Stem Taper Models for Volume and Biomass Estimation of Japanese Cedar in Jeju Island, Korea: A Tool for Climate Change Mitigation

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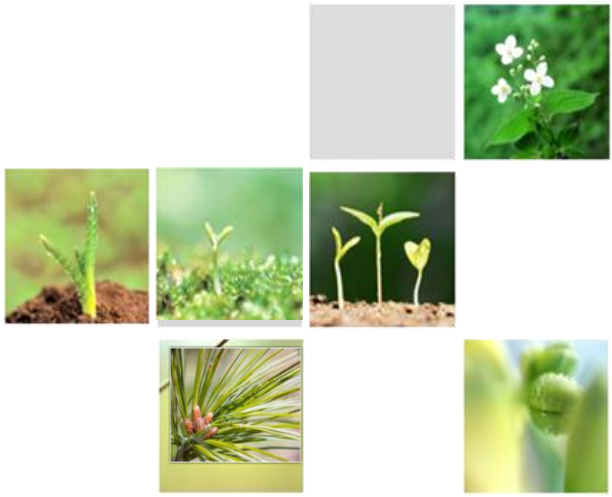
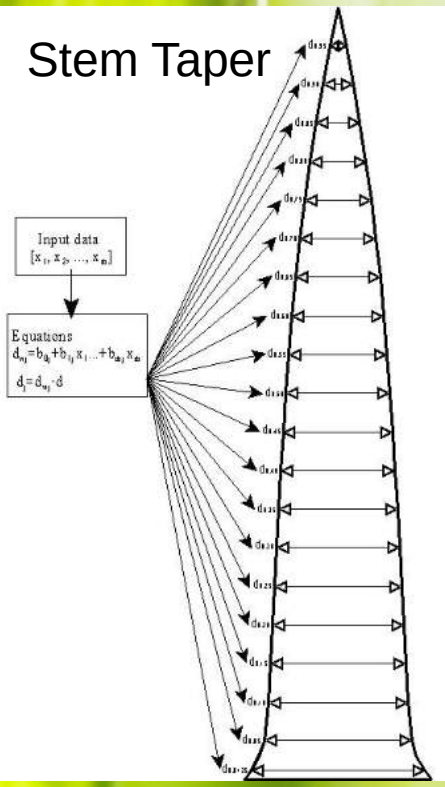


Introduction

- Biomass and carbon stock estimations in forests have become a major research interest because of the **CRUCIAL ROLE OF FORESTS** in global climate change

- **United Nations Framework Convention on Climate Change**
  - different countries are required to accurately assess the carbon stocks available in their forests

Introduction



- **Stem taper equation-** one of the most useful tools to accurately predict the:
  - Stem diameter at any given height (*d*),
  - Volume and
  - Biomass and CO_2 of a tree

Objectives

- Develop stem taper models for Japanese cedar in Korea

- Evaluate the performance of these stem taper models in predicting *d* and total stem volume.

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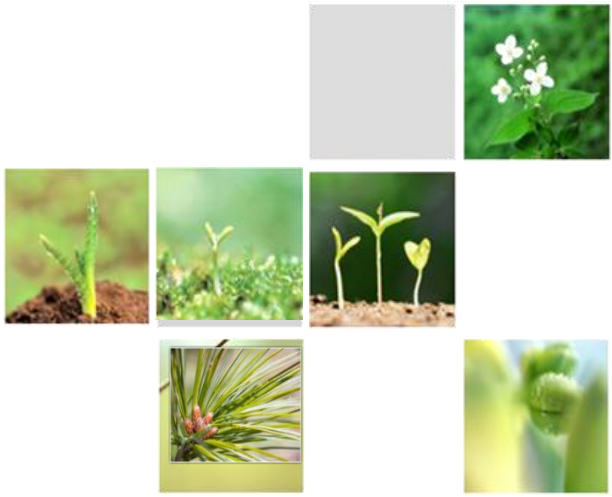
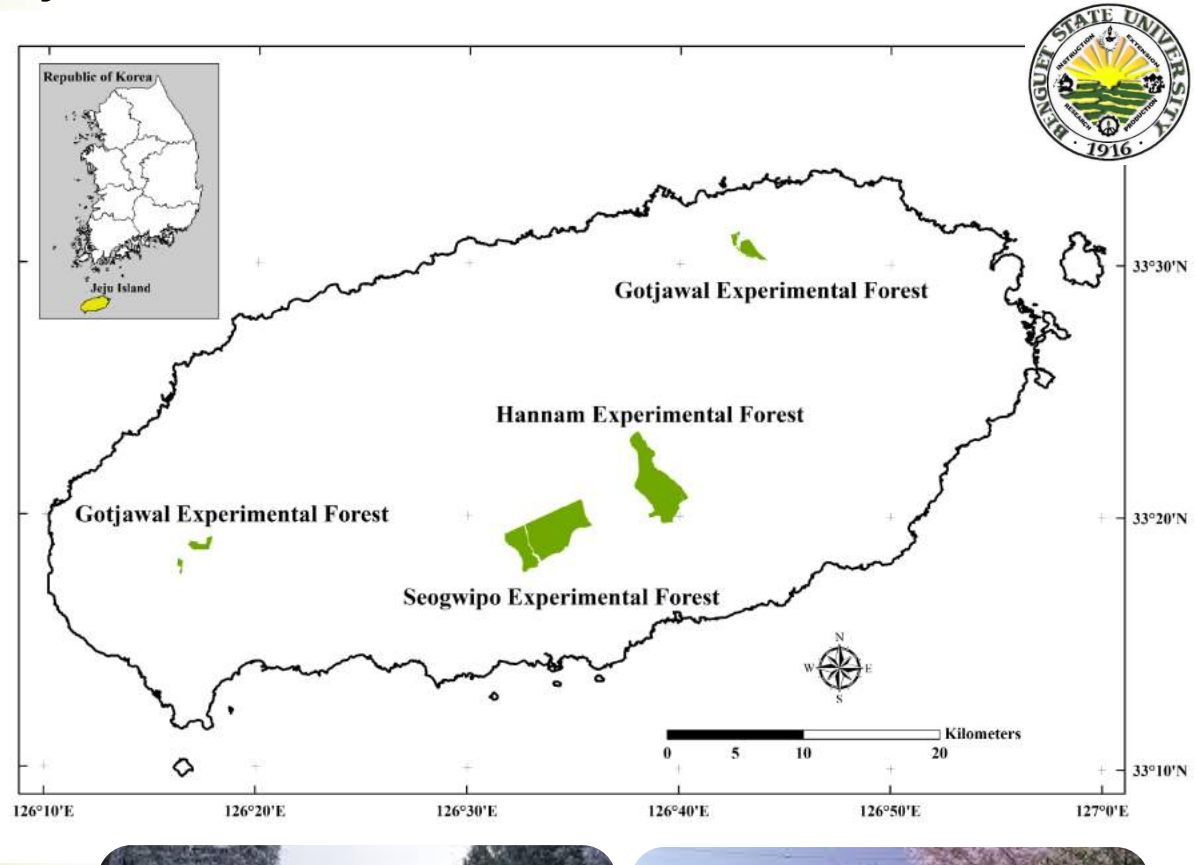


Study sites: Jeju Island, South Korea

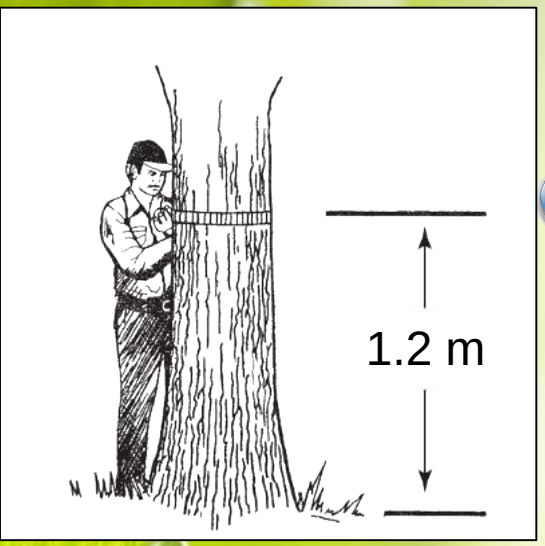
- **Location:**
  33º 11‘ to 33º 33‘ N
  126º 08' to126º 58‘ E

- **Total land area:**
  184 ,400 ha

- **Forest:** 88 874 ha
  ha (48%)



Materials and Methods



- A total of 120 trees were harvested for the measurement of *DBH* (*D* in cm), Total height (*H,* in m), diameter *(d* in cm) and height of *d* from the ground (*h* in m).

- Most of the stem taper models use *H*, *D*, and *h* as predictor variables

- *H* and *d* from 2.2 m up to the top of the tree with 1 m interval were measured after felling.

Materials and Methods

Variable	n	Mean	Minimum	Maximum	SD
Height	120	20.40	9.00	26.80	4.20
DBH	120	32.60	9.80	55.90	9.80

Materials and Methods

- Six commonly used stem taper equations:
  a. *variable exponent or form taper models*

    - Kozak88 equation (Kozak 1988)

Kozak88: $$d = a_1 D^{a_2} a_3^{\,D} X^{b_1 Z^2 + b_2 \ln(Z+0.001) + b_3 Z^{1/2} + b_4 e^Z + b_5 (D/H)}$$

    - Kozak01 equation (Kozak 2004)

Kozak01: $$d = a_1 D^{a_2} X^{b_1 + b_2 (1/e^{D/H}) + b_3 D^X + b_4 X^{D/H}}$$

    - Kozak02 equation (Kozak 2004)

Kozak02: $$d = a_1 D^{a_2} H^{a_3} X^{b_1 Z^4 + b_2 (1/e^{D/H}) + b_3 X^{0.100} + b_4 (1/D) + b_5 H^Q + b_6 X}$$

Materials and Methods

- Six commonly used stem taper equations:
  a. *variable exponent or form taper models*
    - Lee03 equation (Lee et al. 2003)

Lee03 $$\hat{d} = a_1 D^{a_2} (1 - Z)^{b_1 Z^2 + b_2 Z + b_3}$$

    - Modified Lee 2003 equation (Berhe and Arnoldsson 2008)

Mod Lee03 $$\hat{d} = a_1 D^{a_2} (1 - \sqrt{Z})^{b_1 Z^2 + b_2 Z + b_3}$$

  b. *segmented polynomial taper model*
    - MB76 equation (Max and Burkhart 1976)

MB76: $$\frac{d^2}{D^2} = b_1(Z - 1) + b_2(Z^2 - 1) + b_3(a_1 - Z)^2 I_1 + b_4(a_2 - Z)^2 I_2$$

Materials and Methods

$$SEE = \sqrt{\frac{\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2}{n-k}}$$

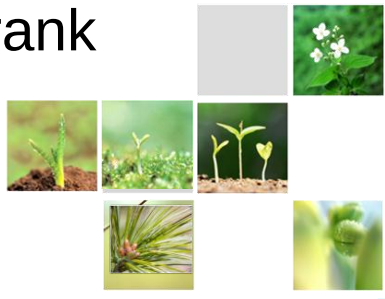
$$\overline{E} = \frac{\sum_{i=1}^{n}(Y_i - \hat{Y}_i)}{n}$$

$$MAB = \frac{\sum_{i=1}^{n}\left|Y_i - \hat{Y}_i\right|}{n}$$

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2}{\sum_{i=1}^{n}(Y_i - \overline{Y})^2}\right]$$

Evaluation Statistics

- Model parameters were estimated using the Statistical Analysis System Non-linear (SAS NLIN) procedure *(SAS Institute Inc. 2004)*
- Kozak (2004) recommended : standard error of estimate (*SEE*), mean bias, mean absolute bias (*MAB*) and coefficient of determination (R^2),
- To determine the best model, rank analysis was employed



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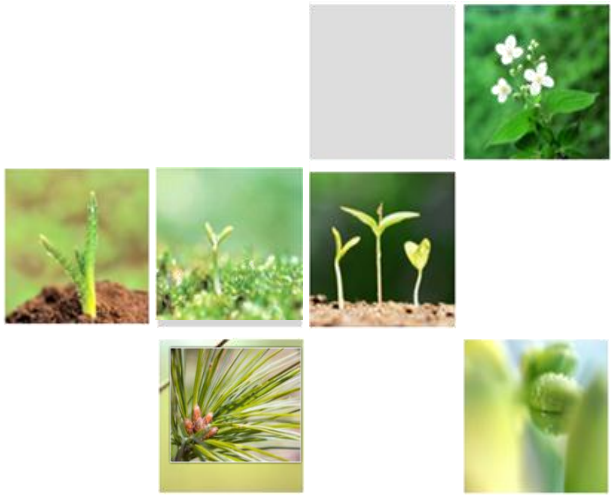


Results and Discussion

- Estimated parameters of the six candidate stem taper models

Parameter	Kozak88	Kozak01	Kozak02	MB76	Lee03	Mod Lee03
a_1	0.7683	1.3946	0.9769	0.8843	1.9034	2.2673
a_2	1.2363	0.9892	0.8589	0.0801	0.8885	0.8896
a_3	0.9922		0.1767			
b_1	2.1374	0.5105	0.3628	-7.1620	3.7015	1.6992
b_2	-0.9214	-0.2523	-0.6183	3.5605	-5.5723	-2.3628
b_3	2.9157	0.0418	0.3388	-3.4286	2.8764	1.4579
b_4	-1.6652	-0.2028	3.2012	189.9000		
b_5	0.0949		0.1055			
b_6			-0.2497			

Results and Discussion

- Evaluation statistics of the different fitted stem taper models

Model	SEE	MAB	MB	R^2	Rank
Kozak88	1.5126	1.0460	-0.0160	0.9959	1
Kozak01	1.8596	1.3420	-0.1350	0.9938	5
Kozak02	1.5234	1.0490	-0.0060	0.9958	2
MB76	1.7331	1.2000	0.1610	0.9946	3
Lee03	2.1822	1.5170	0.0540	0.9914	6
Mod Lee03	1.7785	1.2590	0.0210	0.9943	3

Results and Discussion

- Performance of the taper models to accurately predict **total stem volume** was also assessed using lack of fit statistics

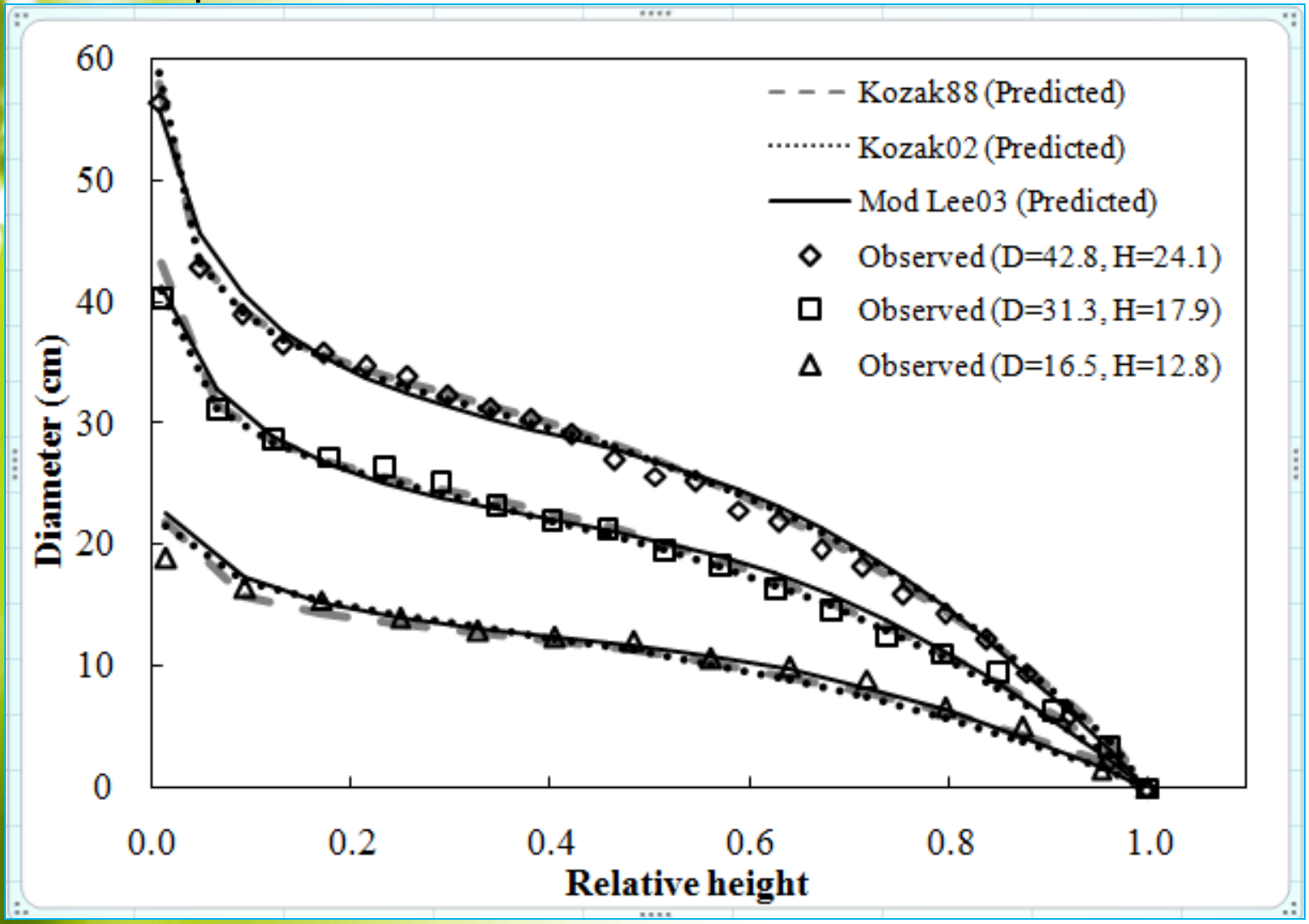
Statistics	DBH class	Kozak88	Kozak01	Kozak02	MB76	Lee03	ModLee03
SEE	<15	0.0146	0.0153	0.0164	0.0167	0.0126	0.0119
	15-25	0.0174	0.0216	0.0231	0.0302	0.0155	0.0148
	25-35	0.0505	0.0505	0.0534	0.0586	0.0493	0.0497
	35-45	0.0900	0.0924	0.0934	0.1011	0.0921	0.0942
	>45	0.1521	0.1558	0.1499	0.3122	0.2121	0.2066
MB	<15	0.0061	-0.0064	-0.0025	0.0101	-0.0072	-0.0065
	15-25	0.0069	0.0000	0.0023	0.0236	-0.0053	-0.0036
	25-35	-0.0092	0.0030	-0.0024	0.0294	-0.0023	0.0025
	35-45	0.0121	0.0340	0.0245	0.0100	0.0161	0.0240
	>45	0.0017	-0.0373	-0.0368	-0.2328	-0.1116	-0.0998
MAB	<15	0.0071	0.0097	0.0073	0.0106	0.0077	0.0073
	15-25	0.0119	0.0155	0.0153	0.0237	0.0106	0.0101
	25-35	0.0358	0.0392	0.0405	0.0457	0.0364	0.0367
	35-45	0.0600	0.0626	0.0604	0.0743	0.0659	0.0662
	>45	0.1094	0.1098	0.1078	0.2791	0.1741	0.1653
Sum		35	55	46	85	47	47
Overall rank		1	5	2	6	3	3

Results and Discussion

- Several studies proved that Kozak88 stem taper model can provide accurate estimate of *d* for various species in different countries.
  - Huang et al. (2000) -*Picea glauca* in Alberta, Canada
  - Klos et al. (2007)- for the five major commercial trees (*Populus balsamifera*, *Populus tremuloides*, *Picea glauca*, *Picea mariana* and *Pinus banksiana*) in Manitoba, Canada.
  - In Sweden, Hjelm (2013) - *Populus maximowiczii* x *P. trichocarpa*
  - In Ethiopia, Berhe and Arnoldsson (2008) -for *Cupressus lusitanica*
  - Son et al. (2009) – for *Acacia mangium* and *Eucalyptus pellita* in Kalimantan, Indonesia

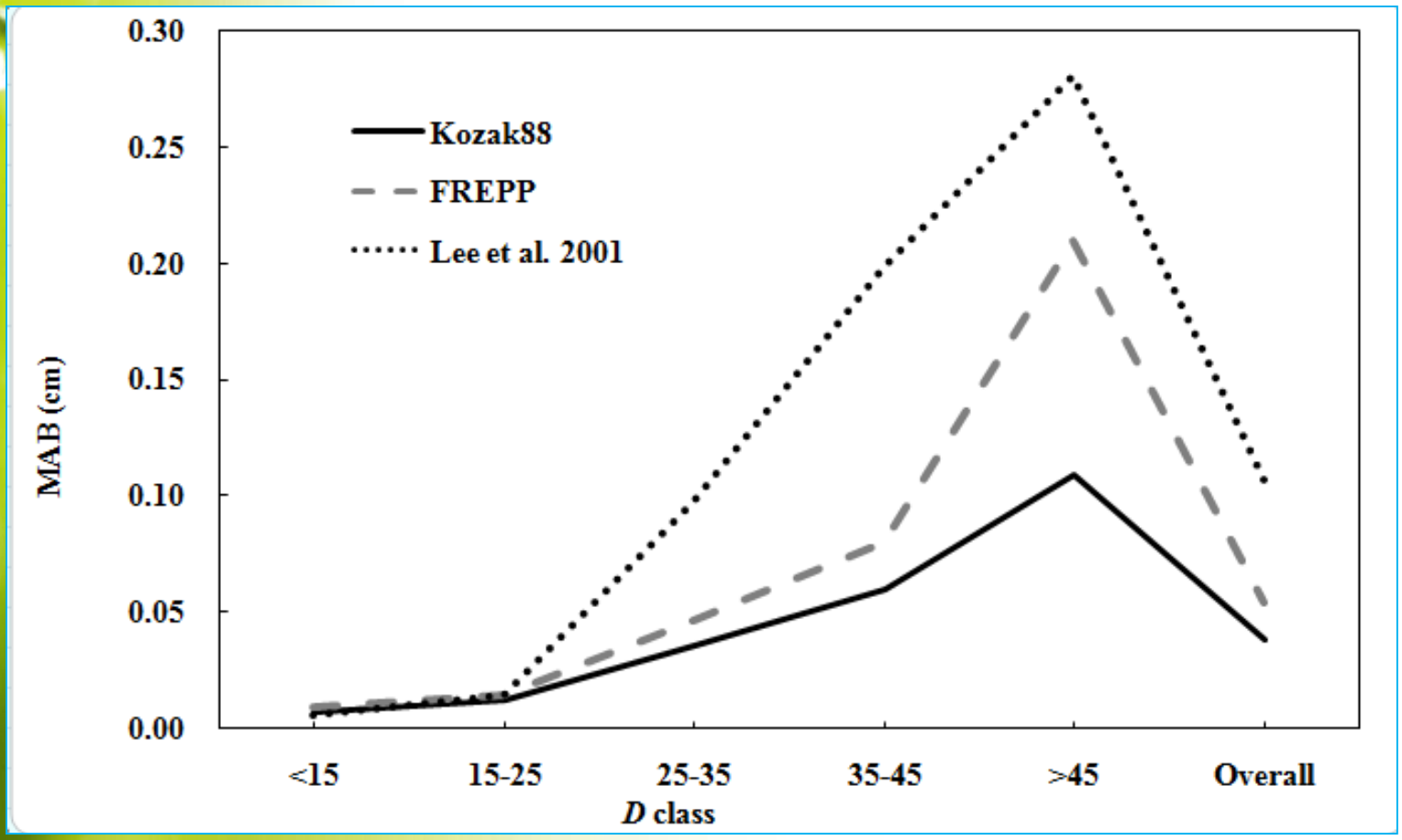
Results and Discussion

- The stem taper models can be applied in the estimation of stem form of Japanese cedar.



Results and Discussion

- **Kozak88 model** VS **volume model developed for Japanese cedar by Lee et al. (2001)** VS computer program called **Forest Resources Evaluation and Prediction Program (FREPP)** in predicting volume of Japanese cedar



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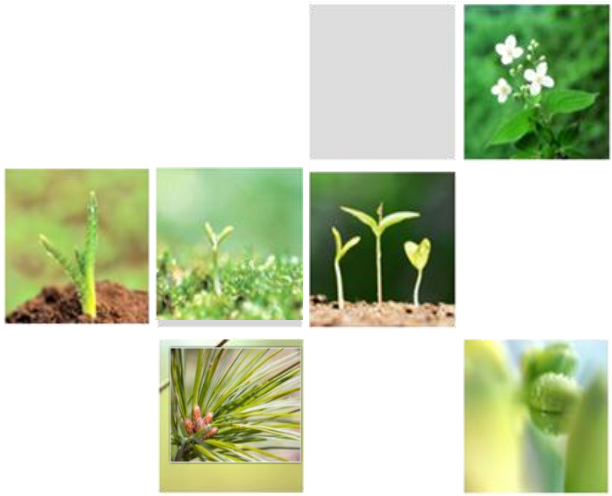

Application

- What is the Volume, Biomass, and Carbon sequestered of a Japanese cedar with a DBH of 32 cm and total height of 20 m?

- You cannot cut this tree!

Application

- Volume, Biomass, Carbon prediction of Japanese cedar
  - The *d* in the different *h* should be predicted first using the best model (Kozak88)
  - Using the Smalian formula, the volume of the different log section can be determined and summed up for the total stem volume estimation.

Smalian's Formula:

$$\text{Volume} = 0.00007854 \times [(d_1^2 + d_2^2)/2] \times L$$

Application

- The *d* starting from the stump height (0.20 from the ground) to the *H* with intervals of 0.50 m, can be predicted as follows:

$$d_1 = 0.7683 \times 32^{1.2363} \times 0.9922^{32} \times 1.01^{[2.1374 \times 0.01^2] + [-0.9214 \ln(0.01 + 0.001)] + [2.9157 \times 0.01^{1/2}] + [-1.6652 \exp^{0.01}] + [0.0949(32/20)]}$$

$d_1 = 44.10$ cm

- The *d* of the next height position (h_2 = 0.70 m) can also be predicted as follows:

$$d_2 = 0.7683 \times 32^{1.2363} \times 0.9922^{32} \times 0.91^{[2.1374 \times 0.04^2] + [-0.9214 \ln(0.04 + 0.001)] + [2.9157 \times 0.04^{1/2}] + [-1.6652 \exp^{0.04}] + [0.0949(32/20)]}$$

$d_2 = 35.67$ cm

Application

- This process will be done at every 0.5 m height position until the 19.70 m.
- After the estimation of *d*, the volume for each log section can now be determined as shown below:

$$\text{Volume}_1 = 0.00007854 \times [(44.10^2 + 35.67^2)/2] \times 0.5$$

$$\text{Volume}_1 = 0.0632\ \text{m}^3$$

- By summing up the volumes from the different sections, the total stem volume of this tree **is 0.7272 m³**

Volume prediction using

No	H	D	h	Predicted D	Sectional Volume	Total volume
1	20.00	32.00	0.20	44.10		0.7272
2	20.00	32.00	0.70	35.67	0.0632	
3	20.00	32.00	1.20	32.60	0.0458	
4	20.00	32.00	1.70	30.81	0.0395	
5	20.00	32.00	2.20	29.59	0.0358	
6	20.00	32.00	2.70	28.67	0.0333	
7	20.00	32.00	3.20	27.94	0.0315	
8	20.00	32.00	3.70	27.32	0.0300	
9	20.00	32.00	4.20	26.78	0.0287	
10	20.00	32.00	4.70	26.29	0.0277	
11	20.00	32.00	5.20	25.84	0.0267	
12	20.00	32.00	5.70	25.40	0.0258	
13	20.00	32.00	6.20	24.97	0.0249	
14	20.00	32.00	6.70	24.54	0.0241	
15	20.00	32.00	7.20	24.10	0.0232	
16	20.00	32.00	7.70	23.65	0.0224	
17	20.00	32.00	8.20	23.17	0.0215	
18	20.00	32.00	8.70	22.68	0.0206	
19	20.00	32.00	9.20	22.15	0.0197	
20	20.00	32.00	9.70	21.60	0.0188	
21	20.00	32.00	10.20	21.01	0.0178	
22	20.00	32.00	10.70	20.39	0.0168	
23	20.00	32.00	11.20	19.73	0.0158	
24	20.00	32.00	11.70	19.03	0.0148	

Application

- Wood density of Japanese cedar is **0.37 g cm^{-3}** (Jung et al. 2014)
- Stem Biomass of this tree: **269.06 kg**
- Carbon (Stem) sequestered (47% of Biomass is Carbon as suggested by IPCC): **126.46 kg**
- **CO_2 sequestered**: **464.11 kg**

Conclusion

- The Kozak88 model provided the best performance in accurately predicting *d* of Japanese cedar in the southern part of Korea..
- The Kozak88 model also showed its superiority in total volume estimation as compared to the other stem taper models.
- This model was also superior as compared to the FREPP computer program and volume model developed by Lee et al. (2001) in accurately estimating the total stem volume of Japanese cedar

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Thank You very much !