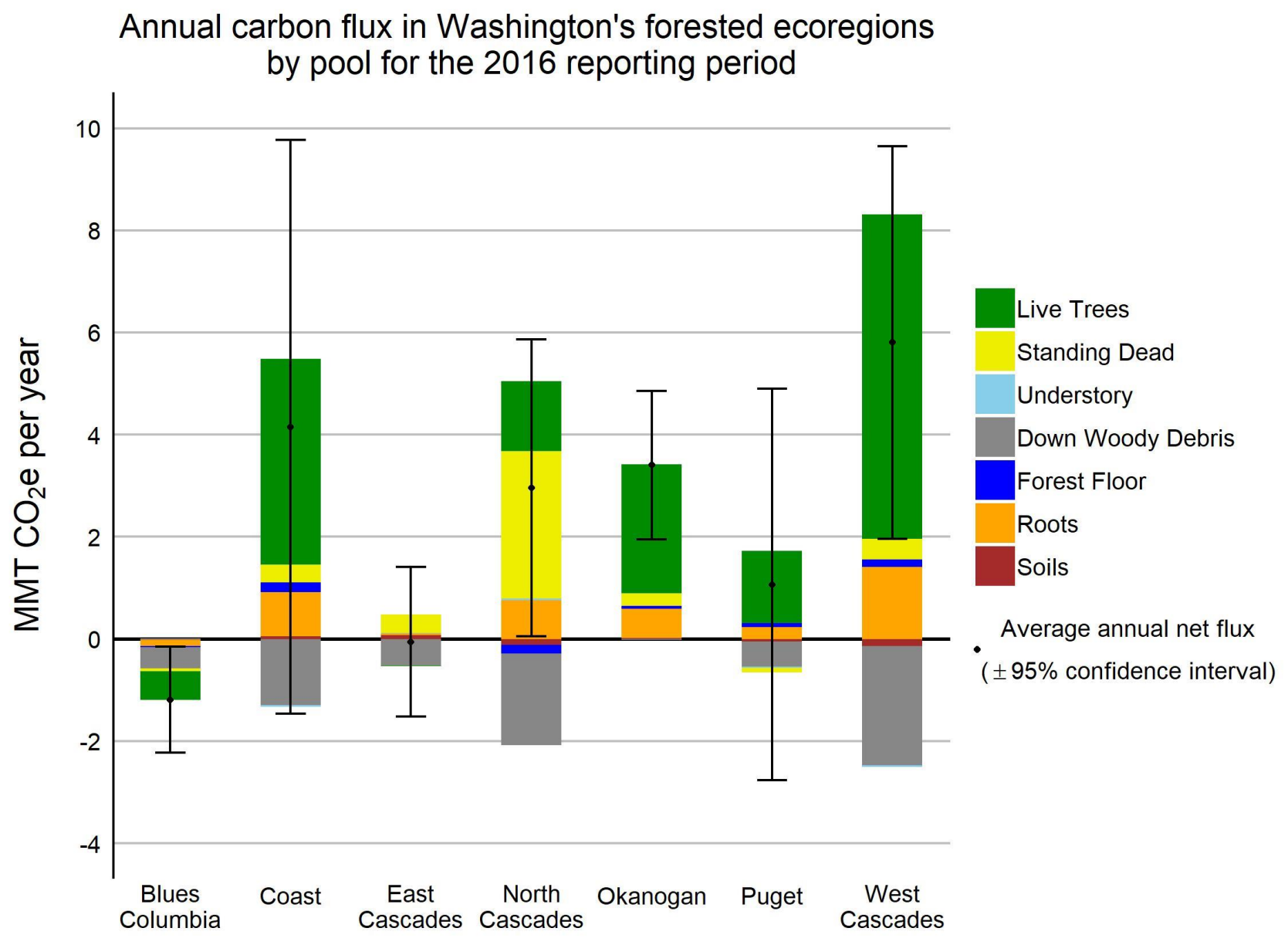
Western Washington		
	Net flux (CO_2e)	
Forest Carbon Pool	Total *(MMT/yr)*	Per Ac *(MT/yr)*
Live Trees	16.3	1.37
Standing Dead	0.7	0.06
Understory Veg	-0.21	-0.01
Down Woody Debris	-5.5	-0.46
Forest Floor	0.4	0.04
Roots	3.3	0.28
Soil	-0.1	-0.01
Net flux All Pools	15.0	1.26

Eastern Washington		
	Net flux (CO_2e)	
Forest Carbon Pool	Total *(MMT/yr)*	Per Ac *(MT/yr)*
Live Trees	-1.2	-0.12
Standing Dead	3.3	0.33
Understory Veg	0.1	0.01
Down Woody Debris	-1.4	-0.13
Forest Floor	-0.2	-0.02
Roots	0.4	0.04
Soil	<-0.1	<0.01
Net flux All Pools	1.1	0.11



Carbon Stocks and Flux on Forest Land by Ecological Region


Carbon stocks in Washington's forests by ecoregion and pool
for the 2016 reporting period
MMT Carbon
800
700
600
500
400
300
200
100
0
Blues Columbia
Coast
East Cascades
North Cascades
Okanogan
Puget
West Cascades
Live Trees
Standing Dead
Understory Veg
Down Woody Debris
Forest Floor
Roots
Soil


Annual carbon flux in Washington's forested ecoregions
by pool for the 2016 reporting period
MMT CO_2e per year
10
8
6
4
2
0
-2
-4
Blues Columbia
Coast
East Cascades
North Cascades
Okanogan
Puget
West Cascades
Live Trees
Standing Dead
Understory
Down Woody Debris
Forest Floor
Roots
Soils
Average annual net flux
(±95% confidence interval)

Annual change in forest land area to/from other IPCC land-use classes in Washington, 2002-2006 to 2012-2016

Nonforest land use	Forest to nonforest		Nonforest to forest		Net change to forest	
	Total	SE	Total	SE	Total	SE
			Acres per year			
Cropland	2,677	1,781	576	370	-2,101	1,819
Developed	10,778	2,131	8,996	1,390	-1,781	2,534
Grassland	2,273	2,051	1,057	592	-1,215	2,135
Other	1,671	1,030	3,768	2,343	2,097	2,560
Water	3,450	1,417	81	60	-3,369	1,418
Total	20,848	3,981	14,479	2,811	-6,369	4,878

Note: Totals may be off because of rounding

Annual change in carbon pools due to change in land-use between forest and non-forest in Washington, 2002-2006 to 2012-2016.

	Forest to nonforest		Nonforest to forest		Net change	
	Total	**SE**	**Total**	**SE**	**Total**	**SE**
Carbon pool	*Thousand metric tons CO2 equivalent per year*					
Live tree	-3,108	630	1,555	266	-1,552	649
Standing dead	-177	69	57	10	-120	70
Down wood	-342	77	197	30	-145	81
Understory veg	-201	35	122	24	-79	42
Litter	-690	114	417	72	-273	134
Soil*	0		0		0	
All pools	-4,518	771	2,348	349	-2,170	810

* No changes in landuse involved cultivated land so soil organic carbon change w as assumed to be zero (Ogle et al. 2003)

Forest Carbon Net Flux: California's changing forests?

Reporting year	**Net flux***	**SE** *(MMT CO2e/yr)*
2006-2015 Report (50%)		
• Aboveground live:	25.0	2.3
• Aboveground dead:	3.2	1.5
• **Net flux:**	**33.6**	**2.8**
2007-2016 Report (60%)		
• Aboveground live:	23.4	2.3
• Aboveground dead:	3.3	1.4
• **Net flux:**	**31.8**	**2.6**
2008-2017 Report (70%)		
• Aboveground live:	19.1	2.2
• Aboveground dead:	5.8	1.5
• **Net flux:**	**29.2**	**2.5**
2009-2018?		

**HWP not included*

Next Steps WA:

- Harvested wood products analysis
- Complete reconciliation and revisions of report, appendix of all tables
- Regional forest carbon report – CA, OR, WA, and BC

Next Steps PNW FIA:

- Implement California accelerated inventory, 5-year measurement cycle
- Implement Oregon spatial intensified inventory on ODF managed forests
- PNW Carbon Initiative: Forest carbon modeling and projections

Thank you!