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RECENT EFFORTS TO QUANTIFY POTENTIAL LEAKAGE IN FOREST CARBON OFFSET MARKETS

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Disclaimer: Results and views expressed here do not reflect EPA or EPA policy

OBJECTIVES

- Bring it back to the US
  - And focus on the IFM programs being used (ARB and ACR)

DIFFERENCE FROM DAIGNEAULT AND SOHNGEN

The Mitigation is not activity based – but instead market driven

- Use a carbon payment to entice landowners to participate in the offset market

That means –

- Activities aren’t directly as important
- But the Credit Computational Methodologies **are**
  - That means we need to focus on - ***What you pay for and how you calculate***

WHAT LANDOWNERS ARE PAID FOR

Avoided emissions

- An indirect mitigation activity
  - I don't harvest what I say I would have harvested and get paid for the carbon stocks *(above some threshold)* that I leave in the forest

Removals

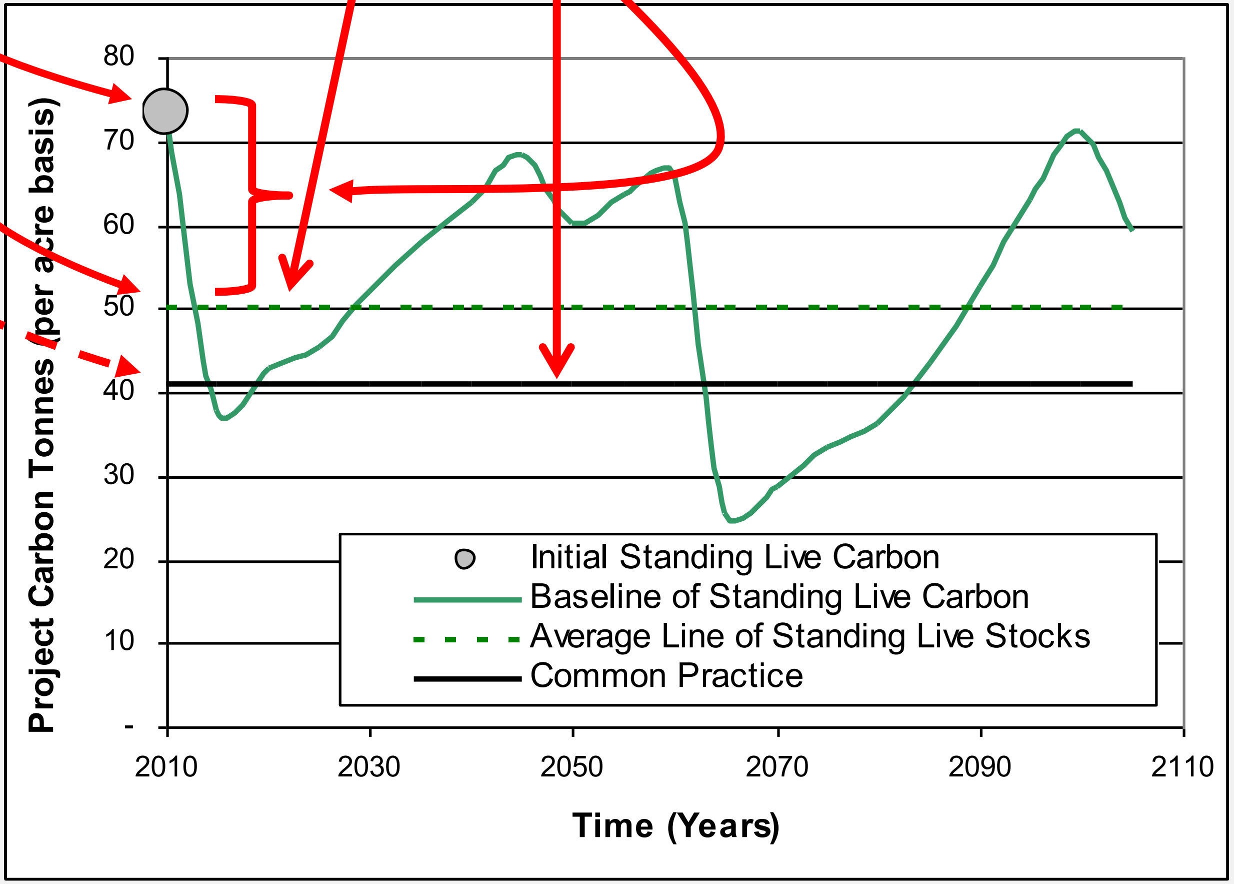
- A direct mitigation activity
  - when my carbon stocks increase, I am paid for it

HOW ARB IFM *(IMPROVED FOREST MANAGEMENT)* WORKS

1. Conduct forest inventory
2. Determine Common Practice for your region / forest type
3. Landowner gets payment allocation for carbon above Common Practice – Avoided emission
4. Average the 100 year live carbon stock value
5. Model a 100 year harvest schedule *(legal and economically viable of course)*
6. New annual carbon payments for 100 years

This Average Line

Must be above this Common Practice Line

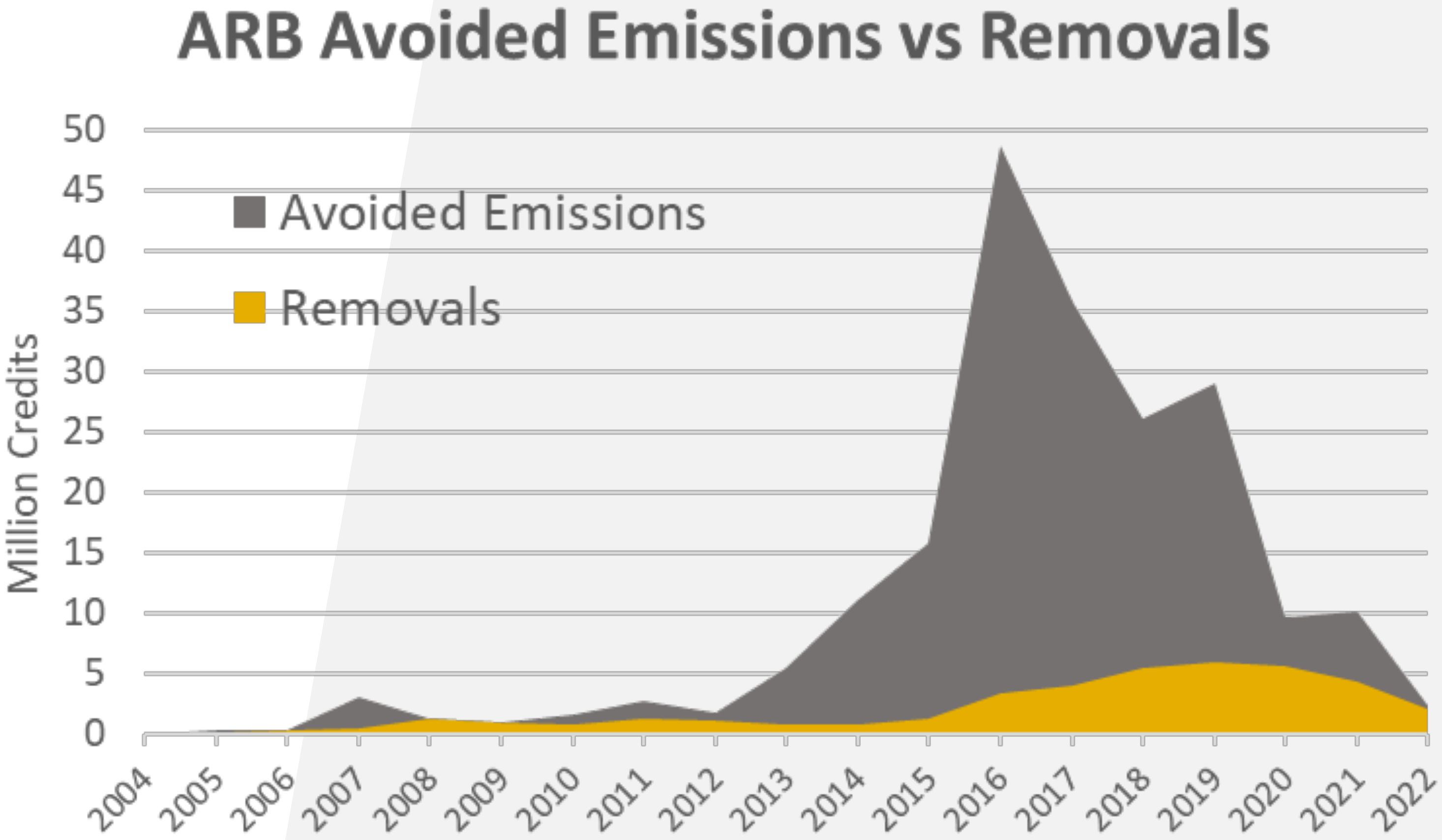


CLIMATE ACTION RESERVE

California Environmental Protection Agency AIR RESOURCES BOARD

WHAT LANDOWNERS ARE DOING

Program	Projects	Acres
ARB IFM	153	6,087,661
ACR IFM	60	1,560,498



Avoided emissions

- An indirect mitigation activity – I don't harvest what I say I would have harvested and am paid for the carbon stocks *(above some threshold)* that I leave in the forest

Removals

- A direct mitigation activity – when my carbon stocks increase, I am paid for it

This is as of October 2023

LEAKAGE IN PRACTICE

Credits (tons CO2e)

Simplified ARB Quantified GHG emissions reduction (QR) equation:

Leakage

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

Tree Carbon | Wood Product Carbon | Harvested Tree Carbon

A – project
B - baseline

- Leakage applied to **harvest** *(related to 100-year average harvest)*

Credits (tons CO2e)

Simplified ACR Emissions reduction ton (ERT) equation:

Leakage

$$ERT_{RP,t} = [(\Delta C_{P,t} - \Delta C_{BSL,t}) + (C_{P,HWP,t} - \bar{C}_{BSL,HWP})] \cdot (1 - LK) \cdot (1 - UNC_{DED,t})$$

Tree Carbon | Wood Product Carbon

- Leakage applied to additional **carbon** sequestration *(related to 20-year average HWP)*

MURRAY, MCCARL, & LEE (2004)

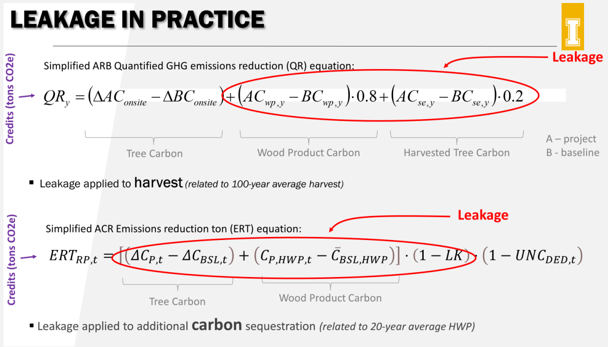
- Estimates of **carbon leakage** *(which is good)*

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

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

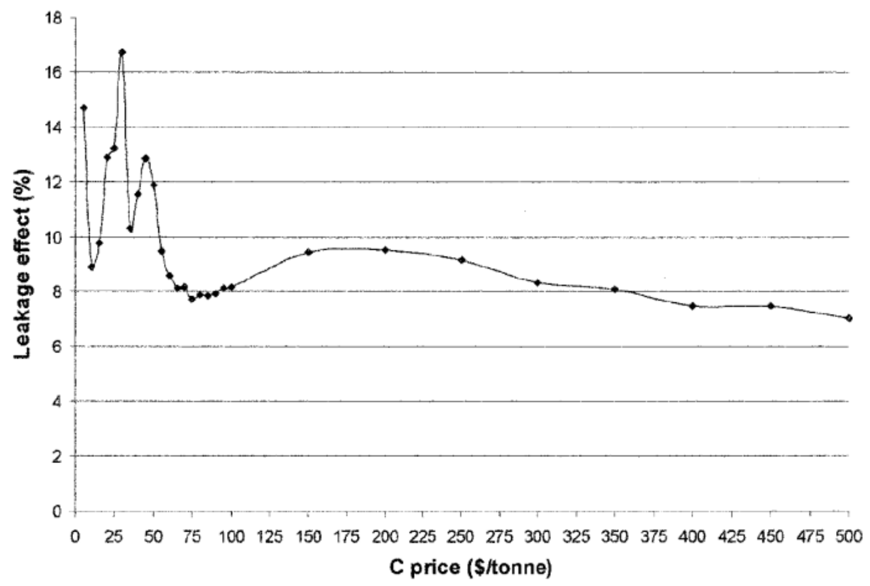


FIGURE 2
Leakage Effects as a Function of the Carbon Price; Afforestation-Avoided Deforestation Scenario

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

FASOM-GHG

(THE FOREST AND AGRICULTURE SECTOR OPTIMIZATION MODEL WITH GREENHOUSE GASES)

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.

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:**
  1. choose to participate in the offset market and get paid for sequestration (while also paying for emissions)
  2. Or choose not to participate and not get paid or pay for sequestration and emissions.

Crediting Scenarios

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

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

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USING A MARKET MECHANISM *(A CARBON PRICE)* IN A MARKET MODEL *(FASOM-GHG)*

Scenario 1) Removals Only

Marginal Abatement Cost Curve (MACC)

Steps:

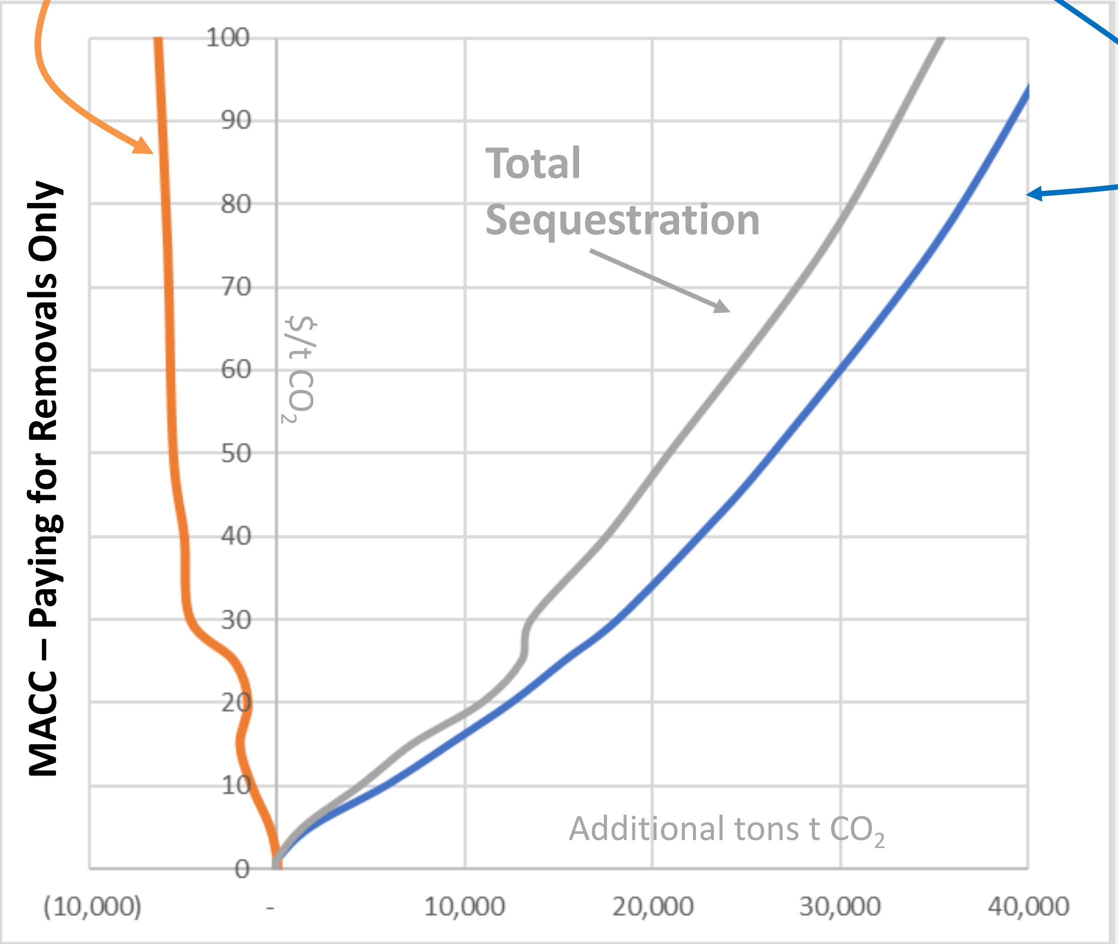
1. Run the Carbon Price Scenarios through 2090 in 5-year time periods
2. Calculate additional sequestration in each time period
3. Discount the additional carbon using 4% *(similar to Murray et al (2004))*
4. Calculate the annual annuity value that would equal the sum of the first 40 years of discounted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

Non-Participants – additional emissions at each carbon price

Offset Participants – additional sequestration at each carbon price



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.

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

USING A MARKET MECHANISM *(A CARBON PRICE)* IN A MARKET MODEL *(FASOM-GHG)*

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Steps:

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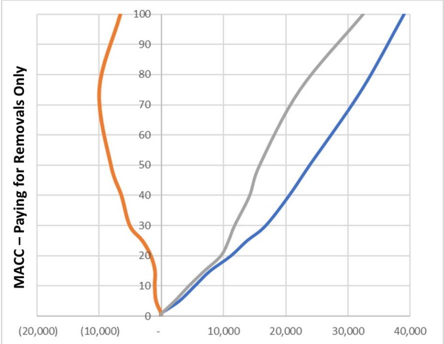
2. Calculate additional sequestration in each time period
3. Discount the additional carbon using 4% *(similar to Murray et al (2004))*
4. Calculate the annual annuity value that would equal the sum of the first 40 years of discounted additional carbon
5. Calculate leakage using Equation 12 in Murray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



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

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-

Offset Participants – additional sequestration at each carbon price

Total Sequestration

CO_2 Price	Participants PV_P	Non-Participants	Total PV_T	Leakage L^T
	----------*thousand tons of CO2/year* ----------			
0	0	0	0	
5	1,828	-390	1,438	21%
10	5,850	-1,361	4,488	23%
15	9,240	-1,988	7,253	22%
20	12,526	-1,988	10,538	16%
25	15,329	-2,280	13,048	15%
30	18,183	-4,617	13,566	25%
40	22,508	-4,934	17,574	22%
50	26,428	-5,522	20,906	21%
75	35,051	-5,821	29,230	17%
100	41,715	-6,323	35,392	15%

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

WHAT ABOUT AVOIDED EMISSIONS

- **Avoided emissions** extends the carbon calculation to a combination of payments for:
  - **direct mitigation** fluxes *(yes – I know they are stock changes – just relax)*

  and
  - **indirect mitigation** stocks

  - *That means the leakage calculation is a little different*

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

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

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 only *(solid lines)*

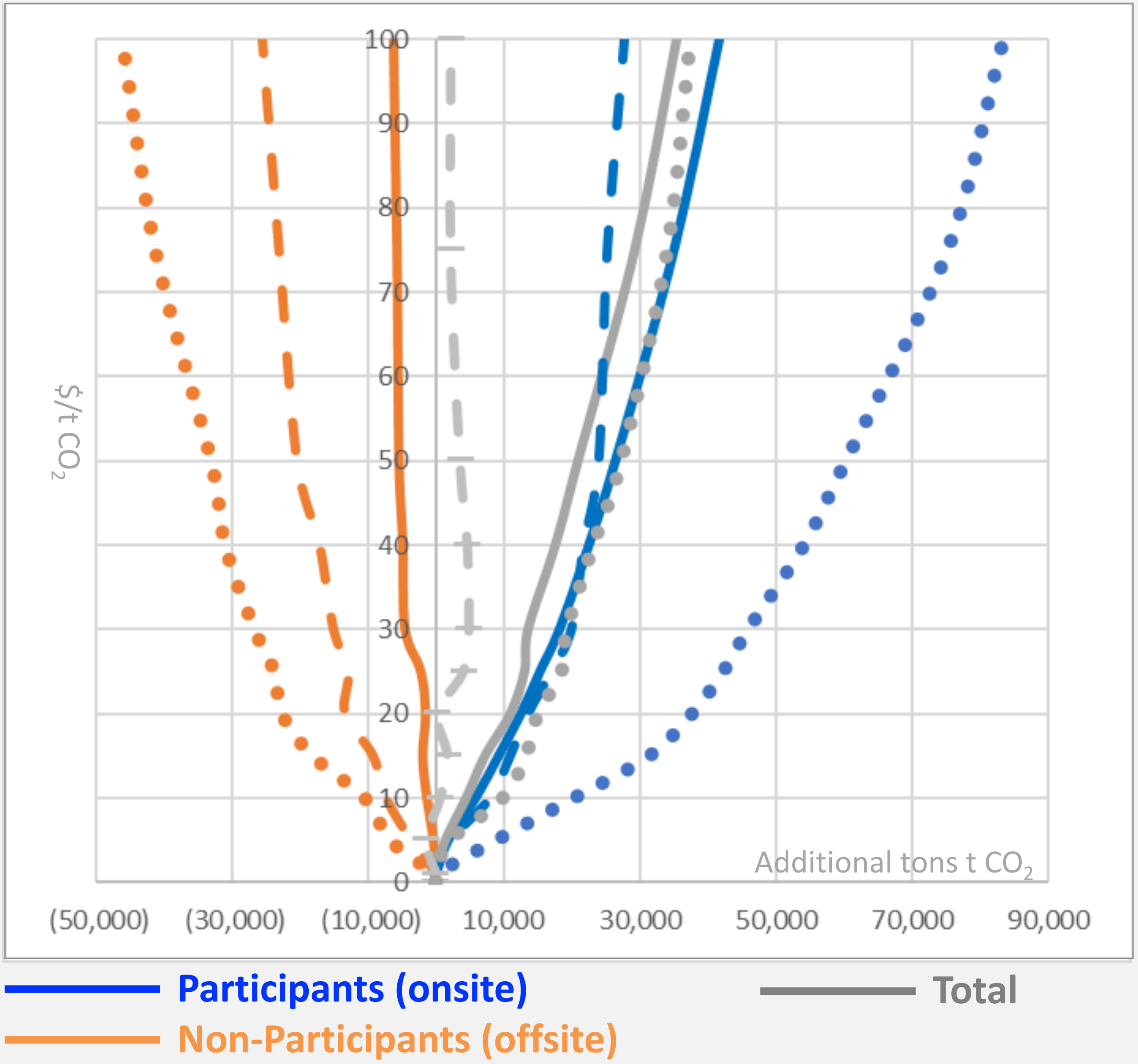
Leakage **12-25%**

2) Payments only for above average stocks (avoided emissions – *dashed lines*)

Leakage **75 – 98%**

3) Combined #1,#2 *(dotted lines)*

Leakage **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

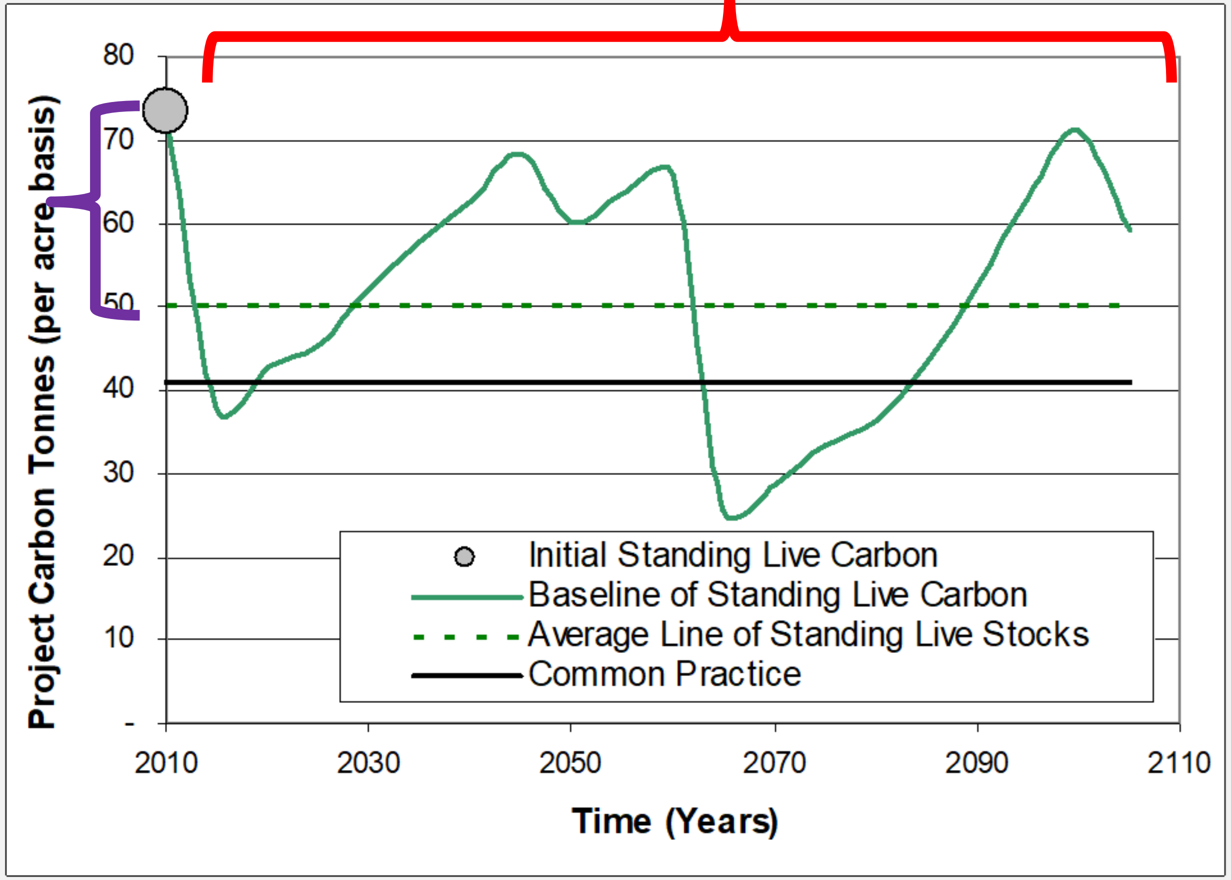
12-25% **avg 20%**

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

75 – 98% **avg 86%**

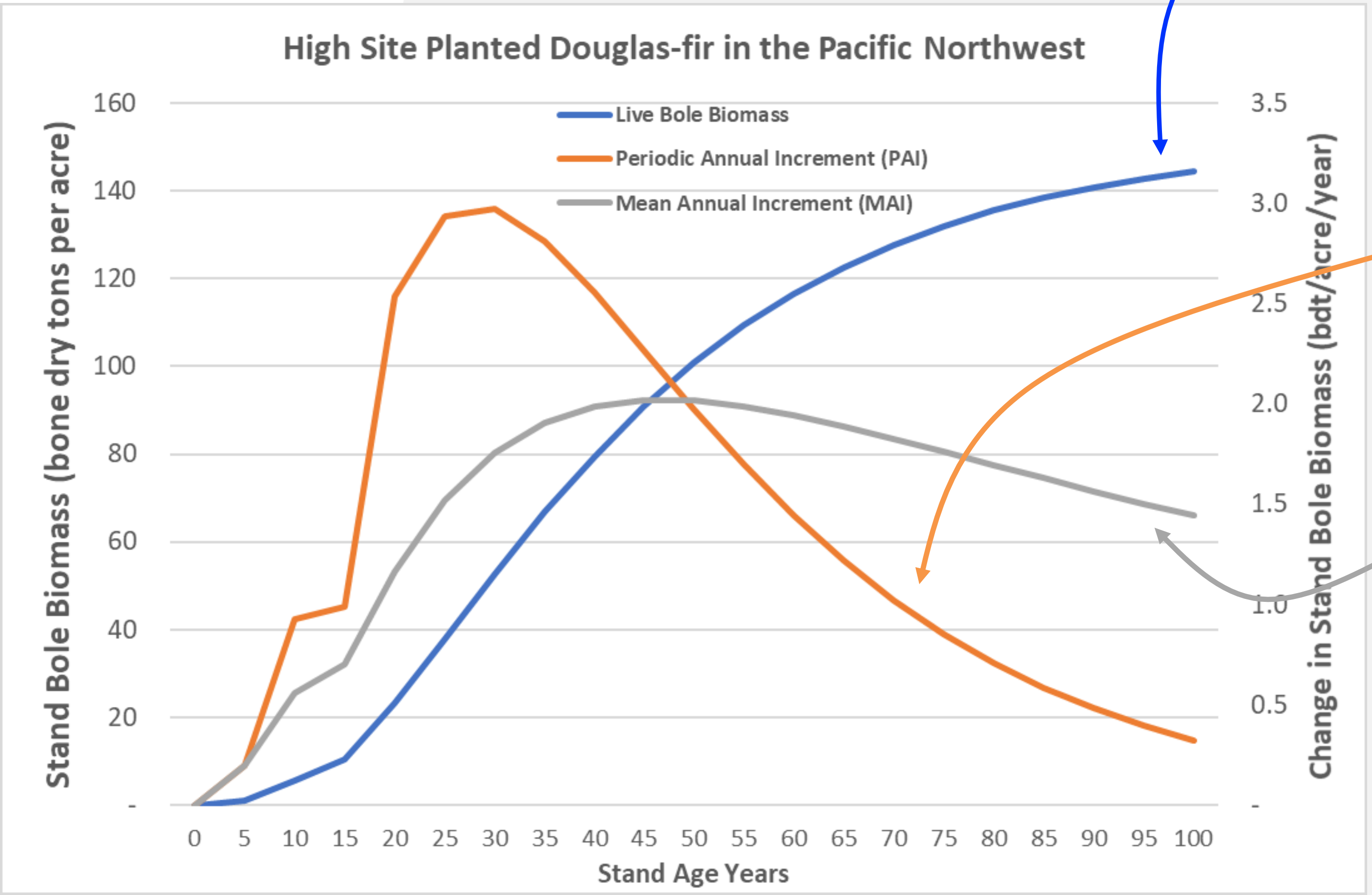
3) Combined #1,#2

51 – 60%



WHAT EXACTLY ARE WE INCENTIVIZING

BASIC STAND GROWTH AND YIELD



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

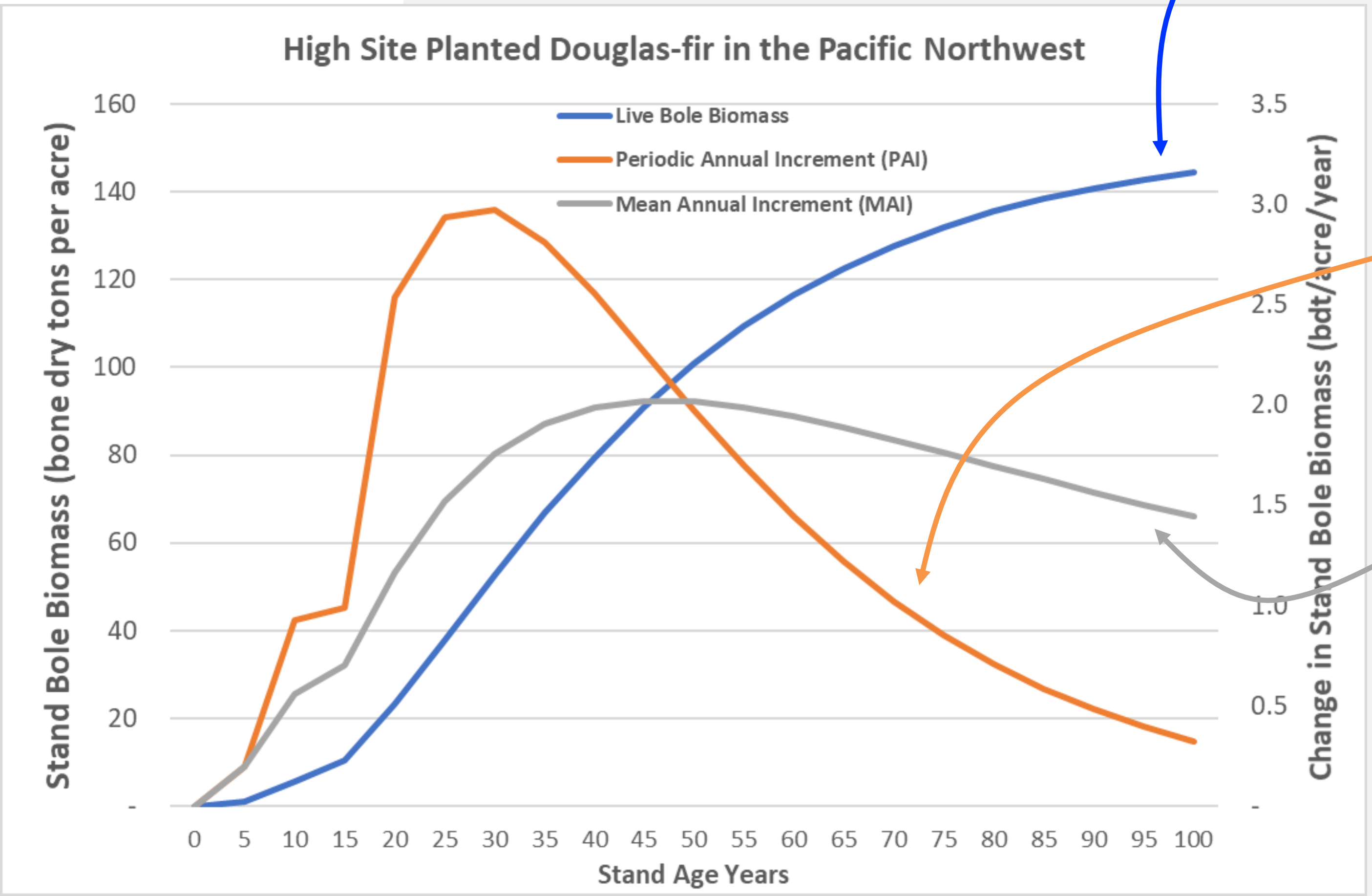
- Peaks when the stand growth rate changes from increasing to decreasing (yield curve inflection point)

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)

WHAT EXACTLY ARE WE INCENTIVIZING

BASIC STAND GROWTH AND YIELD



Carbon Stocks (CO_2) – this is what we think of as carbon stored in tree biomass. It does include small tree, tops, branches, or stump biomass

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

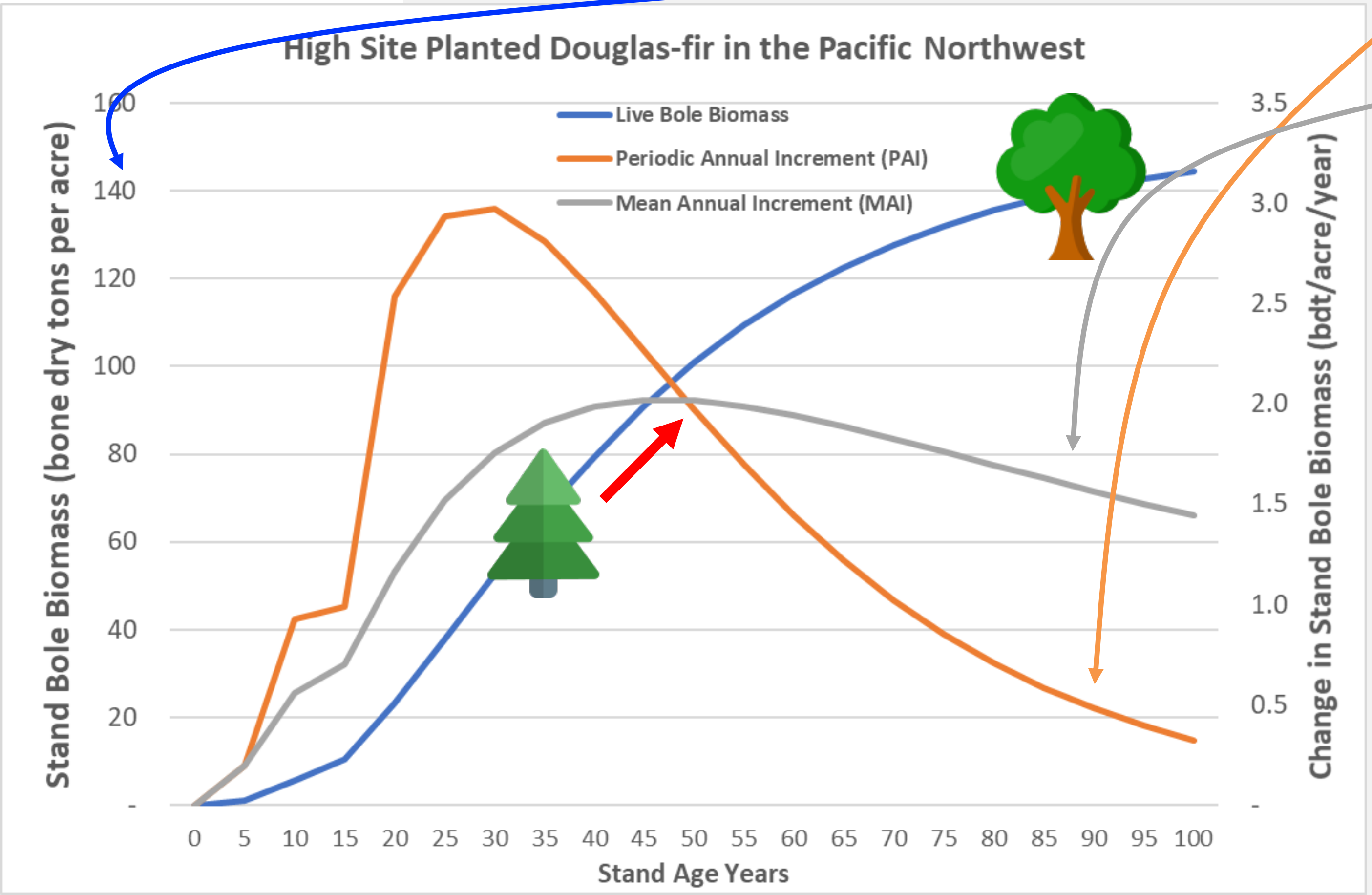
Carbon Flux (CO_2/year) – this is what we think of annual sequestration rate

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

Average Carbon Flux (CO_2/year) – this is what we think of average sequestration rate

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

BASIC IFM ACTIVITIES *(WHAT ARE WE TRYING TO INCENTIVIZE)*



With avoided emissions – high stocks means:

- High payment to landowner
- typically means annual lower growth *(on a per acre basis)*
- Lower average annual growth over time
- High fire risk *(reversal)*
- Extending the rotation exacerbates these issues

With removals – high annual sequestration rate means:

- The incentive is to increase average annual growth
  Harvesting
  - To “capture” mortality and provide space for healthy trees
  - To alter species composition
  - To “reset” the stand – just plain start over

  Planting
  - Interplanting to improve stocking or species composition
  - On regeneration – choosing the right trees
- The focus is on getting from the economic rotation to the biological rotation

FOREST CARBON LEAKAGE UPDATE

- 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 and markets aren't exactly easy*
2. *Leakage depends on how the credits are quantified (Methodology matters)*
   - *Leakage may be different for methodologies that target removals as opposed to those that target maintenance of stocks*
3. *Leakage depends on market penetration (how much of the market is affected)*
4. *Leakage is not constant over time (future markets are affected by current market effects)*

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

FOREST OFFSET LEAKAGE UPDATE

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?

Bonus Slide

- 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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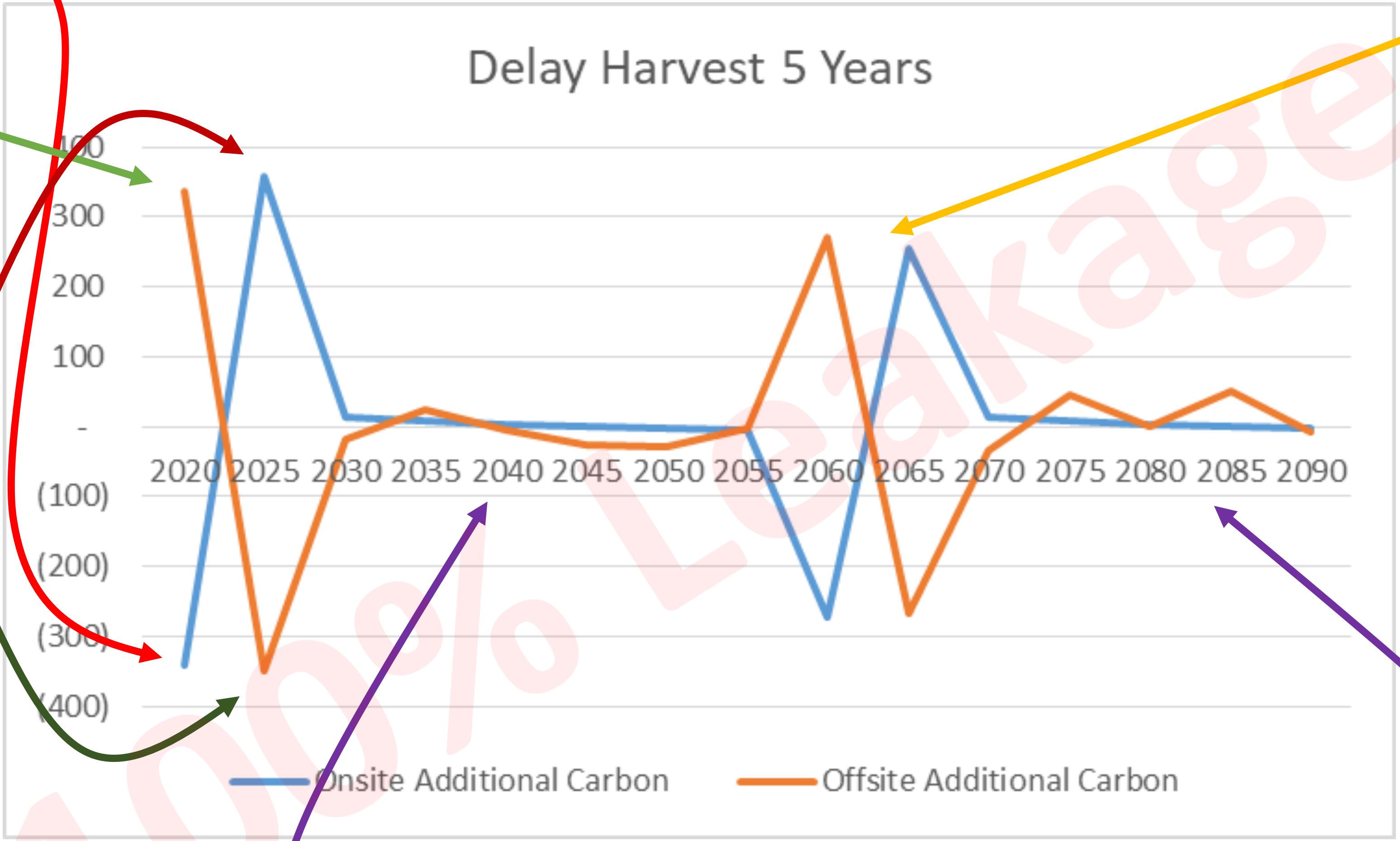
[d] Yangtze River Delta Economics and Social Development Research Center, Nanjing University, Nanjing, China

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))

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

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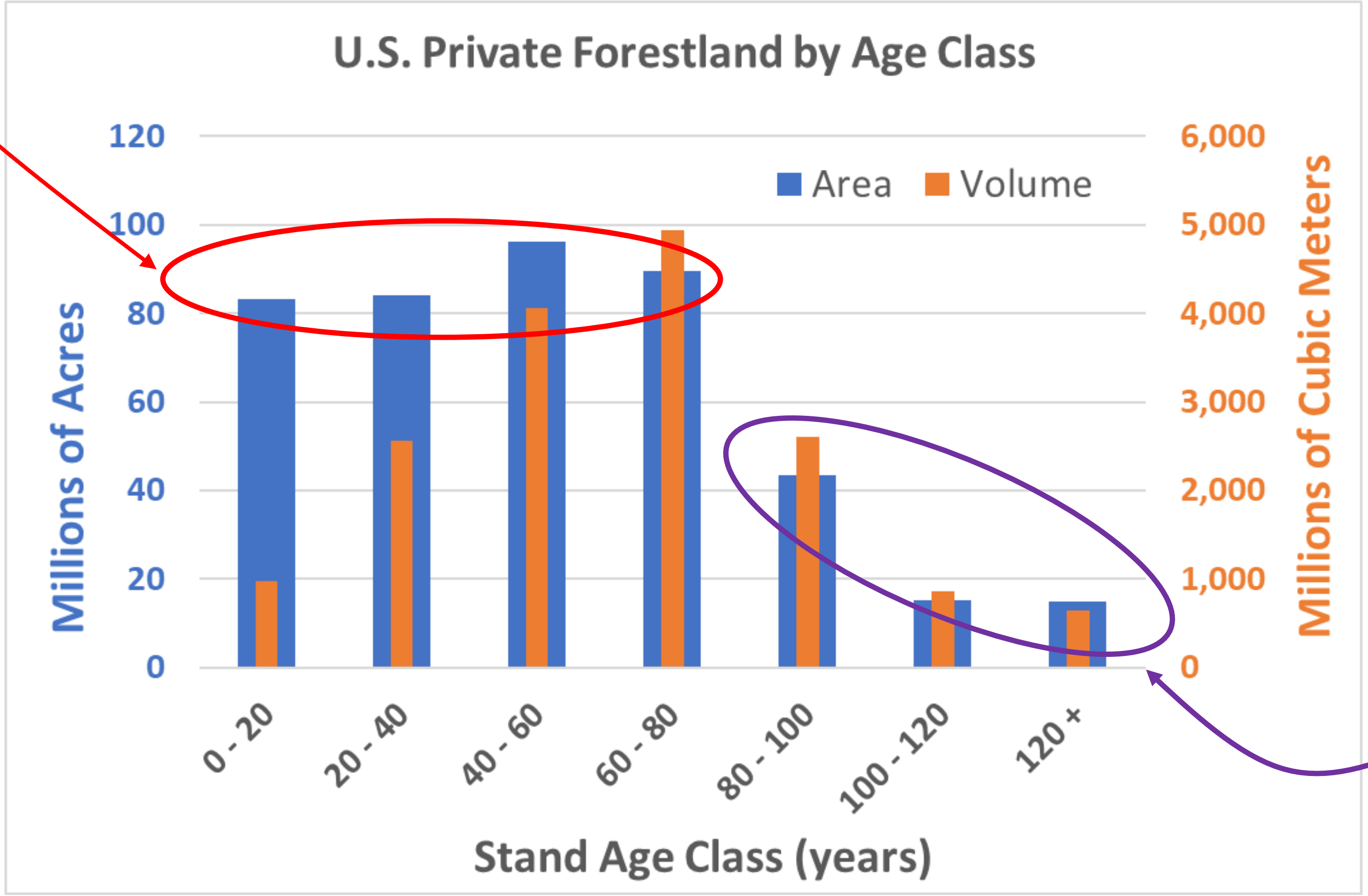
- There is a lot of harvestable material on private forest land in the US

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



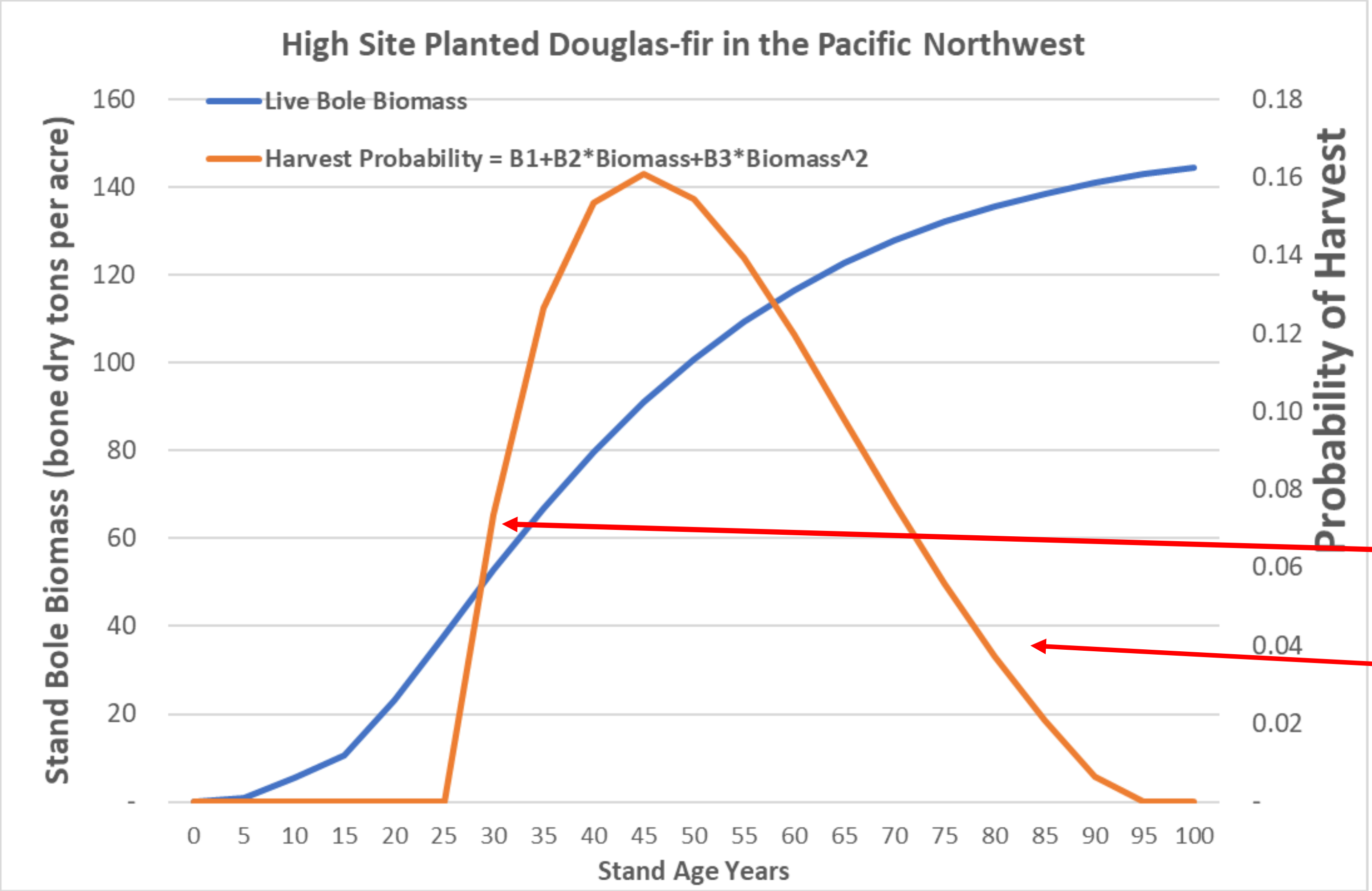
80 years plus land –

- 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)*

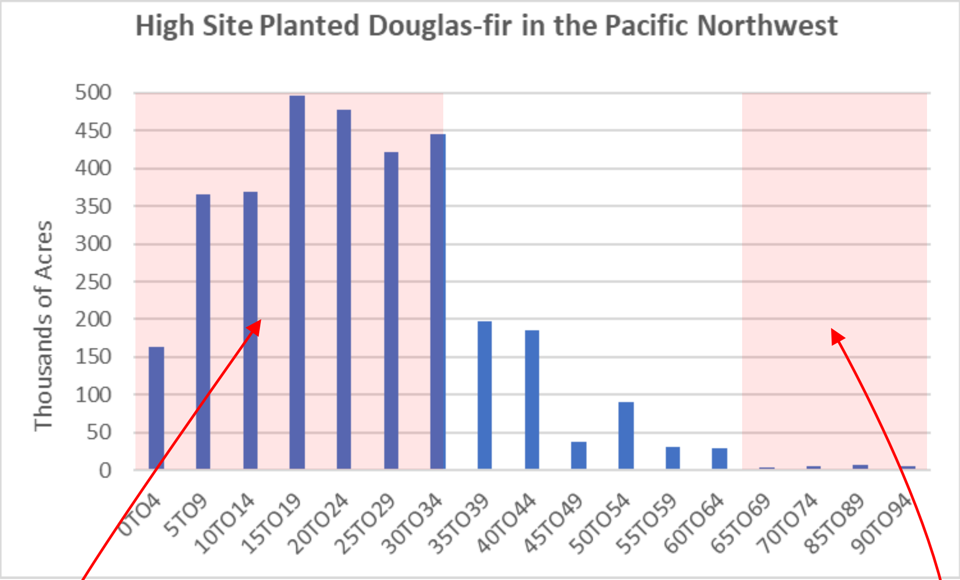
So: There is a lot of Slack in the system

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

Harvest Probability



Actual Age Class Distribution in FASOM

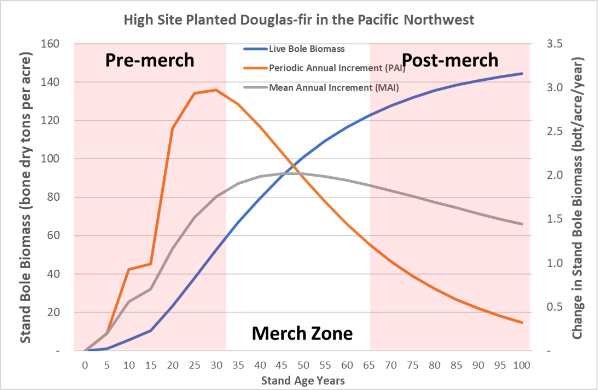


Increases as stand volume increases or as stand ages

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