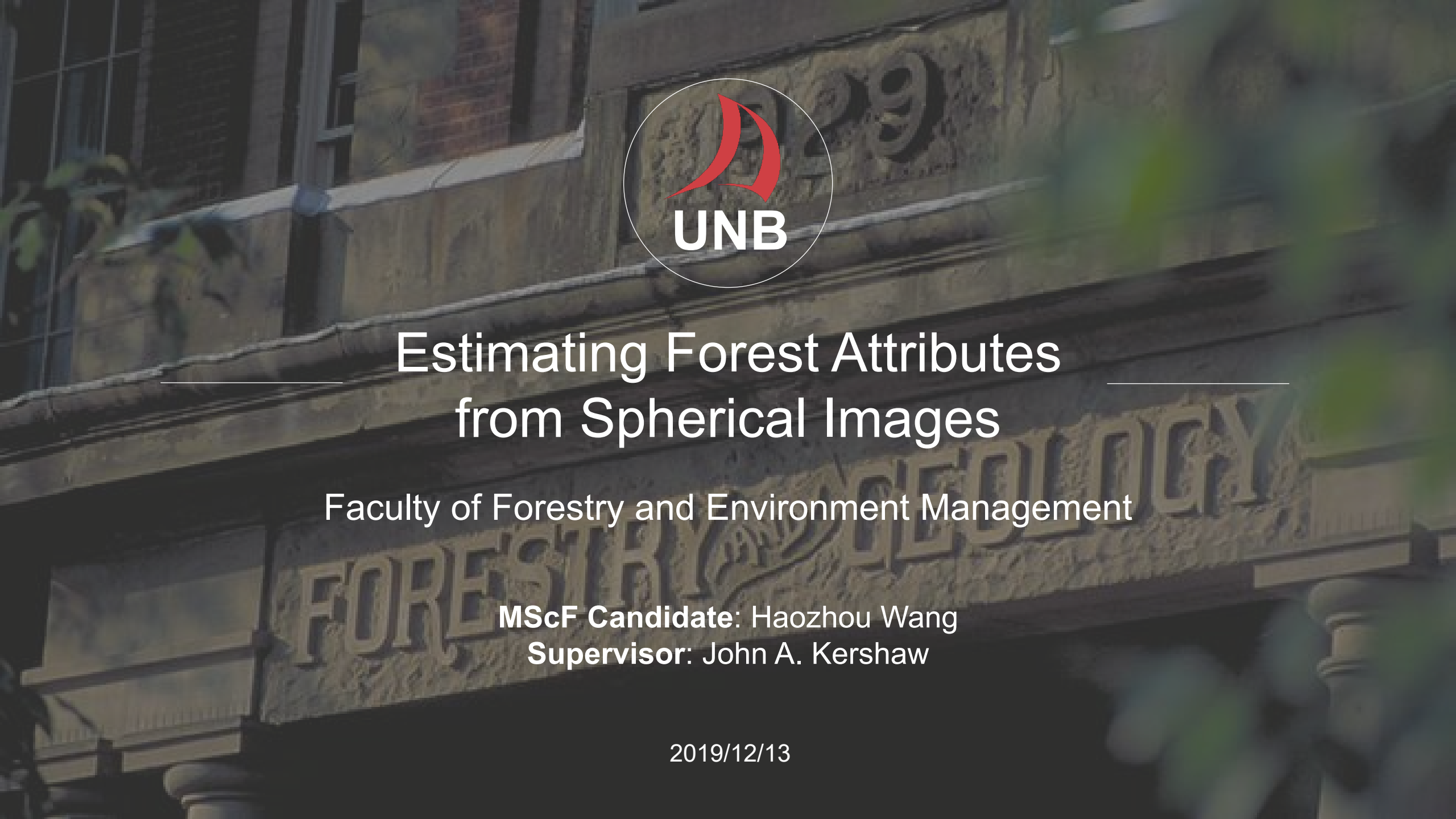


Estimating Forest Attributes from Spherical Images

Faculty of Forestry and Environment Management

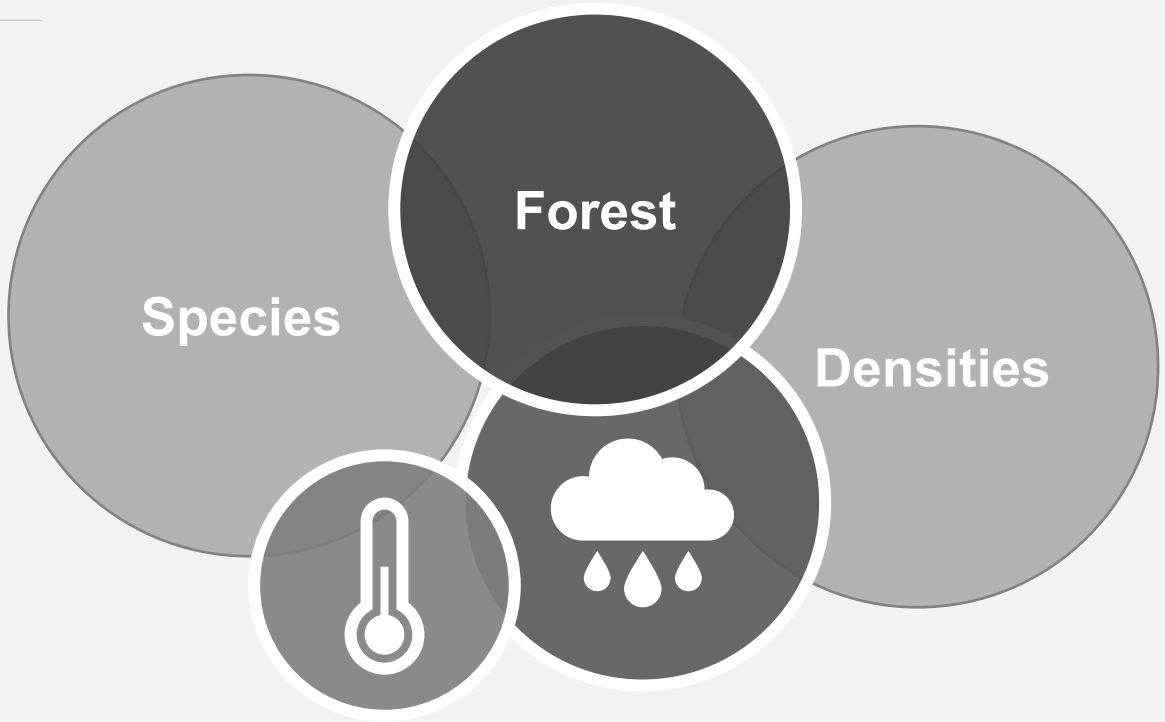
MScF Candidate: Haozhou Wang
Supervisor: John A. Kershaw

2019/12/13

Introduction

Dominant Terrestrial Ecosystem

- **75%** biosphere gross primary productivity
- **80%** of plant biomass



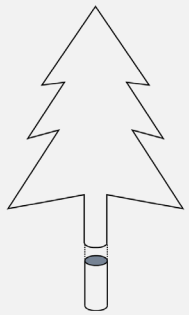
Service

- Watershed protection
- Soil maintenance
- Carbon Storage

How?

Complex Forest Conditions → Simple Attributes

1.2 Attributes



Single Tree Attributes

Trunk Info.

Height

Diameter

Stand BA

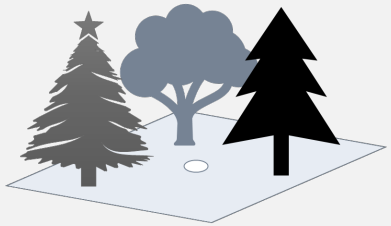
Clinometer

Measuring tape

Diameter tape

Angle gauge

Stand-level Attributes



Or “Plant Fraction” (PF)

Crown Info.

Gap Fraction

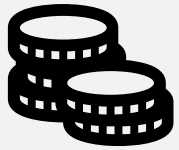
Fisheye camera

1.3 Current problems

Time consuming

Labor intensive

Revisit Validation



Unfriendly Price

Trunk Info.

- Height
- Diameter
- Stand BA

Crown Info.

Or “Plant Fraction” (PF)

- Gap Fraction

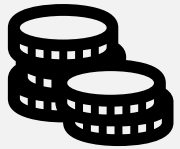
- **Clinometer** + **Measuring tape**

- **Diameter tape**

- **Angle gauge**

- **Fisheye camera**

1.3 Current problems



Trunk Info.

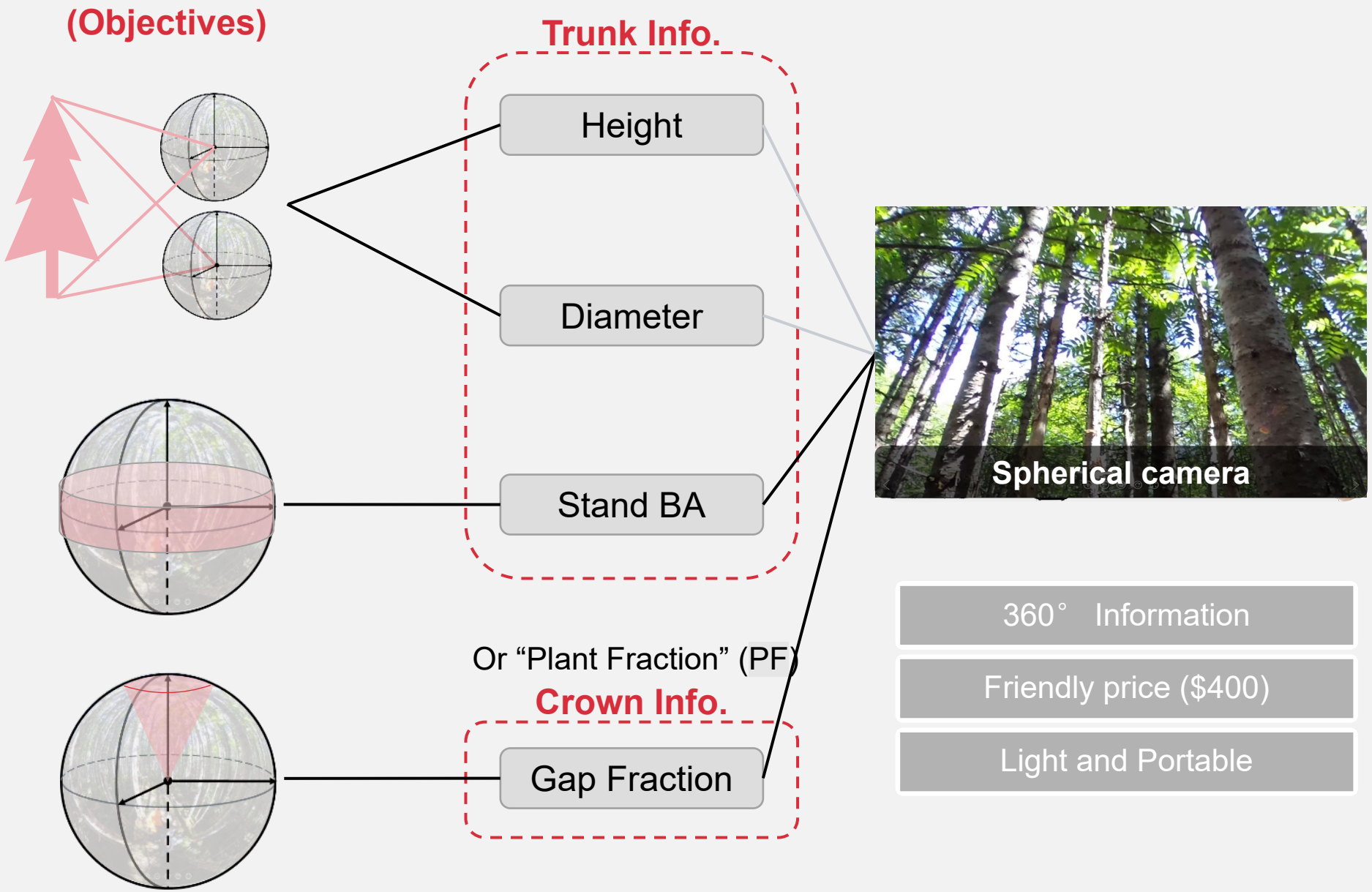
- Height
  - Clinometer
  - Measuring tape
- Diameter
  - Diameter tape
- Stand BA
  - Angle gauge

Or “Plant Fraction” (PF)

Crown Info.

- Gap Fraction
  - Fisheye camera

1.4 Integrated tool: Ricoh spherical camera



1.5 Outline of thesis

Chapter 1

- General Introduction

Chapter 2

- Stand basal area

Chapter 3

- Plant fractions (stem, foliage, sky)

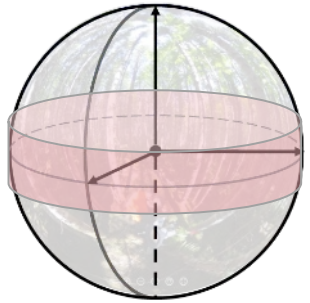
Chapter 4

- Individual tree attributes (distance, DBH, HT)

Chapter 5

- General Conclusion

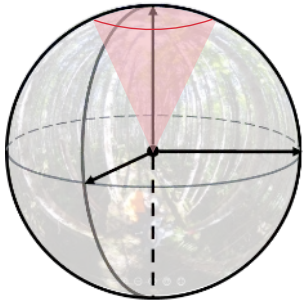
1.6 Short summary



Chapter 2

1 Spherical photos are suitable for estimating stand basal area based on modified angle-count sampling methods.

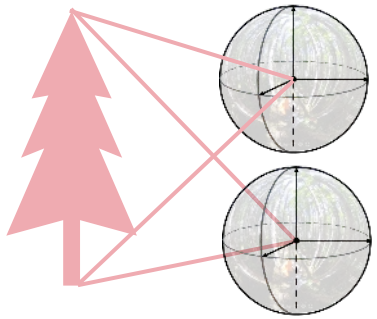
2 Generally good repeatability among different people, very complex forest structure effects stability to some extent.



Chapter 3

3 The novel HSV performs better than BC for plant fraction classification, and the directly routine proved applicable

4 HSV-3 classification not performs as expected on Foliage class, further improvements should be done in the future



Chapter 4

5 Using vertical spherical image pairs to estimate individual tree DBH and height is applicable in both sites

6 Surprisingly, urban and real forest validation drew reversed conclusions, pairwise comparison for real forest is necessary

2

Study Sites

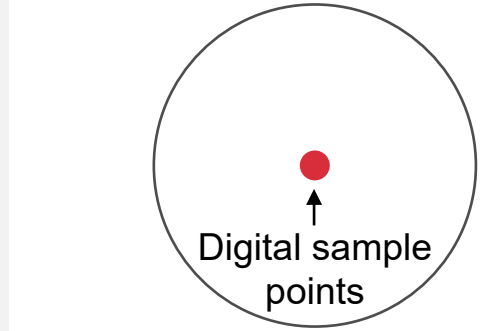
2.1 Location Map

2.2 Plot Overview

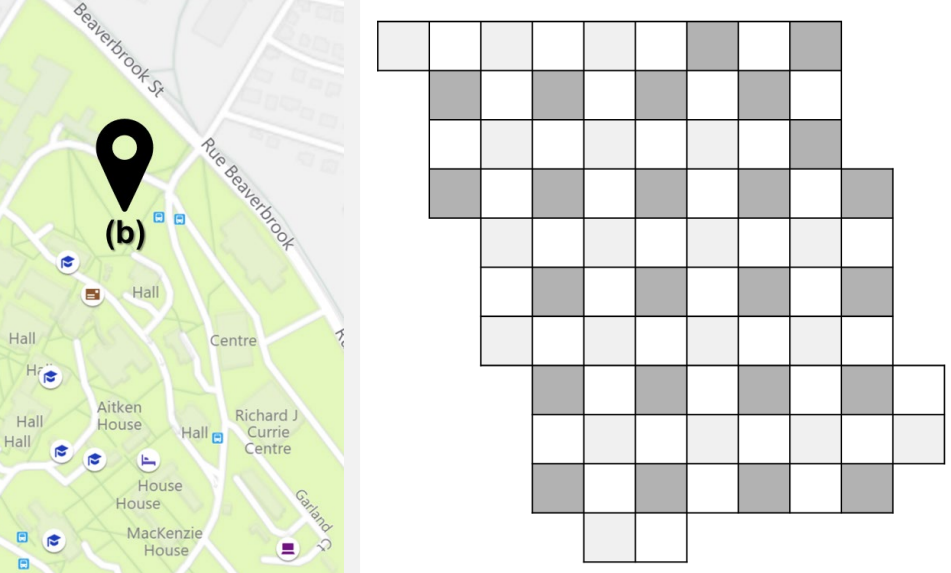
UNB	NRF	NL
2 plots	83 plots (grids)	3 x 15 plots
Manmade urban forest	Natural forest	Managed forest (early spacing)
Sparse	Dense	Various density
Large trees	Small to large trees	Small trees
Deciduous trees	Mixed species	Balsam fir dominant

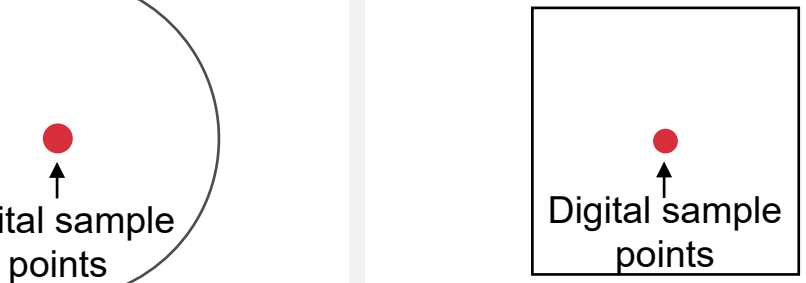
2.3 Digital Sample Points (DSP)

UNB

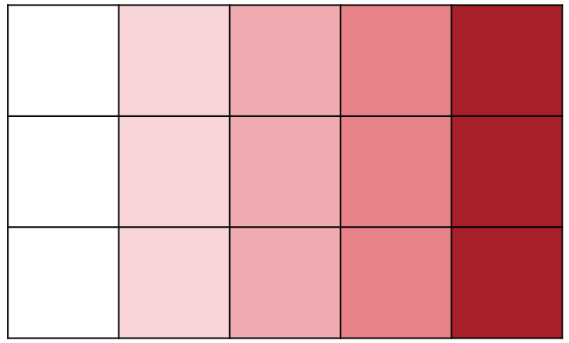


NRF



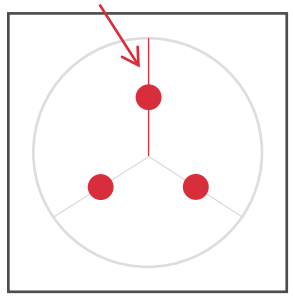


NL



ctrl	1.2	1.8	2.4	3.0
0.0m	1.2m	1.8m	2.4m	3.0m
5.2m	7.2m	10.4m	15m	18m

Plot radii

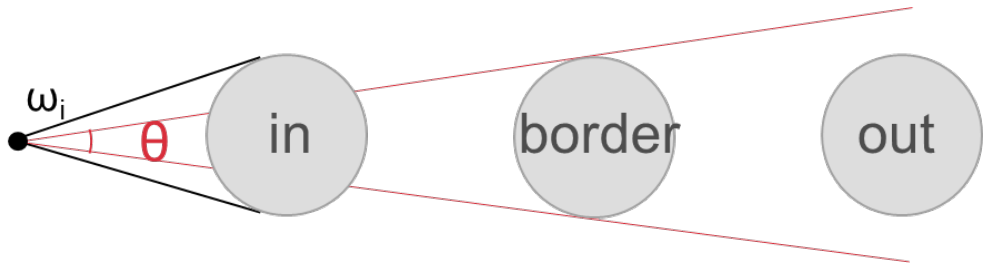


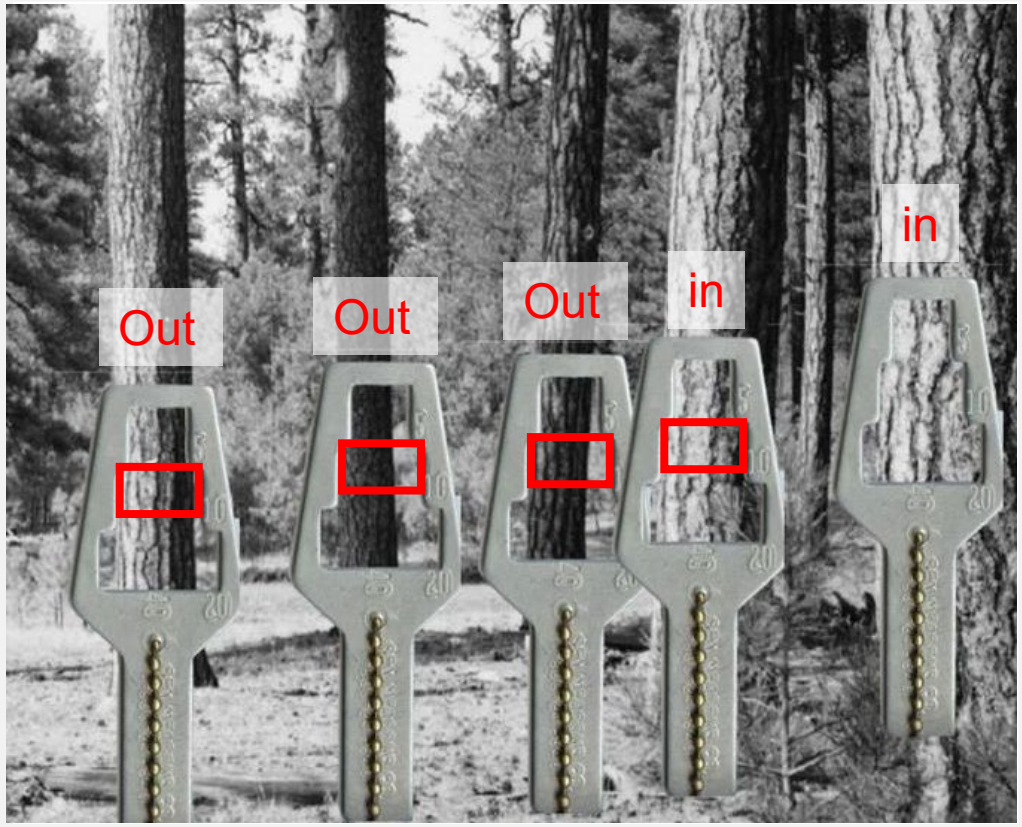
Stand BA

Angle-count Sampling

Compare view angle (ω_i) of each tree, if $\omega_i \geq \theta$, then this tree is counted.

$$BA_{stand} = count \cdot BAF(\theta)$$

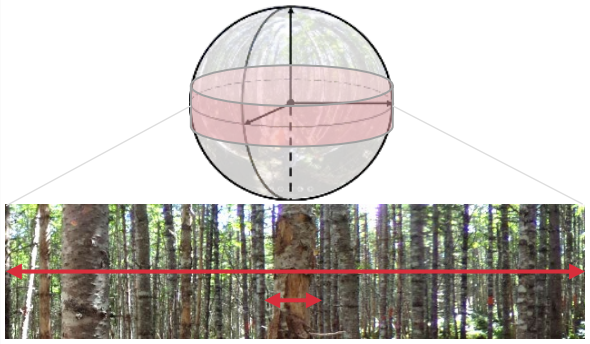


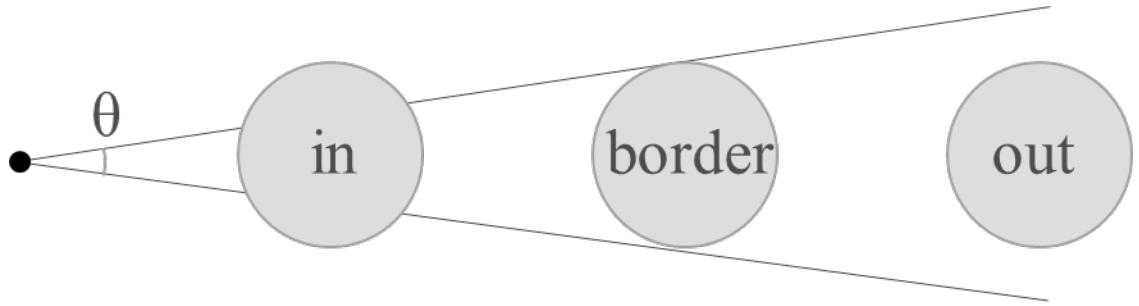


In the NRF plots,
using the **angle gauge** to provide the view angle threshold (θ) to determine whether a tree is counted or not.

In the NL plots,
the stand basal area is summarized by each tree's basal area calculated from DBH measured by **diameter tape**.

3.2 Image Processing



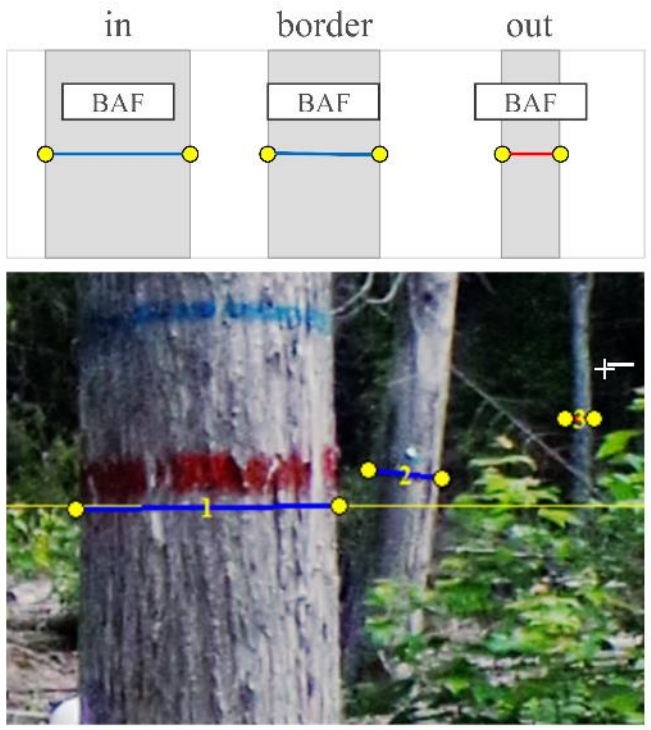


Edge Marking

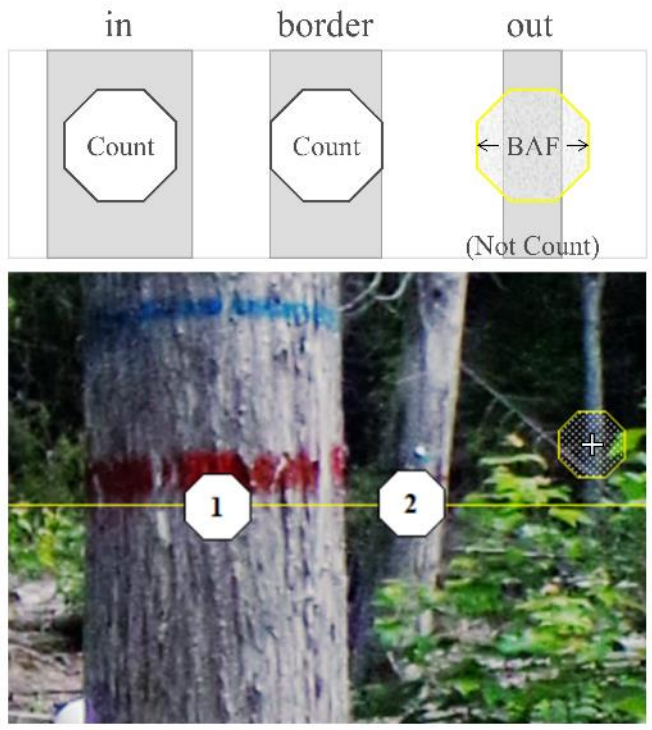
Need to mark the edge of each tree

Target Counting

Only click those trees greater than the target

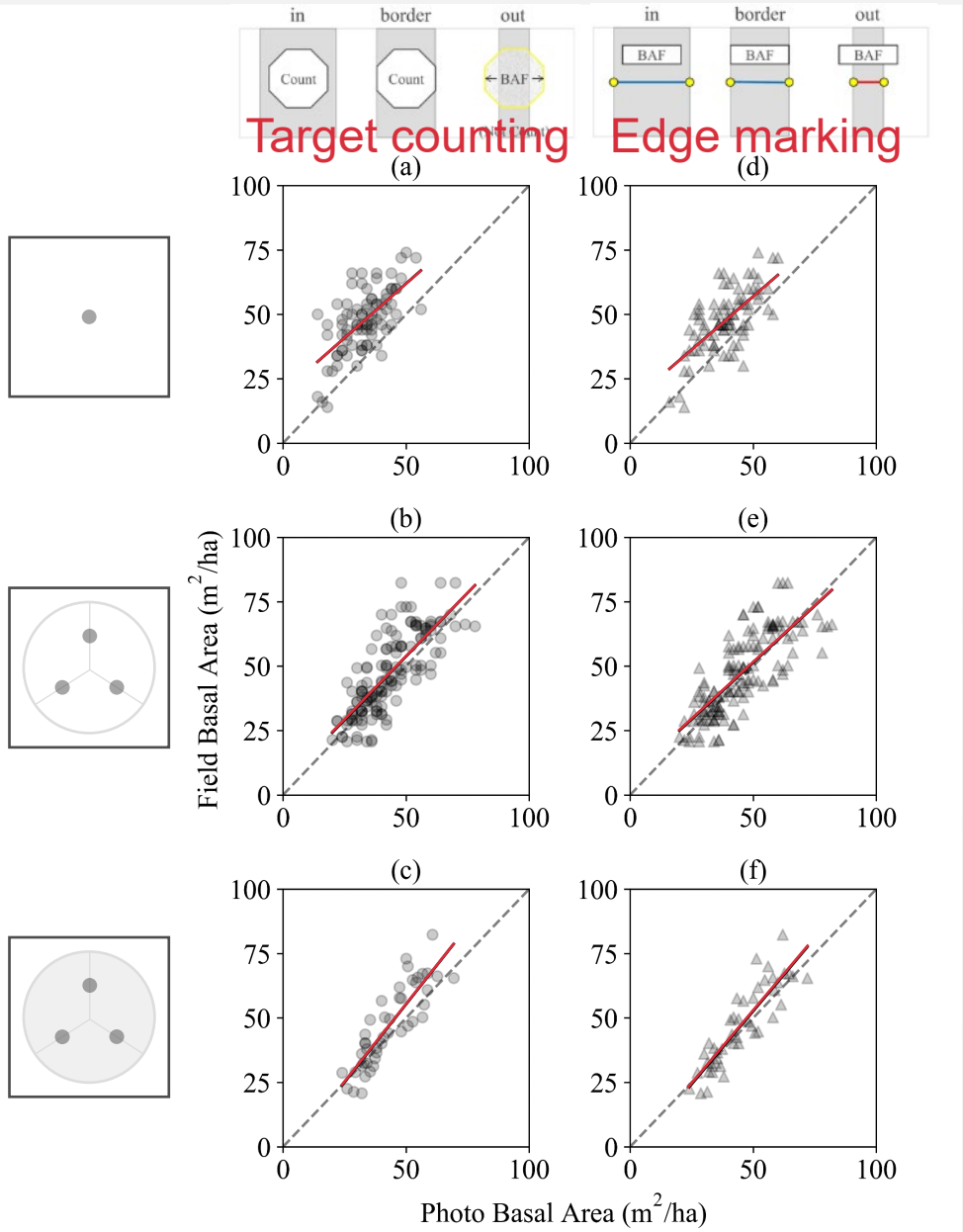


(a) Edge Marking



(b) Target Count

3.3 Field Validation



$$FBA = b_0 + b_1 \cdot PBA$$

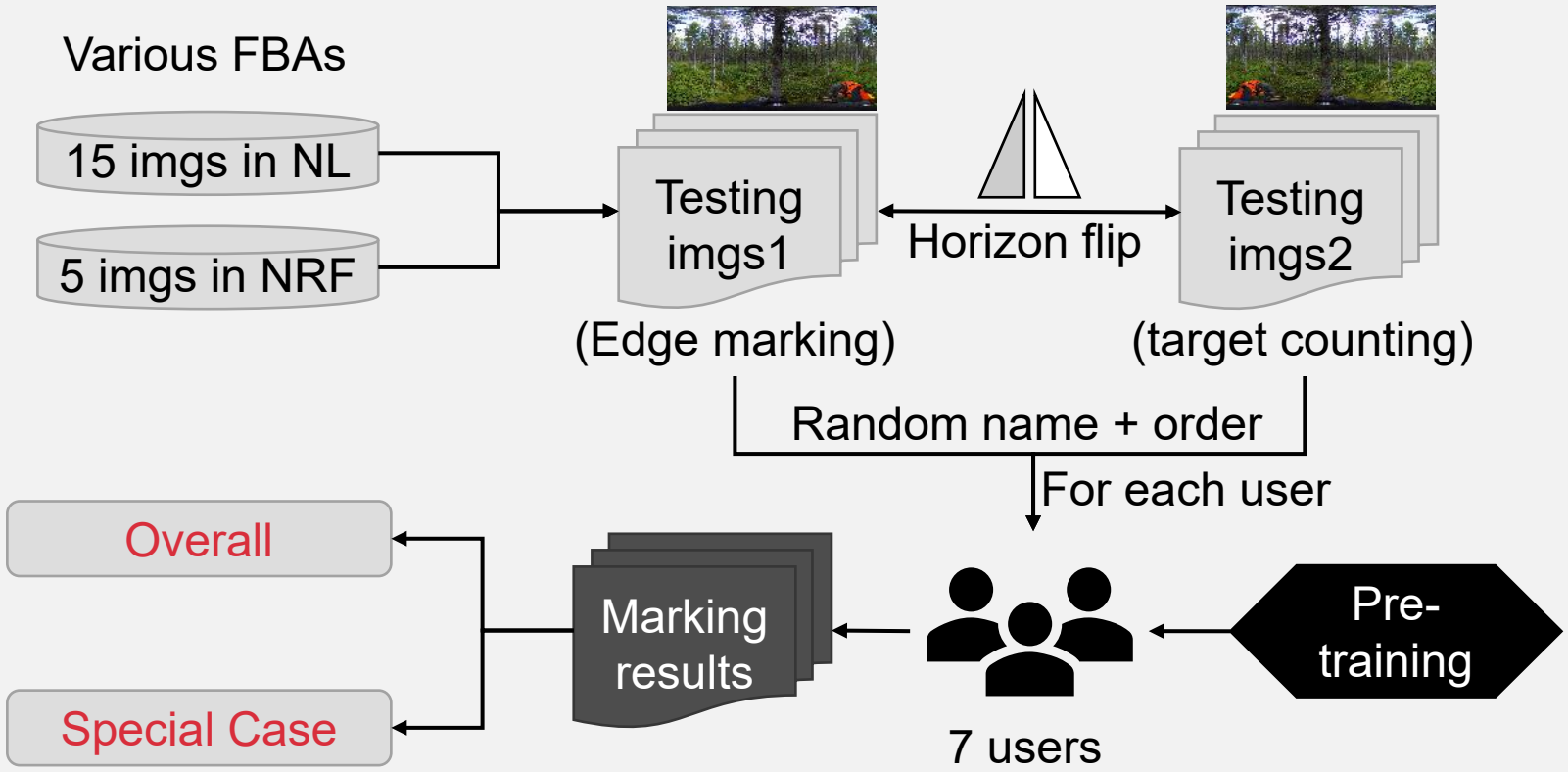
	Param.	Estimate	Std. Err.	p-value	r^2	rMSE
(a)	b0	19.74	3.85	<0.001	0.41	9.27
	b1	0.84	0.11	0.150		
(b)	b0	4.44	3.08	0.152	0.61	9.66
	b1	0.99	0.06	0.868		
(c)	b0	-5.22	4.79	0.282	0.75	7.77
	b1	1.21	0.11	0.063		
(d)	b0	15.69	4.09	<0.001	0.44	9.00
	b1	0.83	0.10	0.093		
(e)	b0	7.34	2.91	0.013	0.60	9.72
	b1	0.88	0.06	0.048		
(f)	b0	-4.04	4.32	0.355	0.78	7.30
	b1	1.13	0.09	0.158		

1. Good linear relationship between FBA and PBA (high r^2 & low rMSE)

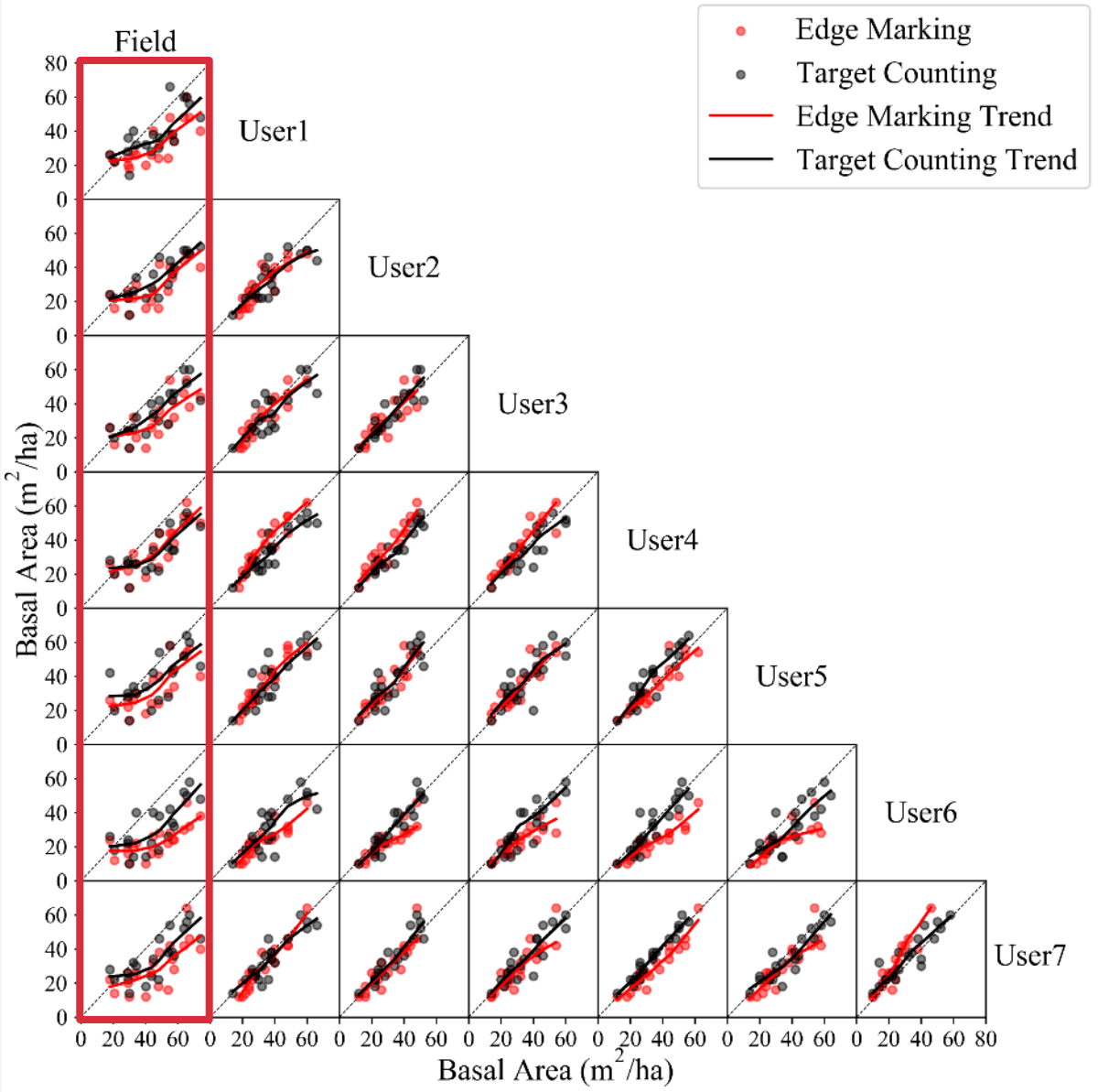
2. All regression lines show PBA under-estimate FBA (occluded hidden tree)

3. Multiple DSPs performs better than single DSP (decrease hidden tree)

3.4 Inter-observer error and stability



3.4 Inter-observer error and stability



Compared with FBA

All users consistently under-estimate
(Field column)

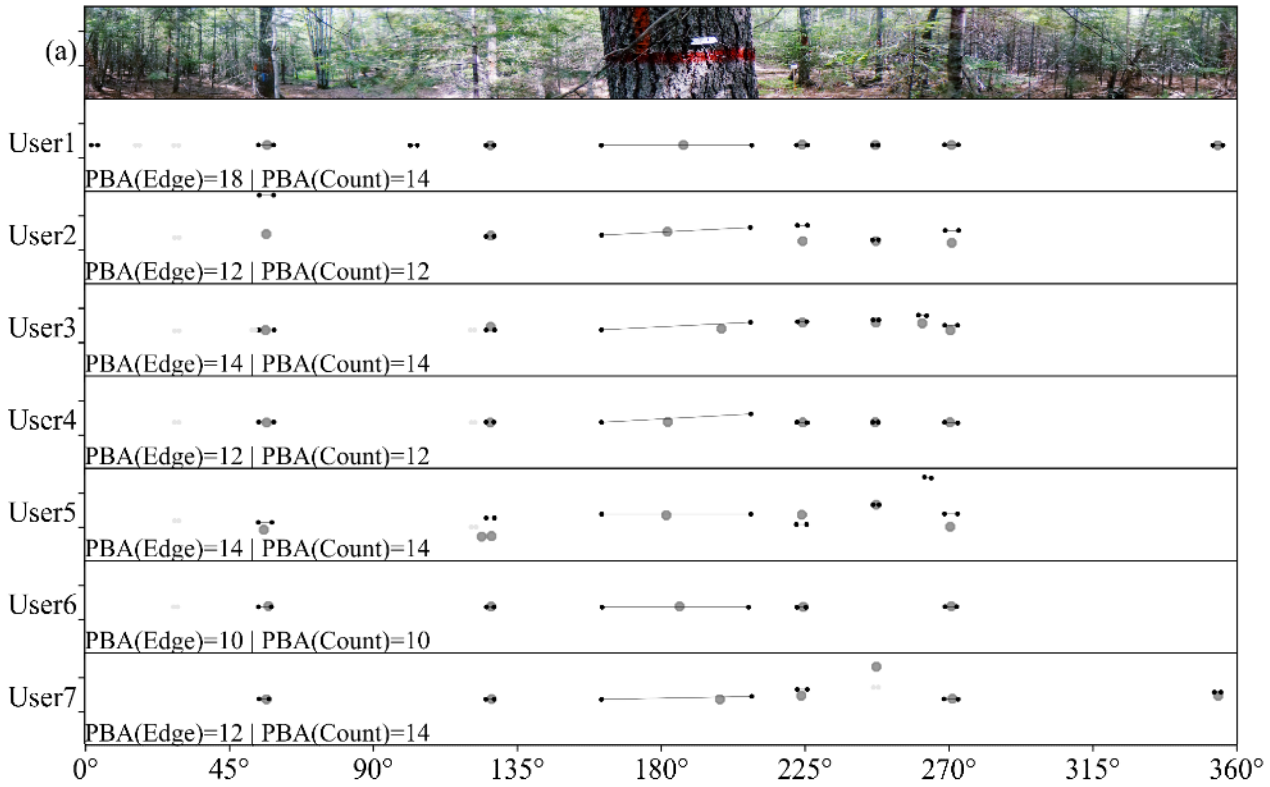
Fit previous results, caused by occluded hidden trees

Compared among modes

Both modes have high consistently with field measure

Target counting is more consistent (closer to standard broken lines) than edge marking

3.4 Inter-observer error and stability



Least Deviations

BAF = 2
FBA = 30 $m^2 \cdot ha^{-1}$

Edge marking: out tree

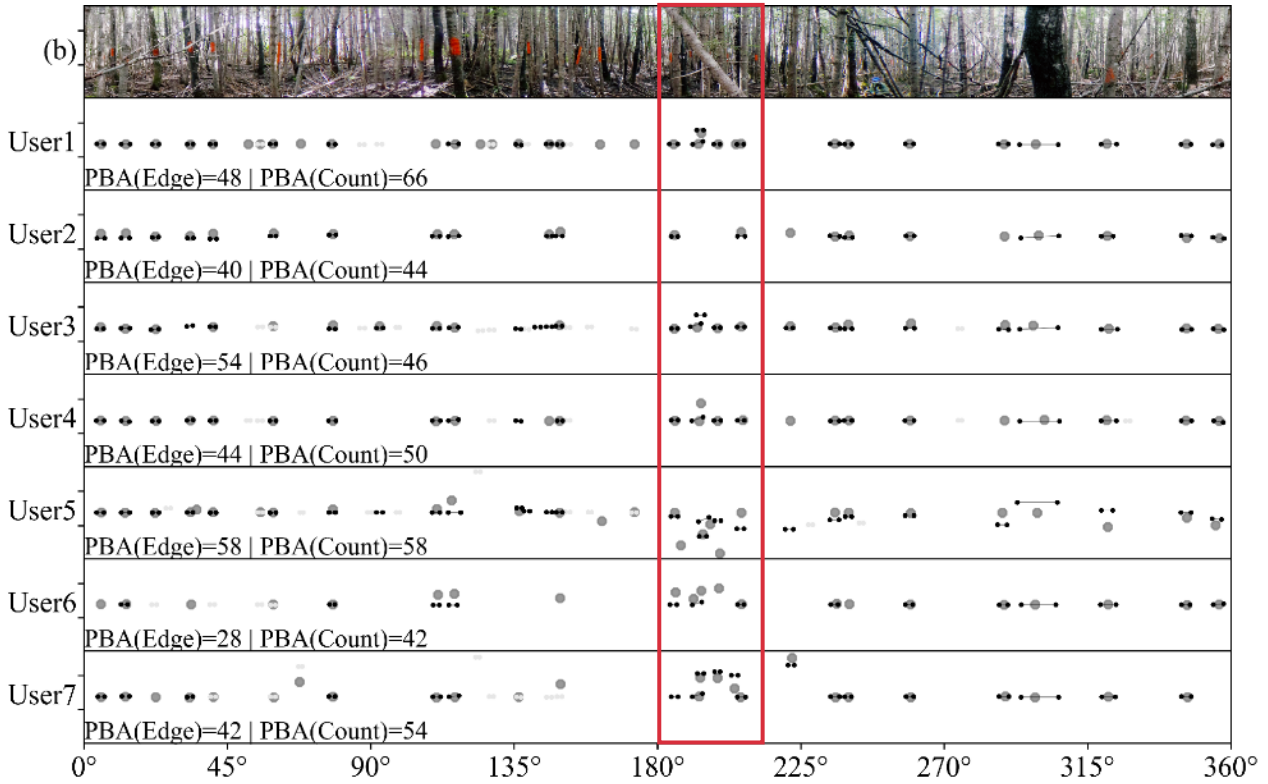
Edge marking: in tree

Target counting

Almost give the same estimates among users
and between two modes.

The PBA (~12) is smaller than FBA (30), due to a big tree in the front.

3.4 Inter-observer error and stability



Greatest Deviations

BAF = 2
FBA = 55.2 $m^2 \cdot ha^{-1}$

Edge marking: out tree

Edge marking: in tree

Target counting

Neither “in” and “out” tree the same among users,
nor two modes the same of each users in complex forest structures

3.5 Discussion

Pros.

Cost-effective
(CAD$ 400)

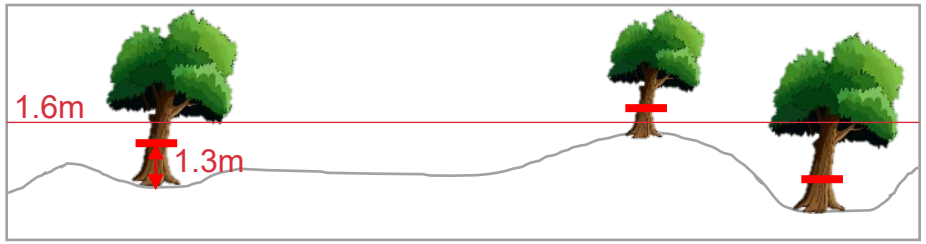
Time-effective
(<1 min taking photo)
(<3 min marking photo)

Keep permanent digital records of plot
(benefits for future checking and new attributes calculating)

Easier to trace errors among users
(compare with field measure)

Cons.

Camera height is 1.6m, rather than 1.3m (breast height) of each tree



Dark light condition unable to identify tree trunks

Need manually marking, change labor from field to lab

4

DBH & HT

4.1 Image processing workflow

1. Cylindrical coordinate to spherical latitude and longitude angle

2. Mark tree bases in image pairs

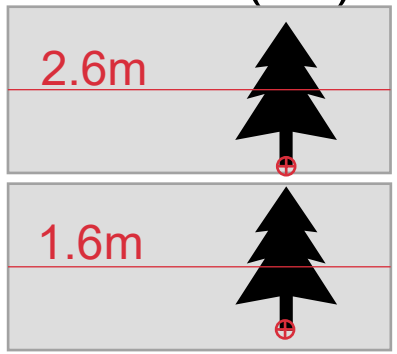
3. Mark tree trunk left & right edges

4. Mark tree tops

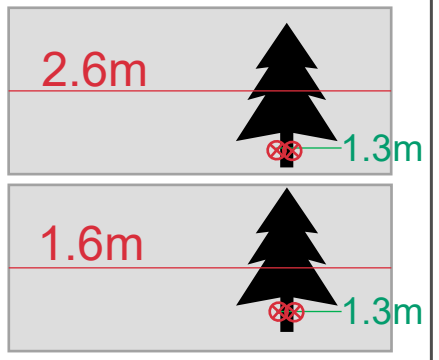
The base

Distance (R)

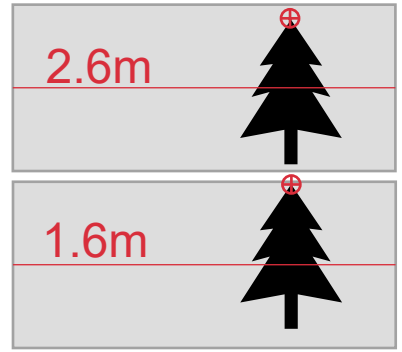
Elevation (Δh)

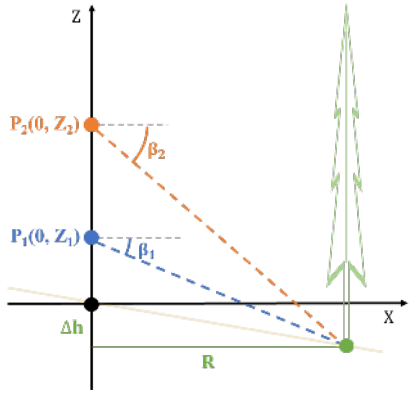


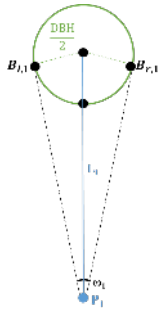
1.3m DBH

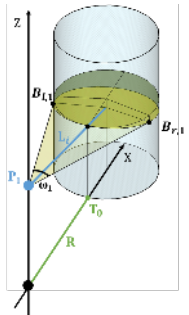


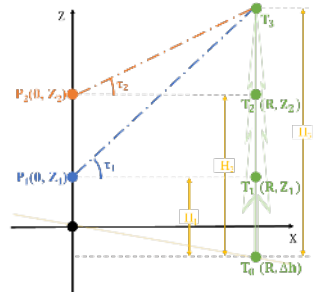
Height





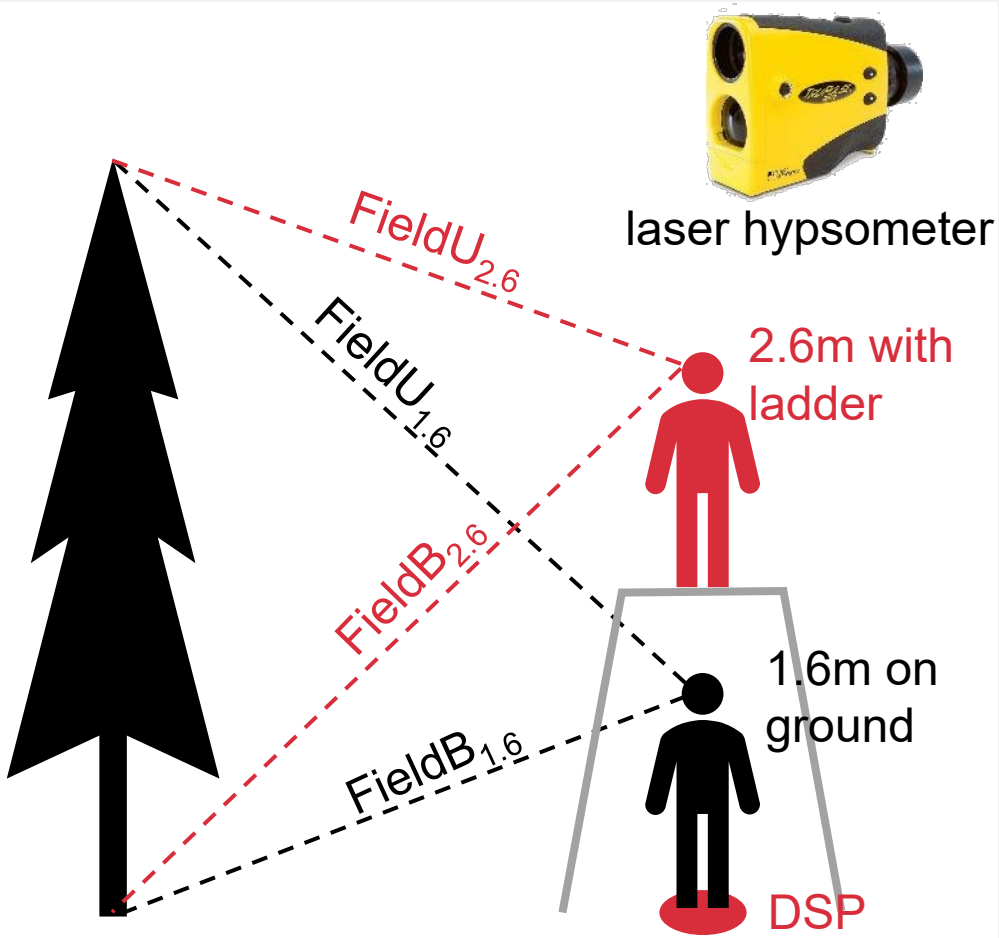






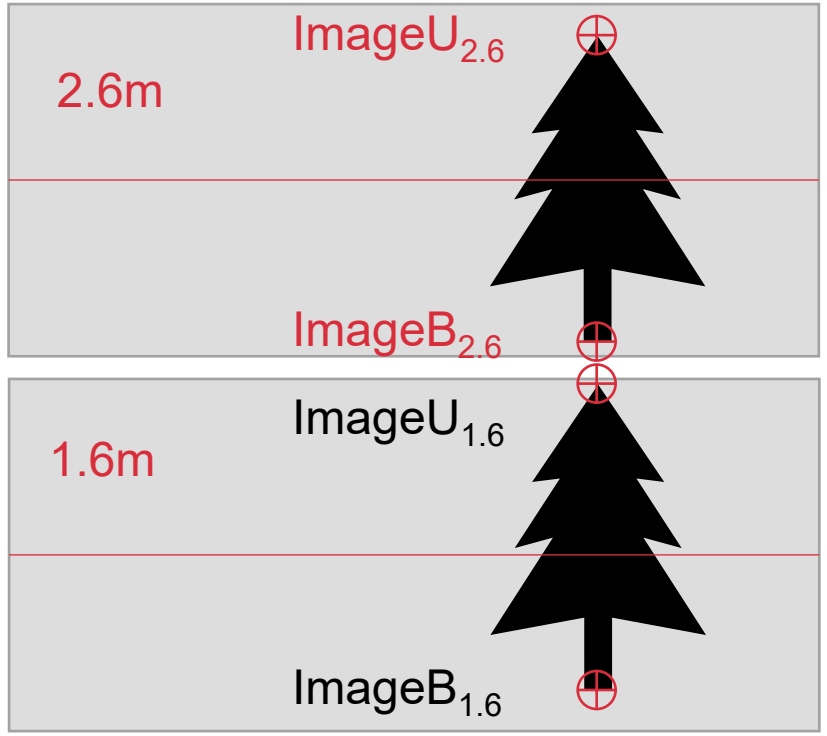
4.2.1 Angle validation

Field Angle



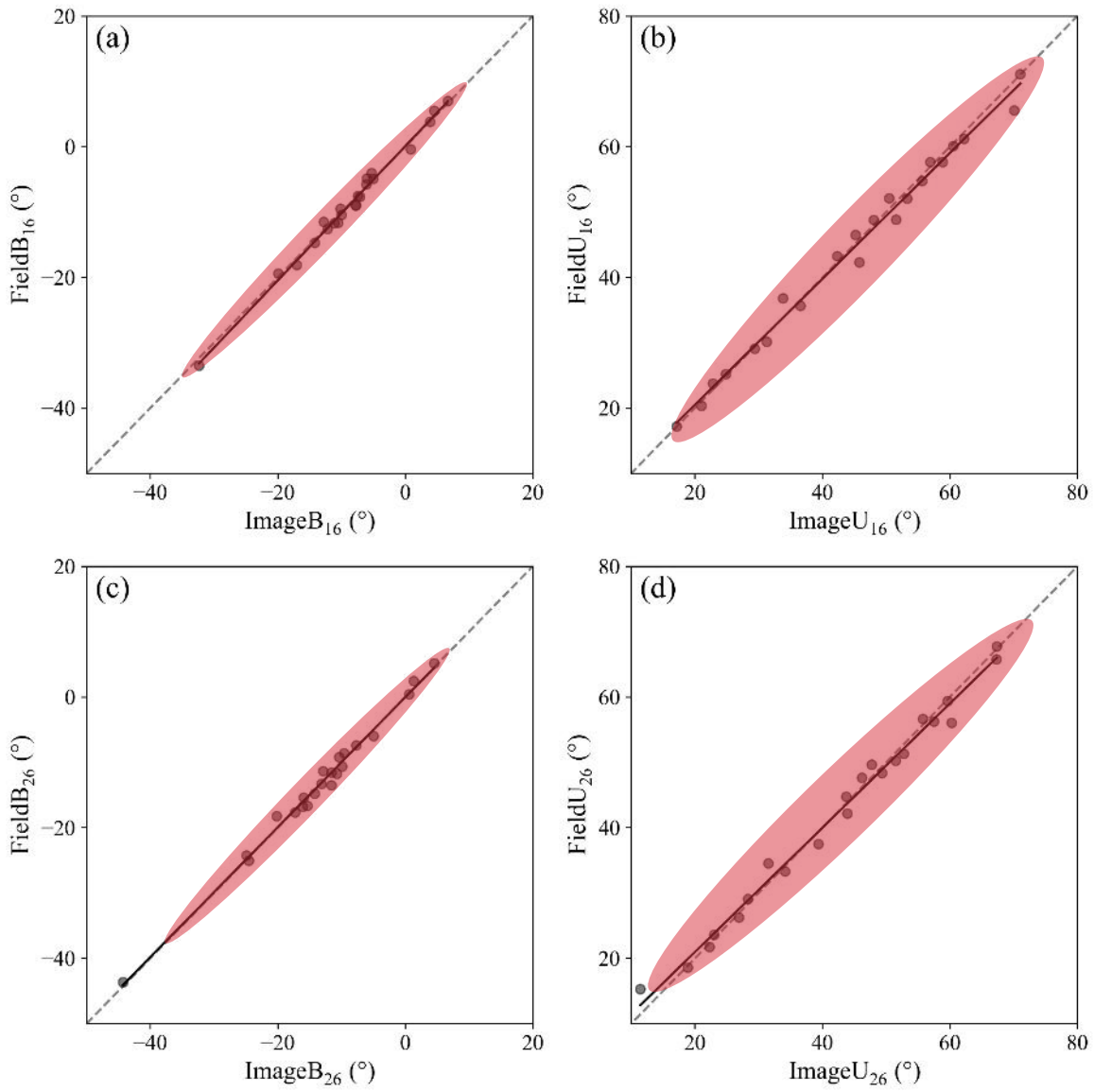
The same position of spherical camera

Photo angle



Mark the same key points

4.2.1 Angle validation



$$Field_{angle} = b_0 + b_1 \cdot Photo_{angle}$$

	Param.	Esti.	Std. Err.	p-value	r^2	rMSE
(a)	b_0	0.093	0.258	0.722	0.991	0.809
	b_1	1.028	0.022	0.209		
(b)	b_0	1.247	1.064	0.255	0.989	1.557
	b_1	0.963	0.224	0.116		
(c)	b_0	-0.039	0.357	0.914	0.991	0.964
	b_1	0.994	0.022	0.800		
(d)	b_0	1.941	1.008	0.069	0.989	1.563
	b_1	0.951	0.022	0.040		

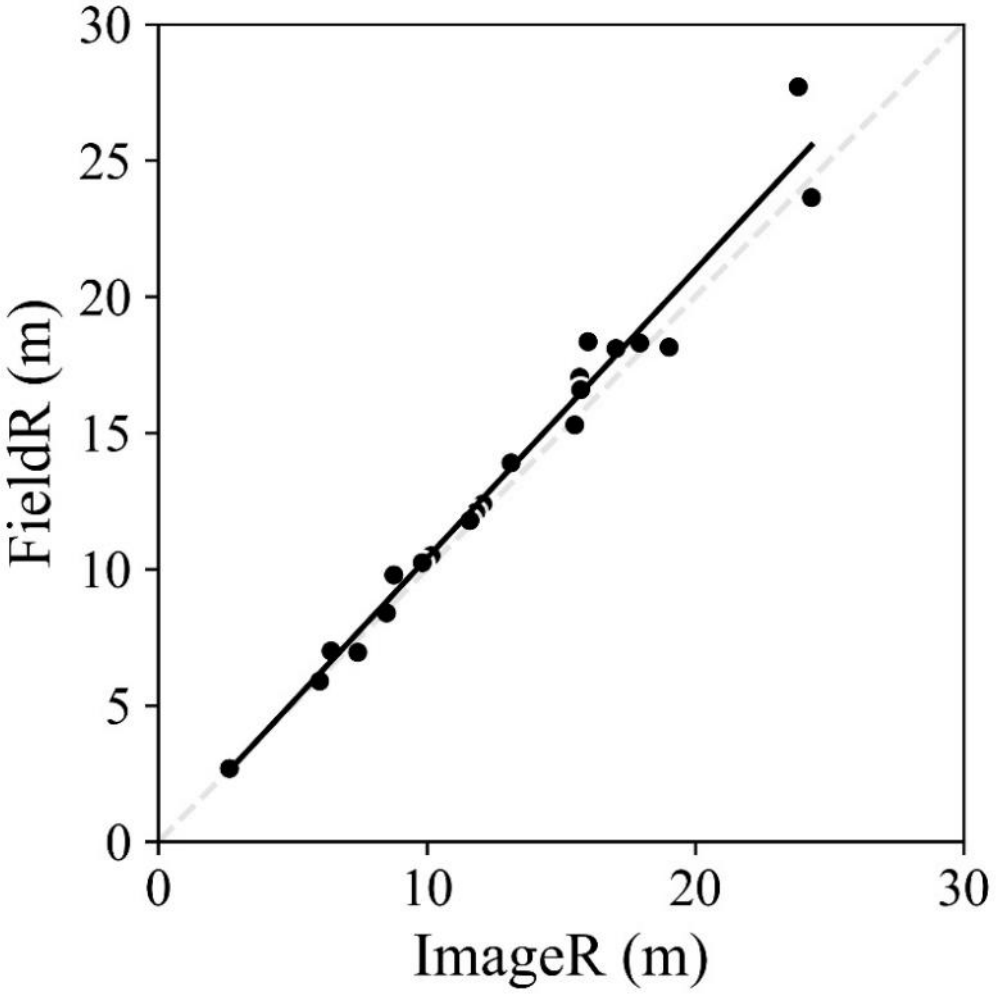
High correspondence between field angle with photo angle

$p > 0.05$ | high r^2 | low rMSE

More deviations in tree tops than tree base

Key points marked correctly
No logic error in angle calculation

4.2.2 Distance validation



Param.	Est.	Std. Err.	p-value	r^2	rMSE
b_0	-0.180	0.542	0.743	0.974	0.153
b_1	1.058	0.039	0.153		

$$FieldR = b_0 + b_1 \cdot ImageR$$

While the ImageR was slightly overestimated compared with FieldR,

The linear regression showed no significant differences ($p>0.05$) with a high r^2 and low rMSE.

4.2.3 Height validation

Field HT

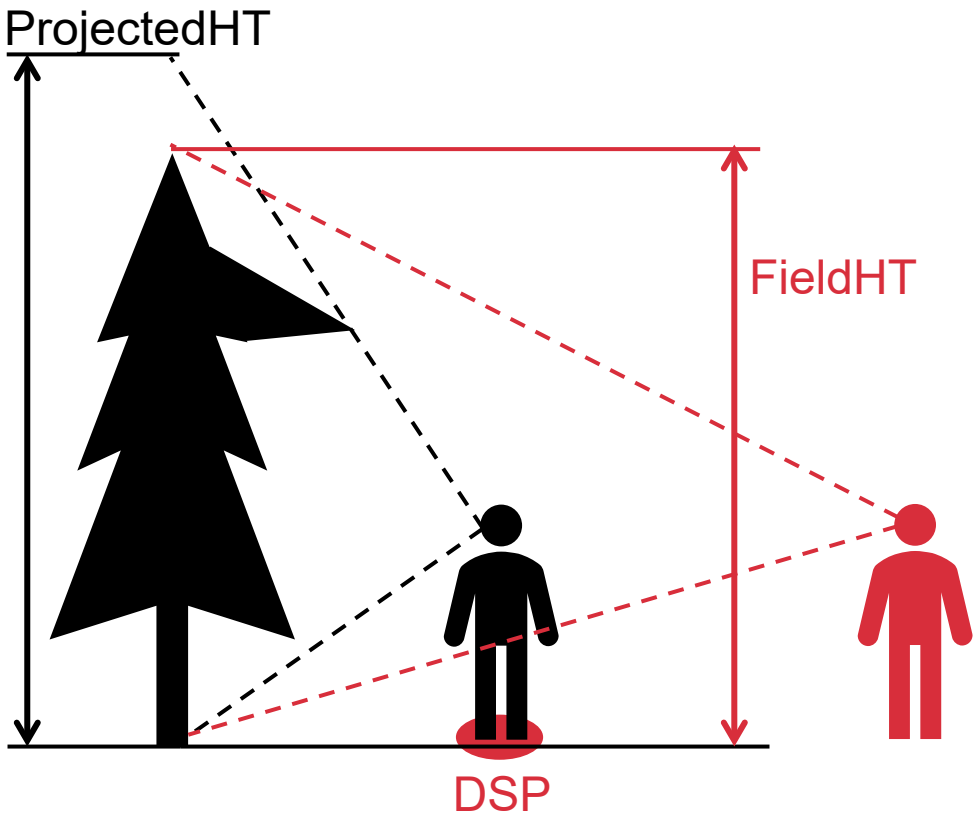
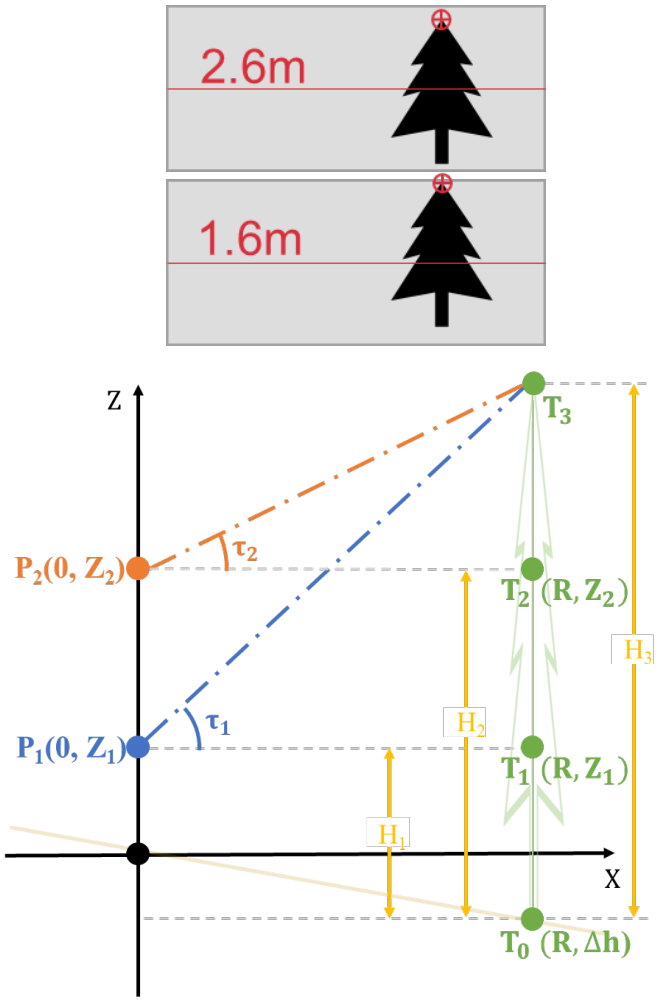
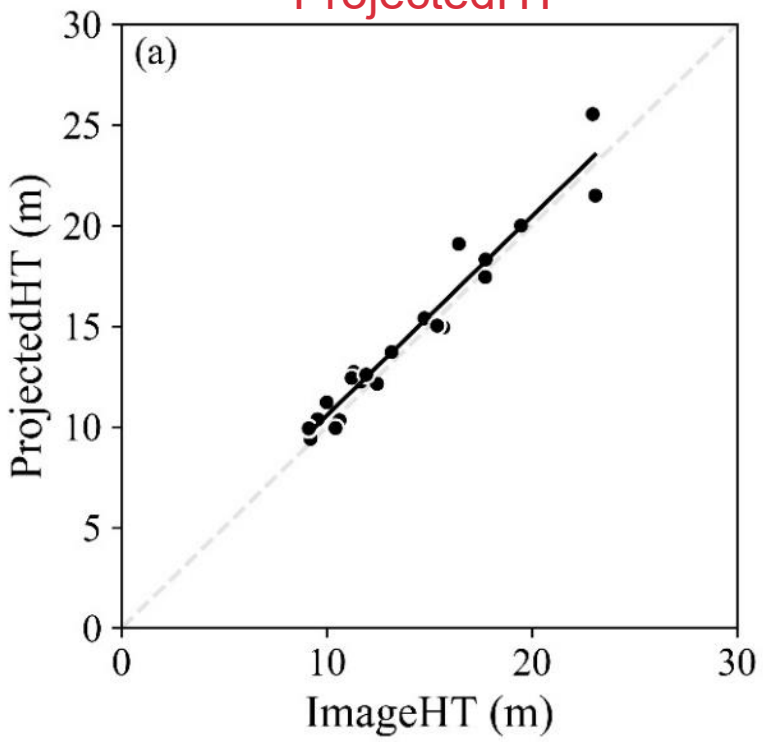


Image HT

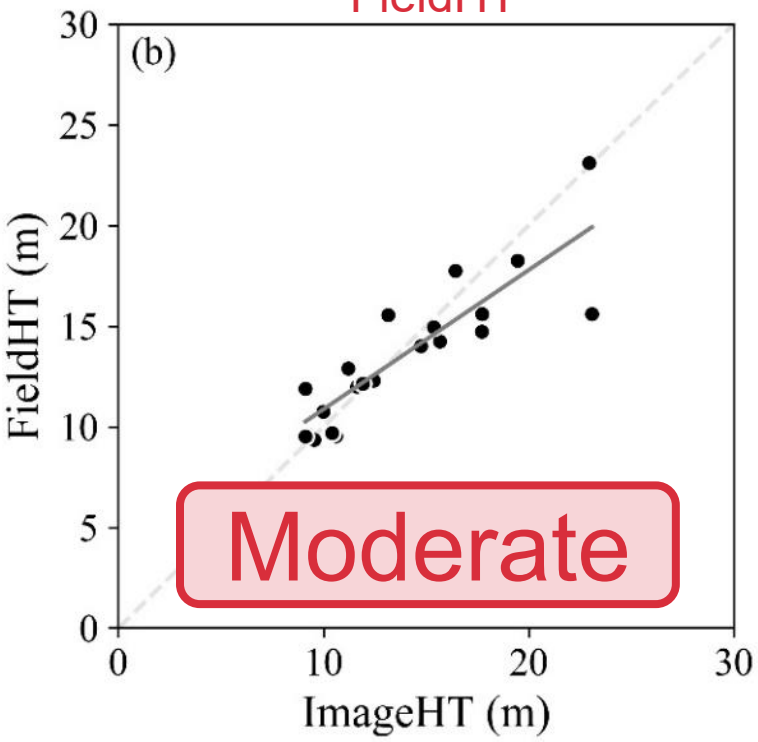


4.2.3 Height validation

ProjectedHT



FieldHT



$$Y = b_0 + b_1 \cdot X$$

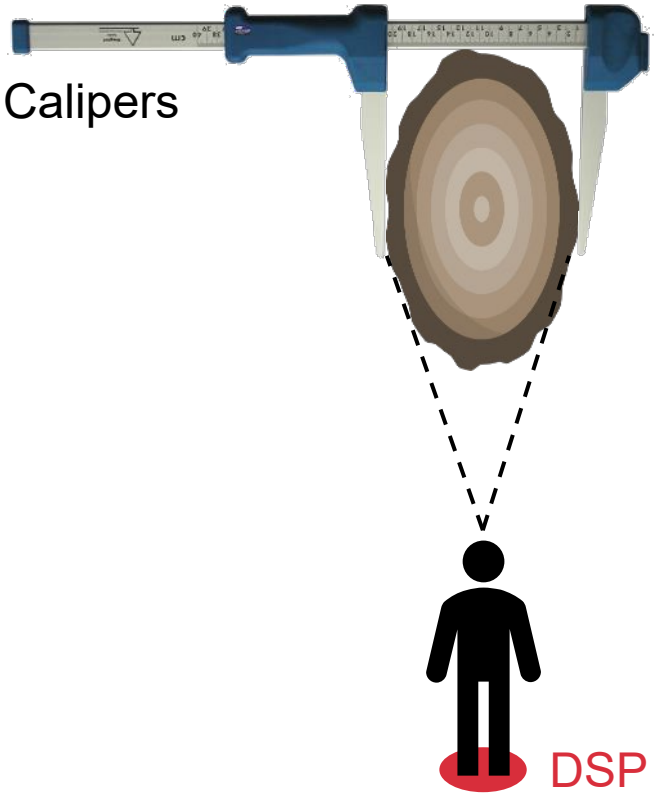
	Param.	Est.	Std. Err.	p-value	r^2	rMSE
(a)	b_0	0.653	0.743	0.390	0.949	0.971
	b_1	0.990	0.052	0.851		
(b)	b_0	3.954	1.245	0.005	0.762	1.627
	b_1	0.692	0.087	0.002		

No significant difference between ImageHT & ProjectedHT both from DSP

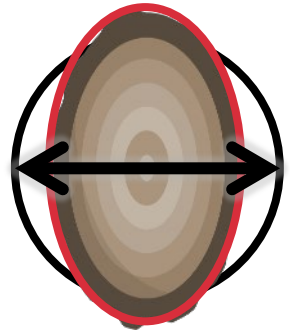
ImageHT does different from FieldHT, and trend to increasing overestimation

4.2.4 DBH validation

ProjectedDBH



FieldDBH

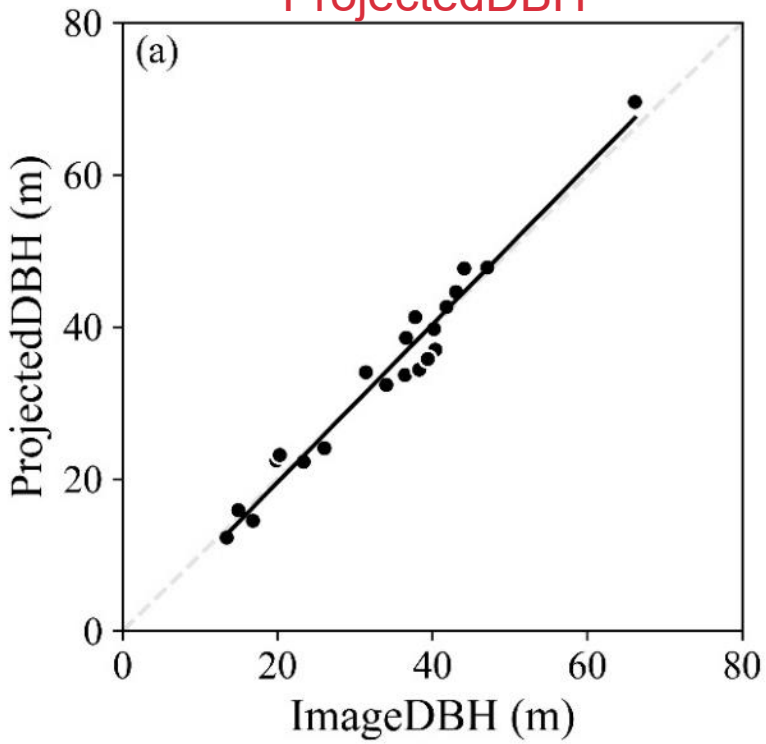


$$diameter = \frac{perimeter}{\pi}$$

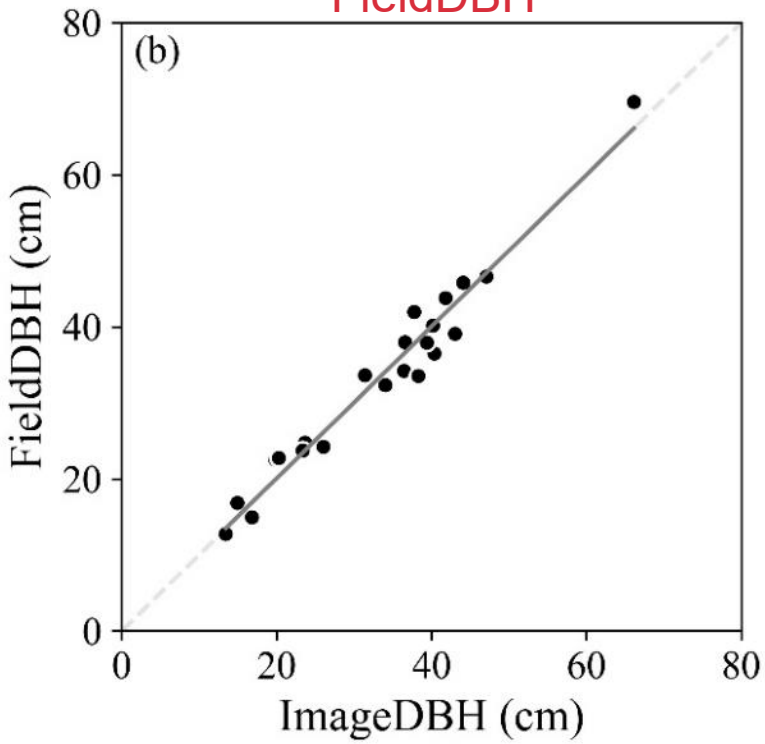
The ProjectedDBH is the same view as the trunk in the images (ImageHT).

4.2.4 DBH validation

ProjectedDBH



FieldDBH

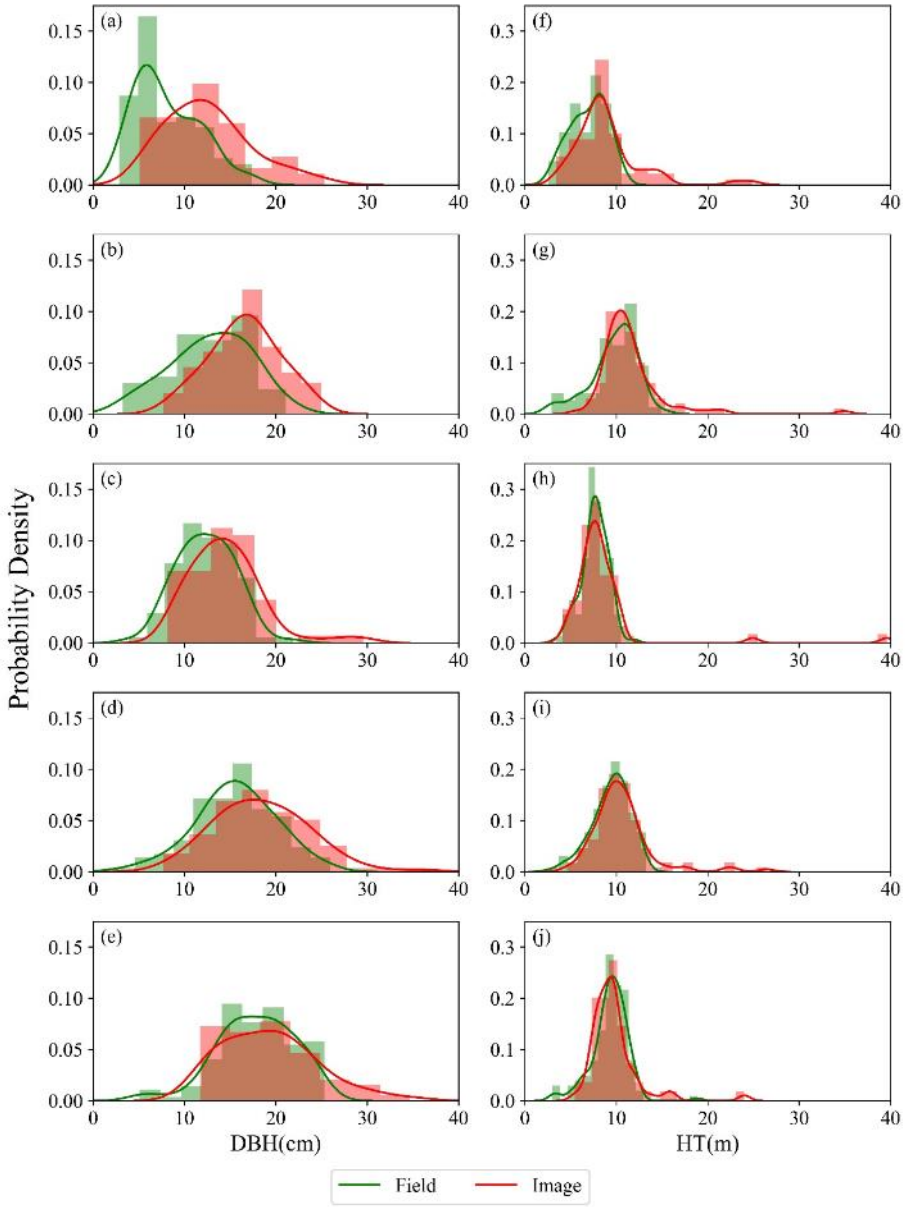


$$Y = b_0 + b_1 \cdot X$$

	Param.	Est.	Std. Err.	p-value	r^2	rMSE
(a)	b_0	-1.246	1.546	0.430	0.966	2.398
	b_1	1.039	0.044	0.378		
(b)	b_0	0.116	1.578	0.942	0.962	2.448
	b_1	0.999	0.044	0.963		

The ImageDBH has high correspondence with both ProjectedDBH and FieldDBH (high r2 and low rMSE).

4.3 Forest validation



Plot	Field Tree #	Image Tree #	Factor	KS Value	p-value
S00	94	63	DBH	0.4262	<0.001
			HT	0.2518	0.0134
S12	56	92	DBH	0.3602	<0.001
			HT	0.2096	0.079
S18	103	60	DBH	0.2589	0.0097
			HT	0.1126	0.6697
S24	137	96	DBH	0.2600	<0.001
			HT	0.1393	0.1982
S30	122	59	DBH	0.1555	0.2573
			HT	0.1188	0.5774

DBH looks fine but statically performs bad (Only S30 fail to reject null hypothesis),

while HT performs good (most reject null hypothesis),

this is reversed with urban validation.

4.4.1 Discussion: reverse result

Why real forest validation get reversed results with urban validation?

(DBH bad, HT good) (DBH good, HT fair)

1	The urban trees are larger and more variate than forest trees. (ranges; NL HT stable 10m; small DBH more pixel error; small HT less pixel error)
2	 Different tree (forest) density (NL hard to identify edges, occluded hidden tree) 
3	 Tree crown type is different (esay to see top for conifer, hard for broadleaf) 
4	Duplicate counting from different digital sampling points (NL HT same, duplicate no effects; Larger DBH easier be duplicate counted)

4.4.2 Future work

1	**Integrate with Big BAF sampling** (Yingbing's work) Small BAF to measure basal area, Big BAF to select trees to measure (mark key points)
2	**Pairing forest measurements …** Use pairwise comparison rather than distributional comparison to judge how it works in real forest
3	**Automatic key points detection** Apply image processing or deep learning to mark individual key points automatically.

Thanks for listening!
Questions?