BIODIVERSITAS
Volume 22, Number 3, March 2021
Pages: 1235-1242

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d220320

Forest cover changes in Indonesia's terrestrial national parks between 2012 and 2017

ASRI A. DWIYAHRENI[1,2,3,♥], HABIBURRACHMAN A.H. FUAD[2], SUNARYO[2,3], TRI EDHI BUDHI SOESILO[1], CHRIS MARGULES[3,5], JATNA SUPRIATNA[1,2,3,4]

[1]School of Environmental Science, Universitas Indonesia. Jl. Salemba Raya No. 4, Jakarta Pusat 10430, Jakarta, Indonesia. Tel.: +62-21-31930251, 3145563, Fax. +62-21-3146662, ♥email: aadwiyahreni@gmail.com

[2]Research Center for Climate Change, Faculty of Mathematics and Natural Sciences, Universitas Indonesia. Jl. Prof. DR. Sudjono D. Pusponegoro (Lingkar UI), Lab. Riset Multidisiplin FMIPA Building, UI Campus, Depok 16424, West Java, Indonesia

[3]Institute for Sustainable Earth and Resources, Faculty of Mathematics and Natural Sciences, Universitas Indonesia. Jl. Prof. DR. Sudjono D. Pusponegoro (Lingkar UI), Lab. Riset Multidisiplin, FMIPA Building, UI Campus, Depok 16424, West Java, Indonesia

[4]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia. Jl. Prof. DR. Sudjono D. Pusponegoro (Jl. Lingkar UI), E Building, UI Campus, Depok 16242, West Java, Indonesia

[5]Centre for Tropical Environmental Sustainability Science, Faculty of Science and Engineering, James Cook University. 1 James Cook Drive, Townsville City, QLD 4814, Australia

Manuscript received: 16 October 2020. Revision accepted: 11 February 2021.

Abstract. *Dwiyahreni AA, Fuad HAH, Sunaryo, Soesilo TEB, Margules C, Supriatna J. 2021. Forest cover changes in Indonesia's terrestrial national parks between 2012 and 2017. Biodiversitas 22: 1235-1242.* Tropical rainforests are among the most important ecosystems on earth. After Brazil, Indonesia has the second-largest tropical forest area in the world. Since the 1970s, Indonesia's forests have decreased from covering 87% to 50% of its land area. With the ever-increasing pressures from economic and human development, it appears likely that much of the biodiversity and ecosystem services provided by forests in Indonesia will only remain in protected areas. National parks currently cover around 60% or 16 Mha of the total area of protected areas in Indonesia. Between 2012 and 2017, 43 terrestrial national parks in Indonesia lost 1.62% of their total forest cover. However, primary forest cover increased by 0.07%. National parks in the Jawa Bali bioregion, through their better management inputs and community collaborations, ecosystem services to the surrounding areas, as well as natural mountainous conditions, have contributed to the increase of primary forest covers and keeping total forest loss relatively low in Indonesia's national parks.

Keywords: bioregions, deforestation, human footprint, primary forest, protected areas

INTRODUCTION

Conservation of natural resources plays an important role in sustainable development (WCED 1987), and forest ecosystems are one of the most important natural resources. More specifically, the tropical rainforests provide major share of the global ecosystem goods and services. Tropical rainforests profoundly influence weather patterns and freshwater resources, help protect against natural disasters, and harbor great biodiversity. At least half of all species on earth live in tropical rainforests (Miller and Spoolman 2016) and out of the world's 36 biodiversity hotspots, 22 are in the tropics (Hrdina and Rompoltl 2017). Ecosystem processes that occur in tropical rainforests are highly complex. The interactions between the high biodiversity and the natural abiotic elements make up this complexity, which is very vulnerable to disruption (Lewis et al. 2015; Miller and Spoolman 2016). However, this important ecosystem continues to be under threat of deforestation due to human pressures (Turubanova et al. 2018). Deforestation and degradation of tropical rainforests will increase the vulnerability of billions of people to various damaging impacts (Brandon 2014; Lewis et al. 2015).

Indonesia has experienced very high rates of deforestation (Hansen et al. 2013). After Brazil, Indonesia has the second-largest tropical forest globally, but between 1950 and 2015, around 68 Mha of forest has been lost (Tsujino et al. 2016). It is reported that forest loss in Indonesia within 10 to 12 years from 2000 ranged from 2.18% in the Wallacea region (CEPF 2014) to 22% in Sumatra (Supriatna et al. 2017) and 15.44% in Kalimantan (Miettinen et al. 2011).

The rate of primary forest cover loss in Indonesia is also very high. In 2012, Indonesia lost 0.84 million ha of primary forest, compared to 0.46 million ha in Brazil (Margono et al. 2014). Primary forest naturally regenerates with native plant species where there is no disturbance from human activities. Primary forest conservation should be a global concern, especially given its role as a store of carbon and in maintaining the natural carbon cycle (Mackey et al. 2013).

The ever-increasing deforestation means that forest ecosystems, biodiversity, and natural ecosystem processes will remain in protected areas (PAs) (Laurance et al. 2012). In Indonesia, primary forest cover of Sumatra in 2000 mostly occurred in PAs and their surrounding areas (Supriatna et al. 2017). Unfortunately, PAs are not immune to human pressures. During 1990–2015, the world's forest cover fell by 2.5% and as much as 10% was in the tropics, including within PAs (Morales-Hidalgo et al. 2015).

Protected areas in Indonesia, which are public assets and managed by the government for the public interest, have not been protected from damage, reduction in area, or being contested by various parties who want to use them for other purposes. No single National Park (NP) has reported to be without pressure from human activities (Mulyana et al. 2010). National parks are very important because currently, around 60% of all the PAs in Indonesia are NPs, covering around 16 million ha (Wiratno 2018).

This study estimated forest cover change in Indonesia's terrestrial NPs in a relatively short time (5 years from 2012 to 2017 while other studies (Miettinen et al. 2011; Margono et al. 2014; Gaveau et al. 2018, Supriatna et al. 2020) usually looked at long term forest cover changes in Indonesia. Between 2000 and 2017, forest cover in Kalimantan declined by 14% or 6.04 Mha, including 3.06 Mha of forest converted into industrial plantations (Gaveau et al. 2018), while Sulawesi lost 10.89%. or 2.07Mha of its forest cover (Supriatna et al. 2020).

This study also provides an update on primary forest in NPs, one of the most important ecosystems in the tropics. Human pressures as the drivers behind forest cover changes are also reviewed. The years analyzed (2012 and 2017) were chosen based on data availability for analyzing the human pressures. Roads data, one of important drivers for deforestation (Alamgir et al. 2019) was only available for 2014, thus it was considered sufficient to be used for both 2012 and 2017.

MATERIALS AND METHODS

This study covers 43 established terrestrial NPs between 2012 and 2017 in Indonesia (Figure 1), all of them having their own management units. Indonesia has another 4 terrestrial NPs which were not included in this study. In 2017, the 4 NPs were relatively new and did not yet have separate management units. The 43 NPs were divided into 7 bioregions (Sumatra, Kalimantan, Sulawesi, Maluku, Papua, Jawa Bali, and Nusa Tenggara) following Supriatna (2018).

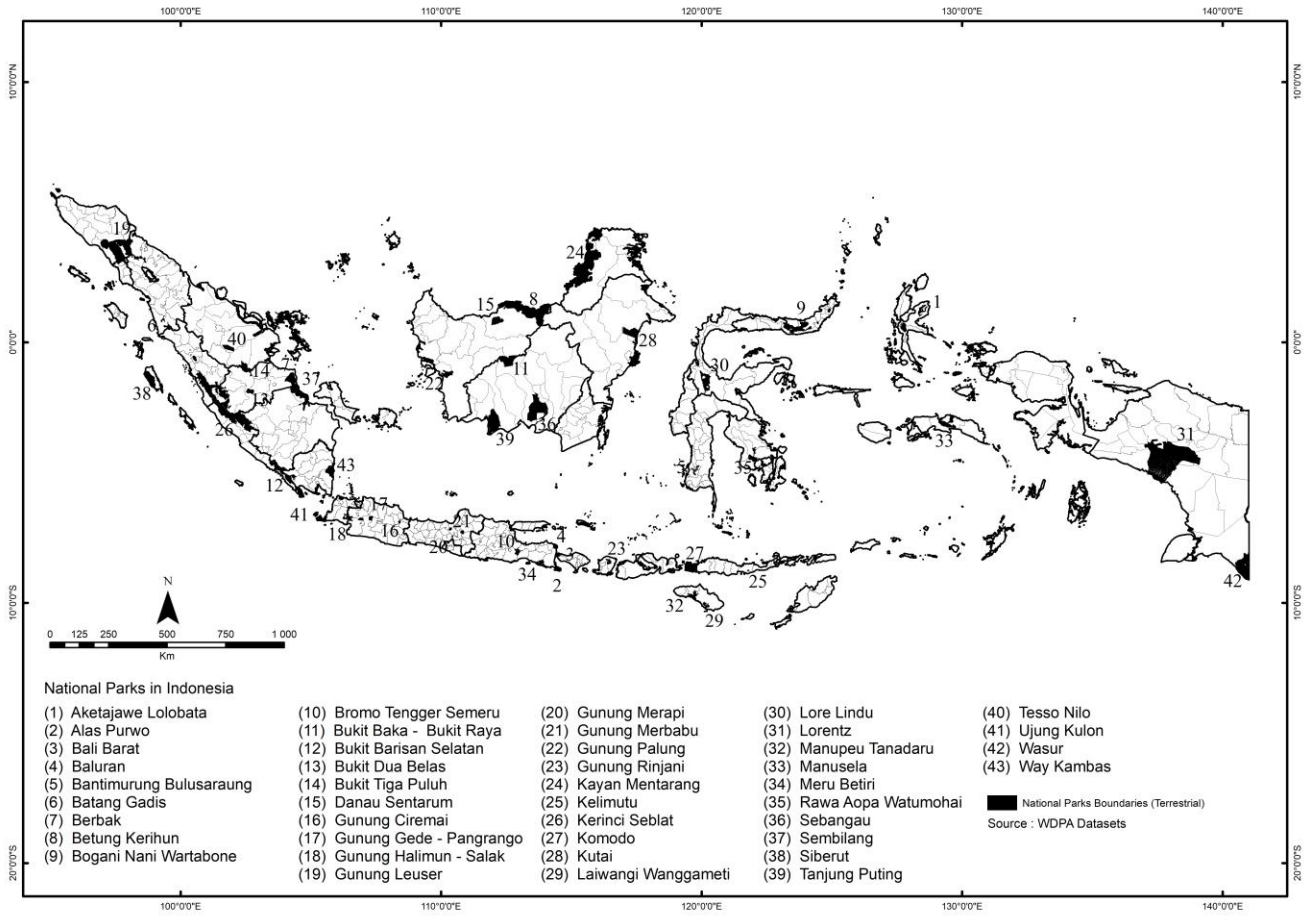

Figure 1. Forty-three (43) terrestrial national parks in Indonesia included in this study

Forest cover data for all NPs were calculated using ARC GIS analysis (Esri ArcMap 10.8 https://www.arcgis.com) for 2012 and 2017 from the Thematic Land Cover map obtained from the Ministry of Environment and Forestry. The thematic land cover map was developed from manual interpretation of satellite image data (digitizing on screen) by the Directorate of Inventory and Monitoring of Forest Resources, Directorate General of Forestry and Environmental Planning, Ministry of Environment and Forestry (Direktorat Inventarisasi dan Pemantauan Sumber Daya Hutan, Direktorat Jenderal Planologi Kehutanan dan Tata Lingkungan, Kementrian Lingkungan Hidup dan Kehutanan) that is responsible to monitor land cover in Indonesia. In conducting this monitoring, Directorate IPSDH collaborates with Indonesia's National Institute of Aeronautics and Space (Lembaga Penerbangan dan Antariksa Nasional-LAPAN) and Geospatial Information Agency (Badan Informasi Geospasial-BIG). More information on the thematic land cover map can be obtained from http://webgis.menlhk.go.id:8080/pl/pl.htm.

The thematic land cover map classifies Indonesia's land cover into 23 categories. In this classification, the primary forest is distinguished from secondary and non-forest habitats. There are 3 different types of primary and secondary forests viz. dry land, peatland, and mangroves (BSN 2010). In this study, total forest cover was taken as the sum of primary and secondary forests in dry land, peatland, and mangroves. Percent changes of forest cover and primary forest cover between 2012 and 2017 were calculated to see any forest cover loss or gain in each NP. National parks borders were taken from The World Database on Protected Areas (https://www.protectedplanet.net/en).

Drivers of forest cover change were calculated using human footprint (HF) analysis following Sanderson et al. (2002). Human Footprint analysis was also conducted using ARC GIS analysis (Esri ArcMap 10.8 https://www.arcgis.com). The HF pressures comprised of human population, land transformation (agriculture, industrial plantation, built-up environments, and other land uses), settlements, roads, and access. In the HF analysis, all of these pressure types were given scores of 0 to 10 (0 = no pressure; 10 = maximum pressure) based on expert judgment. These scores were assigned on each 30m × 30m pixel of Thematic Land Cover map (2012 and 2017) for land transformation and settlements, Binamarga map (2014) was obtained for roads and access, and UN-WPP map was obtained from CIESIN (2018) for human population (2010 and 2015). Scores from all maps were summed to get total scores for each pressure or the Human Influence Index (HII). The total HII scores were then standardized for per ha area of NPs in each bioregion. Percent changes of HII from 2012 to 2017 were also calculated. For further details on HF analysis, Sanderson et al. (2002) and Venter et al. (2016) may be consulted. Simple linear regression analysis was performed using the R statistic packages (R Core Team 2014) to check the relation significance between forest cover and HF.

RESULTS AND DISCUSSION

Forest cover in bioregions

In this study, forest cover is the summation of total primary and secondary forests of drylands, peatlands, and mangroves occurring within all terrestrial NP areas. NPs in all 7 bioregions in Indonesia in total suffered a 1.62% loss of forest cover between 2012 and 2017 (Table 1). There was a significant relationship between forest cover in Indonesia's terrestrial NPs and Human Footprint (R^2=0.33, df=41, P<0.5). The higher the Human Footprint (HF) inside NPs, the lower the forest cover. In this study, HF comprised pressures from roads, access (from roads, railways, big rivers, and coastlines), settlements, land transformation (agriculture, industrial plantations, built-up environment and other land uses such as bare lands and shrubs) and human population. Among these pressures, the highest forest cover loss drivers were direct road developments within NPs and access to park areas caused by those roads, plus rivers and coastlines (Table 2). In Indonesia, protected areas are largely threatened by ongoing and planned roads and other access developments. In Sumatra, the planned trans-Sumatra highway would likely affect Kerinci Seblat and Leuser, two of the last large forest areas on the island (Sloan et al. 2019a), and shall likely have many negative ecological impacts, including fragmentation of large expanses of intact forest. Landscape connectivity will likely reduce from 89% to 55% due to the planned and ongoing road and rail-line developments in Kalimantan (Alamgir et al. 2019). The remaining large intact forest in the two islands might be largely fragmented if all planned development proceeds (Alamgir et al 2019; Sloan et al. 2019a). Human population was also a strong driver of forest cover loss (Table 2). A study by Verma et al. (2020) also showed that changes in human pressures seemed to relate to human population in and around PAs in Sundaland. Protected areas can be economically detrimental or beneficial to human population thus attracting or deterring new settlements around them. Human population increase near PAs may threaten their potential to conserve forest and biodiversity. Thus saving PAs has to become priority as global network of PAs is becoming more isolated due to growing human population (Joppa et al. 2009).

Apart from those three main drivers of forest cover loss in Indonesia's terrestrial NPs, land transformation that comprises agriculture areas, industrial plantations, built-up environments and other uses, also plays an important part in driving deforestation. During those five years, the highest forest cover loss occurred in Kalimantan. This bioregion lost 2.34% of forests of its NPs. Agriculture areas increased by 42.17% and industrial plantation areas increase very high within the park areas in 5 years. These were also the highest increases of those drivers among bioregions. Sumatra follows Kalimantan in forest cover loss in NPs. National parks in Sumatra lost 2.28% of their forests. There were increases in other land uses (bare lands and shrubs) by 29.65% and agriculture areas by 16.96% within the parks. Among the 7 bioregions, Nusa Tenggara suffered the third highest forest cover loss. National parks

in Nusa Tenggara lost 1.43% of forest covers. Huge increase in industrial plantation and built-up environment occurred in Nusa Tenggara between 2012 and 2017. Sulawesi lost 0.84% of forest cover and experienced increases in other land use (41.40%). With an increase in agricultural areas by 9.76%, Maluku has lost 0.24% of its NPs' forests. Forest cover in Papua's NPs decreased 0.21%, driven mainly by roads and access (Table 1 and 2). Previous studies (Alamgir et al. 2019; Laurance et al. 2012; Sloan et al. 2019b) showed that various human activities have negative effects on the condition of protected areas. Increased human activities usually correlate with forest loss, and the ability of forest to regenerate increases with the decrease in human activities (Allan et al. 2017).

Tabel 1. Forest cover changes in 43 terrestrial national parks in Indonesia between 2012 and 2017.

National Parks (NP)	Total forest cover (ha)			Primary forest (ha)		
	2012	2017	%Changes	2012	2017	%Changes
Sumatra (total)	**3,001,218.53**	**2,932,804.57**	**-2.28**	**2,267,139.82**	**2,266,416.89**	**-0.03**
Batang Gadis	59,895.90	59,511.84	-0.64	40,569.52	39,907.54	-1.63
Berbak	118,330.59	101,994.79	-13.81	118,129.89	99,934.02	-15.40
Bukit Barisan Selatan	234,349.96	232,776.56	-0.67	129,250.92	186,629.43	44.39
Bukit Dua Belas	50,308.89	48,116.39	-4.36	0.00	0.00	
Bukit Tiga Puluh	137,369.65	132,995.83	-3.18	21,450.45	21,386.99	-0.30
Gunung Leuser	807,808.44	805,103.03	-0.33	718,507.01	710,741.71	-1.08
Kerinci Seblat	1,241,337.72	1,217,065.13	-1.96	1,167,521.97	1,128,801.19	-3.32
Sembilang	121,398.90	122,947.78	1.28	70,623.91	78,847.56	11.64
Siberut	156,696.94	155,919.75	-0.50	164.08	164.08	0.00
Tesso Nilo	29,255.85	15,506.72	-47.00	0.00	0.00	
Way Kambas	44,465.69	40,866.75	-8.09	922.07	4.37	-99.53
Kalimantan (total)	**3,211,786.02**	**3,136,631.52**	**-2.34**	**2,232,413.65**	**2,224,570.19**	**-0.35**
Betung Kerihun	802,002.55	801,790.58	-0.03	801,377.04	800,585.19	-0.10
Bukit Raya Bukit Baka	232,741.61	232,239.55	-0.22	195,900.88	193,898.96	-1.02
Danau Sentarum	45,342.26	41,199.33	-9.14	1,051.45	827.21	-21.33
Gunung Palung	88,471.38	85,353.79	-3.52	22,653.84	22,649.13	-0.02
Kayan Mentarang	1,261,496.92	1,262,154.38	0.05	1,186,539.62	1,185,373.96	-0.10
Kutai	144,510.67	131,244.46	-9.18	7,170.83	4,247.96	-40.76
Sebangau	459,810.04	428,217.70	-6.87	0.00	0.00	
Tanjung Puting	177,410.59	154,431.73	-12.95	17,719.99	16,987.78	-4.13
Sulawesi (total)	**540,925.36**	**536,384.53**	**-0.84**	**387,762.70**	**386,163.89**	**-0.41**
Bantimurung Bulusaraung	29,957.49	29,948.68	-0.03	348.22	348.22	0.00
Bogani Nani Wartabone	266,941.96	265,998.54	-0.35	200,603.82	198,922.79	-0.84
Lore Lindu	204,384.65	203,240.80	-0.56	186,787.54	186,869.76	0.04
Rawa Aopa Watumohai	39,641.26	37,196.51	-6.17	23.12	23.12	0.00
Maluku (total)	**324,483.45**	**323,709.53**	**-0.24**	**134,814.26**	**125,125.89**	**-7.19**
Aketajawe Lolobata	159,219.24	158,585.96	-0.40	57,354.47	47,768.20	-16.71
Manusela	165,264.21	165,123.57	-0.09	77,459.79	77,357.69	-0.13
Papua (total)	**1,915,354.85**	**1,911,384.16**	**-0.21**	**1,762,690.29**	**1,758,308.65**	**-0.25**
Lorentz	1,814,714.35	1,814,664.81	0.00	1,733,652.25	1,729,366.65	-0.25
Wasur	100,640.50	96,719.35	-3.90	29,038.04	28,942.00	-0.33
Java Bali (total)	**238,916.15**	**241,858.57**	**1.23**	**15,791.34**	**31,758.00**	**101.11**
Alas Purwo	35,914.16	38,207.01	6.38	533.27	750.45	40.73
Bali Barat	7,557.93	7,274.41	-3.75	1,586.19	1,510.68	-4.76
Baluran	4,027.21	4,293.99	6.62	113.91	12.06	-89.41
Bromo Tengger Semeru	41,115.79	41,097.55	-0.04	0.00	3,683.04	
Gunung Ciremai	4,899.16	5,346.03	9.12	1,363.31	1,283.83	-5.83
Gunung Gede Pangrango	17,799.86	17,629.10	-0.96	4,805.46	4,883.66	1.63
Gunung Halimun Salak	38,404.23	39,798.26	3.63	1,912.67	1,887.23	-1.33
Gunung Merapi	1,487.83	1,702.86	14.45	0.00	0.00	
GunungMerbabu	0.00	0.00	0.00	0.00	0.00	
Meru Betiri	45,309.25	44,104.05	-2.66	0.00	12,270.52	
Ujung Kulon	42,400.73	42,405.31	0.01	5,476.53	5,476.53	0.00
Nusa Tenggara (total)	**117,622.05**	**115,945.21**	**-1.43**	**60,885.86**	**73,828.80**	**21.26**
Gunung Rinjani	24,502.67	23,942.44	-2.29	22,527.79	19,230.81	-14.64
Kelimutu	4,989.50	4,829.41	-3.21	0.00	0.00	
Komodo	17,399.46	17,399.74	0.00	3,568.58	839.66	-76.47
Laiwangi Wanggameti	27,521.37	27,485.91	-0.13	9,427.02	27,473.61	191.43
Manupeu Tanah Daru	43,209.05	42,287.71	-2.13	25,362.46	26,284.72	3.64
All bioregions (total)	**9,350,306.41**	**9,198,718.09**	**-1.62**	**6,861,497.91**	**6,866,172.31**	**0.07**

Table 2. Changes of Human Influence Index (HII) per hectare areas of national park in Indonesia's 7 bioregions between 2012 and 2017

Bioregions	Human population	Other land use	Agriculture	Industrial plantation	Built-up environment	Settlement	Road	Access
Sumatra 2012	13.56	4.79	5.60	0.24	0.02	0.00	9.10	13.27
Sumatra 2017	13.67	6.21	6.55	0.12	0.02			
% Changes	0.81	29.65	16.96	-50.00	0	-	-	-
Kalimantan 2012	11.23	8.72	0.83	0.00	0.10	0.01	4.90	11.46
Kalimantan 2017	11.44	9.42	1.18	0.04	0.11			
% Changes	1.87	8.03	42.17	~	10.00	-	-	-
Sulawesi 2012	12.41	3.72	4.53	0.03	0.10	0.00	19.68	29.90
Sulawesi 2017	12.94	5.26	4.72	0.03	0.10			
% Changes	4.27	41.40	4.19	0	0	-	-	-
Maluku 2012	11.11	2.04	0.41	0.00	0.00	0.00	21.43	28.02
Maluku 2017	11.11	2.00	0.45	0.00	0.00			
% Changes	0	-1.96	9.76	-	-	-	-	-
Papua 2012	11.59	7.10	0.86	0.00	0.00	0.00	7.42	10.93
Papua 2017	11.59	7.05	0.86	0.00	0.00			
% Changes	0	-0.70	0	-	-	-	-	-
Jawa Bali 2012	69.48	3.45	6.83	14.23	0.15	0.00	33.43	44.44
Jawa Bali 2017	70.44	3.34	7.16	13.12	0.11			
% Changes	1.38	-2.32	4.83	-7.80	-26.67	-	-	-
Nusa Tenggara 2012	28.23	18.01	3.69	0.04	0.01	0.00	29.65	44.44
Nusa Tenggara 2017	28.49	10.88	1.97	0.08	0.06			
% Changes	0.92	-65.53	-87.31	50	500	-	-	

Bioregion Jawa Bali is the only bioregion that in total experienced an increase in forest cover (Table 1). Dwiyahreni (2021) reported that compared to other NPs in Indonesia, NPs in the Jawa Bali bioregion have higher management budgets and numbers of forest guards. It is suggested that along with their natural mountainous steep terrain and their function as the main water sources for both small and large cities around them (Damayanti 2008; Smiet 1992), NPs in the Jawa Bali bioregion managed to protect their forest cover better than other NPs in Indonesia (Table 1). There have been stricter regulation of forestry practices in Indonesia since 2011. This policy coupled with a tree-planting movement has reduced deforestation rates (Tsujino et al. 2016). In 2019, 94.1 Mha or 50.1% of Indonesia's land was covered in forests (KLHK 2020).

Forest cover in national parks

Distribution of forest cover loss between 2012 and 2017 in 43 of Indonesia's terrestrial NPs was too subtle to be shown on the country level scale, so it is not presented here. Three NPs (Tesso Nilo in Sumatra, Tanjung Puting in Kalimantan, and Rawa Aopa in Sulawesi) with the highest forest cover loss (>5%) are presented in Figure 2. Tesso Nilo experienced the highest forest cover loss (47%) in just a 5-year span, which was much higher than any other NP. Berbak NP, also in Sumatra, which suffered the second-highest forest cover loss, only lost 13.81% of its forest cover (Table 1). Forest cover loss in Tesso Nilo was due to road construction and forest fires during the dry season, which almost always occurs. In addition, this NP also suffered from illegal logging, new settlements and new agricultural practices that have penetrated into the park (Mariati et al. 2014). A study by Brun et al. (2015) found that using production forest concessions as buffer areas for protected areas can increase the effectiveness of area management in protecting forests and biodiversity. However, this did not apply in Tesso Nillo. The park is surrounded by Hutan Tanaman Industri (HTI) or industrial forest plantations and oil palm plantations (Mariati et al. 2014). These plantations experience relatively stable pressures, but Tesso Nilo still lost almost 50% of its forest in just 5 years. There was more than 2,400 km of roads within the Tesso Nilo NP in 2016, which amount to a 10 fold increase since 2002. Almost all forest areas in Tesso Nilo were located within 100 m to 1000 m of road edges. the endemic ecosystem in Tesso Nilo is facing continued pressures from roads and associated impacts of access created by roads (Poor et al. 2019a).

The lowest forest cover loss (0.03%) occurred in Bantimurung Bulusaraung, Sulawesi, and Betung Kerihun, Kalimantan (Table 1). Bantimurung Bulusaraung NP attracts tourists on a year-round basis due to its live butterfly collections and eases to see other wildlife close to urban centers. Local communities around the NP are highly involved in tourism activities, especially in collecting, breeding and selling butterflies as souvenirs (Ansari et al. 2019). Betung Kerihun, located in the heart of Borneo, is an area of isolation with steep terrains (Anon 2018, Harefa et al. 2018). There were 8 NPs out of 43 that managed to increase their forest cover, 6 in Jawa Bali, 1 in Sumatra, and 1 in Kalimantan. The 6 NPs were Gunung Merapi NP (14.45% forest increase), Gunung Ciremai (9.12%), Baluran (6.62%), Alas Purwo (6.38%), Gunung Halimun Salak (3.63%), and Ujung Kulon (0.01%). Sembilang NP in Sumatra increased its forest cover by 1.28% and Kayan Mentarang in Kalimantan by 0.05% (Table 1).

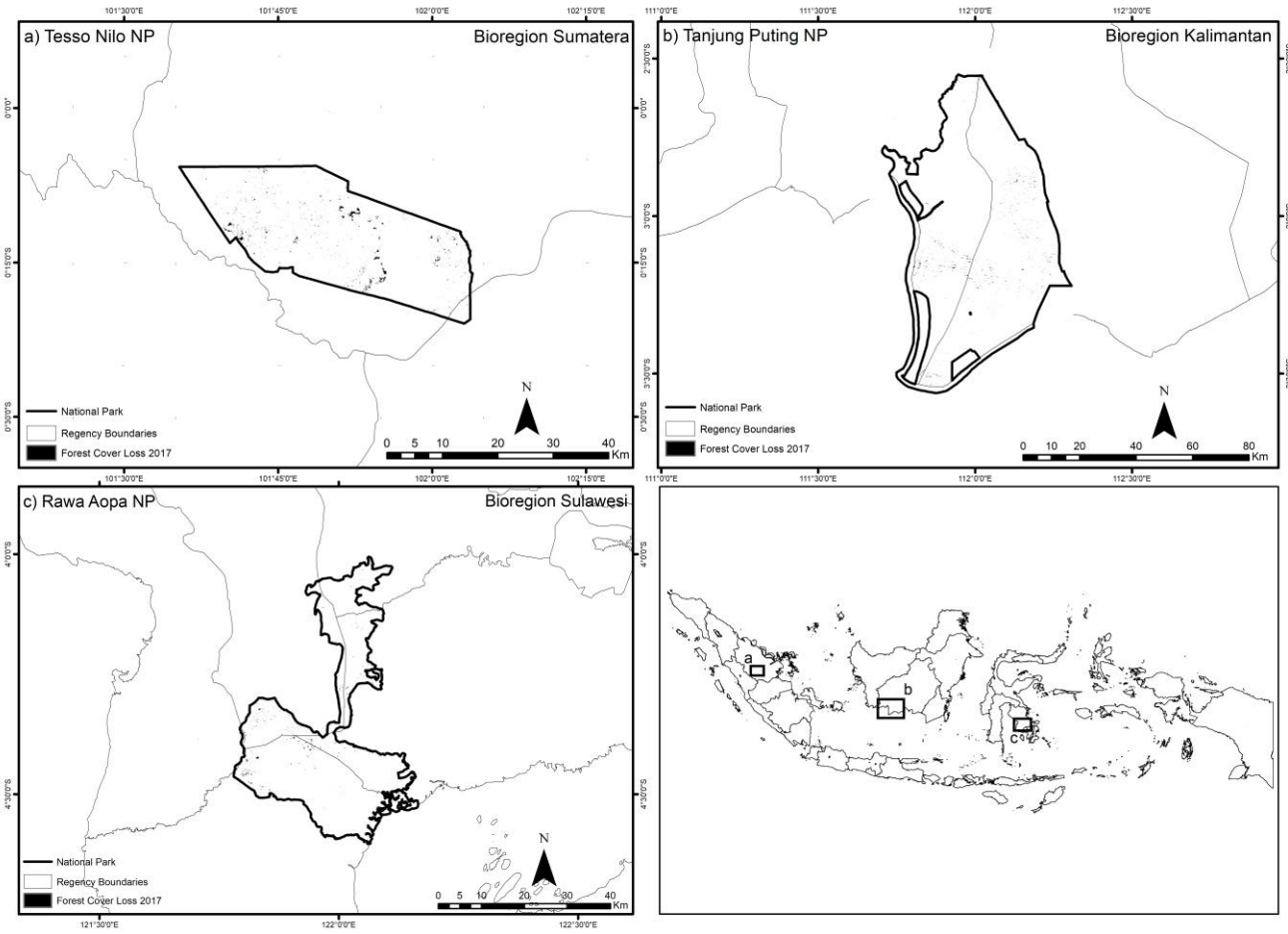

Figure 2. Map of forest loss distributions in 3 national parks with the highest forest cover loss (>5%) between 2012 and 2017 in bioregion Sumatra, Kalimantan, and Sulawesi.

As in Gunung Merapi, Gunung Ciremai, and Gunung Halimun Salak, high mountainous areas and steep terrain as in Betung Kerihun and Kayang Mentarang, reduce human access and activities that can lead to forest loss (Smiet 1992; Baier et al. 2009; Anderson and Mammides 2019). Poor et al. (2019b) reported that Bukit Tigapuluh in Sumatra may experience some protection, independent from its management policy, from the NP's mountainous terrain and difficult access, thus it managed to have the highest avoided deforestation rate compared to other NPs under study. However, not all NPs having mountainous and steep terrain managed to protect and increase their forest cover. In addition to the beneficial natural contour, Gunung Ciremai, in particular, issued a lot more permits for the communities to utilize the park's environmental services than any other NP. This involvement of the communities has had positive effects on the park's forest protection (Dwiyahreni 2021) and the same was also seen in Bantimurung Bulusaraung NP. Betung Kerihun and Kayan Mentarang are also protected from external influences by traditional Dayak communities with high-value natural ecosystems (Anonim 2018; Anau et al. 2019).

Primary forests

Primary rainforest is those which are still in their original condition, characterized by a tall canopy with dense cover. The primary forest floor is relatively clear of understorey plants because the forest canopy blocks the entry of sunlight to the forest floor (Mackey et al. 2013). Almost all terrestrial NPs in Indonesia still have primary forest, but only 7 (0.2%) were able to increase their forest cover. They are Alas Purwo, Gunung Gede Pangrango, and Meru Betiri in the Jawa Bali bioregion, Laiwangi Wanggameti, and Manupeu Tanah Daru in Nusa Tenggara, and Bukit Barisan Selatan and Sembilang in Sumatra. The contributions from those 7 NPs have increased the total primary forest cover in NPs by 0.07%. In 2012, Indonesia's total primary forest cover was 6,861,497.91 ha, and increased to 6,866,172.31 ha in 2017. Kerinci Seblat in Sumatra, Kayan Mentarang in Kalimantan, and Lorentz in Papua are 3 NPs that still have more than 1 Mha of primary forest. Between 2012 and 2017, Kerinci Seblat lost 3.32%of its primary forest, while Lorentz lost 0.25% and Kayan Mentarang lost 0.1% (Table 1).

Protecting primary forests is very important since they store more carbon than other habitat types. Keeping them intact will significantly help alleviate atmospheric carbon load and maintain ecosystem services (Mackey et al. 2013). In addition, primary forests also have important health benefits. A study by Grag (2019) in Indonesia has shown that maintaining primary forest cover by 1% can reduce malaria incidence by 10%. Only about 36% or approximately 14.4 million km^2 of primary forest remain in the world, and about 22% of this is in protected areas, including national parks (Mackey et al. 2013, 2015).

Recommendations for conservation management

This study showed that most terrestrial national parks in Indonesia suffered forest cover loss due to human activities. Jones et al. (2018) reported that 6 million km^2 (32.8%) of the world's protected areas are under very high pressure from human activities. Although each protected area (PA) in Indonesia has its own unique biophysical conditions that are all worthy of protection, as a start, conservation management priority can be given to PAs that still have large primary forest cover.

Mackey et al. (2015) recommend 4 important actions that need to be considered in global negotiations for climate change, biodiversity, and sustainable development. They include (i) recognizing primary forests as a matter of global concern within international negotiations, (ii) including primary forests in environmental accounting, (iii) prioritizing the 'avoid loss' principle for primary forests, and (iv) accepting the important role of customary forest areas and forests managed by communities. To achieve this fourth action, it will be necessary to reconcile the global public goods that primary forests represent, with the aspirations of local forest owners, who need to use their forest resources to improve their livelihoods (Sayer and Margules 2017). Without special policies for the management and protection of primary forests, the values of biodiversity and their unique ecosystems, and the ecosystem services they provide will continue to be eroded (Mackey et al. 2015).

The effectiveness of PAs in stopping forest encroachment, reducing forest cover loss, reducing hunting, and preventing forest fires, are all linked to management activities and the resources available for management. Bruner et al. (2001) explained that basic management activities such as enforcing regulations and establishing clear boundaries have succeeded in increasing the effectiveness of PA management. Increasing the effectiveness of conservation efforts through management inputs and increasing utilization of ecosystem services by the public at large, as has happened in the Jawa Bali bioregion, might help other PAs in Indonesia.

ACKNOWLEDGEMENTS

We acknowledge the University of Indonesia for financial support through the PITMA A research grant program, grant ID NKB-0889/UN2.R3.1/HKP.05.00/2019. We thank the Indonesian Ministry of Environment and Forestry for providing reference maps. We also thank the Research Center for Climate Change, University of Indonesia, Depok, for this study's administrative support.

REFERENCES

Alamgir M, Campbell MJ, Sloan S, Suhardiman A, Supriatna J, Laurance WF. 2019. High-risk infrastructure projects pose imminent threats to forests in Indonesian Borneo. Sci Rep 9 (1): 1-10. DOI: 10.1038/s41598-018-36594-8.

Allan JR, Venter O, Maxwell S, Bertzky B, Jones K, Shi Y, Watson JEM. 2017. Recent increases in human pressure and forest loss threaten many natural world heritage sites. Biol Conserv 206: 47-55. DOI: 10.1016/j.biocon.2016.12.011.

Anau N, Hakim A, Lekson AS, Setyowati E. 2019. Local wisdom practices of Dayak indigenous people in the management of Tana' Ulen in the Kayan Mentarang National Park of Malinau Regency, North Kalimantan Province, Indonesia. Russian J Agric Socio-Econ Sci 7: 156-167.

Anderson E, Mammides C. 2019. The role of protected areas in mitigating human impact in the world's last wilderness areas. Ambio 49 (2): 434-441. DOI: 10.1007/s13280-019-01213-x.

Anon. 2018. Laporan kinerja Balai Besar Taman Nasional Betung Kerihun dan Danau Sentarum Tahun 2017. Kementrian Lingkungan Hidup dan Kehutanan. Direktorat Jenderal Konservasi Alam dan Sumber Daya Alam. [Indonesian]

Ansari F, Jeong Y, Putri IASLP, Kim SI. 2019. Sociopsychological aspects of butterfly souvenir purchasing behavior at Bantimurung Bulusaraung National Park in Indonesia. Sustainability 11 (6): 1789. DOI: 10.3390/su11061789.

Badan Standarisasi Nasional. 2010. Standar Nasional Indonesia SNI 7645: 2010. Klasifikasi penutup lahan. BSN, Jakarta [Indonesian].

Baier M. 2009. The Kayan Mentarang National Park: Indonesia's new national park in North Central Borneo bordering Northern Sarawak and Sabah. Borneo Res Bull 40: 297-309.

Binamarga Map. 2014. Indonesian Ministry of Public Works. [Indonesian]

Brandon K. 2014. Ecosystem services from tropical forests: Review of current science. CGD Working Paper 380. Center for Global Development, Washington DC.

Brun C, Cook AR, Lee JSH, Wich SA, Koh LP, Carrasco LR. 2015. Analysis of deforestation and protected area effectiveness in Indonesia: A comparison of Bayesian spatial models. Glob Environ Chang 31: 285-295. DOI: 10.1016/j.gloenvcha.2015.02.004.

Bruner A, Gullison G, Rice RE, da Fonseca RE, Gustavo AB. 2001. Effectiveness of parks in protecting tropical biodiversity. Science 291 (5501): 125-128. DOI: 10.1126/science.291.5501.125.

CIESIN. 2018. United Nation's World Population Prospects (UN WPP)-Adjusted Population Density Available at https://sedac.ciesin.columbia.edu/data/set/gpw-v4-population-density-adjusted-to-2015-unwpp-country-totals-rev11,

Critical Ecosystem Partnership Fund. 2014. Ecosystem Profile. Wallacea Biodiversity Hotspot. Burung Indonesia, Bogor.

Damayanti EK. 2008. Legality of National Parks and Involvement of Local People: Case Studies in Java, Indonesia and Kerala, India. [Dissertation]. University of Tsukuba, Japan.

Dwiyahreni AA. 2021. Model Praktik Pengelolaan Kawasan Konservasi di Indonesia. Analisis Interaksi Tekanan-Kondisi-Respon Taman Nasional Darat di Indonesia dan Hubungannya dengan Efektivitas Pengelolaan Kawasan. [Dissertation]. Universitas Indonesia, Jakarta. [Indonesian]

Gaveau DLA, Locatelli B, Salim MA, Yaen H, Pacheco P, Sheil D. 2018. Rise and fall of forest loss and industrial plantations in Borneo (2000-2017). Cons Lett 12 (3): e12622. DOI: 10.1111/conl.12622.

Grag T. 2019. Ecosystems and human health: The local benefits of forest cover in Indonesia. J Environ Econ Manage 98: 102271. DOI: 10.1016/j.jeem.2019.102271.

Hansen MC, Potapov PV, Moore R, Hancher M, Turubanova SA, Tyukavina A, Thau D, Stehman SV, Goetz SJ, Loveland TR, Kommareddy A, Egorov A, Chini L, Justice CO, Townshend JRG. 2013. High-resolution global maps of 21st-century forest cover change. Science 342 (6160): 850-853. DOI: 10.1126/science.1244693

Harefa RK, Widodo P, Supriyatno M. 2018. Pengelolaan Taman Nasional Betung Kerihun (TNBK) di perbatasan Indonesia dan Malaysia (Studi

penjagaan keamanan perbatasan di Kalimantan Barat). Manajemen Pertahanan 4: 16-30. [Indonesian]

Hrdina A, Rompoltl D. 2017. Evaluating global biodiversity hotspots - Very rich and even more endangered. J Landsc Ecol 10: 108-115. DOI: 10.1515/jlecol-2017-0013.

Indonesian Ministry of Environment and Forestry. 2012, 2017. Landuse thematic map 2012 and 2017. Indonesian Ministry of Environment and Forestry, Jakarta.

Jones KR, Venter O, Fuller RA, Allan JR, Maxwell SL, Negret PJ, Watson JEM. 2018. One-third of global protected land is under intense human pressure. Science 360 (6390): 788-791. DOI: 10.1126/science.aap9565.

Joppa LN, Loarie SR, Pimm SL. 2009. On population growth near protected areas. PLoS ONE 4: e4279. DOI: 10.1371/journal.pone.0004279.

KLHK. 2020. Hutan dan Deforestasi Indonesia Tahun 2019. http://ppid.menlhk.go.id/siaran_pers/browse/2435#:~:text=Berdasarkan%20data%20Direktorat%20Jenderal%20Planologi,%2C1%25%20dari%20total%20daratan. [Indonesian]

Laurance WF, Useche DC, Rendeiro J, Kalka M, Bradshaw CJA, Sloan SP, et al. 2012. Averting biodiversity collapse in tropical forest protected areas. Nature 489 (7415): 290-294. DOI: 10.1038/nature11318.

Lewis SL, Edwards DP, Galbraith D. 2015. Increasing human dominance of tropical forests. Science 349: 827-832. DOI: 10.1126/science.aaa9932.

Mackey B, DellaSala DA, Kormos C, Lindenmayer D, Kumpel N, Zimmerman B, Hugh S, Young V, Foley S, Arsenis K, Watson JEM. 2015. Policy options for the world's primary forests in multilateral environmental agreements. Conserv Lett 8 (2): 139-147. DOI: 10.1111/conl.12120.

Mackey B, Prentice IC, Steffen W, House JI, Lindenmayer D, Keith H, Berry S. 2013. Untangling the confusion around land carbon science and climate change mitigation policy. Nature Clim Change 3 (6): 552-557. DOI: 10.1038/nclimate1804.

Margono BA, Potapov PV, Turubanova S, Stolle F, Hansen MC. 2014. Primary forest cover loss in Indonesia over 2000-2012. Nat Clim Chang 4 (8): 730-735. DOI: 10.1038/nclimate2277.

Mariati S, Kusnoputranto H, Supriatna J, Koestoer RH. 2014. Habitat loss of Sumatran elephants (*Elephas maximus sumatranus*) in Tesso Nilo forest, Riau, Indonesia. Aust J Basic Appl Sci 8 (2): 248-255.

Miettinen J, Shi C, Liew SC. 2011. Deforestation rates in insular Southeast Asia between 2000 and 2010. Glob Chang Biol 17 (7): 2261-2270. DOI: 10.1111/j.1365-2486.2011.02398.x.

Miller GT, Spoolman SE. 2016. Environmental Science 5th ed. Cengage Learning, Australia.

Morales-Hidalgo D, Oswalt SN, Somanathan E. 2015. Status and trends in global primary forest, protected areas, and areas designated for conservation of biodiversity from the Global Forest Resources Assessment 2015. For Ecol Manag 352: 68-77. DOI: 0.1016/j.foreco.2015.06.011.

Mulyana A, Moeliono M, Minnigh P, Indriatmoko Y, Limberg G, Utomo NA, Iwan R, Saparuddin, Hamzah. 2010. Kebijakan pengelolaan zona khusus. Dapatkah meretas kebuntuan dalam menata ruang taman nasional di Indonesia. Brief 1: 0-0. DOI: 10.17528/cifor/003100. [Indonesian]

Poor EE, Frimpong E, Imron MA, Kelly MJ. 2019a. Protected area effectiveness in a sea of palm oil: A Sumatran case study. Biol Conserv 234: 123-130. DOI: 10.1016/j.biocon.2019.03.018.

Poor EE, Jati VIM, Imron MA, Kelly MJ. 2019b. The road to deforestation: Edge effects in an endemic ecosystem in Sumatra, Indonesia. PloS ONE 14 (7): e0217540. DOI: 10.1371/journal.pone.0217540.

R Core Team. 2014. A Language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.

Sanderson EW, Jaiteh M, Levy MA, Redford KH, Wannebo AV, Woolmer G. 2002. The human footprint and the last of the wild. Bioscience 52 (10): 891-904. DOI: 10.1641/0006-3568(2002)052[0891:THFATL]2.0.CO;2.

Sayer J, Margules C. 2017. Biodiversity in locally managed lands. Land 6 (2): 41. DOI: 10.3390/land6020041.

Sloan S, Alamgir M, Campbell MJ, Setyawati T, Laurance WF. 2019a. Development corridors and remnant-forest conservation in Sumatra, Indonesia. Trop Conserv Sci 12: 1-9. DOI: 10.1177/1940082919889509.

Sloan S, Campbell MJ, Alamgir M, Lechner AM, Engert J, Laurance WF. 2019b. Transnational conservation and infrastructure development in the Heart of Borneo. PLoS ONE 14: e0221947. DOI: 10.1371/journal.pone.0221947.

Smiet AC. 1992. Forest ecology on Java: human impact and vegetation of montane forest. J Trop Ecol 8: 129-152.

Supriatna J, Dwiyahreni AA, Winarni N, Mariati S, Margules C. 2017. Deforestation of primate habitat on Sumatra and adjacent islands, Indonesia. Primate Conserv 31: 1-12.

Supriatna J, Shekelle M, Fuad HAH, Winarni NL, Dwiyahreni AA, Farid M, Mariati S, Margules C, Prakoso B, Zakaria Z. 2020. Deforestation on the Indonesian island of Sulawesi and the loss of primate habitat. Glob Ecol Conserv 24: e01205. DOI: 10.1016/j.gecco.2020.e01205

Supriatna J. 2018. Konservasi Biodiversitas. Teori dan Praktik di Indonesia. Yayasan Pustaka Obor, Jakarta. [Indonesian]

Tsujino R, Yumoto T, Kitamura S, Djamaluddin I, Darnaedi D. 2016. History of forest loss and degradation in Indonesia. Land Use Policy 57: 335-347. DOI: 10.1016/j.landusepol.2016.05.034

Turubanova S, Potapov PV, Tyukavina A, Hansen MC. 2018. Ongoing primary forest loss in Brazil, Democratic Republic of the Congo, and Indonesia. Environ Res Lett 13: 074028. DOI: 10.1088/1748-9326/aacd1c.

Venter O, Sanderson EW, Magrach A, Allan JR, Beher J, Jones KR, Possingham HP, Laurance WF, Wood P, Fekete BM, Levy MA, Watson JEM. 2016. Global terrestrial human footprint maps for 1993 and 2009. Sci Data 3 (1): 160067. DOI: 10.1038/sdata.2016.67.

Verma M, Symes WS, Watson JEM, Jones KR, Allan JR, Venter O, Rheindt FE, Edwards DP, Carrasco LR. 2020. Severe human pressures in the Sundaland biodiversity hotspot. Conserv Sci Pract 2 (2): e169. DOI: 10.1111/csp2.169.

Wiratno. 2018. Sepuluh cara baru kelola kawasan konservasi di Indonesia: Membangun 'organisasi pembelajar'. Direktorat Jenderal KSDAE Kementrian Lingkungan Hidup dan Kehutanan, Jakarta. http://ksdae.menlhk.go.id/, accessed on 20.01.2021. [Indonesian]

World Commission on Environment and Development. 1987. Our common future. University Press, Oxford.