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Ecological perspective to sustainably manage the secondary forest in the lowland of Doberai Peninsula, Indonesia

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Abstract. *Marwa J, Ungirwalu A, Imburi CS, Djitmau DA, Murdjoko A, Benu NMH. 2024. Ecological perspective to sustainably manage the secondary forest in the lowland of Doberai Peninsula, Indonesia. Biodiversitas 25: 2720-2732.* This research aims to examine the composition of flora and fauna in secondary forests, with the aim of using the results to provide input for sustainable forest management. Suggestions for proper ecological management have been put forward, as they are crucial for preserving ecosystem functions and protecting species. We revealed that the identified area was a secondary forest with a composition of 225 species and 83 families of vegetation. The distribution was fairly uniform, encompassing 6 life forms: ferns, herbs, lianas, palms, shrubs, and trees. For fauna, the result indicated the presence of 10 species of mammalia, 37 species of aves, 6 species of reptiles, and 4 species of insects. The secondary forest still supports a high species richness of vegetation and fauna. These findings suggest that the secondary forest is undergoing a successional process in which various vegetation, particularly lianas and herbs, compete to gain more sunlight due to increased canopy openness. Forest management must optimize multi-factors, as in this research, and we suggest considering development and conservation, utilization of buffer zones, monitoring vegetation and animal breeding, and reforestation. The balance between development and conservation is critical, offering opportunities for sustainable practices and community involvement.

Keywords: Conservation status, lifeforms, lowland forests, New Guinea, tropical biodiversity

INTRODUCTION

The tropical forest contributes significantly to global biodiversity, including vegetation richness and diversity (Liang et al. 2022). Recently, tropical forests have played a crucial role in global aspects, particularly as carbon stock to regulate climate (Pan et al. 2011; Philipson et al. 2020). In contrast, deforestation and forest degradation as factors to decrease the tropical forest areas and their function, particularly in developing countries. Furthermore, anthropogenic activities are the main driver for forest degradation and deforestation (Ferrer Velasco et al. 2020; Seydewitz et al. 2023). Some areas in the tropics are experiencing the successional process of reaching the initial condition as old-growth forests. Hence, many areas of tropical forest are seen as secondary forests as a result of human activities such as logging and shifting cultivation (Hiltner et al. 2018; Ellis 2019; Gaveau et al. 2021). More canopy gaps, less density of trees, and less topsoil characterize the ecological conditions of the secondary forests. Hence, this situation initiates the colonization and competition of vegetation to obtain sunlight, water, and habitat. Consequently, the secondary forest also provides considerable biodiversity. Globally, tropical secondary forests play a crucial role by providing ecosystem services such as biodiversity conservation, carbon sequestration, and water or nutrient regulation (Mukul et al. 2016; Murdjoko et al. 2017; Widiyatno et al. 2017; Tawer et al. 2021). Moreover, the secondary forests have contributed to local livelihoods for decades, such as shifting cultivation. Identifying the significance of tropical secondary forests is essential for sustainable use and promoting the conservation that is imperative for not only the well-being of developing countries but also the global environment (Toledo-Aceves et al. 2009; N'Guessan et al. 2019; Sonbait et al. 2021).

Human activities have shaped the forests for generations in which species composition, structure, and functioning of secondary forests altered then impacting their biodiversity and ecological processes. Therefore, understanding the impact of anthropogenic factors on secondary forests is crucial for effective conservation and sustainable management of these valuable ecosystems (Chazdon 2003; Pyles et al. 2022; Rosenfield et al. 2022). In the tropics, the tropical secondary forest harbors a diverse group of vegetation and fauna. The ecological process provides habitat for a variety of plant species or lifeforms, including epiphytes, lianas, and understory plants (Letcher et al. 2012; Edwards et al. 2014; Murdjoko et al. 2021b, 2022; Tawer et al. 2021). This diverse vegetation supports a wide range of animal life, such as birds, mammals, reptiles, and insects. The complex ecosystem of the tropical secondary forest is important to maintain biodiversity and ecological balance (Malhi et al.

2022). Hence, managing tropical secondary forests is crucial for sustainable land use and conservation. Effective management strategies must consider the forest's ecological, social, and economic aspects.

As part of Indo-Malesian realms for floristic regionalization and Oceanian realms for the terrestrial zoogeographic region, Indonesian New Guinea experiences forest dynamics like secondary forests, mostly in lowland (Holt et al. 2013; Murdjoko 2013; Gaveau et al. 2021; Liu et al. 2023). In contrast, the Indonesian New Guinea is part of the most floristic island in the world; some of the vegetation has not been described taxonomically (Cámara-Leret et al. 2020), and part of Melanesia is the world's most diverse amphibian fauna (Oliver et al. 2022). Some studies conducted as well in this area to describe the vegetation ranging from lowlands to highlands have been conducted to share useful information (Cámara-Leret and Dennehy 2019; Trethowan et al. 2022, 2024). Hence, efforts to restore and conserve the lowland forest are crucial in order to mitigate the environmental impact and preserve the natural habitats from a conservation perspective. Then, sustainable management practices must bit is imperative that sustainable management practices are implemented to deal with the degradation and promote the recovery of the degraded lowland forest (Trauernicht et al. 2018; Ellis 2019; Matsuo et al. 2021). Logging activity is seen as a major driver in shaping secondary forests in which some areas have been logged, leaving them to recuperate naturally. Consequently, the biodiversity may be lower compared to primary forests, but these forests can function as an ecosystem where certain vegetation colonizes and competes to establish the species composition, impacting providing habitat for wildlife (Brown and Lugo 1990; Murdjoko et al. 2017; Hiltner et al. 2018).

Understanding the biodiversity in secondary forests is important to the standardization of sustainability in terms of forest management, particularly taking into account the ecological and economic perspective. Thus, this research focused more on the biotic drivers like vegetation and wildlife factors in order to support land use management. Both factors were part of the biological threshold during the utilization by taking into account not only the presence but also the ecological value as the successional stage takes place. The studies of secondary forests in the tropics revealed that certain species of vegetation are accommodated as the ecological conditions favor those species (Sandor and Chazdon 2014; Rumayomi et al. 2024).

Therefore, this research aims to analyze the composition of flora and fauna in secondary forests. The findings of this study can be used to guide sustainable forest management, particularly in the biological aspect, which is considered one of the main drivers. The study's findings are instrumental in proposing appropriate management strategies for the restoration and preservation of these forests, which are crucial for preserving ecosystem functions and protecting species. The diversity and abundance of vegetation and fauna in secondary forests are key for conservation and ecological restoration efforts. These forests, with their ability to support a wide range of plant species, including many endemic and rare species, play a significant role in maintaining the overall biodiversity of the region.

MATERIALS AND METHODS

Study area

The research was conducted in a secondary forest in Doberai Peninsula, Indonesia (Figure 1). Administratively, the forests are part of Sorong District, Southwest Papua Province, Indonesia. The forests are located in lowland forests and ex-logging concessions in which the secondary forests have been re-growed for decades. The legal status of this area is forest production based on the central government through SK.783/Menhut-II/2014, dated 22 September 2014. The elevation ranges from 23 to 119 masl, and topographically, the location is relatively flat. The forest remains unmanaged in terms of the recovery process since the logging company has stopped the operation. The areas are visually seen as secondary forests where logging roads can be seen using satellite images via the Historical Imagery menu in Google Earth Pro. Moreover, many rivers are distributed in this area, and residential areas are in the northern and western parts of the forests, whilst oil palm plantations are in the eastern part of this area.

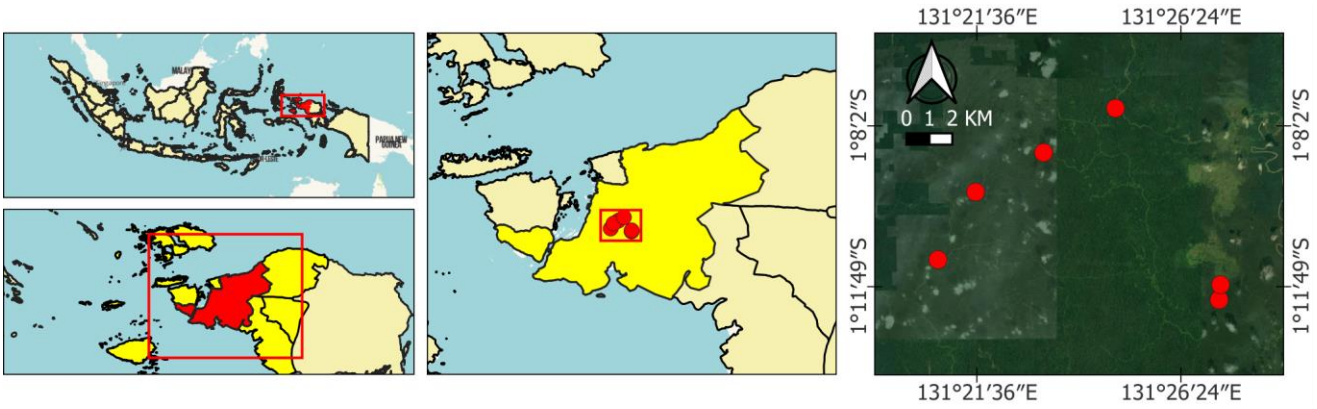

Figure 1. Study area in the secondary forest of Doberai Peninsula, Sorong District, Southwest Papua Province, Indonesia where plots distributed in six locations symbolized as red circle

Survey and field sampling

We conducted the data collection in six locations to represent the distribution of secondary forests. To collect vegetation data, we applied square plots in each location, the five plots were placed in which the minimal distance among plots was 200 m to reduce the pseudoreplication. The vegetation data is collected based on the lifeforms like ferns, herbs, lianas, palms, shrubs, and trees. Then, we followed the methods outlined by Murdjoko et al. (2022); Tawer et al. (2021). We designated a main plot (A) measuring 20x20 m for recording vegetation with a diameter of at least 20 cm. Additionally, subplots (B, C, and D) were set where subplot (B) with 10x10 m to collect vegetation with diameters less than 20 cm but greater than 10 cm; subplot (C) with 5x5 m to record vegetation with diameters less than 10 cm but greater than 5 cm and with a minimum height of 1.5 m; and subplot (D) with 2x2 m to collect vegetation with diameters less than 5 cm and heights less than 1.5 m. Then, the identification was executed in the field, and the unidentified vegetation was set as vouchers and sent to Herbarium Manokwariense (MAN) Biodiversity Research Center of Universitas Papua *(PPKH-UNIPA)*, Manokwari. Then, we used scientific names according to World Flora Online (at the website: http://www.worldfloraonline.org/ accessed on 22 June 2024), Catalogue of Life for *Plantae* (https://www.catalogueoflife.org/index?taxonKey=P accessed on 23 June 2024) and Plants of the World Online (at the website https://powo.science.kew.org/ accessed on 22 June 2024).

To collect fauna data, we applied the transect in each location where, in each plot, a minimum of 3 km line transects were set to observe the fauna with a maximum observation distance of 25 m from the transect where the individual number and species were recorded. We also set steel-mesh traps and checked every mourning for 4 days, and after recording the data, the fauna was released back into the forest. The binoculars were used to observe fauna directly. At the same time, we also applied an indirect method by observing the nests and wildlife traces, interviewing the local people, and asking them to join the survey, particularly those who were engaged in traditional hunting, to obtain information regarding the presence of wildlife. Then the scientific name of fauna, we followed GBIF—the Global Biodiversity Information Facility (https://www.gbif.org/what-is-gbif accessed on 22 June 2024), Animal Diversity Web (ADW) (https://animaldiversity.org/about/ accessed on 22 June 2024), Catalogue of Life (COL) for Animalia menu (https://www.catalogueoflife.org/index?taxonKey=N assessed on 23 June 2024) and Birds of the World (https://birdsoftheworld.org/bow/content/about-birds-of-the-world accessed on 22 June 2024).

Moreover, the conservation status of species was based on The International Union for Conservation of Nature's Red List of Threatened Species (at the website: https://www.iucnredlist.org/ accessed on 22 June 2024). To know the national status of conservation, we checked the list on Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number P.106/Menlhk/Setjen/Kum.1/12/2018 concerning the Second Amendment to Regulation of the Minister of Environment and Forestry Number P.20/Menlhk/Setjen/Kum.1/6/2018, concerning types of protected plants and animals.

Data analysis

The data on vegetation and fauna were analyzed using the list of species based on family, species, and conservation status. Then, we also applied the diversity through the Shannon-Wiener index, and the evenness distribution was analyzed through Pielou's evenness index:

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

$$J = \frac{H'}{\ln(S)}$$

Where: *H'*: Shannon-Wiener index; ρ_j: proportion of individuals to the species; *J* and S: total number of species (Spellerberg and Fedor 2003). The computation of those analyses was conducted via software of PAST (PAleontological STatistics) version 4.03 (Hammer et al. 2001).

RESULTS AND DISCUSSION

Floristic richness and diversity

The identified area is generally a secondary forest with 225 species and 83 families. The distribution of vegetation is almost even, consisting of 6 life forms: ferns, herbs, lianas, palms, shrubs, and trees. Tables 1 and 2 provide details of the species and their percentages in each life form.

The most abundant species are scattered among the trees (60%) that dominate the vegetation landscape in this location. In addition, the existence of other lifeforms, such as lianas (9.33%), herbs, and shrubs (11.11%) that are quite abundant in this forest, can be an indicator that the forest is undergoing a succession process.

Table 1. Number of species and percentage of lifeforms

Lifeforms	Species number	Percentage (%)
Ferns	14	6.22
Herbs	26	11.55
Lianas	21	9.33
Palms	4	1.78
Shrubs	25	11.11
Trees	135	60.00
Total	225	100.00

Table 2. List of families and species along with lifeforms, conservation status, and population trend

Lifeform	Species	Family	Conservation status	Population trend
Ferns	*Asplenium nidus* L.	Aspleniaceae		
	Dicranopteris linearis (Burm.f.) Underw.	Gleicheniaceae	Least concern	Stable
	Dryopteris hirtipes (Blume) Kuntze	Dryopteridaceae		
	Helminthostachys zeylanica (L.) Hook.	Ophioglossaceae		
	Nephrolepis cordifolia (L.) C.Presl	Nephrolepidaceae		
	Nephrolepis falcata (Cav.) C.Chr.	Nephrolepidaceae		
	Pityrogramma calomelanos (L.) Link	Pteridaceae		
	Platycerium bifurcatum (Cav.) C.Chr.	Polypodiaceae		
	Psilotum complanatum Sw.	Psilotaceae		
	Pyrrosia longifolia (Burm.f.) Morton	Polypodiaceae		
	Selaginella plana (Desv. ex Poir.) Hieron.	Selaginellaceae		
	Selaginella willdenowii (Desv.) Baker	Selaginellaceae		
	Sphaeropteris aeneifolia (Alderw.) R.M.Tryon	Cyatheaceae	Least concern	Unknown
	Taenitis sp.	Pteridaceae		
Herbs	*Alpinia* sp.	Zingiberaceae		
	Amorphophallus galbra F.M.Bailey	Araceae		
	Appendicula fasciculata J.J.Sm.	Orchidaceae	Data deficient	Unknown
	Begonia rieckei Warb.	Begoniaceae		
	Bulbophyllum macranthum Lindl.	Orchidaceae	Least concern	Unknown
	Coelogyne pandurata Lindl.	Orchidaceae		
	Corymborkis veratrifolia (Reinw.) Blume	Orchidaceae		
	Crinum asiaticum L.	Amaryllidaceae		
	Curculigo latifolia Dryand. ex W.T.Aiton	Hypoxidaceae		
	Dianella ensifolia (L.) Redouté	Asphodelaceae		
	Donax canniformis K.Schum.	Marantaceae		
	Dracaena angustifolia (Medik.) Roxb.	Asparagaceae		
	Etlingera sp.	Zingiberaceae		
	Fittingia paniculata Takeuchi	Primulaceae		
	Grammatophyllum pantherinum Rchb.f.	Orchidaceae		
	Habenaria sp.	Orchidaceae		
	Hellenia speciosa (J.Koenig) S.R.Dutta	Costaceae	Least concern	Stable
	Hornstedtia cyathifera Valeton	Zingiberaceae		
	Hornstedtia scottiana (F.Muell.) K.Schum.	Zingiberaceae		
	Imperata cylindrica (L.) Raeusch.	Poaceae		
	Meistera aculeata (Roxb.) Škorničk. & M.F.Newman	Zingiberaceae	Least concern	Stable
	Miconia crenata (Vahl) Michelang.	Melastomataceae		
	Myrmecodia pendens Merr. & L.M.Perry	Rubiaceae		
	Peristylus affinis (D.Don) Seidenf.	Orchidaceae		
	Phrynium pubinerve Blume	Marantaceae		
	Trichoglottis papuana Schltr.	Orchidaceae		
Lianas	*Abrus precatorius* L.	Fabaceae		
	Alsomitra *macrocarpa* M.Roem.	Cucurbitaceae		
	Arcangelisia flava Merr.	Menispermaceae		
	Aristolochia sp.	Aristolochiaceae		
	Artabotrys suaveolens (Blume) Blume	Annonaceae		
	Calamus heteracanthus Zipp. ex Blume	Arecaceae	Least concern	Stable
	Calamus papuanus Becc.	Arecaceae		
	Causonis trifolia (L.) Mabb. & J.Wen	Vitaceae		
	Derris elliptica (Wall.) Benth.	Fabaceae		
	Flagellaria indica L.	Flagellariaceae		
	Gnetum gnemonoides Brongn.	Gnetaceae	Least concern	Unknown
	Iodes scandens (Becc.) Utteridge & Byng	Icacinaceae		
	Korthalsia zippelii Blume	Arecaceae		
	Oxera splendida (F.Muell.) Gâteblé & Barrabé	Lamiaceae		
	Rhaphidophora sp.	Araceae		
	Salacia sororia Miq.	Celastraceae		
	Smilax leucophylla Blume	Smilacaceae		
	Smilax sp.	Smilacaceae		
	Stenochlaena palustris (Burm.) Bedd.	Blechnaceae		
	Tecomanthe dendrophila (Blume) K.Schum.	Bignoniaceae		
	Uncaria cordata (Lour.) Merr.	Rubiaceae		

Palms	*Arenga pinnata* (Wurmb) Merr.	Arecaceae	Least concern	Stable
	Caryota rumphiana Mart.	Arecaceae	Least concern	Stable
	Hydriastele pinangoides (Becc.) W.J.Baker & Loo	Arecaceae	Least concern	Unknown
	Licuala telifera Becc.	Arecaceae	Least concern	Stable
Shrubs	*Adina multifolia* Havil.	Rubiaceae	Least concern	Unknown
	Agrostistachys borneensis Becc.	Euphorbiaceae	Least concern	Stable
	Aporosa carrii Schot	Phyllanthaceae	Least concern	Stable
	Archidendron aruense (Warb.) de Wit	Fabaceae	Least concern	Unknown
	Ardisia javanica A.DC.	Primulaceae		
	Callicarpa longifolia Lam.	Lamiaceae	Least concern	Stable
	Cheilolejeunea vittata (Steph. ex G. Hoffm.) R.M. Schust. & Kachroo	Lejeuneaceae		
	Cleistanthus papuanus (Lauterb.) Jabl.	Phyllanthaceae	Least concern	Stable
	Commersonia bartramia (L.) Merr.	Malvaceae	Least concern	Stable
	Desmodium sp.	Fabaceae		
	Drypetes globosa (Merr.) Pax & K.Hoffm.	Putranjivaceae	Vulnerable	Decreasing
	Hydnophytum cordifolium Valeton	Rubiaceae		
	Kibara bullata Philipson	Monimiaceae		
	Kibara sp.	Monimiaceae		
	Leucosyke capitellata (Poir.) Wedd.	Urticaceae	Least concern	Stable
	Litsea ledermannii Teschner	Lauraceae		
	Litsea timoriana Span.	Lauraceae	Least concern	Unknown
	Melastoma malabathricum L.	Melastomataceae		
	Piper aduncum L.	Piperaceae	Least concern	Stable
	Piper cacuminum C.DC.	Piperaceae		
	Piper majusculum Blume	Piperaceae		
	Pipturus argenteus (G.Forst.) Wedd.	Urticaceae	Least concern	Stable
	Popowia sp.	Annonaceae		
	Senna alata (L.) Roxb.	Fabaceae	Least concern	Stable
	Strychnos dalzellii C.B.Clarke	Loganiaceae		
Trees	*Aglaia argentea* Blume	Meliaceae	Least concern	Unknown
	Aglaia flavescens C.DC.	Meliaceae	Least concern	Unknown
	Aglaia sp.	Meliaceae		
	Alphitonia incana (Roxb.) Teijsm. & Binn. Ex	Rhamnaceae		
	Alstonia angustifolia A.DC.	Apocynaceae	Least concern	Unspecified
	Alstonia macrophylla Wall. ex G.Don	Apocynaceae	Least concern	Unknown
	Alstonia scholaris (L.) R.Br.	Apocynaceae	Least concern	Unknown
	Artocarpus altilis (Parkinson) Fosberg	Moraceae		
	Artocarpus fretessii Teijsm. & Binn. ex Hassk.	Moraceae		
	Artocarpus integer (Thunb.) Merr.	Moraceae	Least concern	Stable
	Barringtonia lauterbachii R.Knuth	Lecythidaceae	Least concern	Stable
	Blumeodendron kurzii (Hook.f.) J.J.Sm.	Euphorbiaceae	Least concern	Unknown
	Buchanania arborescens Blume	Anacardiaceae	Least concern	Unknown
	Calophyllum costatum F.M.Bailey	Calophyllaceae		
	Campnosperma brevipetiolatum Volkens	Anacardiaceae	Least concern	Unknown
	Cananga odorata (Lam.) Hook.f. & Thomson	Annonaceae	Least concern	Stable
	Canarium hirsutum Willd.	Burseraceae	Least concern	Stable
	Canarium indicum L.	Burseraceae	Least concern	Unknown
	Canarium sp.	Burseraceae		
	Celtis philippensis Blanco	Cannabaceae	Least concern	Unknown
	Ceodes longirostris (Teijsm. & Binn.) Merr. & L.M.Perry	Nyctaginaceae	Least concern	Unknown
	Cerbera inflata S.T.Blake	Apocynaceae	Least concern	Unknown
	Chionanthus macrocarpus Blume	Oleaceae		
	Chisocheton ceramicus Miq.	Meliaceae	Least concern	Decreasing
	Cryptocarya sp.	Lauraceae		
	Cynometra browneoides (Harms) Rados.	Fabaceae		
	Cynometra sp.	Fabaceae		
	Dillenia papuana Martelli	Dilleniaceae	Least concern	Decreasing
	Diospyros hebecarpa A.Cunn. ex Benth.	Ebenaceae	Least concern	Stable
	Dracontomelon dao (Blanco) Merr. & Rolfe	Anacardiaceae	Least concern	Unknown
	Duabanga moluccana Blume	Lythraceae	Least concern	Stable
	Dysoxylum arborescens (Blume) Miq.	Meliaceae		
	Dysoxylum excelsum Blume	Meliaceae		
	Dysoxylum gaudichaudianum Miq.	Meliaceae	Least concern	Stable
	Dysoxylum mollissimum Blume	Meliaceae	Least concern	Stable
	Dysoxylum parasiticum (Osbeck) Kosterm.	Meliaceae		
	Elaeocarpus oblongus Gaertn. ex Sm.	Elaeocarpaceae		

Embelia brassii Sleumer	Primulaceae		
Endiandra rubescens (Blume) Miq.	Lauraceae	Least concern	Unknown
Endospermum medullosum L.S.Sm.	Euphorbiaceae	Vulnerable	Decreasing
Ficus pungens Reinw. ex Blume	Moraceae	Least concern	Stable
Ficus racemifera Roxb	Moraceae		
Ficus robusta Corner	Moraceae	Least concern	Stable
Ficus septica Burm.f.	Moraceae	Least concern	Stable
Ficus sp.	Moraceae		
Ficus uniglandulosa Wall. & Miq.	Moraceae	Least concern	Stable
Ficus variegata Blume	Moraceae	Least concern	Stable
Flacourtia inermis Roxb.	Salicaceae		
Flindersia pimenteliana F.Muell.	Rutaceae	Least concern	Decreasing
Garcinia sp.	Clusiaceae		
Gironniera subaequalis Planch.	Cannabaceae	Least concern	Stable
Glochidion zeylanicum (Gaertn.) A.Juss.	Phyllanthaceae	Least concern	Stable
Gnetum gnemon L.	Gnetaceae	Least concern	Unknown
Gymnacranthera farquhariana (Wall. ex Hook.f. & Thomson) Warb.	Myristicaceae		
Haplolobus celebicus H.J.Lam	Burseraceae		
Harpullia carrii Leenh.	Sapindaceae		
Hernandia ovigera L.	Hernandiaceae		
Hibiscus tilliaceus L.	Malvaceae	Least concern	Unknown
Homalium foetidum Kurz	Salicaceae	Least concern	Unknown
Hopea nodosa Slooten	Dipterocarpaceae	Least concern	Decreasing
Horsfieldia irya (Gaertn.) Warb.	Myristicaceae	Least concern	Stable
Horsfieldia sylvestris (Houtt.) Warb.	Myristicaceae	Least concern	Unknown
Huberantha gracilis (Burck) Chaowasku	Annonaceae		
Huberantha rumphii (Blume ex Hensch.) Chaowasku	Annonaceae		
Inocarpus papuanus Kosterm.	Fabaceae	Least concern	Stable
Intsia palembanica Miq.	Fabaceae	Near threatened	Decreasing
Jagera pseudorhus Radlk.	Sapindaceae	Least concern	Unknown
Kleinhovia hospita L.	Malvaceae	Least concern	Stable
Koompassia grandiflora Kosterm.	Fabaceae	Vulnerable	Unknown
Lepiniopsis ternatensis Valeton	Apocynaceae	Least concern	Stable
Maasia glauca (Hassk.) Mols, Kessler & Rogstad	Annonaceae	Least concern	Unknown
Macaranga aleuritoides F.Muell.	Euphorbiaceae	Least concern	Stable
Macaranga brachythyrsa Pax & K.Hoffm.	Euphorbiaceae	Data deficient	Unknown
Macaranga densiflora Warb.	Euphorbiaceae	Least concern	Unknown
Macaranga mappa Müll.Arg.	Euphorbiaceae	Least concern	Stable
Mallotus paniculatus Müll.Arg.	Euphorbiaceae	Least concern	Stable
Mallotus philippensis (Lam.) Müll.Arg.	Euphorbiaceae	Least concern	Stable
Medusanthera laxiflora (Miers) R.A.Howard	Stemonuraceae	Least concern	Decreasing
Melanolepis multiglandulosa Rchb. & Zoll.	Euphorbiaceae	Least concern	Stable
Melicope bonwickii (F.Muell.) T.G.Hartley	Rutaceae	Least concern	Unknown
Melicope elleryana (F.Muell.) T.G.Hartley	Rutaceae	Least concern	Stable
Melochia umbellata (Houtt.) Stapf	Malvaceae	Least concern	Stable
Micromelum minutum (G.Forst.) Wight & Arn.	Rutaceae	Least concern	Stable
Muntingia calabura L.	Muntingiaceae	Least concern	Stable
Mussaenda philippica A.Rich.	Rubiaceae	Least concern	Stable
Myristica gigantea King	Myristicaceae	Near threatened	Unspecified
Myristica hollrungii Warb.	Myristicaceae	Least concern	Stable
Myristica hooglandii J.Sinclair	Myristicaceae	Near threatened	Decreasing
Myristica sp.	Myristicaceae		
Nauclea orientalis (L.) L.	Rubiaceae	Least concern	Stable
Nauclea tenuiflora (Havil.) Merr.	Rubiaceae	Least concern	Unknown
Neolamarckia cadamba (Roxb.) Bosser	Rubiaceae		
Neuburgia celebica (Koord.) Leenh.	Loganiaceae	Least concern	Stable
Ochrosia ficifolia Markgr.	Apocynaceae	Least concern	Unknown
Octomeles sumatrana Miq.	Tetramelaceae	Least concern	Stable
Palaquium lobbianum Burck	Sapotaceae	Least concern	Unknown
Parkia speciosa Hassk.	Fabaceae	Least concern	Unknown
Pentaspadon motleyi Hook.f.	Anacardiaceae	Data deficient	Unspecified
Pericopsis mooniana (Thwaites) Thwaites	Fabaceae	Vulnerable	Unspecified
Pimelodendron amboinicum Hassk.	Euphorbiaceae	Least concern	Stable
Pisonia umbellifera (J.R.Forst. & G.Forst.)	Nyctaginaceae	Least concern	Stable
Pittosporum moluccanum (Lam.) Miq.	Pittosporaceae		
Planchonella keyensis H.J.Lam	Sapotaceae	Least concern	Unknown

	Planchonella obovata Pierre	Sapotaceae		
	Planchonella sp.	Sapotaceae		
	Planchonia papuana R.Knuth	Lecythidaceae	Least concern	Stable
	Polyalthia sp.	Annonaceae		
	Polyscias nodosa (Blume) Seem.	Araliaceae	Least concern	Stable
	Pometia pinnata J.R.Forst. & G.Forst.	Sapindaceae	Least concern	Decreasing
	Premna serratifolia L.	Lamiaceae	Least concern	Stable
	Prunus arborea (Blume) Kalkman	Rosaceae	Least concern	Unspecified
	Prunus javanica (Teijsm. & Binn.) Miq.	Rosaceae	Least concern	Unspecified
	Pterygota horsfieldii (R.Br.) Kosterm.	Malvaceae		
	Rhus lamprocarpa Merr. & L.M.Perry	Anacardiaceae		
	Rhus taitensis Guill.	Anacardiaceae	Least concern	Stable
	Saurauia panayensis Merr.	Actinidiaceae	Vulnerable	Decreasing
	Semecarpus papuana Lauterb.	Anacardiaceae		
	Siphonodon celastrineus Griff.	Celastraceae	Least concern	Unspecified
	Sloanea pullei O.C.Schmidt ex A.C.Sm.	Elaeocarpaceae		
	Spondias dulcis G.Forst.	Anacardiaceae		
	Sterculia macrophylla Vent.	Malvaceae		
	Sterculia shillinglawii F.Muell.	Malvaceae	Least concern	Stable
	Syzygium sp.	Myrtaceae		
	Tabernaemontana aurantiaca Gaudich.	Apocynaceae	Least concern	Stable
	Teijsmanniodendron bogoriense Koord.	Lamiaceae	Least concern	Stable
	Terminalia canaliculata Exell	Combretaceae	Least concern	Unknown
	Terminalia complanata K.Schum.	Combretaceae	Least concern	Decreasing
	Terminalia procera Roxb.	Combretaceae	Least concern	Unknown
	Trema orientalis (L.) Blume	Cannabaceae	Least concern	Unknown
	Utania racemosa (Jack ex Wall.) Sugumaran	Gentianaceae		
	Vatica rassak (Korth.) Blume	Dipterocarpaceae	Least concern	Decreasing
	Virola surinamensis (Rol. ex Rottb.) Warb.	Myristicaceae	Endangered	Unspecified
	Vitex *pinnata* L.	Lamiaceae	Least concern	Stable
	Xanthophyllum papuanum Whitmore ex Meijden	Polygalaceae	Least concern	Decreasing
	Ziziphus sp.	Rhamnaceae		

Table 3. Number of species and conservation status

Category	Conservation status	Species	Percentage (%)
Threatened	Endangered	1	0.44
	Vulnerable	5	2.22
Lower Risk	Near Threatened	3	1.33
	Least Concern	108	48.00
	Data Deficient	3	1.33
	Not Available	105	46.67
Total		225	100.00

The number of species included in the threatened category is about 3% of the vegetation in this area (Table 3). For the endangered category, there are the species of *Virola surinamensis* (Rol. ex Rottb.) Warb. and for the Vulnarable category is *Drypetes globosa* (Merr.) Pax & K.Hoffm., *Endospermum medullosum* L.S.Sm., *Koompassia grandiflora* Kosterm., *Pericopsis mooniana* (Thwaites) Thwaites, and *Saurauia panayensis* Merr. The vegetation condition in the area is classified as a secondary forest where there is very little living vegetation, especially large individual trees. In addition, when observing this area, land cover plants are dominated by shrubs, ferns, lianas, and herbs. Ecologically, this area is experiencing a secondary succession where competition is taking place between lifeforms to obtain growing space, especially getting sunlight. Based on the value of diversity, this area has a high diversity with a high number of species, and fluctuations in the number of individuals varied. The Shannon Weiner index (H') value for this region is 4.38, and the Pielou index value is 80.86%, which illustrates that the distribution of the number of individuals in each species is almost uniform. The distribution of the number of individuals in species that are included in high is the main characteristic of mixed forests in tropical forests where there is competition between living creatures to obtain space to grow, especially sunlight. Based on its diversity value, this area has high diversity with a high number of species and varying fluctuations in the number of individuals.

Faunal richness and diversity

The results of data collection in the field were carried out in accordance with the method in the frame of reference. However, in its implementation, procedures have been added to obtain valid information regarding the whereabouts of animals. In this study, animals are focused on fauna that is classified as natural and occupies areas that will be used for company activities. This additional method is exploration and identification in the area using indirect methods, namely the nesting and habitat approach along with tracks in the area. In addition, interviews with key respondents in communities who use the forest were conducted to strengthen information about the existence of these animals. Determination of scientific identification is carried out by discussions with animal experts and also information on the website for scientific names at GBIF—

the Global Biodiversity Information Facility (https://www.gbif.org/what-is-gbif), Animal Diversity Web (ADW) (https://animaldiversity.org/about/), and Birds of the World (https://birdsoftheworld.org/bow/content/about-birds-of-the-world). The identification results in this area are that there are 31 families and 57 species, which are part of four classes, namely mammalia, aves, reptilia, and insects. From these results, it can be detailed that the numbers are for mammalia (10 species), aves (37 species), reptiles (6 species), and insecta (4 species). Under rational circumstances, the number of wild animals present would certainly exceed this number; however, in connection with the consideration of the four previous things, animals are obtained, which are indicators for the condition of the fauna (Table 4).

In the description of this area, the existing vegetation is the secondary forest with a dominance of trees and also herbs, shrubs, and lianas which are included in the formation of this forest structure. Therefore, there are indications that wild animals still use this area as a nesting habitat, a crucial role in the ecosystem, and for other activities, such as mating. In this area, some people use forest resources as hunting areas, which is still done traditionally, namely with traps, especially some from the mammalian class. Apart from that, this area is still a stopover place for the aves class, so several species of birds can still be found. Moreover, we also found several species from the reptilia, such as lizards or monitor lizards, and especially insects, actually not only from Papilionidae but due to limited equipment for collecting data from other genera, data collection was only focused on this genus.

From the results of grouping based on conservation status and population trend based on the IUCN of Nature's Red List of Threatened Species, in this area, some animals have been identified that are still vulnerable or threatened, namely critically endangered and vulnerable with a declining population tendency. Apart from that, the rest are wild animals that are still in the lower risk, near threatened, and least concern categories. However, attention needs to be paid because these animals have a population trend to decline (Table 5). In this area, 30 species are included in the protected category based on the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number P.106/Menlhk/Setjen/Kum, 1/12/2018, concerning the Second Amendment to the Regulation of the Minister of Environment and Forestry Number P. 20/Menlhk/Setjen/Kum, 1/6/2018 concerning types of protected plants and animals.

The analysis results for the Shannon Weiner index (H') and Pielou's Evenness index (J) are as follows: 3.903 and 0.96 for each of these indices; the H'max value is 4.04. For this area, the value of the diversity index could be higher if all classes of animals were taken. However, several publications measure the effect of forest degradation on the existence of animals, and several classes, such as mammalia and aves, can be used to describe the condition of these animals. In this condition, the existence of animals is still supported by the good ecological condition of the vegetation, both as a food source, nesting place, and activity. Therefore, when vegetation is cut down, these animals will move or migrate outside the area. Apart from that, the importance of this accurate scientific study cannot be overstated, especially in understanding each species' response to changes and the home range of each animal.

Discussion

The role of biodiversity in the forest dynamic

In this study, we found that the secondary forest still harbors high species richness of vegetation and fauna. The findings are that the secondary forest is experiencing the successional process in which many vegetation, particularly lianas, and herbs, outcompete to obtain more sunlight resulting from more canopy openness. Several studies on tropical forests have shown that vegetation competition due to the opening of previously dense forest canopies can result in fast-growing plant species and lianas taking over the ecology (Addo-Fordjour et al. 2019; Murdjoko et al. 2022). This situation is explained by early-stage successional plants growing aggressively, as found in other successional forests in the tropics (Yirdaw et al. 2019; Tawer et al. 2021; Murdjoko et al. 2022). The secondary forests are part of forest dynamics in tropical forests as the forests, most of the time, are getting disturbed at many magnitudes (Thomas and Baltzer 2002; Hu et al. 2018). Tropical forests, particularly tropical rainforests, are well-known for their exceptional biodiversity as one of the most varied ecosystems on the planet (Aguirre-Gutiérrez et al. 2022).

Species richness of plants in secondary forests in the tropics refers to the number of different plant species present in forests that have re-grown after being disturbed or cleared. Studying these secondary forests is of significant importance for biodiversity conservation. They provide habitat for a wide variety of plant species, many of which may not be found in primary forests, as many studies have shown in tropical forests (Murdjoko et al. 2017, 2022). In the condition of natural forests, especially in Papua (Indonesian New Guinea), there is still vegetation that is included in the category of conservation status with a high-risk level even though it is in a secondary forest area. The results of research in the Papua region show that the process of spreading vegetation counts on seed dispersal processes such as endozoochory, synzoochory, anemochory, and hydrochory where the animals, wind processes, and water cycle that plays a crucial role (Menezes et al. 2019; Piotto et al. 2019). The species richness of plants in secondary forests in the tropics can vary depending on factors such as the age of the forest, the level of disturbance, and the surrounding landscape (Murdjoko et al. 2016, 2021a; Fatem et al. 2020). The secondary forest provides a place for biodiversity for flora and fauna to benefit wildlife as stepping stones for wildlife movement and gene flow, thereby helping the restoration of fragmented landscapes. These forests also support a variety of plant and animal species, thereby contributing to the health and resilience of the ecosystem as a whole. Lastly, the secondary forests provide food sources, shelter, and nesting sites for wildlife, promoting species survival and population growth (Lugo 2009; Kleinschroth and Healey 2017; Chen et al. 2020; Malhi et al. 2022).

Table 4. Number of animals in the classes mammalia, aves, reptilia, and insecta, along with conservation status and population trend

Class	Family	Species	National status*	Conservation status	Population trend
Mammalia					
1	Cervidae	*Rusa timorensis*	Protected	Vulnerable	Decreasing
2	Macropodidae	*Dendrolagus inustus*	Protected	Vulnerable	Decreasing
3	Macropodidae	*Dorcopsis luctuosa*		Least concern	Stable
4	Muridae	*Pogonomys macrourus*		Least concern	Unknown
5	Peramelidae	*Isoodon macrourus*		Least concern	Stable
6	Phalangeridae	*Spilocuscus maculatus*	Protected	Least concern	Stable
7	Phalangeridae	*Phalanger orientalis*		Least concern	Stable
8	Pteropodidae	*Pteropus melanotus*		Vulnerable	Decreasing
9	Suidae	*Sus scrofa*		Least concern	Unknown
10	Tachyglossidae	*Zaglossus bruijni*	Protected	Critically endangered	Decreasing
Aves					
1	Accipitridae	*Accipiter novaehollandiae*		Least concern	Decreasing
2	Accipitridae	*Accipiter meyerianus*	Protected	Least concern	Decreasing
3	Accipitridae	*Henicopernis longicauda*	Protected	Least concern	Decreasing
4	Accipitridae	*Haliastur indus*	Protected	Least concern	Decreasing
5	Accipitridae	*Harpyopsis novaeguineae*	Protected	Vulnerable	Decreasing
6	Anatidae	*Dendrocygna guttata*		Least concern	Stable
7	Bucerotidae	*Rhyticeros plicatus*	Protected	Least concern	Decreasing
8	Casuariidae	*Casuarius bennetti*	Protected	Least concern	Stable
9	Columbidae	*Goura cristata*	Protected	Vulnerable	Decreasing
10	Columbidae	*Ducula myristicivora*		Least concern	Stable
11	Corvidae	*Corvus orru*	Protected	Least concern	Increasing
12	Cuculidae	*Centropus bernsteini*		Least concern	Stable
13	Dicruridae	*Dicrurus hottentottus*		Least concern	Decreasing
14	Maluridae	*Malurus alboscapulatus*		Least concern	Stable
15	Megapodiidae	*Talegalla cuvieri*	Protected	Least concern	Decreasing
16	Meliphagidae	*Myzomela rosenbergii*		Least concern	Unknown
17	Meliphagidae	*Melipotes ater*		Least concern	Stable
18	Monarchidae	*Monarcha melanopsis*		Least concern	Stable
19	Monarchidae	*Myiagra alecto*		Least concern	Stable
20	Pachycephalidae	*Pachycephala aurea*		Least concern	Stable
21	Paradisaeidae	*Paradisaea rubra*	Protected	Near threatened	Decreasing
22	Paradisaeidae	*Paradisaea minor*	Protected	Least concern	Decreasing
23	Psittacidae	*Charmosyna papou*	Protected	Least concern	Stable
24	Psittacidae	*Charmosyna josefinae*	Protected	Least concern	Stable
25	Psittacidae	*Lorius lory*	Protected	Least concern	Decreasing
26	Psittacidae	*Neopsittacus musschenbroekii*		Least concern	Increasing
27	Psittacidae	*Pseudeos fuscata*	Protected	Least concern	Stable
28	Psittacidae	*Probosciger aterrimus*	Protected	Near threatened	Decreasing
29	Psittacidae	*Cacatua galerita*	Protected	Least concern	Decreasing
30	Psittacidae	*Alisterus chloropterus*	Protected	Least concern	Stable
31	Psittacidae	*Eclectus roratus*	Protected	Least concern	Decreasing
32	Psittacidae	*Chalcopsitta atra*	Protected	Least concern	Stable
33	Psittaculidae	*Glossoptilus goldiei*		Least concern	Decreasing
34	Psittaculidae	*Psittrichas fulgidus*	Protected	Vulnerable	Decreasing
35	Rhipiduridae	*Rhipidura leucophrys*		Least concern	Increasing
36	Strigidae	*Uroglaux dimorpha*		Least concern	Decreasing
37	Zosteropidae	*Zosterops fuscicapilla*		Least concern	Unknown
Reptilia					
1	Elapidae	*Micropechis ikaheka*		Least concern	Stable
2	Scincidae	*Eutropis multifasciata*		Least concern	Stable
3	Scincidae	*Tiliqua scincoides*		Least concern	Stable
4	Varanidae	*Varanus salvadorii*		Least concern	Unknown
5	Varanidae	*Varanus prasinus*	Protected	Least concern	Stable
6	Varanidae	*Varanus jobiensis*		Least concern	Unknown
Insecta					
1	Papilionidae	*Ornithoptera paradisea*	Protected	Near threatened	Unknown
2	Papilionidae	*Ornithoptera tithonus*	Protected	Least toncern	Unknown
3	Papilionidae	*Ornithoptera priamus*	Protected	Least toncern	Unknown
4	Papilionidae	*Ornithoptera goliath*	Protected	Least concern	Unknown

Note: * This national status is based on the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number P.106/Menlhk/Setjen/Kum, 1/12/2018, concerning the second amendment to the Regulation of the Minister of Environment and Forestry Number P. 20/Menlhk/Setjen/Kum, 1/6/2018 concerning types of protected plants and animals

Table 5. Number and percentage of species along with conservation status and population trend

Category	Conservation status	Population trend	Species number	Percentage (%)
Threatened	Critically Endangered	Decreasing	1	1.75
	Vulnerable	Decreasing	6	10.53
Lower Risk	Near Threatened	Decreasing	2	3.51
		Unknown	1	1.75
	Least Concern	Decreasing	13	22.81
		Increasing	3	5.26
		Stable	22	38.60
		Unknown	9	15.79
		Total	57	100.00

When examining vegetation, the number of different plant species in a given area is a key indicator of the diversity and abundance of plants within an ecosystem. This diversity is crucial for the stability and proper functioning of the ecosystem. Plants, as primary producers, establish the foundation of food chains, supporting various animal species (Chazdon et al. 2010; Matsuo et al. 2021). Hence, the species richness in secondary forests can be seen as the process of resilience against environmental changes and disturbances. Likewise, the richness of fauna species significantly contributes to overall biodiversity. The presence of a variety of animal species in an ecosystem is indicative of its ecological well-being and equilibrium. Fauna diversity is essential for maintaining intricate food webs, pollination processes, seed dispersal, and other ecological interactions that uphold ecosystems (Barlow et al. 2016; Malhi et al. 2021). The combined richness of vegetation and fauna provides a comprehensive representation of biodiversity within a specific area, such as this study area. It is crucial to monitor and assess both components to comprehend ecosystem dynamics, pinpoint conservation priorities, and evaluate the overall health of natural habitats. Despite the fact that some species have a global increase in population trend like species belonging to Psittacidae or Corvidae, species in some parts of Papua tend to decrease as a result of the alteration of forest conditions as we observed in this location. Hence, those species are grouped by national regulation as "protected".

Ecological management of secondary forest

Forest management considers planning and implementation of practices to ensure long-term sustainability following activities such as harvesting, regeneration, protection, and biodiversity conservation (Edwards et al. 2014; Cleary and Eichhorn 2018). In this investigation, the secondary forest was the result of anthropogenic factors like logging because this area is grouped as a production forest. Based on observation and analysis of species richness and diversity, this forest is re-growing as part of the forest dynamic since it has experienced the disturbance and the forest is naturally regenerating. This process plays an important role in biodiversity conservation and ecosystem services by providing an area for certain plants to grow and colonize. It can be seen that the secondary forest accommodates species with conservation status, such as endangered and vulnerable, where the category level is grouped as threatened.

Even though this research has underlined the role of ecological conditions during the successional stage in secondary forests, other factors must be included systematically to sustainable forest management aims to balance ecological, economic, and social objectives. Furthermore, the biological aspect is the main driver as the threshold to measure the forest dynamic. Hence, this involves maintaining productivity while conserving biodiversity, protecting soil and water resources, and supporting forest-dependent communities. Therefore, the secondary forest is part of the successional process where it is more dynamic than the primary forest (Mukul et al. 2016; Powers and Marín-Spiotta 2017). From an economic perspective, sustainable forest management seeks to optimize the value derived from forest resources while ensuring their long-term availability. This includes promoting natural regeneration during timber harvesting, diversifying income sources through non-timber forest products and ecotourism, and creating employment opportunities in forest-dependent communities (Naime et al. 2020; Sinacore et al. 2023). However, the possibility of converting this forest is higher since it does not support enough of the product, either log or non-wood. For this reason, it is alarming that proper management and consistency in controlling the implementation are required.

Forest management should be considered carefully to anticipate the conversion of forest in order to minimize the impact of deforestation such as habitat loss of vegetation and fauna and decrease of species richness. The following programs should be considered if the process is done based on regulation in which the adverse impact of forest utilization could be systematically minimized. This area is declared a production forest and has been used as a logging concession for decades. Recently, the permit to convert the forest to other functions is possible, such as palm crops or forest plantation. This will ecologically change the forest from a tropical mixed forest to a monoculture ecosystem. Hence, the management must consider the process such as

a balance between economic and ecological goals. Understanding the initial conditions, such as vegetation and fauna, is imperative in uncovering the role of secondary forests in species assemblages. By knowing that, the guide to managing the secondary forest can be recommended like preparing the buffer zone to accommodate not only the vegetation but also the fauna that could benefit as a habitat. Buffer zones serve as natural pools of biodiversity where the enrichment planting could be suggested as part of the preservation of the original habitat (Cole et al. 2020; de Almeida-Rocha and Peres 2021). Buffer zones can support conservation areas, and local governments can delineate these areas and then legally support them by making regulations (Sonbait et al. 2021). Buffer zones can be established in riverine corridors where biodiversity and soil are conserved while fauna can be inhabited. Zoning can be regulated using traditional knowledge because Papua includes many tribes with local knowledge developed over generations (Ungirwalu et al. 2014, 2017; Sonbait et al. 2021; Sagrim 2022; Saiba et al. 2023). Moreover, the permanent sampling plots for monitoring vegetation are useful to obtain the population and species composition. At the same time, animal captivities are useful to observe faunal diversity, and the fauna can be released into the wild. In the end, those can be a guide to managing the secondary forest by taking into account not only the ecological aspects but also socio-economic factors. Managing secondary forests presents challenges, including striking a balance between economic development and conservation priorities and the potential risk of compromising their ecological integrity through human activities. However, there are opportunities to restore degraded land through reforestation, encourage sustainable agroforestry practices, establish protected areas within secondary forests, and involve local communities in decision-making processes, such as land use planning and resource management, to ensure their needs and perspectives are fulfilled.

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