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Historical Assessment of Forestland Conversion to Oil Palm Plantations in Riau and West Kalimantan, Indonesia

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Authors' contributions

This work was carried out in collaboration between all authors. Author SS designed the study. Author SAUR wrote the first draft of the manuscript. Authors SA and US managed the literature searches, analyses of the study and supervised the overall work of author SAUR.

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ABSTRACT

Forest's conversion associated with the expansion of industrial scale oil palm plantations in the two provinces of Indonesia (Riau and West Kalimantan) was documented using Landsat images that were visually interpreted to create a province-wide map of 11 different land cover types spanning three temporal periods (1990 to 2000, 2000 to 2010 and 2010 to 2013). After analyzing all regions and temporal periods in both provinces only 1.66% (30,452 ha) of oil palm plantations originated on land derived directly from undisturbed forests (0.01% Primary Dryland Forest, 0.00% Primary Mangrove Forest and 1.65% Primary Swamp Forest), while 64.78% (1.18 Mha) were established on land previously covered with disturbed forest (12.14% Secondary Dryland Forest, 0.67% Secondary Mangrove forest and 51.97% Secondary Swamp Forest). Conversion of Dry and Wet Scrublands was documented as 23.82% (0.43 Mha) with 7.43% from Dry Scrubland and 16.39% from Wet Scrubland. Forest conversion to establish oil palm, including both undisturbed and disturbed forest of all types of habitats summed over all temporal periods was proportionally greater

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in Riau (70.03%: 0.84 Mha), compare to West Kalimantan (59.52%: 0.37 Mha). In both provinces, the largest sources of land for new plantations were Secondary Swamp Forest (43.43%: 0.27 Mha) in West Kalimantan, while (56.40%; 0.68 Mha) in Riau.

Keywords: Conversion; forest; land cover; land use change; oil palm; Riau; West Kalimantan.

1. INTRODUCTION

Indonesia is facing huge challenges to protect and manage its forest resources. The archipelago is well known not only for the extraordinary biodiversity and productivity of its forests, but high rates of deforestation and illegal logging are also being reported from the country [1]. In the late 1960s, Indonesian national development policy shifted towards export-oriented economic growth underpinned by natural resource exploitation. Thus, forestry sector has since played a crucial role in national development throughout the three decades particularly after the introduction of HPH (*Hak Pengusahaan Hutan*) in early 1970s, a system for the allocation of forest concessions [2]. But on the other hand, this situation brought Indonesia into the list of top five countries with highest rates of forest loss, the others being Brazil, Papua New Guinea, Gabon and Peru. A case in point is oil-palm agriculture in Indonesia and Malaysia, both are the world's top producers of palm oil (≈43 million Mg/y), accounting for 87% of global production. Since 1990, the combined harvested area for oil palm in both countries have expanded by 6.5 million ha, or almost fourfold. Even if only half of oil-palm expansion resulted in forest loss, this single crop would have contributed to >10% of total deforestation in Indonesia and Malaysia between 1990 and 2010 [3].

The data published by the Indonesian Ministry of Forestry based on a Forest Zone determined by a so-called "harmonization" process that involved the Department of Forestry and local governments, combining the results of a "Forest land use by consensus" reported a legally designated Forest Zone (*Kawasan Hutan*) of 120 million ha, corresponding to 62% of the total land surface of Indonesia [1]. Over the last three decades, Indonesian government has allocated over 60 million hectares of forest to commercial logging companies, and the country's forestry sector industries have long ranked second only to petroleum in terms of their contribution to Gross National Product [4]. This resulted in dramatic land use changes across the country that can be primarily characterized by forest cover loss on 40 Mha of land, a 30% reduction in forest land. Moreover, projections of additional land demand for palm oil production in 2020 range from 1 to 28 Mha in Indonesia [5]. This historical forest loss can be attributed to unsustainable logging followed by the impact of fire, which in combination led to the progressive transition of large areas of forest landscape into agroforest or shrub land [6].

The forest's conversion to oil palm plantations has been investigated in various studies having different time periods and spatial scales. In 1986, the oil palm plantation area was about 606,800 ha, and in 1997 it increased to 2.25 million ha, mainly located in the provinces of North Sumatra (905,000 ha), Riau (544,700 ha), West Kalimantan (211,400 ha) and South Sumatra (206,000 ha) [7]. Kartodihardjo [8] further reported that the oil palm plantations grew relatively rapidly in the period 1978-1997, with a high annual increase in area of 21.7% for privately-owned plantations, and a rate of 2.9% for state-owned plantations and 19.3% for smallholder plantations. Whereas, according to Miettinen [9] in 2012 the majority (62%) of the industrial-scale plantations were located on the island of Sumatra, and over two-thirds (69%) were developed for oil palm cultivation. Historical analysis shows strong acceleration of plantation development in recent years i.e. 70% of all industrial plantations have been established since 2000 and only 4% of the current plantation area existed in 1990.

Hence, it appears that Indonesian oil palm plantation increased significantly only after the 1970s. This is related to the new order government policy for the agricultural sectors, which included plantation development [10]. The lack of objective up-to-date information on the extent of industrial plantations has complicated quantification of their regional and global environmental consequences, both in terms of loss of forest and biodiversity as well as increases in carbon emissions [9]. The paper in hand is thus an attempt to reveal the historical land use changes with special emphasis to the forestland's conversion to oil palm plantations in two provinces of Indonesia i.e. Riau and West

Kalimantan, which are preferred for oil palm plantations especially Riau.

2. MATERIALS AND METHODS

2.1 Study Area

The study area comprised of two provinces in Indonesia namely Riau and West Kalimantan. Riau Province is located on the island of Sumatra (Equator and 101ºE).The annual rate of forest cover loss was 2.2% in 2002, 4.2% in 2004 and 6.8% in 2005, and is covered with more timber plantations and more oil palm concessions than any other province in Indonesia. Between 1988 and 2005, half of Riau's forests disappeared at an average rate of 170,000 ha per year or 460 ha per day. Whether in the name of oil palm or of timber plantation development, forest clearing in Riau has provided a steady source of mixed tropical hardwood [11].

The Province of West Kalimantan is also called as the land in equator. With the Carimata Strait and Natuna Ocean in the west and the Central Kalimantan and East Kalimantan to the east, it neighbors Malaysia in its northern part with Java Ocean to the south. Coastal area of West Kalimantan is composed of plain land with mountain and highland in its inland. Daily average temperature ranges from 22 and 32 Cº, with the average humidity rate at 85.2%, which keeps changing based on the rainfall, the average annual rainfall is between 3,000 and 3,900 millimeters [12].

2.2 Secondary Data

The research involved construction of maps and time series analysis, thus secondary data in form of land use maps (raw data) were obtained from Ministry of Forestry, Indonesia. The Landsat satellite imagery (4, 5, 7 and 8) were downloaded from United States Geological Survey website http://glovis.usgs.gov/.

2.3 Spatial Data Analysis

We used Landsat imagery captured by different satellites i.e. 4, 5, 7 and 8 because of availability and gradual development in the satellite technology over time, with the obvious better resolution found in Landsat 8 compare to the older versions i.e. Landsat 4 and 5. Meanwhile, we noticed that obtaining scenes with no or least cloud cover to be challenging; however attempts were made to select the images with cloud cover< 20%, thus preference was given to pick scene with a lesser amount of cloud distortions rather than time within the same year. To make the imageries further reliable and usable, multiple scenes in the same year had cloud covers were preprocessed by using Erdas Imagine 9.2 software before mosaicking and onward interpretation. The software was used to apply the 'subtraction' function on the cloudy scenes and then 'addition' function to add part of the scene with less or no cloud using the spatial modeler tools for the respective time and space.
Afterwards, the Landsat satellite imagery (4, 5, 7 and 8) were processed through ArcGIS® 9.3 software using on-screen analysis and discriminating land use and land cover types. The direct identification of land cover using on-screen analysis technique comprised of computer mouse as tracing tool [13]. During on-screen interpretation in multistage visual technique images were displayed as false colour composites say Landsat bands: 3(0.63-0.69 µm, red), 4(0.76-0.90 µm, near infrared) and 5 (1.55-1.75 µm, mid-infrared); scheme with bands 5-4-3 displayed as red, green and blue respectively were followed to displays the combination of the selected channels on the screen. The primary output of the data analysis was land cover change matrix, However, to better understand the dynamics of oil palm plantation development and facilitate communication of the results, the output of the land use change analysis has been presented in the form of maps and tables depicting increment in the oil palm plantation on yearly basis [14].

3. RESULTS AND DISCUSSION

3.1 Land use Changes Driven by Oil Palm Plantations

The land use changes driven by oil palm plantations were tested such that all those forestland categories were considered which could possibly be used for oil palm plantations. Thus ten different land use types were investigated namely primary dryland forest, secondary dryland forest, primary swamp forest, secondary swamp forest, primary mangrove forest, secondary mangrove forest, wetland, scrubland, wet scrubland and oil palm plantation itself. The graphical summary of the land use change is given (Fig. 1) which only presents the land uses that has been significantly changed during course of time.

The land use change graphs show the forest cover types that have been drastically reduced, such as secondary swamp forest and secondary dryland forest. The details of the changes detected in all land cover types are presented in form of maps and charts (Figs. 2, 3 and 4) given at the end. Similarly the area of oil palm plantations increases temporally both in Riau (Table 1) and in West Kalimantan (Table 2), while the secondary swamp forest and secondary dryland forest decreases.

3.2 Forest Conversion to Oil Palm Plantations

The analysis focused on tracing the conversion of different land use categories particularly forest to oil palm plantations in both provinces.

The results shows that in West Kalimantan over all during all temporal periods only 0.63% (3,981 ha) of oil palm plantations originated on land derived directly from undisturbed forests i.e. 0.02% primary dryland forest, 0.0% primary mangrove forest and 0.06% primary swamp forest. Similarly 58.88% (0.36 Mha) were established on land previously covered with secondary forests i.e. 15.11% secondary dryland forest, 0.11 % secondary mangrove forest and 43.43% secondary swamp forest. Conversion of scrublands and wet scrublands was documented as 30.34% (0.19 Mha) with 11.44% from dry scrubland and 18.90% from wet scrubland. The summary of the whole land use changes in West Kalimantan is given in Table 3.

We noticed similar dynamics in Riau with more conversion of secondary swamp forests and after averaging all the regions and temporal periods only 2.19% (26,472 ha) of oil palm plantations originated on land derived directly from undisturbed forests (0.00 % primary dryland forest, 0.00 % primary mangrove forest and 2.19 % primary swamp forest), while 68.84% (0.82 Mha) were established on land previously covered with disturbed forest (10.48% secondary dryland forest, 0.97% secondary mangrove forest and 56.40% secondary swamp forest). Conversion of scrublands and wet scrublands was documented as 20.44% (0.24 Mha) with 5.34% from dry scrubland and 15.09% from wet scrubland. Thus 70.03% of the oil palm plantations in Riau today is standing on land acquired from forest of certain type that corresponds to 0.84 Mha. The details conversion of different land use categories is given below (Table 4).

Due to the impacts of deforestation and its threats to climate change and biodiversity conservation, land use change has been the focus of a number of studies in Indonesia [3,13,14,15,16,17,18]. Our principal objective was to evaluate land use change linked to the expansion of oil palm plantations specially investigating the conversion of forests.

Our results are both alike and distinct from other studies (Table 5), clearly because of using different types of classification methodologies, definitional criteria and remote sensing data; and further because of evaluating change on complex landscape typologies. The growth of oil palm plantations in Malaysia and Indonesia is one of several drivers of deforestation; however, it is a misconception to assert that all oil palm plantations originate from forest conversion. This was recognized by Koh [19] they estimated that between 1990 and 2005 between 55 to 59% of oil palm expansion in Malaysia and at least 56% in Indonesia were established as a direct result of forest conversion. In a more comprehensive study by Wicke [5], the palm oil sector was identified as a major driver of forest cover loss in Sumatra and Kalimantan; these authors similarly recognized the complex nature of land cover change and the role of the forest sector as part of that dynamic. In both cases, the results and conclusions were limited by a reliance on secondary data derived largely from ministerial and sector reports.

Our study is based on a direct interpretation of satellite imagery for the entire region and after analyzing all regions and temporal periods in both provinces only 1.66 % (30,452 ha) of oil palm plantations originated on land derived directly from undisturbed forests (0.01 % primary dryland forest, 0.00 % primary mangrove forest and 1.65 % primary swamp forest), while 64.78% (1.18 Mha) were established on land previously covered with disturbed forest (12.14% secondary dryland forest, 0.67 % secondary mangrove forest and 51.97 % secondary swamp forest). Conversion of scrublands and wet scrublands was documented as 23.82% (0.43 Mha) with 7.43 % from dry scrubland and 16.39% from wet scrubland.

The differentiation of primary and degraded or secondary forest is one point of confusion during understanding the role of forest conversion to oil palm plantations. For example, the palm oil sector has made a point of emphasizing that they do not clear primary forests to establish plantations, a point which is essentially validated by our results. However, disturbed forests also have biodiversity value [20] and maintain significant carbon stocks [21] and because of this reason some authors used terminologies such as “Primarily Intact Forests” [13] or the oxymoronic “Primary Degraded Forests” [18]. Similarly the definition of what is called “degraded” also varies widely among authors, but in Indonesia it is assumed that areas classified as degraded land are a direct consequence of forest degradation [15,18].

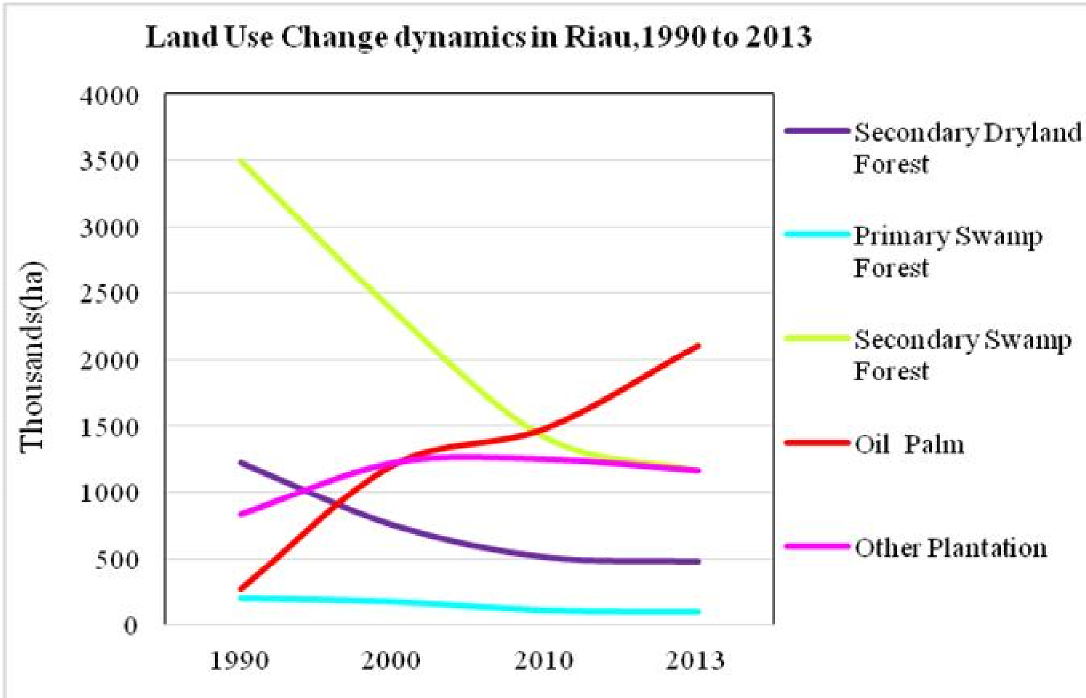
Our results also support the phenomenon that the relatively low biomass landscapes that are converted to oil palm are themselves the result of forest degradation and conversion due to logging practices. This dynamic is best described as a land use trajectory, and other studies have documented the impact of logging on forest cover prior to land clearing [18,17].

Table 1. Temporal changes in the acreage of different land uses across Riau

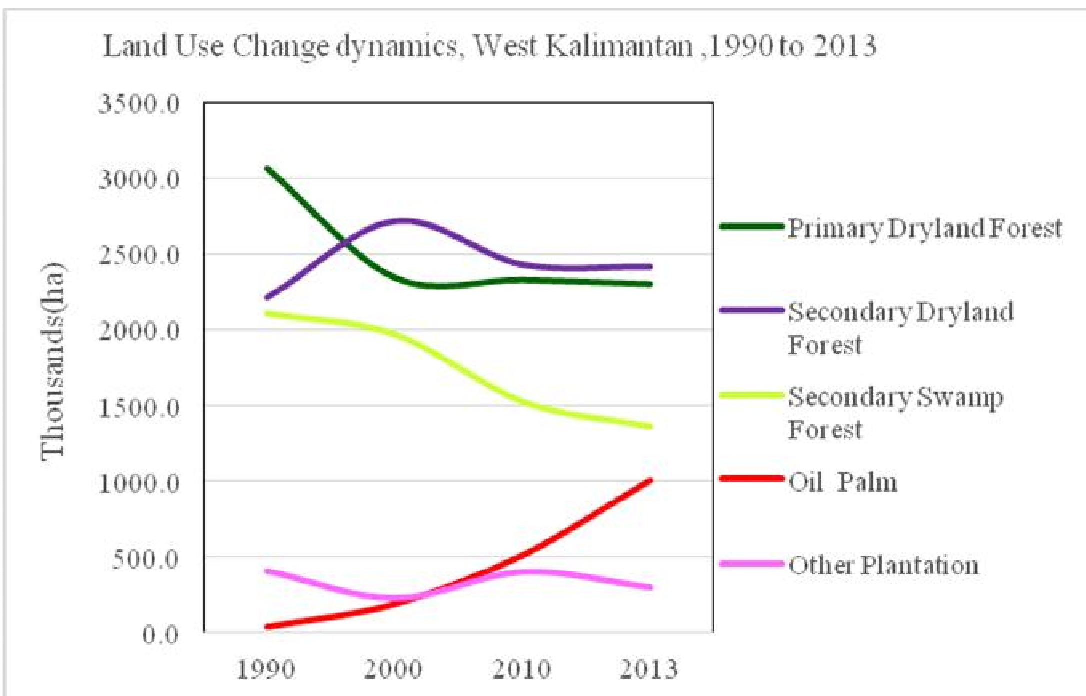
Land Use	Area (ha)			
	1990	2000	2010	2013
Primary Dryland Forest	157,995	157,821	156,847	156,711
Secondary Dryland Forest	1,226,361	750,108	508,710	475,817
Primary Mangrove Forest	6,123	6,123	5,460	5,209
Secondary Mangrove Forest	176,251	171,731	155,881	155,103
Primary Swamp Forest	206,048	177,275	109,121	96,599
Secondary Swamp Forest	3,488,886	2,367,825	1,414,564	1,170,320
Forestry Plantation	140,245	288,007	401,643	238,648
Oil Palm	268,536	1,207,096	1,484,486	2,112,195
Other Plantation	832,134	1,224,674	1,251,945	1,165,346
Wetland	26,485	27,098	27,362	27,360
Scrubland	385,540	432,067	694,004	673,761
Wet Scrubland	530,844	406,850	843,331	817,097

Table 2. Temporal changes in the acreage of different land uses across West Kalimantan

Land use	Area (ha)			
	1990	2000	2010	2013
Primary Dryland Forest	3,064,341	2,351,038	2,336,375	2,308,972
Secondary Dryland Forest	2,213,970	2,718,381	2,432,925	2,418,921
Primary Mangrove Forest	75	32	32	32
Secondary Mangrove Forest	117,992	115,238	112,757	111,900
Primary Swamp Forest	73,450	29,049	27,263	25,578
Secondary Swamp Forest	2,111,735	1,974,886	1,531,011	1,365,172
Forestry Plantation	105,68	12,540	12,451	12,451
Oil Palm	43,749	194,178	513,491	1,004,845
Other Plantation	413,923	233,576	407,793	306,017
Wetland	106,464	123,836	122,696	120,303
Scrubland	557,071	532,392	475,406	453,256
Wet Scrubland	408,373	560,348	751,787	699,865

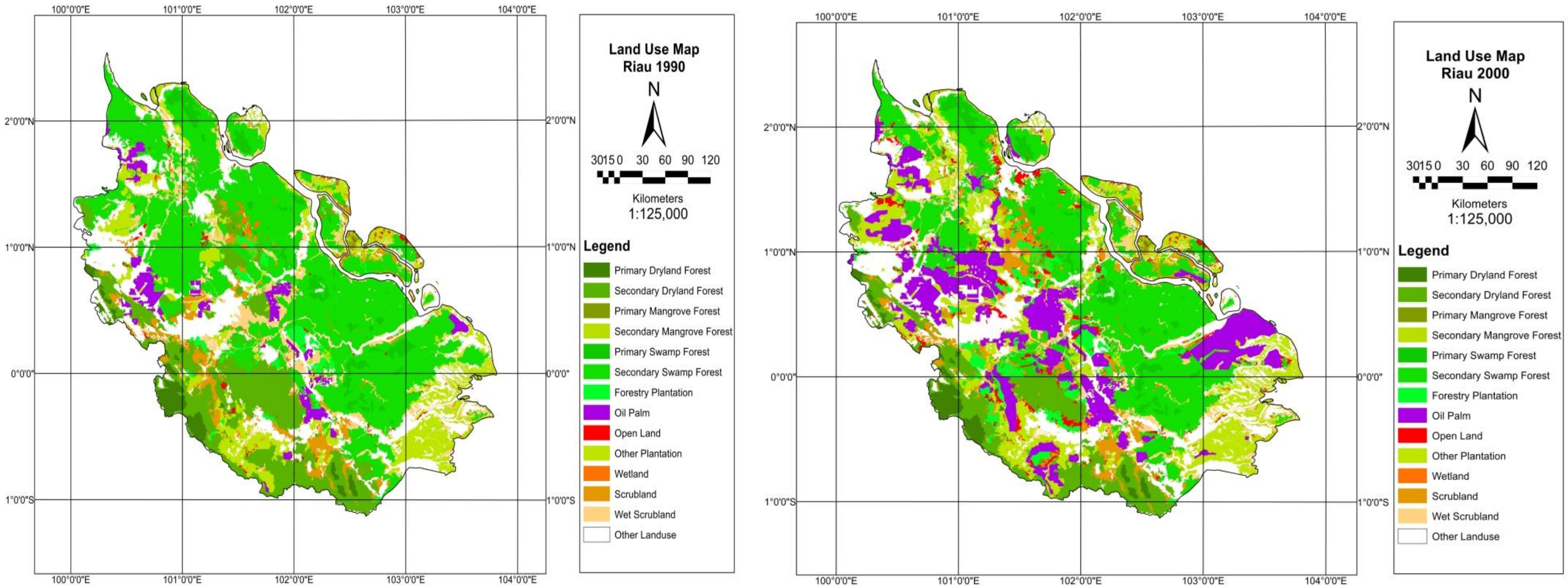


(a)



(b)

Fig. 1. Graphical illustration of the land use changes from 1990 to 2013; a) Riau: b) West Kalimantan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Other Landuse
Land Use Map
Riau 2000
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Primary Dryland Forest
Secondary Dryland Forest
Primary Mangrove Forest
Secondary Mangrove Forest
Primary Swamp Forest
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Forestry Plantation
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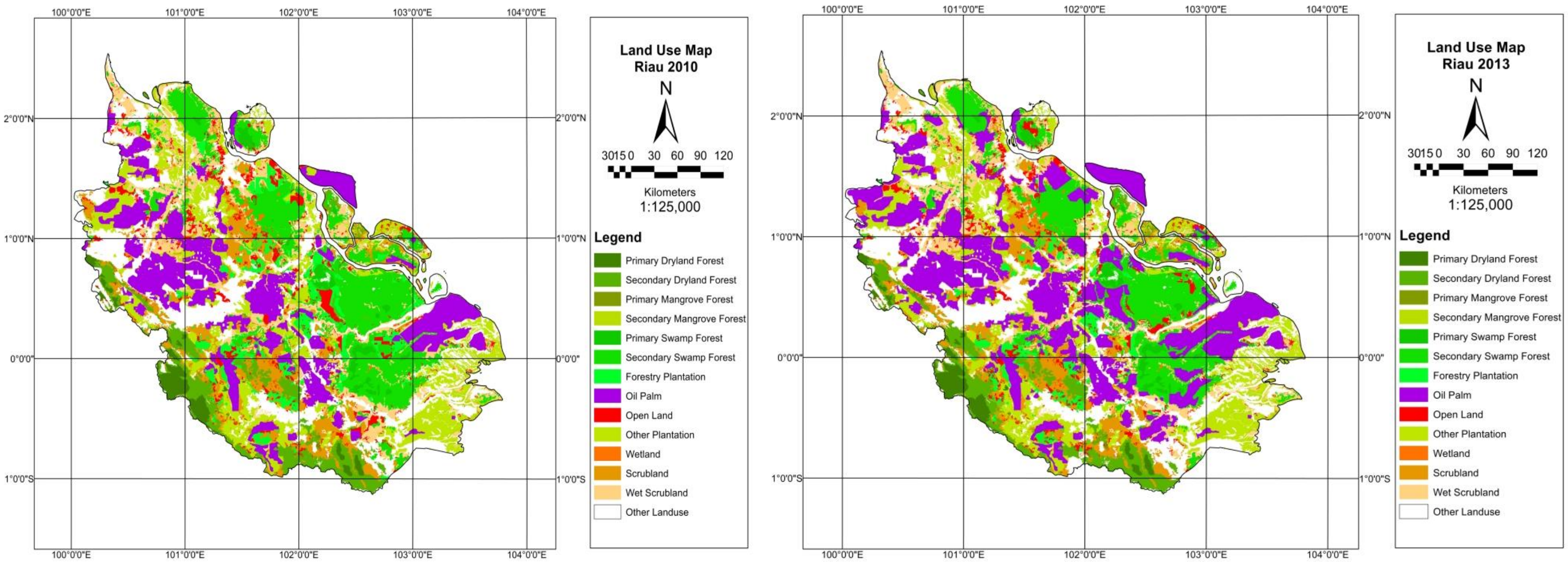
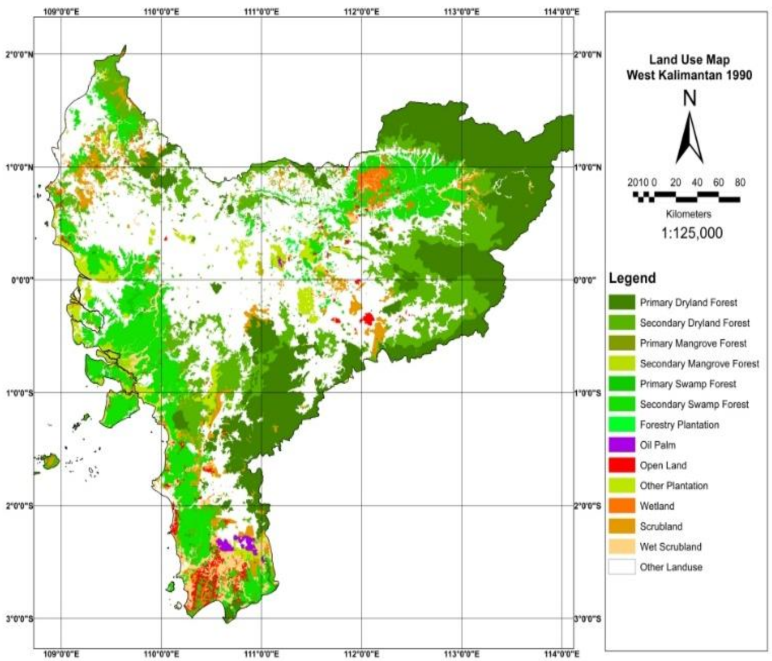
Wet Scrubland
Other Landuse

(a) (b)



(c) (d)

Fig. 2. Land use change maps of 1990(a), 2000(b), 2010(c) and 2013(d), Riau


Land Use Map
West Kalimantan 1990
N
Kilometers
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Primary Dryland Forest
Secondary Dryland Forest
Primary Mangrove Forest
Secondary Mangrove Forest
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Forestry Plantation
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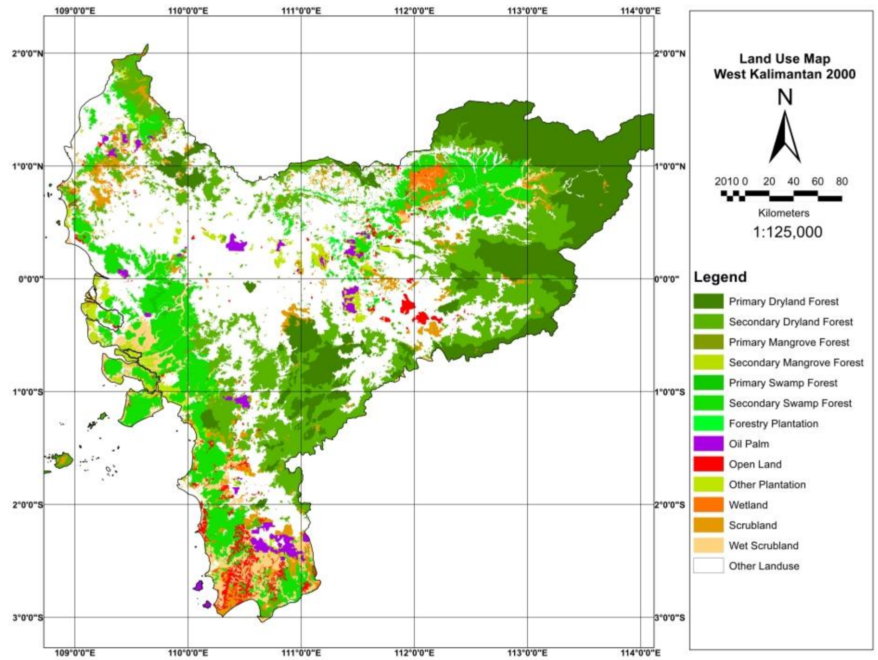
Other Landuse

(a)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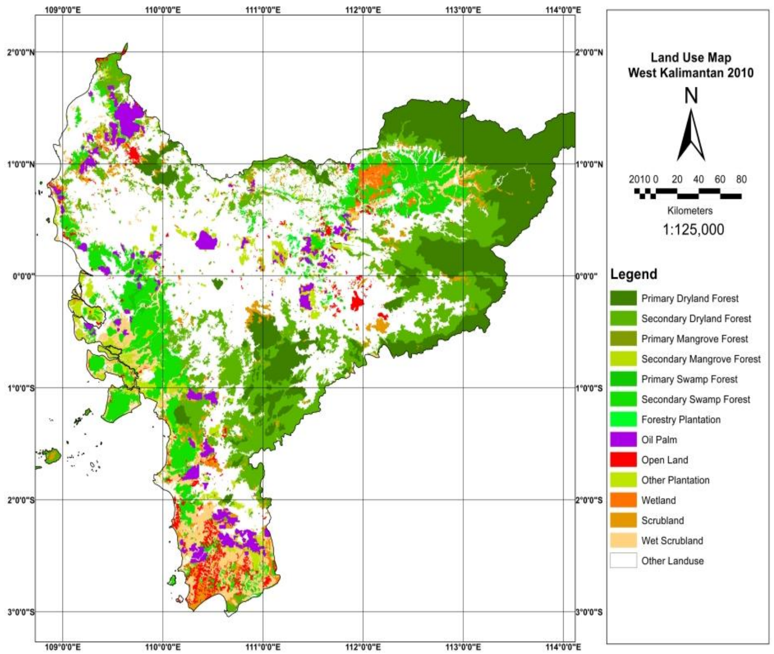
Other Landuse

(b)



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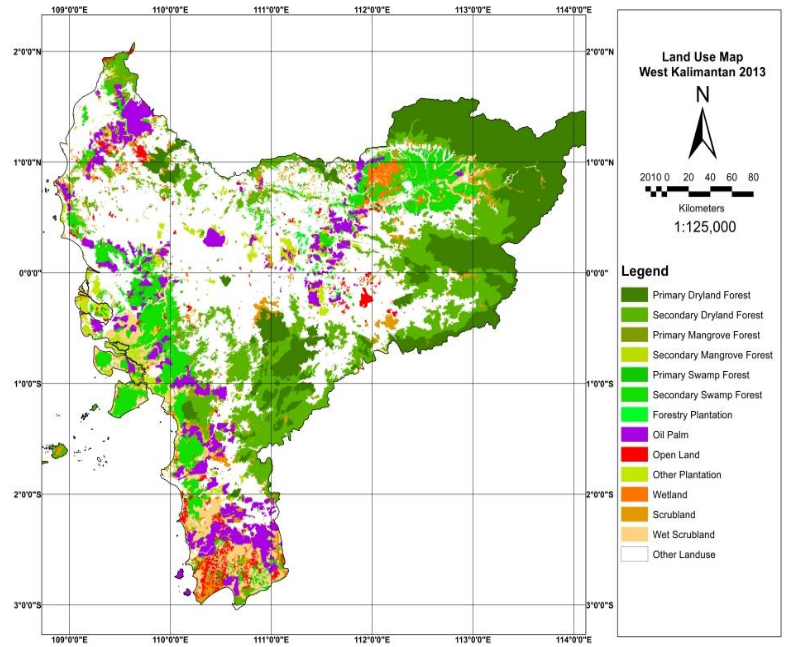

(d)

Fig. 3. Land use change maps of 1990(a), 2000(b), 2010(c) and 2013(d), West Kalimantan

Table 3. Depicting conversion of forestlands to oil palm plantations in West Kalimantan (ha)

Primary Landuse	1990	1990 to 2000			2000 to 2010			2010 to 2013		
		Un-changed	Other	OPP	Un- changed	Other	OPP	Un- changed	Other	OPP
Primary Dryland Forest	3064,340	2350938	713284	117	2336375	14564	Nil	2308972	27352	51
Secondary Dryland Forest	2213970	2718876	132394	1408	2438335	224459	71306	2418934	23212	23508
Primary Mangrove Forest	75	32	Nil	Nil	32	Nil	Nil	32	Nil	Nil
Secondary Mangrove Forest	117992	115238	2816	Nil	112757	2727	137	111900	276	581
Primary Swamp Forest	73450	29049	44400	Nil	28328	721	1064	25578	1.1	2749
Secondary Swamp Forest	2111735	1978620	136929	3980	1549775	334986	112871	1368957	25202	155615
Open Land	187904	271598	6867	246	319728	39966	7064	298430	1208	53230
Wetland	106464	124026	6793	152	122996	1139	369	120492	Nil	2503
Scrubland	557071	532392	105729	9449	480727	138625	29545	453258	328	32797
Wet Scrubland	408373	561197	17875	4647	773391	46224	30372	700725	1522	83545

Unchanged: the land cover remained unaltered at the end of respective period, Other: conversion to land uses other than Oil Palm Plantations, OPP: Oil Palm Plantations

Table 4. Conversion of forestlands to oil palm plantations in Riau (ha)

Primary Landuse	1990	1990 to 2000			2000 to 2010			2010 to 2013		
		Un-disturbed	Other	OPP	Un-disturbed	Other	OPP	Un-disturbed	Other	OPP
Primary Dryland Forest	157,995	157,822	134	40	156,847	974	Nil	156,711	136	Nil
Secondary Dryland Forest	1,229,099	750,108	355,609	123,516	508,711	240,029	2,390	475,817	32,548	736
Primary Mangrove Forest	6,123	6,123	Nil	Nil	5,461	663	Nil	5,210	243	8
Secondary Mangrove Forest	176,251	171,731	1,648	2,872	155,881	7,740	8,776	155,104	996	25
Primary Swamp Forest	206,049	177,275	6,637	22,136	109,121	68,154	Nil	96,600	8,234	4,288
Secondary Swamp Forest	3,488,955	2,367,826	680,825	440,523	1,414,565	908,378	98,676	1,170,320	105,915	142,719
Open Land	57,454	230,338	873	8,793	382,937	98,879	8,109	328,652	14,172	98,134
Wetland	26,485	27,099	Nil	137	27,363	Nil	48	27,360	Nil	2
Scrubland	385,564	432,068	102,653	22,150	694,159	40,870	16,609	673,916	6,640	25,825
Wet Scrubland	532,447	406,851	166,649	87,178	843,331	24,458	15,791	817,098	3,572	79,505

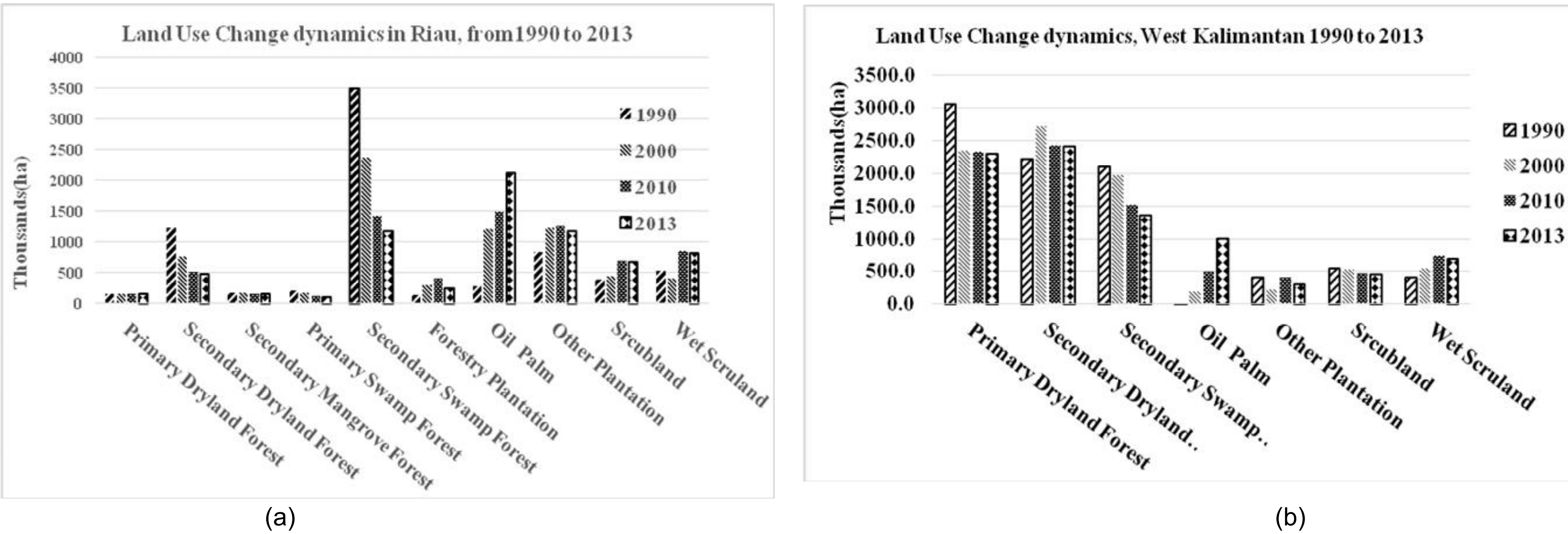

Fig. 4. Land use change dynamics from1990 to 2013 in Riau (a), West Kalimantan(b)

Table 5. Oil palm plantations land sources and forest cover change exhibiting distinctive temporal dynamics as reported in literature

Source	Methods and materials	Study area	Time period					
			1990-2000	2000-2005	2000-2010	1990-2010	2000-2008	Others
Hansen et al. 2009 [17]	Annual forest cover loss indicator maps	Sumatra and Kalimantan	- 1.78 Mha/yr	-0.71 Mha/yr	NR	NR	NR	NR
Carlson et al. 2013 [15]	Landsat satellite images for OPP development coupled with above and below-ground carbon accounting	Kalimantan	278% rise in OPP from1990-2000)	NR	NR	90% of land for OPP were forested (47% intact, 22% logged, 21% agroforests).	NR	NR
Broich et al. 2011 [14]	Multi-resolution remote sensing data from the Landsat enhanced thematic mapper plus (ETM+) and moderate resolution imaging spectroradiometer (MODIS) sensors	All provinces in Kalimantan and Sumatra Islands.	NR	NR	NR	NR	-5.39 Mha 13.6% of forest cover loss occurred where clearing was legally restricted.	NR
Margono et al. 2012 [18]	Geoscience Laser Altimeter System (GLAS) data set was employed.	Sumatra	7.34 Mha (both forest cover loss and forest degradation)	NR	NR	-7.54 Mha (Of the 7.54 Mha cleared, 7.25 Mha was in a degraded state, and 0.28 Mha was in a primary state) 2.31 Mha has been degraded	NR	NR
Koh et al. 2011 [3]	250-m spatial resolution map of closed canopy were produced.	Malaysia and Indonesia(Peninsular Malaysia, Borneo and Sumatra)	NR	NR	NR	NR	NR	6% (0.88 Mha) of peatlands in the region had been converted to OPP by the early 2000s. By 2010, 2.3 Mha of peat swamp forests were clear-felled and found degraded.
Carlson et al. 2012 [13]	Spatially explicit land change/carbon bookkeeping model, parameterized by high-resolution satellite time	West Kalimantan	NR	NR	NR	NR	NR	Plantation land sources comprised 81% forests on mineral soils (1994–

Source	Methods and materials	Study area	Time period					
			1990-2000	2000-2005	2000-2010	1990-2010	2000-2008	Others
	series and informed by socioeconomic surveys.							2001), shifting to 69% peatlands (2008–2011).
Miettinen et al. 2011 [16]	A pair of 250m spatial resolution land cover maps produced with regional methodology and classification scheme.	Southeast Asia (including the Indonesian part of New Guinea)			1.0% yearly decline in forest cover with peat swamp forests the highest deforestation of 2.2%/yr, while lowland evergreen forests declined by 1.2%/yr			

NR: Not Reported; OPP: Oil Palm Plantations; - (minus) sign: decline in forest cover/area

4. CONCLUSION

In both provinces, the extant of industrial-scale oil palm plantations has grown continuously from a low starting point 24 years ago. This expansion has accelerated considerably over each time interval (1990 to 2000, 2000 to 2010, and 2010 to 2013), but the rate of acceleration (in both absolute and relative terms) was greatest in the latest period i.e. 2010 to 2013. The research carries substantial importance in terms of forests resource management and can be further applied to forecast the future land use changes and predict pressure on forestlands. The differences in methodological approaches, including the use of different temporal periods, land cover definitions, and classification protocols determines how the causes of deforestation are characterized and consequently, attributed to different economic sectors. The challenges linked to documenting land use change on highly dynamic landscapes can be managed by using short temporal periods to track changes and by using more sophisticated remote sensing technologies followed by field surveys and ground surveys to identify the economic and social actors that drive land use change. In the specific case of Indonesia, our results show that there are multiple drivers of deforestation and that selection of temporal periods and the definitions of the parameters that define degradation and deforestation can influence the allocation of forests conversion to different economic sectors. Therefore oil palm plantation development is not the sole cause of changing land uses particularly forest loss.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Contreras-Hermosilla, Fay AC, Effendi E. Strengthening forest management in Indonesia through land tenure reform: issues and framework for action. Forest Trends; 2005. ISBN: 0-9713606-7-7
2. Wardojo W, Masripatin N. Trends in Indonesian Forest Policy, Policy Trend Report. 2002;77-87.
3. Koh LP, Miettinen J, Liew SC, Ghazoul J. Remotely sensed evidence of tropical peatland conversion to oil palm. Proceedings of the National Academy of Sciences. 2011;108(12):5127-5132.
4. McCarthy JF. Decentralisation and forest management in Kapuas district, Central Kalimantan. 2001;2. CIFOR.
5. Wicke B, Sikkema R, Dornburg V, Faaij A. Exploring land use changes and the role of palm oil production in Indonesia and Malaysia. Land Use Policy. 2011;28(1): 193-206.
6. Gunarso P, Hartoyo ME, Agus F, Killeen TJ. Oil palm and land use change in Indonesia, Malaysia and Papua New Guinea. Reports from the Technical Panels of the Second RSPO GHG Working Group, Roundtable for Sustainable Palm Oil, Kuala Lumpur; 2013.
7. Susila WR. Development and Prospects of the Main Plantation Commodity (in Indonesian). Center of Economic Study. Agriculture Research and Development. Bogor; 1998.
8. Kartodihardjo H, Supriono A. The impact of sectoral development on natural forest conversion and degradation: The case of timber and tree crop plantations in Indonesia. Center for International Forestry Research. 2000;26.
9. Miettinen J, Hooijer A, Shi C, Tollenaar D, Vernimmen R, Liew SC, Malins C, Page SE. Extent of industrial plantations on Southeast Asian peatlands in 2010 with analysis of historical expansion and future projections. GCB Bioenergy. 2012;4(6): 908-918.
10. Budidarsono S, Susanti A, Zoomers A. Oil palm plantations in Indonesia: The implications for migration, settlement/ resettlement and local economic development Book Ch (06): In Biofuels - Economy, Environment and Sustainability. 2013;173-193.
11. WWF (World Wildlife Fund for Nature) The Eleventh Hour for Riau's Forests: Two

global pulp and paper companies will decide their fate, WWF Indonesia; 2006. Available:http://www.wwf.or.jp/activities/upfiles/20060721b.pdf
12. GDFAO Guangdong Foreign Affairs.. Province of West Kalimantan Indonesia, edited 2006; 1995. Viewed on April 23, 2014.
Available:http://www.gdfao.gov.cn/english/relationship/fcp/200610130127.html
13. Carlson KM, Lisa M. Curran DR, Alice M. Pittman, Britaldo SS, Gregory P. Asner, Simon N. Trigg DA. Gaveau DL, Hermann OR. Committed carbon emissions, deforestation, and community land conversion from oil palm plantation expansion in West Kalimantan, Indonesia. Proceedings of the National Academy of Sciences. 2012;109(19):7559-7564.
14. Broich M, Hansen M, Stolle F, Potapov P, Margono BA, Adusei B. Remotely sensed forest cover loss shows high spatial and temporal variation across Sumatera and Kalimantan, Indonesia 2000–2008. Environmental Research Letters. 2011; 6(1):014010.
15. Carlson KM, Curran LM, Asner GP, Pittman AM, Trigg SN, Adeney, JM. Carbon emissions from forest conversion by Kalimantan oil palm plantations. Nature Climate Change. 2013;3(3):283-287.
16. Miettinen J, Shi C, Liew SC. Deforestation rates in insular Southeast Asia between 2000 and 2010. Global Change Biology. 2011;17(7):2261-2270.
17. Hansen MC, Stehman SV, Potapov PV, Arunarwati B, Stolle F, Pittman K. Quantifying changes in the rates of forest clearing in Indonesia from 1990 to 2005 using remotely sensed data sets. Environmental Research Letters. 2009; 4(3):034001.
18. Margono BA, Turubanova S, Zhuravleva I, Potapov P, Tyukavina A, Baccini A, Goetz S, Matthew C. Hansen. Mapping and monitoring deforestation and forest degradation in Sumatra (Indonesia) using Landsat time series data sets from 1990 to 2010. Environmental Research Letters. 2012;7(3):034010.
19. Koh LP, Wilcove DS. Is oil palm agriculture really destroying tropical biodiversity? Conservation Letters. 2008;1:60-64.
20. Hamer KC, Hill JK, Benedick S, Mustaffa N, Sherratt TN, Maryati M. Ecology of butterflies in natural and selectively logged forests of northern Borneo: the importance of habitat heterogeneity. Journal of Applied Ecology. 2003;40:150-162.
21. Putz FE, Zuidema PA, Pinard MA., Boot RGA, Sayer JA, Sheil D, Sist P. Vanclay J K. Improved tropical forest management for carbon retention. PLoS Biology. 2008; 6(7)166.

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