Supplementary Material to draft manuscript:

"A MACHINE LEARNING APPROACH TO MAP TROPICAL SELECTIVE LOGGING "

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Table S1. Confusion matrix summarizing Random Forest (RF) model classifications of logged and unlogged observations at Jamari derived from Landsat data at labelled points (observations before and after selective logging). Data were split into 75% training and 25% validation. Matrix numbers are pixel counts with the validation data (early n = 17,809 and late n = 17,847). The classification threshold (T) for RF models was set during model calibration such that the proportion of detections that were truly logged (d_{pL}) was fixed at 0.85, resulting in a T of 0.69 and 0.66 for the early and late datasets, respectively. The corresponding values for overall accuracy (OA), Cohen's kappa (k), the proportion of detected pixels that were truly logged (d_{pL}), and the detection probability (P_d) are provided.

EARLY					**LATE**				
OA: 89.96 k: 0.50 d_{pL}: 0.77 P_d: 0.43		Reference Class Logged	 Unlogged	Commission Error (%)	OA: 91.0% k: 0.60 d_{pL}: 0.81 P_d: 0.54		Reference Class Logged	 Unlogged	Commission Error (%)
Predicted Class	Logged	1116	328	22.7	Predicted Class	Logged	1390	331	19.2
	Unlogged	1470	14900	9.0		Unlogged	1187	14943	7.4
Omission Error (%)		56.8	2.2		Omission Error (%)		46.1	2.2	

1. Landsat pixel inputs for Random Forest models

Table S2. Number of pixels from each forest management unit (FMU) used to build Random Forest models to detect selective logging with early and late Landsat scenes. Numbers of pixels from imagery acquired in 2012 are lower because of missing data regions resulting from the scan-line corrector error aboard Landsat 7.

Time period	Cut status	FMU	Image year								
EARLY			2008	2009	2010	2011	2012	2013	2014	2015	2016
	Unlogged										
		FMU 1	2554	2554							
		FMU 2	2728	2728	2728						
		FMU 3	1633	1633	1633	1633					
		FMU 4	2128	2128	2128	2128	1540				
		FMU 5	2658	2658	2658	2658	1898	2658			
		FMU 6	2000	2000	2000	2000	1474	2000	2000		
	Logged										
		FMU 1				2555					
		FMU 2					2035				
		FMU 3						1633			
		FMU 4							2128		
		FMU 5								2658	
LATE											
	Unlogged										
		FMU 1	2554	2554							
		FMU 2	2728	2728	2728						
		FMU 3	1633	1633	1633	1633					
		FMU 4	2128	2128	2128	2128	1531				
		FMU 5	2658	2658	2658	2658	1870	2658			
		FMU 6	2000	2000	2000	2000	1463	2000	2000		
	Logged										
		FMU 1					1894				
		FMU 2						2728			
		FMU 3							1633		
		FMU 4								2128	
		FMU 5									2658

2. Detection of selective logging through time at Jamari

Table S3. Landsat 8 (OLI) scene dates used from path 232, row 066 used to create Figure 8 from the manuscript.

UPA2013	UPA2014	UPA2015	Unlogged
2013-07-10	2014-06-11	2015-06-14	2015-06-14
2013-07-26	2014-07-13	2015-06-30	2015-06-30
2013-08-11	2014-08-30	2015-08-01	2015-08-01
2013-08-27		2015-08-17	2015-08-17
		2015-09-02	2015-09-02

3. Comparisons with CLASlite

3.1 The CLASlite software

CLASlite is an unsupervised, pixel-based classification program developed specifically for mapping tropical deforestation and forest degradation (Asner et al., 2009a). It employs a spectral unmixing model that utilizes a vast spectral library (>250,000 observations) to distinguish the proportion of three endmembers within each image pixel: Bare Ground (BG), Photosynthetic Vegetation (PV), and Non-Photosynthetic Vegetation (NPV) that collectively sum to 100%. Changes in endmember values between time steps (i.e. image pairs) are used to identify forest disturbances. Specifically, CLASlite looks for a sharp rise in NPV (i.e. dead and dying vegetation from felled trees) and a simultaneous drop in PV (i.e. canopy cover) or an increase in BG (from roads, skid trails, or log decks used to stack cut tree before transport) to identify forest disturbance associated with loss of tree cover. Detection of forest degradation by CLASlite is automated and changes in pixel values between time steps are labelled as degraded using an internal decision tree (Asner et al., 2009a).

3.2 Methods

CLASlite version 3.3 was used to process Landsat 5 TM, Landsat 7 ETM+ and Landsat 8 OLI scenes spaced approximately annually over the Jamari site between 2008 and 2016. CLASlite is actively

maintained and updated (e.g. Sentinel-2 capabilities have been recently added) and the developers have continued to add features that enable the user to adjust settings, given their knowledge of the study site. One such feature attempts to filter out pixels erroneously labelled as degraded by insisting that a pixel can only be classified as degraded if 5 pixels within its surrounding 7x7 window are also classified as degraded. This is because forest disturbances do not occur in isolation and other pixels in the neighbourhood would be expected to experience changes in endmember values related to degradation. This feature was turned off since the spectral signature of logging at Jamari was likely to be very subtle and we wished to give CLASlite the best opportunity to identify real changes. Hence all pixels that met CLASlite's criteria for changes in endmember values between time steps were labelled as degraded.

3.3 Results

3.3.1 CLASlite detection of degradation at Jamari

CLASlite did not label a single pixel as logged when using post-disturbance Landsat scenes (late), and, out of the 184 pixels labelled as logged in the full set of early time period images, only 34 (out of 11,006) had actually been logged. In addition, approximately 40% of CLASlite's detections were from the expansion of logging roads (Figure S2 and Table S2). Hence almost no degradation was detected by CLASlite in either the early or late time period Landsat scenes. Similarly, road networks were largely invisible, with only 74 pixels detected from more than 100 km of roads digitized in the Jamari site.

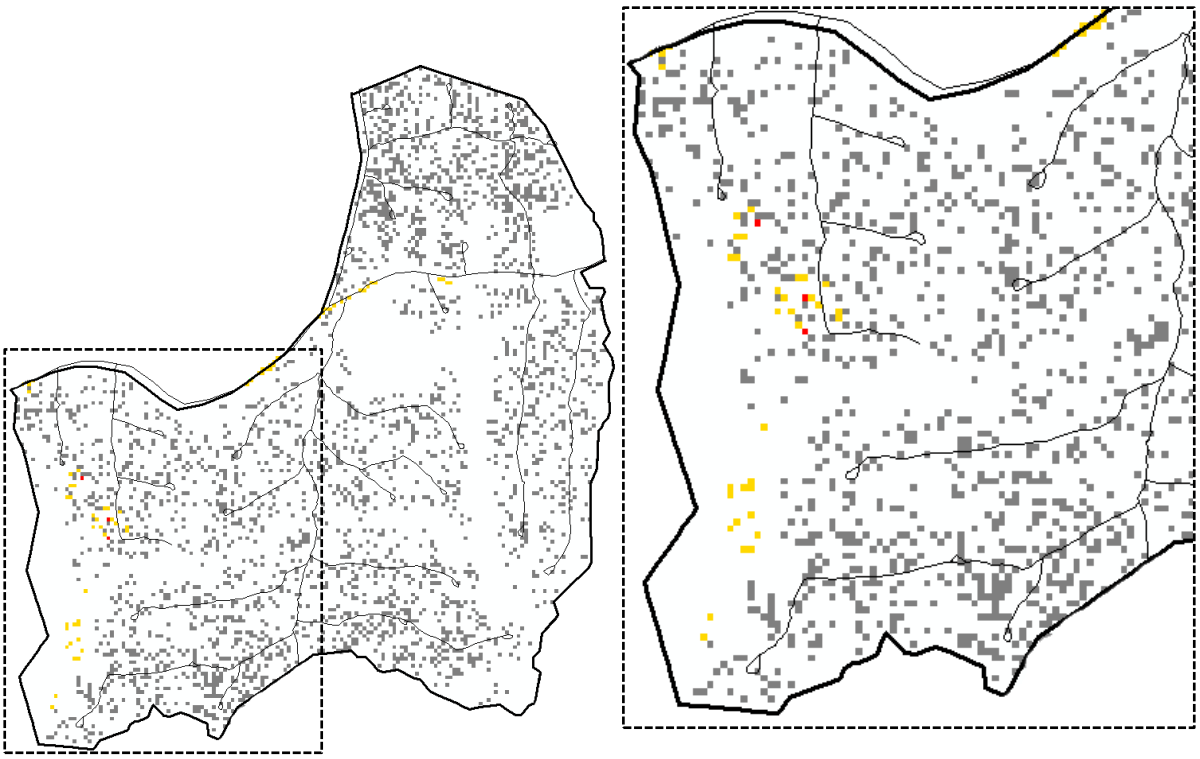

Figure S2. Example of a forest management unit in Jamari (logged in 2011) showing the locations of pixels that were logged in grey. CLASlite true and false detections using early Landsat scenes are shown as red and yellow respectively. GPS digitized logging roads are displayed as thin black lines. Pixels that coincided with mapped logging roads were removed from tallies of false detections.

Table S3. Summary of degradation detections by CLASlite using early Landsat scenes from the Jamari site between 2010 and 2015, with N_L and N_{UL} being the number of logged and unlogged observations, respectively. The time periods correspond to pre-logging and the year of logging for each forest management unit (FMU). From 2010 to 2014 logging road pixels were excluded from the number of false detections, however, only a partial road layer (a single, main access road) was available for the final FMU logged in 2015. Consequently road detections are underestimated and false detections are likely overestimated for FMU 5. The corresponding values for true (P_d) and false (P_{fd}) detection probabilities, the proportion of detections that were truly logged ($d_{p\mathrm{L}}$), and Cohen's kappa (κ) are also given.

FMU logged	Time period (years)	Approximate logging intensity (m^3 ha^{-1})	N_L (pixels)	N_{UL} (pixels)	CLASlite detections (pixels)	Road detections (pixels)	True detections (pixels)	False detections (pixels)	P_d (%)	P_{fd} (%)	$d_{p\mathrm{L}}$ (%)	Cohen's kappa[1] (κ)
1	2010-2011	8.5	2554	15109	70	32	3	35	0.12	0.23	7.89	-0.002
2	2011-2012	9.9	2724	13647	12	3	2	7	0.07	0.05	22.22	0.001
3	2012-2013	8.2	1633	19959	12	4	5	3	0.31	0.02	62.50	0.005
4	2013-2014	8.0	2128	17648	21	17	3	1	0.14	0.01	75.00	0.002
5	2014-2015	11.3	2658	18755	69	18	21	30	0.79	0.16	41.17	0.011

[1] negative values for Cohen's Kappa occur when agreement is smaller than would be expected by chance

3.3.2 CLASlite detections at Jari

CLASlite only labelled 71 ha of forest as degraded (Fig. S3). In addition, CLASlite does not correct for the Landsat 7 scan-line corrector error and missing data regions are not ignored. In contrast, RF models with early data labelled 2316 ha as logged (Fig. S3). Importantly, our method has the advantage of being able to make predictions about forest disturbances on a single scene to map degradation, as opposed to requiring successive cloud-free images, like CLASlite.

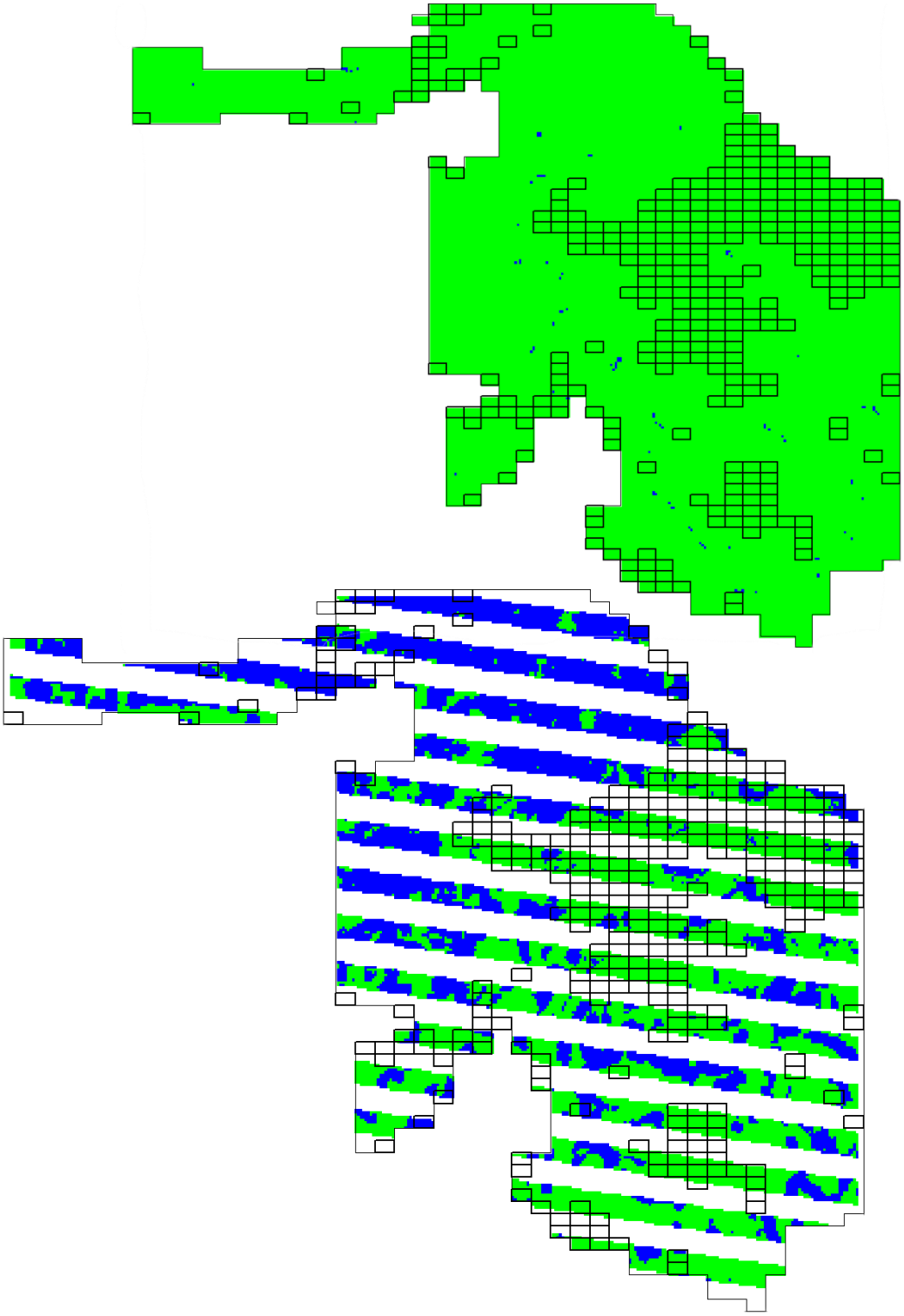

Figure S3. Classified maps of the Jari study site using CLASlite (top) and Random Forest (RF) models trained with early Landsat data (bottom). The image pairs used to create the classifications were from 8 November 2011 and 10 November 2012. Note that CLASlite does not correct for the Landsat 7 scan-line corrector error and missing data regions do not appear as white stripes. A threshold value of 0.65 was used for labelling logged pixels in RF models (see Table 2 in manuscript). Logged and unlogged forest pixels are displayed in blue and green, respectively. Black boxes are the 10 hectare blocks inside the Jari concession that were not logged.