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Species Richness and Diversity in Secondary Lowland Forest, Bintuni, Bird's Head Peninsula, West Papua, Indonesia

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Abstract

Tropical forests play an important role in ecosystem services, yet anthropological activities have changed the ecological conditions. Thus, this research was designed to reveal the species richness and diversity in secondary forests, including the lifeform alteration. The 50 perpendicular plots were placed in both forests and distributed 25 for each. The study revealed that the secondary forest represents a stage of ecological succession in which species richness and diversity decreased. Additionally, the composition of life forms in the secondary forest changed, with dominant herbs indicating more dynamic vegetation due to shifting ecological conditions. Species classified as Threatened have disappeared due to human activities in the forest. However, the secondary forest has provided a habitat for certain species, including those with conservation status, such as Threatened or Extinct, to thrive and colonize, where approximately 15.7% of species exclusively thrive in secondary forests, including Antiaropsis uniflora C.C.Berg. *Therefore, to promote sustainable forest management, this study suggests monitoring the species in secondary forests, particularly since the use of forests has traditionally been determined by local communities, including in restricted forest areas. Moreover, the local government could officially designate traditional forest use, thereby allowing restricted forests to be conserved as old-growth forests.*

Keywords: *lifeforms, successional stage, swidden, tropical forest, vegetation*

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Introduction

New Guinea Island contributes the highest species richness of flora in the world (Cámara-Leret et al., 2020) and contains the remaining primary forest (Grantham et al., 2020). The high species richness and diversity of vegetation were stated in the latitudinal diversity gradient (LDG) as New Guinea Island is located close to the equator (Slik et al., 2015; Liang et al., 2022). Moreover, the geographical history and climatic conditions result in a high variety of forests, such as lowland to tropical alpine, affecting the vegetation distribution (Murdjoko et al., 2016; Sadili et al., 2018; Murdjoko et al., 2021a; Trethowan et al., 2024). Nowadays, Indonesian New Guinea is experiencing massive development leading to the disturbance and conversion of primary forest. This condition is the main pressure of primary forest in Indonesian New Guinea, where another threat is the development of a new government administratively (Spracklen et al., 2015; Gaveau et al., 2021; Lamei et al., 2021). Hence, Teluk Bintuni is one of the developing districts in which infrastructure establishment is the main priority. Furthermore, forest utilizations have been conducted for decades either in traditional or modern methods (Yudha et al., 2021; Kasihiw et al., 2024).

Local people in Teluk Bintuni have engaged in forest utilization for millennia as part of their livelihood, and the forests have been part of their social activities (Kasihiw et al., 2024). In this area, remaining primary forests exist, while some areas have been used for other uses such as logging concessions, development priorities, and local utilization. In this study, we focused on the ecological change resulting from the local utilization as the practice has been part of local people. The utilization by local people seems to alter the forest conditions in terms of ecological factors, especially the density and reduction of species richness. However, local people have applied local wisdom to protect the forest, such as the implementation of restricted areas in the forest. So, it can be a positive approach to conserving the forest from a conservation perspective.

The ecologically functional traits alter during the successional stage, including in secondary forests (Finegan, 1984). Hence, species richness and diversity are the most common ecological parameters in forest ecology (Whittaker,

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1972; Peet, 1974; Brown & Lugo, 1990). Some studies in Papua have shown the ecological change during the early- to late-successional stage, most of them revealed that the species composition and diversity in primary forest or old-growth forest differed from the forest succession, particularly the secondary forest. The forests in Papua have been experiencing ecological change mainly as a result of shifting cultivation, as shown by some studies (Murdjoko et al., 2021b; 2022; Sagrim, 2022). Certain areas of forest have been traditionally designed to allow local people to conduct the shifting cultivation, hunting, and gathering while they have also set a particular forest as a restricted area locally known as *pemali* (Sonbait et al., 2021). The majority of local people are intensively practicing local utilization in the forest, usually taking place in the lowlands of Bintuni Forest. Therefore, this research examined mainly the ecological change in secondary forests resulting from the local utilization and compared to the primary forest as a reference. We hypothesized that species richness and richness in secondary forests decreased. Moreover, floristic composition and vegetation structure measuring using the variation of lifeforms were different between the primary and secondary forests. As the scientific information during the successional process in the Bintuni lowland forest is less known, this research aimed to reveal the vegetation condition during fallow forest as a result of local utilization, where the species diversity and composition were the main focus accompanied by lifeform change. Furthermore, the information was essential as part of monitoring forest dynamics in terms of supporting the conservation program.

Methods

Study area The study was located in Teluk Bintuni Forest, where the status of the forest is as Other Purposes (*Areal penggunaan lain* or APL) and Forest Production based on the Ministerial Decree of Forestry through SK.783/Menhut-II/2014 dated September 22, 2014. The geographical position of location is S1°59'46.01" and E133°36'10.75" for the primary forest as well as S2°6'58.94" and E133°32'37.88" for the secondary forest, as shown in Figure 1. The elevation is between 50 and 200 m above sea level where the topographical condition is relatively flat while the climatic condition is described in Table 1.

In the forest, some areas have been traditionally set as

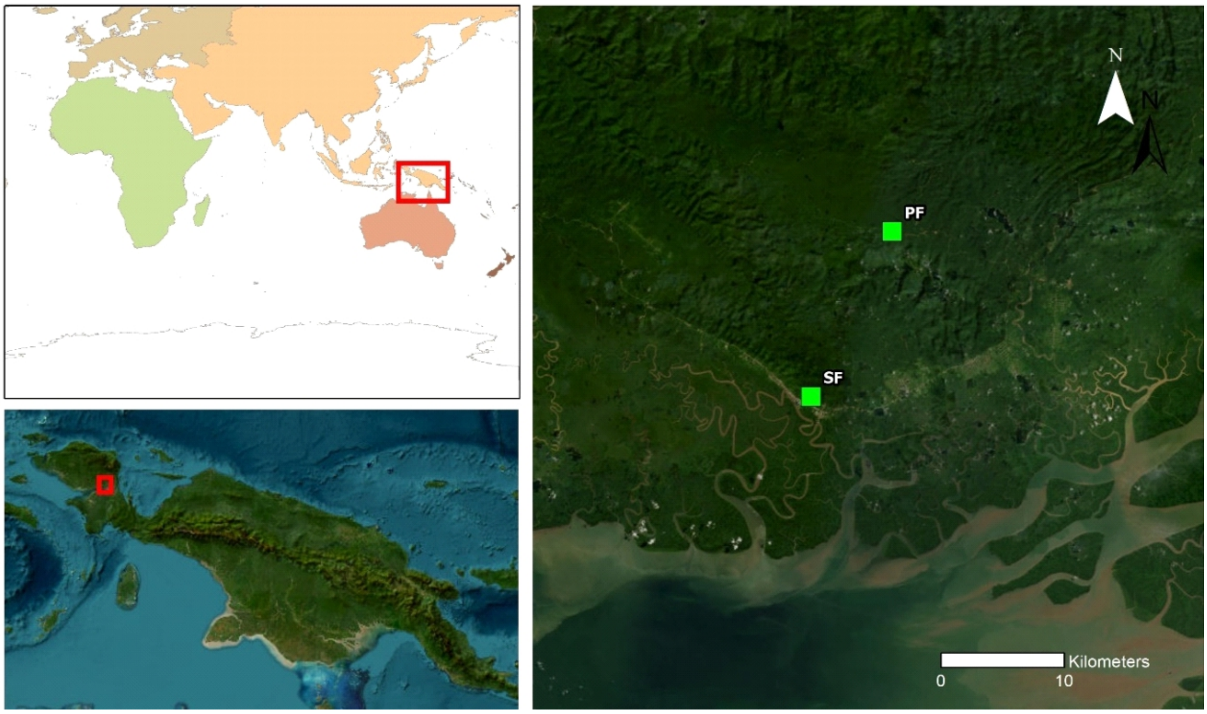

Figure 1 Location of research in Teluk Bintuni, Bird's Head Peninsula, West Papua, Indonesia. The plots were placed in primary forest (PF) and secondary forest (SF) as symbolized as green boxes for both locations.

Table 1 Monthly data of climatic conditions with mean, standard deviation (SD), maximum (max), and minimum (min)

Climatic variable	Mean	SD	Max	Min
High temperature (°C)	30.37	0.725	31.2	29.1
Mean temperature (°C)	26.81	0.47	27.3	26.0
Low temperature (°C)	23.26	0.26	23.6	22.8
Rainfall (mm)	189.5	55.24	260	108

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utilization by local people, while at the same time, logging concessions had been part of PT YST that had been left for decades (>20 years), particularly in the northern part of Bintuni. To obtain information on chronological events causing secondary forests, we interviewed *Martinus Tiri*-one of the society figures of the *Sough* tribe, *Marthen Asmorom*-village heads of Bina Desa, and some local people in this area where there are at least five villages here. The forests have experienced the shifting cultivation conducted by ownership rights, namely the *Sough* tribe another local people of the *Moskona* tribe also practices shifting cultivation in this area by getting a permit from the *Sough* tribe. The mechanism of shifting cultivation in Tanah Papua is comparatively similar across the tribes. It means that they have applied traditional knowledge by setting the shade of remaining trees in the field. Moreover, fertilizers are not applied, and the growth of crops depends on the nutrients processed by decomposition resulting from burning during field preparation. Moreover, local people consisting of seven tribes in Bintuni as part of Papuan people have been engaging in traditional crops like swidden for generations. However, the practice does not entirely cut vegetation in the area and burn it, but local people leave some certain vegetation, such as trees growing along with the local crops, as stated in many studies (Manner, 1981; Lepš et al., 2002; Murdjoko et al., 2022). Then, during the fallow period, the areas allow a secondary successional process to take place. Hence, we confidently assumed that the secondary forests resulted from shifting cultivation in the fallow period >10 years. Furthermore, utilization of forests is also conducted by hunting and gathering in forests, in which local people perform the cutting of vegetation but not as massive as slash and burn cultivation. Hereafter, those forests are identified as secondary forests. In certain areas of forest, local people have already set up restricted areas where the forests are not allowed to be utilized, as they have the traditional belief locally known as *pemali*. So, the areas are not disturbed by local people, resulting in the forest growing naturally, and here it can be classified as primary forest or old-growth forest.

Survey and data collection The data were recorded in primary and secondary forests by setting perpendicular plots. Previously, the forest types were identified by obtaining information from local people by means of conducting an informal interview. Furthermore, after getting the location of the primary and secondary forests, we then checked visually using satellite images via Google Earth Pro to validate forest conditions by jumping backward in time using the Historical Imagery menu to see land cover changes. Moreover, the information was crucial to setting plots in locations related to accessibility to the forests. Then, data on vegetation were collected using square plots consisting of 25 in primary forests and 25 in secondary forests with 100 m as minimal distance among plots in each location to avoid pseudoreplication. The data in the plot were taxonomic information to the species level and number of individuals per plot. The vegetation was grouped based on lifeform, namely: lianas, ferns, herbs, shrubs, palms/screw palms, and trees. To collect the vegetation data in the forests, the plot was set up using plot (A) and three subplots (B, C, and D), making a nested plot where the plot size (A) is 20 m × 20 m for collecting vegetation data with a diameter of at least 20 cm within the plot, a subplot of 10 m × 10 m (B) to obtain data of vegetation with a diameter less than 20 cm and larger than 10 cm, a subplot of 5 m × 5 m (C) to obtain data of vegetation with a stem diameter less than 10 cm and larger than 5 cm, as well as the height of at least 1.5 m, and a subplot of 2 m × 2 m (D) for vegetation with a diameter less than 5 cm and a height less than 1.5 m. The size of plots and subplots has been studied for vegetation in forests by Bormann (1953) using a species-area curve as a determination (Cain, 1938). The nested plots have been implemented by much research in tropical rainforests (Do et al., 2016; Katovai et al., 2021). The plots were placed in the field purposively, particularly in secondary forests, as disturbed areas were partially distributed. In the primary forest, we conducted five transects, and each transect consisted of five plots.

The taxonomic identification was based on vouchers and sent to Herbarium Manokwariense (MAN) Pusat Penelitian Keanekaragaman Hayati Universitas Papua (PPKH-UNIPA), Manokwari. Then, the scientific names of vegetation were standardized through World Flora Online (WFO) (http://www.worldfloraonline.org/) and Plants of the World Online (https://powo.science.kew.org/) while the conservation status of vegetation species was checked on the International Union for Conservation of Nature's Red List of Threatened Species (https://www.iucnredlist.org/).

Data analysis The species richness was used to describe each location using sample rarefaction (Mao's tau) (Colwell et al., 2004). The vegetation of subplots (B, C, and D) was standardized as the size of plot A to enable the rarefaction analysis. Then, the diversity was implemented via the Shannon-Wiener index, as shown in Equation *[1]*.

$$H'_i = -\sum_{j=1}^{S} p_j \ln\ (p_j) \qquad [1]$$

Then, the evenness distribution was also analyzed through Pielou's evenness index, calculated as shown in Equation *[2]* (Pielou, 1966).

$$J_i = \frac{H'_i}{\ln(S_i)} \qquad [2]$$

The symbols in the Equation *[1]* and Equation *[2]* can be explained as H'_i is Shannon-Wiener index in the location of , p_j is the proportion of individuals to the species *j* (species in the location of *i*), *i* is forest type (primary and secondary forest), and *S* is the total number of species in location *i* (Shannon, 1948; Spellerberg & Fedor, 2003). To compare the floristic composition between primary and secondary forests, the similarity index was executed using the Sørensen–Dice coefficient. Then, the calculation was as shown in Equation *[3]*.

$$DC = \frac{2(A \cap B)}{(|A|+|B|)} \times 100\% \qquad [3]$$

The symbols in the Equation *[3]* can be explained as *DC* is Sørensen–Dice coefficient (%), $A \cap B$ is the number of species sharing in primary and secondary forests, $|A|$ is the number of species belonging to primary forest, and $|B|$ is the number of species belonging to secondary forests (Sørensen,

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1948). The computation of those analyses was conducted via software of PAST (PAleontological STatistics) version 4.03 (Hammer et al., 2001).

Results

Floristic composition and diversity In both forests, the vegetation was distributed taxonomically as 99 families, 224 genera, and 310 species. Of these species, 246 were found in the primary forest, while 162 species grew in the secondary forest. The primary forest was more diverse than the secondary forest, where the Shannon-Wiener index (*H'*) in the primary forest was 4.955 while *H'* in the secondary forest was 4.618, with the Pielou's evenness index in the primary and secondary forest being 0.577 and 0.6253, respectively, indicating that vegetation in the secondary forest was distributed more equally than in the primary forest (Figure 2). We analyzed the similarity index by means of the Sørensen–Dice index where we found that 98 out of 310 species (Dice similarity coefficient = 48%) were shared between both forests. Then, 36.3% of species were exclusive to primary forest and 15.7% to secondary forest.

Vegetation structure of forest The vegetation was categorized as six lifeforms to analyze the vertical structure of both forests. The lifeforms were ferns, herbs, lianas, shrubs, trees, palms/screw palms where in total the species richness of each lifeform was higher in the primary forest except herbs. The lifeforms of ferns, trees, and palms/screw palms had a difference of species richness of at least about 40%, while lifeforms of lianas and shrubs had a difference of species richness below 40% (Figure 3).

Conservation status of vegetation In both forests, we identified conservation status as grouped by the International Union for Conservation of Nature's Red List of Threatened Species as Critically endangered, Endangered, Vulnerable, Near threatened, Least concern, Data deficient, and Not available (Figure 4). The species with conservation status at least classified as Threatened were Critically endangered (*Alocasia sanderiana* Hort. ex Bull found in primary forest and *Antiaropsis uniflora* C.C.Berg found in secondary forest); Endangered (*Acronychia reticulata* Lauterb. found in primary forest, *Artocarpus lacucha* Roxb. ex Buch.-Ham. found in primary forest and secondary forest, *Asplenium nidus* L. found in primary forest, *Cryptocarya palmerensis* C.K.Allen found in primary forest, *Gomphandra javanica* (Blume) Valeton found in primary forest and secondary forest, and *Pandanus furcatus* Roxb. found in primary forest); and Vulnerable (*Koompassia grandiflora* Kosterm. found in the primary forest, *Myristica argentea* Warb. found in the primary forest, *Neonauclea acuminata* Ridsdale found in the primary forest and secondary forest, and *Pterocymbium beccarii* K.Schum. found in the primary forest).

Discussion

The secondary forest plays an important role in the ecosystem as a place for certain species, such as vegetation with conservation status categorized as threatened. Studies in abandoned forests showed that secondary forests can be vital for species conservation by fostering the establishment and growth of rare species (Sandor & Chazdon, 2014). In previous research, many studies focus more on the commercial trees in secondary forests to support timber production (Yamada et al., 2013; Abbas et al., 2016; Zuo et al., 2017; Rozendaal et al., 2019; Mazón et al., 2020). However, since environmental issues such as ecosystem services have been underlined, then some studies focused mainly on biodiversity degradation (Rozendaal et al., 2019; Sheil et al., 2021) and carbon stock in tropical forests (Paniagua-Ramirez et al., 2021; Heinrich et al., 2023). This finding contributes significantly to forest science concerning the role of secondary forests which is part of the forest

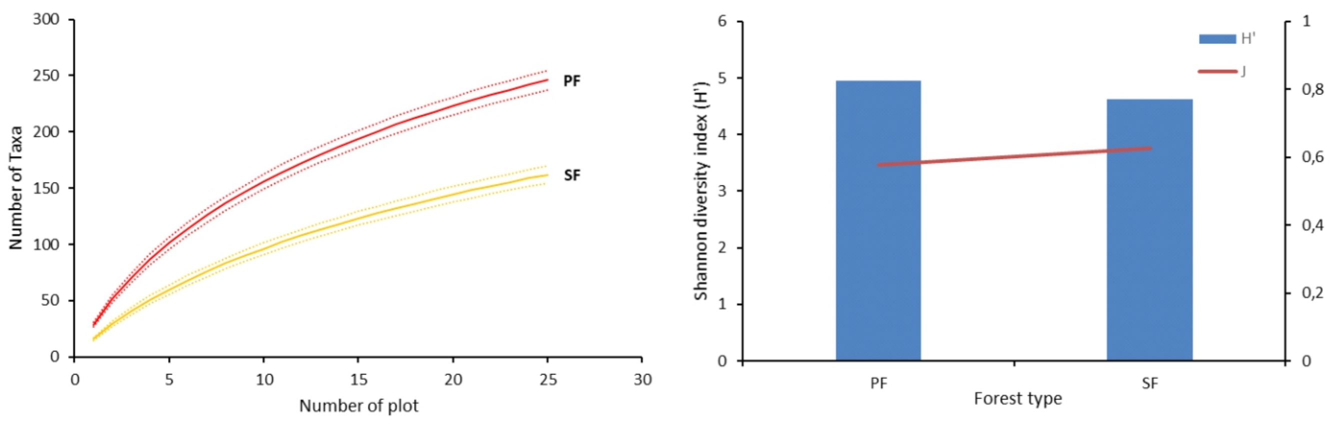

Figure 2 The sample rarefaction (Mao's tau) with a solid-red line for primary forest (PF) and a solid-yellow line for secondary forest (SF). The dashed lines above the solid line are the upper limit, and the dashed lines below the solid lines are the lower limit where the upper and lower limits explain the 95 % confidence interval (left). The Shannon-Wiener index (*H'*) in the first y-axis, and Pielou's evenness index (*J*) in the second y-axis for primary forest (PF) and secondary forest (SF) (right).

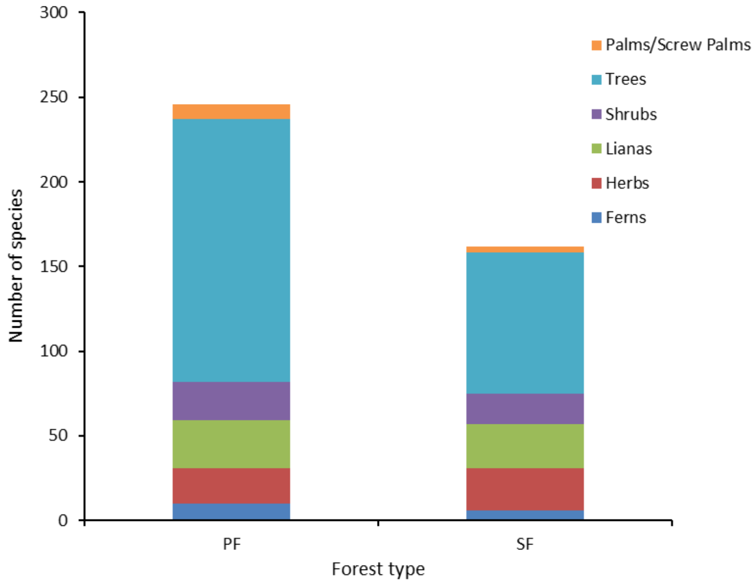

Figure 3 The number of species over lifeforms of ferns, herbs, lianas, shrubs, trees, palms/screw palms in primary forest (PF) and secondary forest (SF).

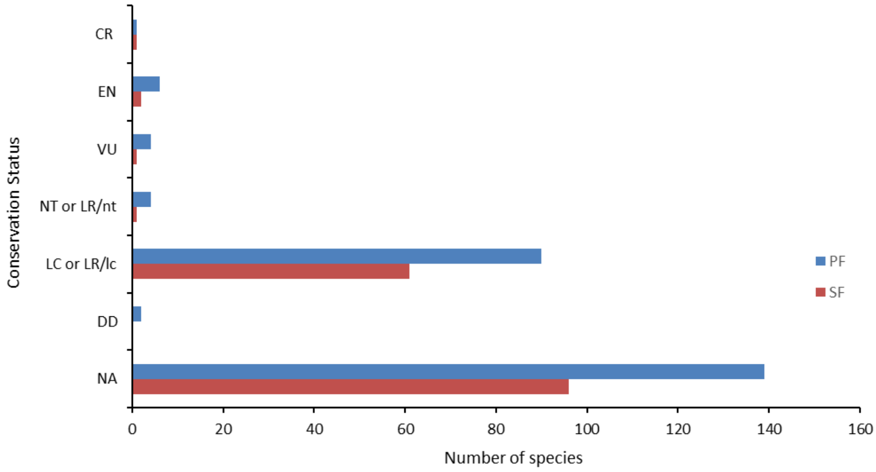

Figure 4 The number of species in primary forest (PF) and secondary forest (SF) with conservation status CR (Critically endangered), EN (Endangered), VU (Vulnerable), NT or LR/nt (Near threatened), LC or LR/lc (Least concern), DD (Data deficient), NA (Not available).

dynamic and mainly supports information on the secondary successional process in tropical forests. Moreover, the lifeforms of vegetation along with the conservation status are addressed here to accommodate the ecological function of secondary forests. Furthermore, we include the non-tree lifeforms as part of compositional species in this study, and then the result describes the ecological alteration following the successional stage in disturbed forests. The compositional species in the secondary forest differed from the primary forest in which only more or less half of the total species are in common indicating that the secondary forest has exclusive vegetation to grow and to spread. The compositional species will take a long time to be similar to old-growth forests (Oberleitner et al., 2021).

This study revealed that the secondary forests were experiencing ecological alteration particularly since the primary forests were disturbed by reducing the density of vegetation during anthropological activities. The floristic composition in the primary forest differed from the secondary forest, as shown in this study, and the species richness reduced from 246 species to 162 species. Secondary forests in the tropics had lower species richness compared to the primary forest as the secondary forests follow the early-, intermediate-, and late-successional stages and the species composition is different between both forests (Villa et al., 2018; Rozendaal et al., 2019; Murdjoko et al., 2022). It indicated that the ecological condition particularly vegetation structure such as the canopy layers and density

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play an important role in the change in light penetration and temperature, so plant species growing at various points along a successional gradient have distinct environmental needs. Therefore, the species colonized in secondary forests are likely to be light-demanding species or pioneer species. Following the pioneers in the succession process, secondary species come into play. They emerge after the pioneers and play a role in the gradual transition towards a more diverse and stable forest ecosystem. These secondary species often possess traits that enable them to thrive in shade or cope with limited resources more effectively than pioneers, thus flourishing as the forest matures. More species living as herbs are taking advantage of this condition resulting in the number of herbs being higher in secondary forests compared to primary forests where some of them were grouped as fast-growing species (Decocq et al., 2014; Moonen et al., 2019). Moreover, the species diversity in secondary forests was lower as a result of the decrease in species number as well as density. However, Pielou's evenness index pointed out that the vegetation in the secondary forest is more evenly distributed as shown the index slightly went up.

In this study, the floristic composition showed that 48% of all species belong to both forests where the species composition is distinguishable. The secondary forest here was characterized by species growing as herbs while other lifeforms particularly trees had a lower number of species. The species growing and appearing after disturbance presumably result from the remnant vegetation and legacy of vegetation that has seed dispersal such as endozoochory, synzoochory, anemochory, and hydrochory (Chen et al., 2020; Wendt et al., 2022). The secondary forest experiences more canopy openness and less density of original vegetation just after abandonment resulting in some species starting colonizing and this condition has favored light-demanding species and shade-intolerant species to establish (Pasion et al., 2018; Likoski et al., 2021; Matsuo et al., 2021). Furthermore, some original vegetation regenerated through re-sprouting and suckering in secondary forests while the remnant vegetation particularly large individuals was left growing since the practices of anthropological activities in Papua do not remove completely the vegetation of the area during land utilization like swidden system, hunting, and gathering. The secondary and primary forests encompass similar lifeforms as the secondary forests resulted mainly from the conversion of primary forests to traditional crops where the areas were not massive as semi-subsistence farming was as main purpose (Manner, 1981; Kartawinata et al., 2001). Moreover, the fallow periods were more than decades leading to the process of re-growing vegetation during the post-traditional crops. Thus, the history of the local area contributes significantly to the diversity of species found within these forests. Those procedures led to some parts of forests growing resulting in secondary forests consisting of structure as the references as well in this study about half of the species were similar between both forests.

The reduction of species during successional stages (early-, intermediate-, and late-stages) has led to the loss of vegetation including the species with conservation status particularly at levels threatened and extinct (Critically endangered, Endangered, and Vulnerable). As shown in this study, both forests have provided a place for vegetation with conservation status at the level of threatened and lower risk. Not only in the primary forest, but the secondary forest also plays an important role as home to species such as *A. uniflora*. Since the early successional stage, the fecundity of vegetation has led to the compositional alteration in secondary forests. Studies in tropical forests have revealed that some species with conservation status as high risk also grow in secondary forests. The change in floristic composition can benefit from a conservation perspective where other vegetation colonizes the secondary forest (Murdjoko et al., 2022). In contrast, the secondary forests themselves have experienced the loss of species during the disturbance. Hence, the monitoring of vegetation in primary forests is indispensable to record the species composition. Moreover, the number of vegetation has not been taxonomically described yet in tropical forests.

This study suggests that recommendations such as the primary forest as a reference forest must be legally stated by the local government as the status of forests is APL and Forest Production based on the Ministerial Decree of Forestry through SK.783/Menhut-II/2014 dated September 22, 2014. Controlling the anthropogenic activities in secondary forests is vital. In this study, in tropical lowland forests, the variety of plant life plays a vital role in supporting the overall health and resilience of the ecosystem. When comparing degraded forests to secondary forests, noticeable differences in plant diversity emerge due to varying levels of disturbance and recovery processes. Degraded forests, which have suffered significant human-induced disruptions like logging, agriculture, or infrastructure development, often experience a decrease in biodiversity, shifts in ecosystem functions, and changes in plant composition. As a result, the diversity of plant life in degraded forests is generally lower than in primary or undisturbed forests. These disturbances can lead to the disappearance of delicate species, disturbance of ecological interactions, and the fragmentation of habitats. Consequently, degraded forests may display simpler plant communities dominated by a few pioneering species that are resilient to disturbances.

To manage sustainably the secondary forest, collaborations among stakeholders are highly required to support one of the goals of Manokwari Declaration which is to conserve about 70% of forest cover (Cámara-Leret et al., 2019). Moreover, this area has a high probability of being converted to a non-forest as a consequence of economic goals where the trees do not support to supply of logs for timber production. Then, local authorities such as local government must delineate the areas that are not to be converted and strictly implement the regulation of buffer zone protocols. Additionally, studies of traditional knowledge are necessary to obtain information on traditionally restricted areas based on cultural views. Hence, the management will not only support the culture but also at the same time the biodiversity of the forest can be protected. As stated by many studies, local people are the main drivers in supporting conservation since they earn the benefit of protecting the forest (Parrotta & Agnoletti, 2007; Kumar et al., 2021).

Conclusion

The secondary forest resulting from anthropogenic activities is part of the successional stage where the species richness and diversity declined. Moreover, the lifeform composition altered in the secondary forest with dominant herbs indicating the vegetation was more dynamic since the ecological conditions changed. The species with the Threatened category disappeared during anthropological activities in the forests where based on the research the species with the status Endangered and Vulnerable vanished. However, the secondary forest provided a place for certain species to colonize that was possible with species with conservation status whether Threatened or Extinct to grow. It can be seen that about 15.7% of species are growing only in secondary forests including the *A. uniflora*. Hence, to support sustainable forest management, this research suggests monitoring the species in secondary forests while the use of forest has been traditionally designed by local people including restricted forests. Furthermore, the local government could set officially the traditional use of forest, then the restricted forest could be set as conservation of old-growth forests.

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