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A NEW LOOK AT QUANTIFYING LEAKAGE IN VOLUNTARY US FOREST CARBON OFFSET PROJECTS

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Objectives

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Background

- Status of US Forest Carbon Markets

Methods

- Forest and Agricultural Sector Optimization Model

Preliminary Results

- Graphs etc.

Leakage in practice

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Credits (tons CO2e)

Leakage

Simplified ARB Quantified GHG emissions reduction (QR) equation:

$$QR_y = \left(\Delta AC_{onsite} - \Delta BC_{onsite}\right) + \left(AC_{wp,y} - BC_{wp,y}\right)\cdot 0.8 + \left(AC_{se,y} - BC_{se,y}\right)\cdot 0.2$$

Standing Tree Carbon | Wood Product Carbon | Harvested Tree Carbon

A – project
B - baseline

- Activity-shifting leakage –the shifting of harvest activities from within the project boundaries to areas outside the project boundaries

$$\left(AC_{se,y} - BC_{se,y}\right)\cdot 0.2$$

Uses 20% leakage factor and can't be greater than 0

- Market-shifting leakage –the increase of harvest activities outside the project's boundaries as a result of the project's effects on market demand (wood products)

$$\left(AC_{wp,y} - BC_{wp,y}\right)\cdot (1-0.2)$$

Also uses 20% leakage factor and can be greater than 0

Where did this 20% come from???

Murray, McCarl, & Lee (2004)

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- Use a structural market model, the Forest and Agricultural Sector Optimization Model (FASOM), to specifically evaluate leakage
- Looked over time 2000-2070 decadal
- Considered forest set-asides, afforestation, and avoided deforestation
- Simulated variables include carbon stocks and flows, timber harvest volumes, forest management intensity, harvest rotation lengths, international trade volume
- **This is carbon leakage**
- To handle time, he discounts future carbon values by 4%

Murray, McCarl, and Lee: Forest Carbon Sequestration Programs

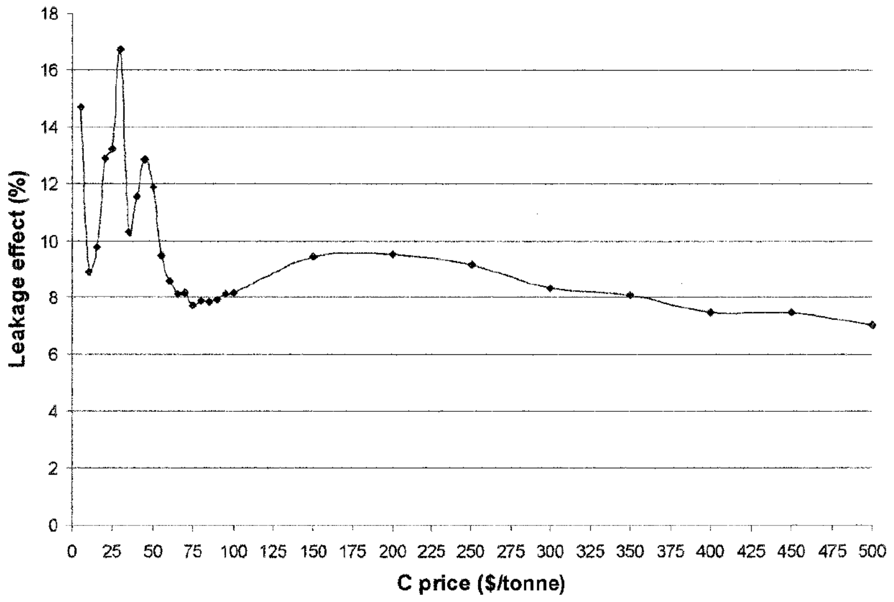

FIGURE 2
Leakage Effects as a Function of the Carbon Price; Afforestation-Avoided Deforestation Scenario

Murray, B.C., B.A. McCarl, and H. Lee. 2004. Estimating Leakage from Forest Carbon Sequestration Programs. *Land Economics* 80(1):109-124.

Better source for the FASOM leakage results

Murray, B.C., B.L. Sohngen, A.J. Sommer, B.M. Depro, K.M. Jones, B.A. McCarl, D. Gillig, B. DeAngelo and K. Andrasko. 2005. Greenhouse gas mitigation potential in U.S. forestry and agriculture. EPA-R-05-006, U.S. Environmental Protection Agency, Office of Atmospheric Programs, Washington, D.C.

Gan & McCarl (2007)

- Use a General Equilibrium modeling approach (GTAP model)
- Look at Forest Conservation but really they just shift the supply curve for forest production up and in
  - Remember that they have to be very general to have all countries involved

- They find U.S. leakage of approx. 64%
- **This is total net change in forestry output leakage**
  - No way to know what that means for forest carbon leakage

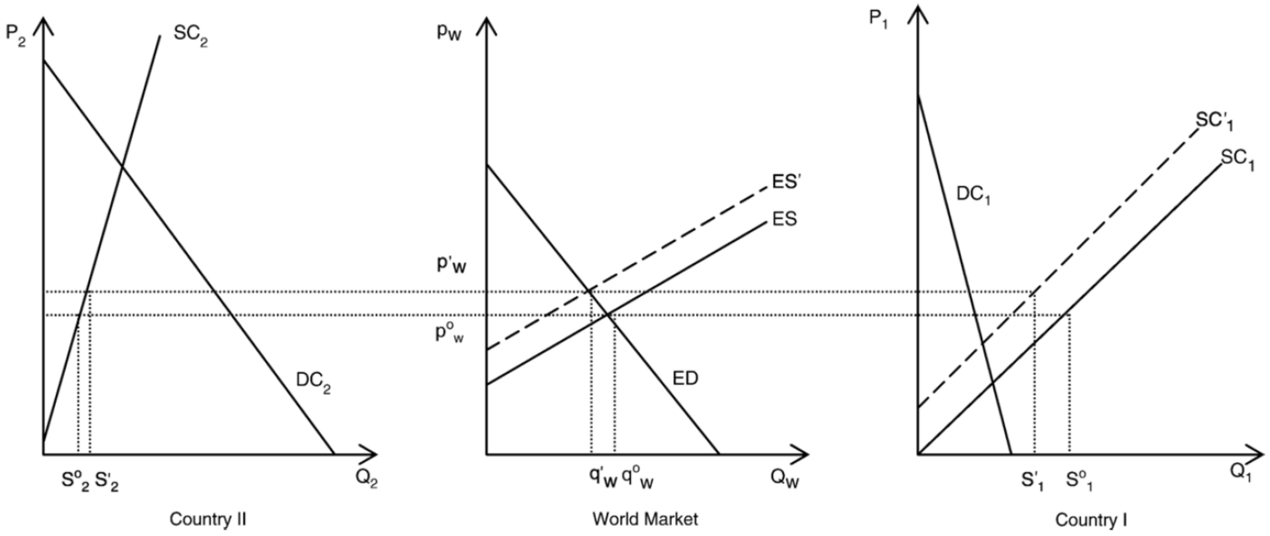

Fig. 1 – Forest conservation leakage in the two-country case.

Gan, J. & B. A. McCarl. 2007. Measuring transnational leakage of forest conservation. *Ecological Economics,* 64(2), 423-432.

Wear & Murray (2004)

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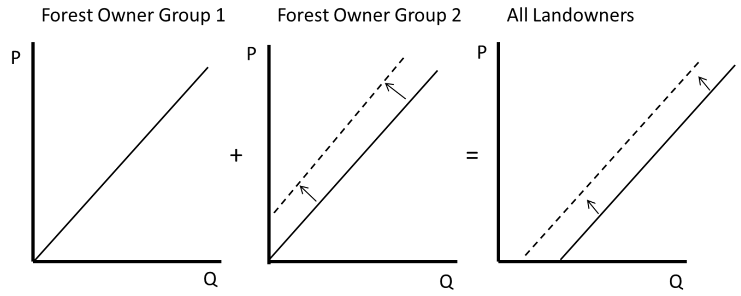
- An econometric (statistical) estimation of U.S. lumber market related to a reduction in federal harvest in the PNW
- So a reserve program, not carbon program

- They do a with and without analysis of federal harvest reductions for 1990-95 to arrive at leakage estimate of 43% in PNW, 58% in the US and 84% in North America
- **This is harvest leakage, not forest carbon leakage**



Like this simple example yet looking at more than 2 owners (PNWpublic, PNWprivate, Inland, South, Canada)

Wear, D. N. & B. C. Murray. 2004. Federal timber restrictions, interregional spillovers, and the impact on US softwood markets. *Journal of Environmental Economics and Management,* 47(2), 307-330.

Murray, McCarl, & Lee (2004) *part 2*

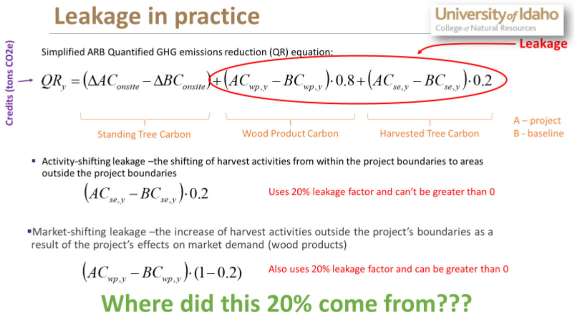
- Estimates of **carbon leakage** *(which is good)*

$$L^T = \left[\left(PV_P - PV_T \right) \Big/ PV_P \right] \cdot 100$$

Where PV_P is the time discounted present value of carbon sequestration on lands targeted by the policy and PV_T is the corresponding discounted value of carbon increments on all lands (targeted and non-targeted)

- **However** – that means the leakage estimate relates to total project sequestration not just reduction in harvesting

(which means ARB is using it incorrectly – which is bad)



Murray, McCarl, and Lee: Forest Carbon Sequestration Programs

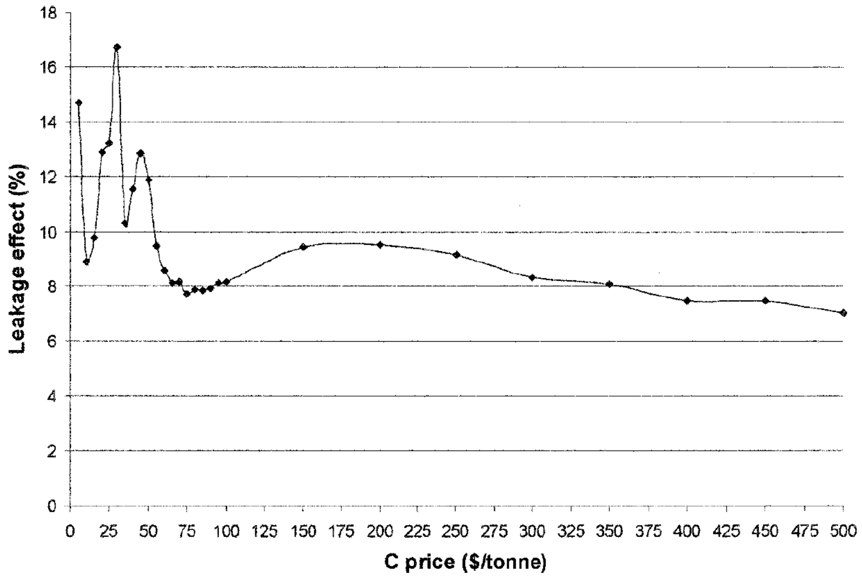


FIGURE 2
Leakage Effects as a Function of the Carbon Price;
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Forest Carbon Quantification Consortium

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History

- TNC – Amazon - TerraCarbon discussion *(AKA the Leakage Spiritual Journey)* ***summer 2020***
  - Redoing the Murray study *(This is where I came in)*

FCQC – Forest Carbon Quantification Consortium

Greg Latta (Univ. of Idaho),
Adam Daigneault (Univ. of Maine),
Christopher Galik and Justin Baker (North Carolina State Univ)

FASOM-GHG

(the Forest and agriculture Sector Optimization Model with Greenhouse Gases)

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Long history modeling carbon markets and forestry

For policy analysis

EPA analysis of **S 843** *(Clean Air Planning Act of 2003)*, **S 280** *(Climate Stewardship and Innovation Act of 2007)*, **S 1766** *(Low Carbon Economy Act of 2007)*, and **S 2191** *(Lieberman-Warner Climate Security Act of 2007)*, **HR 2454** *(American Clean Energy and Security Act of 2009)*, **S 1733** *(Clean Energy Jobs and American Power Act)*

And journal articles

Adams, R., Adams, D., Callaway, J., Chang, C., and McCarl. B.: **1993**, 'Sequestering Carbon on Agricultural Land: Social Cost and Impacts on Timber Markets', *Contemporary Policy Issues* XI (1), 76–87.

Adams, D., Alig, R., McCarl, B., Callaway, J., and Winnett. S.: **1999**, 'Minimum Cost Strategies for Sequestering Carbon in Forests', *Land Economics 75 (3), 360–374.*

R Alig, G. Latta, D. Adams, and B. McCarl. **2010**. Mitigating Greenhouse Gases: The Importance of Land Base Interactions Among Forests, Agriculture, and Residential Development in the Face of Changes in Bioenergy and Carbon Prices. *Forest Policy and Economics* 12(1): 67-75.

Latta, G., D. Adams, R. Alig and E. White. **2011**. Simulated effects of mandatory versus voluntary participation in private forest carbon offset markets in the United States. Journal of Forest Economics 17(2): 127-141.

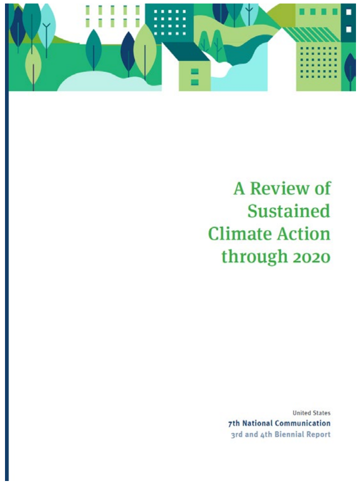
Wade, C.M., J.S. Baker, J.P.H. Jones, K.G. Austin, Y. Cai, A.B. de Hernandez, G.S. Latta, S.B. Ohrel, S. Ragnauth, J. Creason and B. McCarl. **2022**. Projecting the Impact of Socioeconomic and Policy Factors on Greenhouse Gas Emissions and Carbon Sequestration in US Forestry and Agriculture. Journal of Forest Economics: Vol. 37: 127–161.

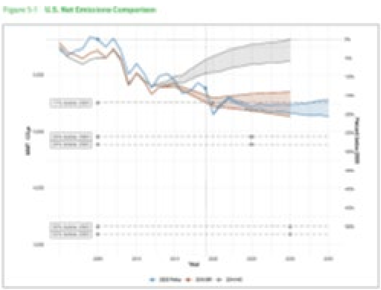
FCQC Leakage Studies

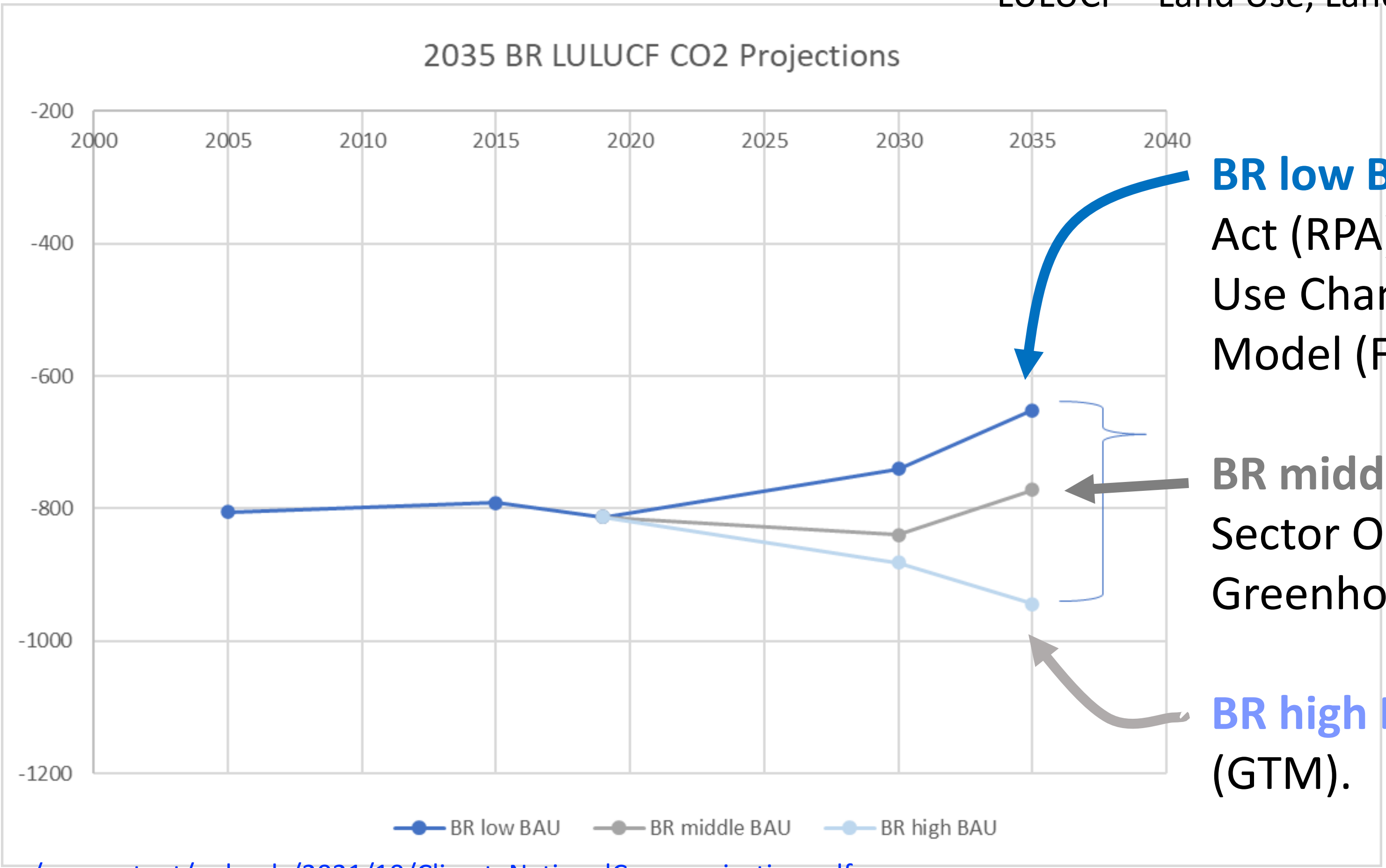
There are really 2:

1. FASOM-based domestic study *(what I will talk about today)*
2. GTM-based international study

LULUCF – Land Use, Land Use Change, and Forestry







BR low BAU - USFS Resources Planning Act (RPA) Forest Dynamics model, Land Use Change model, and Global Trade Model (FOROM).

BR middle BAU - Forest and Agriculture Sector Optimization Model with Greenhouse Gases (FASOMGHG).

BR high BAU - Global Timber Model (GTM).

❖ https://www.whitehouse.gov/wp-content/uploads/2021/10/ClimateNationalCommunication.pdf

Using a market mechanism *(a carbon price)* in a market model *(FASOM-GHG)*

- Use the strength of the model to inform the leakage analysis
  - In other words: use a carbon price and observe the market/resource response
  - This will be like the Wade et al. (2022) model with the Latta et al. (2011) additions allowing voluntary participation
    - So private forest owners can:
      - choose to participate in the offset market and get paid for sequestration (while also paying for emissions)
      - Or choose not to participate and not get paid or pay for sequestration and emissions.
    - To flush out that was not participating in the market anyway (non-additional) I will use \$1/tCO_2 as the base level against which to measure additionality
- Scenarios
  - 0,1,5,10,15,20,25,30,40,50,75,100 \$/tCO2 for offset market participants *(and \$0 for non-participants)*
  - Carbon Price paid only on above and below-ground live tree carbon *(so not soils, litter, or dead wood)*
  - No Harvest in Post-Merch private acres

Also, a glitch in these runs not paying for harvested wood products

Wade, C.M., J.S. Baker, J.P.H. Jones, K.G. Austin, Y. Cai, A.B. de Hernandez, G.S. Latta, S.B. Ohrel, S. Ragnauth, J. Creason and B. McCarl. *2022*. Projecting the Impact of Socioeconomic and Policy Factors on Greenhouse Gas Emissions and Carbon Sequestration in US Forestry and Agriculture. *Journal of Forest Economics*: Vol. 37: http://dx.doi.org/10.1561/112.00000545

Latta, G., D. Adams, R. Alig and E. White. 2011. Simulated effects of mandatory versus voluntary participation in private forest carbon offset markets in the United States. *Journal of Forest Economics* 17(2): 127-141.

Using a market mechanism *(a carbon price)* in a market model *(FASOM-GHG)*

- All Scenarios
  - 0,1,5,10,15,20,25,30,40,50,75,100 $/tCO2 for offset market participants *(and $0 for non-participants)*
  - Carbon Price paid only on above and below-ground live tree carbon *(so not soils, litter, or dead wood)*
  - No Harvest in Post-Merch private acres

Also, a glitch in these runs not paying for harvested wood products

- Crediting Scenarios
  1. *Credit for all sequestration (removals)*
  2. *One-time payment for stocks above average (avoided emissions)*
  3. Combined schemes 2 and 3 (removals and avoided emissions)

Using a market mechanism *(a carbon price)* in a market model *(FASOM-GHG)*

Allowing Harvest in Post-Merch private acres

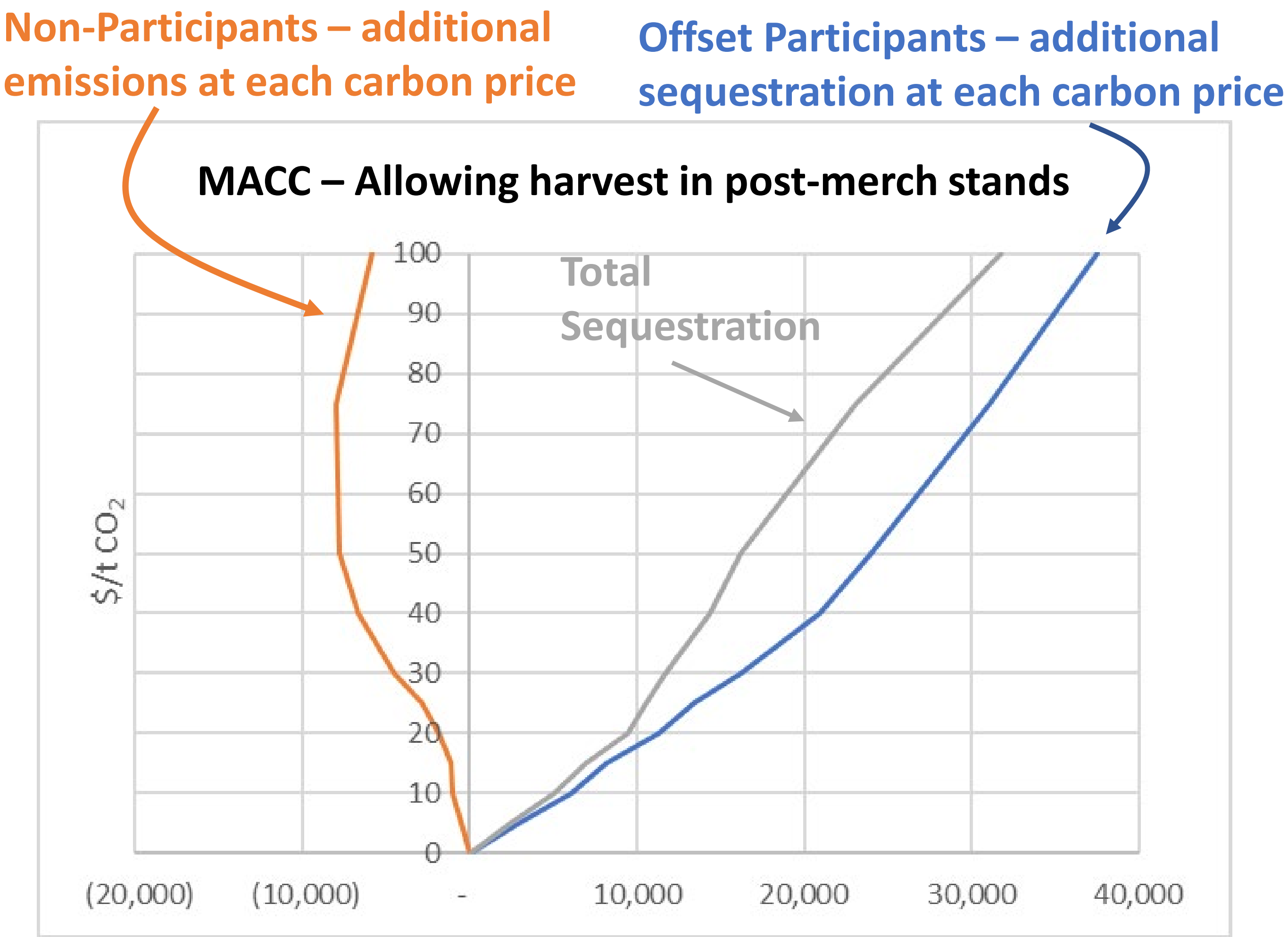
Marginal Abatement Cost Curve (MACC)
Steps:

1. Run the Carbon Price Scenarios through 2090 in 5-year time periods
2. Calculate additional sequestration in each time period
3. Discount the additional carbon using 4% *(similar to Murray et al (2004))*
4. Calculate the annual annuity value that would equal the sum of the first 40 years of discounted additional carbon

$$V_0 = \frac{a*[(1+i)^t-1]}{i*(1+i)^t}$$

V_0 is the sum of the discounted additional carbon over the first 40 years
i is the discount rate (here 4%)
t is the time period over which the annuity is calculated (here 40 years)
a is the annuity value (or a single value that could be applied annually for 40 year and give us the discounted sum of additional sequestration – it basically makes it so we have one value for each carbon price)

Murray, B.C., B.A. McCarl, and H. Lee. 2004. Estimating Leakage from Forest Carbon Sequestration Programs. Land Economics 80(1):109-124.



Note: the blue line (participants) is only the above and below ground carbon. Gains in other carbon pools are part of the non-participating total.

Using a market mechanism *(a carbon price)* in a market model *(FASOM-GHG)*

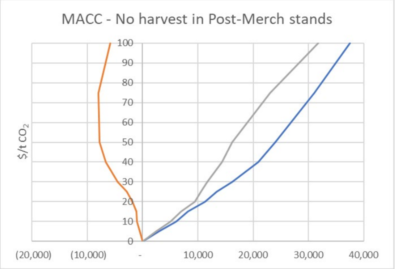
- Allowing Harvest in Post-Merch private acres

Marginal Abatement Cost Curve (MACC)
Steps:

1. Run the Carbon Price Scenarios through 2090 in 5-year time periods
2. Calculate additional sequestration in each time period
3. Discount the additional carbon using 4% *(similar to Murray et al (2004))*
4. Calculate the annual annuity value that would equal the sum of the first 40 years of discounted additional carbon
5. Calculate leakage using Equation 12 in Murray et al (2004)

$$L^T = [(PV_P - PV_T)/PV_P]*100. \qquad [12]$$

PV_P is the time-discounted present value of carbon sequestration increment on lands targeted by the policy. PV_T is the corresponding discounted value of carbon increments on all lands (targeted and non-tar-



CO_2 Price	Participants PV_P	Non-Participants	Total PV_T	Leakage L^T
	------------------thousand tons of CO2/year	------------------		
0	0	0	0	
5	2,976	-543	2,433	18%
10	6,078	-1,022	5,056	17%
15	8,168	-1,164	7,003	14%
20	11,282	-1,877	9,405	17%
25	13,398	-2,836	10,563	21%
30	16,213	-4,532	11,681	28%
40	20,964	-6,639	14,325	32%
50	24,006	-7,802	16,204	32%
75	31,103	-7,982	23,121	26%
100	37,561	-5,796	31,765	15%

Murray, B.C., B.A. McCarl, and H. Lee. 2004. Estimating Leakage from Forest Carbon Sequestration Programs. Land Economics 80(1):109-124.

Calculating leakage with avoided emissions

$$L^T = [(PV_P - PV_T)/PV_P]*100. \qquad [12]$$

PV_P is the time-discounted present value of carbon sequestration increment on lands targeted by the policy. PV_T is the corresponding discounted value of carbon increments on all lands (targeted and non-tar-

These we observe within the model

$$L^T = \left[{(PV_P + PV_{AE} - PV_T)}/{(PV_P + PV_{AE})} \right] \cdot 100$$

We need to add these in and assume that they happened

Scenario Leakage

$$L^T = \left[{}^{(PV_P + PV_{AE} - PV_T)} \Big/ {}_{(PV_P + PV_{AE})} \right] \cdot 100$$

1) Payments for removals

12-25%

2) Payments only for above average stocks (avoided emissions)

75 – 98%

3) Combined #1,#2

51 – 60%

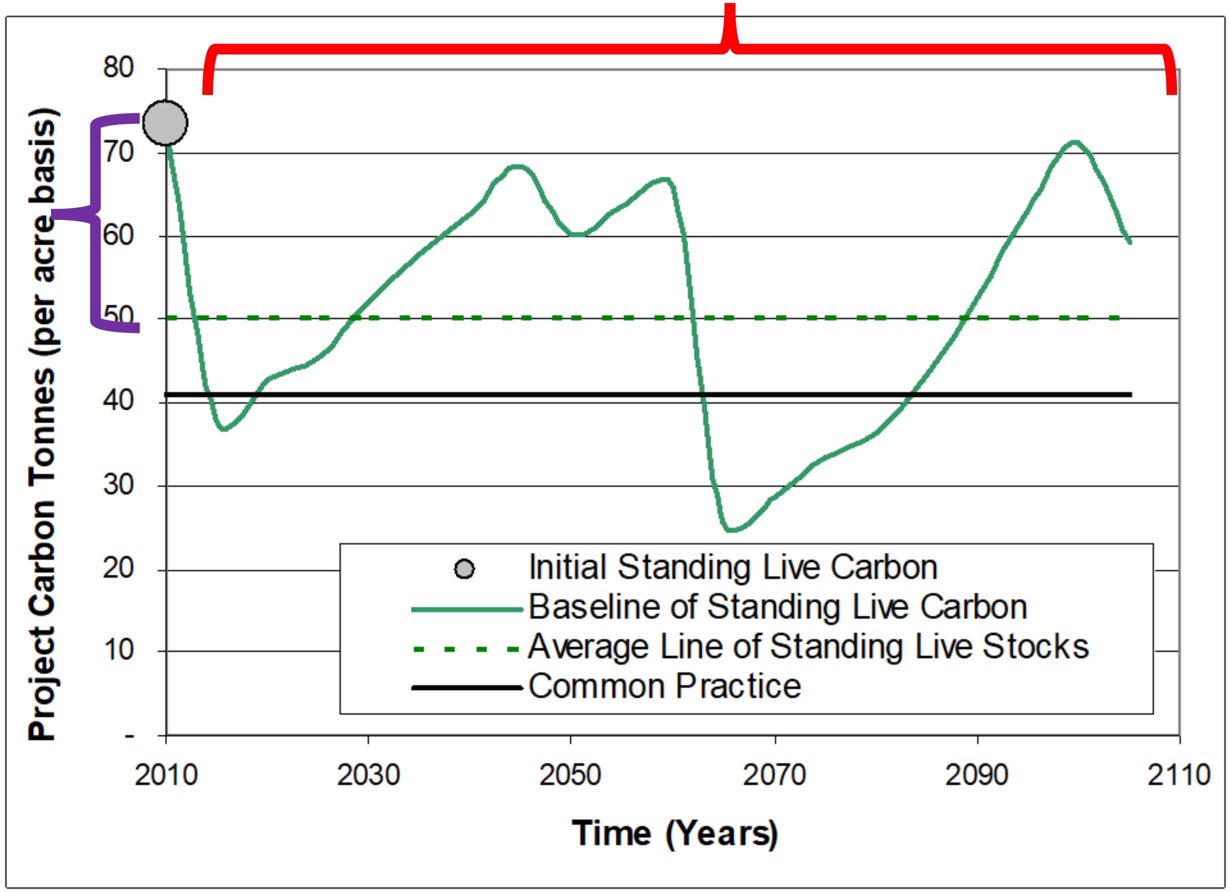
Applying these Leakage Factors

$$L^T = \left[{(PV_P + PV_{AE} - PV_T)} \Big/ {(PV_P + PV_{AE})} \right] \cdot 100$$

1) Payments for removals
   12-25% **avg 20%**

2) Payments only for above average stocks (avoided emissions)
   75 – 98% **avg 86%**

3) Combined #1,#2
   51 – 60%



FCQC Forest Offset Leakage Update

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This is the part where you roll your eyes and curse “models”

- *I knew this was all BS*

Remember models don’t provide answers, rather they inform the decision space

- *What did we learn?*
  1. *Leakage is not an easy issue*
     - *We didn’t really learn this, but we know it is a market response*
  2. *Leakage depends on how the credits are quantified (how much you take to market Methodology matters)*
  3. *Leakage depends on market penetration (how much of the market is affected)*
  4. *Leakage may be different for methodologies that target removals as opposed to those that target maintenance of stocks*
  5. *Leakage is not constant over time (future markets are affected by current market effects)*

FCQC Forest Offset Leakage Update

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Leakage Option B

- Elasticity Route:

$$L' = \frac{100 * e * \gamma * C_N}{[e - E*(1 + \gamma*\phi)]C_R}$$

- **Pros**
  - elegant, equation-based approach
  - Handles
- **Cons**
  - Requires elasticities we don't have
  - Methodology doesn't affect it

e is the supply price elasticity

E is the price elasticity of demand

C_N is the c seq. reduction per unit of non-reserved forest

C_R is the carbon sequestration per unit of (foregone) harvest gained by preserving the reserved forest

Φ preservation parameter

γ substitutability

Murray et al. (2004) - Why go through the paper and 2005 EPA Mitigation Report scenarios if the equation was enough?

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e-newsletter and **reports**
http://www.uidaho.edu/cnr/pag

Bonus Slide

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- For those of you who muttered ”you cherry-picked your past studies” Greg

Table 2
Selected studies in the meta-regression analysis: the forest sector.

Model type	Model Name	References	Number of Estimates	Magnitude (%)	Range (%)
GEM[a]		[28] Baylis et al. (2013)	2	0.96	−10.31–7.45
GEM	CGE[c]	[29] Kuik (2014)	11	3.84	0.57–10.73
	d	[30] Alix-Garcia et al. (2012)	1	4	n/a
	e	[31] Fortmann et al. (2017)	1	4.4	−5.7–14.5
PEM[b]	f	[32] Kim et al. (2014)	1	14.85	14.8–14.9
	g	[33] Acosta-Morel (2011)	7	17.14	9–22
	h	[34] Sohngen and Brown (2004)	2	19.50	18–21
		[35] Meyfroidt and Lambin (2009)	1	22.7	n/a
PEM	FASOM[i]	[36] Murray et al. (2004)	8	25.86	−4.4–92.2
PEM	EUFASOM[j]	[37] Zech and Schneider (2019)	1	43	n/a
PEM	GCAM[k]	[38] González-Equino et al. (2017)	12	48.53	10.0–93.0
	l	[39] Sun and Sohngen (2009)	1	49.50	47.0–52.0
PEM	m	[40] Wear and Murray (2004)	3	61.80	43.3–84.4
		[41] Jadin et al. (2016)	1	68	n/a
GEM	CGE	[42] Gan and McCarl (2007)	12	75.31	42.3–95.4
PEM	EFI-GTM[n]	[43] Kallio et al. (2018)	1	76	65–87
PEM	EFI-GTM	[44] Kallio and Solberg (2018)	1	80	60.0–100.0
PEM	USFPM/GFPM[o]	[45] Nepal et al. (2013)	3	81.33	71.0–88.0
GEM	GTAP[p]	[46] Hu et al. (2014)	1	84.25	79.7–88.8
		Average		39.60	−10.31–100.0

Notes: [a] General Equilibrium Model; [b] Partial Equilibrium Model; [c] Computable General Equilibrium; [d] A simple model of household production and land allocation; [e] A matched difference-in-differences (DID) approach; [f] Leakage discount formula; [g] A Land Use Share Model; [h] Dynamic optimization model; [i] The forest and agricultural sector optimization model; [j] European Forest and Agricultural Sector Optimization Model; [k] Global Change Assessment Model from Joint Global Change Research Institute; [l] Global land use and forestry model; [m] A full econometric model of the US softwood lumber market; [n] European Forest Institute Global Trade Model; [o] US Forest Products Module and Global Forest Products Model; [p] Global Trade Analysis Project model.

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Carbon leakage in energy/forest sectors and climate policy implications using meta-analysis

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BASIC FASOM STAND DYNAMICS

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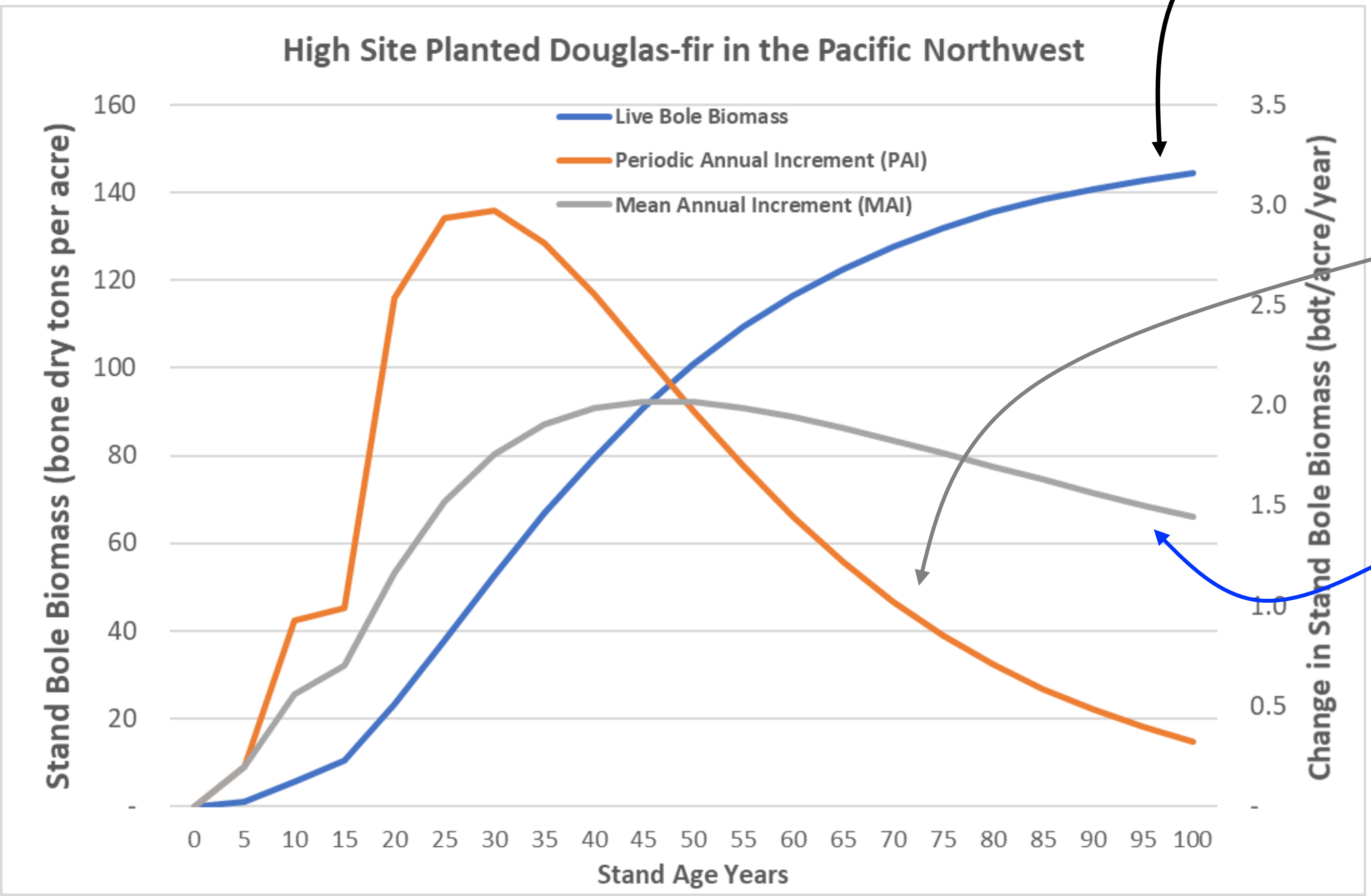


Live Bole Biomass – this is what we think of as yield in logs. It does not include small tree, tops, branches, or stump biomass

- Sigmoidal – so increasing growth rate when young and then decreasing growth when older

Periodic Annual Increment (PAI) – this is what we think of annual growth rate

- Peaks when the stand growth rate changes from increasing to decreasing (yield curve inflection point)

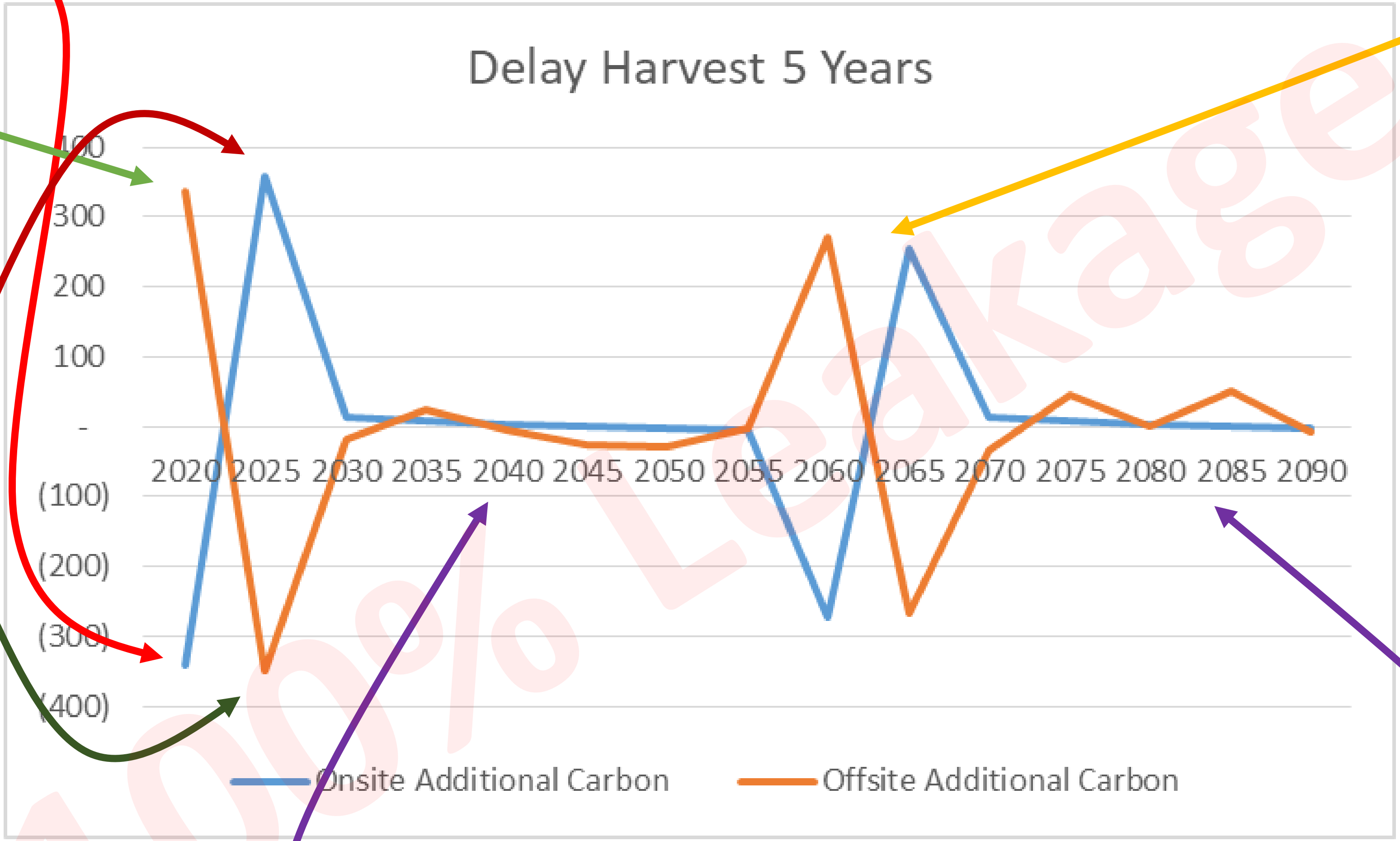
Mean Annual Increment (MAI) – this is what we think of average growth rate

- The peaks is often defined as the biological rotation age (where PAI crosses MAI)

Delaying Single Harvest

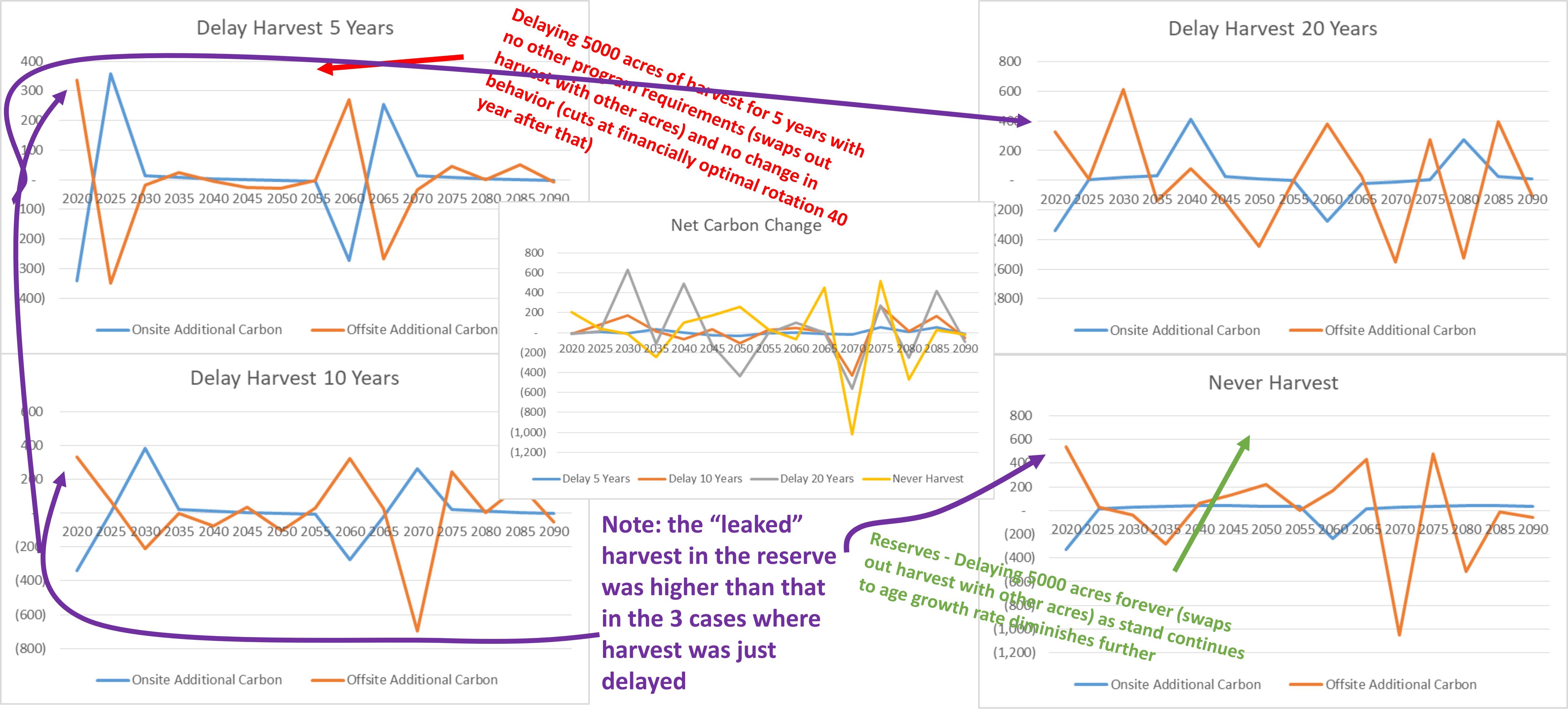
1) Initial onsite reduction in emissions when harvest delayed on 5000 acres
2) Offsite response in same period
3) Second period we cut the stand and therefore there is an increase in onsite emissions
4) And reduction offsite as the harvest displaced offsite harvesting

Same compensating harvests occur when the regenerated stand is harvested again



Not much going on outside of the harvest shifting periods

(because no payment for sequestration (only avoided emissions))



	Discounted (4%) sum of net emissions	Net Emissions														
		2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090
Delay 5 years	**0**	(7)	8	(3)	19	(1)	(9)	(10)	(2)	(0)	(2)	(3)	6	1	4	(1)
Delay 10 Years	**127**	(13)	63	116	9	(29)	14	(32)	6	10	1	(61)	31	1	13	(3)
Delay 20 years	**380**	(14)	11	426	(63)	225	(47)	(134)	(1)	21	(0)	(79)	32	(24)	33	(6)
Never harvest	**231**	207	34	(8)	(135)	46	65	79	9	(14)	77	(143)	60	(45)	2	(1)

Issues with that approach *– focus on the old stuff*

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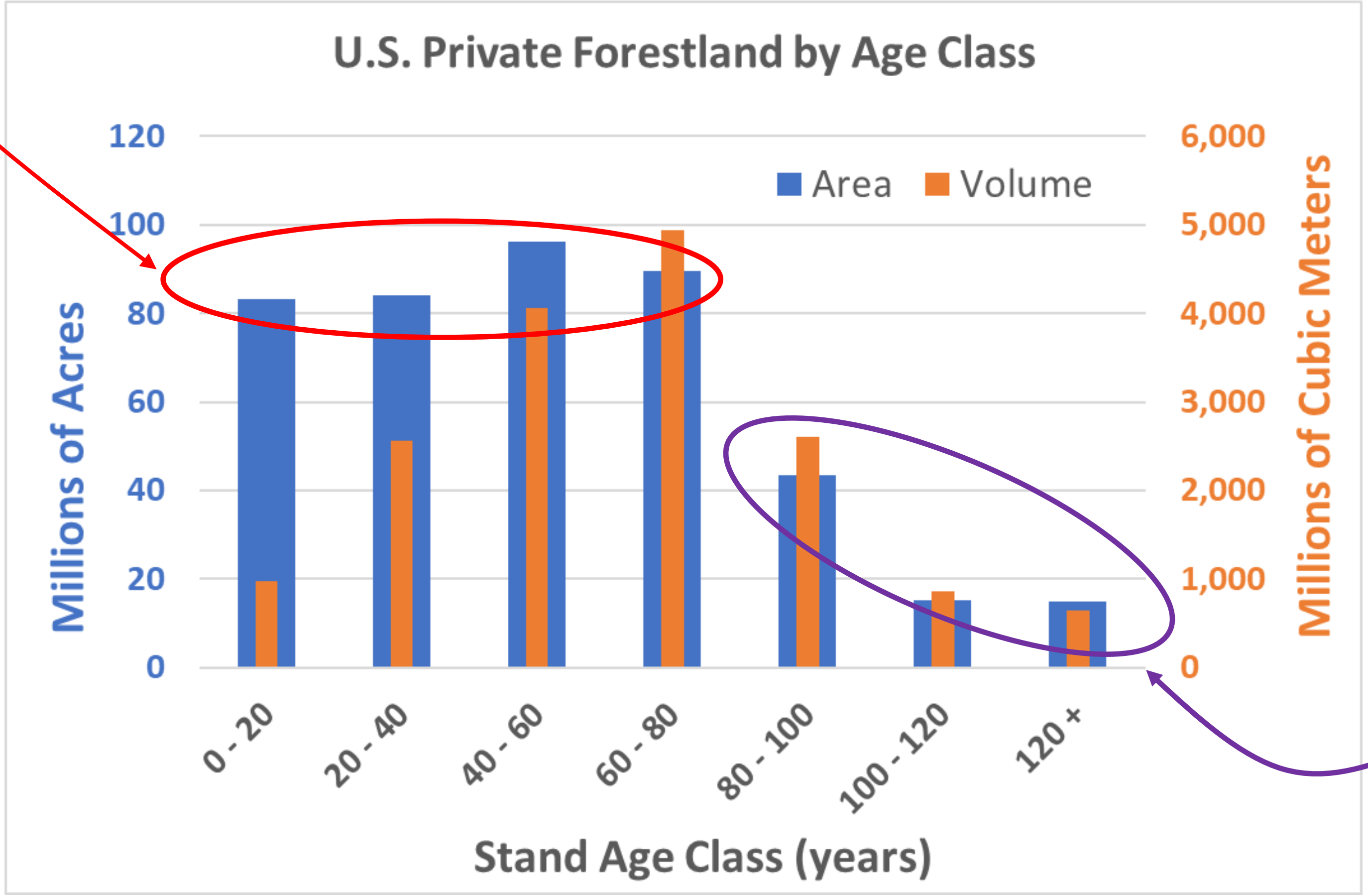
- There is a lot of harvestable material on private forest land in the US

Most actively managed land in 0-80 acre classes *(fairly evenly distributed)*



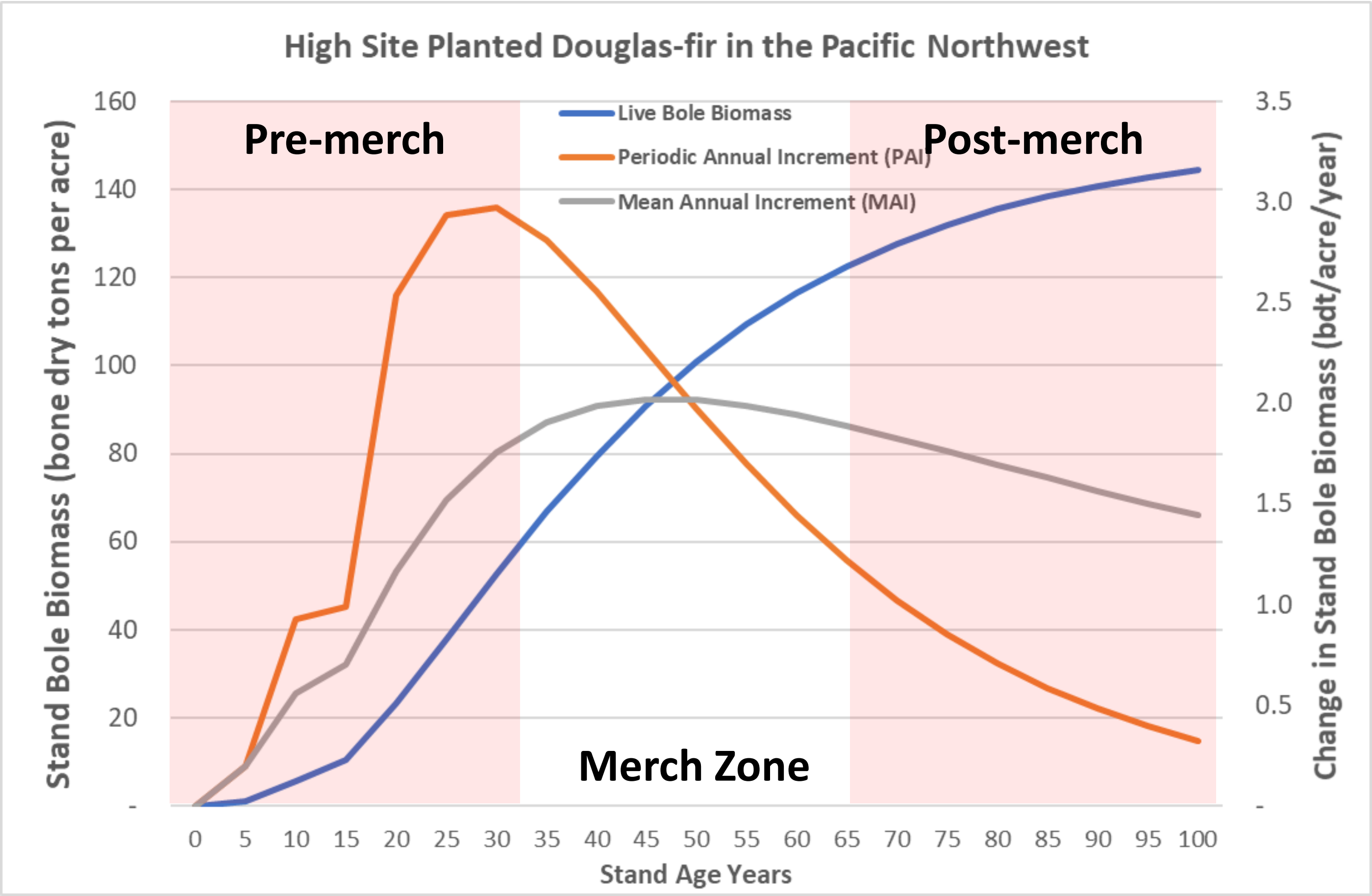
80 years plus land –

- 17% of the area and 24% of the volume
- That's 4.1 billion cubic meters
  - Annual harvest on all land in US is 0.35 billion cubic meters
  - So close to 12 years of volume on those older forest land
  - Only 2% of that land (and volume) shows up in the Protected Lands Database *(so it would appear harvestable)*

So: There is a lot of Slack in the system

We don't know how much of this land is not really part of the manageable land base *(riparian, inaccessible, or otherwise encumbered)*

Basic FASOM Stand Dynamics



Defining Merchantability Limits in FASOM

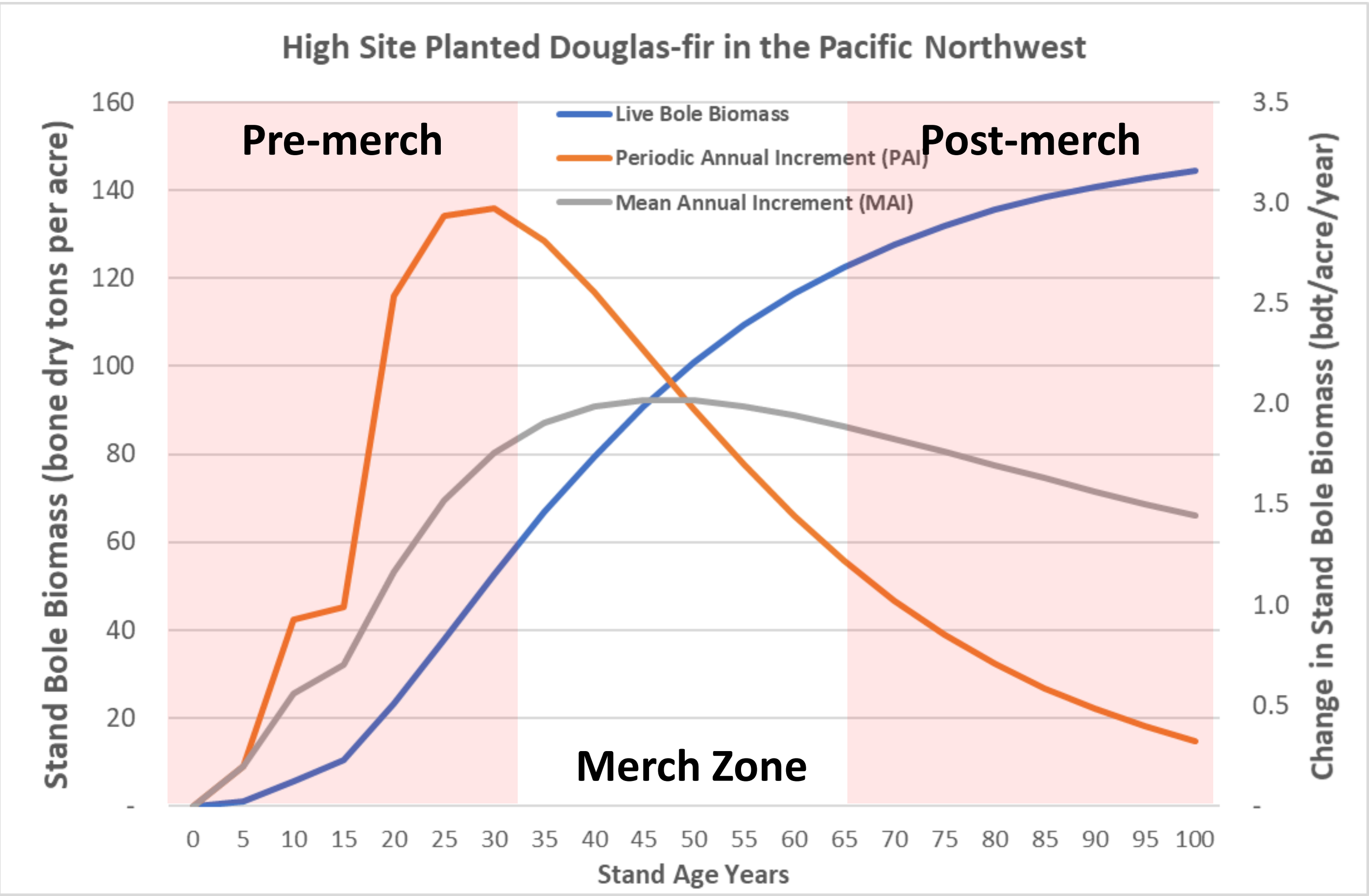
- We have always had a minimum harvest age
- What if we add a maximum harvest age?

Pre-merch – defined as younger than 2/3 of biological rotation *(here biological rotation is 50 so pre-merch limit is 33). Can't harvest stands younger than this age.*

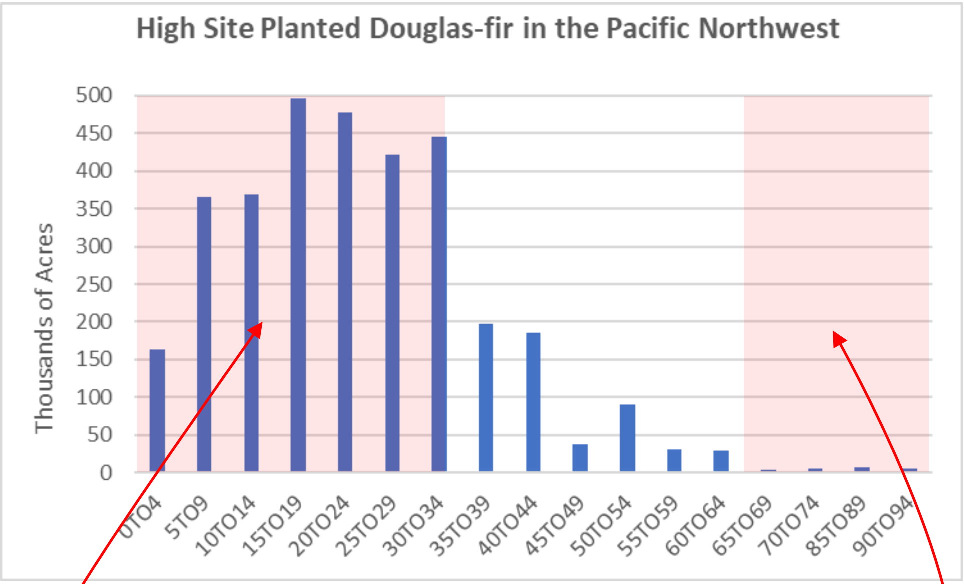
Merch Zone – defined as a range of rotations most likely used in a working forest *(so not a reserve).* Where harvesting will occur.

Post-merch – defined as younger than 2 time pre-merch age *(here biological rotation is 50 so pre-merch limit is 33 and post-merch is 66). We will experiment with harvesting stands older than this age.* Remember, we don't know how many of then are actually not harvestable.

Basic FASOM Stand Dynamics



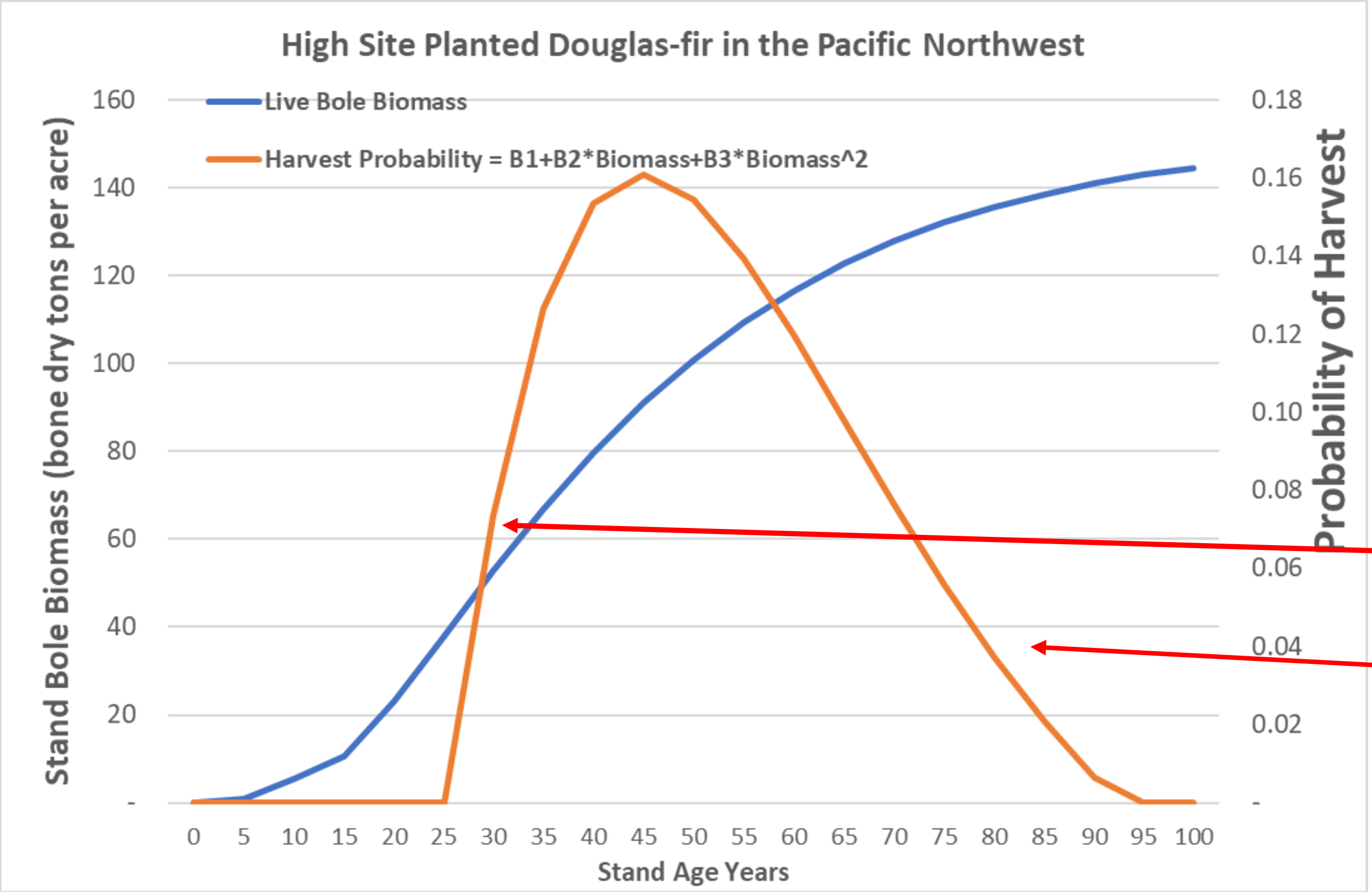
Actual Age Class Distribution in FASOM



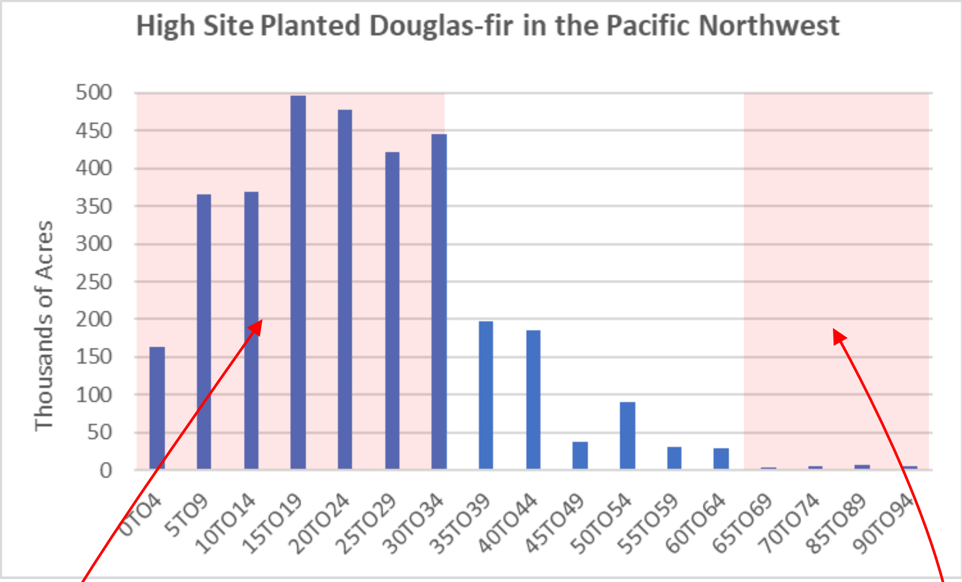
Not additional - Too young to do anything but grow *(not exactly true as there are other management options possible outside of FASOM)*

Not additional? – Possible reason for not harvesting *(not exactly true as there are other management options possible outside of FASOM)*

Harvest Probability



Actual Age Class Distribution in FASOM

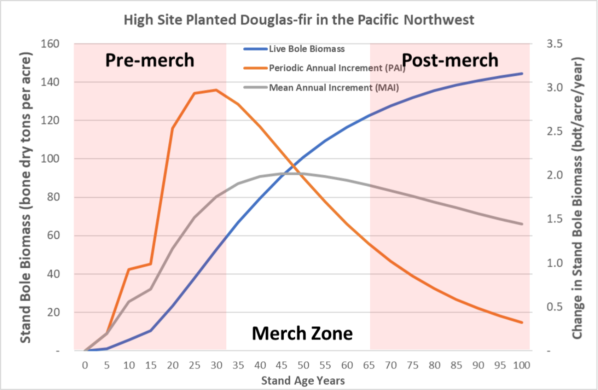


Increases as stand volume increases or as stand ages

Decreases as stand volume increases or as stand continues to age

So can we Delay Harvest in FASOM (and get meaningful output)

Not Currently – even with maximum harvest ages determined at the Region / Forest Type / Site Class level



FASOM Acres by Merchantability Class

Owner	Pre-Merch	Merch	Post-Merch
BLM	6,739,735	11,411,837	12,906,422
Ofederal	4,541,396	7,506,631	7,444,887
Private	**142,388,578**	**207,167,584**	**77,169,087**
State	15,213,991	27,394,858	14,284,514
USFS	27,614,011	55,296,615	52,531,503

We've been focusing on this as a concern ***(slack in the model)***

There are 207 million acres of harvestable (merchantable) private forest acres. Assuming 9 million acres harvested each year, that would be about 23 years worth.

So: When we move 5 thousand acres or even 1 million acres, a model like FASOM has plenty of other harvestable acres available it can replace it with

100% Leakage for Harvest Delay pretty much every time with current model formulation