Why multitemporal ALS forest metrics remain challenging: Insights from operational airborne laser scanning

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Supplementary Material

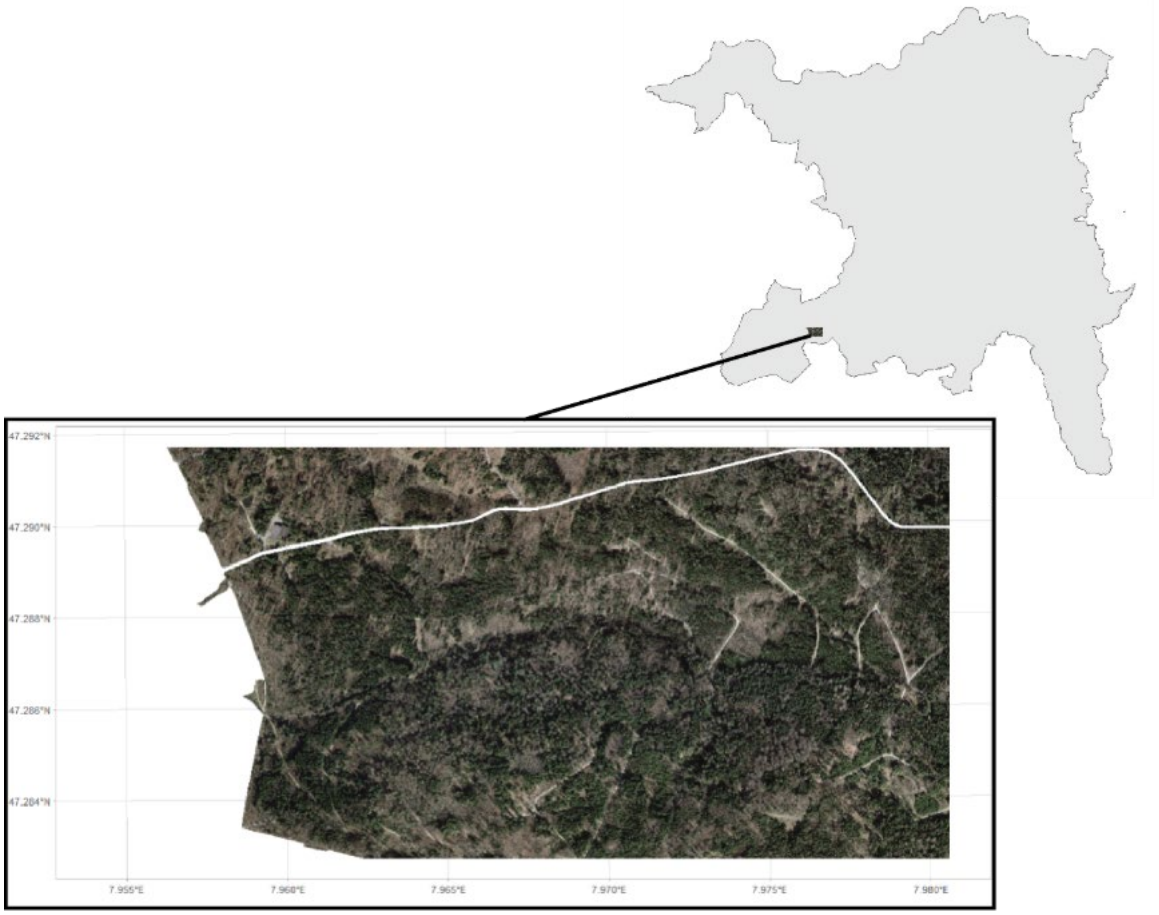

Figure S1. Forest used for the sensitivity analysis and its location in the Canton Aargau. (Federal Office of Topography swisstopo, 2022)

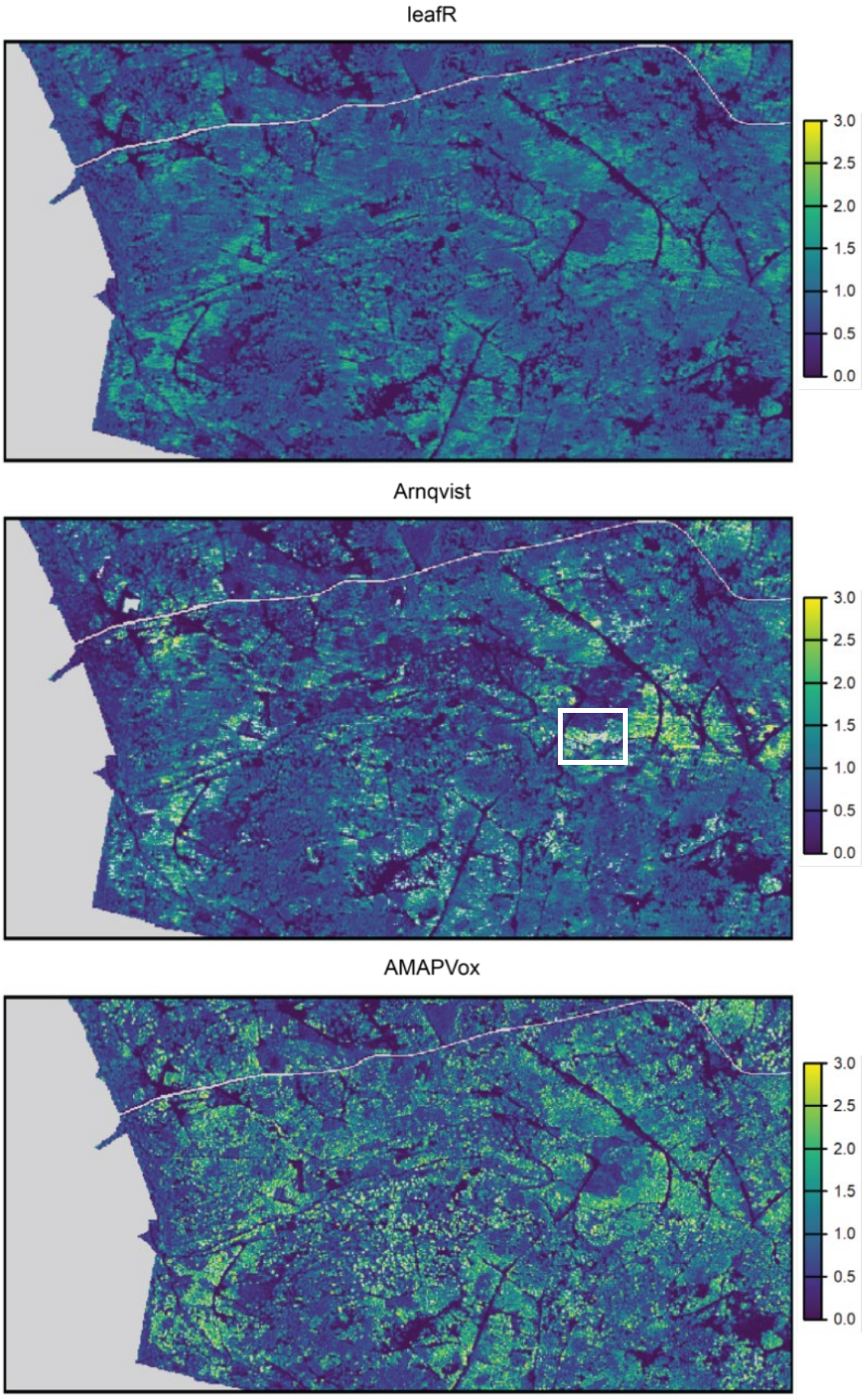

Figure S2. Outputs of the three PAI estimation methods in the forest used for the sensitivity analysis (see Figure S1). In dense forest areas (see white square), no values (=grey pixels) were estimated using the Arnqvist method due to the lack of ground points.

Overview of test areas

Table S1. List of different test areas used in the study, including their exact use.

	Area [km^2]	Usage	Notes
Total CH test area	144.9	CH (H95 and Hmax)	
Total PAI test area	56.1	PAI leafR PAI Arnqvist PAI AMAPVox	
Reference forest	2.2	Comparison between the different PAI estimation methods.	The reference forest consists of multiple isolated pixels distributed over the entire area.
Sensitivity test area	1.7	Forest patch used for the sensitivity analysis (see Figure S1)	

Statistical analysis of interannual consistency

Summary for CH

Table S2. Summary of paired Wilcoxon signed-rank and Kolmogorov–Smirnov test results for canopy height (**CH**) across all interannual comparisons (2014–2019, 2014–2020 and 2019–2020). Reported values include median and interquartile range (IQR) of pixel-wise differences, Wilcoxon test statistics, and Kolmogorov–Smirnov D statistics.

Comparison	Median_diff	IQR_diff	Wilcox_W	Wilcox_p	KS_D	KS_p
2014 vs 2019	0.92	2.52	1.53E+14	0	0.013	0
2014 vs 2020	1.14	2.99	1.6E+14	0	0.013	0
2019 vs 2020	0.13	0.68	1.71E+14	0	0.006	0

Summary for PAI: leafR, Arnqvist, AMAPVox

Table S3. Summary of paired Wilcoxon signed-rank and Kolmogorov–Smirnov test results for PAI (**leafR**) across all interannual comparisons (2014–2019, 2014–2020 and 2019–2020). Reported values include median and interquartile range (IQR) of pixel-wise differences, Wilcoxon test statistics, and Kolmogorov–Smirnov D statistics.

Comparison	Median_diff	IQR_diff	Wilcox_W	Wilcox_p	KS_D	KS_p
2014 vs 2019	-0.251	0.627	4.83E+14	<0.001	0.234	<0.001
2014 vs 2020	0.104	0.675	2.62E+14	<0.001	0.070	<0.001
2019 vs 2020	0.347	0.473	7.54E+13	<0.001	0.282	<0.001

Table S4. Summary of paired Wilcoxon signed-rank and Kolmogorov–Smirnov test results for PAI (**Arnqvist**) across all interannual comparisons (2014–2019, 2014–2020 and 2019–2020). Reported values include median and interquartile range (IQR) of pixel-wise differences, Wilcoxon test statistics, and Kolmogorov–Smirnov D statistics.

Comparison	Median_diff	IQR_diff	Wilcox_W	Wilcox_p	KS_D	KS_p
2014 vs 2019	-0.450	1.117	4.35E+14	<0.001	0.223	<0.001
2014 vs 2020	0.244	1.065	2.1E+14	<0.001	0.069	<0.001
2019 vs 2020	0.670	0.943	7.88E+13	<0.001	0.282	<0.001

Table S5. Summary of paired Wilcoxon signed-rank and Kolmogorov–Smirnov test results for PAI (**AMAPVox**) across all interannual comparisons (2014–2019, 2014–2020 and 2019–2020). Reported values include median and interquartile range (IQR) of pixel-wise differences, Wilcoxon test statistics, and Kolmogorov–Smirnov D statistics.

Comparison	Median_diff	IQR_diff	Wilcox_W	Wilcox_p	KS_D	KS_p
2014 vs 2019	-0.263	1.758	5.65E+13	<0.001	0.159	<0.001
2014 vs 2020	0.275	1.719	3.66E+13	<0.001	0.032	<0.001
2019 vs 2020	0.564	1.195	2.22E+13	<0.001	0.187	<0.001

Summary for PAI: forest classes and reference forest

Table S6. Summary of paired Wilcoxon signed-rank and Kolmogorov–Smirnov test results for PAI (**leafR**) across all interannual comparisons (2014–2019, 2014–2020 and 2019–2020) and forest classes including reference forest (con = coniferous forest, mix_con = mixed coniferous forest, mix_dec = mixed deciduous forest, dec = deciduous forest, ref_forest = reference forest). Reported values include median and interquartile range (IQR) of pixel-wise differences, Wilcoxon test statistics, and Kolmogorov–Smirnov D statistics.

ForestClass	Comparison	Median_diff	IQR_diff	Wilcox_W	Wilcox_p	KS_D	KS_p
con	2014 vs 2019	-0.156	1.623	5.98707E+12	<0.001	0.083	<0.001
con	2014 vs 2020	0.147	1.635	4.79862E+12	<0.001	0.016	<0.001
con	2019 vs 2020	0.279	1.153	3.64163E+12	<0.001	0.095	<0.001
mix_con	2014 vs 2019	-0.291	1.413	9.65693E+12	<0.001	0.140	<0.001
mix_con	2014 vs 2020	0.180	1.428	6.46779E+12	<0.001	0.024	<0.001
mix_con	2019 vs 2020	0.426	0.999	3.58087E+12	<0.001	0.152	<0.001
mix_dec	2014 vs 2019	-0.436	1.157	3.37233E+13	<0.001	0.221	<0.001
mix_dec	2014 vs 2020	0.240	1.127	1.68979E+13	<0.001	0.055	<0.001
mix_dec	2019 vs 2020	0.641	0.923	5.56613E+12	<0.001	0.266	<0.001
dec	2014 vs 2019	-0.552	0.886	8.62596E+13	<0.001	0.316	<0.001
dec	2014 vs 2020	0.296	0.854	2.64932E+13	<0.001	0.127	<0.001
dec	2019 vs 2020	0.851	0.731	4.24017E+12	<0.001	0.432	<0.001
ref_forest	2014 vs 2019	-0.069	0.988	10914891488	<0.001	0.059	<0.001
ref_forest	2014 vs 2020	0.128	1.006	8261595940	<0.001	0.070	<0.001
ref_forest	2019 vs 2020	0.205	0.682	6307103155	<0.001	0.127	<0.001

Table S7. Summary of paired Wilcoxon signed-rank and Kolmogorov–Smirnov test results for PAI (**Arnqvist**) across all interannual comparisons (2014–2019, 2014–2020 and 2019–2020) and forest classes including reference forest (con = coniferous forest, mix_con = mixed coniferous forest, mix_dec = mixed deciduous forest, dec = deciduous forest, ref_forest = reference forest). Reported values include median and interquartile range (IQR) of pixel-wise differences, Wilcoxon test statistics, and Kolmogorov–Smirnov D statistics.

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con	2019 vs 2020	0.279	1.153	3.64163E+12	<0.001	0.095	<0.001
mix_con	2014 vs 2019	-0.291	1.413	9.65693E+12	<0.001	0.140	<0.001
mix_con	2014 vs 2020	0.180	1.428	6.46779E+12	<0.001	0.024	<0.001
mix_con	2019 vs 2020	0.426	0.999	3.58087E+12	<0.001	0.152	<0.001
mix_dec	2014 vs 2019	-0.436	1.157	3.37233E+13	<0.001	0.221	<0.001
mix_dec	2014 vs 2020	0.240	1.127	1.68979E+13	<0.001	0.055	<0.001
mix_dec	2019 vs 2020	0.641	0.923	5.56613E+12	<0.001	0.266	<0.001
dec	2014 vs 2019	-0.552	0.886	8.62596E+13	<0.001	0.316	<0.001
dec	2014 vs 2020	0.296	0.854	2.64932E+13	<0.001	0.127	<0.001
dec	2019 vs 2020	0.851	0.731	4.24017E+12	<0.001	0.432	<0.001
ref_forest	2014 vs 2019	-0.043	1.662	6224539151	<0.001	0.046	<0.001
ref_forest	2014 vs 2020	0.325	1.529	4443584968	<0.001	0.095	<0.001
ref_forest	2019 vs 2020	0.338	1.331	4232206256	<0.001	0.126	<0.001

Table S8. Summary of paired Wilcoxon signed-rank and Kolmogorov–Smirnov test results for PAI (**AMAPVox**) across all interannual comparisons (2014–2019, 2014–2020 and 2019–2020) and forest classes including reference forest (con = coniferous forest, mix_con = mixed coniferous forest, mix_dec = mixed deciduous forest, dec = deciduous forest, ref_forest = reference forest). Reported values include median and interquartile range (IQR) of pixel-wise differences, Wilcoxon test statistics, and Kolmogorov–Smirnov D statistics.

ForestClass	Comparison	Median_diff	IQR_diff	Wilcox_W	Wilcox_p	KS_D	KS_p
con	2014 vs 2019	-0.156	1.623	5.98707E+12	<0.001	0.083	<0.001
con	2014 vs 2020	0.147	1.635	4.79862E+12	<0.001	0.016	<0.001
con	2019 vs 2020	0.279	1.153	3.64163E+12	<0.001	0.095	<0.001
mix_con	2014 vs 2019	-0.291	1.413	9.65693E+12	<0.001	0.140	<0.001
mix_con	2014 vs 2020	0.180	1.428	6.46779E+12	<0.001	0.024	<0.001
mix_con	2019 vs 2020	0.426	0.999	3.58087E+12	<0.001	0.152	<0.001
mix_dec	2014 vs 2019	-0.436	1.157	3.37233E+13	<0.001	0.221	<0.001
mix_dec	2014 vs 2020	0.240	1.127	1.68979E+13	<0.001	0.055	<0.001
mix_dec	2019 vs 2020	0.641	0.923	5.56613E+12	<0.001	0.266	<0.001
dec	2014 vs 2019	-0.552	0.886	8.62596E+13	<0.001	0.316	<0.001
dec	2014 vs 2020	0.296	0.854	2.64932E+13	<0.001	0.127	<0.001
dec	2019 vs 2020	0.851	0.731	4.24017E+12	<0.001	0.432	<0.001
ref_forest	2014 vs 2019	0.270	2.710	4460829642	<0.001	0.056	<0.001
ref_forest	2014 vs 2020	0.561	2.916	3730766504	<0.001	0.074	<0.001
ref_forest	2019 vs 2020	0.307	2.005	4357924009	<0.001	0.037	<0.001