MODELLING TREE-LEVEL WESTERN HEMLOCK RESPONSES TO FERTILIZATION

Woongsoon Jang[a,b], Bianca N.I. Eskelson[b], Kim M. Littke[c], Eric Turnblom[c]

[a] British Columbia Ministry of Forests

[b] University of British Columbia

[c] University of Washington

Stand Management Cooperative

SILVICULTURE • NUTRITION
WOOD QUALITY • MODELING

FOREST GROWTH
ORGANIZATION OF WESTERN CANADA

Growth and Yield Innovations Conference 2023

WESTERN HEMLOCK (*TSUGA HETEROPHYLLA* (RAF.) SARG.)

- Most common and important timber species in the PNW coastal forests
  - Account for up to 30% of total harvested log volume
  - In BC, ~0.7 mil ha pure Hw stands
- Providing ecosystem values
  - Esthetics, wildlife habitat and food, genetic diversity, carbon sequestration, and long-term productivity

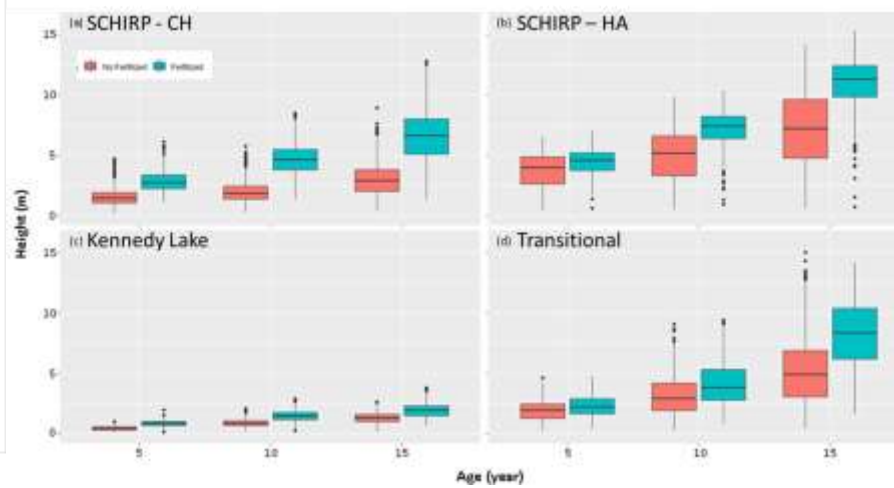
(Image source: databasin.org)

VARIATIONS OF FERTILIZATION RESPONSES

- Forest fertilization
  - Increase productivity, sequestrate carbon, enhance vitality of soil and stands, promote stand development, and increase diversity of wildlife habitat conditions
- Variable fertilization responses
  - Inconsistent outcomes, ranging from negative to positive
  - TIPSY: default response is **0**% for all sites and ages

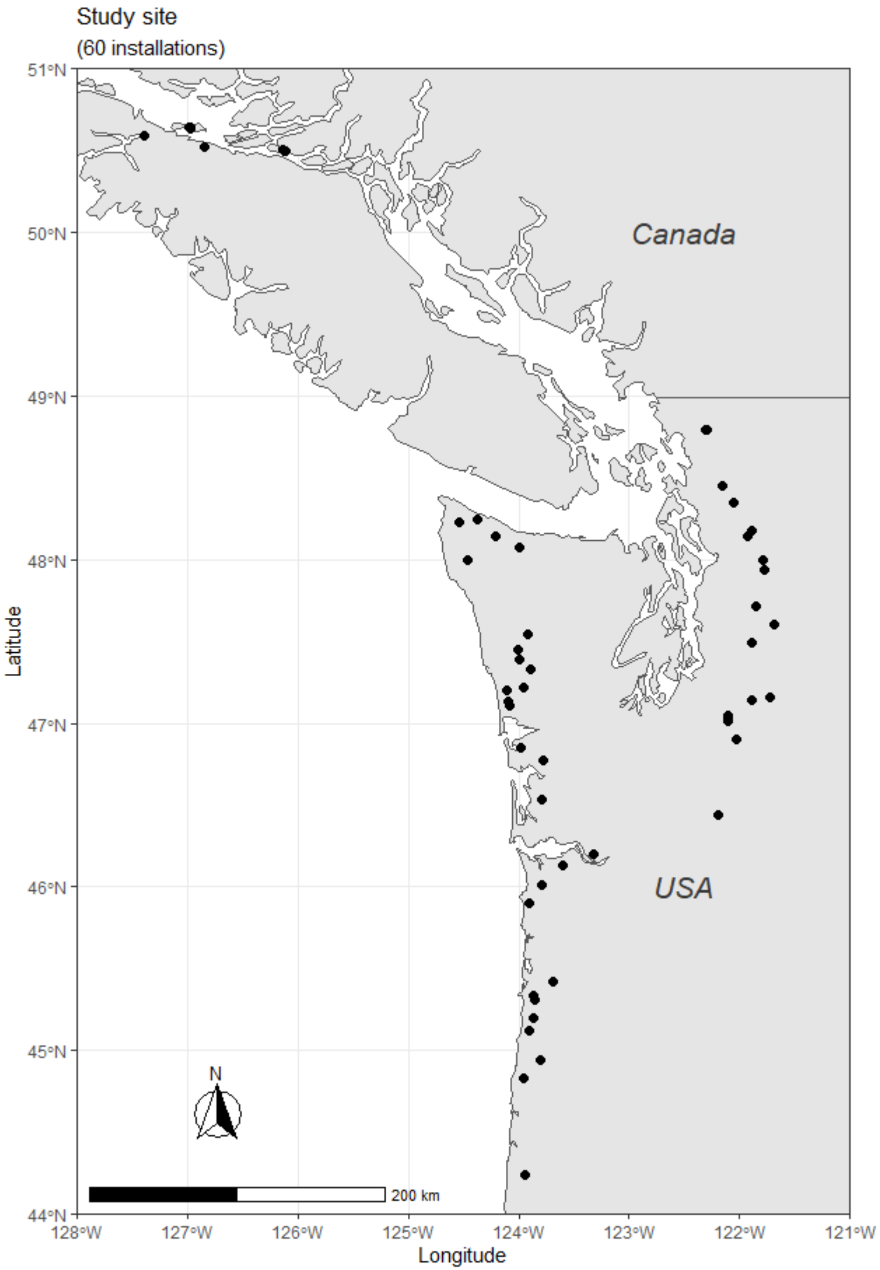
SMC (US)

SCHIRP (BC)



OBJECTIVE

- Develop the tree-level fertilization response models of western hemlock
  - Quantify mortality, dbh, and height growth responses
  - Examine if social standing, crown characteristics affect these responses
  - Predict tree-level fertilization response



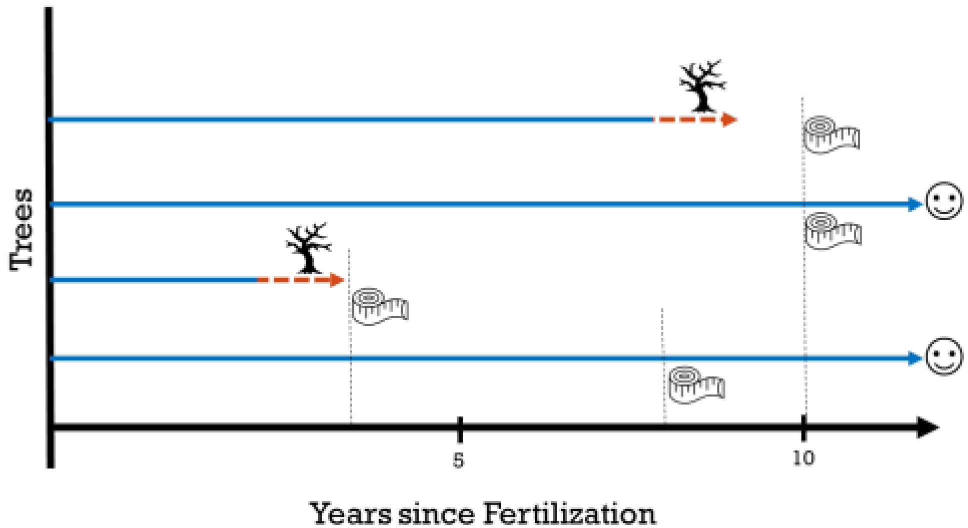
DATA & MODELS

- Data sources
  - EP703: 9 installations
  - SMC: 51 installations
  - Estab. 1969-1980 (19-56 yrs old)
  - 224-975 kg N ha^{-1} of urea
  - Remeasured every 2-3 years
- Data compilation
  - Single-time application
  - DBH
    - <12 year-since-fertilization (ysf)
    - 124,982 obs. / 31,736 trees
  - HT
    - <12 ysf
    - 13,950 obs. / 4,460 trees
  - Mortality
    - Latest but not exceeding 10 ysf
    - 51,626 obs. & trees

VARIABLES USED FOR MODEL CONSTRUCTION

Notation	Variable	Unit	Range	Mean
MAI	Mean annual increment of DBH	cm $year^{-1}$	0.08–2.51	0.43
DBH	Diameter at breast height	cm	2.29–75.95	17.00
HT	Total height	m	3.05–48.5	16.18
CR	Crown ratio	-	0.17–1.00	0.57
SBA	Stand basal area	m^2 ha^{-1}	2.66–111.40	50.54
BAL	Sum of basal area of larger trees	m^2 ha^{-1}	0.13–111.28	28.33
rBAL	Relative BAL	-	0.00–1.00	0.58
SI	Site index	m	19.51–59.13	39.57
N	Nitrogen application rate	N tons ha^{-1}	0.00–0.98	0.22
P	Phosphorus application	-		
SDI	Stand density index	-	65.1–1063.9	539.0

MODEL CONSTRUCTION - MORTALITY



- Variations in measurement intervals and differing times of mortality observation
  - Shaffer's (2004) "logistic-exposure link function"
- 2-level nested random effects (installation, plot)
- Stand-level, tree-level variables were tested for explanatory variables

$$logit(P_{mort}) = (\beta_0 + b_i + b_{ip}) + \beta_1 \cdot MAI + \beta_2 \cdot N + \beta_3 \cdot rBAL + \beta_4 \cdot SBA + \beta_5 \cdot DBH + \beta_6 \cdot MAI \cdot N + \beta_7 \cdot rBAL \cdot N$$

MODEL CONSTRUCTION - GROWTH RESPONSES

$$\Delta y = \boxed{F_{base}} \cdot \boxed{F_{fert}}$$

- Multiplicative form with baseline growth model (F_{base}) and fertilization effect (F_{fert})
  - Modified Hynynen et al. (1998) & Kuehne et al. (2022)
- F_{base} – reference growth
  - 3-level nested random effects (installation, plot, trees)
  - Stand-level & tree-level variables including initial size were tested
- F_{fert} – fertilization modifier
  - Stand-& tree-level variables, fertilization rate, P addition were included
  - Weibull pdf to model the size of fertilization effect by year

$$f_{ysf} = \frac{\kappa}{\lambda} \cdot \left(\frac{ysf}{\lambda}\right)^{\kappa-1} \cdot e^{-(ysf/\lambda)^{\kappa}}$$

GROWTH RESPONSE MODELS - DBH

$$\Delta dbh = \boxed{F_{base}} \cdot \boxed{F_{fert}}$$

$$\boxed{F_{base}} = \exp\begin{pmatrix} (\beta_0 + b_i + b_{ip} + b_{ipt}) + \beta_1 \cdot DBH + \beta_2 \cdot \log(DBH) + \\ \beta_3 \cdot CR + \beta_4 \cdot BAL^2 + \beta_5 \cdot \log(SBA) + \beta_6 \cdot \log(SI) \end{pmatrix}$$

$$\boxed{F_{fert}} = \left(1 + \begin{pmatrix} \alpha_1 + \alpha_2 \cdot P + \alpha_3 \cdot SDI + \alpha_4 \cdot rBAL + \\ \alpha_5 \cdot rBAL^2 + \alpha_6 \cdot CR \end{pmatrix} \cdot N \cdot \boxed{f_{ysf}}\right)$$

$$\boxed{f_{ysf}} = \frac{\kappa}{\lambda} \cdot \left(\frac{ysf}{\lambda}\right)^{\kappa-1} \cdot e^{-(ysf/\lambda)^{\kappa}}$$

GROWTH RESPONSE MODELS - HEIGHT

$$\Delta HT = F_{base} \cdot F_{fert} = PHG \cdot HMOD \cdot F_{fert}$$

$$PHG = f(SI, GEA + 1) - Ht$$

$$GEA = f^{-1}(SI, Ht)$$

- F_{base} for height is a product of potential growth (PHG) and a height growth modifier (HMOD; Weiskittel et al. 2007)
- PHG: potential height growth of a site tree given site index and growth effective age (GEA)
- GEA: age of site trees with the same height as the subject tree in the given site (index)

$$HMOD = \exp\left(\begin{matrix}(\beta_0 + b_i + b_{ip} + b_{ipt}) + \beta_1 \cdot \log(Ht) + \beta_2 \cdot CR + \\ \beta_3 \cdot BAL^2 + \beta_4 \cdot \log(SI)\end{matrix}\right)$$

$$F_{fert} = (1 + (\alpha_1 + \alpha_2 \cdot rBAL + \alpha_3 \cdot CR + \alpha_4 \cdot P) \cdot N \cdot f_{ysf})$$

RESULTS – MORTALITY

$$logit(P_{mort}) = (\beta_0 + b_i + b_{ip}) + \beta_1 \cdot MAI + \beta_2 \cdot N + \beta_3 \cdot rBAL + \beta_4 \cdot SBA + \beta_5 \cdot DBH + \beta_6 \cdot MAI \cdot N + \beta_7 \cdot rBAL \cdot N$$

Parm	Estimate	SE	z-value	P-value	Note
β_0	0.7179	0.3448	2.082	0.03732	Int
β_1	-1.9339	0.3949	-4.897	<0.0001	MAI
β_2	4.1232	0.7508	5.492	<0.0001	N
β_3	2.1726	0.1902	11.423	<0.0001	rBAL
β_4	0.6978	0.2649	2.634	0.00844	SBA/100
β_5	-6.1808	0.8372	-7.383	<0.0001	DBH/100
β_6	-4.0159	0.8282	-4.849	<0.0001	MAI:N
β_7	-2.6226	0.5452	-4.811	0.00197	N:rBAL

- Fertilization increase mortality probability
  - Facilitate self-thinning process
- But, the interactions indicate:
  - Hw with the higher avg. dbh growth rate has lower mortality
  - Fertilization ameliorates the mortality for relatively suppressed Hw
    - Fertilization can alleviate below-ground competition for nutrition

RESULTS – GROWTH RESPONSES

$$\Delta dbh, ht = F_{base} \cdot F_{fert} = F_{base} \cdot \left(1 + f(\alpha,\ x) \cdot f_{ysf}\right)$$

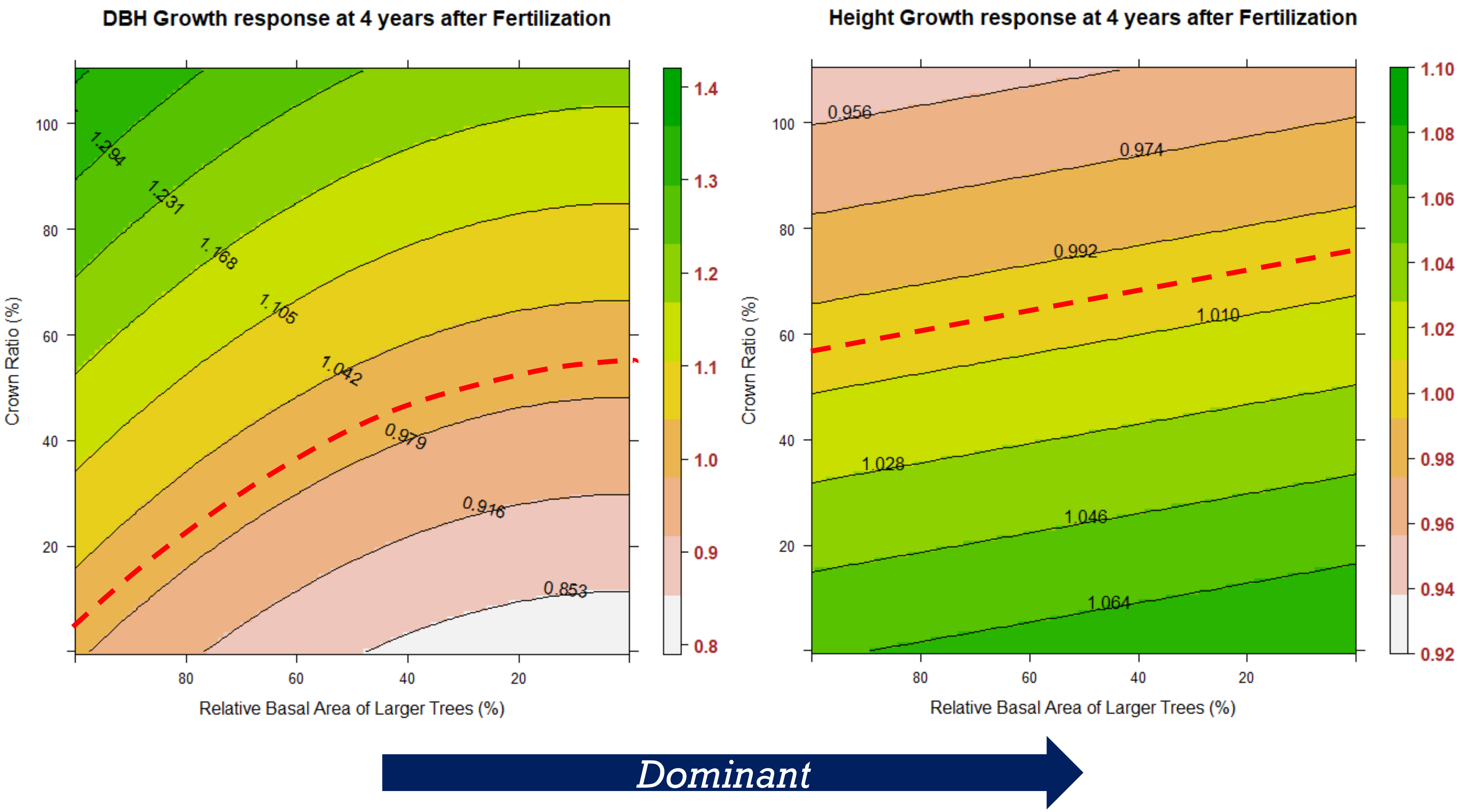
DBH model

Parm	Estimate	P-value	Note
β_0	1.111522	0.2208	Int.
β_1	-0.017257	<0.0001	DBH
β_2	1.364692	<0.0001	log(DBH)
β_3	-1.150056	<0.0001	CR
β_4	-0.000207	<0.0001	BAL
β_5	-0.731281	<0.0001	log(SBA)
β_6	-0.568521	0.0180	log(SI)
α_1	-9.866462	<0.0001	N
α_2	-0.930669	<0.0001	P:N
α_3	0.006888	<0.0001	SDI:N
α_4	-0.007593	0.9848	rBAL:N
α_5	5.683386	<0.0001	$rBAL^2$:N
α_6	11.187504	<0.0001	CR:N
λ	4.908749	<0.0001	scale
K	1.765493	<0.0001	shape

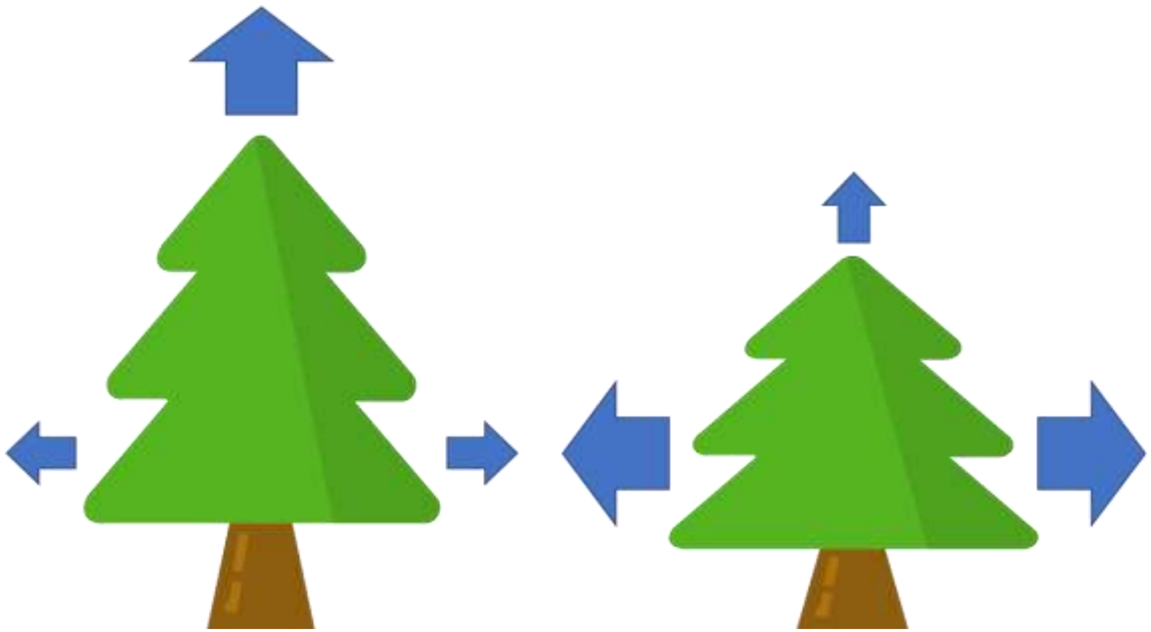
HT model

Parm	Estimate	P-value	Note
β_0	3.454878	<0.0001	Int
β_1	0.233705	<0.0001	log(Ht)
β_2	0.216848	0.0335	CR
β_3	-0.000112	<0.0001	BAL^2
β_4	-1.249609	<0.0001	log(SI)
α_1	2.359009	<0.0001	N
α_2	-0.567380	0.0033	rBAL:N
α_3	-3.077309	<0.0001	CR: N
α_4	0.698335	0.0059	P:N
λ	5.783165	<0.0001	scale
K	4.781137	<0.0001	shape

DBH VS. HT GROWTH RESPONSE

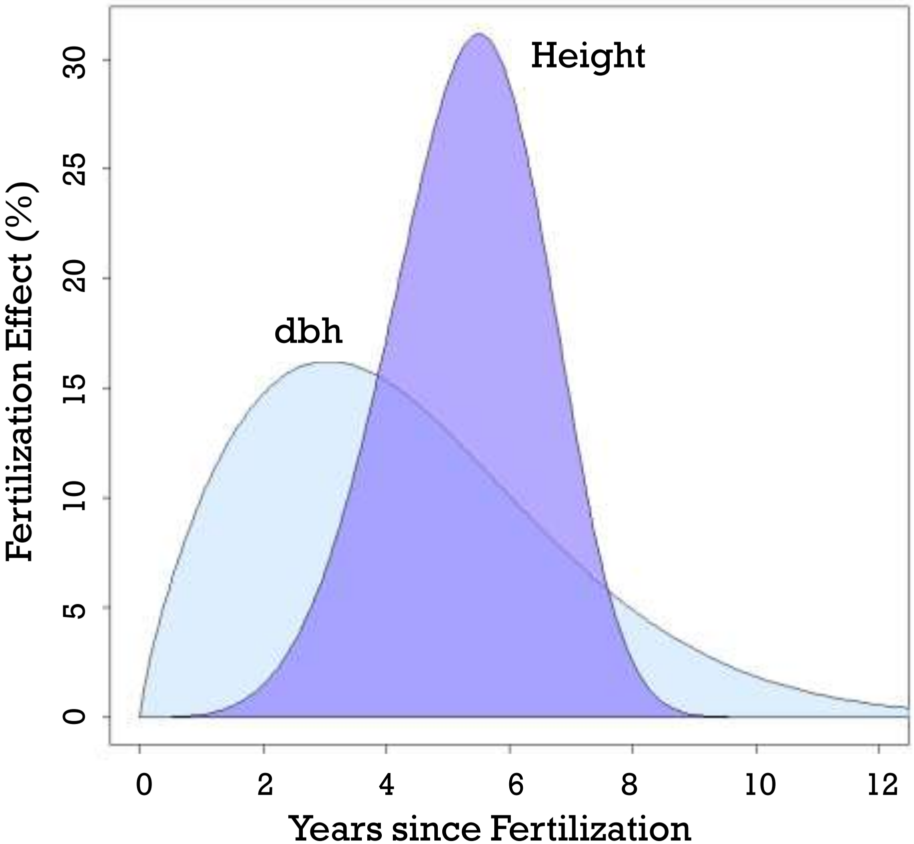


DBH VS. HT GROWTH RESPONSE



Dominant trees	Suppressed trees
• Prioritize vertical growth • Maintain competitive advantage to capture sunlight • Or, might be experiencing intense competition for full sunlight	• Prioritize lateral growth • Increase crown projected area and maximize light capture in the low light level (rel. with shade-tolerance)

RESULT – FERTILIZATION EFFECTS



$$f_{ysf} = \frac{\kappa}{\lambda} \cdot \left(\frac{ysf}{\lambda}\right)^{\kappa-1} \cdot e^{-(ysf/\lambda)^{\kappa}}$$

- Fertilization effects peaked
  - DBH: ~ 3 ysf
  - HT: ~ 6 ysf
- Lateral growth can be favored over vertical growth during the resource re-allocation process (Kuehne et al. 2022)
- Crown responds immediately after fertilization, and stem growth follows in a way to maintain structural stability (Valinger 1993)

CONCLUSION

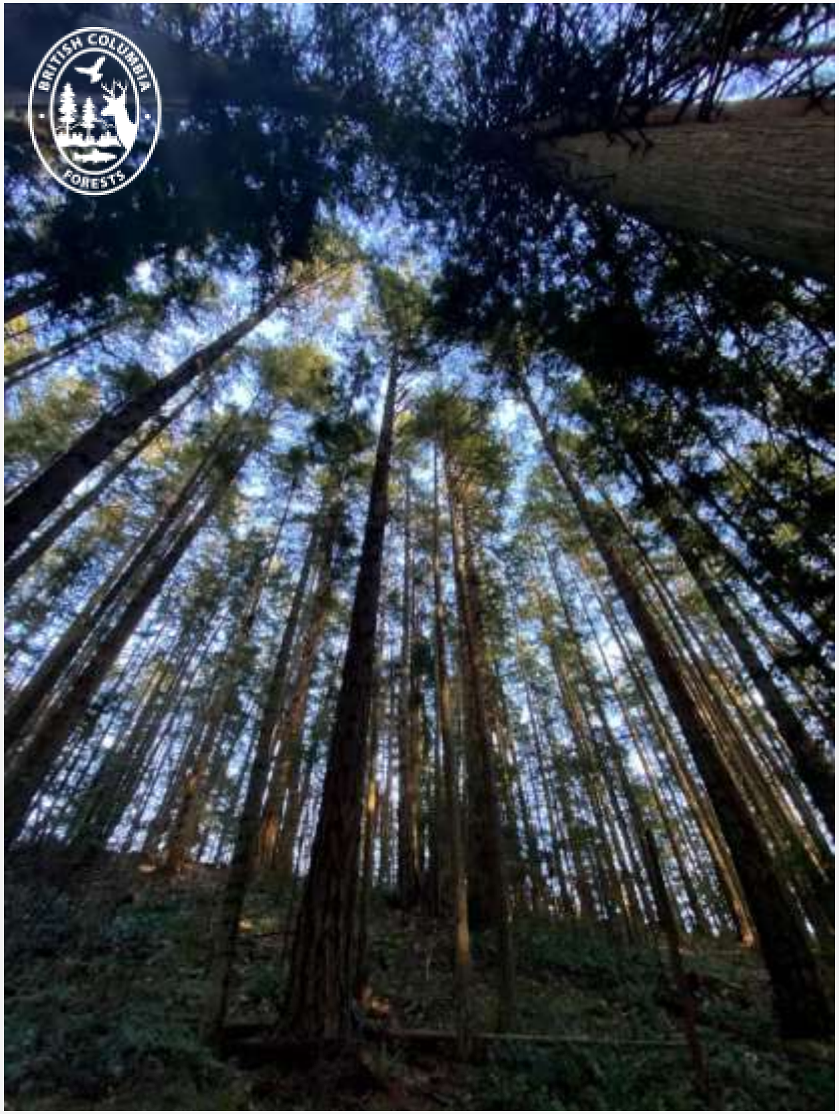
- More precisely quantify fertilization responses by individual's social standing and crown ratio (and other stand-level variables)

- Provide inspirations to the relationship among Hw's resource allocation strategy, physiological characteristics (e.g., shade tolerance), tree-level attributes including social standing

- Not easily applicable to identify the optimum sites for investment
  - But incorporated in TASS, enable to estimate stand-level mortality, growth response of Hw to fertilization

- Will implement to other species, including interior species (e.g., EP 886) & other treatments

THANK YOU!



Questions?

Woongsoon.Jang@gov.bc.ca