Supplementary Materials: Identifying Establishment Years and Pre-Conversion Land Cover of Rubber Plantations in Hainan Island, China Using Landsat Data during 1987–2015. *Remote Sensing* 2018, *8*, Article No. remotesensing-322362

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2. Material and Methods

2.1. Landsat Imagery and Processing

The statistical information of Landsat imagery on Hainan Island is presented in Figure 2, and annual cloud-free observations is shown in Figure S1.

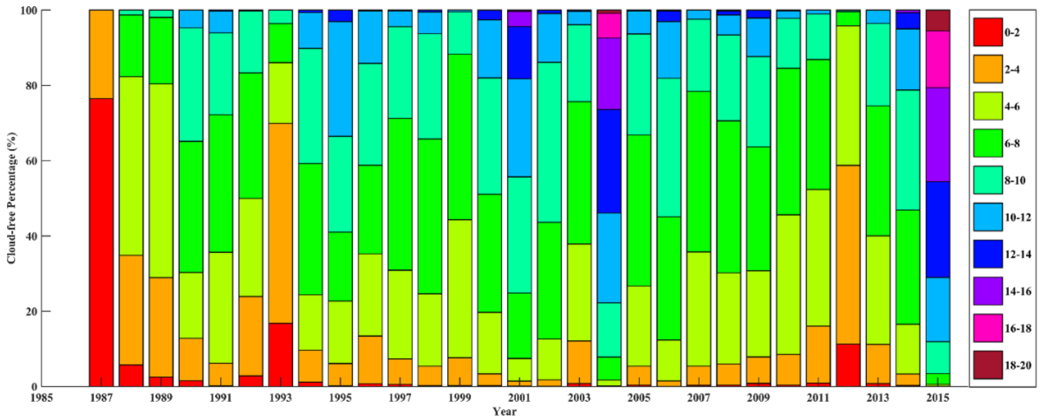

Figure S1. Percentage and count of annual cloud-free pixels statistics based on images acquired in rubber leaf-on season (April–December).

2.3.2. Data for Establishment Year Map of Rubber Plantation

The spatial distribution of these ROI samples was presented in Figure 1b and plantation statistics by year was presented in Figure S2.

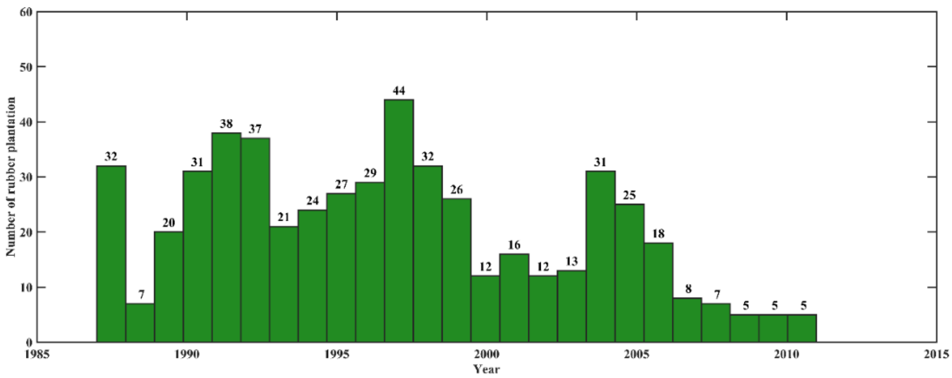

Figure S2. Statistical information of stand age for 522 rubber plantations in Hainan Island used for age map accuracy assessment.

2.4.2. Algorithm for Mapping Rubber Plantations in 2015

To generate the rubber plantation map of 2015, we first identified forest, then distinguished deciduous rubber plantations from the forest base map using phenological metrics [23,35,36]. The 2015 forest base map came from our previous study on the annual spatial-temporal of forest on Hainan Island during 2007–2015 using PALSAR/PALSAR-2 and time series Landsat TM/ETM+/OLI images [34,37]. This forest base map had an overall accuracy (OA) of ~96% when validated with ground reference data [34] and, therefore, can serve as a reliable base map for mapping rubber plantation. Then, deciduous rubber plantations were identified from this forest base map using the criteria of dense canopy in the growing season ($NDVI_{max} > 0.85$) and the criteria of rapid defoliation and foliation ($LSWI_{RDF\_min} < 0.1$, and $LSWI_{RDF\_Std.Dev} > 0.08$, See Figure S3 for justification). The $LSWI_{RDF\_min}$ and $LSWI_{RDF\_Std.Dev}$ were composited with Landsat ETM+/OLI images acquired in the RDF period of 2014 and 2015. A 3 × 3 median filter was performed on the resultant map to reduce the salt-and-pepper noise.

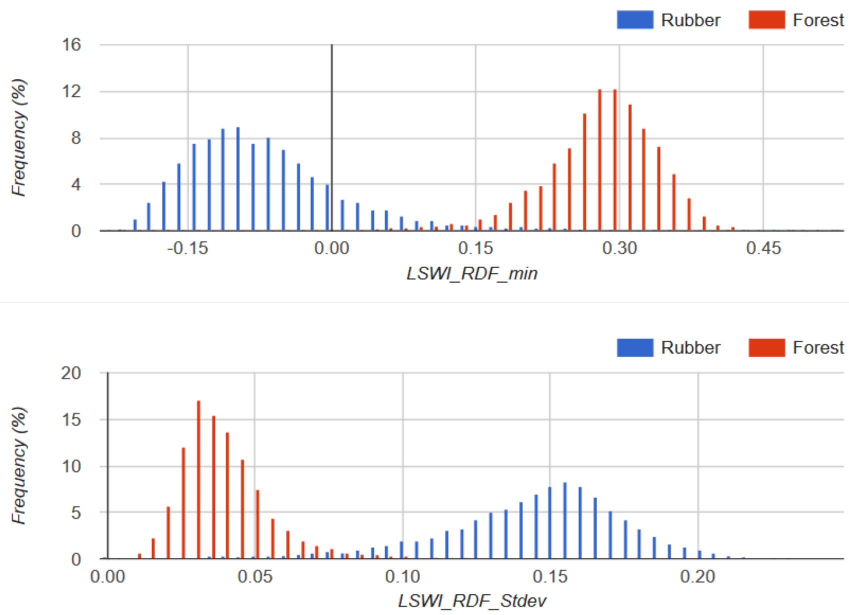

Figure S3. Separability of forest and rubber plantation based on $LSWI_{RDF\_min}$ and $LSWI_{RDF\_Stdev}$ which are composited from Landsat collection 1 TOA data acquired during RDF period (January–March) of 2014 and 2015. $LSWI_{RDF\_min} < 0.1$ and $LSWI_{RDF\_Stdev} > 0.08$ was selected for discriminating rubber plantations from the forest base map.

2.4.3. Algorithm for Identifying Establishment Year of Rubber Plantation

The thresholds of T0 and TSlope were determined by the statistical value of the training ROI samples. The LSWILeafon_min was always less than zero in the year that rubber plantation was established, and remained relatively small in the first few years (Figure 5). The SLSWI ranged from 0.03 to 0.05, with a mean value (μ) of about 0.04 (Table S1). We set T0 as 0 and the rounded value of mean $\mu - \sigma$ from the five rubber plantations as the Ts (0.03 here), where σ is the standard deviation. However, the rapid recovery of understory in young rubber plantations and frequent presence of clouds in the tropics made it difficult to acquire ideal observations (un-vegetated during plantation establishment and linear increase of LSWILeafon_avg). Thus, we employed the algorithm again with slightly higher thresholds of 0.1 for T0 and 0.02 for Ts to address the less optimal conditions (**Table S1**).

Table S1. Statistical information of slope (SLSWI), LSWILeafon_avg, and LSWILeafon_min based on rubber plantations established in 1990, 1995, 2000, 2005, and 2010, respectively.

		1990	1995	2000	2005	2010
Slope (S_{LSWI})	μ	0.05	0.03	0.04	0.04	0.04
	σ	0.01	0.00	0.03	0.01	0.01
	$\mu-\sigma$	0.04	0.02	0.01	0.04	0.04
	$\mu-2\sigma$	0.03	0.02	–0.02	0.03	0.03
$LSWI_{Leaf\_on\_avg}$	μ	–0.01	0.15	0.05	0.03	0.17
	σ	0.06	0.01	0.10	0.04	0.04
	$\mu+\sigma$	0.05	0.16	0.15	0.07	0.21
	$\mu+2\sigma$	0.11	0.18	0.24	0.12	0.25
$LSWI_{Leaf\_on\_min}$	μ	–0.06	–0.09	–0.07	–0.14	–0.05
	σ	0.05	0.02	0.11	0.06	0.03
	$\mu+\sigma$	–0.02	–0.07	0.04	–0.08	–0.02
	$\mu+2\sigma$	0.03	–0.05	0.15	–0.02	0.01

* μ indicates mean values, and σ stands for standard deviation, respectively.

We used $F_{Greenness} > 90\%$ as the criteria (see Figure S4 for justification) because rubber plantations on Hainan Island frequently suffered canopy damage from severe typhoons, which may cause rubber plantations to not meet a higher greenness criterion.

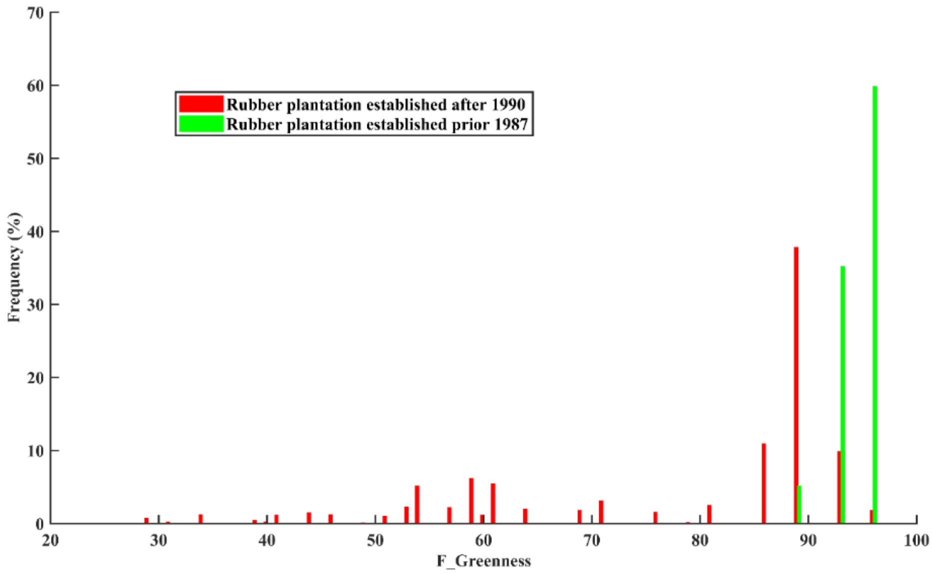

Figure S4. *F_Greenness* of rubber plantations established in different years. Field data of rubber plantations established after 1990 come from the five rubber plantations established in 1990, 1995, 2000, 2005, and 2010, respectively. Different pre-conversion land covers for five rubber plantations established after 1990 degrade *F_Greenness* values.

3. Results

3.1. Rubber Plantation Map and Accuracy Assessment

The PA, UA, and OA for the resultant map of rubber plantations were 95.18% (± 0.16%), 88.20% (± 0.29%), and 96.99% (± 0.07%) when validated with ground reference data (**Table S2**). The total mapped area of rubber plantations in 2015 was 5.83 × 105 ha, and the adjusted area was (6.30 ± 0.04) × 105 ha.

Table S2. Accuracy assessment of the 2015 rubber plantation map on Hainan Island using ROIs.

			Reference							
		Class	**Rubber**	**Non-Rubber**	**Total**	**Area (ha)**	**Wi (%)**	**UA (%)**	**PA (%)**	**OA (%)**
Map	**Sample Count-based**	**Rubber**	17,667	894	18,561	583,387	17.12	95.18	93.07	96.31
		Non-Rubber	1291	47,768	49,698	2,824,117	82.88	97.37	98.16	
		Total	18,958	48,662	67,620	3,407,504	100			
	Estimated area Proportions-based	**Rubber (%)**	16.30	0.82	17.12	629,605 ± 4385	18.48	95.18 ± 0.16	88.20 ± 0.29	96.99 ± 0.07
		Non-rubber (%)	2.18	80.70	82.88	2,777,899 ± 4385	81.52	97.37 ± 0.07	98.99 ± 0.03	
		Total (%)	18.48	81.52	100	3,407,504 ± 4385	100			

***PA**: producer's accuracy; **UA**: user's accuracy; **OA**: overall accuracy. Values followed with ± designate 95% confidence interval.

3.4. Pre-Conversion Land Covers of Rubber Plantations on Hainan Island

The PA, UA, and OA of the pre-conversion land cover map were >86.60% (±0.05%), >84.21% (±0.07%), and >88.60% (±0.03%), respectively (**Table S3**). Rubber plantations converted from cropland were densely distributed in the northwest and northern regions, specifically in Danzhou City and Changjiang, Baisha, Lingao, and Chengmai Counties (Figure 10). In addition, we found that many scattered rubber plantations in the western region (Dongfang City and Ledong County) were previously cropland. Rubber plantations converted from old rubber plantations were mainly located in the northwest (e.g., Baisha County and Danzhou City) and northern-central regions (e.g., Qiongzhong, Tunchang, and Chengmai Counties) (Figure 10). In Baoting County, Qionghai City, and Wanning City we also found that many rubber plantations were established on old rubber plantations (Figure 10). Rubber plantations converted from evergreen forests were mainly distributed in Chengmai County, near the boundary between Dingan and Tunchang Counties, and in the interior mountainous area. However, these evergreen forests were relatively sparsely distributed. We did not observe any large hotspots where evergreen forests were converted to rubber plantations.

Table S3. Accuracy assessment of the pre-conversion land cover map of rubber plantations on Hainan Island using random ROIs.

			Reference								
		Class	**EF**	**ORP**	**C**	**Total**	**Area (ha)**	**Wi (%)**	**UA (%)**	**PA (%)**	**OA (%)**
Map	**Sample Count-based**	**EF**	80	12	3	95	68,166	23.63	84.21	95.24	88.15
		ORP	1	102	9	112	125,652	43.56	91.07	80.31	
		C	3	13	123	139	94,607	32.81	88.49	91.11	
		Total	84	127	135	346	288,425	100			
	Estimated area Proportions-based	**EF (%)**	19.90	2.99	0.75	23.63	60,567 ± 9750	23.63	84.21 ± 0.07	94.78 ± 0.05	88.60 ± 0.03
		ORP (%)	0.39	39.68	3.50	43.46	131,892 ± 9750	43.56	97.37 ± 0.05	86.60 ± 0.05	
		C (%)	0.71	3.07	29.03	32.80	95,967 ± 9750	32.81	88.49 ± 0.05	87.24 ± 0.07	
		Total (%)	21.00	45.73	33.27	100	288,425 ± 9750	100			

* . **EF**: Evergreen forests; **ORP**: old rubber plantation; **C**: cropland.

4. Discussion

4.2. Uncertainties for Mapping Plantation Establishment Year and Pre-Conversion Land Covers

Severe natural disasters: Rubber trees always experience several natural disasters during their economic life cycle (~30 years) in China. Typhoon, cold injury, and droughts often hit Hainan Island and Yunnan Province [11]. For example, Hainan Island experienced one of its most severe droughts between September 2004 and July 2005, which was followed by the strongest super typhoon since 1974 on 25 September 2005 (Darry) [50] and a severe cold spell in 2008 [51]. Severe typhoons will harm the canopy (Figure 12c) while drought and disease can delay phenology or cause leaves to shed (Figure 12d). Such disasters will affect LSWI significantly (Figure S5). Therefore, it is better to avoid using satellite images acquired during these periods. Figure S6 shows a serious overestimation of new rubber plantations established in 2004 and 2005 when images acquired during severe drought and post-typhoon were used. However, overestimation was relieved when excluding these images (by only using images on DOY of 90–304 for 2004, and DOY of 120–268 for 2005) (Figure 6d).

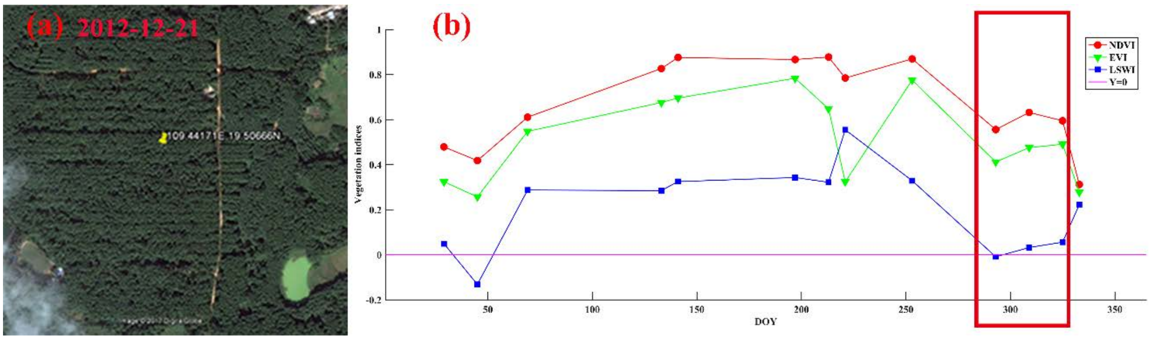

Figure S5. Demonstration of rubber plantation (109.44171E, 19.50666N) affected by the severe Typhoon Darry in 2005: (**a**) VHR satellite imagery of rubber plantations that recovered from the typhoon. The VHR imagery was acquired on 21 December 2012, and (**b**) NDVI/EVI/LSWI time series in 2005. LSWI decreased significantly after Typhoon Darry hit Hainan Island on 26 September 2005 (DOY = 268).

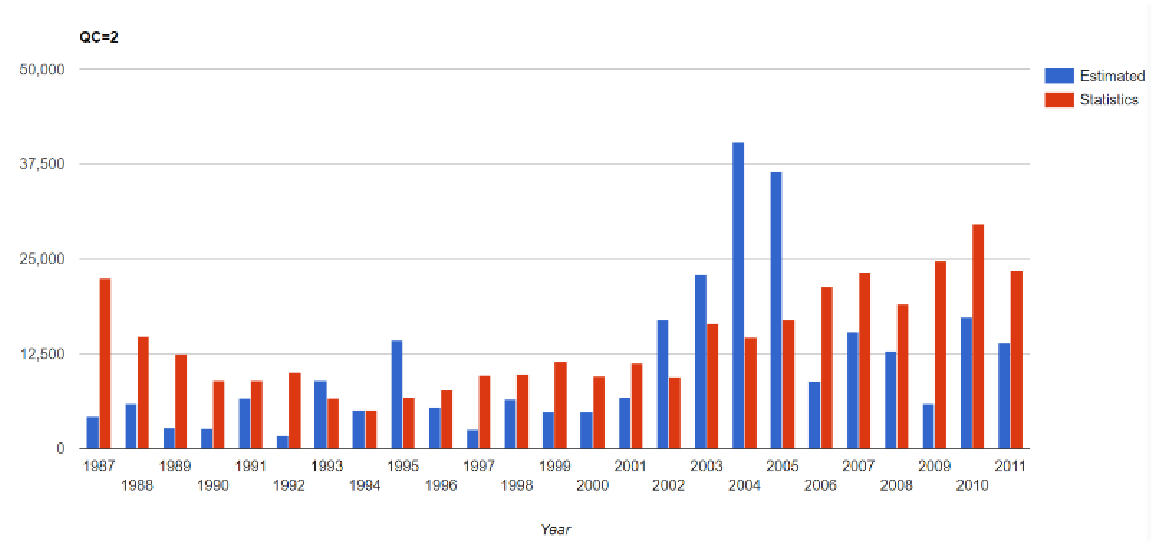

Figure S6. Overestimation of rubber plantation established in 2004 and 2005 due to images acquired in the periods of severe drought (1 November 2004 to 1 May 2005) and post-hurricane (26 September 2005 to 31 December 2005) were used.

4.3. The Spatial-Temporal Dynamic of Rubber Plantations on Hainan Island.

The expansion pattern of rubber plantations on Hainan Island was quite different from that of Xishuangbanna in Yunnan Province, another important natural rubber production base in China. The area of rubber plantations in Xishuangbanna doubled from 2002 to 2010 [4]. The common practice for rubber plantation expansion in Xishuangbanna was to clear-cut evergreen forests on entire mountainsides and then contour ledges were built for rubber trees (Figure S7).

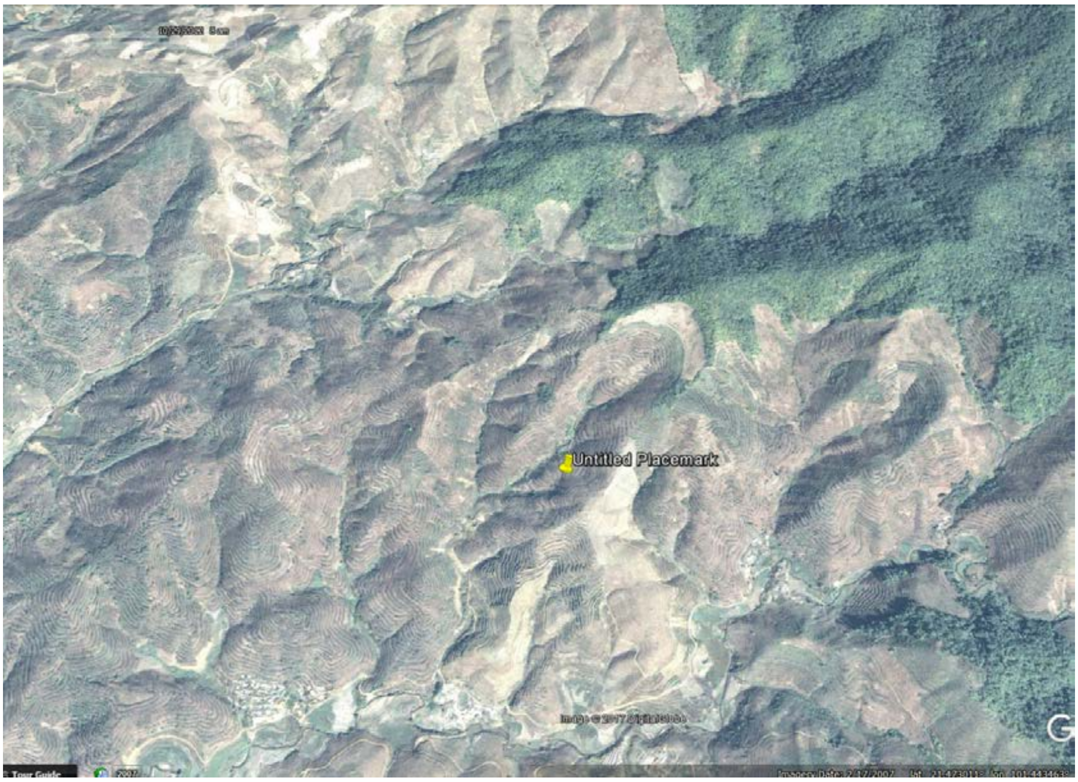

Figure S7. Typical landscape of rubber plantations established in Xishuangbanna, Yunnan Province. The forest on the whole mountain was cleared and then a contour ledge was built to plant rubber trees.