Supplementary Materials: Detection of spatial and temporal patterns of liana infestation using satellite-derived imagery

Chris J. Chandler, Geertje M.F. van der Heijden, Doreen S. Boyd and Giles M. Foody
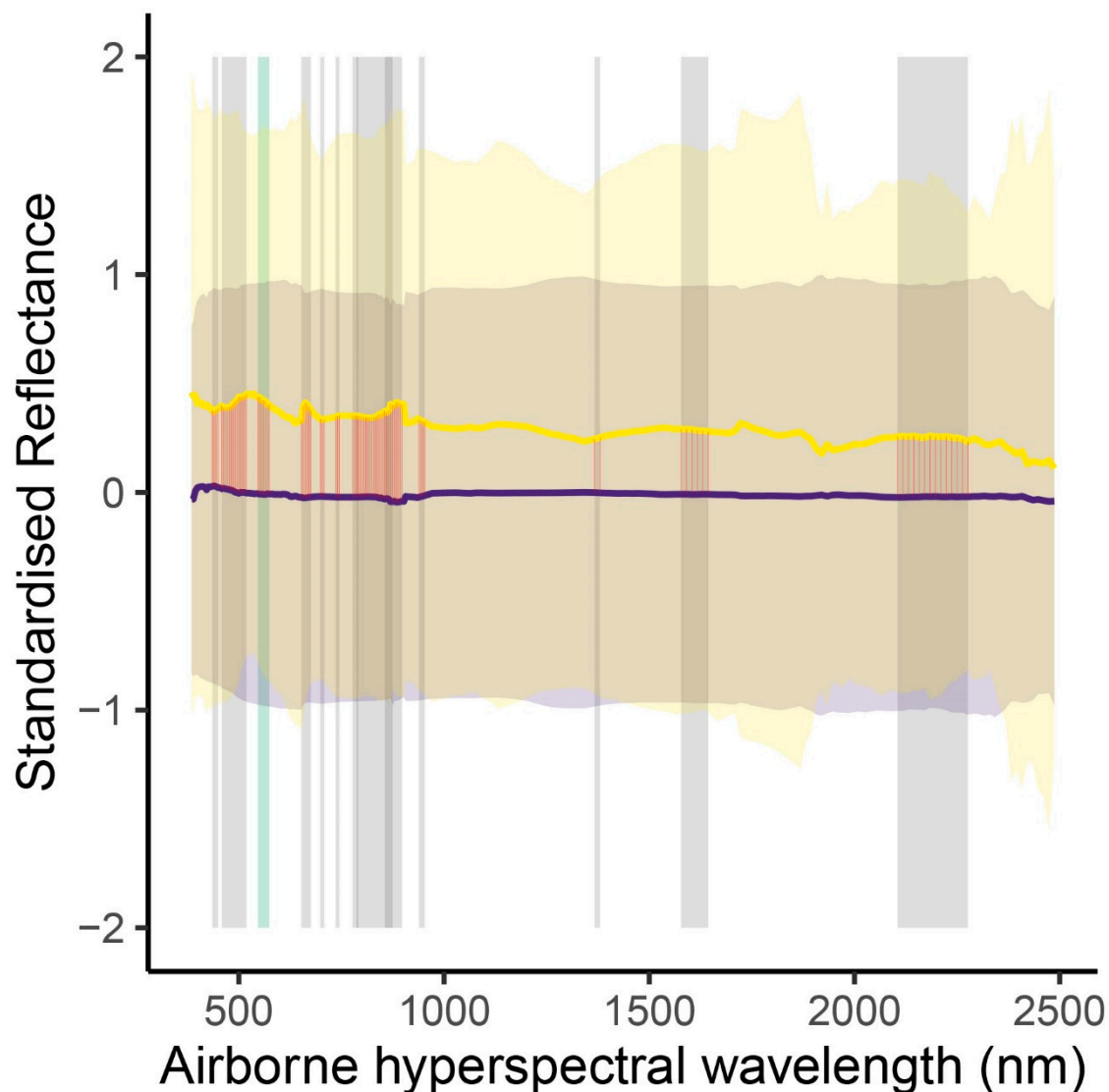
Figure S1. Airborne-derived standardised ($\mu = 0$, $\sigma = 1$) hyperspectral reflectance of liana-free trees and trees severely infested with liana leaves. Lines are mean reflectance values for all trees (shading ± 1 SD). Blue lines represent liana-free trees ($n_{trees} = 226$, $n_{pixels} = 7826$), yellow lines represent trees highly infested with liana leaves ($n_{trees} = 41$, $n_{pixels} = 1001$). Grey vertical bars represent the position of Sentinel-2 bands. Red vertical lines correspond to airborne hyperspectral bands that are within Sentinel-2 bands. The green vertical bar indicates the green region of the spectra that shows the greatest difference between liana-free and liana-infested trees.

Table S1. Comparison of vegetation indices for the seperation of low (≤25%) and severe (≥75%) liana infestation classes within the primary and logged forests and across the full landscape for each of the four satellite-derived images (2016-2019). Values correspond to Cliff's *delta* effect sizes. Overall average corresponds to the average of the 4-year average for all locations. .

Year	Metric	All	Primary	Logged	Overall Average
2016	Green	0.43	0.32	0.09	
2017	Green	0.27	0.14	0.1	
2018	Green	0.2	0.11	0.27	
2019	Green	0.07	0.15	0.08	
Average	**Green**	**0.2425**	**0.18**	**0.135**	**0.185833**
2016	Greenness	0.39	0.41	0.27	
2017	Greenness	0.32	0.26	0.4	
2018	Greenness	0.22	0.15	0.32	
2019	Greenness	0.3	0.22	0.3	
Average	**Greenness**	**0.3075**	**0.26**	**0.3225**	**0.296667**
2016	CLG	0.05	0.13	0.02	
2017	CLG	0.07	0.07	0.17	
2018	CLG	0.09	0.03	0.08	
2019	CLG	0.34	0.33	0.27	
Average	**CLG**	**0.1375**	**0.14**	**0.135**	**0.1375**
2016	CLRE	0.13	0.08	0.03	
2017	CLRE	0.21	0.1	0.13	
2018	CLRE	0.05	0.03	0.13	
2019	CLRE	0.22	0.28	0.23	
Average	**CLRE**	**0.1525**	**0.1225**	**0.13**	**0.135**
2016	CTVI	0.23	0.37	0.21	
2017	CTVI	0.12	0.12	0.37	
2018	CTVI	0.21	0.16	0.3	
2019	CTVI	0.39	0.36	0.37	
Average	**CTVI**	**0.2375**	**0.2525**	**0.3125**	**0.2675**
2016	EVI	0.37	0.39	0.15	
2017	EVI	0.17	0.09	0.25	
2018	EVI	0.22	0.14	0.31	
2019	EVI	0.23	0.14	0.31	
Average	**EVI**	**0.2475**	**0.19**	**0.255**	**0.230833**
2016	GEMI	0.36	0.36	0.15	
2017	GEMI	0.16	0.08	0.26	
2018	GEMI	0.21	0.13	0.31	
2019	GEMI	0.18	0.1	0.28	
Average	**GEMI**	**0.2275**	**0.1675**	**0.25**	**0.215**
2016	GNDVI	0.21	0.3	0.14	
2017	GNDVI	0.04	0.01	0.27	
2018	GNDVI	0.18	0.11	0.26	
2019	GNDVI	0.25	0.21	0.3	
Average	**GNDVI**	**0.17**	**0.1575**	**0.2425**	**0.19**
2016	MNDWI	0.08	0.1	0.02	
2017	MNDWI	0.19	0.2	0.06	
2018	MNDWI	0.24	0.25	0.04	
2019	MNDWI	0.49	0.52	0.25	
Average	**MNDWI**	**0.25**	**0.2675**	**0.0925**	**0.203333**
2016	MSAVI	0.32	0.37	0.18	
2017	MSAVI	0.15	0.09	0.3	
2018	MSAVI	0.22	0.14	0.32	
2019	MSAVI	0.27	0.21	0.33	
Average	**MSAVI**	**0.24**	**0.2025**	**0.2825**	**0.241667**
2016	MSAVI2	0.35	0.37	0.16	
2017	MSAVI2	0.16	0.09	0.28	

Year	Index			
2018	MSAVI2	0.22	0.13	0.31	
2019	MSAVI2	0.22	0.15	0.3	
Average	**MSAVI2**	**0.2375**	**0.185**	**0.2625**	**0.228333**
2016	MTCI	0.31	0.18	0.13	
2017	MTCI	0.42	0.32	0.2	
2018	MTCI	0.17	0.03	0.06	
2019	MTCI	0.22	0.14	0.07	
Average	**MTCI**	**0.28**	**0.1675**	**0.115**	**0.1875**
2016	NBRI	0.04	0.12	0.12	
2017	NBRI	0.14	0.21	0.25	
2018	NBRI	0.11	0.18	0.19	
2019	NBRI	0.18	0.25	0.03	
Average	**NBRI**	**0.1175**	**0.19**	**0.1475**	**0.151667**
2016	NDREI	0.08	0.13	0.01	
2017	NDREI	0.13	0.02	0.19	
2018	NDREI	0.02	0.07	0.16	
2019	NDREI	0.24	0.31	0.24	
Average	**NDREI**	**0.1175**	**0.1325**	**0.15**	**0.133333**
2016	NDREI2	0.13	0.08	0.03	
2017	NDREI2	0.21	0.1	0.13	
2018	NDREI2	0.05	0.03	0.13	
2019	NDREI2	0.22	0.28	0.23	
Average	**NDREI2**	**0.1525**	**0.1225**	**0.13**	**0.135**
2016	NDVI	0.23	0.37	0.21	
2017	NDVI	0.12	0.12	0.37	
2018	NDVI	0.21	0.16	0.3	
2019	NDVI	0.39	0.36	0.37	
Average	**NDVI**	**0.2375**	**0.2525**	**0.3125**	**0.2675**
2016	NDWI	0.21	0.3	0.14	
2017	NDWI	0.04	0.01	0.27	
2018	NDWI	0.18	0.11	0.26	
2019	NDWI	0.25	0.21	0.3	
Average	**NDWI**	**0.17**	**0.1575**	**0.2425**	**0.19**
2016	NDWI2	0.13	0.2	0.14	
2017	NDWI2	0.11	0.16	0.21	
2018	NDWI2	0.05	0.1	0.24	
2019	NDWI2	0.21	0.26	0.06	
Average	**NDWI2**	**0.125**	**0.18**	**0.1625**	**0.155833**
2016	NRVI	0.23	0.37	0.21	
2017	NRVI	0.12	0.12	0.37	
2018	NRVI	0.21	0.16	0.3	
2019	NRVI	0.39	0.36	0.37	
Average	**NRVI**	**0.2375**	**0.2525**	**0.3125**	**0.2675**
2016	REIP	0.02	0.21	0.07	
2017	REIP	0.04	0.11	0.24	
2018	REIP	0.05	0.11	0.12	
2019	REIP	0.27	0.32	0.21	
Average	**REIP**	**0.095**	**0.1875**	**0.16**	**0.1475**
2016	RVI	0.23	0.37	0.21	
2017	RVI	0.12	0.12	0.37	
2018	RVI	0.21	0.16	0.3	
2019	RVI	0.39	0.36	0.37	
Average	**RVI**	**0.2375**	**0.2525**	**0.3125**	**0.2675**
2016	SLAVI	0.17	0.26	0.17	
2017	SLAVI	0.05	0.08	0.28	
2018	SLAVI	0.007	0.05	0.26	
2019	SLAVI	0.02	0.07	0.16	

Average	**SLAVI**	**0.06175**	**0.115**	**0.2175**	**0.131417**
2016	SR	0.23	0.37	0.21	
2017	SR	0.12	0.12	0.37	
2018	SR	0.21	0.16	0.3	
2019	SR	0.39	0.36	0.37	
Average	**SR**	**0.2375**	**0.2525**	**0.3125**	**0.2675**
2016	TTVI	0.23	0.37	0.21	
2017	TTVI	0.12	0.12	0.37	
2018	TTVI	0.21	0.16	0.3	
2019	TTVI	0.39	0.36	0.37	
Average	**TTVI**	**0.2375**	**0.2525**	**0.3125**	**0.2675**
2016	TVI	0.23	0.37	0.21	
2017	TVI	0.12	0.12	0.37	
2018	TVI	0.21	0.16	0.3	
2019	TVI	0.39	0.36	0.37	
Average	**TVI**	**0.2375**	**0.2525**	**0.3125**	**0.2675**

Green, Green reflectance; **Greenness**, Greenness Index; **CLG**, Green-band Chlorophyll Index; **CLRE**, Red-edge-band Chloropphyll Index; **CTVI**, Corrected transformed vegetation index; **EVI**, Enhanced vegetation index; **GEMI**, Global environmental monitoring index; **GNDVI**, Green normalised difference vegetation index; **MNDWI**, modified normalised difference water index; **MSAVI**, modified soil adjusted vegeation index; **MSAVI2**, modified soil adjusted vegeation index 2; **MTCI**, MERIS terrestrail chlorophyll index; **NBRI**, normalised burn ratio index; **NDREI1**, normalised difference red edge index1; **NDREI2**, normalised difference red edge index2; **NDVI**, normalised difference vegetation index; **NDWI**, normalised difference water index; **NDWI2**, normalised difference water index2; **NRVI**, normalised ration vegetation index; **REIP**, red edge inflection point; **RVI**, ratio vegetation index; **SLAVI**, specific leaf area vegetation index; **SR**, simple ratio vegetation index; **TTVI**, Thiam's transformed vegeation index; **TVI**, transformed vegetation index.

Table S2. Accuracy assessment for predicted liana infestation in satellite-based multispectral imagery using three different sets of input variables: 1) all Sentinel 2-bands, 2) Greenness Index 3) all Sentinel 2-bands and Greenness Index within the primary and selectively logged forests. 95%CI, 95% confidence intervals for accuracy; Bal. Acc., Balanced Accuracy = (*sensitivity* + *specificity*)/2; F$_1$, F$_1$ score or F-measure; AUC, Area under the curve.

Class	Accuracy	95% CI	Sensitivity	Specificity	Bal. Acc	F1	AUC
1)	**All Sentinel-2 bands**						
	Primary						
	2 classes: [0-25], [75-100]						
	0.99	0.976-1	1	0.97	0.98	0.99	0.98
	4 Classes: [0-25], [25-50], [50-75], [75-100]						
	0.45	0.44-0.462					0.76
Class: L			0.56	0.78	0.67	0.3	
Class: M			0.55	0.53	0.54	0.54	
Class: H			0.32	0.87	0.6	0.42	
Class: S			0.24	0.98	0.61	0.32	
	Secondary						
	2 classes: [0-25], [75-100]						
	0.84	0.802-0.875	1	0.82	0.91	0.61	0.91
	4 Classes: [0-25], [25-50], [50-75], [75-100]						
	0.35	0.34-0.361					0.7
Class: L			0.38	0.86	0.62	0.08	
Class: M			0.59	0.51	0.55	0.41	
Class: H			0.28	0.75	0.51	0.37	

Class: S		0.2	0.96	0.58	0.29	

2)   Greenness Index

Primary

2 classes: [0-25], [75-100]

0.86	0.798-0.908	0.97	0.69	0.83	0.89	0.83

4 Classes: [0-25], [25-50], [50-75], [75-100]

0.45	0.442-0.464					0.61
Class: L		0.14	0.89	0.52	0.13	
Class: M		0.73	0.32	0.52	0.6	
Class: H		0.21	0.85	0.53	0.29	
Class: S		0.1	0.99	0.55	0.16	

Secondary

2 classes: [0-25], [75-100]

0.25	0.03-0.65	0	0.33	0.17	0	0

4 Classes: [0-25], [25-50], [50-75], [75-100]

0.39	0.38-0.401					0.59
Class: L		0	1	0.5	0	
Class: M		0.68	0.43	0.55	0.41	
Class: H		0.4	0.6	0.5	0.46	
Class: S		0	1	0.5	0	

3)   All Sentinel-2 bands + Greenness Index

Primary

2 classes: [0-25], [75-100]

0.99	0.978-0.996	1	0.98	0.99	0.99	0.99

4 Classes: [0-25], [25-50], [50-75], [75-100]

0.48	0.473-0.495					0.8
Class: L		0.61	0.79	0.7	0.32	
Class: M		0.51	0.64	0.58	0.54	
Class: H		0.43	0.84	0.64	0.5	
Class: S		0.39	0.96	0.68	0.4	

Secondary

2 classes: [0-25], [75-100]

0.88	0.849-0.914	0.947	0.874	0.91	0.7	0.91

4 Classes: [0-25], [25-50], [50-75], [75-100]

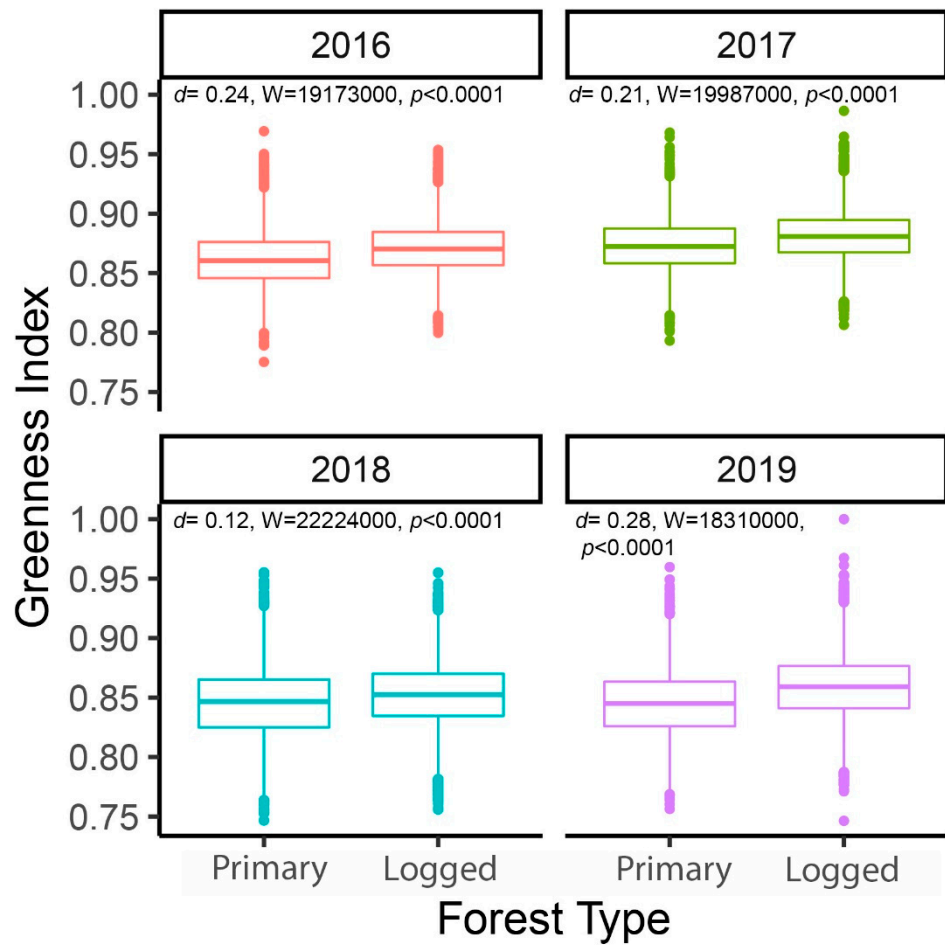|						
0.37	0.359-0.38					0.71
Class: L		0.36	0.86	0.61	0.08	
Class: M		0.58	0.52	0.55	0.41	
Class: H		0.32	0.75	0.53	0.41	
Class: S		0.21	0.97	0.59	0.3	

Figure S2. Difference in greenness between the primary and logged forest for imagery collected from 2016 to 2019. Statistically significant differences in greenness values between primary and logged forests are indicated with Cliff's *delta* (*d*), as a measure of effect size, and a 2 sample Wilcox test.