IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

Mangrove deforestation and CO_2 emissions in Indonesia

To cite this article: V B Arifanti *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **874** 012006

Mangrove deforestation and CO_2 emissions in Indonesia

V B Arifanti[1*], N Novita[2], Subarno[2], and A Tosiani[3]

[1]Research and Development Center for Socio-Economics, Policy and Climate Change, Ministry of Environment and Forestry of the Republic of Indonesia, Jl Gunung Batu No. 5 Bogor, Indonesia
[2]Yayasan Konservasi Alam Nusantara, Graha Iskandarsyah Floor 3. Jl. Iskandarsyah Raya No.66 C. Kebayoran Baru, South Jakarta, Indonesia
[3]Directorate of Forest Resource Monitoring and Inventory, Ministry of Environment and Forestry of the Republic of Indonesia, Manggala Wanabakti Building, 7th Floor, Jalan Gatot Subroto, Jakarta, Indonesia

*virniarifanti@gmail.com (ORCID ID: 0000-0002-6829-4055)

Abstract. Mangroves are unique intertidal ecosystems that are experiencing high rates of deforestation throughout the world. Indonesia that has the highest mangrove cover in the world has lost its mangroves significantly in 1980s with the expansion of aquaculture development due to the increased shrimp price during the Asian economic crisis. Mangrove loss emits a significant amount of greenhouse gas to the atmosphere that contributes to the global warming. This study aims to estimate the extent of mangrove deforestation in Indonesia and the potential greenhouse gas emissions generated from mangrove deforestation in the last decade. We analyzed the land cover maps produced by the Indonesian Ministry of Environment and Forestry from 2009 to 2019 to calculate mangrove deforested areas as activity data. The average emission factor from mangrove deforestation is 136.9 $MgCO_2e\ ha^{-1}yr^{-1}$, based on a meta-analysis from mangrove studies in Indonesia. Our result shows the total mangrove loss in the period of 2009 – 2019 covers an estimated area of 182,091 ha. The spatial analysis suggests that the main drivers of mangrove deforestation were derived from conversion of mangroves to low vegetated areas, aquaculture and agriculture practices. Mangrove deforestation potentially generates a significant amount of 182.6 $MtonCO_2e$ to the atmosphere within 10 years. If mangrove loss continues, a significant amount of greenhouse gases will be accumulated in the atmosphere and negatively affect their unique biodiversity. Halting mangrove deforestation and conserving the remaining mangrove forests is the most cost effective and efficient measure to reduce CO_2 emissions and mitigate climate change.

1. Introduction

Mangroves serve important functions for fisheries [1], provide protection of coastlines from erosion, storms, sea-level rise and maintaining water quality [2] and important habitat for species. This ecosystem is characterized with a large below-ground nutrient storage and significant capacity to sequester and store carbon [3,4,5,6,7] These functions underscore the importance of mangroves in climate change mitigation and adaptation [3,8].

Mangroves are unique wetland ecosystems covering about 137,760 km^2 and distributed in 118 countries along the equator [9]. Between 1980-2005, Indonesia as a country with the highest mangrove cover in the world (3.3 Mha) [10], has lost about 30% of their mangroves or with a deforestation rate of 52,000 ha yr^{-1} [11]. To date, there are an estimated 637,000 ha of degraded mangroves in Indonesia [10]. Mangrove conversion to agriculture, aquaculture, oil and gas, and urban development are identified as the major causes of the loss of mangrove forests worldwide [3,12,13].

Mangrove deforestation in Indonesia is estimated to generate a significant annual loss of carbon ranging from 0.96 Pg CO_2e yr^{-1} (14) to 0.19 Pg CO_2e yr^{-1} [3]. If this condition continues, the mangroves in Indonesia with a potential carbon storage of 3.14 billion tons [3] will be under severe threat.

The Government of Indonesia has commited in Indonesia's first Nationally Determined Contributions (NDC) to reduce the national GHG emission by 29% with the Government of Indonesia's own effort and 41% with the international support by 2030. Given their significant emission reduction potential, mangrove ecosystems could contribute to the Government of Indonesia's climate agenda to reduce its greenhouse gas (GHG) emissions. The objective of this study is to estimate the extent of mangrove deforestation that has occurred in Indonesia and the potential greenhouse gas emissions generated from mangrove deforestation in the last decade. We used the official land cover maps from the Indonesian Ministry of Environment and Forestry to acquire activity data and emission factors specifically calculated for Indonesia. This study will provide information to the Government of Indonesia to understand the condition of mangrove ecosystems in Indonesia, its drivers of deforestation and the resulted GHG emissions arising from mangrove loss in Indonesia.

2. Methods

2.1. Study site

This study is conducted in Indonesia, an archipelagic country in Southeast Asia with seven major regions, i.e. Java, Kalimantan, Bali-Nusa Tenggara Islands, Maluku Islands, Papua, Sulawesi and Sumatra (Figure 1).

2.2. Land cover change analysis

Land cover maps from 2009 to 2019 produced by the Indonesian Ministry of Environment and Forestry (MoEF) were used to analyze land cover change at the national level [14]. The land cover maps of Indonesia had a minimum scale of 1:250.000 and were interpreted from Landsat image mosaic data (Landsat 5 Thematic Mapper / TM, Landsat 7 Enhanced Thematic Mapper Plus / ETM + and Landsat 8 Operational Land Imager/ OLI). In this study mangrove deforestation was determined based upon the change of primary and secondary mangroves to non-forests or other land uses [14]. The change in forest land use over a given time period is also called as the activity data.

Figure 1. The map of Indonesia with the seven major regions

2.3. Emission factors and emissions from mangrove deforestation

Emission factor is the mean annual quantity of carbon emissions following forest conversion. The emission factor for mangrove deforestation in this study is calculated for (1) emissions of primary mangrove forests to non-forest areas or other land uses and (2) emissions of secondary mangrove forests to non-forest areas or other land uses.

Emission factors in this study consisted of the total emissions due to shifts in ecosystem carbon stocks due to land cover change and the emissions associated with shifts in the net ecosystem productivity due to land conversion.The average emission factor from mangrove deforestation is 136.9 $MgCO_2e$ $ha^{-1}yr^{-1}$, based on a meta-analysis from mangrove studies in Indonesia [3,7,15,16]. The CO2 emissions from mangrove deforestation were calculated by multiplying the emission factor by the activity data of each region.

3. Results and discussion

3.1. Mangrove deforestation

Mangrove (gross) deforestation in Indonesia from 2009-2019 was totaled at 182,091 ha. Within this period, mangrove deforestation rate in Indonesia is estimated at 18,209 ha yr^{-1}. There is an increasing trend of mangrove deforestation in the period of 2015 to 2019 where the highest deforestation occurred significantly in secondary mangrove forests (Figure 2, Table 1).

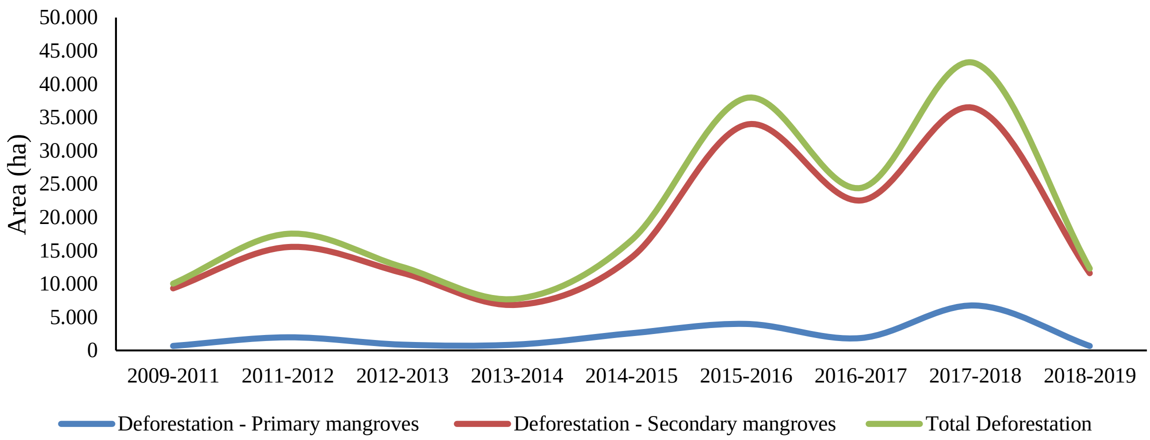

Figure 2. Gross mangrove deforestation in Indonesia (2009-2019)

In the last decade, mangrove deforestation predominantly occurred in secondary mangroves at a rate of 16,173ha yr^{-1} or totaling about 161,725 ha. Mangrove loss deriving from the secondary mangrove forests is eight times higher or comprising about 89% from primary mangrove loss (Table 1).

Table 1. Areas of mangrove deforestation from 2009 to 2019 and mangrove deforestation rates in Indonesia.

Deforestation	2009-2011 (ha)	2011-2012 (ha)	2012-2013 (ha)	2013-2014 (ha)	2014-2015 (ha)	2015-2016 (ha)	2016-2017 (ha)	2017-2018 (ha)	2018-2019 (ha)	Total area (ha)	Deforestation rate (ha yr^{-1})
Primary	695	1,984	885	903	2,594	3,992	1,871	6,753	688	20,365	2,037
Secondary	9,334	15,526	11,654	6,856	13,953	33,901	22,523	36,371	11,608	161,725	16,173
Total Deforestation	10,028	17,510	12,539	7,758	16,547	37,893	24,395	43,124	12,295	182,091	18,209

Note: Primary deforestation is the loss of primary mangroves to non-forests and secondary deforestation is the loss of secondary mangroves to non-forests. Total deforestation is the sum of primary and secondary mangrove deforestation.

Deforestation is defined as the permanent alteration of a forested to non-forested structure as a result of human activities [10]. Indonesia's mangrove deforestation rate from 2009 to 2019 (18,209 ha yr^{-1}) had been significantly decreased for almost three times from the period of 1980-2005 (52,000 ha yr^{-1}) [11]. However, mangrove deforestation rate in Indonesia is still high compared to mangrove loss in SE Asia (9,535 ha yr^{-1}) [17].

According to the forest function (forest types) classification, the highest mangrove deforestation in Indonesia occurred mainly in non-forest areas (APL) which totaled at 88,426 ha during 2009 – 2019 or covering about 48.6% of the total mangrove deforestation (Figure 3). This trend was followed by mangrove loss in the production forests (HP) (49,226 ha or 27%), protection forests (HL) (30,336 ha or 17%). The lowest mangrove loss was observed in the conservation forests (HK) (14,103 ha or 8%) (Figure 3).

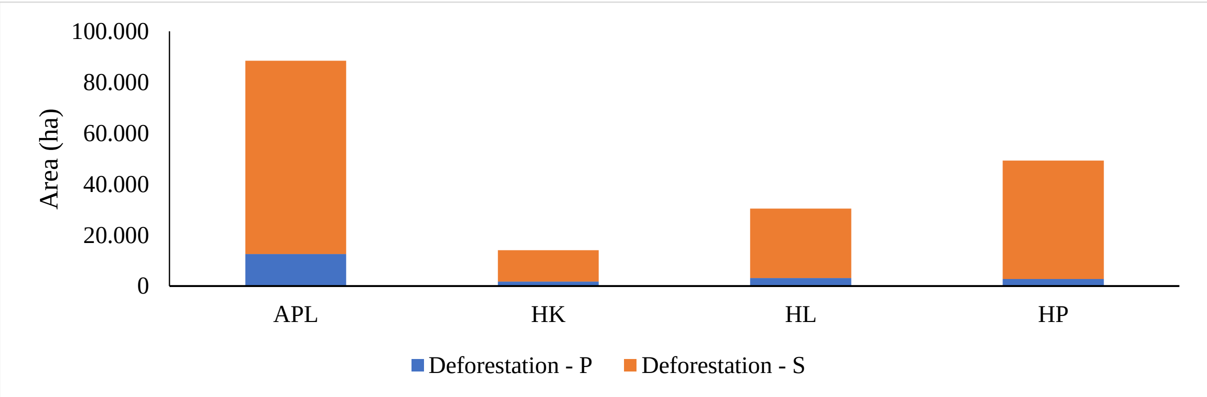

Figure 3. Total gross mangrove deforestation area in Indonesia by forest function from 2009 - 2019.

Note: APL is non forest areas, HK is conservation forest, HL is protection forest and HP is production forest. The blue bar refers to primary mangrove deforestation and the orange bar refers to secondary mangrove deforestation.

Our results show that the highest mangrove loss occurred in secondary mangroves (16,173 ha yr^{-1}) or about eight times higher than in primary mangroves (Table 1). We also found that the highest mangrove deforestation took place predominantly in non-forest areas (APL) (Figure 3). Non-forest areas (APL) are areas that are managed by the local government. Mangrove deforestation is also observed in primary forests (2,037 ha yr^{-1}), protection (HP) and conservation forests (HK) (Figure 3). These mangrove forests are managed by the Central Government where logging is prohibited. The proportion of mangrove forests under conservation management is approximately 22% of the total mangrove extent in Indonesia [18].

Kalimantan and Sumatra are two regions with the highest mangrove loss in Indonesia with mangrove deforestation rates of 6850 ha yr^{-1} and 5832 ha yr^{-1} respectively (Figure 4). Other regions such as Java and Papua still have low mangrove deforestation areas compared to other regions (Figure 4).

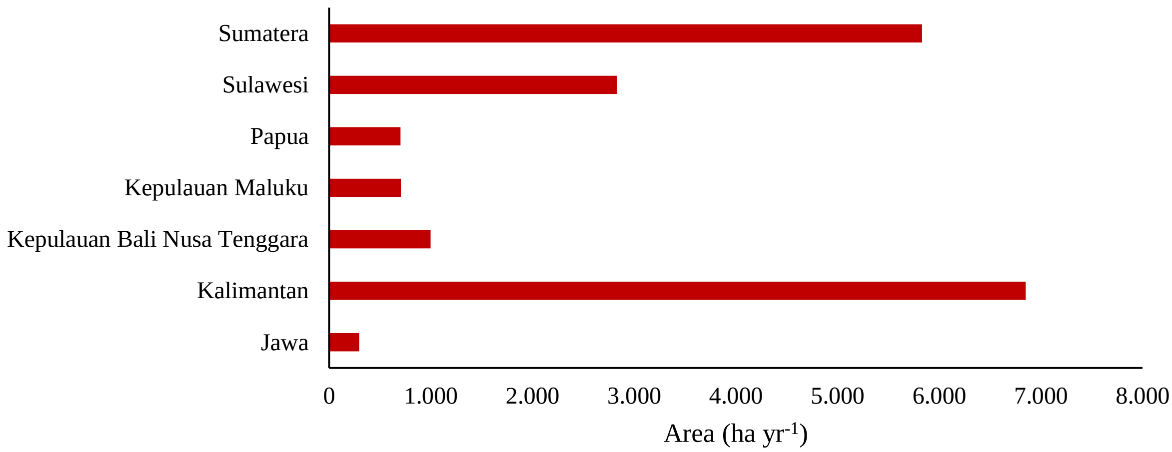

Figure 4. Rates of mangrove deforestation in 2009 - 2019 by region in Indonesia

Our results show that Papua, Kalimantan and Sumatra are regions with the highest mangrove area in Indonesia. However, we found that high mangrove loss occurred in Kalimantan and Sumatra from 2009-2019. The same trend had been observed during the 2000-2012 time period in Indonesia [17]. Kalimantan and Sumatra are two regions that contributed the highest shrimp production in Indonesia [19]. Mangrove conversion to aquaculture are the major causes of the high mangrove loss in these regions. Java has the lowest mangrove deforestation rate because the natural mangroves once occupying the Javan coast had disappeared due to the development and increased population in this region.

3.2. Drivers of mangrove deforestation

To understand the drivers of mangrove deforestation, we classified the mangrove cover change into four categories:

(1) aquaculture, consisting of fish ponds, open water and open swamp
(2) agriculture, consisting of estate crops, mixed dryland agriculture, plantation forests and transmigration areas
(3) low vegetation, consisting of shrubs, bare grounds, savannas and grasses
(4) infrastructure development, consisting of mining areas, settlements and ports/harbours

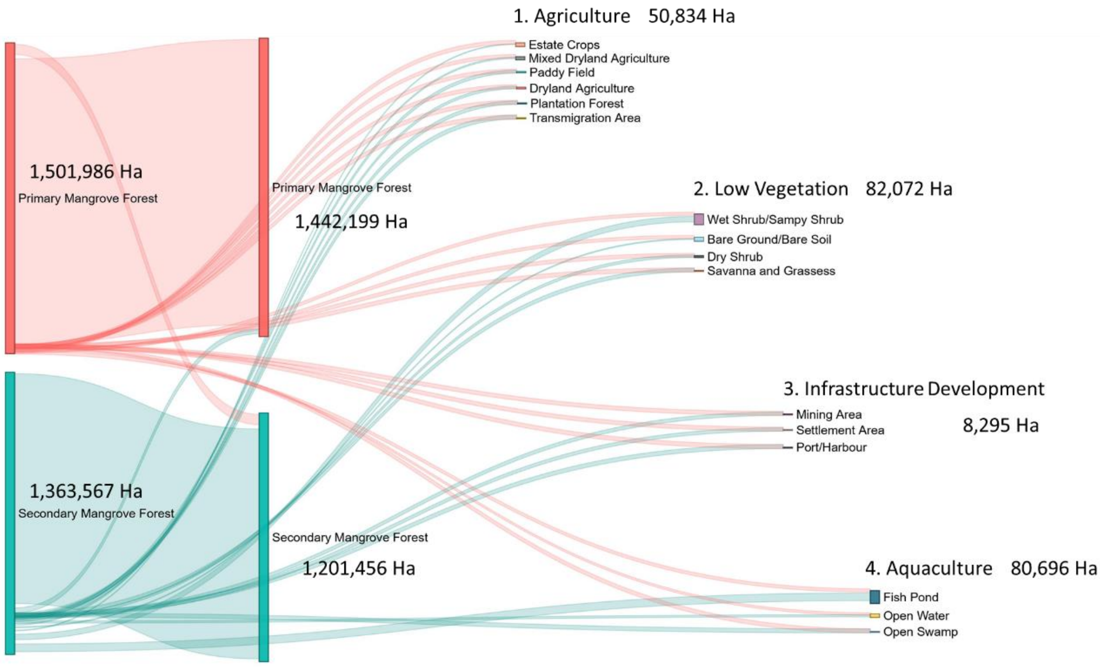

Figure 5. Drivers of mangrove deforestation from 2009-2019 in Indonesia

We found that the major drivers of mangrove deforestation in Indonesia resulted from low statured vegetation (land use transition from mangroves to aquaculture), aquaculture, agriculture, and infrastructure development (Figure 5).

Mangrove forest cover change occurred predominantly in low vegetation (82,072 ha), followed by aquaculture (80,696 ha), agriculture (50,834 ha) and infrastructure development (8,295 ha) (Figure 5). Low vegetation in this analysis refers to the land cover with low cover density resulting due to the transition or lag period from mangroves conversion to aquaculture. After mangroves had been cut, most of them are left during a certain period before turning into ponds. During this lag period, new vegetation such as shrubs, grasses and even bare lands took over the formerly mangrove cover. The vast amount of these low stature vegetated areas indicated that most of the mangroves are in the process of alteration to another types of land uses. Our analysis indicated that aquaculture contributes as the main driver of mangrove deforestation in Indonesia. Aquaculture has been identified as a long-time cause of mangrove deforestation in Indonesia, especially in Kalimantan, Sumatra and Sulawesi since 1980's. During 1994 -2015, mangroves in the area of the Mahakam Delta, in East Kalimantan, had been deforested for about 62% [20]. Overall, we estimate that aquaculture contributes about 36% to mangrove deforestation in Indonesia.

In addition to conversion to coastal aquaculture, mangroves in Indonesia are also subject to conversion to agriculture, logging and infrastructure development. Agriculture contributed quite significant to mangrove deforestation in Indonesia. The establishment of oil palms are one of the factors leading to destruction of mangrove forests. The development of oil palm plantations as a potential major driver of mangrove loss in Sumatra and Kalimantan was also observed [17]. One example of mangrove conversion to oil palm took place in Langkat District, North Sumatra Province, where 1,786 ha (87%) of mangroves were converted to oil palm plantations since 2006. Mangrove conversion to oil palm plantations in Langkat District resulted in the closure of 13 tributaries, increased flood frequency and disrupted endemic species habitat [21].

3.3. Emissions from mangrove deforestation

CO_2 emissions from mangrove deforestation from 2009-2019 totaled at 182.6 $MtCO_2e$. The average CO_2 emissions resulting from primary and secondary mangrove deforestation in Indonesia is estimated at 18.26 $MtCO_2e$ per year (Table 2). Our results show that secondary mangrove deforestation generates three folds of CO_2 emissions than the primary mangroves. Significant increase of CO_2 emissions was indicated in 2015-2018 and an abrupt decrease showed from 2019 onward.

Table 2. CO_2 emissions from mangrove deforestation in Indonesia from 2009 to 2019

Sub-Categories	CO_2 emissions ($MtCO_2e$)									
	2009-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	Total
Primary mangroves deforestation	1.42	4.39	1.77	1.95	5.99	8.51	3.98	14.36	1.46	43.83
Secondary mangroves deforestation	8.46	13.68	9.34	5.80	12.21	29.64	19.57	28.73	11.31	138.73
Total deforestation	9.88	18.07	11.11	7.75	18.20	38.15	23.54	43.09	12.77	182.56

Note: Primary deforestation is the loss of primary mangroves to non-forests and secondary deforestation is the loss of secondary mangroves to non-forests. Total deforestation is the sum of primary and secondary mangrove deforestation.

The average CO_2 emissions from mangrove deforestation in Indonesia is estimated at 18.26 $MtCO_2e$ yr^{-1} with the highest emissions resulted in the secondary mangroves (Table 2). This is resulted as the largest mangrove deforestation area occurred in the secondary mangroves.

The Ministry of Environment and Forestry of the Republic of Indonesia has calculated the averaged annual emission from deforestation in Indonesia in the period 2006/2007 – 2015/2016 at 236.9 $MtCO_2$-eyr^{-1} [22]. If we compare this estimate with the annual CO_2 emissions from mangrove deforestation from this study, emissions from mangroves contributes about 8% to the total emissions of forest loss in Indonesia. This highlights the disproportional relationship between the existence of mangroves that constitute only about 2.6% of the total forest area in Indonesia, but contribute quite significantly to the overall CO_2 emissions from all forest types in Indonesia.

4. Conclusions

Mangrove forest areas in Indonesia had been heavily reduced in the last five decades. Their significant capacity to store and sequester carbon can make this ecosystem become a large carbon emitter when they are converted into other land uses Mangrove conversion to aquaculture ponds, agriculture, oil palms, and infrastructure development are the major drivers of mangrove loss in Indonesia. High mangrove deforestation rates resulting in high CO_2 emissions was indicated especially in Kalimantan, Sumatra and Sulawesi. The disproportional contribution of the 2.6% of the existing mangrove area to 8% of the overall emissions of the forest sector in Indonesia underscores the importance of this fragile ecosystem in climate mitigation.

Acknowledgements

The authors wish to thank Yayasan Konservasi Alam Nusantara (YKAN) for their support in providing grant to conduct this study. We would also acknowledge the Directorate of Forest and Land Inventory, the Ministry of Environment and Forestry of the Republic Indonesia for providing the spatial dataset used in this study.

Author Contributions

Virni Budi Arifanti as the main contributor conceived and designed the study, analyzed the data and wrote the initial draft. Nisa Novita involved in developing the concept of the project and analyzed the data. Subarno analyzed the spatial dataset and modeled projections. AnnaTosiani provided and analyzed the spatial dataset. Virni Budi Arifanti led the writing process. All authors contributed to editing subsequent drafts.

References

[1]. Nagelkerken I, Blaber SJM, Bouillon S, Green P, Haywood M, Kirton LG, et al. The habitat function of mangroves for terrestrial and marine fauna: A review. Aquat Bot [Internet]. 2008 Aug [cited 2014 Jan 21];89(2):155–85. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0304377007001830

[2]. Barbier, Edward B.; Hacker, Sally D.; Kennedy, Chris; Kock, Evamaria W.; Stier AC and BRS. The value of estuarine and coastal ecosystem services. Ecol Monogr. 2011;81(2):169–93.

[3]. Murdiyarso D, Purbopuspito J, Kauffman JB, Warren MW, Sasmito SD, Donato DC, et al. The potential of Indonesian mangrove forests for global climate change mitigation. Nat Clim Chang [Internet]. 2015;(July):8–11. Available from: http://www.nature.com/doifinder/10.1038/nclimate2734

[4]. Alongi DM. Carbon Cycling and Storage in Mangrove Forests. Annu Rev Mar Sci. 2014;6:195–219.

[5]. Donato DC, Kauffman JB, Murdiyarso D, Kurnianto S, Stidham M, Kanninen M. Mangroves among the most carbon-rich forests in the tropics. Nat Geosci [Internet]. 2011 Apr 3 [cited 2014 Jan 21];4(5):293–7. Available from: http://www.nature.com/doifinder/10.1038/ngeo1123

[6]. Kauffman JB, Adame MF, Arifanti VB, Schile-Beers LM, Bernardino AF, Bhomia RK, et al. Total ecosystem carbon stocks of mangroves across broad global environmental and physical gradients. Ecol Monogr. 2020;90(2):1–18.

[7]. Arifanti VB, Kauffman JB, Hadriyanto D, Murdiyarso D, Diana R. Carbon dynamics and land use carbon footprints in mangrove-converted aquaculture: The case of the Mahakam Delta, Indonesia. For Ecol Manage. 2019;432.

[8]. Arifanti VB. Mangrove management and climate change: A review in Indonesia. IOP Conf Ser Earth Environ Sci. 2020;487(1).

[9]. Giri C, Ochieng E, Tieszen LL, Zhu Z, Singh A, Loveland T, et al. Status and distribution of mangrove forests of the world using earth observation satellite data. Glob Ecol Biogeogr. 2011;20(1):154–9.

[10]. Ministry of Environment and Forestry Republic of Indonesia. The State of Indonesia’s Forests 2020. Nurbaya S, Efransjah, Murniningtyas S, Erwinsyah, Damayanti EK, editors. The State of the World’s Forests 2020. Jakarta, Indonesia: Ministry of Environment and Forestry, Republic of Indonesia; 2020.

[11]. FAO. The world’s mangroves 1980-2005. Vol. 153, FAO Forestry Paper. 2007.

[12]. Alongi DM. Present state and future of the world’s mangrove forests. Environ Conserv [Internet]. 2002 Nov 13 [cited 2014 Jan 23];29(03):331–49. Available from: http://www.journals.cambridge.org/abstract_S0376892902000231

[13]. Giri C, Zhu Z, Tieszen LL, Singh A, Gillette S, Kelmelis JA. Mangrove forest distributions and dynamics (1975–2005) of the tsunami-affected region of Asia. J Biogeogr [Internet]. 2008 Mar [cited 2014 Jan 21];35(3):519–28. Available from: http://doi.wiley.com/10.1111/j.1365-2699.2007.01806.x

[14]. Ministry of Environment and Forestry Republic of Indonesia. Akurasi Data Penutupan Lahan Nasional Tahun 1990-2016 Akurasi Data Penutupan Lahan Nasional Tahun 1990-2016. Jakarta, Indonesia; 2020.

[15]. Cameron C, Hutley LB, Friess DA, Brown B. Community structure dynamics and carbon stock change of rehabilitated mangrove forests in Sulawesi , Indonesia Community structure

dynamics and carbon stock change of rehabilitated mangrove forests in Sulawesi , Indonesia. Ecol Appl. 2019;29(1):293–7.
[16]. Sasmito SD, Taillardat P, Clendenning J, Friess DA, Murdiyarso D, Hutley LB. Carbon stocks and fluxes associated with land-use and land-cover change in mangrove ecosystems: A systematic review protocol. Bogor, Indonesia; 2016. Report No.: 211.
[17]. Richards DR, Friess DA. Rates and drivers of mangrove deforestation in Southeast Asia, 2000–2012. Proc Natl Acad Sci [Internet]. 2016;113(2):344–9. Available from: http://www.pnas.org/lookup/doi/10.1073/pnas.1510272113
[18]. Kementerian Kehutanan - Kementerian Kelautan dan Perikanan (KK - KKP). Analisis Kesenjangan Keterwakilan Ekologis Kawasan Konservasi Di Indonesia. Jakarta, Indonesia; 2010.
[19]. Ministry of Marine Affairs and Fisheries of the Republic of Indonesia. Marine and Fisheries in Figures 2018. Marine and Fisheries in Figures 2018. Jakarta, Indonesia: The Center for Data, Statistics and Information, MMAF; 2018. 1–384 p.
[20]. Aslan A, Rahman AF, Robeson SM, Ilman M. Science of the Total Environment Land-use dynamics associated with mangrove deforestation for aquaculture and the subsequent abandonment of ponds. Sci Total Environ [Internet]. 2021;791:148320. Available from: https://doi.org/10.1016/j.scitotenv.2021.148320
[21]. Marpaung NR. Dampak konversi hutan mangrove menjadi kebun kelapa sawit terhadap lingkungan di Kec. Brandan Barat, Kab. Langkat (The impacts of mangrove conversion to oil palm plantation in Brandan Barat, Langkat District). Medan State University; 2012.
[22]. Ministry of Environment and Forestry Republic of Indonesia. Emission reduction report for the Indonesia-Norway Partnership. Jakarta, Indonesia; 2020.