



Stand Structure

Classification

& Indexing of Diameter and Height Distributions

Prelude



- The reasonable man adapts himself to the world.
- The unreasonable one persists in trying to adapt the world to himself.
- Therefore, all progress depends on the unreasonable man.

George Bernard Shaw

Quoted in: *Symmetry*
... by Mario Livio

Outline

- What is stand structure
- Why is the topic important?
- How best to describe it?
- Indices: easy to calculate
- The data
- The results: classifications
- Conclusions

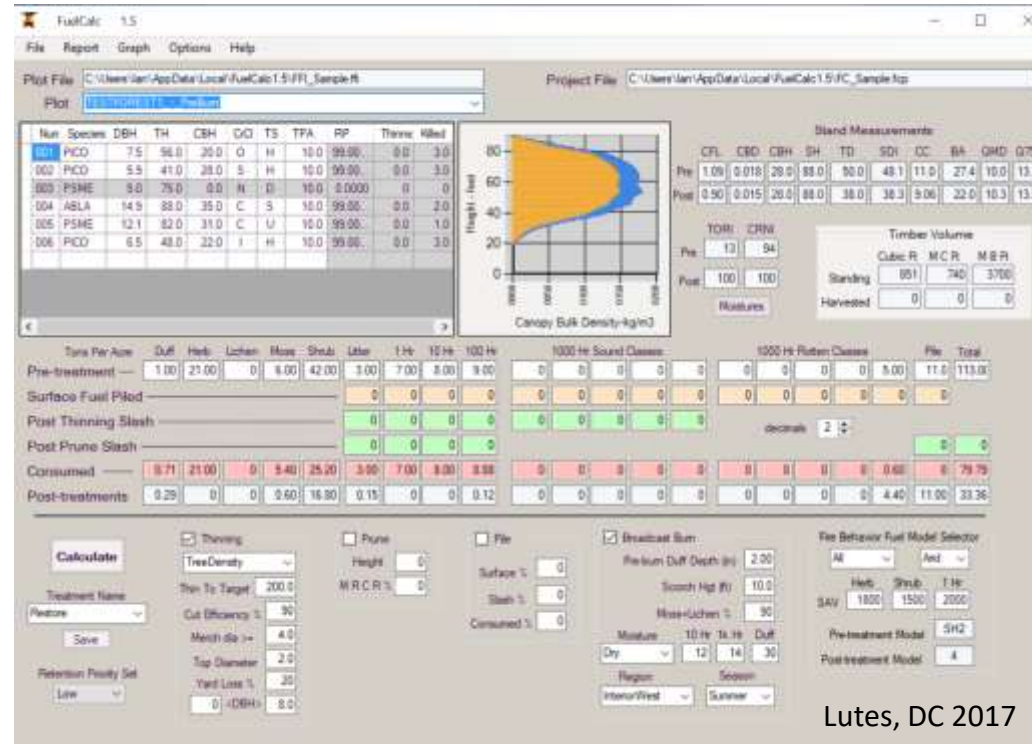


What is Stand Structure?

Stand structures are identified in relation to their joint diameter & height distributions, by species.



Why is Stand Structure Important?



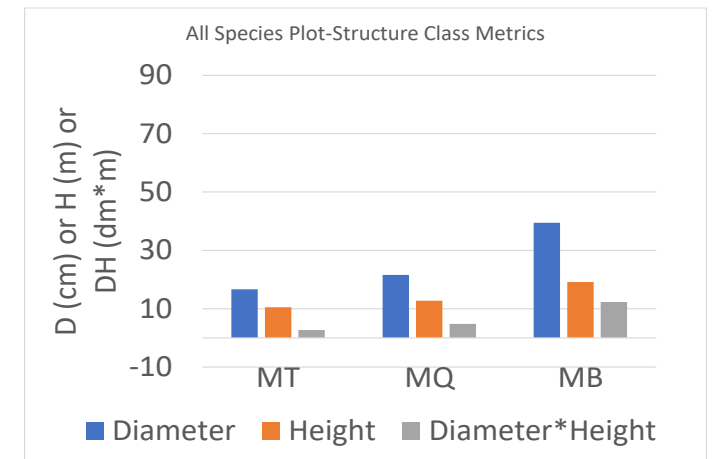
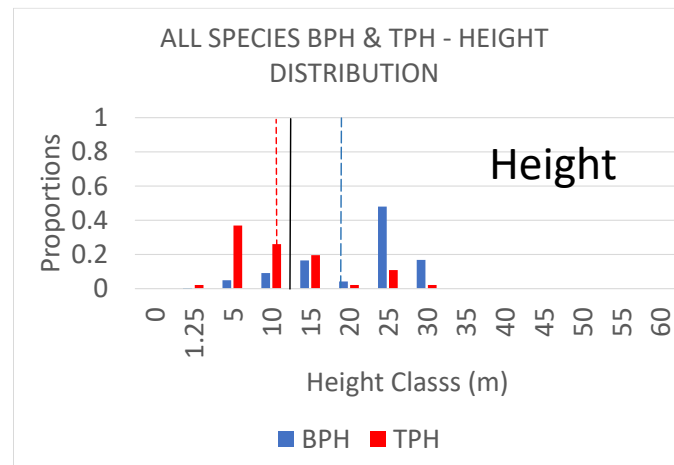
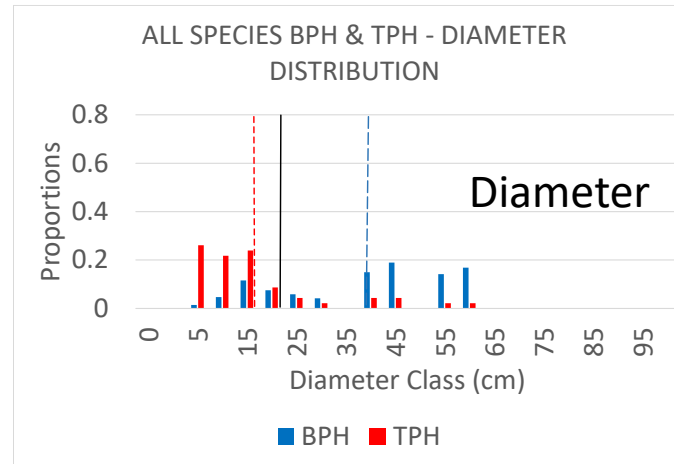
Lutes, DC 2017



Oyamel Fir
Abies religiosa

How Best to Describe It?

- MTD: Mean Tree Diameter
- MQD: Mean Quadratic Diameter
- MBD: Mean Basal Area Diameter
- Height Analogues: (MTH, MQH, and MBH)
- Diameter * Height Analogues: (MTDH, MQDH, MBDH)



Easy to Calculate

- Builds on *allometric relations*.
- Follows from *method of moments*.
- *Proportions (p)* can be used directly *instead of tph*.
- Applies to *parametric and non-parametric distributions* (hence: "Indices").
- *Power inequality*:
 - $HM \leq GM \leq AM \leq QM \dots$
 - $MTD \leq MQD \leq M3D \leq MBD \dots$

Parameter	Function	Raw Moment Proportional to:	Dimensional Scaling
MTD	$= \frac{\sum_{i=1}^n (dbh_i * tph_i)}{\sum_{i=1}^n tph_i}$	First Mean	$L^1 N^{-1}$ Length / Individual
MQD	$= \sqrt{\frac{\sum_{i=1}^n (dbh_i^2 * tph_i)}{\sum_{i=1}^n tph_i}}$	Second Standard Deviation	$L^2 N^{-1}$ Area / Individual Adjusted to L^1
M3D	$= \left(\frac{\sum_{i=1}^n (dbh_i^3 * tph_i)}{\sum_{i=1}^n tph_i} \right)^{\frac{1}{3}}$	Skew	$L^3 N^{-1}$ Volume / Individual
MBD	$= \frac{\sum_{i=1}^n (dbh_i^3 * tph_i)}{\sum_{i=1}^n (dbh_i^2 * tph_i)}$	Third/Second Skew/Variance (Gini & Lehmer Mean)	$L^1 = L^3/L^2$ Volume / Area

Inventory Attribution

SYSTEM of EQUATIONS

$$\text{TPH} * 0.00007854 * \text{MQD} - \text{BPH} = 0 \quad 1$$

$$\text{MTD}^2 + \text{S}^2 - \text{MQD}^2 = 0 \quad 2$$

$$\text{M3D}^3 * \text{MQD}^{-2} - \text{MBD} = 0 \quad 3$$

These equations and attributes can be used to:

- Produce consistency among attributes using imputation.
- Impute or recover non-parametric height and diameter distributions.

The Data: By Stand Structure Class

BCDH25NEW	MTD	MQD	MBD	MTH	MQH	MBH	MTDH	MQDH	MBDH	CDI_D	CDI_H	CDI_DH	Z1	Z2	Z3	TPH	BPH	MVPH	GVPH	N
1	4.7	5.4	7.9	4.3	4.6	5.7	0.3	0.4	1.0	0.035	0.053	0.008	4.60	4.01	3.15	5427	10	6	28	122
2	8.2	9.2	12.8	7.1	7.6	9.4	0.7	0.9	2.0	0.051	0.086	0.015	7.56	6.18	4.63	3587	20	35	78	188
3	6.6	9.4	21.6	5.8	7.2	12.7	0.7	1.5	5.7	0.166	0.258	0.058	9.59	4.82	6.85	5045	24	109	136	102
4	5.6	9.7	39.9	5.1	6.8	15.3	0.7	2.2	15.7	0.381	0.380	0.172	13.86	2.53	10.80	8909	34	213	238	42
5	10.8	11.9	15.6	9.6	10.2	12.0	1.2	1.5	2.6	0.053	0.087	0.016	9.57	7.67	5.25	2504	26	78	130	177
6	10.9	12.9	19.7	8.9	10.0	13.2	1.3	1.9	4.1	0.097	0.159	0.032	10.63	7.13	5.98	2156	27	110	140	90
7	9.2	13.7	35.5	7.2	9.3	17.4	1.3	2.9	11.9	0.293	0.380	0.122	14.27	4.67	9.32	2734	36	224	246	55
8	11.6	14.7	25.5	9.4	11.1	16.2	1.6	2.7	6.8	0.155	0.254	0.059	12.67	6.93	7.04	2298	37	204	234	85
9	13.8	15.1	19.1	11.8	12.5	14.2	1.9	2.3	3.6	0.058	0.090	0.020	11.70	8.71	5.64	1635	29	128	165	135
10	15.1	16.4	20.4	13.9	14.7	16.7	2.4	2.9	4.3	0.058	0.102	0.022	12.97	9.53	5.80	1713	35	205	246	138
11	14.3	17.9	30.2	11.1	13.0	18.2	2.3	3.6	8.5	0.177	0.265	0.072	14.86	7.33	7.28	1526	39	245	271	58
12	11.4	18.3	53.3	8.0	10.6	20.6	2.0	4.7	19.2	0.466	0.465	0.197	19.26	3.11	11.60	2358	42	305	320	37
13	17.6	19.3	24.4	13.3	14.1	16.2	2.7	3.3	5.1	0.076	0.107	0.028	14.26	9.10	5.88	1033	31	173	191	87
14	15.4	20.5	40.3	10.9	13.2	20.2	2.7	4.8	13.4	0.277	0.343	0.122	17.60	6.05	8.46	1351	42	309	328	38
15	19.6	21.3	26.0	16.8	17.8	20.0	3.7	4.4	6.4	0.071	0.118	0.031	16.10	9.99	5.71	1259	43	320	348	106
16	19.5	22.7	32.6	15.5	17.2	21.5	3.8	5.2	9.5	0.145	0.221	0.065	17.58	8.64	6.38	1255	49	363	387	44
17	23.0	25.0	31.0	15.4	16.4	18.7	4.0	4.8	7.2	0.089	0.121	0.036	17.59	9.30	5.68	548	28	184	193	68
18	23.6	26.1	33.1	19.1	20.5	23.5	5.2	6.4	9.7	0.105	0.164	0.051	19.35	9.45	5.32	974	49	424	445	63
19	23.1	28.9	47.7	15.6	18.3	25.7	5.2	8.1	17.8	0.273	0.377	0.145	22.27	6.02	6.67	790	50	438	452	39
20	27.4	29.9	37.3	21.0	22.4	25.6	6.6	7.9	11.7	0.110	0.172	0.059	21.64	8.96	4.52	555	38	352	362	52
21	24.5	32.6	61.9	15.0	18.2	27.5	6.0	10.2	25.7	0.415	0.462	0.227	25.81	3.26	7.48	909	74	583	598	17
22	30.2	33.3	42.3	23.8	25.4	29.5	8.4	10.2	15.5	0.135	0.212	0.082	24.16	7.73	3.32	665	59	649	664	34
23	32.1	42.7	78.7	19.4	23.3	34.5	9.9	16.3	37.1	0.518	0.562	0.313	32.35	-1.29	4.03	725	95	932	951	14
24	41.4	44.1	51.8	23.6	24.7	27.4	10.7	12.3	16.5	0.116	0.143	0.066	28.34	5.87	1.25	228	37	394	399	19
25	52.7	60.7	83.6	30.5	33.4	40.0	20.1	25.7	41.6	0.343	0.351	0.248	39.34	-8.48	-8.46	350	106	1127	1136	8
ALL	14.4	16.7	25.2	11.5	12.6	16.0	2.5	3.4	6.9	0.120	0.169	0.050	13.36	7.12	5.81	2412	33	201	230	1818

REGION	REGION NAME	PLOTS
8	Rocky Mountain Subalpine Reg	15
9	Rocky Mountain Montain Regic	193
10	Upper Foothills	38
11	Lower Foothills	4
101	Cariboo and Central Interior	793
102	Prince George TSA CMI Plots	202
201	Saskatchewan Fort al a Corne	96
400	Coastal BC	457
500	Little Harbour and Deep Harbo	20
TOTAL		1818

Cumulative Distribution Indices

- $CDI_D = (MBD-MTD)/90$
- $CDI_H = (MBH-MTH)/27$
- $CDI_DH = (MBDH-MTDH)/87$
- *Discriminant Z-Scores are used to better display the classes in 2-Dimensions.*

Given a Marginal \uparrow MBD:
M3D \uparrow , MTD \downarrow and S \uparrow for Given MQD

By Way of Substitution:
(MTD²+S²) for MQD² in Eq. 3.

$$MTD = \left(\frac{M3D^3}{MBD} - S^2 \right)^{\frac{1}{2}}$$

$$\frac{d(MTD)}{d(MBD)} = - \frac{M3D^3}{(2 * (M3D^3 - S^2 * MBD))^{\frac{1}{2}} MBD^{\frac{3}{2}}}$$

SS 14	INITIAL	UPDATE
MTD	15.40	15.35
S	13.53	13.59
MQD	20.50	20.50
M3D	22.19	22.22
MBD	26.00	26.10
DeltaMBD	0.1	-0.1
DeltaMTD	-0.525	-0.525

How Can This Be?



Proportions of Trees $<$ MTD \uparrow
Proportions of Trees $>$ M3D \uparrow
MQD remains the same.

This implies that TPH and BPH also \uparrow while MQD remains the same.



Proportions of Trees $>$ MTD \downarrow
Proportions of Trees $<$ M3D \downarrow
MQD remains the same.

This implies TPH and BPH \downarrow , i.e., cut out the middle, while MQD remains the same.

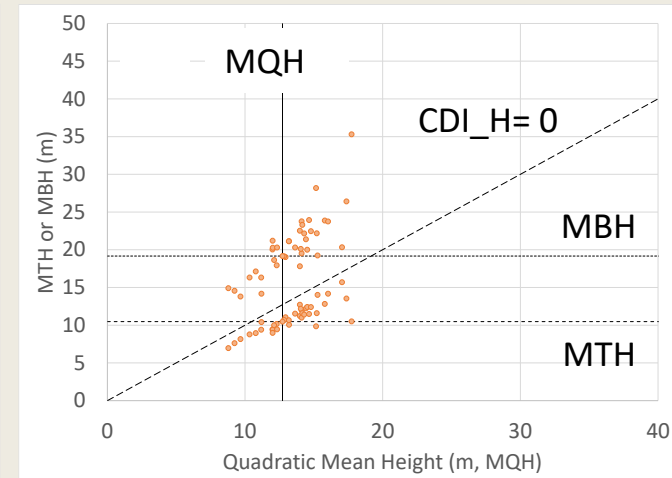
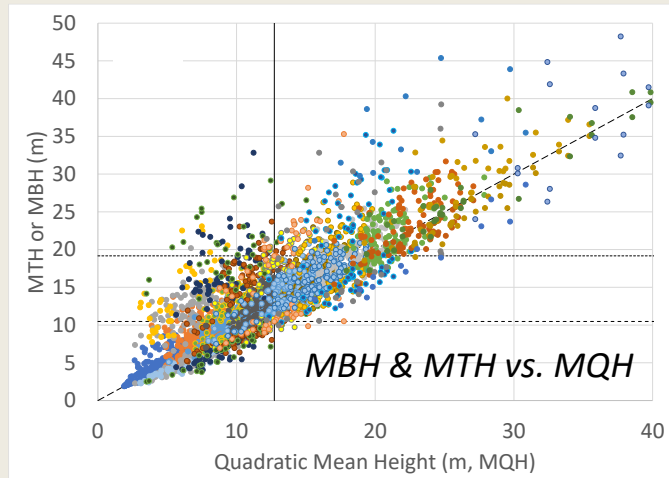
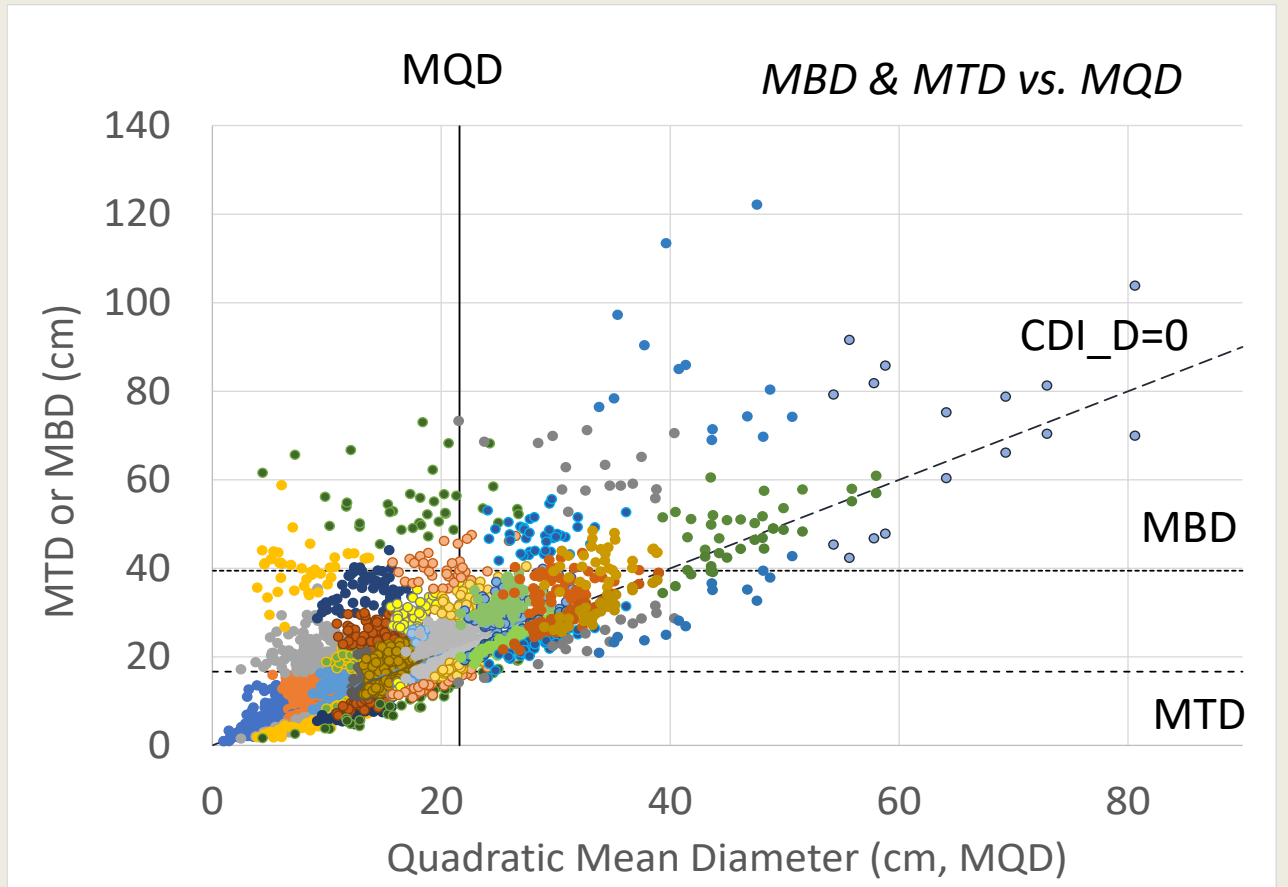
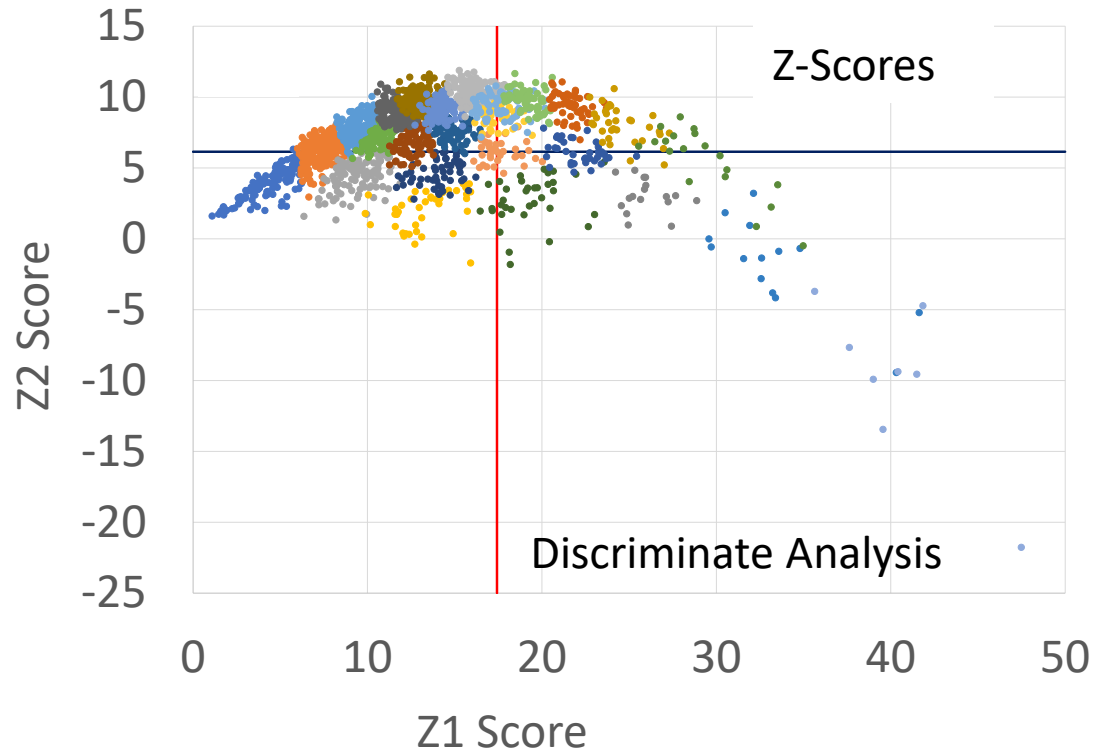


Some combination of the above.
These are dual outcomes.



This indicates a potential to use these indices in modeling stand dynamics with more explicit accounting of underlying diameter and height distributions.

The Results: SS 14



- 1 • 2 • 3 • 4 • 5 • 6 • 7 • 8 • 9
- 10 • 11 • 12 • 13 • 14 • 15 • 16 • 17 • 18
- 19 • 20 • 21 • 22 • 23 • 24 • 25 -Z1 -Z2

The Results: Classification Scenarios

PRODUCER CLASS USING ONLY MTD, MQD, & MBD																										N	USER		PRODUCER			
USER CLASS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25		TOTAL	P	TOTAL	P		
1	114	8																								114	122	0.934	131	0.870		
2	17	147	1		23																					147	188	0.782	187	0.786		
3		3	93	1	1	2		2																		93	102	0.912	105	0.886		
4			2	39								1														39	42	0.929	50	0.780		
5		29			126	4			18																	126	177	0.712	182	0.692		
6			3		3	65		2	12	5																65	90	0.722	90	0.722		
7			1	8			39	2			5															39	55	0.709	43	0.907		
8			5			6	1	63				9		1												63	85	0.741	82	0.768		
9					25	9				56	41										4					56	135	0.415	123	0.455		
10				4	4			3	37	83											7					83	138	0.601	136	0.610		
11								8			41		2	1		6											41	58	0.707	63	0.651	
12			2									31									3		1				31	37	0.838	33	0.939	
13								2		1			56		25	2	1										56	87	0.644	100	0.560	
14						3							31		2					2							31	38	0.816	33	0.939	
15										6	2		30		63		5										63	106	0.594	95	0.663	
16										6					2	30	1	4			1						30	44	0.682	49	0.612	
17															4	4	35	12			12			1			35	68	0.515	67	0.522	
18															1	5	24	28			5						28	63	0.444	54	0.519	
19											1		1								33		1	3			33	39	0.846	41	0.805	
20																	1	10			32		9				32	52	0.615	57	0.561	
21																			1		15			1			15	17	0.882	17	0.882	
22																			2	7			25				25	34	0.735	38	0.658	
23																								14				14	14	1.000	15	0.933
24																									19			19	19	1.000	19	1.000
25																									8			8	8	1.000	8	1.000
N	114	147	93	39	126	65	39	63	56	83	41	31	56	31	63	30	35	28	33	32	15	25	14	19	8	1286						
TOTAL	131	187	105	50	182	90	43	82	123	136	63	33	100	33	95	49	67	54	41	57	17	38	15	19	8	1818		1818				
P	0.87	0.79	0.89	0.78	0.69	0.72	0.91	0.77	0.46	0.61	0.65	0.94	0.56	0.94	0.66	0.61	0.52	0.52	0.80	0.56	0.88	0.66	0.93	1.00	1.00		0.707		0.707			

ID	CLASSIFICATION SCENARIO	SUCCESS (%)
1	D	71
2	H	45
3	DH	55
4	D,H	95
5	D,H,DH	100
4	FIRST 3 Z-Scores (95%)	87



Species Crown Position Class

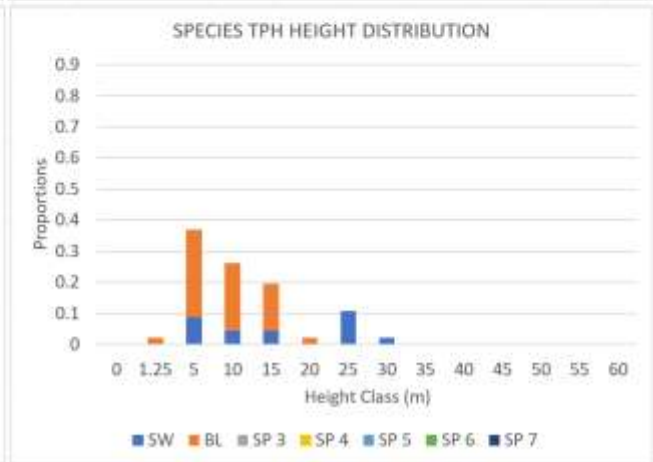
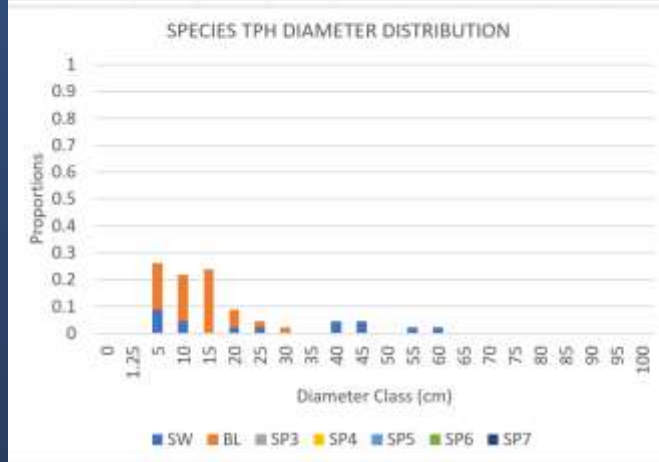
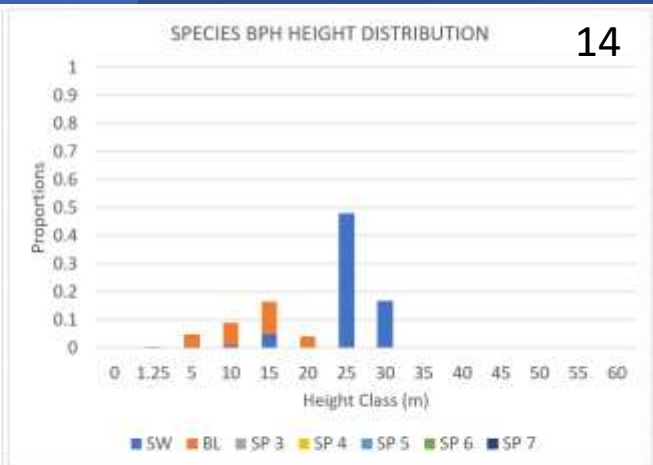
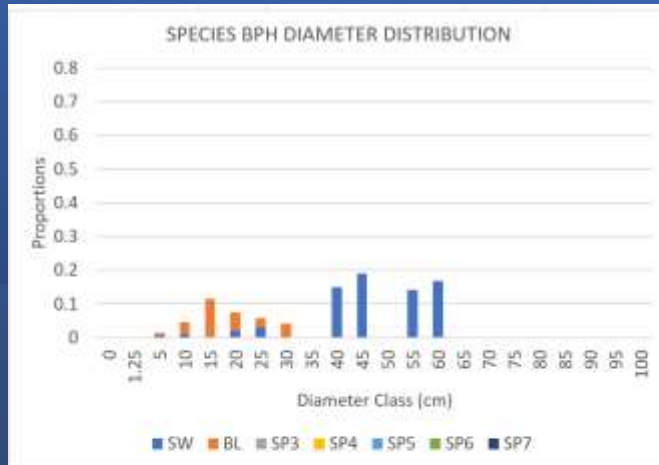
$$MXXR = \frac{MXX_{SPECIES}}{MXX_{ALL}}$$

Fuzzy C Means Memberships → Continuum

SPECIES CLASS: Each ratio is the species index divided by the whole stand value. Class (0) indicates the species distributions are equivalent to the distributions for the whole stand. Decreasing negative numbers indicate increasing understory positions. Increasing positive numbers indicate increasing overstory positions.

CLASSNO	MTDR	MQDR	M3DR	MBDR	MTHR	MQHR	M3HR	MBHR	MTDHR	MQDHR	M3DHR	MBDHR
-9	0.338	0.283	0.256	0.218	0.390	0.339	0.312	0.272	0.110	0.085	0.077	0.071
-8	0.556	0.488	0.446	0.384	0.617	0.567	0.535	0.485	0.286	0.226	0.204	0.179
-7	0.679	0.622	0.585	0.526	0.732	0.696	0.673	0.634	0.442	0.376	0.347	0.310
-6	0.775	0.708	0.661	0.587	0.878	0.838	0.811	0.765	0.607	0.510	0.463	0.398
-5	0.804	0.787	0.781	0.778	0.800	0.788	0.785	0.786	0.629	0.620	0.618	0.633
-4	0.867	0.795	0.740	0.652	0.979	0.935	0.903	0.849	0.759	0.634	0.563	0.460
-3	0.875	0.857	0.845	0.830	0.911	0.899	0.894	0.887	0.780	0.756	0.740	0.725
-2	0.939	0.910	0.888	0.853	1.018	1.000	0.987	0.967	0.924	0.871	0.834	0.778
-1	0.944	0.947	0.953	0.970	0.977	0.976	0.978	0.986	0.931	0.948	0.956	0.981
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1	1.067	1.058	1.049	1.034	1.020	1.012	1.007	0.999	1.077	1.052	1.034	1.003
2	1.294	1.138	1.031	0.859	1.206	1.104	1.037	0.921	1.286	0.974	0.823	0.606
3	1.225	1.182	1.148	1.090	1.157	1.125	1.102	1.063	1.342	1.235	1.168	1.054
4	1.442	1.332	1.255	1.123	1.341	1.261	1.208	1.113	1.702	1.432	1.288	1.056
5	1.655	1.530	1.429	1.257	1.423	1.345	1.286	1.184	2.088	1.722	1.516	1.189
6	2.007	1.576	1.333	0.974	1.893	1.586	1.403	1.109	2.559	1.586	1.242	0.788
7	2.010	1.817	1.655	1.386	1.643	1.522	1.435	1.287	2.811	2.171	1.823	1.302
8	2.910	1.999	1.552	0.962	2.695	2.064	1.702	1.177	4.237	2.047	1.449	0.757
9	2.485	2.118	1.846	1.417	1.961	1.751	1.603	1.357	3.789	2.583	2.029	1.268
10	2.987	2.468	2.094	1.526	2.345	2.037	1.828	1.494	5.162	3.238	2.393	1.326
11	3.911	2.497	1.868	1.085	3.231	2.374	1.902	1.247	6.130	2.683	1.834	0.886
12	4.330	2.988	2.287	1.379	3.241	2.538	2.085	1.436	7.797	3.608	2.458	1.162
13	4.928	3.625	2.853	1.805	3.436	2.729	2.261	1.584	10.078	4.956	3.295	1.481
14	6.792	3.747	2.533	1.189	5.282	3.518	2.554	1.378	13.497	4.249	2.492	0.903
15	7.512	4.847	3.370	1.652	4.485	3.391	2.654	1.645	17.086	6.069	3.557	1.249
16	12.486	5.854	3.495	1.247	8.155	5.129	3.393	1.485	30.838	6.627	3.542	1.014

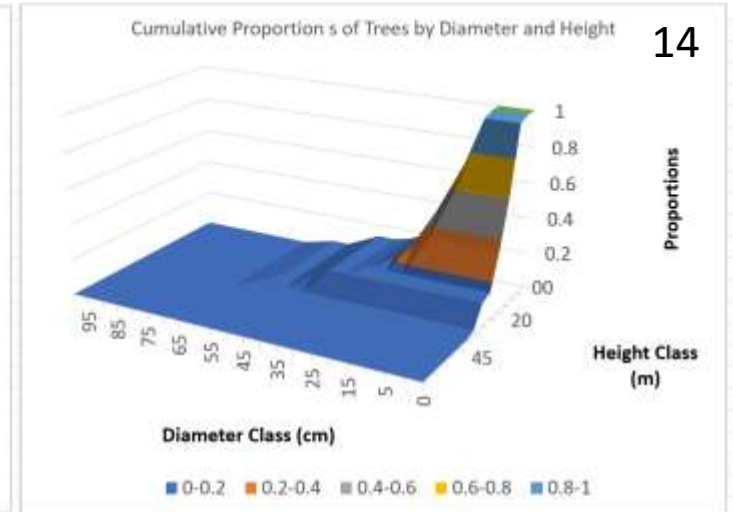
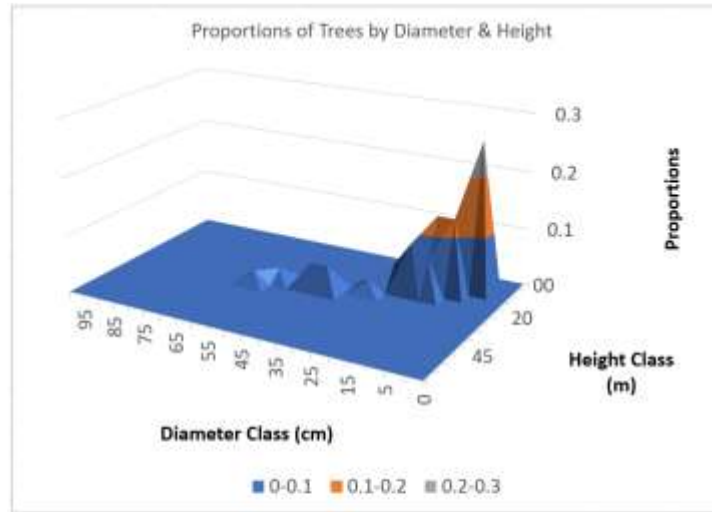
The Results: Species Diameter & Height Distributions



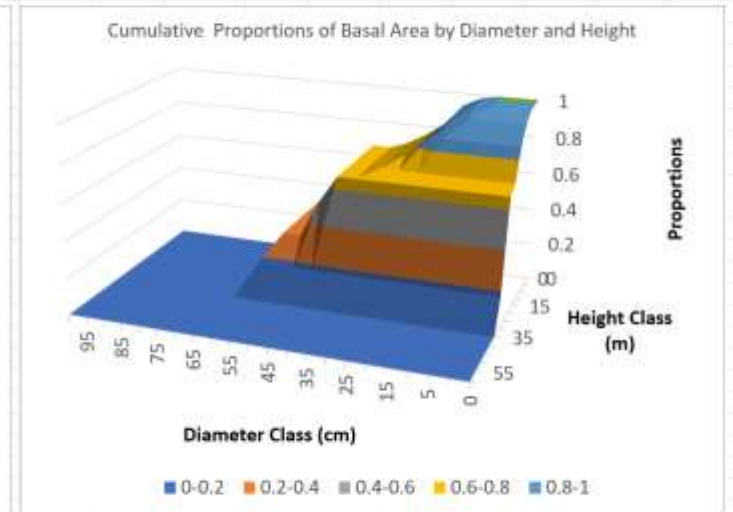
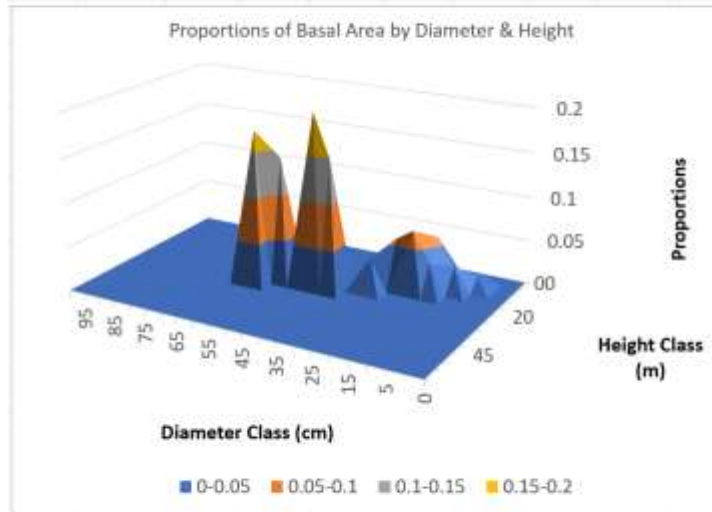
PLOT ID	1035					Z1	17.42157						
STRUCTURE	14	COMPILE PLOT DATA		RUN ROTISSERIE		Z2	6.14047						
RANK	1					Z3	7.783523						
MEMBERSHIP	0.987989												
REGION	102												
	PLOT	DIAMETER			HEIGHT			DIAMETER*HEIGHT					
		TPH	BPH	MVPH	MTD	MQD	MBD	MTH	MQH	MBH	MTDH	MQDH	MBDH
ALL		1150	42.088	317.515	16.674	21.587	39.464	10.474	12.724	19.169	2.675	4.791	12.285
SW		350	30.483	271.556	26.643	33.301	47.922	15.329	17.992	23.334	5.891	8.273	13.195
BL		800	11.604	45.959	12.312	13.59	17.245	8.35	9.545	12.695	1.268	1.747	3.357
SP3													

SPECIES.%G.**CROWN POSITION CLASS**
 SW.72.5 BL.28.-7
 UCID-198; RANK-58 | 1085; 5 Cases | 2558

The Results: 3D Distributions with Respect to Diameter & Height



14

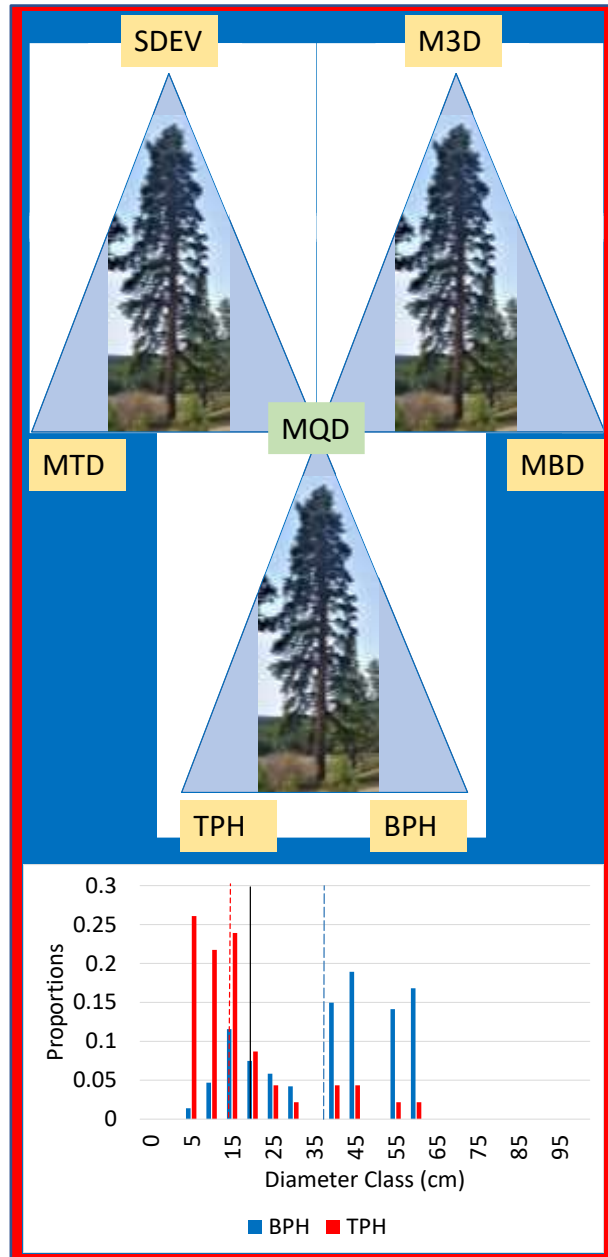


STRUCTURE	14	COMPILER_DH_PLOTID	MTD	MQD	MBD	MTH	MQH	MBH	MTDH	MQDH	MBDH	TPH	BPH	MVPH
PLOT NO	1635		16.674	21.587	39.464	10.474	12.724	19.169	2.675	4.791	12.285	1150	42.088	317.515
REGION	102													
MEMBERSHIP	0.987989													
			RUN ROTISSERIE			NEXT BEST IN CLASS								

Conclusion I

We Can:

- Index diameter and height distributions.
- Classify stand structures.
- Account for differences in species crown class positions and associated distributions.





Conclusion II

Potential For:

- Improving prescription guidelines .
- Improving forest type definitions.
- Producing more reliable inventory tree list and/or stand and stock table attributes.
- Extend understanding of stand dynamics.
 - Maximum Density: $SDI = f(MTD, MQD, MBD)$?



Conclusion III

Applications

- Habitat management
- Fire risk management
- Watershed management
- Timber supply management
- Wood processing (log quality, bucking rules)
- Forest valuation
- Modeling stand & tree dynamics
- ...

A Few References

- Carvalho, M. 2016. Mean, what do you mean? *The American Statistician*: 70(3):270-274.
- Curtis and Marshall (2000): Why Quadratic Mean Diameter? WJAF
- [https://artofproblemsolving.com/wiki/index.php/Power Mean Inequality](https://artofproblemsolving.com/wiki/index.php/Power_Mean_Inequality)
- https://en.wikipedia.org/wiki/Lehmer_mean (Derrik Henry Lehmer, 1905-1991)





Institutional Credits

- *Ground Plot Data:*
 - Tolko (Lignum, Riverside) Innovative Forest Practices Agreement
 - UBC Alex Fraser Research Forest
 - Mosaic Forest Management
 - Chinook & Dunster Community Forests
 - Spray Lakes Sawmills
 - Saskatchewan Forest Service (Fort a la Corne)
 - BC Ministry of Forests (Prince George TSA CMI Plots in collaboration with ECORA)
 - Newfoundland Forest Service



Human Credits

- There are many people who have contributed to this work over the years – too many to count.
- Special thanks: *Dr. Valerie LeMay, Ken Day, Dr. Bill Bourgeois, Dr. Temesgen Hailemariam*; many folks that worked at Lignum.
- This has been a work in progress starting in 2003. It would have never progressed without the engagement in related inventory projects involving the compilation and use of many of these datasets. This includes Lignum Ltd., *Phil Winkle* & work in Quesnel TSA, UBC and involvement with *Peter Marshall's* long-term Interior Douglas-fir trial in the UBC Alex Fraser Research Forest, and Tesera Systems Inc.
- Ninety percent of the work was done on my own time and funded by my self or my company, Forestree Dynamics Ltd.



Thank You

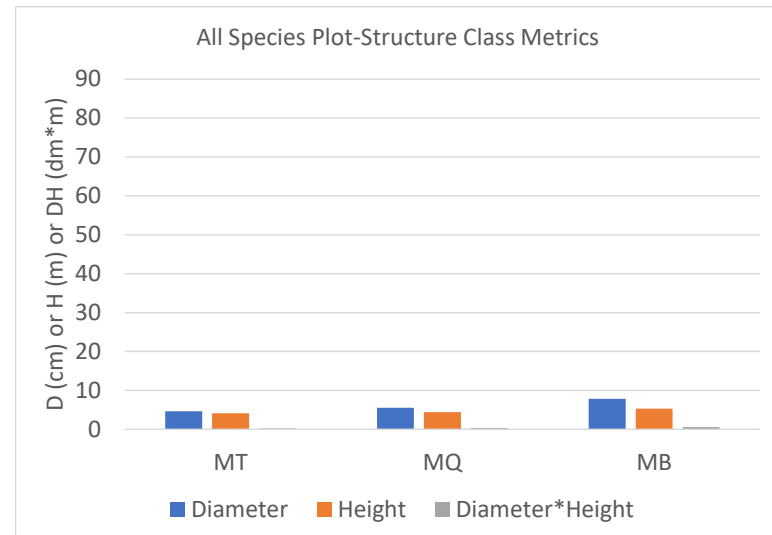
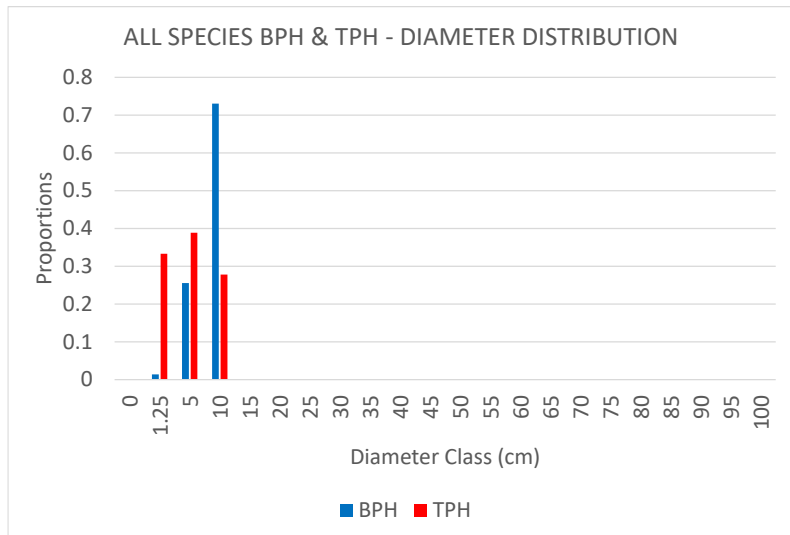
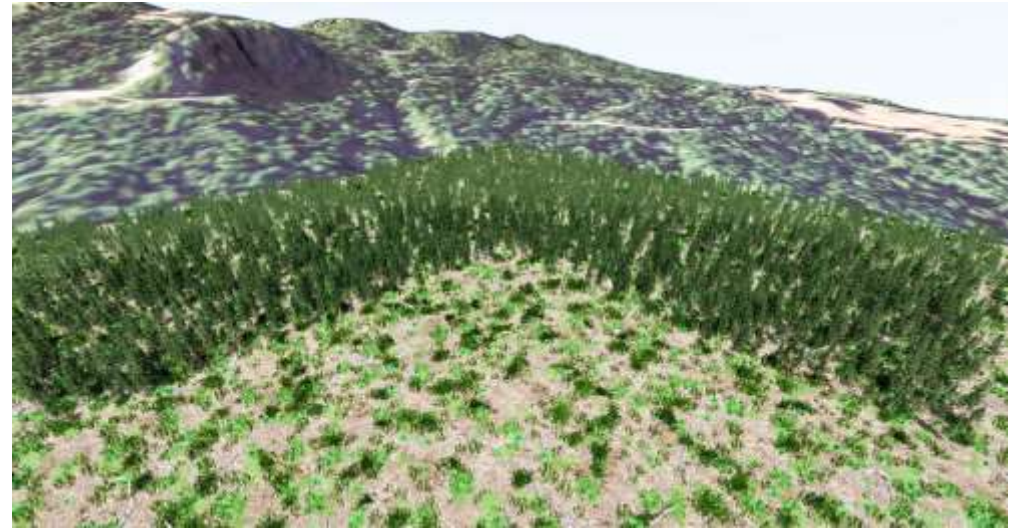
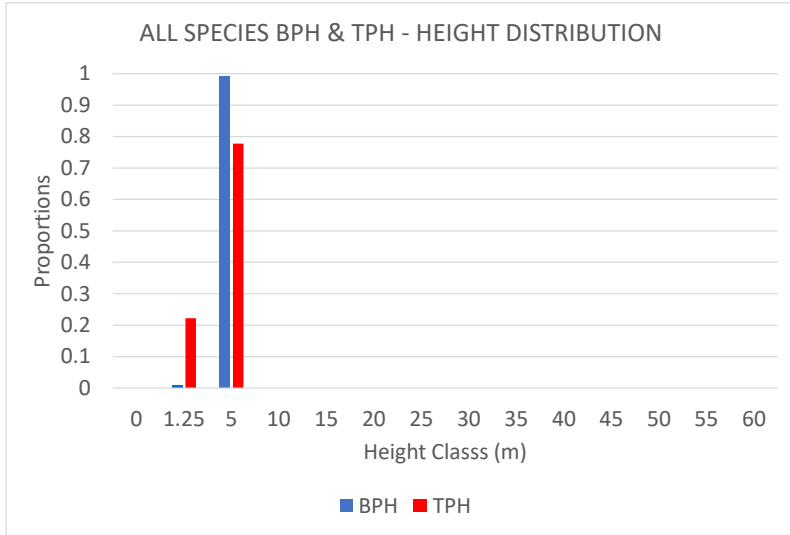
Forestreet Dynamics Ltd.
619 Goldie Avenue,
Victoria BC, V9B 6C1
Canada
Email: forestreet@shaw.ca

Appendix: The 25 BC stand structure classes

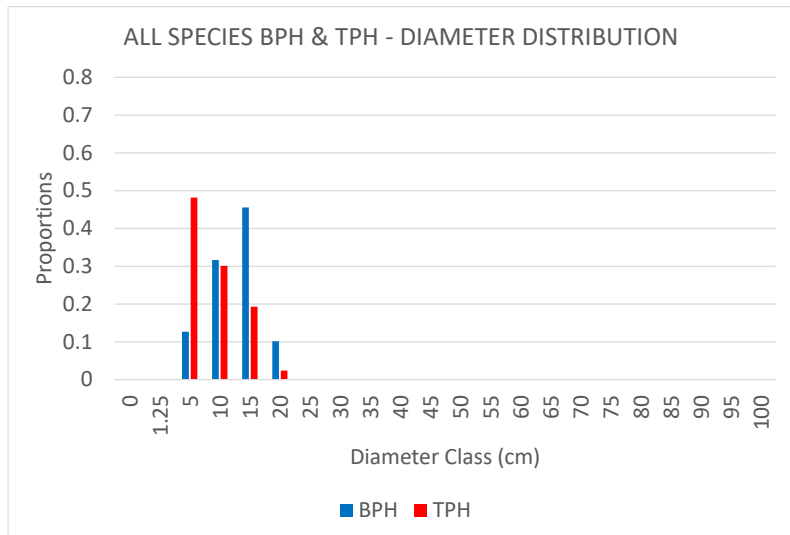
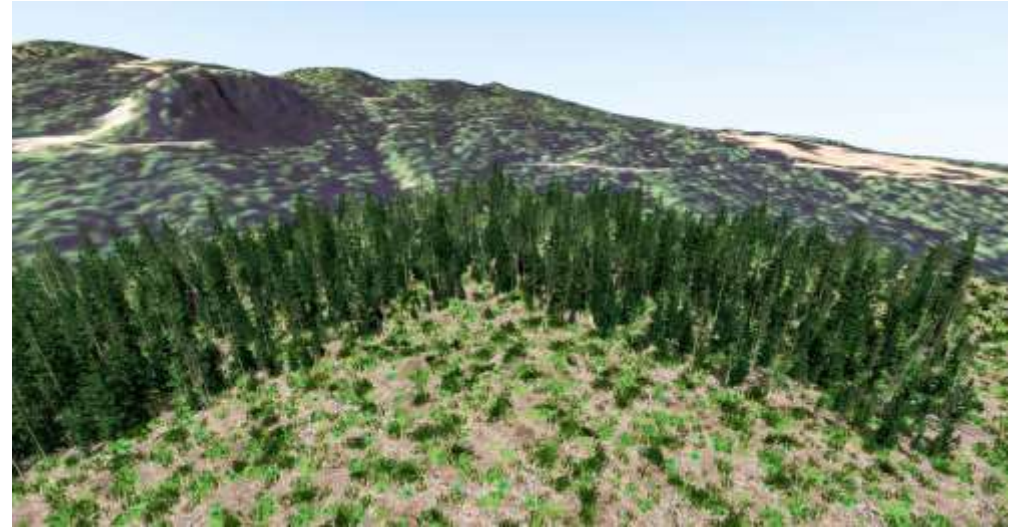
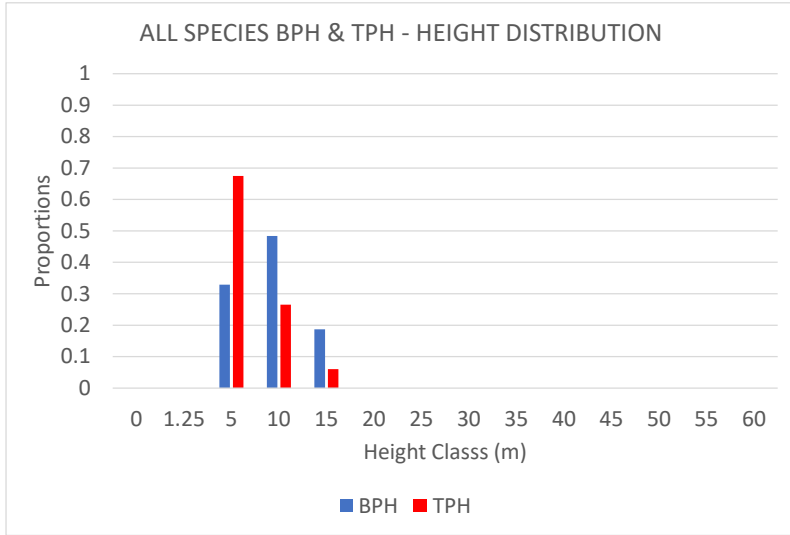
- The photo-like images in the following slides were produced using *ALPINE Visual Forester Software* available at visualforester.com.



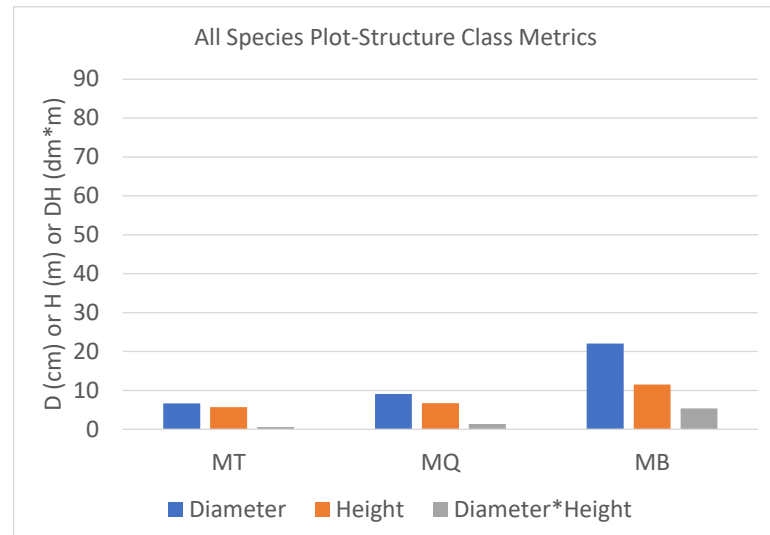
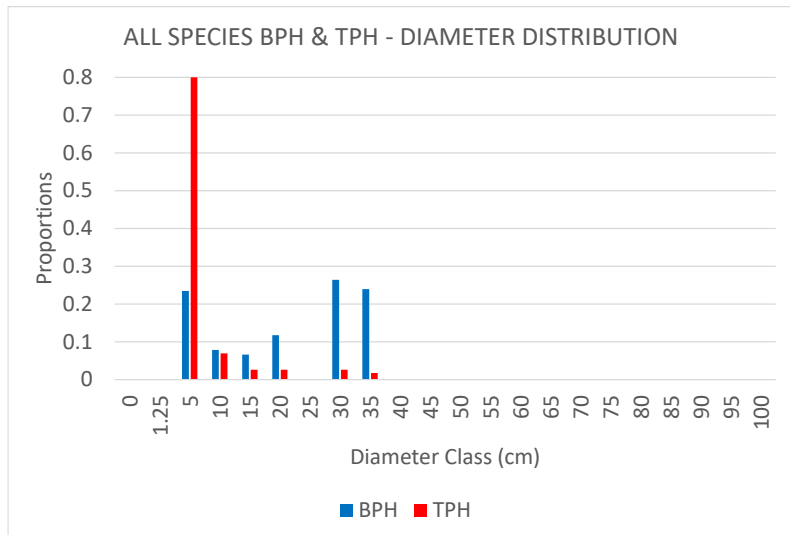
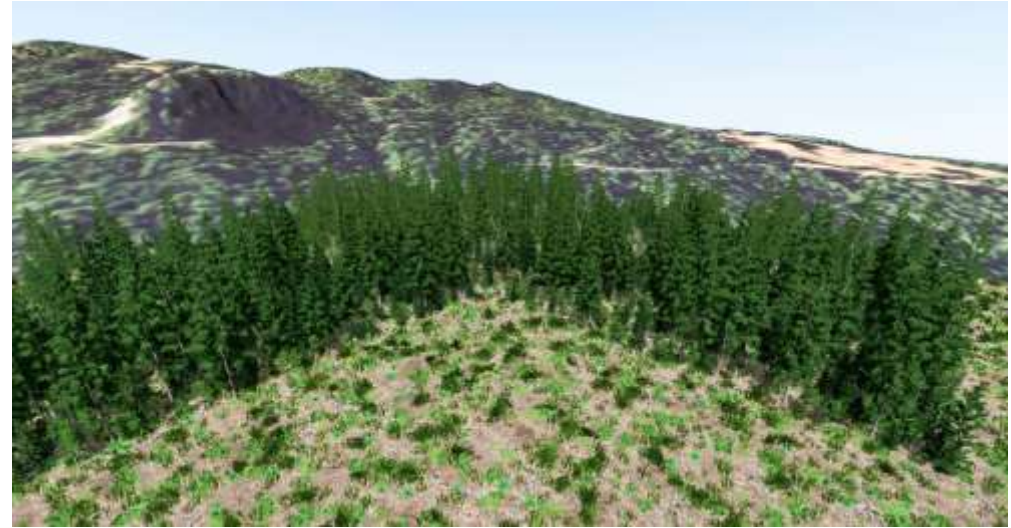
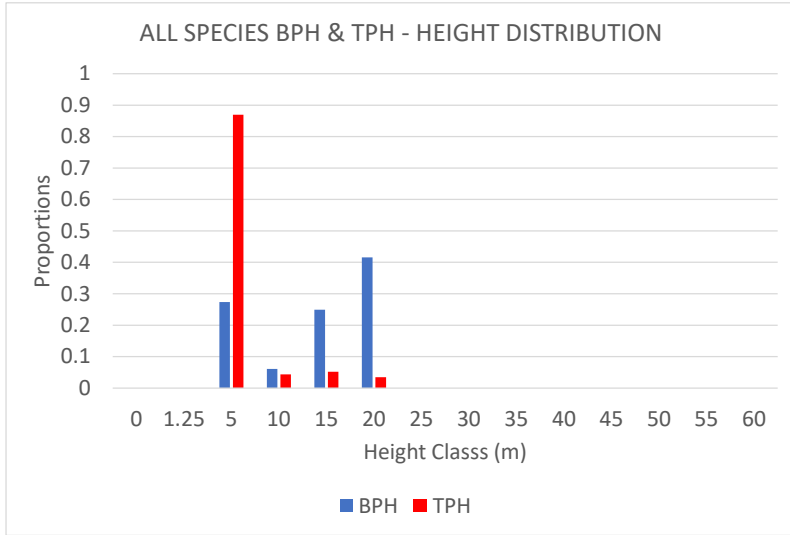
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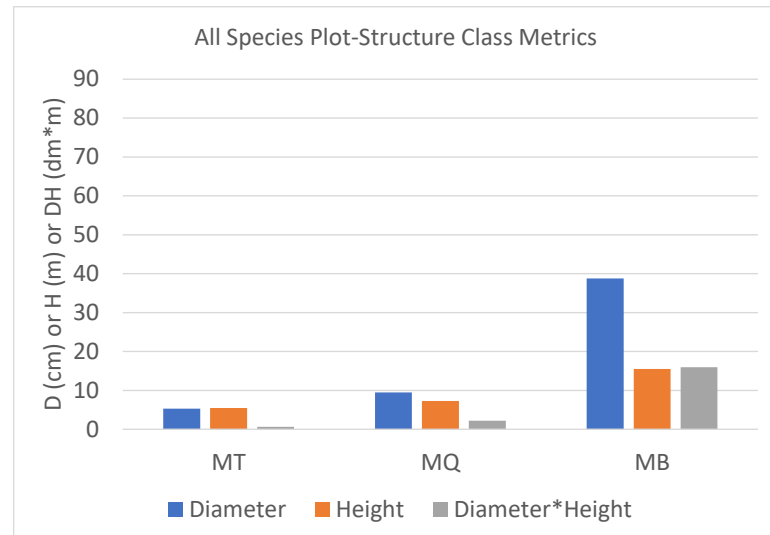
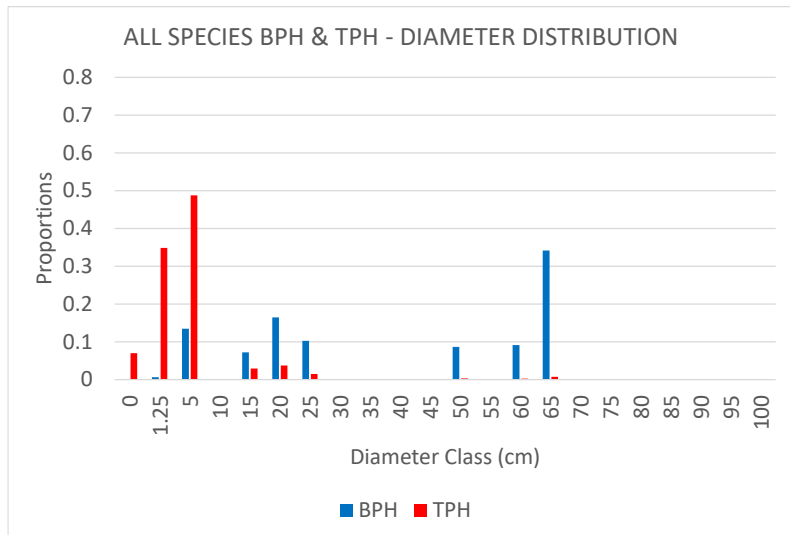
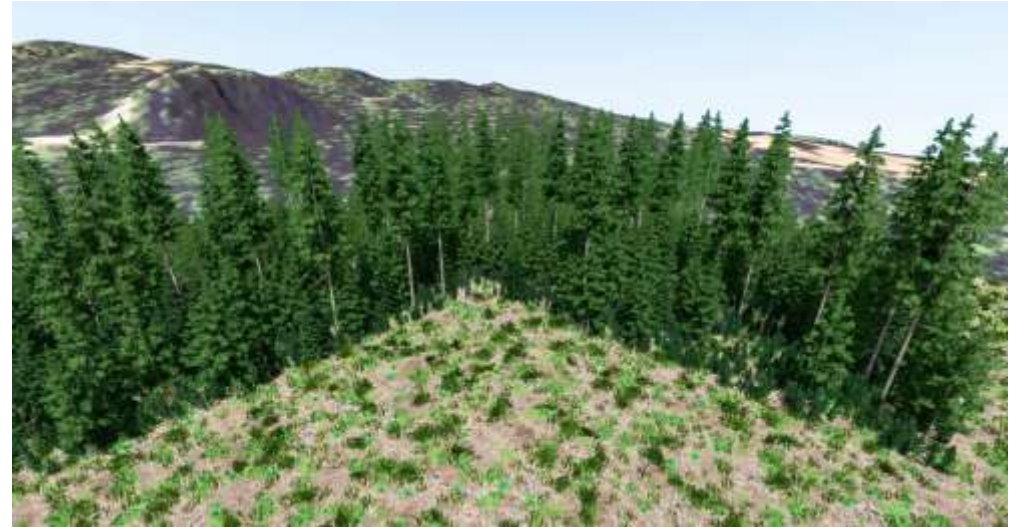
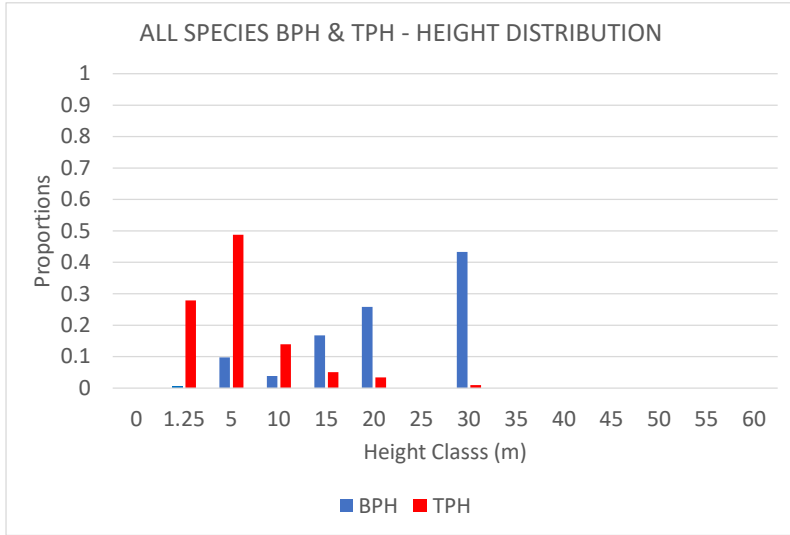
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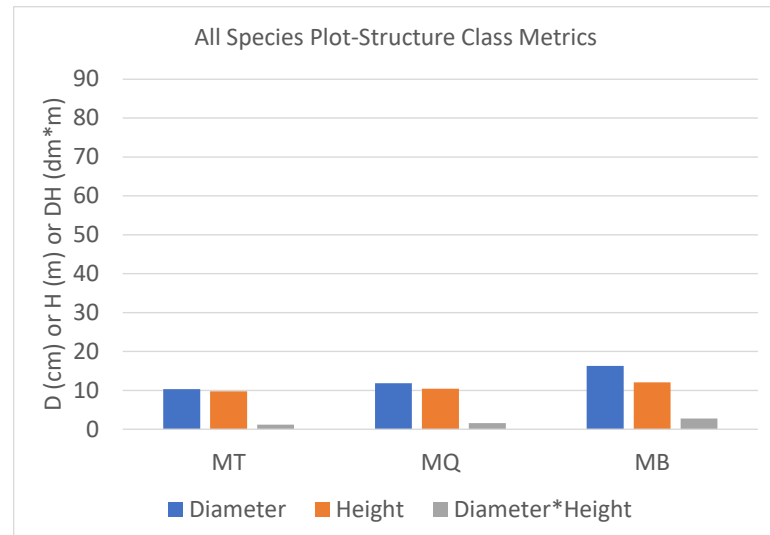
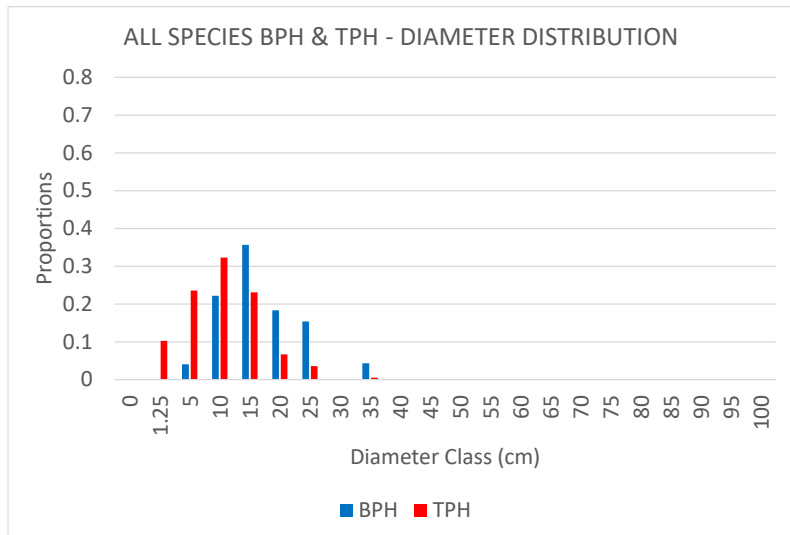
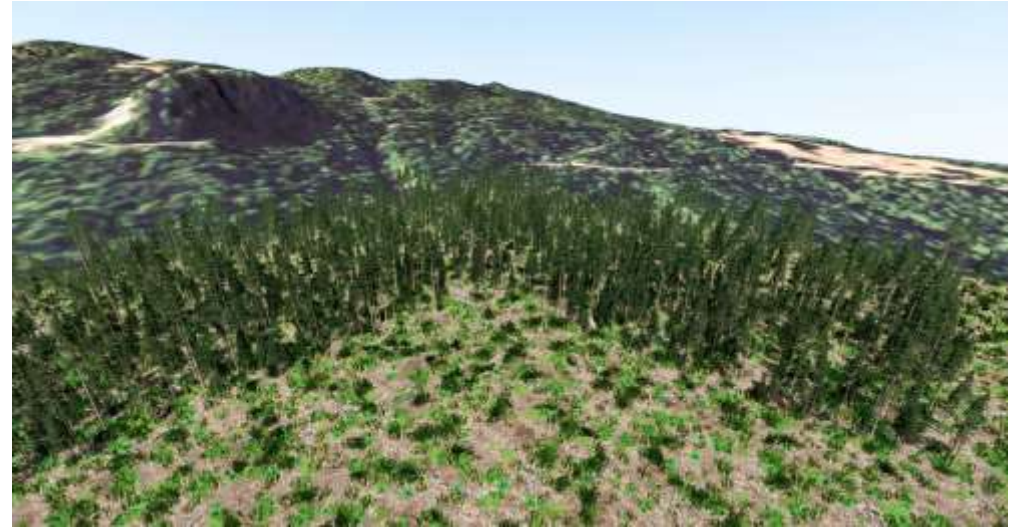
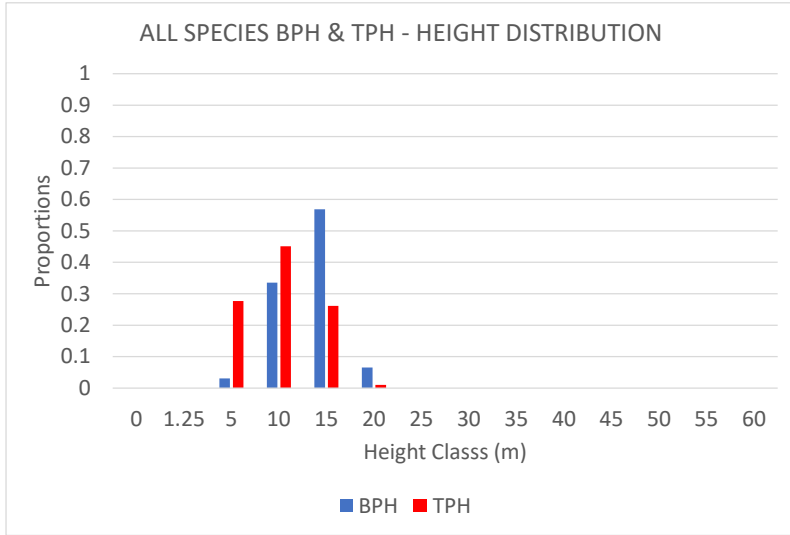
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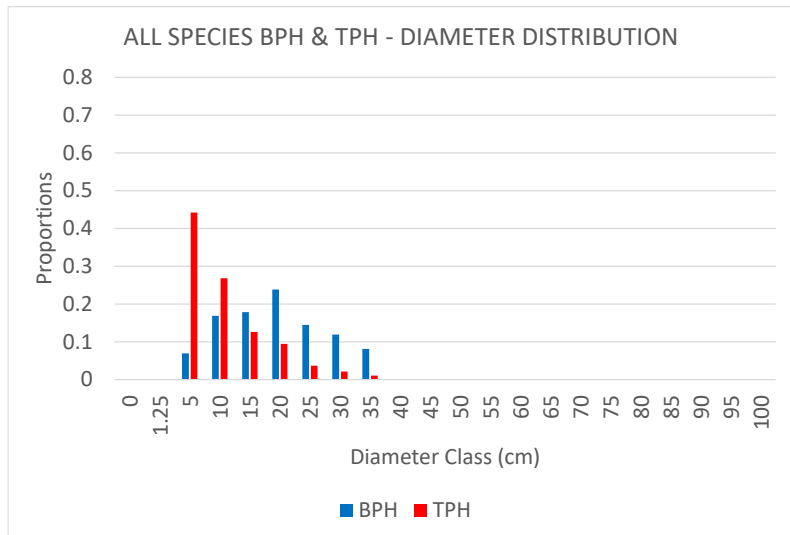
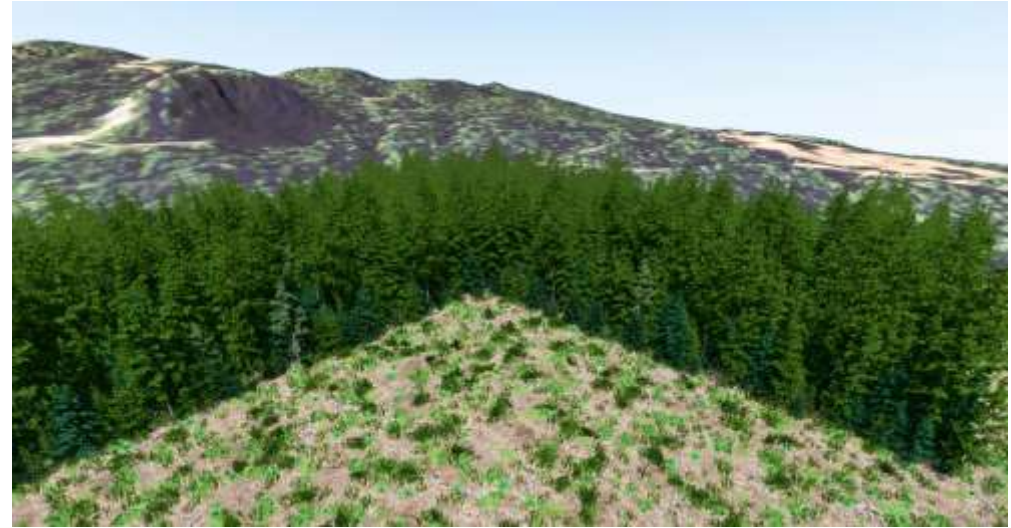
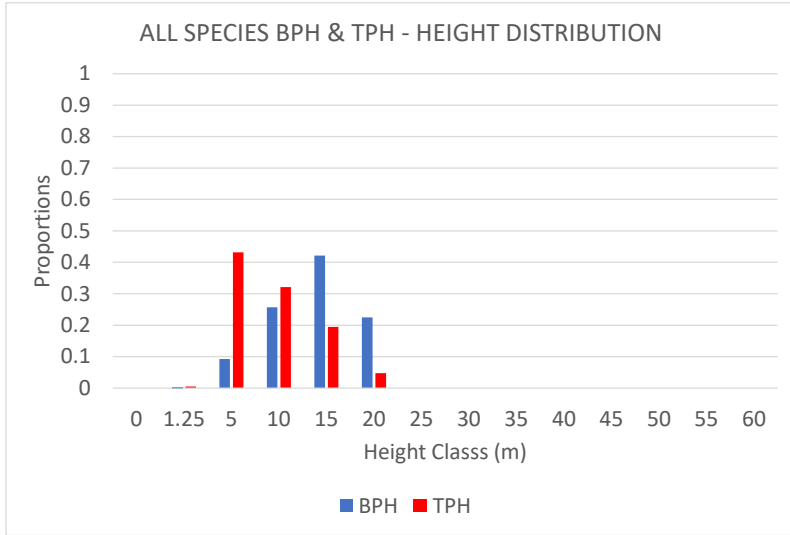
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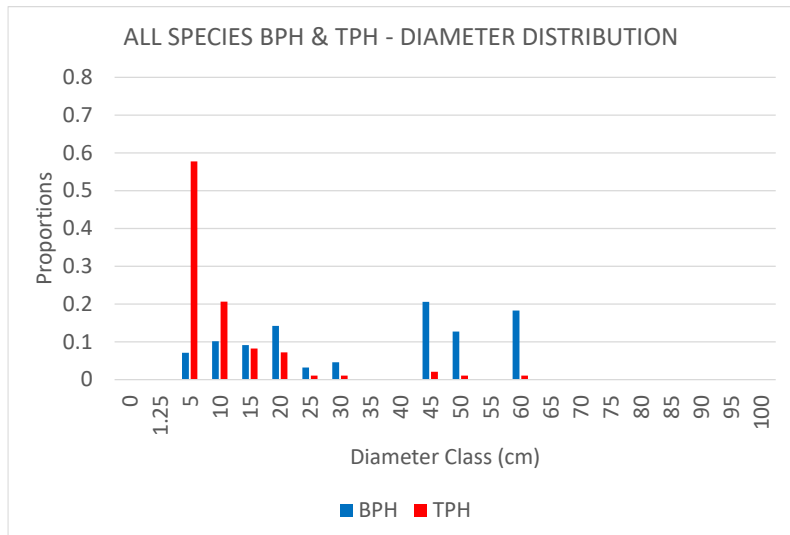
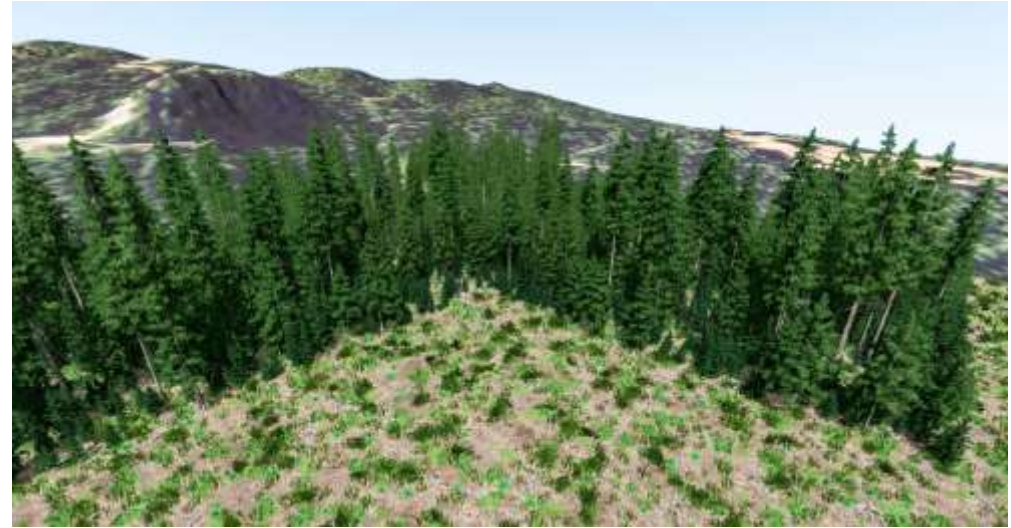
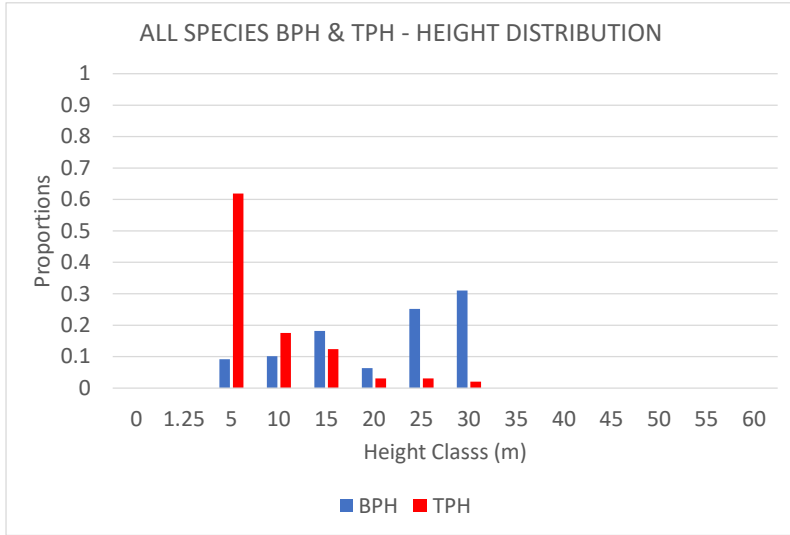


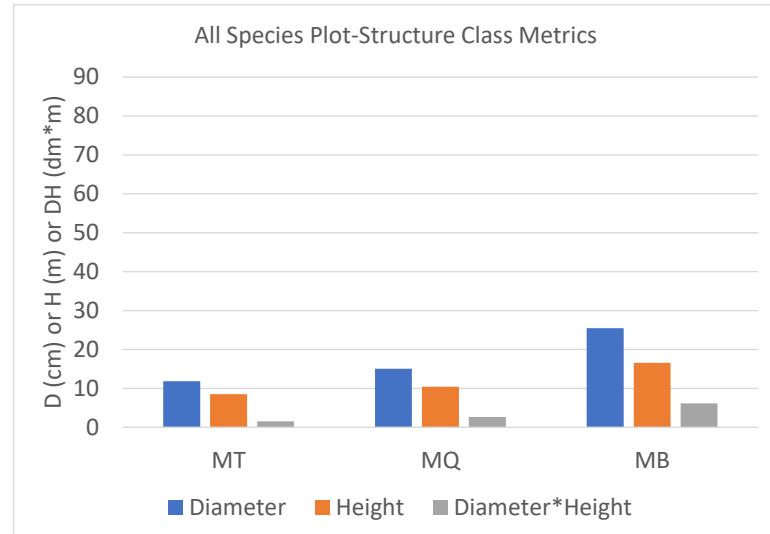
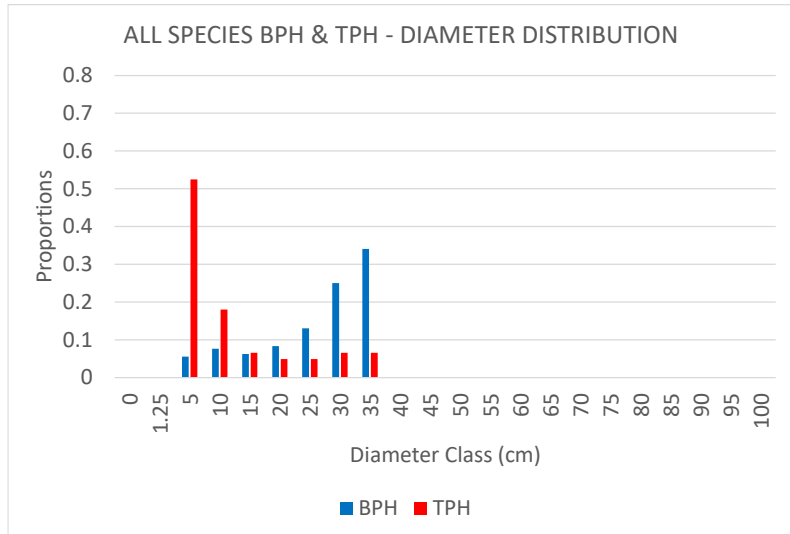
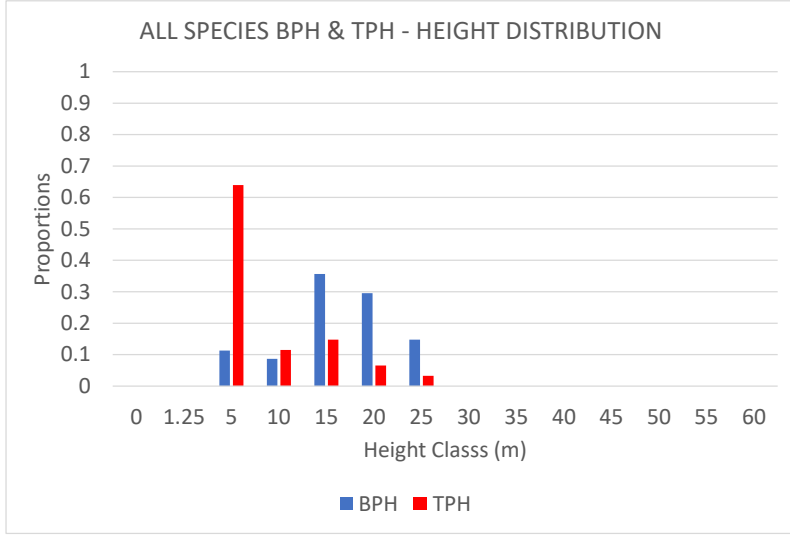
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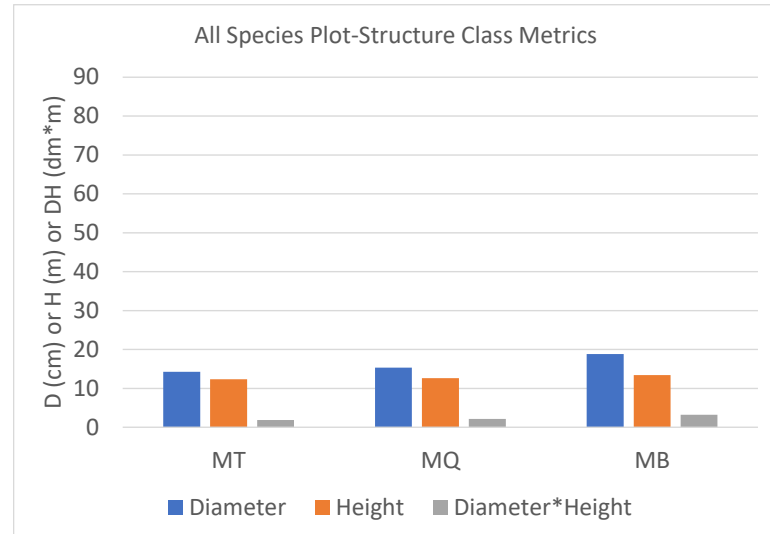
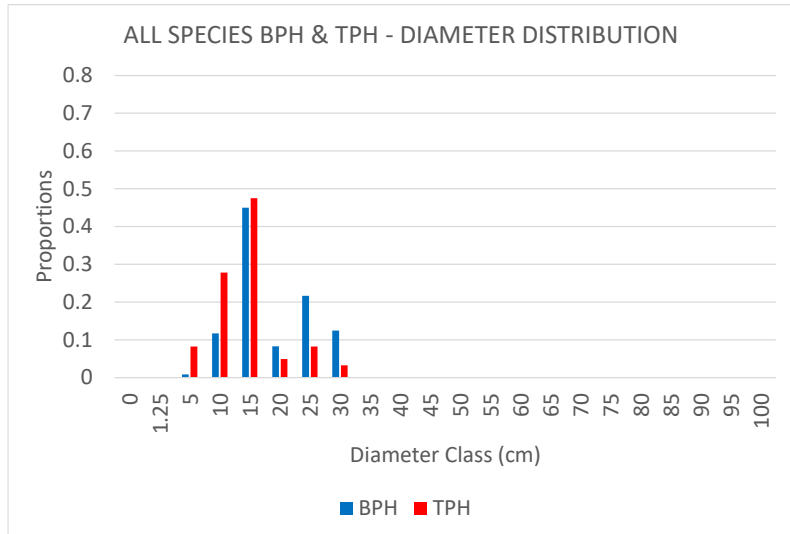
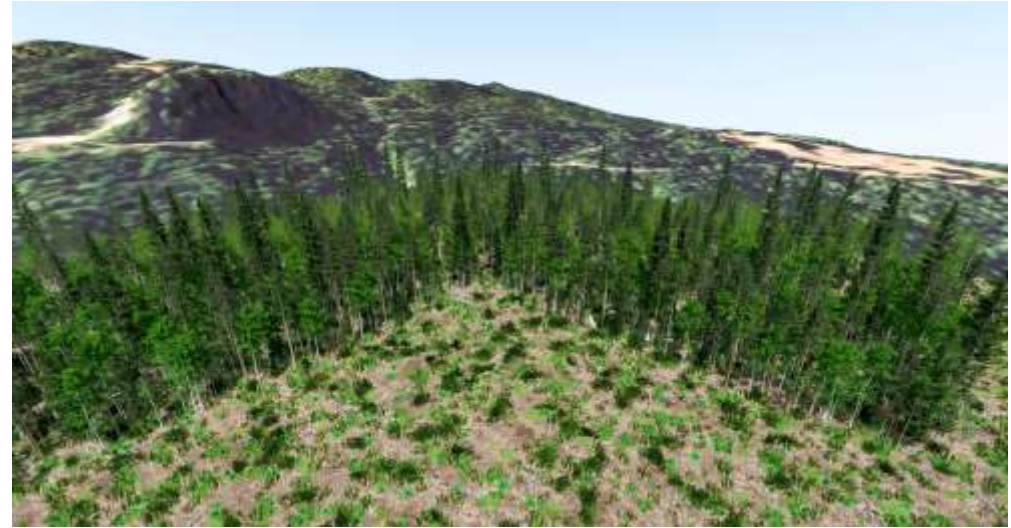
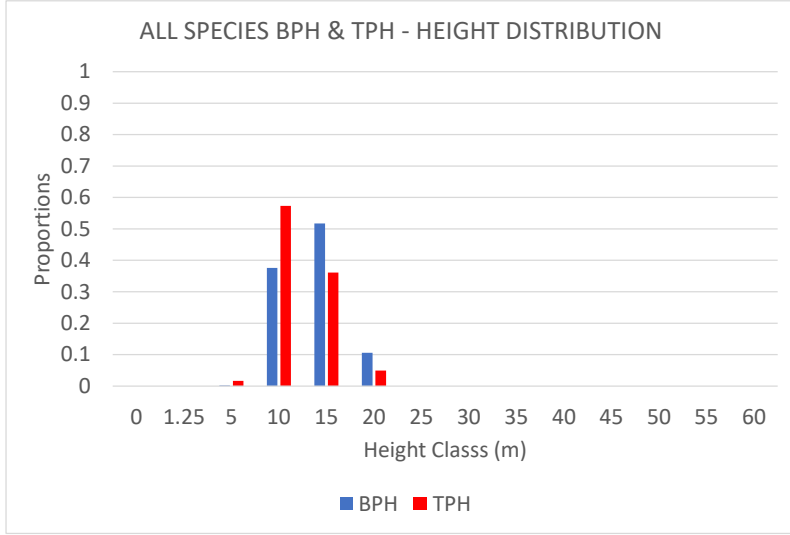


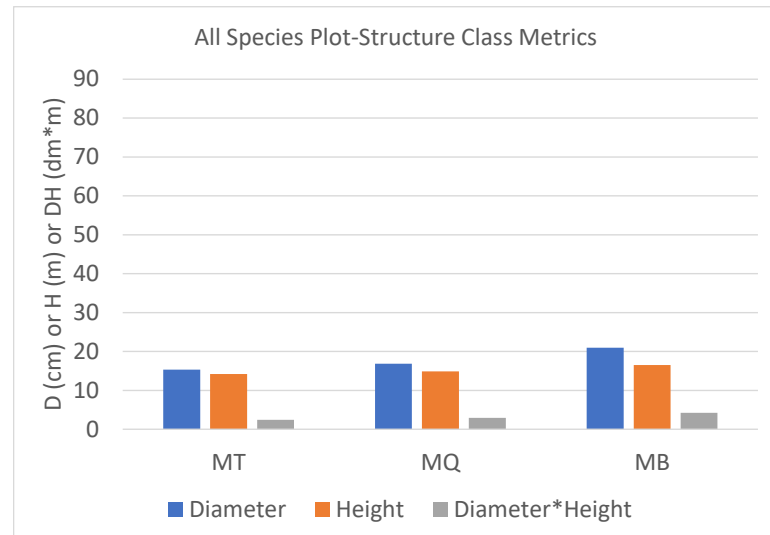
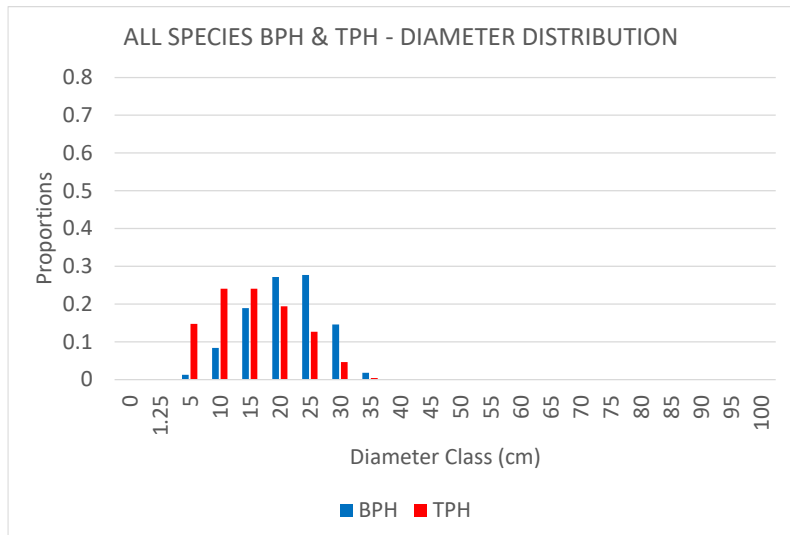
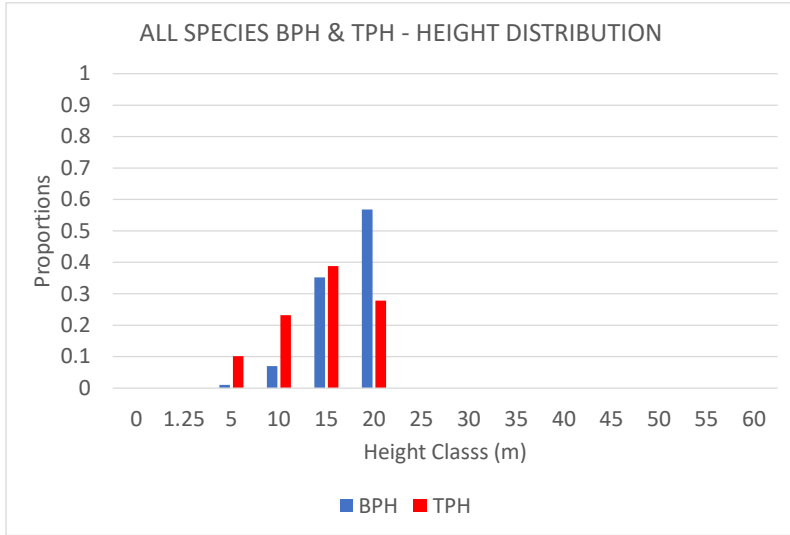
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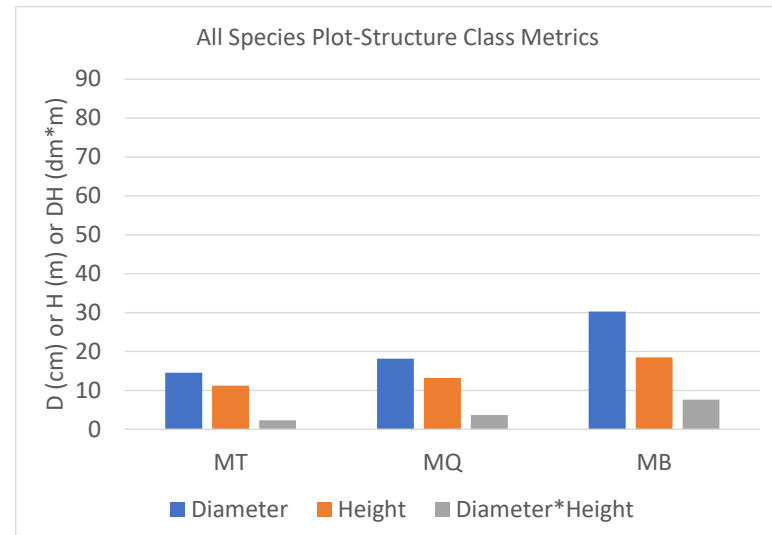
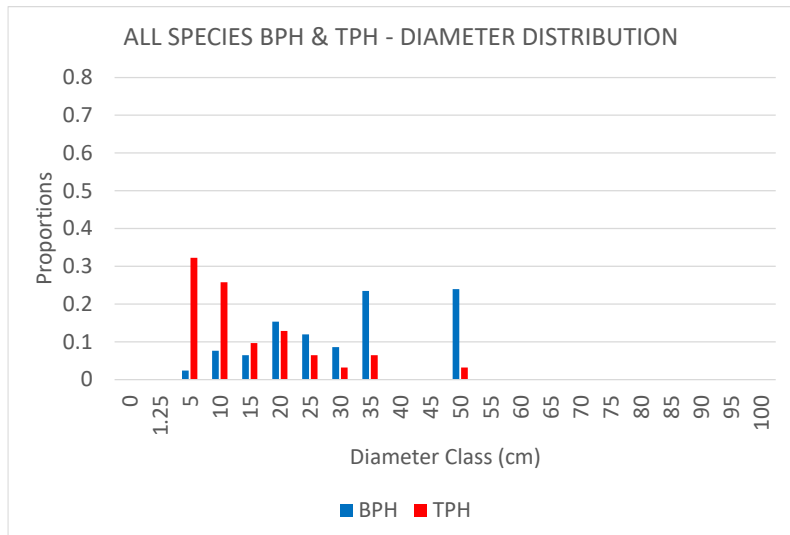
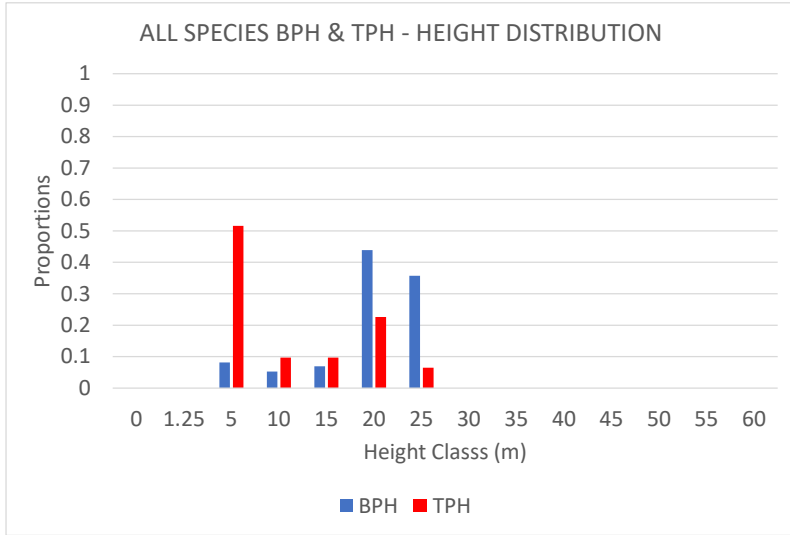


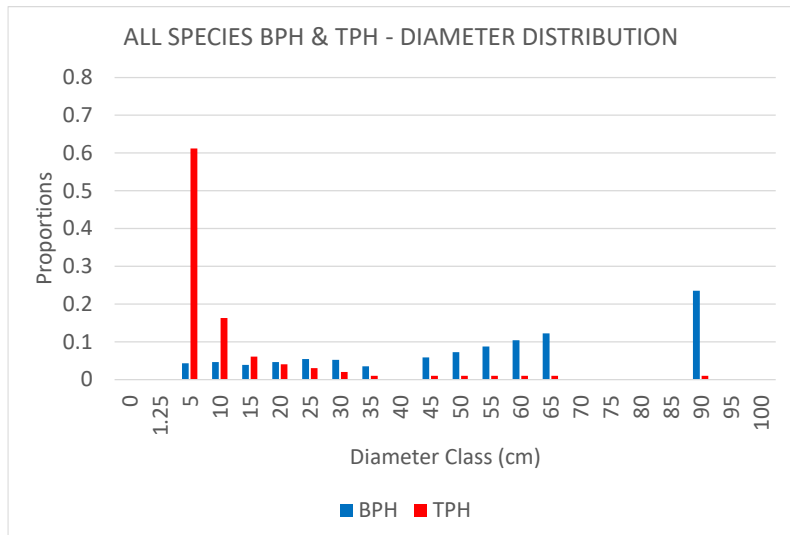
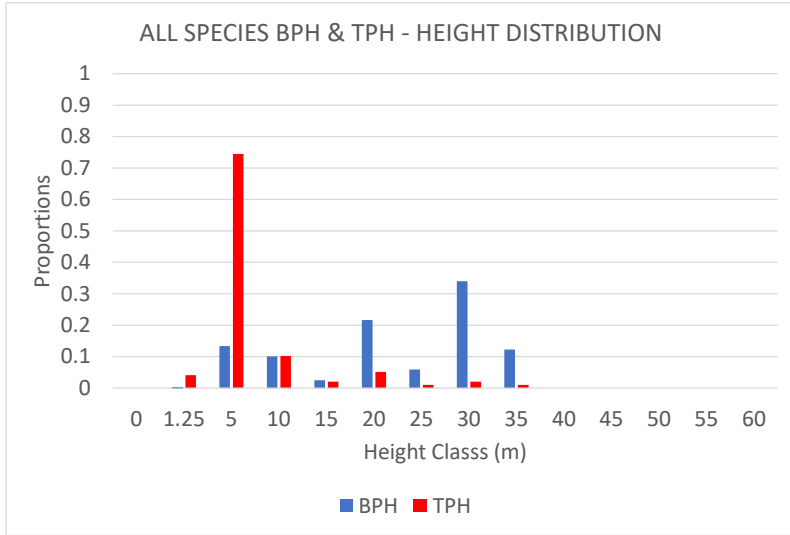


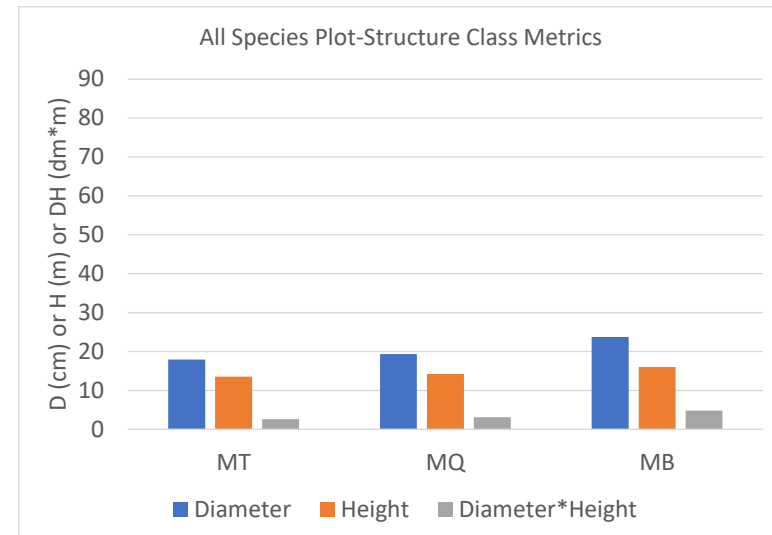
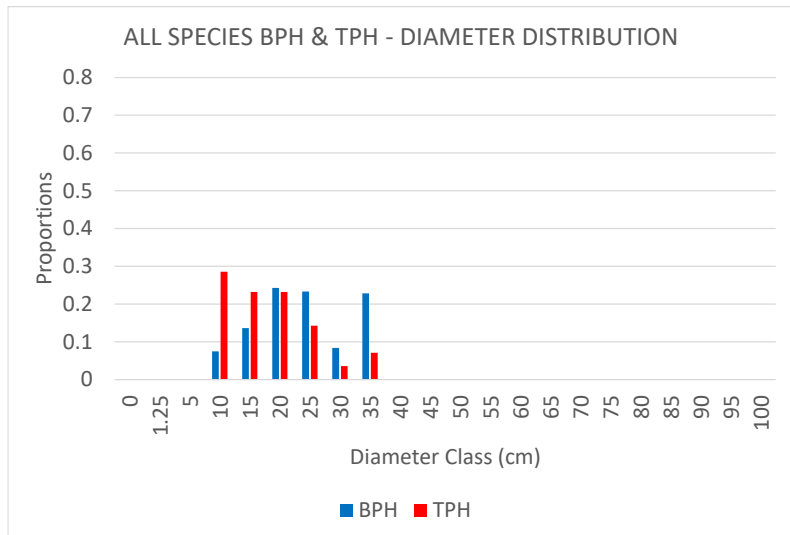
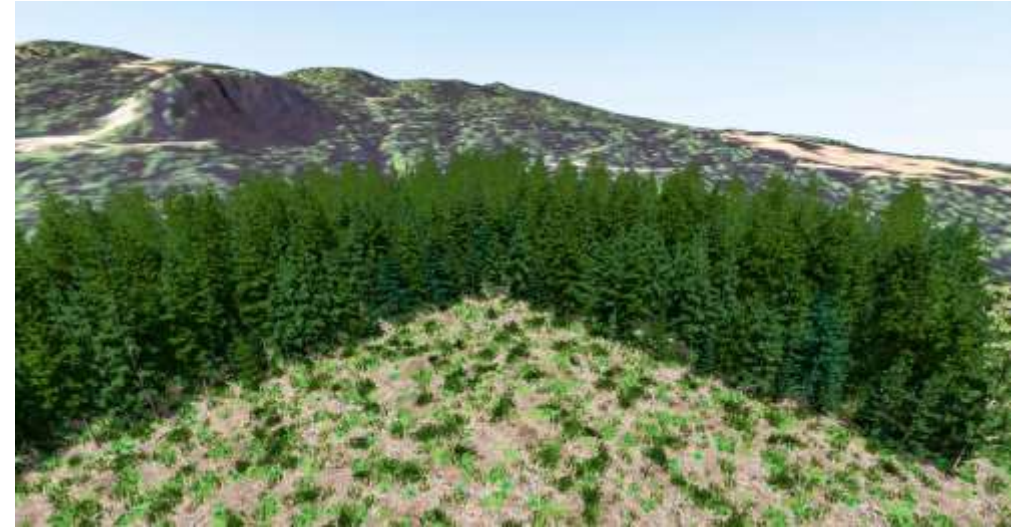
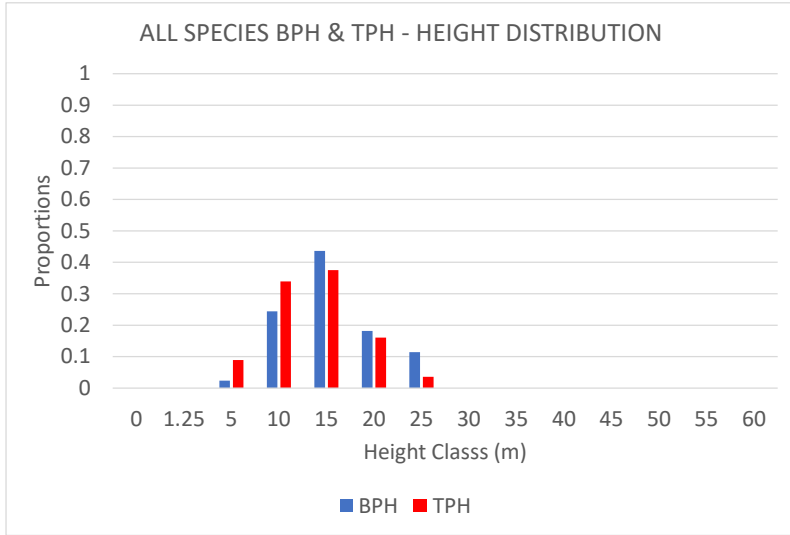


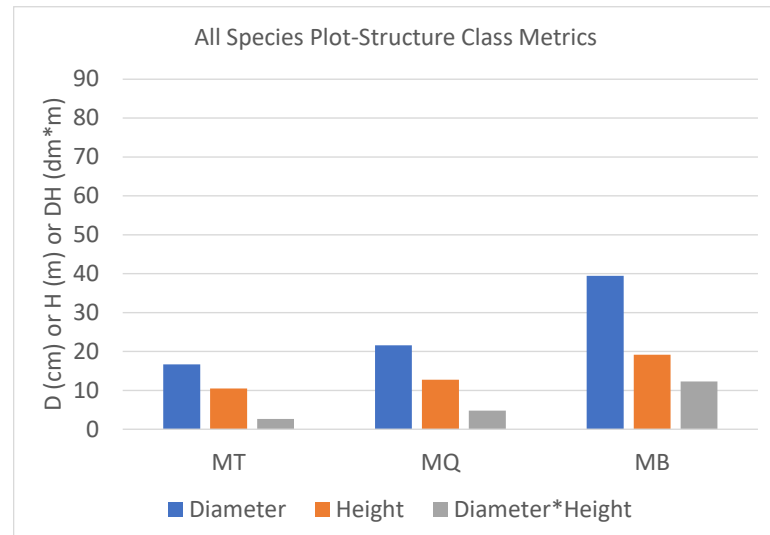
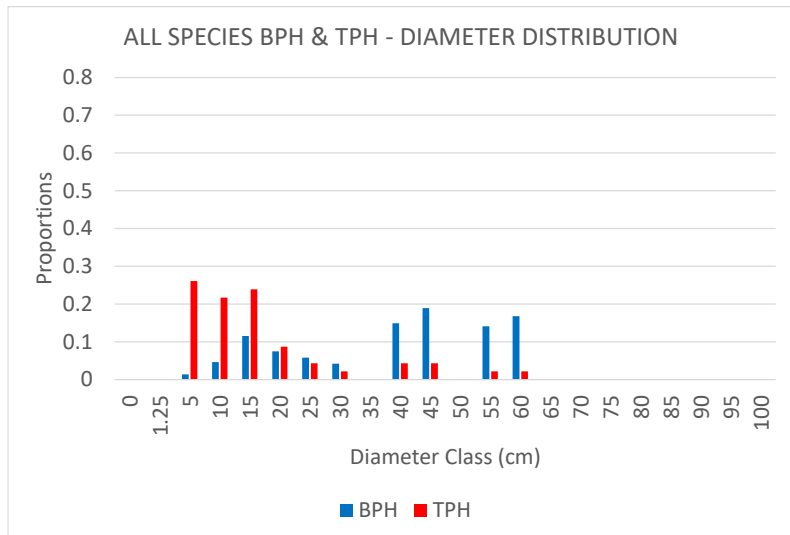
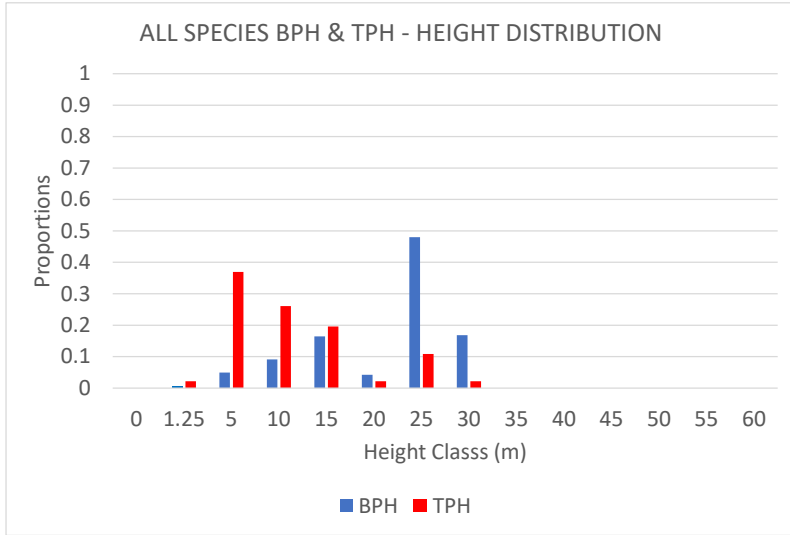


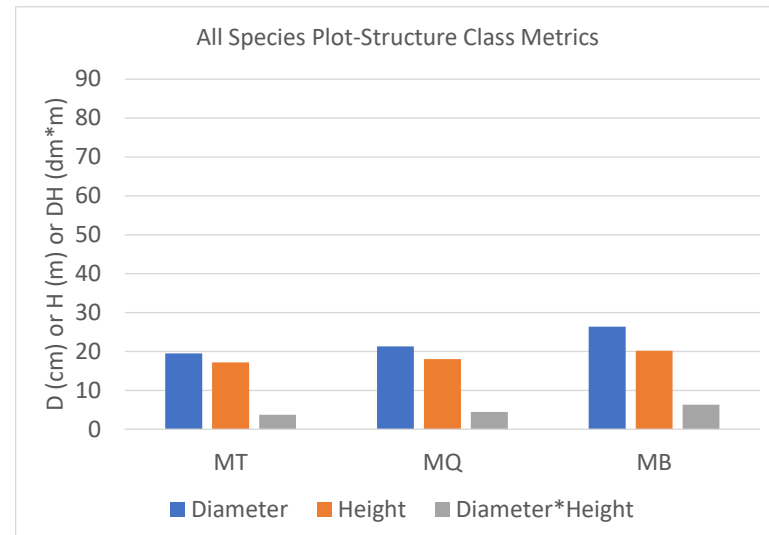
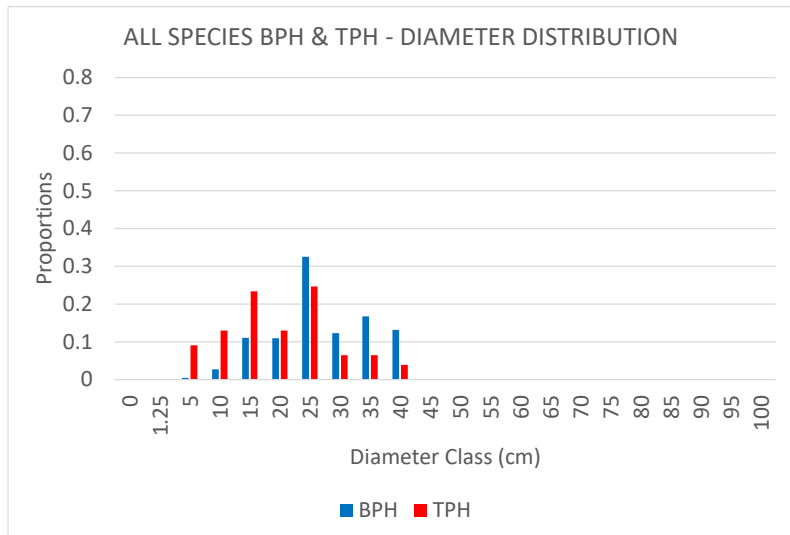
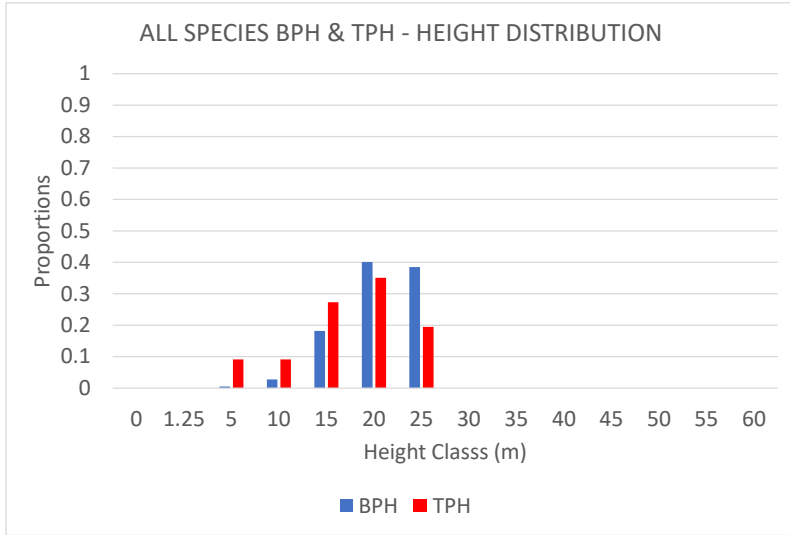


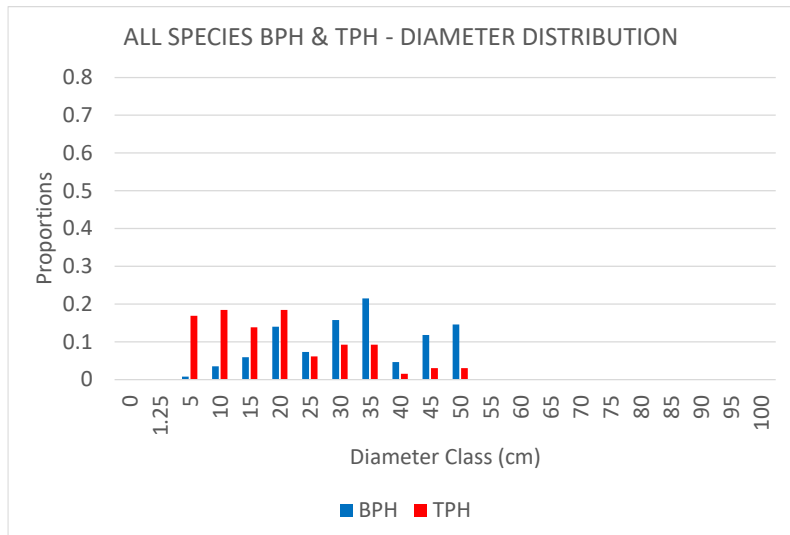
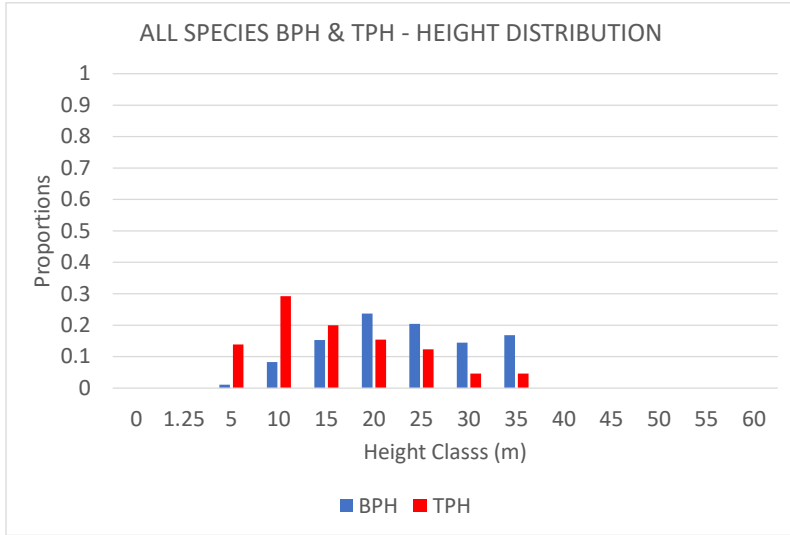


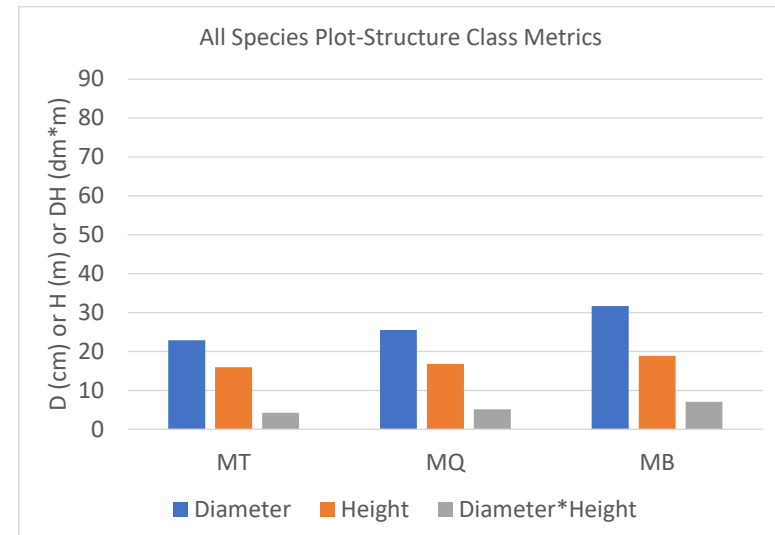
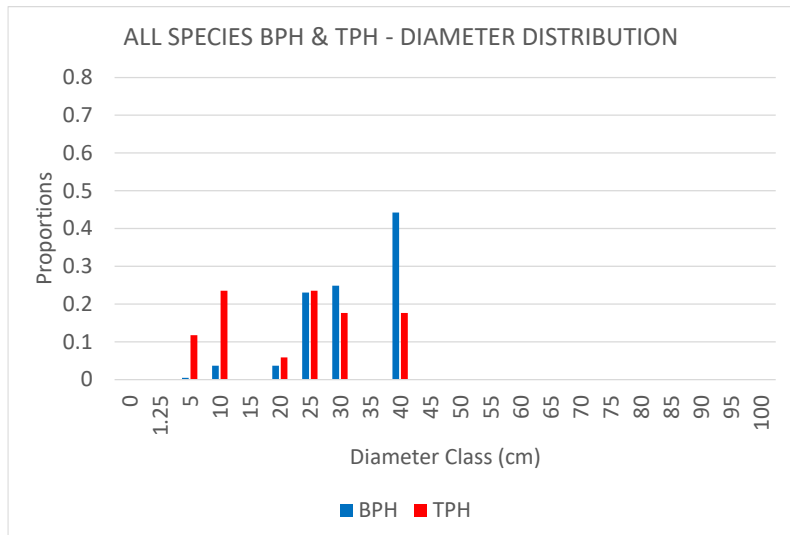
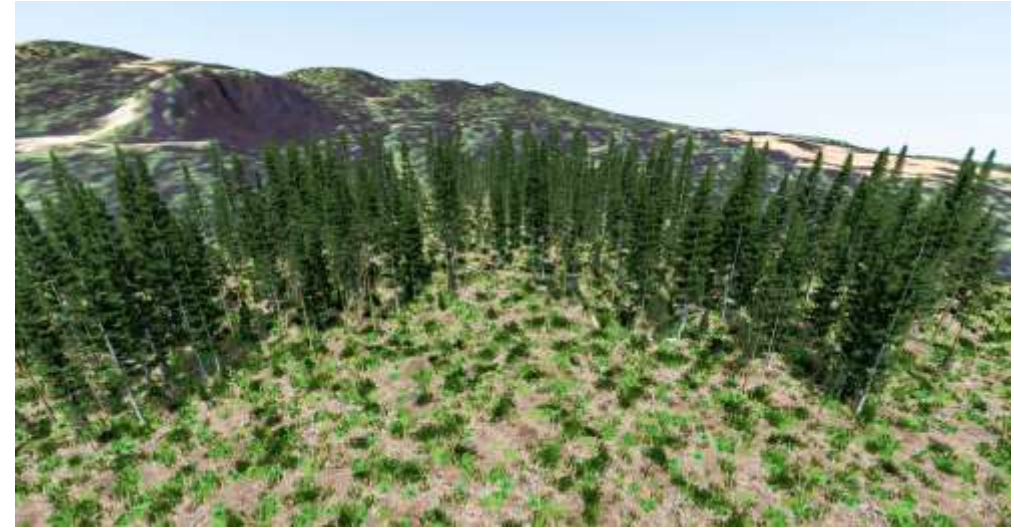
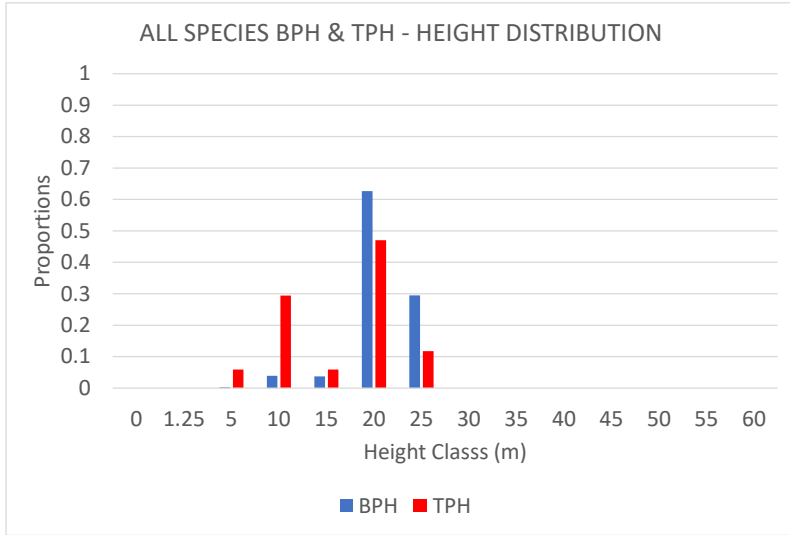


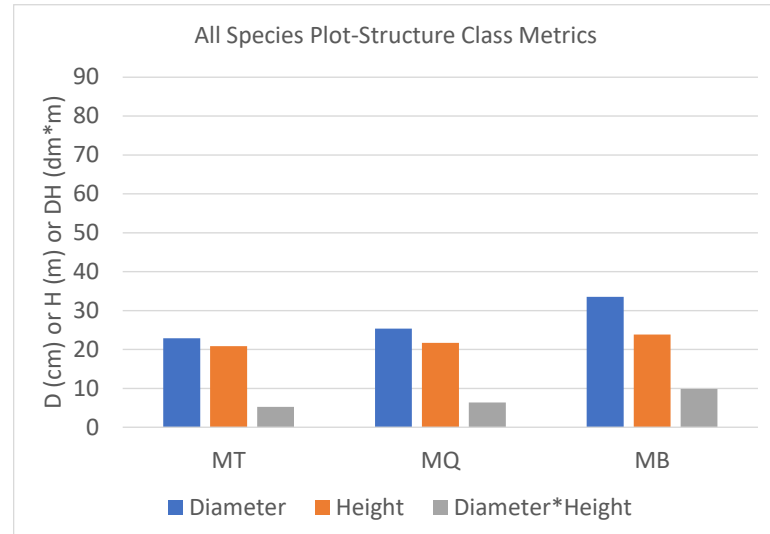
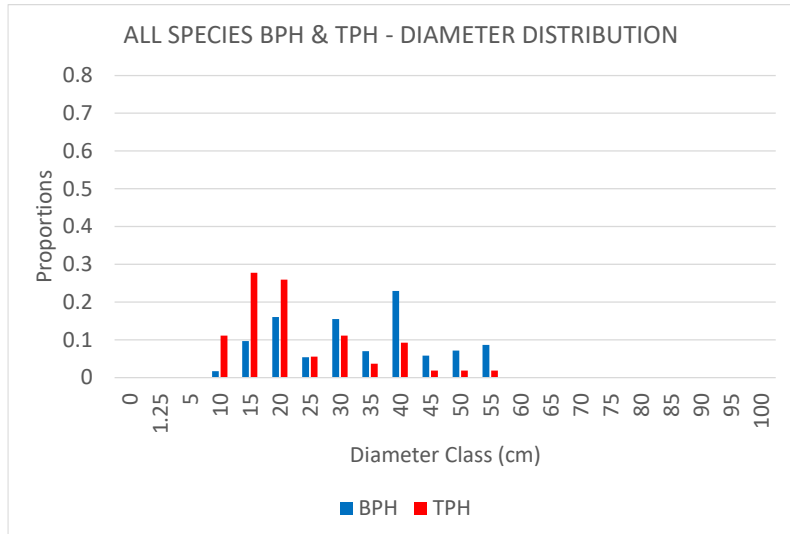
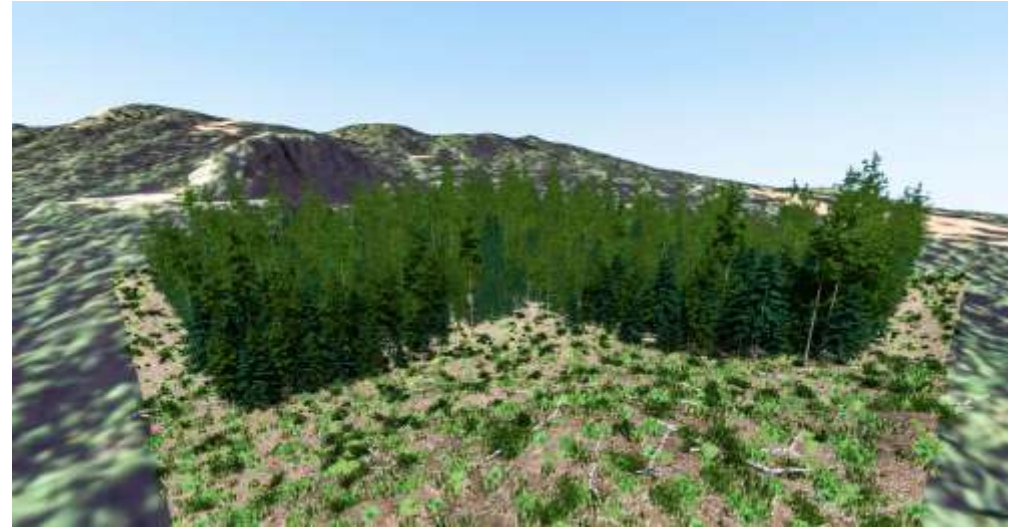
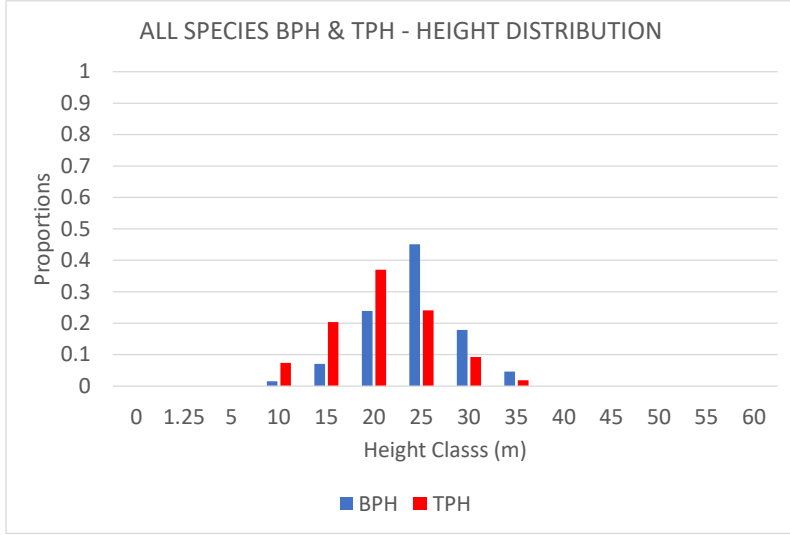


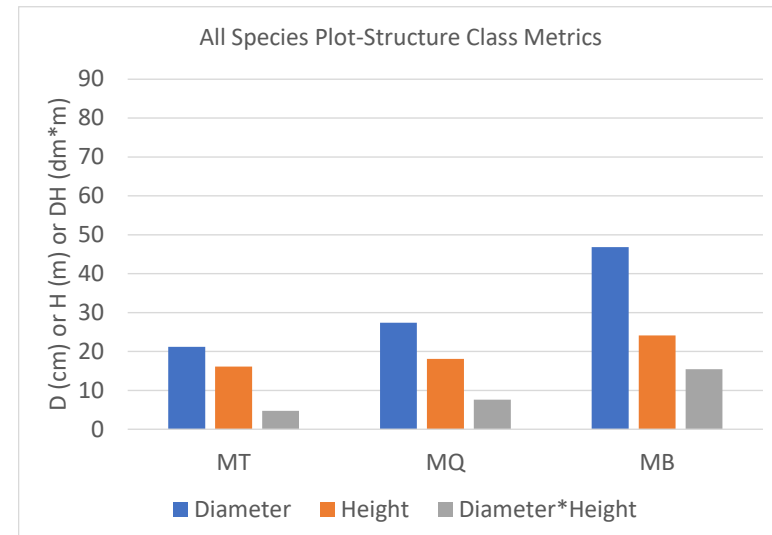
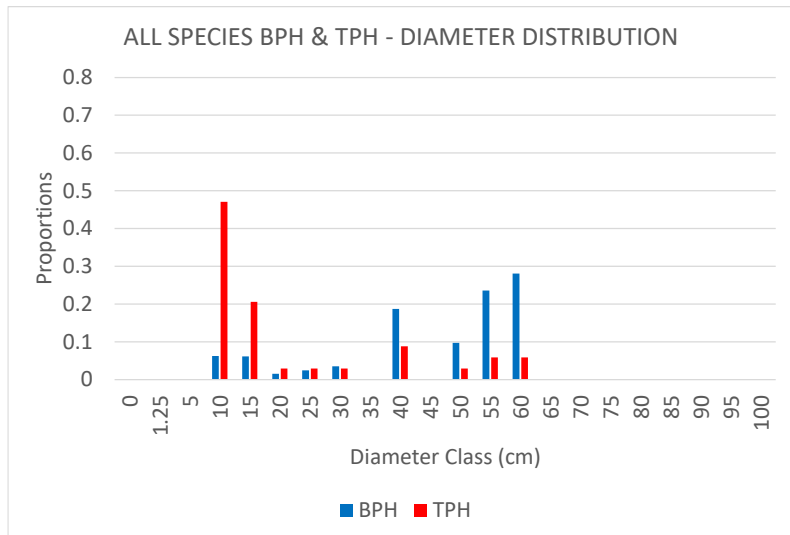
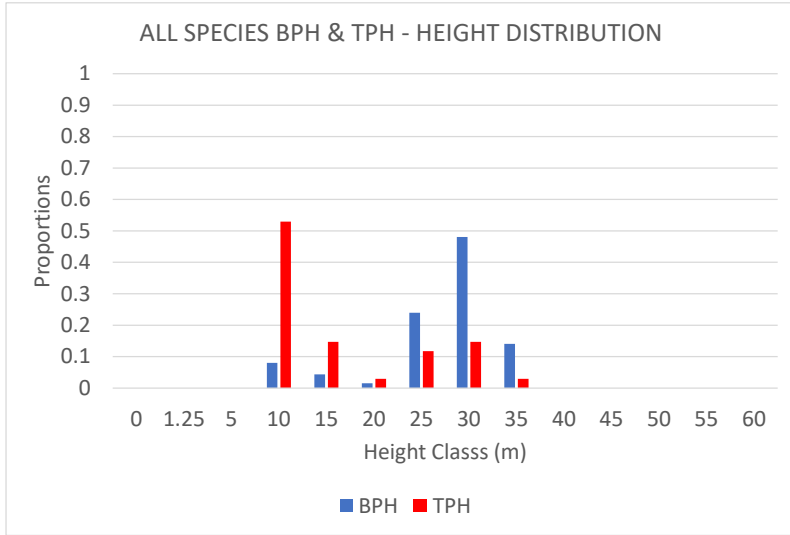


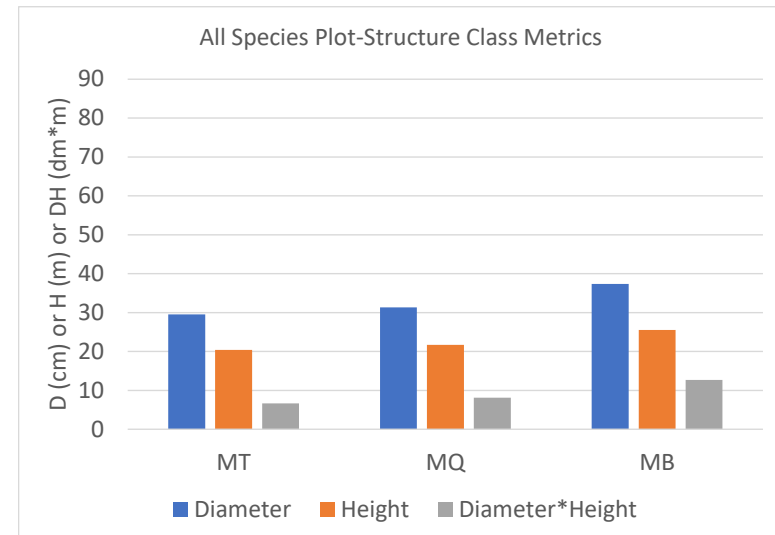
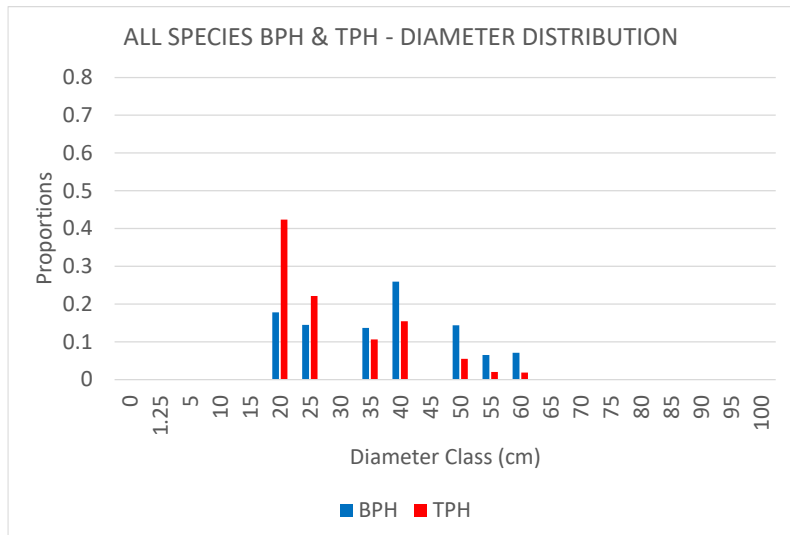
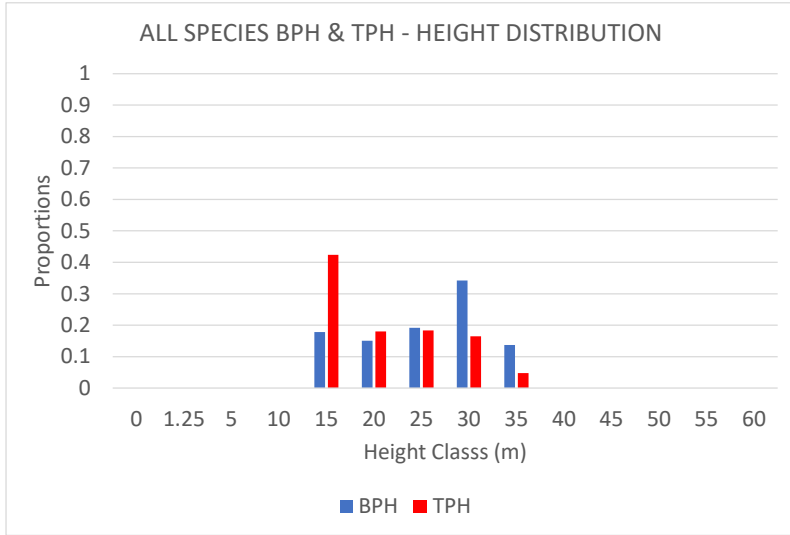


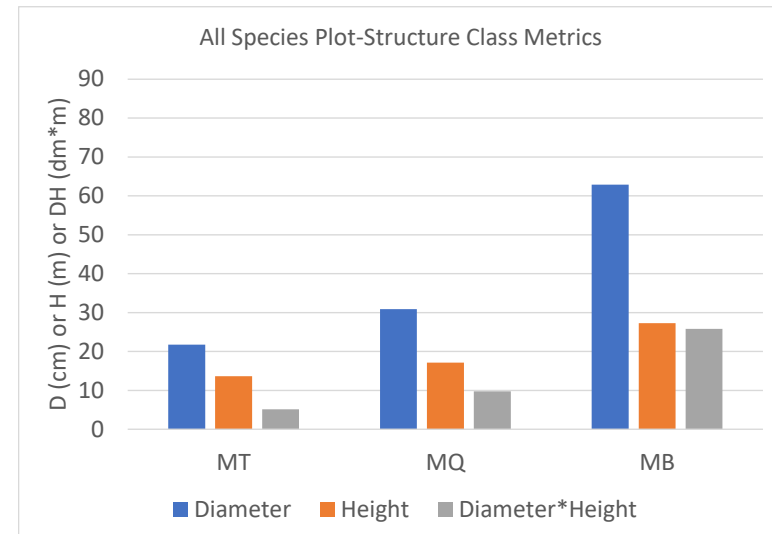
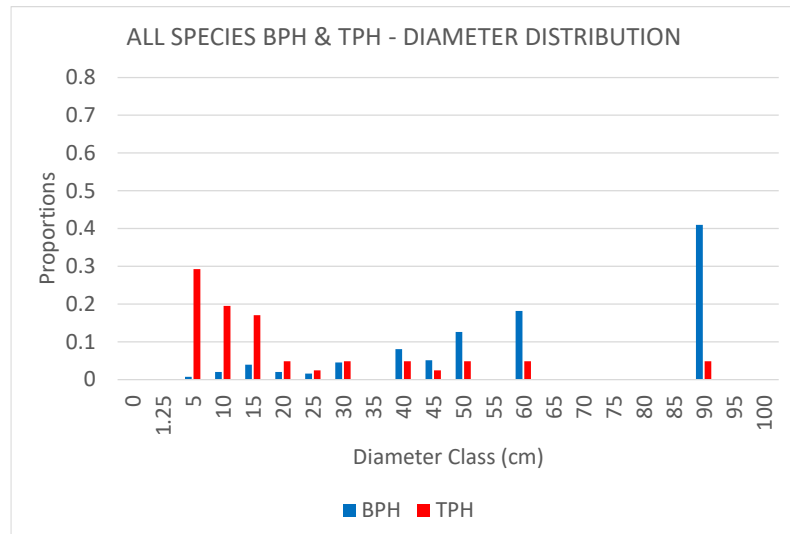
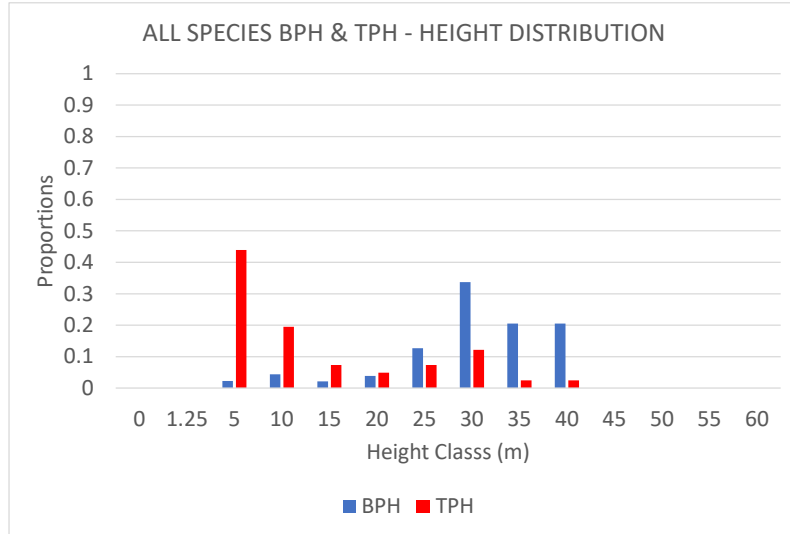


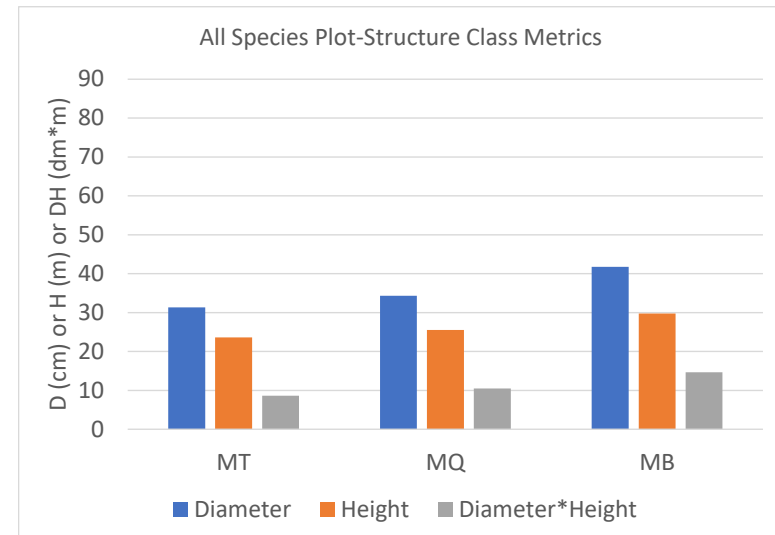
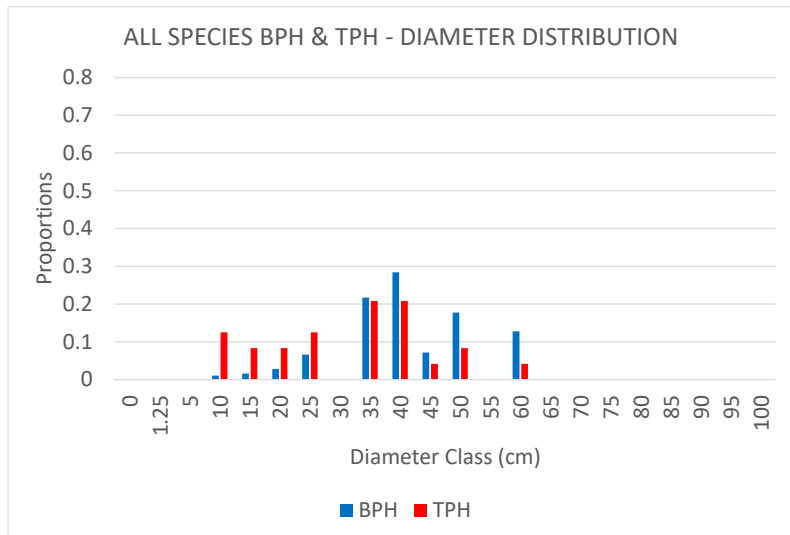
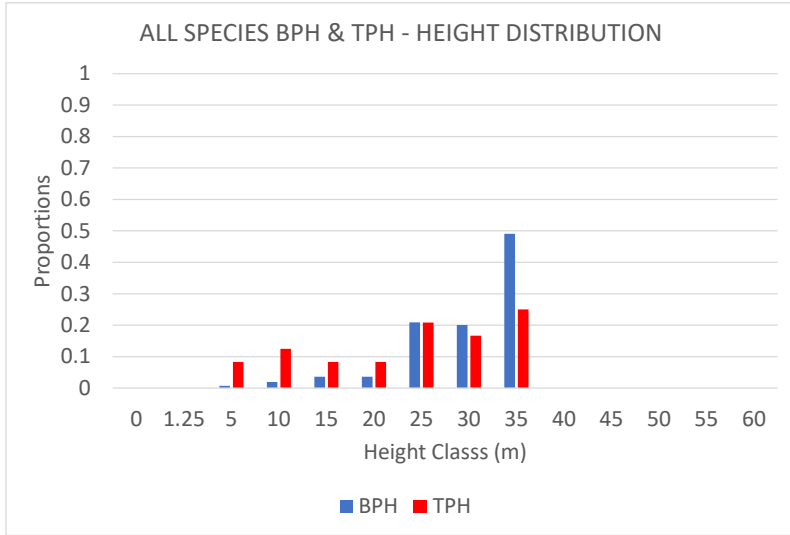


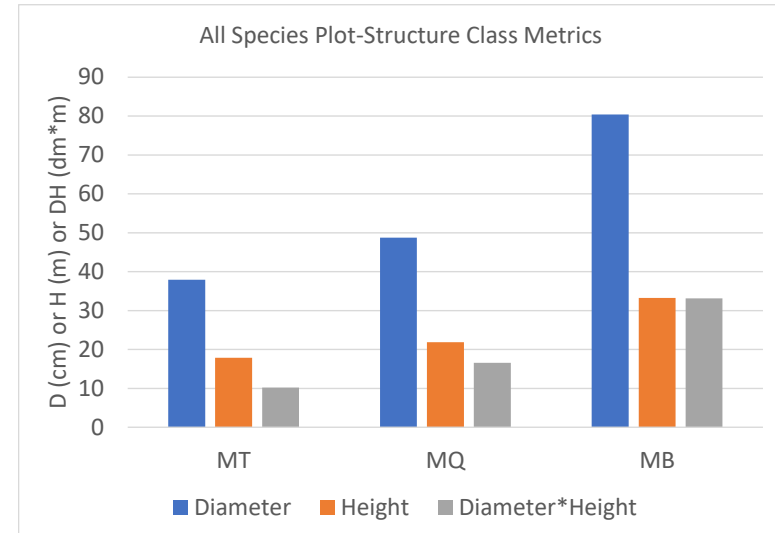
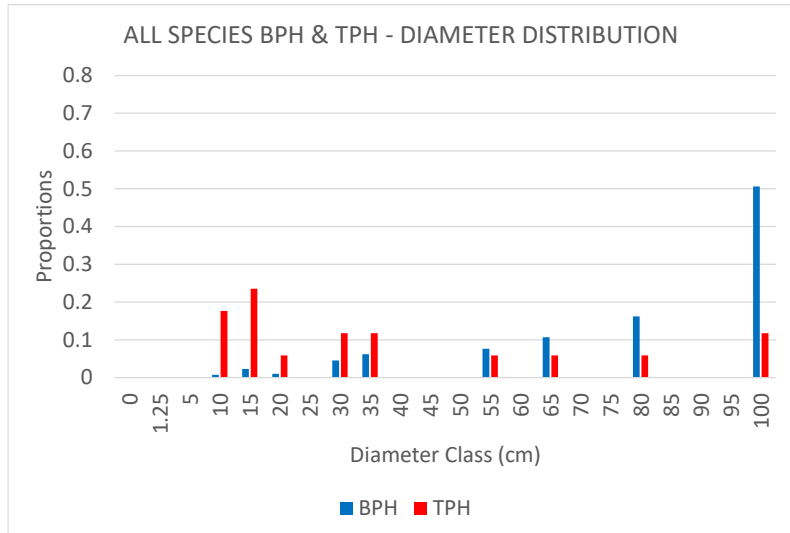
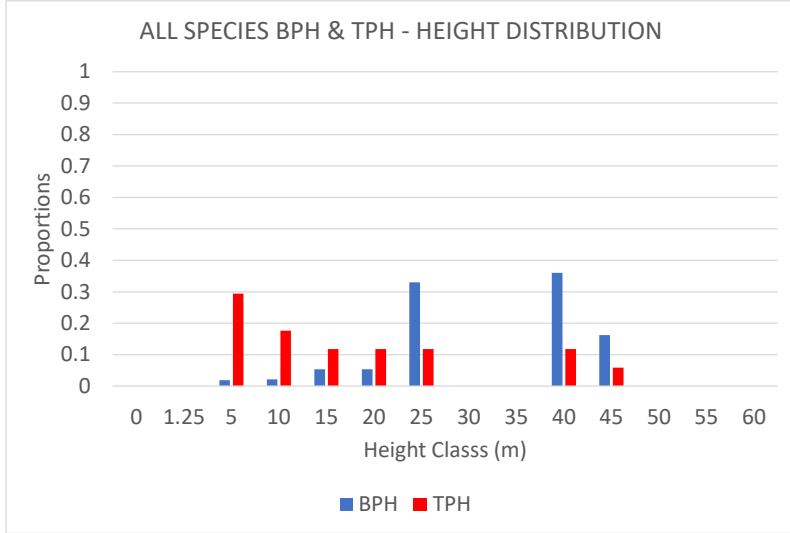


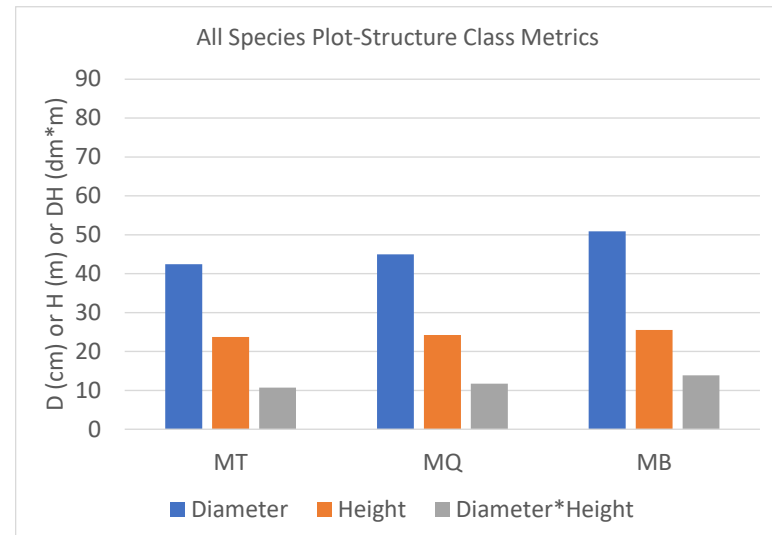
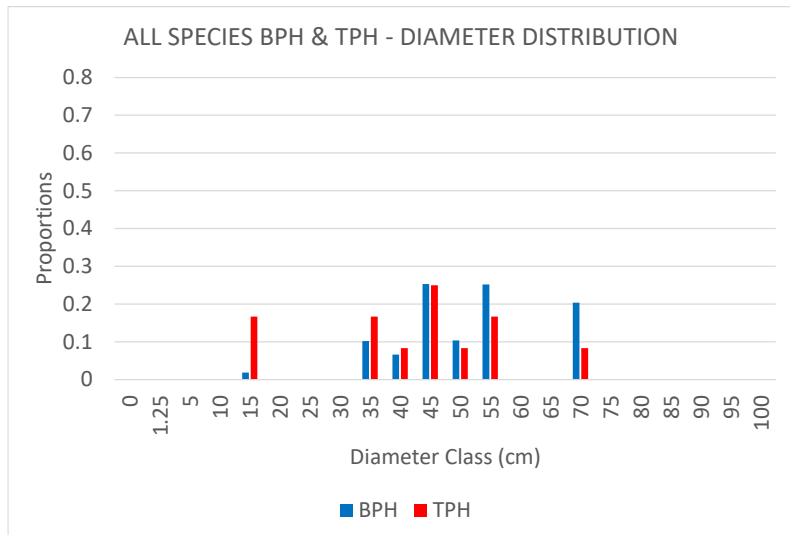
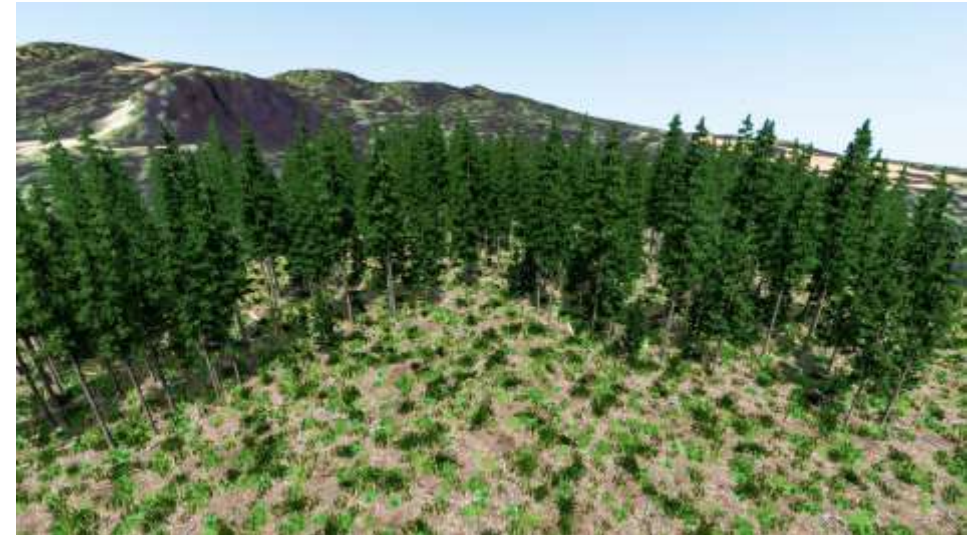
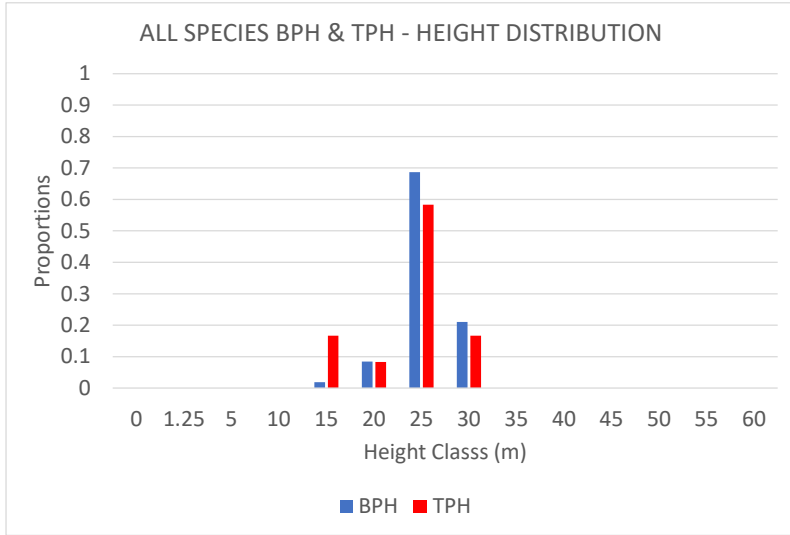


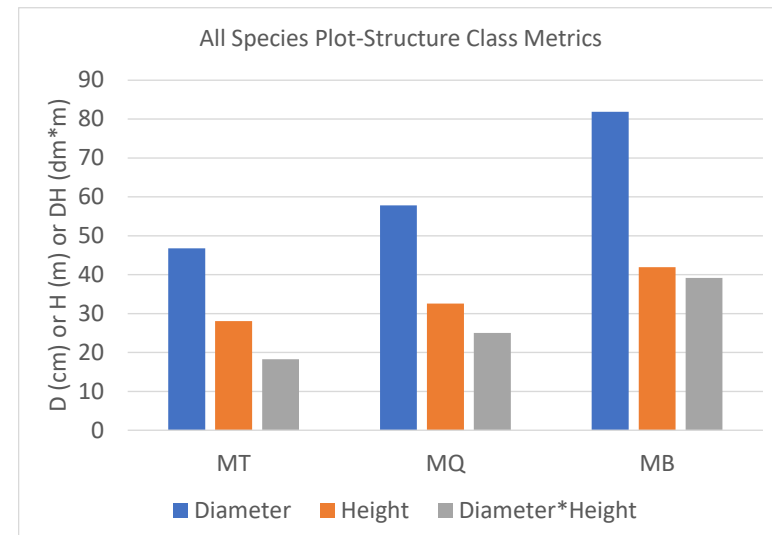
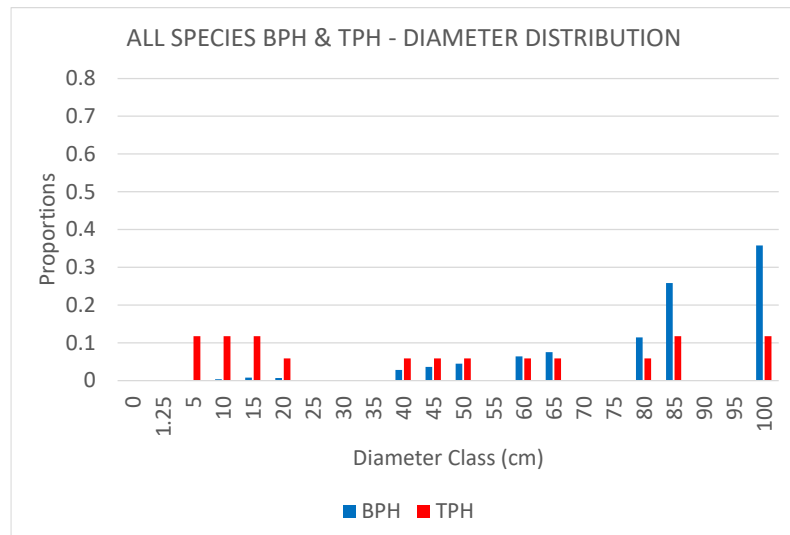
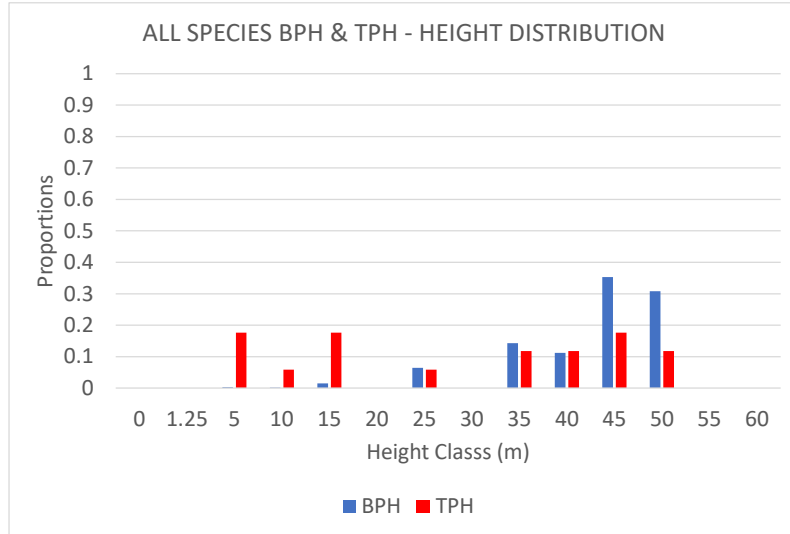














Thank You Again!

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