"USFWS: Brent Lawrence. "Diablo Lake in the Northern Cascades" Flickr, 3 November 2023, https://www.flickr.com/photos/52133016@N08/53362751/.

Forest Carbon Modelling Results

November 13, 2024

Outline

- Introduction
- **Part 1**: Methods Refresher

Next Time (December 11)…

- **Part 2**: Full Landscape Results w/Q&A
- **Part 3**: Climate Change Results w/Q&A
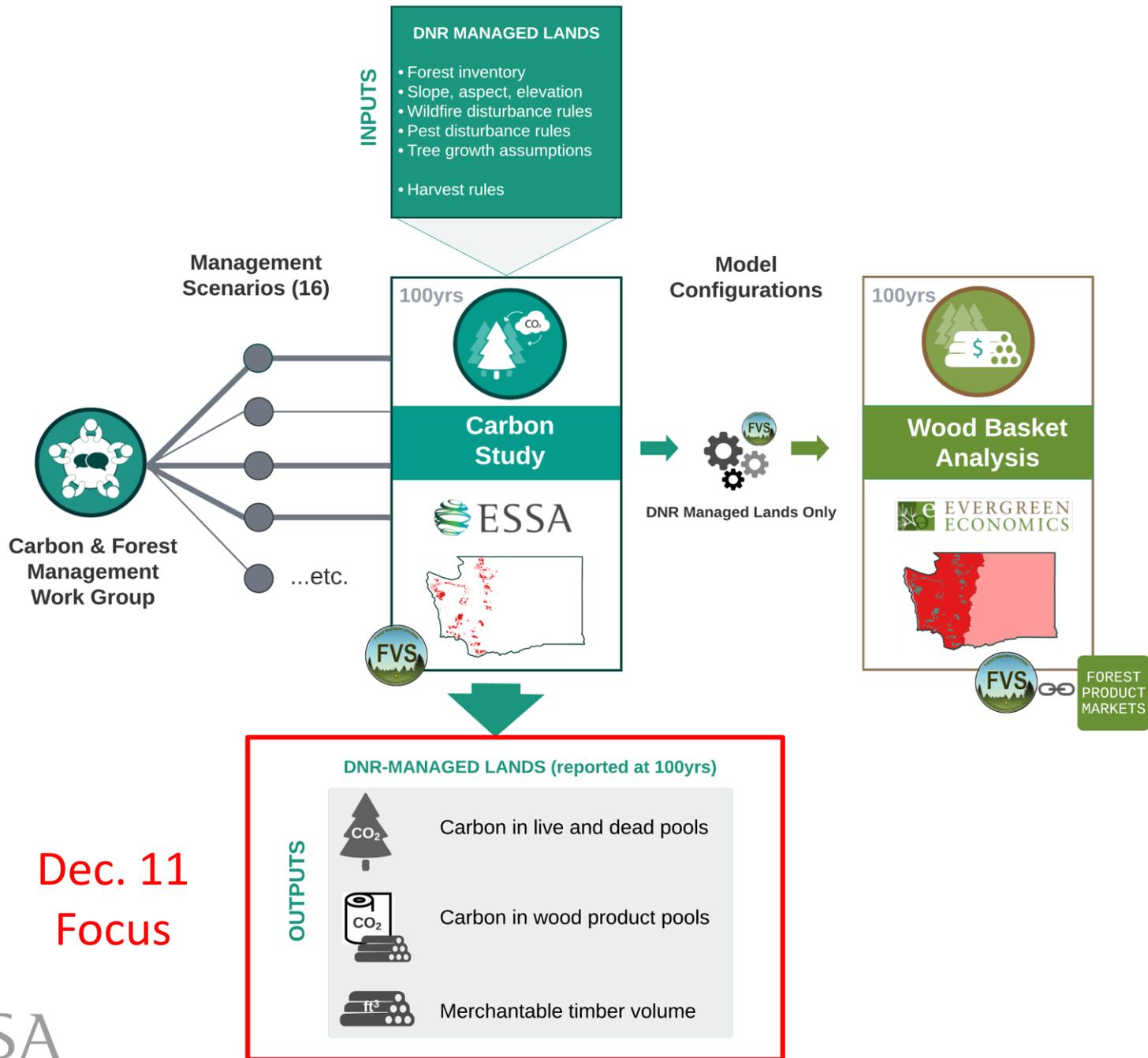
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Study Objective

"Support the Work Group in examining relationship between forest management and carbon in DNR-managed forests"

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Study Objective

"Support the Work Group in examining relationship between forest management and carbon in DNR-managed forests"

How much carbon in DNR managed forests under different management scenarios?

DNR MANAGED LANDS

- Forest inventory
- Slope, aspect, elevation
- Wildfire disturbance rules
- Pest disturbance rules
- Tree growth assumptions

- Harvest rules

INPUTS

Management Scenarios (16)

Model Configurations

100yrs

Carbon Study

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FVS

DNR Managed Lands Only

Carbon & Forest Management Work Group

...etc.

100yrs

Wood Basket Analysis

EVERGREEN ECONOMICS

FVS

FOREST PRODUCT MARKETS

Dec. 11 Focus

OUTPUTS

DNR-MANAGED LANDS (reported at 100yrs)

CO_2 Carbon in live and dead pools

CO_2 Carbon in wood product pools

ft³ Merchantable timber volume

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5

Modeling phases

Rescheduled, TBD

~~DNR & WG Review by Nov. 22; Revision requests to ESSA by Dec. 18~~

WE ARE HERE

	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J
Phase 1 - Modeling																	
Phase 2 - Refinement & Finalization																	

ESSA data preparation, model setup, and modeling of scenarios

ESSA refinement of modeling and final reporting

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Adopted Scenarios

Scenario number	Component (s)		
1	DNR current operations		
Single-dial scenarios			
2	Lengthen harvest rotation		
3	Shorten harvest rotation		
4	Significantly increase thinning		
Multi-dial scenarios			
5	Lengthen harvest rotation	Significantly increase thinning	
6	Lengthen harvest rotation	Significantly increase thinning	Increase deferrals
7	Increased emphasis on Silviculture	Significantly increase thinning	
8	Increased emphasis on silviculture	Significantly increase thinning	Shorten harvest rotation

Part 1: Methods Refresher

see also

https://www.dnr.wa.gov/publications/bc_cfm_m6_model_ppt.pdf

Basic model process

PREPARATION	MODELING	RESULTS

Prepare Inputs

Stand Initialization

Simulation

Outputs and Post-processing

Preparation
data icon by
monkik

- Growth
- Carbon fluxes
- Disturbance
- Harvest
- Silviculture

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Forest Inventory

Spatial processing happens outside FVS

Spatial Units: What is a "Stand" in FVS?

Field plots data (DNR): trees and woody debris

+

Forest stand mapping (DNR): ecological attributes and land management classes

=

	STAND_CN	STAND_ID	SITE_INDE	DT_SI
1	1_Clallam	e0979e12-0343-4cba-877a-1c578e07e59d	109	CONIF
2	2_Clallam	d7c953be-fbb9-4ed1-8cfa-3e0bfe527bca	131	CONIF
3	3_Clallam	e62b42b0-fa40-4099-adf2-173eac05142e	95	ALDER
4	4_Clallam	3d289bb2-b0cb-4760-a69e-3f8af146da66	133	CONIF
5	5_Clallam	421596ff-0374-40db-bf12-4df2960effff	134	CONIF
6	6_Clallam	c093ea2e-9f24-477b-980d-fd34a32a9061	134	CONIF
7	7_Clallam	c093ea2e-9f24-477b-980d-fd34a32a9061	134	CONIF
8	8_Clallam	c093ea2e-9f24-477b-980d-fd34a32a9061	133	CONIF
9	9_Clallam	421596ff-0374-40db-bf12-4df2960effff	134	CONIF
10	10_Clallam	421596ff-0374-40db-bf12-4df2960effff	134	CONIF

Final model input

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Spatial Units: Landscape

Legend:
- Study Area
- Washington State Boundary

0   25   50   75 Miles

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March 2024
EPSG:2927 - NAD1983 (HARN) / Washington
South (ftUS)

Output Units

Total stored carbon

Live/dead forest biomass

MtCO2e

Harvested wood products

MtCO2e

CO2 equivalent (CO2e) is the metric used to compare and report on the impact of greenhouse gases on global warming via a common scale

1 mega ton (Mt) Carbon **x 3.67** = 1 Mt CO2e

Output Units

Total stored carbon

Live/dead forest
biomass

MtCO2e

Harvested
wood products

MtCO2e

Harvested
merchantable
timber volume

MBF

Performance Metric

Scenario performance metric:
Mean of total $MtCO_2e$ across simulation time steps

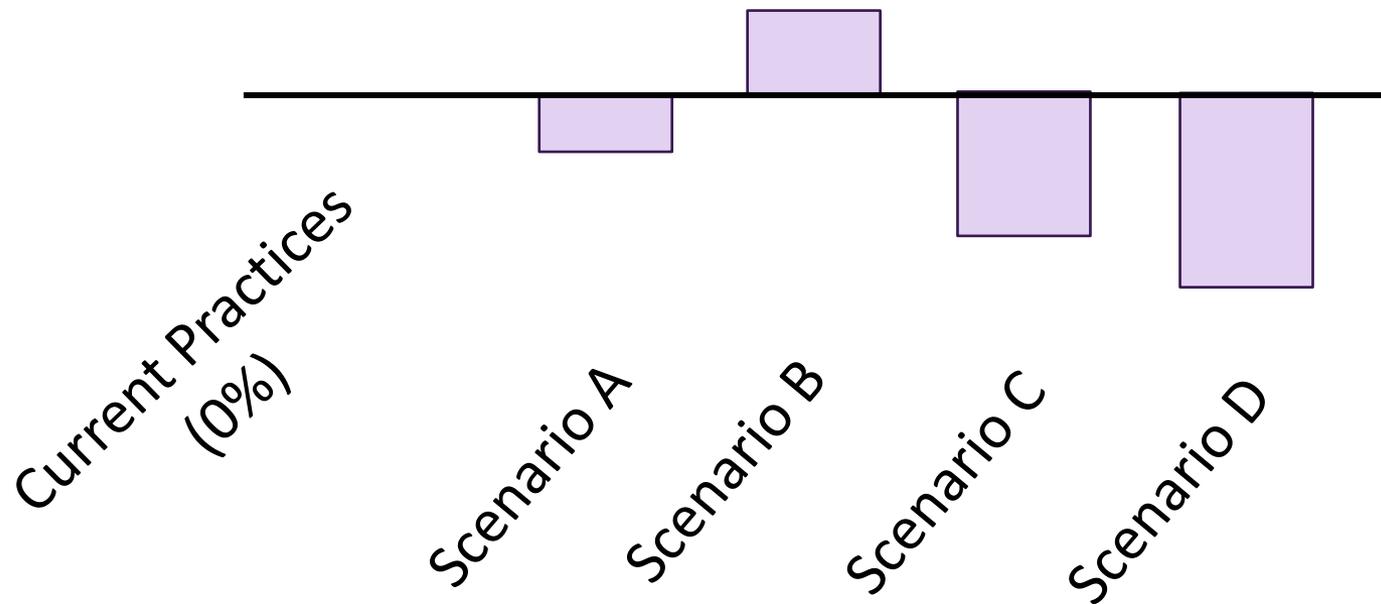# Performance Metric

Scenario performance metric:

Mean of total $MtCO_2e$ across simulation time steps

Performance Metric

Scenario performance metric:

% difference in mean of total $MtCO_2e$ across simulation time steps

Performance Metric

Scenario performance metric:

% difference in mean of total $MtCO_2e$ across simulation time steps

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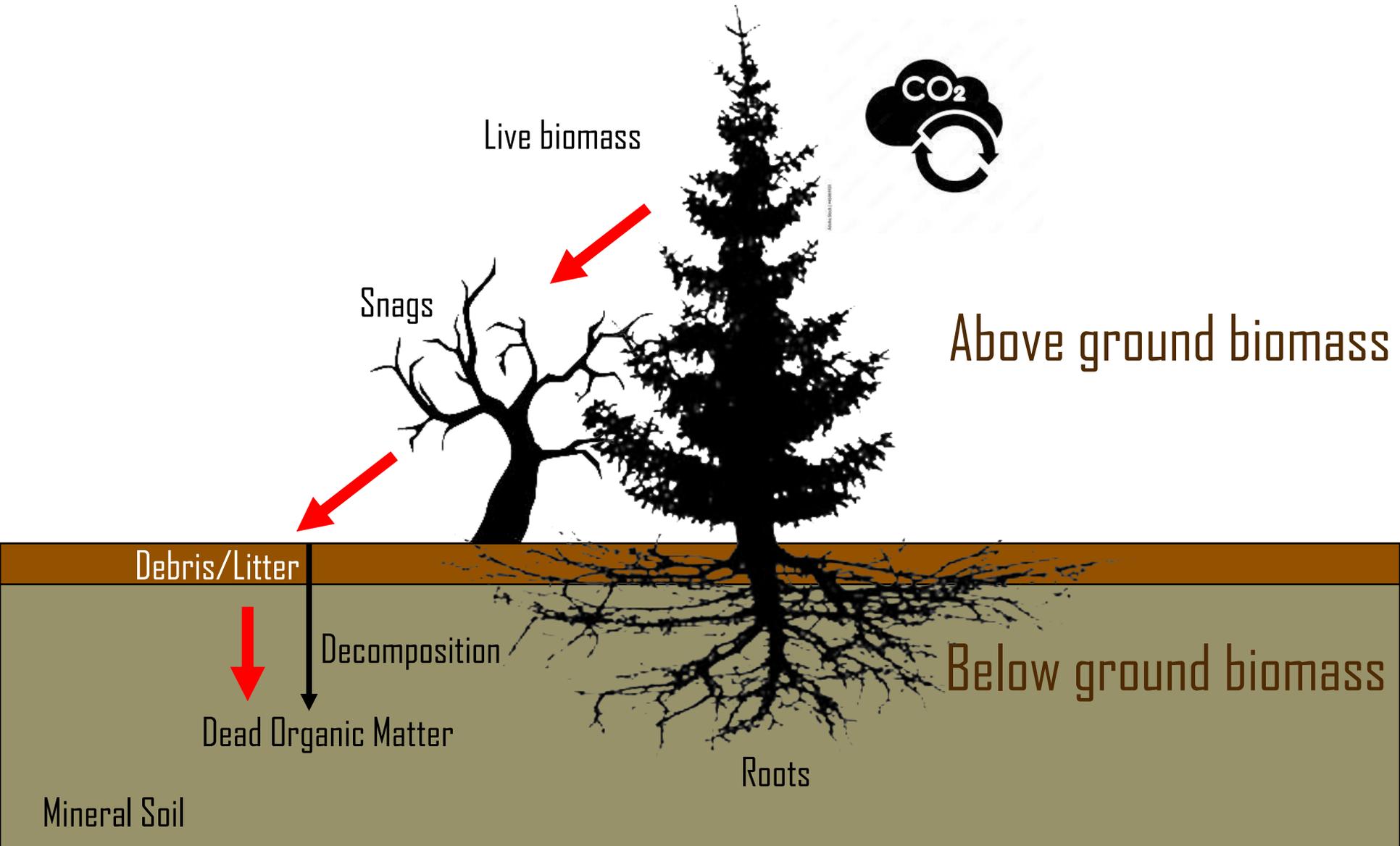# Temporal Units

Time Steps

5

Years

Time Horizon

100

Years

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Carbon Dynamics

Live biomass

CO_2

Above ground biomass

Snags

Debris/Litter

Decomposition

Dead Organic Matter

Below ground biomass

Roots

Mineral Soil

Natural Disturbance

- Wildfire, insect mortality, drought, blowdown

- Calculated from historical data

- Fire rates increase with climate change
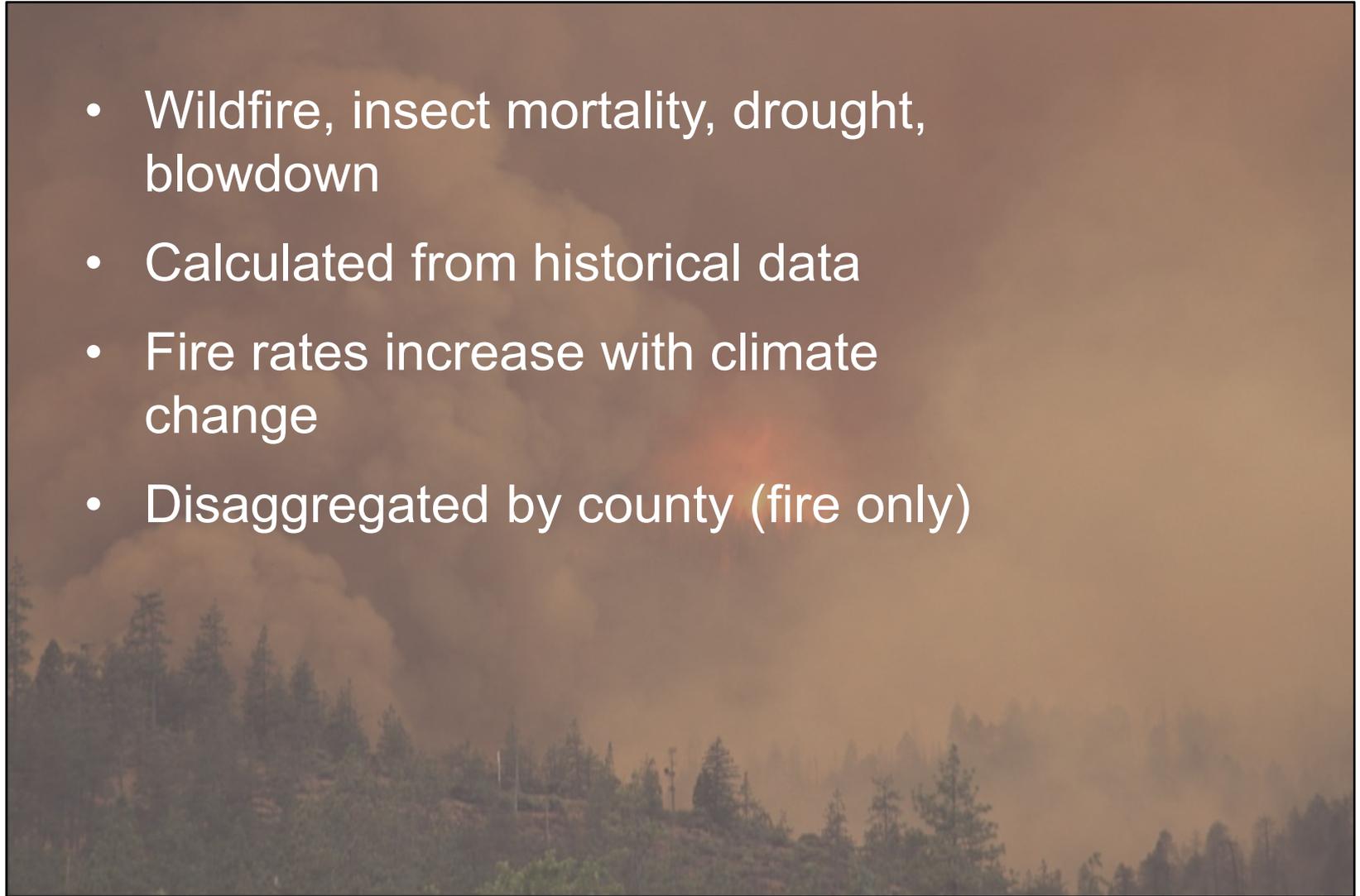
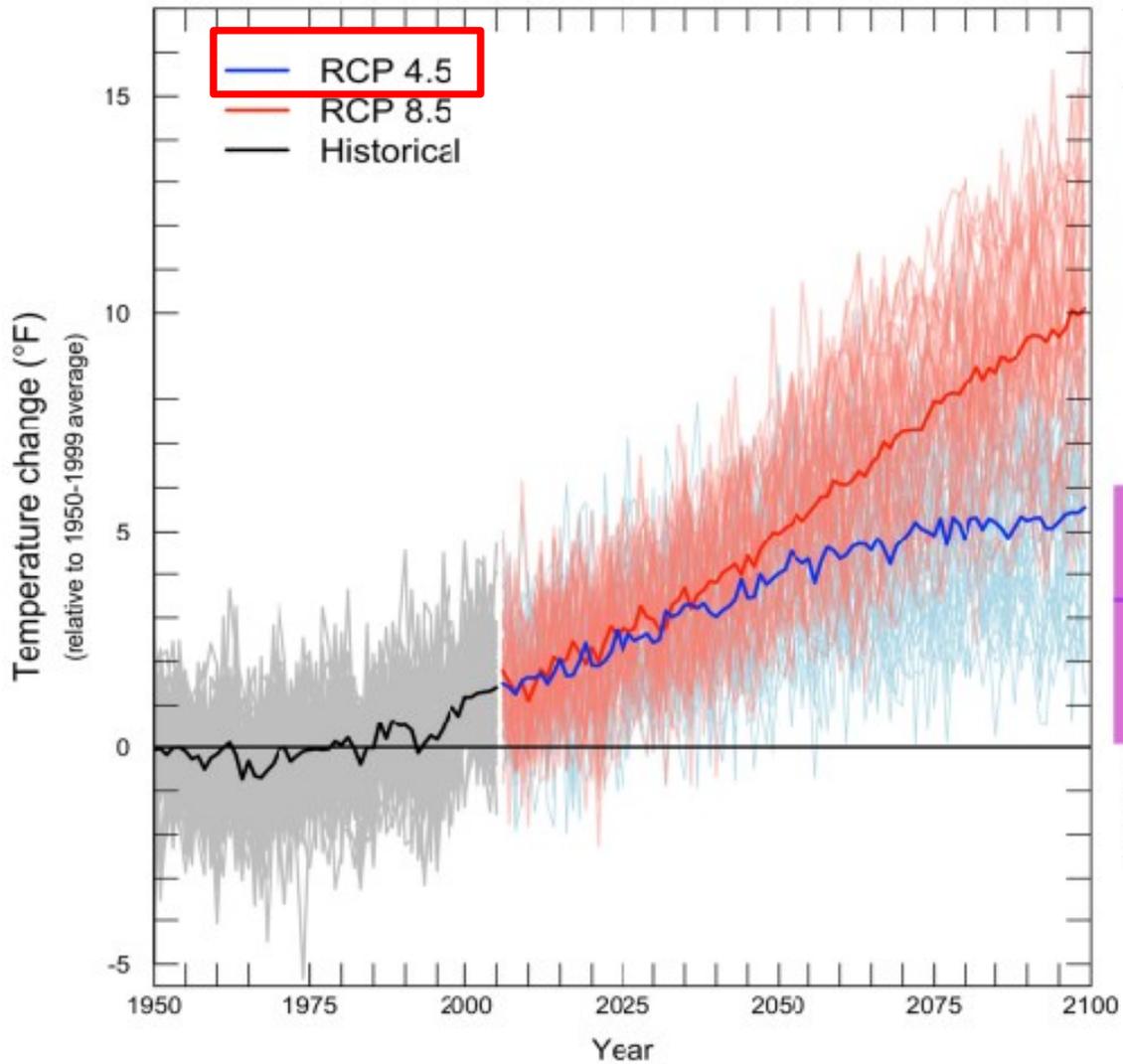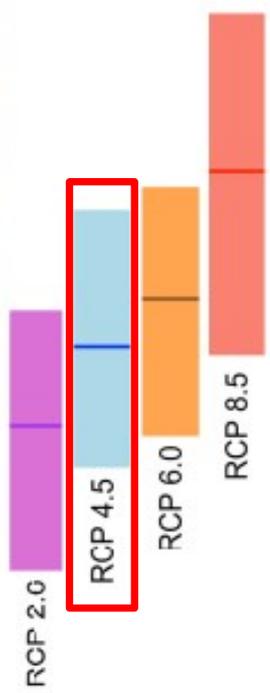- Disaggregated by county (fire only)

Photo Credit: Bureau of Land Management Oregon and Washington

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Climate Change

- 17 GCM ensemble
- Increased wildfire

Refresher: Climate Change Methods
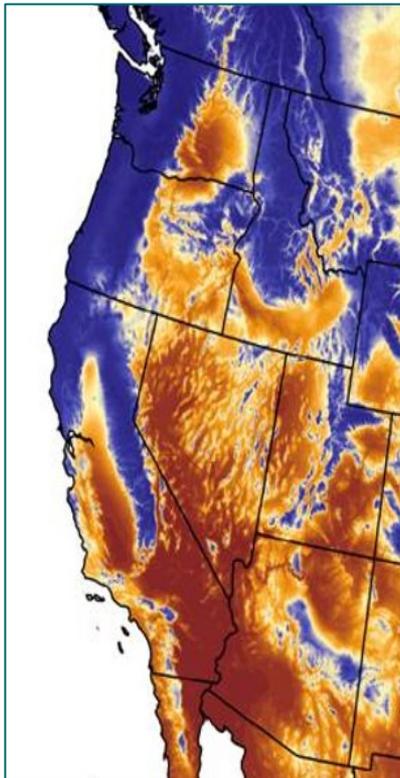
Refresher: Climate Change Methods

Socio-economic Storyline

Emissions Scenario

RCP 4.5
RCP 6.0
RCP 8.5

There are many of these worldwide. FVS combines 17

GCM

Climate Simulation

Climate Projection

Observed Climate

Regional Climate Model

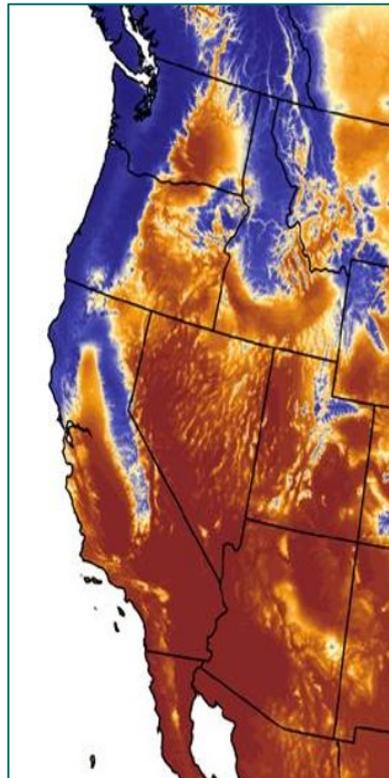*Statistical Downscaling*

Dynamical Downscaling

Downscaled Climate Projection

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24

Refresher: Climate Change Methods

Current

2090

Predictions of **dryness** with one GCM and one RCP

GFDLCM21_A2_Y2090
Annual Dryness Index

0 - 0.01649	0.1046 - 0.11
0.0165 - 0.02749	0.1101 - 0.1155
0.0275 - 0.03849	0.1156 - 0.121
0.0385 - 0.04398	0.1211 - 0.1265
0.04399 - 0.04948	0.1266 - 0.132
0.04949 - 0.05498	0.1321 - 0.1374
0.05499 - 0.06048	0.1375 - 0.1484
0.06049 - 0.06598	0.1485 - 0.1594
0.06599 - 0.07147	0.1595 - 0.1704
0.07148 - 0.07697	0.1705 - 0.1814
0.07698 - 0.08247	0.1815 - 0.1979
0.08248 - 0.08797	0.198 - 0.2144
0.08798 - 0.09346	0.2145 - 0.2364
0.09347 - 0.09896	0.2365 - 0.2639
0.09897 - 0.1045	0.264 - 0.3024
	0.3025 - 0.4233
	0.4234 - 1.402

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Refresher: Climate Change Methods

Douglas-fir
current vs 2060
GFDLCM21 B1

new
recede
stays

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Refresher: Climate Change Methods

Viability Scores

	DF	WH	PP
1990	0.973	0.960	0.376
2030	0.960	0.656	0.290
2060	0.857	0.236	0.546
2090	0.877	0.131	0.596

*Over time **less** suitable for DF & WH*
*Over time **more** suitable for PP*

What Does Climate-FVS Change?

Using the Viability Score, these will all change on a species or tree basis:

- **Stand carrying capacity**
- **Tree mortality**
- **Tree growth**
- **Species regeneration**

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What Is Left Out?

Climate-FVS does not currently simulate changes to these processes

- **Fire dynamics**, which depend on fuel moisture, temperature and wind speed.
- **Decay** rate of down wood
- **Snag** dynamics
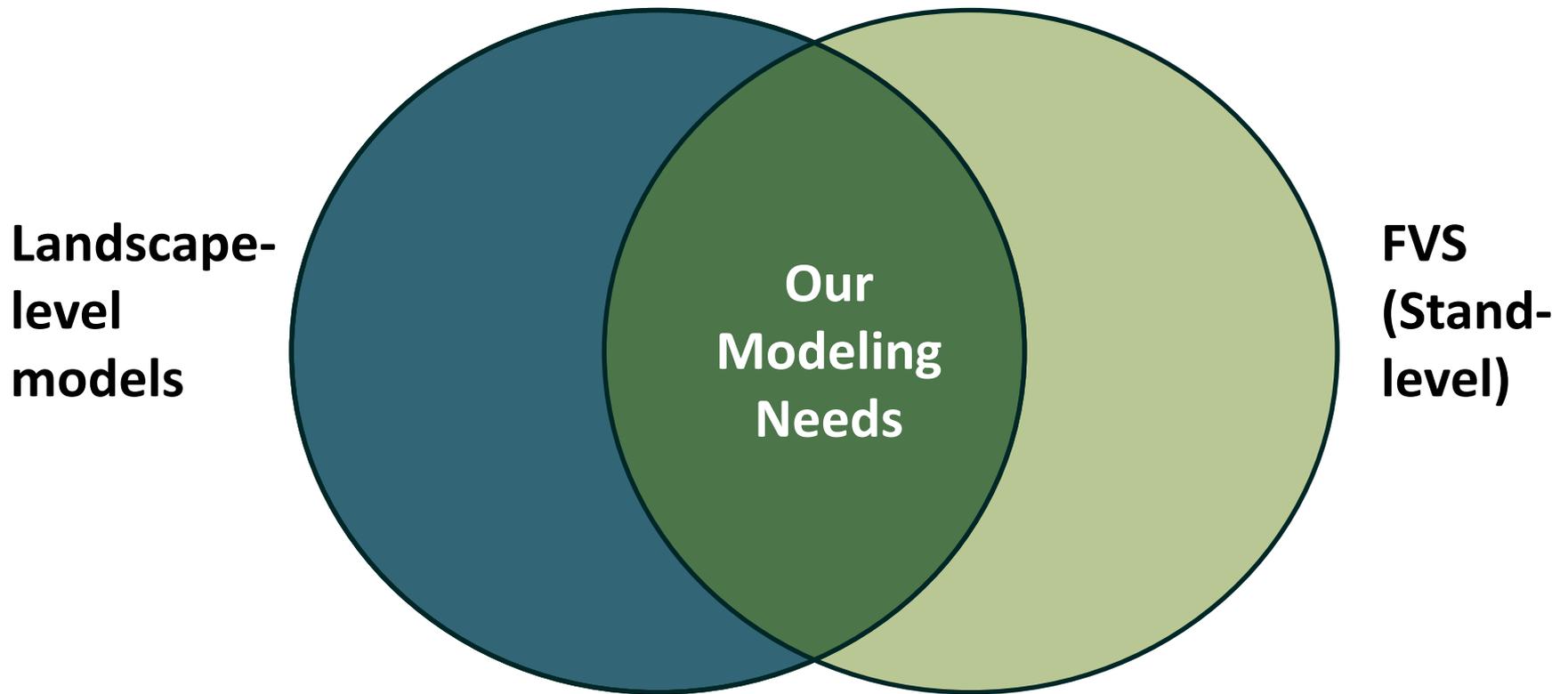- **Elevation sensitivity** (dClim rule) has been disabled

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ESSA Innovations with FVS

ESSA Innovations

- **Custom Management Actions**: Couldn't do pre-commercial thinning, commercial thinning or site preparation without teaching FVS new tricks

- **Need for Speed:** Couldn't run the model over all stands and still meet project timeline

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ESSA Innovations

Our modeling needs were a hybrid between landscape-level modeling and FVS's stand-level capabilities

Landscape-level models

Our Modeling Needs

FVS (Stand-level)

ESSA Innovations

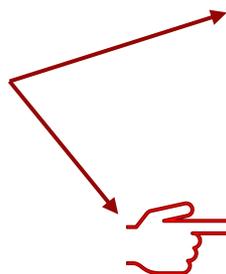| Landscape-level Models	FVS
Landscapes (forest cover)	Stands (plot data)
Generalized growth/yield curves	Not curve dependent
	uses site characteristics and stand history to predict growth
Harvest even flow at landscape	Harvest based on stand triggers

Our Modeling Needs

FVS challenges

Stand and landscapes
Tree growth across diverse sites, silvicultural treatments, and stand histories
☞ Teach FVS to harvest even flow at landscape

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ESSA Innovations

Many thanks to:

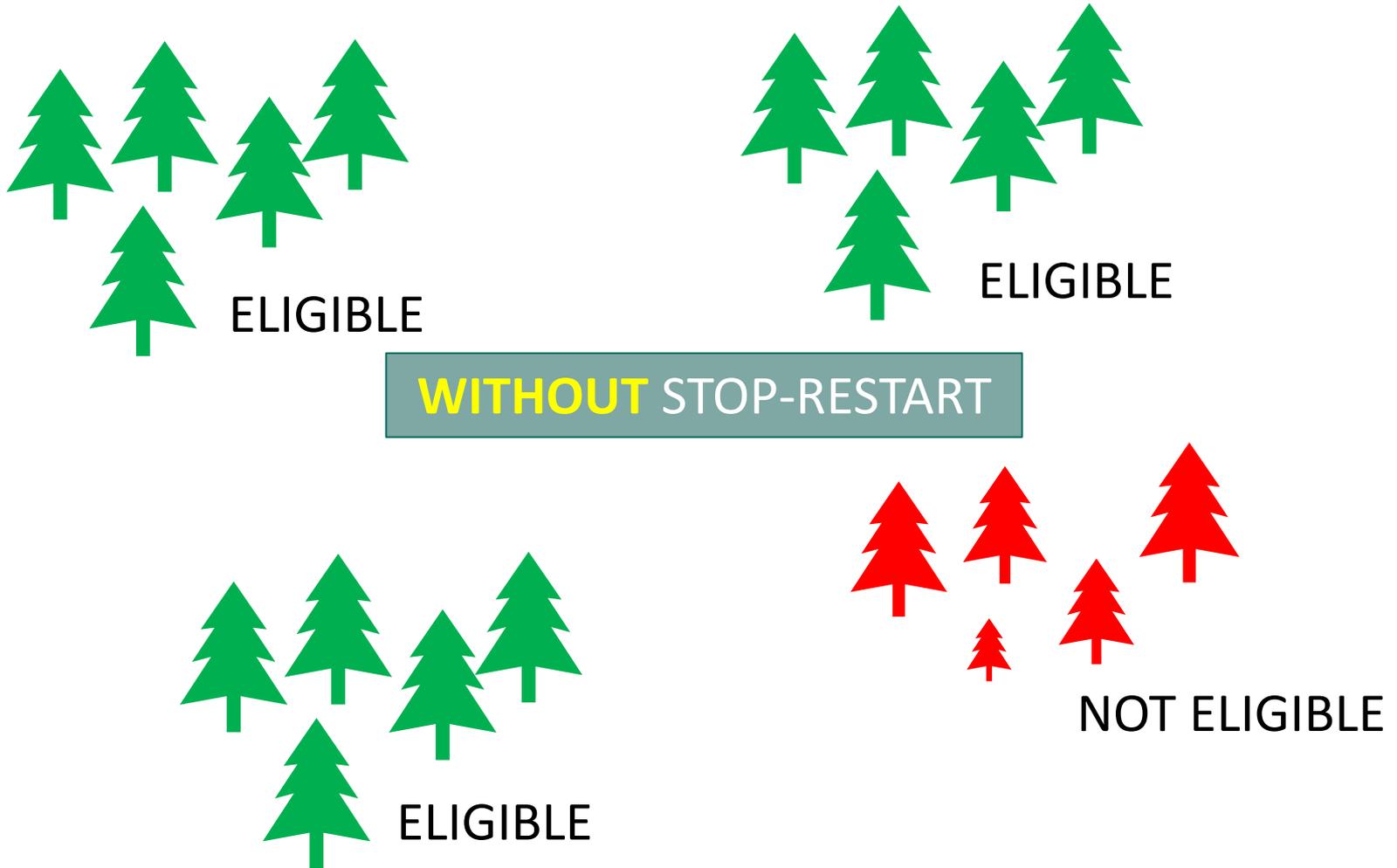- **Lance David**
- **Nick Crookston**
- **Erin Smith-Mateja**

In addition to our own
Don Robinson who worked
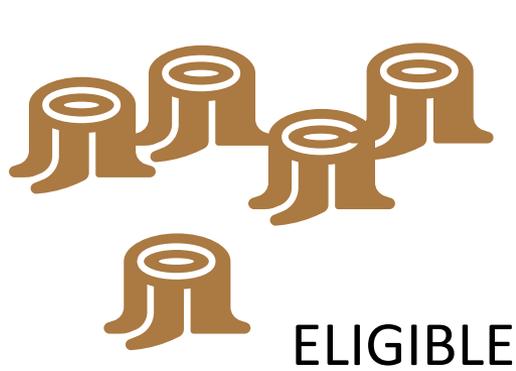closely with these folks

ESSA Innovations

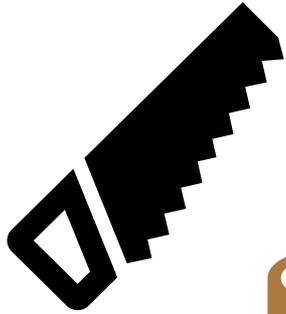| Problem	Solution
Custom Management Actions	• Stop-restart Functionality
Need for Speed	• Cloud Computing & Parallel Processing • Clustering Stands for Speed

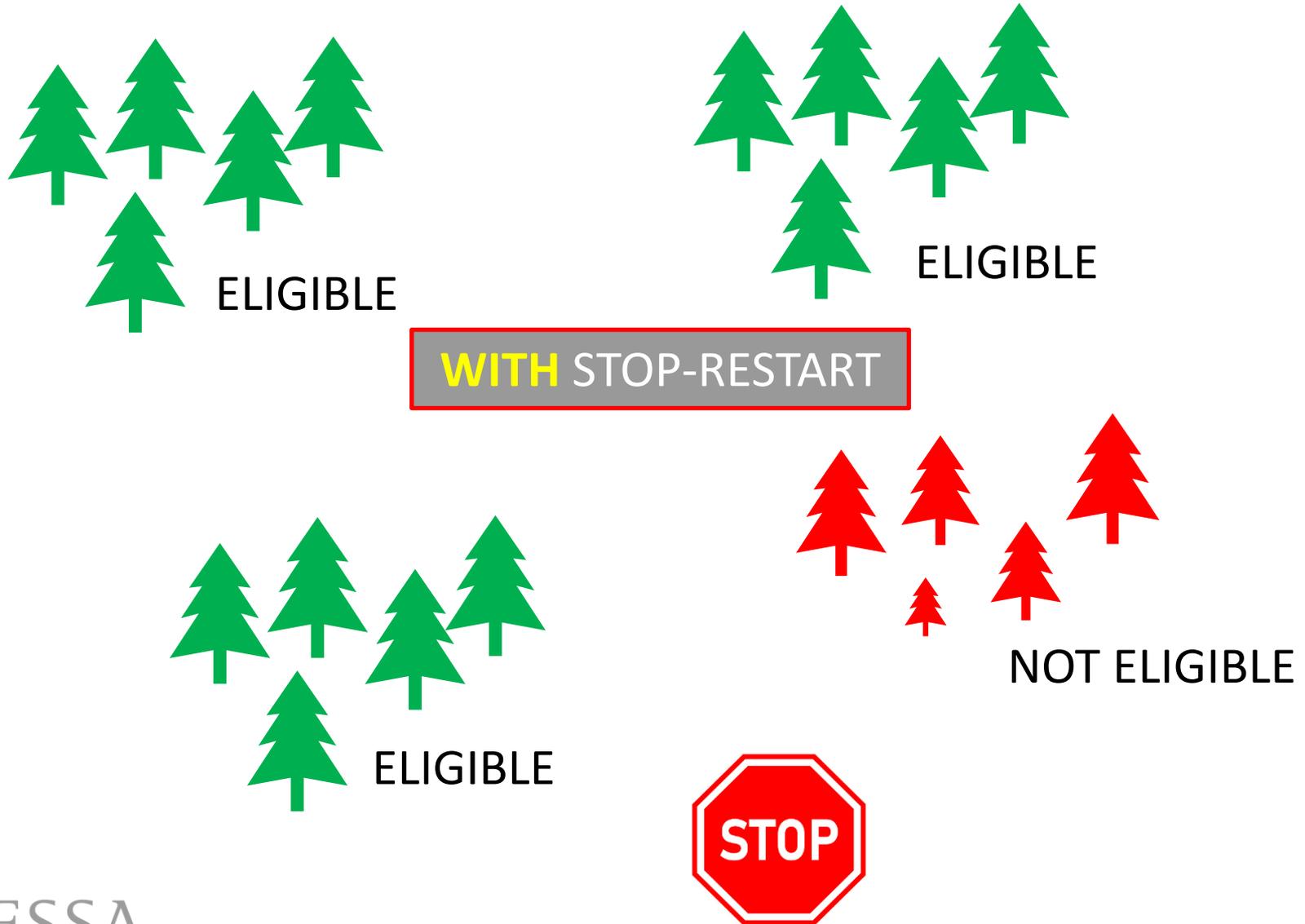ESSA

ESSA Innovations: "Stop-Restart" Functionality

ELIGIBLE

ELIGIBLE

WITHOUT STOP-RESTART

NOT ELIGIBLE

ELIGIBLE

ESSA Innovations: "Stop-Restart" Functionality

ELIGIBLE

ELIGIBLE

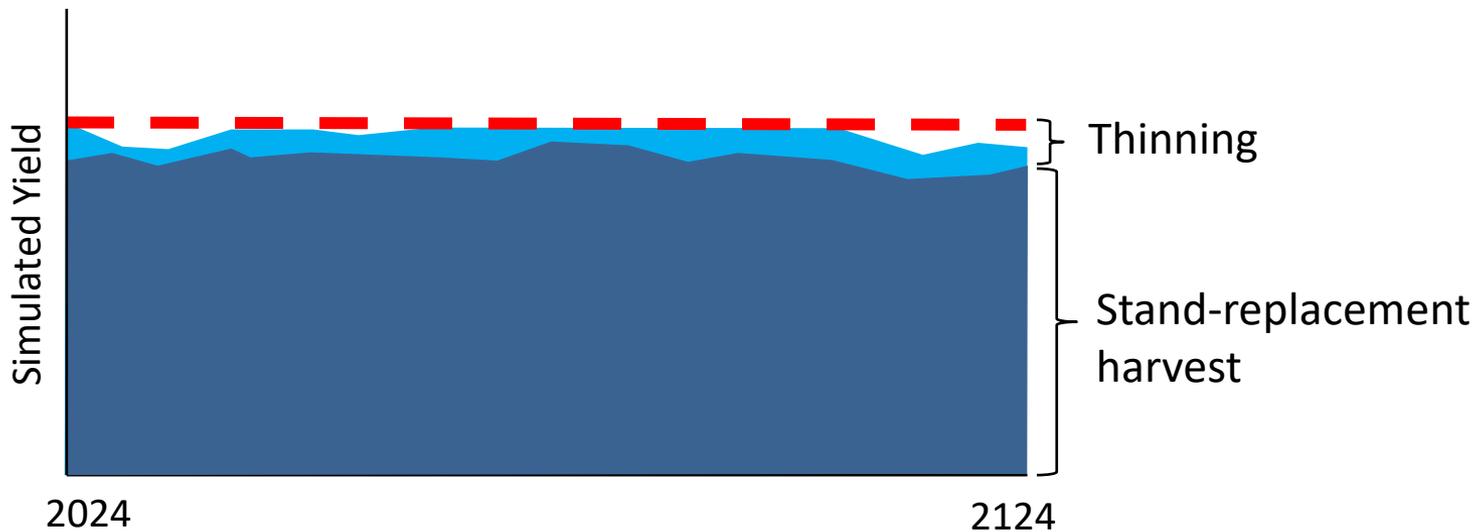**WITH** STOP-RESTART

ELIGIBLE

NOT ELIGIBLE

STOP

ESSA Innovations: "Stop-Restart" Functionality

ELIGIBLE

ELIGIBLE

WITH STOP-RESTART

NOT ELIGIBLE

ELIGIBLE

GO

Yield Target Implementation using Stop-Restart

Set yield target (same for all scenazrios)

Thinning

Stand-replacement harvest

Commercial Thinning Implementation using Stop-Restart

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Eligible
(> BF threshold)

Thin 30% of basal area

10%   **20%**

Corridor harvest (uniform across diameter classes)

Smallest trees thinned first

41

Commercial Thinning Implementation using Stop-Restart

Current Practices:
Thin 4% of eligible stand area per timestep

Significantly Increase Thinning:
Thin 100% of eligible stand area per timestep

Stand Replacement Harvest Implementation using Stop-Restart

Eligible
(> BF threshold,
or age threshold)

Harvest all but
8 large leave
trees

Stand Replacement Harvest Implementation using Stop-Restart

After commercial thinning, select stands for stand replacement harvest to achieve remaining yield target

Site Preparation + Release Treatments Implementation using Stop-Restart

First 10 years of growth

Without site preparation

With site preparation
63% volume increase

Current Practices:
75% of stands have site preparation

Enhanced Silviculture:
90% of stands have site preparation

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Seedling Improvements (Stop-Restart not Required)

First 10 years of growth

Without seedling improvements

With seedling improvements (all stands) 2% volume increase

ESSA Innovations: Cloud Computing and Parallelization of FVS

100 virtual computers

ESSA Innovations: Clustering Stands for Speed

5 sec

5 sec   5 sec

=   15 sec

=   5 sec

ESSA Innovations: Clustering Stands for Speed

Initial Grouping Variables

Land Class	County
Species	Deferred?
Site Class	Age Class

124,657
Stands

ESSA Innovations: Clustering Stands for Speed

Clustering Variables

Slope	Site Index
Elevation	Max SDI
Aspect	Inventory Yr

ESSA Innovations: Clustering Stands for Speed

Slope   Site Index

Elevation   Max SDI

Aspect   Inventory Yr

9,221
Clusters became "stands" in FVS
allowing us to simulate an entire landscape based on site specific attributes without relying on generalized yield curves

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General Model Performance

	# Unique Stands (GEM only, non-deferred)	Total run time per scenario (avg. est.)	Total run time all scenarios (est.)
Single computer (all stands)	46,540	17 days 22 hours 23 mins	9 months 16 days 22 hours 4 mins
Cloud system (all stands)	46,540	2 days 1 hour 19 mins	2 days 20 hours 34 mins
Cloud system (clustering)	2,206	1 hour 12 mins	3 hours 15 mins

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Your Turn!
Questions

Supplementary Slides

Model Parameter Settings by Scenario

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Configuration Settings (GEM)	Scenario #1: Current DNR Management Practice	Scenario #2: Lengthen Harvest Rotation	Scenario #3: Shorten Harvest Rotation	Scenario #4: Significantly Increase Thinning	Scenario #5: Lengthen Harvest Rotation and Significantly Increase Thinning	Scenario #6: Lengthen Harvest Rotation, Significantly Increase Thinning, Increase Deferrals	Scenario #7: Significantly Increase Thinning and Increased Emphasis on Silviculture	Scenario #8: Shorten Harvest Rotation, Significantly Increase Thinning, Increased Emphasis on Silviculture
Stand-replacement harvest board feet requirement (MBF/ac)	30	50	20	30	50, 80 years (site class 3), 90 years (site class 4)	50, 80 years (site class 3), 90 years (site class 4)	30	20
Commercial thinning board feet requirement (MBF/ac)	18	18	18	18	18	18	18	10
Precommercial thinning stand age requirement	Between 8-12 years old							
Precommercial thinning (trees/ac remaining) – High Elevation zone	330	280	330	429	429	429	29	429
Precommercial thinning (trees/ac remaining) – Coastal Low Elevation zone	300	250	300	390	390	390	390	390
Precommercial thinning (trees/ac remaining) – Near to Coast Low Elevation zone	300	250	300	390	390	390	390	390
Precommercial thinning (trees/ac remaining) – Not Near to Coast Low Elevation zone	250	211	250	325	325	325	325	325

Model Parameter Settings by Scenario

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Precommercial thinning (trees/ac remaining) – Mixed Species zone	250	211	250	325	325	325	325	325
Precommercial thinning (trees/ac trigger) – High Elevation zone	660+							
Precommercial thinning (trees/ac trigger) – Coastal Low Elevation zone	600+							
Precommercial thinning (trees/ac trigger) – Near to Coast Low Elevation zone	600+							
Precommercial thinning (trees/ac trigger) – Not Near to Coast Low Elevation zone	500+							
Precommercial thinning (trees/ac trigger) – Mixed Species zone	500+							
Stand-replacement harvest (leave trees/ac)	8 (2 leave trees in the largest diameter class, 6 leave trees in the intermediate diameter class, remove all trees 10 inches DBH or smaller in the intermediate diameter class and smaller classes. Leave trees, on average, account for approximately 10% of stand volume, leaving 90% of volume available for harvest under current practices.)							

Model Parameter Settings by Scenario

ESSA

Configuration Settings (GEM)	Scenario #1: Current DNR Management Practice	Scenario #2: Lengthen Harvest Rotation	Scenario #3: Shorten Harvest Rotation	Scenario #4: Significantly Increase Thinning	Scenario #5: Lengthen Harvest Rotation and Significantly Increase Thinning	Scenario #6: Lengthen Harvest Rotation, Significantly Increase Thinning, Increase Deferrals	Scenario #7: Significantly Increase Thinning and Increased Emphasis on Silviculture	Scenario #8: Shorten Harvest Rotation, Significantly Increase Thinning, Increased Emphasis on Silviculture
Commercial thinning (% stand basal area harvested)	30							
Annual stand-replacement harvest target (BF, full study area)	2,196,831,000							
Commercial thinning harvest target (% of stands or area)	8%	8%	8%	100%				
Precommercial thinning harvest target (% of stands receiving PCT in GEM areas)	50%	50%	50%	75%	75%	75%	75%	75%
Stand-replacement harvest type	Thin from above to a trees per acre target (8 leave trees).							
Commercial thinning harvest type	First, thin across all diameters to 90% of original basal area remaining, then Thin from below to a basal area target (70% of original basal area remaining).							
New harvest deferrals	None	None	None	None	None	Defer all stands ≥ 80 years at start of simulation	None	None
Stand regeneration lag	2 years							
Natural regeneration density (seedlings/acre) – High Elevation zone (Mountain Hemlock and Silver Fir)	20 MH, 20 SF							

Model Parameter Settings by Scenario

ESSA

Configuration Settings (GEM)	Scenario #1: Current DNR Management Practice	Scenario #2: Lengthen Harvest Rotation	Scenario #3: Shorten Harvest Rotation	Scenario #4: Significantly Increase Thinning	Scenario #5: Lengthen Harvest Rotation and Significantly Increase Thinning	Scenario #6: Lengthen Harvest Rotation, Significantly Increase Thinning, Increase Deferrals	Scenario #7: Significantly Increase Thinning and Increased Emphasis on Silviculture	Scenario #8: Shorten Harvest Rotation, Significantly Increase Thinning, Increased Emphasis on Silviculture
Natural regeneration density (seedlings/acre) – Coastal Low Elevation zone (Western Hemlock, Red Alder, Douglas Fir, Western Redcedar)					34 WH, 2 RA, 2 DF, 2 RC			
Natural regeneration density (seedlings/acre) – Near to Coast Low Elevation zone (Western Hemlock, Red Alder, Douglas Fir, Western Redcedar)					34 WH, 2 RA, 2 DF, 2 RC			
Natural regeneration density (seedlings/acre) – Not Near to Coast Low Elevation zone (Western Hemlock, Red Alder, Douglas Fir, Western Redcedar)					17 WH, 1 RA, 1 DF, 1 RC			
Natural regeneration density (seedlings/acre) – Mixed Species zone (Western Hemlock, Red Alder, Douglas Fir, Western Redcedar)					17 WH, 1 RA, 1 DF, 1 RC			

Model Parameter Settings by Scenario

Configuration Settings (GEM)	Scenario #1: Current DNR Management Practice	Scenario #2: Lengthen Harvest Rotation	Scenario #3: Shorten Harvest Rotation	Scenario #4: Significantly Increase Thinning	Scenario #5: Lengthen Harvest Rotation and Significantly Increase Thinning	Scenario #6: Lengthen Harvest Rotation, Significantly Increase Thinning, Increase Deferrals	Scenario #7: Significantly Increase Thinning and Increased Emphasis on Silviculture	Scenario #8: Shorten Harvest Rotation, Significantly Increase Thinning, Increased Emphasis on Silviculture
Planting density (seedlings/acre) – High Elevation zone (Noble Fir)	440	375	440	572	572	572	572	572
Planting density (seedlings/acre) – Coastal Low Elevation zone (Western Hemlock)	400	340	400	520	520	520	520	520
Planting density (seedlings/acre) – Near to Coast Low Elevation zone (Douglas-fir, Western Hemlock)	200 DF, 200WH	170 DF, 170 WH	200 DF, 200WH	260 DF, 260 WH	260 DF, 260 WH	260 DF, 260 WH	260 DF, 260 WH	260 DF, 260 WH
Planting density (seedlings/acre) – Not Near to Coast Low Elevation zone (Douglas Fir, Western Hemlock, Red-cedar)	275 DF, 50 WH	242 DF, 21 WH, 12RC	275 DF, 50 WH	357 DF, 65 WH	357 DF, 65 WH	357 DF, 65 WH	357 DF, 65 WH	357 DF, 65 WH
Planting density (seedlings/acre) – Mixed Species zone (Douglas Fir, Western Hemlock, Red-cedar)	295 DF, 25 HW 15 RC	242 DF, 21 WH, 12RC	275 DF, 50 WH	357 DF, 65 WH	357 DF, 65 WH	357 DF, 65 WH	357 DF, 65 WH	357 DF, 65 WH
Increased growth due to improved genetic stock (% increase in diameter and height growth)	0	0	0	0	0	0	2	2

Model Parameter Settings by Scenario

Configuration Settings (GEM)	Scenario #1: Current DNR Management Practice	Scenario #2: Lengthen Harvest Rotation	Scenario #3: Shorten Harvest Rotation	Scenario #4: Significantly Increase Thinning	Scenario #5: Lengthen Harvest Rotation and Significantly Increase Thinning	Scenario #6: Lengthen Harvest Rotation, Significantly Increase Thinning, Increase Deferrals	Scenario #7: Significantly Increase Thinning and Increased Emphasis on Silviculture	Scenario #8: Shorten Harvest Rotation, Significantly Increase Thinning, Increased Emphasis on Silviculture
Increased growth due to site preparation and release treatments (% increase in diameter and height growth of small trees after 10 years)					84			
Extent of site preparation and release treatments (% of plots)	75	75	75	100	100	100	100	100
Fire rate (% basal area affected annually, by county)					Island = 0.0058% Clallam = 0.0117% Mason = 0.0124% San-Juan = 0.0126% Pierce = 0.0141% Wahkiakum = 0.0155% Jefferson = 0.0179% Pacific = 0.0186019% Lewis = 0.019% Kitsap = 0.0216% Grays-Harbor = 0.0249% Thurston = 0.0255% Clark = 0.0316% Cowlitz = 0.0378% Skamania = 0.0436% King = 0.0892% Snohomish = 0.1310% Skagit = 0.2072% Whatcom = 0.4698%			

Model Parameter Settings by Scenario

ESSA

Configuration Settings (GEM)	Scenario #1: Current DNR Management Practice	Scenario #2: Lengthen Harvest Rotation	Scenario #3: Shorten Harvest Rotation	Scenario #4: Significantly Increase Thinning	Scenario #5: Lengthen Harvest Rotation and Significantly Increase Thinning	Scenario #6: Lengthen Harvest Rotation, Significantly Increase Thinning, Increase Deferrals	Scenario #7: Significantly Increase Thinning and Increased Emphasis on Silviculture	Scenario #8: Shorten Harvest Rotation, Significantly Increase Thinning, Increased Emphasis on Silviculture
Insect mortality rate (% basal area affected annually)	0.0061%							
Blowdown rate (% basal area affected annually)	0.05676%							
Drought rate (% basal area affected annually)	0.0040%							
Disease rate (% basal area affected annually)	0.0806%							
Temporal parameters	100-year time horizon, 5-year time steps, length of first cycle differs to accommodate differing inventory years							
Climate change	1 run without climate change, 1 run with 17 GCM ensemble and RCP4.5 implemented in Climate-FVS							