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Research paper

Vegetation dynamic post-disturbance in tropical rain forest of Birds's Head Peninsula of West Papua, Indonesia

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ABSTRACT The tropical rainforest has a high level of biodiversity and plays an important role as a stable ecosystem. However, an anthropogenic disturbance took place in some parts of the tropical rainforest. The recovery of the disturbed forest is less scientifically understood. Therefore, this study aims to examine the recuperation process of vegetation in Fef, Tambrauw Regency, and West Papua, in Indonesia by comparing the composition of primary forest life forms as control of the natural, five-year disturbed, and seven-year disturbed forest. The results showed that the species diversity in the primary forest was not significantly different from the seven-year disturbed forest while the five-year disturbed forest was significantly different from the two types mentioned earlier. Moreover, the similarity index showed that the primary and seven-year disturbed forest were identical and both were different from the five-year disturbed forest. In addition, eight life forms were enumerated, *viz.* bamboo, climber, fern, herb, rattan, shrub, small tree, and large tree in which they were dynamic during the post-disturbance compared to primary forest. The residual forests should therefore be part of the intention of local people and government, in other not to exploit the forests by allowing the disturbed forests to recuperate naturally.

KEYWORDS: Cluster Dendrogram, Shannon-Wiener index, Pielou's evenness, New Guinea.

Introduction

The tropical rainforest is one-third of the world's surface area, and comprises of high biodiversity, including vegetation (Budiharta et al. 2014, Pan et al. 2013) which has various species, such as taxonomic diversity, functional traits, and life forms (Dezzotti et al. 2019, Murdjoko et al. 2016). The variations in vegetation are a response to the environment, which has morphological characteristics (Sanchez et al. 2013, Webb 1959). Furthermore, the major driving factors of the variation are the competition for light and nutrients in the soil (Chaturvedi et al. 2017, Lozada et al. 2012). The vegetation shows the competition as interaction, resulting in the variation of vertical structure, taxonomic composition, density, and presence in the forest (Laughlin and Abella 2007, Murdjoko et al. 2020, Picard 2019, Zangaro et al. 2016).

The tropical rainforest has long been formed since primary forests were not affected by anthropogenic activities (Berry et al. 2010, Yamada et al. 2013). With this, this forest ecologically has reached the climax phase. Furthermore, the successional process is dynamic since there is a factor that alters the climax phase such as disturbance, fire, disaster, and climatic factors that change the structure, taxonomic diversity, as well as ecological factors. Thereafter, the forest vegetation recovers itself and it requires time depending on the magnitude of alteration (Martínez-Ramos et al. 2018, Martins et al. 2015, Whitfeld et al. 2014).

The Bird's Head Peninsula of Papua has more than 80% area as a natural forest in which the variation of tree species is distributed across (Fatem et al. 2020, Robiansyah 2018), and some of them have been disturbed as logging, conversion, agriculture, and settlement. Furthermore, the vegetation varied, while few of the disturbed forest remains to regrow as forests (Kuswandi et al. 2015, Kuswandi and Murdjoko 2015). The Tambrauw District is located in this area and since it was one of the districts in West Papua Province, the development of infrastructure has consumed materials such as wood. Therefore, during the development especially in Fef (district capital of Tambrauw), the forest is used for several years to meet the wood demand which leads to forest fragmentation. This condition has divided the forest into disturbed and undisturbed forests (Spracklen et al. 2015). Meanwhile, the disturbed forest did not receive specific treatment to recover and only allow the disturbed forest to recuperate naturally.

Therefore, the recovery process in disturbed forests was studied by comparing the species vegetation, life form, density, and distribution with the

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primary forest. This study aims to investigate the vegetation dynamic post-disturbance in the tropical rainforest since the research related to forest recovery in Papua Primary Forest is less known. Then, it was hypothetically assumed that the disturbed forest had a different composition of taxonomic diversity and life forms compared to the primary forest as a result of the recovery process.

Materials and methods

Study Area

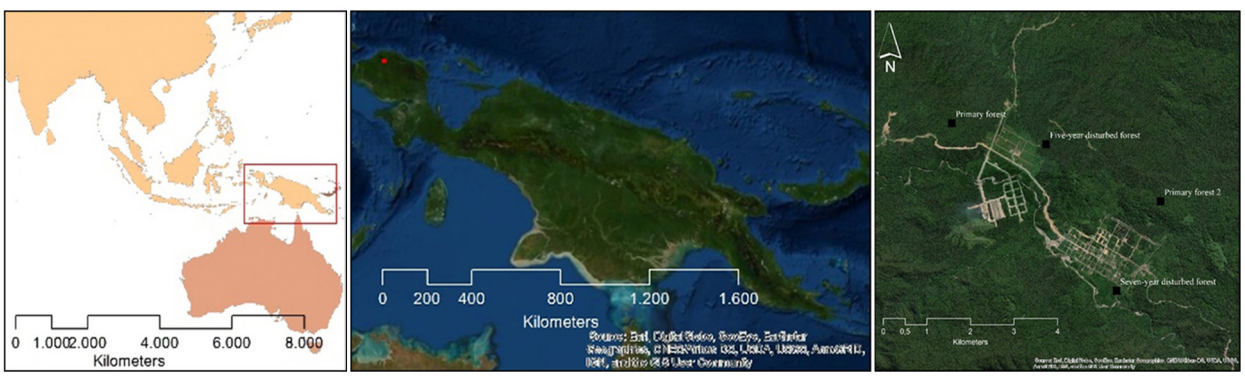
The research took place in the forest of Fef, Tambrauw Regency, West Papua, Indonesia, and the study area was geographically distributed from 0°43'30.45"S to 0°53'46.45"S and from 132°16'40.70"E to 132°32'59.00"E for Latitude and Longitude, respectively. Furthermore, the forest is characterized as a natural forest that was gazetted to be protected. The mean annual rainfall ranges from 2,200 to 2,500 mm in a year, whereby the highest rainfall is 424 mm in December, while the lowest rainfall is 43.94 mm in July. Also, the humidity is between 92.10% and 93.70% with an average of 83%, as well as a maximum, and minimum temperature of 33° C and 22.7° C respectively at an average of 27.3° C. The highest temperature is in October and the lowest temperature is in July. The soil in this area is mainly classified according to Entisol, Inceptisol, and Ultisol (BappedaTambrauw 2015). In addition, the elevation of the area is about 450 m a.s.l. and surrounded by mountainous areas with an altitude ranging from around 800 m to 1,500 m a.s.l.. The area is closed to Fef, the capital of the Tambrauw Regency where the development is still being conducted to prepare the infrastructure facility. Therefore, the forest around this area is disturbed ecologically by taking the timber to meet the development processes. The intensity of timber extraction is unknown clearly. Thereafter, the disturbed forest is left to recuperate naturally where the process took time in 2012 and 2014 (Fig. 1).

Data collection

The forest was grouped into three types, namely primary forest (PF) as control of the natural forest, five-year disturbed forest (5yr) where timber extraction was experienced in 2014, and seven-year disturbed forest (7yr) where timber extraction was performed in 2012. Then, the twenty plots were placed randomly in each forest type assuming that the plots were as representational data for each of these types. For primary forest plots, two locations of forests were taken to cover the condition (ten plots for each primary forest). The plot size (A) is 20 m x 20 m for collecting vegetational data with a diameter of at least 20 cm within the plot, a subplot of 10 m x 10 m (B) to obtain data of vegetation with diameter less than 20 cm and larger than 10 cm, subplot 5 m x 5 m (C) to obtain data of vegetation with stem diameter less than 10 cm and larger than 5 cm, as well as the height of at least 1.5 m and 2 m x 2 m (D) for vegetational data with diameter less than 5 cm and the height less than 1.5 m.

Vegetation data were clustered into eight life forms, which include, bamboo, climber, fern, herb, rattan, shrub, small tree, and large tree. The upper story is vegetation from plots A and B, while the understory is vegetation from plots C and D. Furthermore, vegetation with a diameter of at least 5 cm was measured, and the number of individuals was counted in each plot. Each vegetation was identified taxonomically as species, genus and family, while unidentified vegetation was set as voucher specimen, then sent it to the Herbarium Papuaense of "*Balai Penelitian dan Pengembangan Lingkungan Hidup dan Kehutanan (BP2LHK) Manokwari*" and Herbarium Manokwariense (MAN) *Pusat Penelitian Keanekaragaman Hayati Universitas Papua (PPKH-UNIPA)*, *Manokwari*. The scientific names of vegetation followed The Plant List (TPL) (at the website: http://www.theplantlist.org/) and the conservation status is checked in The International Union for Conservation of Nature's Red List of Threatened Species (at the website: https://www.iucnredlist.org/).

Figure 1 - Location of the research. Twenty plots were located in each five-year disturbed forest and seven-year disturbed forest while ten plots were located in each location of two primary forests (primary forest and primary Forest 2). In total, plots were 60.



Data Analysis

This was to examine the diversity of species among the three types of forest, the Shannon-Wiener index and the calculation is

$$H' = \sum_{i=1}^{S} p_i \ln (p_i) \quad \text{(eq. 1)}$$

where H' is Shannon-Wiener index, p_i is number of samples where species i is present. The Pielou's evenness was applied by using $J=H'/(ln(S))$ in which S is total number of species for each type of forest. One-way ANOVA analysis was performed in order to understand the differences in the diversity and evenness of each forest. Therefore, the calculations were implemented by using the Vegan package in R version 3.5.3.

Taxonomic composition and family structure were analyzed by setting the proportion of density and the life form density was obtained by calculating the number of individuals per hectare (n ha^{-1}). The important values index of species was also calculated to figure out the distribution of each species in terms of dominance.

Furthermore, the index for plots of upper story was determined by adding relative frequency, relative density, and relative dominance as $IV_i=RFr_i+RDe_i+RDo_i$ where IV_i is the important value index of species i, RFr_i is the relative frequency of species i, RDe_i is the relative density of species i, and RDo_i is the relative dominance of species i. Meanwhile, the data index from plots of understory followed $IV_i=RFr_i+RDe_i$.

Results

Taxonomic Diversity of Vegetation between Primary Forest and Disturbed Forests

In all types of forest, 100 species were counted (Appendix 1) out of 81 genera and 54 families in total. Meanwhile, there is a tendency for the number of species, genera, and family number to increase in the primary forest, five-year disturbed forest, and seven-year disturbed forest, respectively (Tab. 1). The forest changed as a result of the disturbance and formed the different types of forest. Therefore, the disturbed forests differed from the primary forest based on the similarity index showing in the dendrogram (Fig. 2). The forests were grouped as two major forests, namely primary forest and disturbed forests (5yr and 7yr) and the species diversity of life form showed the significant differences between the forest types (One-way ANOVA, $F_{2,43}= 4.596$, P=0.016), but the species evenness in the types of the forest did not significantly show the differences (One-way ANOVA, $F_{2,43}=1.207$, P=0.310). In addition, the species diversity in the primary forest does not differ significantly from the seven-year disturbed forest while the five-year disturbed forest was significantly different from the two types earlier mentioned (Tab. 1). However, the similarity index showed that the primary and seven-year disturbed forest were similar and both were different from the five-year disturbed forest (Fig. 2).

Figure 2 - Cluster Dendrogram of primary forest (PF) as control of natural forest, five-year disturbed forest (5yr), and seven-year disturbed forest (7yr) based on similarity index.

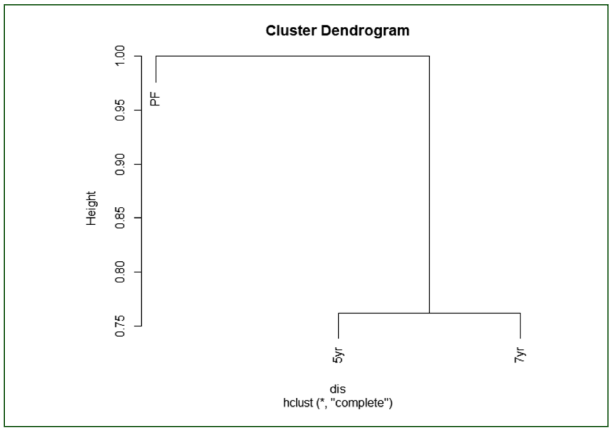


Table 1 - Diversity (H') and evenness (J) indices (mean ± SD), number of families, genus, species in primary forest (PF) as control of natural forest, five-year disturbed forest (5yr) and seven-year disturbed forest (7yr).

Variable	PF	5yr	7yr
Shannon-Wiener index (H')*	2.00±0.14 (b)	1.98±0.16 (a)	2.15±0.20 (b)
Pielou evenness index (J')ns	0.77±0.04	0.80±0,04	0.81±0.06
Families	20	28	41
Genera	25	31	51
Species	29	37	65

* *The significance of F values from the ANOVA is indicated: P < 0.05.*
ns *The no significance of F values from the ANOVA is indicated: P > 0.05.*
Different lowercase letters show the significant differences
SD stands for standard deviation

The three forests showed differences in family dominancy where five families as shown in Figure 3 obtain from the abundance of individuals for each family. Furthermore, the Whittaker plots showed the five most abundant families. The primary forest was dominated by the families of *Dipterocarpaceae* (28.61%), *Lauraceae* (13.88%), *Sapindaceae* (11.33%), *Arecaceae* (11.09%), and *Gnetaceae* (8.51%). The five-year disturbed forest was abundantly formed by *Piperaceae* (18,80%), *Euphorbiaceae* (16.19%), *Malvaceae* (11.86%), *Poaceae* (8.05%), and *Phyllanthaceae* (7.61%). In the seven-year disturbed forest, the families were dominated by *Moraceae* (9.40%), *Phyllanthaceae* (8.66%), *Rutaceae* (7.57%), *Zingiberaceae* (7.40%), and *Dipterocarpaceae* (6.92%).

The dominant species of three types of forest indicated the difference as the dynamic of species composition that compensated for the disturbance. Furthermore, the five-dominant species in each type

Figure 3 - Whittaker plots displaying the relative abundance (%) in the y-axis and the descending rank of abundant family in the x-axis for primary forest (PF) as control of natural forest, five-year disturbed forest (5yr), and seven-year disturbed forest (7yr).

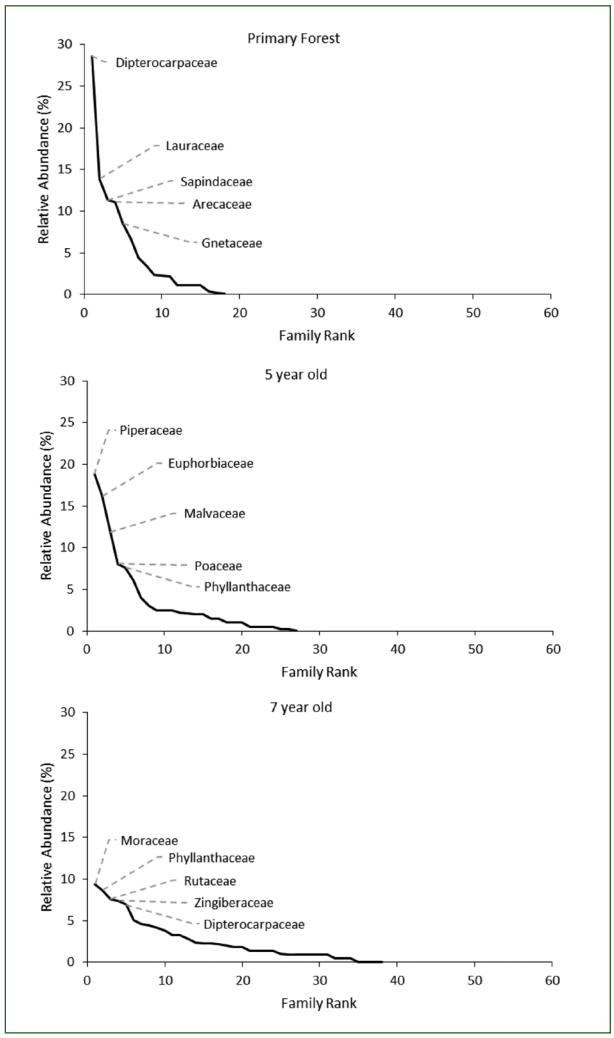
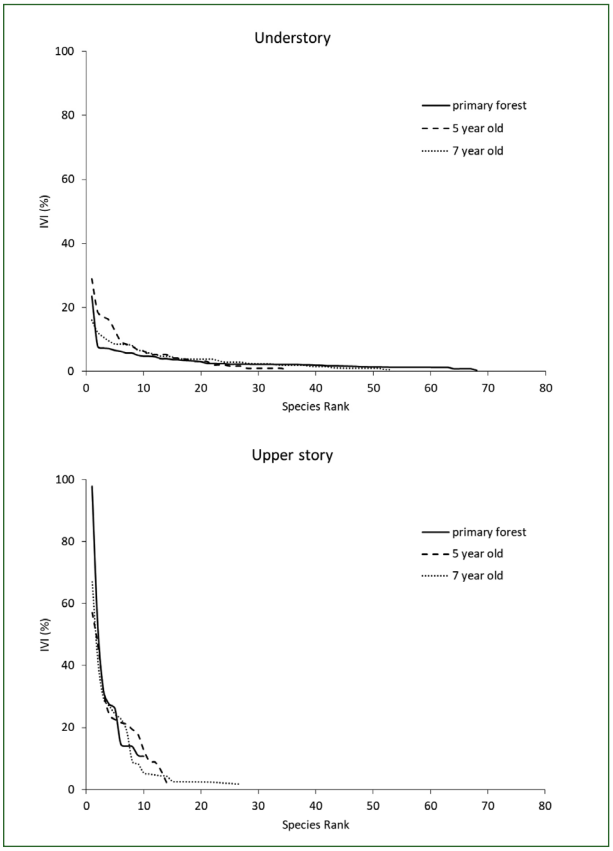


Figure 4 - The important values index (IVI) of the abundant species of understory and upper story in primary forest (PF) as control of natural forest, five-year disturbed forest (5yr), and seven-year disturbed forest (7yr).



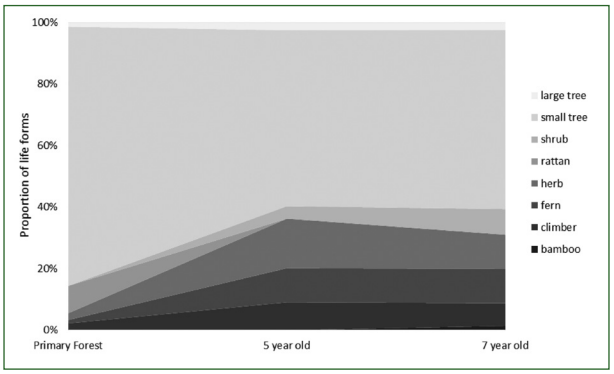
of forest and were divided into two, namely, under and upper story (Fig. 4). The dominant species were based on the importance value index (IVI), and the understory species in the primary forest were mainly dominated by *Vatica papuana* Dyer (23.46%), *Gnetum gnemon* L. (7.94%), *Litsea irianensis* Kosterm. (7.31%), *Glochidion* sp (7.12%), and *Alpinia oceanica* Burkill (6.58%). Also, the five dominant species in five-year disturbed forest were *Piper aduncum* L. (28.94%), *Microcos tomentosa* Sm. (18.72%), *Glochidion* sp (17.12%), *Paspalum conjugatum* P. J.Bergius (16.04%), and *Merremia peltata* (L.) Merr. (12.83%). The five major species in the seven-year disturbed forest were *Glochidion* sp (15.95%), *Vatica papuana* Dyer (12.22%), *Melicope elleryana* (F. Muell.) T.G. Hartley (10.71%), *Merremia peltata* (L.) Merr.(9.44%), and *Alpinia oceanica* Burkill (8.49%). The upper story condition showed the difference in dominant species, while the five-leading species in the primary forest were *Vatica papuana* Dyer (97.82%), *Gnetum gnemon* L. (52.62%), *Baccaurea racemosa* (Reinw. ex Blume) Müll.Arg. (31.77%), *Pimelodendron amboinicum* Hassk. (27.45%), and *Lithocarpus rufovillosus* (Markgr.) Rehder (26.07%). The five-dominant species in the five-year disturbed forests were *Microcos tomentosa* Sm. (57.07%), *Melicope elleryana* (F. Muell.) T.G. Hartley (46.44%), *Glochidion* sp (31.24%), *Macaranga mappa* (L.) Müll.Arg. (24.13%) and *Ficus racemosa* L. (22.58%). In addition, the species of *Microcos tomentosa* Sm. (67.05%), *Alphitonia macrocarpa* Mansf. (41.14%), *Piper aduncum* L. (29.13%), *Ficus racemosa* L. (26.9%), and *Macaranga tanarius* (L.) Müll.Arg. (24.21%) grew mainly in the seven-year disturbed forest. In the three forest types, it was reported that one species (*Aglaia agglomerata* Merr. & L.M.Perry) is Near Threatened (NT) in conservation status, while 27 species are Least Concern (LC), and the remaining species are not evaluated for the population in the natural forest.

Dynamic of Life forms Post-Disturbance

We enumerated eight life forms in this research, *viz.* bamboo, climber, fern, herb, rattan, shrub, small tree, and large tree in which they were dynamic during the post-disturbance compared with primary forest. The proportion of life forms was analyzed by taking into account the number of individuals per hectare (n ha^{-1}). In terms of the number of individuals, there are three trends of life form dynamics

in these three forests (Fig. 5). The number of individuals of bamboo, fern, and shrub increased after disturbance while the rattan, small tree, and large tree decreased in the number of individuals post-disturbance. Furthermore, the reduced number of large tree in the five-year disturbed forest was mainly as a result of the exploitation of forest since the poles and mature trees were harvested to meet the development process. Meanwhile, in terms of the number of individuals, the climber and herb increased five years after disturbance but slightly decreased in seven years after disturbance. The drastic reduction in the disturbed forests was with the rattan and the small tree in which they suffered from the disturbance. On the contrary, there were life forms, *viz.* bamboo, fern, and shrub favored by the altered ecological conditions after disturbance.

Figure 5 - Proportion (%) of lifeforms (bamboo, climber, fern, herb, rattan, shrub, small tree, and large tree) in primary forest (PF) as control of natural forest (PF), five-year disturbed forest (5yr), and seven-year disturbed forest (7yr).



Discussion

The forest encompasses many families, genera, and species in each forest type (Murdjoko et al. 2017, 2016). Therefore, the three forest types are characterized as tropical mixed forests, which harbor a wide range of vegetation diversity (Kuswandi et al. 2015). The research revealed that the dominancy of families was altered in the remaining stands compared with the primary forest. In the remaining stands, some families take advantage of the ecological change, in other to grow and dominate in disturbed forests (Cleary and Eichhorn 2018, Rasingam and Parthasarathy 2009). For example, *Piperaceae*, *Euphorbiaceae*, and *Poaceae* consist of the species that include *Paspalum conjugatum* P.J.Bergius, *Macaranga mappa* (L.) Müll.Arg as fast-growing species, while *Piper aduncum* L. are known as pioneer species during the early successional process. Therefore, in the residual stand, the number of individuals in some families decreases, whereas, the number of individuals in some families grows abundantly after disturbance depending on their morpho-physio-phenological traits (Chazdon et al. 2010, Osazuwa-Peters et al. 2015). Thus, the hierarchical taxonomic ranks of families among forest types were different.

The composition of species between the understory and upper story showed the difference, especially in the dominant species, and this resulted from the change in the reduction of certain species density. The exploitation of forests requires poles and mature trees with a decreased density, and the disturbance produces the space to grow for the remaining vegetation as a positive impact. Furthermore, the exploitation affects adversely certain species contributing to vegetation damage and mortality (Medjibe et al. 2013, Tanner et al. 2014). Meanwhile, specific species survive during the disturbance process, since this condition stimulates the competition among species of different life forms to grow as a response to the alteration of vegetation density (Ishihara et al. 2016, Laurans et al. 2014, Schnitzer and Bongers 2002, Zangaro et al. 2016). The individual number of species between the upper story interacts with one another and shows the influence of conspecific and heterospecific associations (Johnson et al. 2017, Murdjoko et al. 2016, Zhu et al. 2015). In addition, the Allee effect was described as a possible determining factor during the dynamic of species composition, since the density of species is dynamic over the time during post-disturbance in the tropical forest (Davis et al. 2004, Stephens et al. 1999).

The exploitation of forests resulted in the reduction of life form density, which affects the microclimatic change (Lippok et al. 2013, Magrach et al. 2014, Scheffknecht et al. 2010). For instance, the decrease in large trees increased space to grow for remaining vegetation. Furthermore, the canopy gap in disturbed forests is wider compared to the primary forest (Bohlman 2015, Quevedo-Rojas et al. 2016, Saiful and Latiff 2019). Therefore, the intensity of sunlight penetrates more in the extensive canopy gap (Angelini et al. 2015, Montgomery and Chazdon 2001). Consequently, ecological indicators such as moisture, temperature, and space increase. In order to invest more on their growth, this situation benefits life forms such as fern, herb, and climber to invest more in their growth (Montgomery and Chazdon 2001, Rüger et al. 2011, Vizcarra et al. 2017). Some species of fern, herb, and climbers such as *Dicranopteris linearis*, *Alpinia oceanica*, and *Merremia peltata*, grow at a higher intensity of sunlight respectively, as the understory is a favorable condition for shrubs and herbs (Cámara-Leret et al. 2020, Lü and Tang 2010). Therefore, shrubs contributed to the increase of species in the disturbed forest particularly in seven-year disturbed forest, and the understory species often need more sunlight to grow as well. However, these species are outcompeted by the climber, fern, and herb in which the three life forms have the characteristic of fast-growing vegeta-

tion (Chacón-Labella et al. 2014, Magrach et al. 2014, Muler et al. 2014, Rasingam and Parthasarathy 2009, Saldaña et al. 2014).

Implementation of Ecological Understanding to Promote the Natural Forest Recuperation

The disturbed forest showed the increase of the number of species from certain life forms indicating that some species are benefiting from the alteration of ecological conditions. Furthermore, the disturbed forests are the process of secondary succession, in which the species composition of life form changes (Farneda et al. 2018, Paz et al. 2016). The dynamics of remaining forests indicate that the forests are naturally recuperating as part of the process of secondary succession (Piotto et al. 2019). Remaining forest growth is described as the natural ability of the forest to reach the ecosystem equilibrium, in which there is ecological succession. Based on the severe disruption in the past, the remaining forests require a longer time to recover (Murdjoko 2013, Nichol et al. 2017, Rahman and Tsukamoto 2015). Therefore, the residual forests need to be part of the intention of local people and the government not to exploit the forests and allow the disturbed forests to recuperate naturally. Additionally, the silvicultural treatments in the remaining forest are conducted to promote the growth and regeneration of forests such as liberation and liana cutting (Addo-Fordjour et al. 2014, de Avila et al. 2017, Pérez-Salicrup 2001). However, to carry out the silvicultural treatments, the stakeholders and local community need to be taken into a part. Thus, the research must be continued to observe empirically the ecological mechanism up to the climax condition as the stable ecosystem of tropical forest.

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References

Addo-Fordjour P., Rahmad Z. B., Shahrul A. M. S. 2014 - *Impacts of forest management on community assemblage and carbon stock of lianas in a tropical lowland forest, Malaysia.* Tropical Conservation Science 7 (2): 244–259. doi:10.1177/194008291400700206

Angelini A., Corona P., Chianucci F., Portoghesi L. 2015 - *Structural attributes of stand overstory and light under the canopy.* Annals of Silvicultural Research 39 (1): 23–31. doi:10.12899/ASR-993

BappedaTambrauw 2015 - *Rencana Tata Ruang Wilayah Revisi Kabupaten Tambrauw*. (in Indonesian) .

Berry N. J., Phillips O. L., Lewis S. L., Hill J. K., Edwards D. P., Tawatao N. B., Ahmad N., Magintan D., Khen C. V., Maryati M., Ong R. C., Hamer K. C. 2010 - *The high value of logged tropical forests: Lessons from northern Borneo*. Biodiversity and Conservation 19 (4): 985–997. doi:10.1007/s10531-010-9779-z

Bohlman S. A. 2015 - *Species Diversity of Canopy Versus Understory Trees in a Neotropical Forest: Implications for Forest Structure, Function and Monitoring.* Ecosystems 18 (4): 658–670. doi:10.1007/s10021-015-9854-0

Budiharta S., Slik F., Raes N., Meijaard E., Erskine P. D., Wilson K. A. 2014 - *Estimating the aboveground biomass of Bornean forest.* Biotropica 46 (5): 507–511. doi:10.1111/btp.12132

Cámara-Leret R., Frodin D. G., Adema F., Anderson C., Appelhans M. S., Argent G., Guerrero S. A., Ashton P., Baker W. J., Barfod A. S., Barrington D., Borosova R., Bramley G. L. C., Briggs M., Buerki S., Cahen D., Callmander M. W., Cheek M., Chen C.-W. et al. 2020 - *New Guinea has the world's richest island.* Nature (August): 1–5. doi:10.1038/s41586-020-2549-5

Chacón-Labella J., De la Cruz M., Vicuña R., Tapia K., Escudero A. 2014 - *Negative density dependence and environmental heterogeneity effects on tree ferns across succession in a tropical montane forest.* Perspectives in Plant Ecology, Evolution and Systematics 16 (2): 52–63. doi:10.1016/j.ppees.2014.02.003

Chaturvedi R. K., Raghubanshi A. S., Singh J. S. 2017 - *Sapling harvest: A predominant factor affecting future composition of tropical dry forests.* Forest Ecology and Management 384: 221–235. doi:10.1016/j.foreco.2016.10.026

Chazdon R. L., Finegan B., Capers R. S., Salgado-Negret B., Casanoves F., Boukili V., Norden N. 2010 - *Composition and dynamics of functional groups of trees during tropical forest succession in northeastern Costa Rica.* Biotropica 42 (1): 31–40. doi:10.1111/j.1744-7429.2009.00566.x

Cleary D. F. R., Eichhorn K. A. O. 2018 - *Variation in the composition and diversity of ground-layer herbs and shrubs in unburnt and burnt landscapes.* Journal of Tropical Ecology 34 (4): 243–256. doi:10.1017/S0266467418000196

Davis H. G., Taylor C. M., Civille J. C., Strong D. R. 2004 - *An allee effect at the front of a plant invasion: Spartina in a Pacific estuary.* Journal of Ecology 92 (2): 321–327. doi:10.1111/j.0022-0477.2004.00873.x

de Avila A. L., Schwartz G., Ruschel A. R., Lopes J. do C., Silva J. N. M., Carvalho J. O. P. de, Dormann C. F., Mazzei L., Soares M. H. M., Bauhus J. 2017 - *Recruitment, growth and recovery of commercial tree species over 30 years following logging and thinning in a tropical rain forest.* Forest Ecology and Management 385: 225–235. doi:10.1016/j.foreco.2016.11.039

Dezzotti A., Mortoro A., Medina A., Sbrancia R., Beltrán H. A. 2019 - *Plant richness and life form diversity along vegetation and forest use gradients in Northwestern*

Patagonia of Argentina. Cerne 25 (3): 301–313. doi: 10.1590/01047760201925032645

Farneda F. Z., Rocha R., López-Baucells A., Sampaio E. M., Palmeirim J. M., Bobrowiec P. E. D., Grelle C. E. V., Meyer C. F. J. 2018 - *Functional recovery of Amazonian bat assemblages following secondary forest succession.* Biological Conservation 218 (October 2017): 192–199. doi:10.1016/j.biocon.2017.12.036

Fatem S. M., Djitmau D. A., Ungirwalu A., Wanma O. A., Simbiak V. I., Benu N. M. H., Tambing J., Murdjoko A. 2020 - *Species diversity, composition, and heterospecific associations of trees in three altitudinal gradients in Bird's Head Peninsula, Papua, Indonesia.* Biodiversitas 21 (8): 3596–605. doi:10.13057/biodiv/d210824

Ishihara M. I., Konno Y., Umeki K., Ohno Y., Kikuzawa K. 2016 - *A new model for size-dependent tree growth in forests.* PLoS ONE 11 (4): 1–18. doi:10.1371/journal.pone.0152219

Johnson D. J., Condit R., Hubbell S. P., Comita L. S. 2017 - *Abiotic niche partitioning and negative density dependence drive tree seedling survival in a tropical forest.* In: Proceedings of the Royal Society B: Biological Sciences 284 (1869). doi:10.1098/rspb.2017.2210

Kuswandi R., Murdjoko A. 2015 - *Population Structures of Four Tree Species in Loggpopulation Structures of Four Tree Species in Logged-Over Tropical Forest in South Papua, Indonesia: an Integral Projection Model Approach.* Indonesian Journal of Forestry Research 2 (2): 93–101. doi:10.20886/ijfr.2015.2.2.93-101

Kuswandi R., Sadono R., Supriyatno N., Marsono D. 2015 - *Keanekaragaman Struktur Tegakan Hutan Alam Bekas Tebangan Berdasarkan Biogeografi di Papua.* Jurnal Manusia dan Lingkungan 22 (2): 151. doi:10.22146/jml.18737

Laughlin D. C., Abella S. R. 2007 - *Abiotic and biotic factors explain independent gradients of plant community composition in ponderosa pine forests.* Ecological Modelling 205 (1–2): 231–240. doi:10.1016/j.ecolmodel.2007.02.018

Laurans M., Hérault B., Vieilledent G., Vincent G. 2014 - *Vertical stratification reduces competition for light in dense tropical forests.* Forest Ecology and Management 329: 79–88. doi:10.1016/j.foreco.2014.05.059

Lippok D., Beck S. G., Renison D., Gallegos S. C., Saavedra F. V., Hensen I., Schleuning M. 2013 - *Forest recovery of areas deforested by fire increases with elevation in the tropical Andes.* Forest Ecology and Management 295: 69–76. doi:10.1016/j.foreco.2013.01.011

Lozada J. R., Arends E., Sánchez D., Villarreal A., Soriano P., Costa M. 2012 - *Vegetation Succession of Logged Forest in The Western Alluvial Plains of Venezuela.* Journal of Tropical Forest Science 24 (3): 300–311.

Lü X. T., Tang J. W. 2010 - *Structure and composition of the understory treelets in a non-dipterocarp forest of tropical Asia.* Forest Ecology and Management 260 (4): 565–572. doi:10.1016/j.foreco.2010.05.013

Magrach A., Rodríguez-Pérez J., Campbell M., Laurance W. F. 2014 - *Edge effects shape the spatial distribution of lianas and epiphytic ferns in Australian tropical rain forest fragments.* Applied Vegetation Science 17 (4): 754–764. doi:10.1111/avsc.12104

Martínez-Ramos M., Balvanera P., Arreola Villa F., Mora F., Maass J. M., Maza-Villalobos Méndez S. 2018 - *Effects of long-term inter-annual rainfall variation on the dynamics of regenerative communities during the old-field succession of a neotropical dry forest.* Forest Ecology and Management 426 (April): 91–100. doi:10.1016/j.foreco.2018.04.048

Martins K. G., Marques M. C. M., dos Santos E., Marques R. 2015 - *Effects of soil conditions on the diversity of tropical forests across a successional gradient.* Forest Ecology and Management 349: 4–11. doi:10.1016/j.foreco.2015.04.018

Medjibe V. P., Putz F. E., Romero C. 2013 - *Certified and uncertified logging concessions compared in Gabon: Changes in stand structure, tree species, and biomass.* Environmental Management 51 (3): 524–540. doi:10.1007/s00267-012-0006-4

Montgomery R. A., Chazdon R. L. 2001 - *Forest structure, canopy architecture, and light transmittance in tropical wet forests.* Ecology 82 (10): 2707–2718. doi:10.1890/0012-9658(2001)082[2707:FSCAAL]2.0.CO;2

Muler A. E., Rother D. C., Brancalion P. S., Naves R. P., Rodrigues R. R., Pizo M. A. 2014 - *Can overharvesting of a non-timber-forest-product change the regeneration dynamics of a tropical rainforest? The case study of Euterpe edulis.* Forest Ecology and Management 324: 117–125. doi:10.1016/j.foreco.2013.09.001

Murdjoko A. 2013 - *Recuperation of Non-commercial Trees in Logged Forest in Southern Papua, Indonesia.* Jurnal Manajemen Hutan Tropika 19 (2): 94–102. doi:10.7226/jmht.19.2.94

Murdjoko A., Jitmau M. M., Djitmau D. A., Mardiyadi Z., Rumatora A., Mofu W. Y., Sineri A. S., Fatem S. M., Worabai D., May N. L., Tokede M. J., Warmetan H., Wanggai C. B., Wanma J. F., Sirami E. V., Paembonan J. B., Unenor E., Kuswandi R., Lekitoo K. et al. 2020 - *Heterospecific and conspecific associations of trees in lowland tropical forest of New Guinea.* Biodiversitas 21 (9): 4405–4418. doi:10.13057/biodiv/d210960

Murdjoko A., Marsono D., Sadono R., Hadisusanto S. 2017 - *Recovery of residual forest ecosystem as an impact of selective logging in South Papua: An ecological approach.* Biotropia 24 (3): 230–245. doi:10.11598/btb.2017.24.3.732

Murdjoko A., Marsono D., Sadono R., Hadisusanto S. 2016 - *Plant Species Composition and Their Conspecific Association in Natural Tropical Rainforest, South Papua.* Biosaintifika: Journal of Biology & Biology Education 8 (1): 33. doi:10.15294/biosaintifika.v8i1.5217

Nichol J. E., Abbas S., Fischer G. A. 2017 - *Spatial patterns of degraded tropical forest and biodiversity restoration over 70-years of succession.* Global Ecology and Conservation 11: 134–145. doi:10.1016/j.gecco.2017.05.005

Osazuwa-Peters O. L., Jiménez I., Oberle B., Chapman C. A., Zanne A. E. 2015 - *Selective logging: Do rates of forest turnover in stems, species composition and functional traits decrease with time since disturbance? - A 45 year perspective.* Forest Ecology and Management 357: 10–21. doi:10.1016/j.foreco.2015.08.002

Pan Y., Birdsey R. A., Phillips O. L., Jackson R. B. 2013 - *The Structure, Distribution, and Biomass of the World's Forests.* Annual Review of Ecology, Evolution, and

Systematics 44 (1): 593–622. doi:10.1146/annurev-ecolsys-110512-135914

Paz C. P., Goosem M., Bird M., Preece N., Goosem S., Fensham R., Laurance S. 2016 - *Soil types influence predictions of soil carbon stock recovery in tropical secondary forests.* Forest Ecology and Management 376: 74–83. doi:10.1016/j.foreco.2016.06.007

Pérez-Salicrup D. R. 2001 - *Effect of liana cutting on tree regeneration in a liana forest in Amazonian Bolivia.* Ecology 82 (2): 389–396. doi:10.1890/0012-9658(2001)082[0389:EOLCOT]2.0.CO;2

Picard N. 2019 - *Asymmetric Competition Can Shape the Size Distribution of Trees in a Natural Tropical Forest.* Forest Science 65 (5): 562–69. doi:10.1093/forsci/fxz018

Piotto D., Craven D., Montagnini F., Ashton M., Oliver C., Thomas W. W. 2019 - *Successional, spatial, and seasonal changes in seed rain in the Atlantic forest of southern Bahia, Brazil.* PLoS ONE 14 (12): 1–15. doi:10.1371/journal.pone.0226474

Quevedo-Rojas A., Jerez-Rico M., Schwarzkopf Kratzer T., García-Núñez C. 2016 - *Distribution of juveniles of tree species along a canopy closure gradient in a tropical cloud forest of the Venezuelan Andes.* IForest 9: 363–369. doi:10.3832/ifor1568-008

Rahman M. M., Tsukamoto J. 2015 - *Opposing effects of substrate quality and site factors on forest floor turnover rates: An example from the tropics.* Forestry 88 (2): 190–199. doi:10.1093/forestry/cpu043

Rasingam L., Parthasarathy N. 2009 - *Diversity of understory plants in undisturbed and disturbed tropical lowland forests of Little Andaman Island, India.* Biodiversity and Conservation 18 (4): 1045–1065. doi:10.1007/s10531-008-9496-z

Robiansyah I. 2018 - *Diversity and biomass of tree species in Tambrauw, West Papua, Indonesia.* Biodiversitas 19 (2): 377–386. doi:10.13057/biodiv/d190204

Rüger N., Berger U., Hubbell S. P., Vieilledent G., Condit R. 2011 - *Growth strategies of tropical tree species: Disentangling light and size effects.* PLoS ONE 6 (9): e25330. doi:10.1371/journal.pone.0025330

Saiful I., Latiff A. 2019 - *Canopy gap dynamics and effects of selective logging: A study in a primary hill dipterocarp forest in Malaysia.* Journal of Tropical Forest Science 31 (2): 175–188. doi:10.26525/jtfs2019.31.2.175188

Saldaña A., Parra M. J., Flores-Bavestrello A., Corcuera L. J., Bravo L. A. 2014 - *Effects of forest successional status on microenvironmental conditions, diversity, and distribution of filmy fern species in a temperate rainforest.* Plant Species Biology 29 (3): 253–262. doi:10.1111/1442-1984.12020

Sanchez M., Pedroni F., Eisenlohr P. V., Oliveira-Filho A. T. 2013 - *Changes in tree community composition and structure of Atlantic rain forest on a slope of the Serra do Mar range, southeastern Brazil, from near sea level to 1000m of altitude.* Flora: Morphology, Distribution, Functional Ecology of Plants 208 (3): 184–196. doi:10.1016/j.flora.2013.03.002

Scheffknecht S., Winkler M., Hlber K., Rosas M. M., Hietz P. 2010 - *Seedling establishment of epiphytic orchids in forests and coffee plantations in Central Veracruz, Mexico.* Journal of Tropical Ecology 26 (1): 93–102. doi:10.1017/S0266467409990332

Schnitzer S. A., Bongers F. 2002 - *The ecology of lianas and their role in forests.* Trends in Ecology and Evolution 17 (5): 223–230. doi:10.1016/S0169-5347(02)02491-6

Spracklen B. D., Kalamandeen M., Galbraith D., Gloor E., Spracklen D. V. 2015 - *A global analysis of deforestation in moist tropical forest protected areas.* PLoS ONE 10 (12): 1–16. doi:10.1371/journal.pone.0143886

Stephens P. A., Sutherland W. J., Freckleton R. P. 1999 - *What Is the Allee Effect?* Oikos 87 (1): 185. doi:10.2307/3547011

Tanner E. V. J., Rodriguez-Sanchez F., Healey J. R., Holdaway R. J., Bellingham P. J. 2014 - *Long-term hurricane damage effects on tropical forest tree growth and mortality.* Ecology 95 (10): 2974–83. doi:10.1890/13-1801.1

Vizcarra T., Nascimento H. E. M., Vizcarra A., Williamson G. B. 2017 - *Forest Ecology and Management Effects of lightgaps and topography on Amazon secondary forest : Changes in species richness and community composition.* Forest Ecology and Management 396: 124–131. doi:10.1016/j.foreco.2017.04.018

Webb L. J. 1959 - *A Physiognomic Classification of Australian Rain Forests.* The Journal of Ecology 47 (3): 551. doi:10.2307/2257290

Whitfeld T. J. S., Lasky J. R., Damas K., Sosanika G., Molem K., Montgomery R. A. 2014 - *Species richness, forest structure, and functional diversity during succession in the New Guinea Lowlands.* Biotropica 46 (5): 538–48. doi:10.1111/btp.12136

Yamada T., Hosaka T., Okuda T., Kassim A. R. 2013 - *Effects of 50 years of selective logging on demography of trees in a Malaysian lowland forest.* Forest Ecology and Management 310: 531–538. doi:10.1016/j.foreco.2013.08.057

Zangaro W., Lescano L. E. A. M., Matsuura E. M., Rondina A. B. L., Nogueira M. A. 2016 - *Differences between root traits of early- and late-successional trees influence below-ground competition and seedling establishment.* Journal of Tropical Ecology 32 (4): 300–313. doi:10.1017/s0266467416000274

Zhu Y., Comita L. S., Hubbell S. P., Ma K. 2015 - *Conspecific and phylogenetic density-dependent survival differs across life stages in a tropical forest.* Journal of Ecology 103 (4): 957–966. doi:10.1111/1365-2745.12414