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Anthropogenic implications for land cover changes and vegetation structure in coastal protected forest

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Abstract. *Eddy S, Dahlianah I, Mashito C, Oktavia M, Utomo B. 2022. Anthropogenic implications for land cover changes and vegetation structure in coastal protected forest. Biodiversitas 23: 4473-4481.* Anthropogenic activities in coastal areas have largely eliminated mangrove forest cover, including the Air Telang Protected Forest (ATPF). This study aims to analyze land cover changes in 2021 and the vegetation structure in ATPF which covers an area of approximately 12,660.87 ha. The method used in this study is a survey method with two stages of data collection, namely the collection of image data and vegetation data. Image data for 2021 was obtained from Landsat 8 Oli, while vegetation data were collected through the identification of plant species and quantitative analysis through the calculation of the Important Value Index (IVI) and the Shannon Diversity Index (H'). The results of this study show that there has been deforestation in ATPF by 66.4% until 2021 due to land conversion into coconut plantations, oil palm plantations and open areas. The number of plant species obtained was 20 species consisting of seven true mangrove species and 13 associated mangrove species. The diversity index ranges from 0.00 to 0.62 which is included in the low category.

Keywords: Air Telang Protected Forest, anthropogenic, land cover changes, vegetation structure

INTRODUCTION

The mangrove ecosystem is an important and unique natural resource in coastal areas. The uniqueness of the mangrove ecosystem gives this ecosystem very potential to support the existence of a diversity of flora and fauna. It grows along the muddy coasts of estuaries and deltas with high sedimentation intensity supplied from upland catchments (Eddy et al. 2021a). Mangrove forests provide valuable habitat for living things around them, and also play a role in preventing coastal erosion, regulating nutrition, primary productivity, protecting coastal communities from extreme weather, and natural carbon storage (Nagelkerken et al. 2008; Koch et al. 2009; Mukherjee et al. 2014; Sheaves et al. 2016; Atwood et al. 2017; Basyuni et al. 2018; Hochard et al. 2019; Ouyang et al. 2018).

Indonesia is a country that has the largest mangrove forest in the world and is spread across almost all islands with a high biodiversity of mangrove forests (Murdiyarso et al. 2015; Richards and Friess 2016; Ramdani et al. 2019; Bryan-Brown et al. 2020). Indonesia has a mangrove forest area of approximately 2.7 million ha in 2020 with a total flora of around 157 species and fauna consisting of about 122 invertebrate species, 45 fish species and 148 terrestrial fauna species (Basyuni et al. 2022…BC). However, anthropogenic pressures such as deforestation and forest conversion, and sea level rise as a consequence of global warming have threatened the existence of this ecosystem (Giri et al. 2011; Dat and Yoshino 2013; Komiyama 2014; Mayalanda et al. 2014; Lovelock et al. 2017; Schuerch et al. 2018).

Air Telang Protected Forest (ATPF) is one of the coastal protected forests located on the east coast of Sumatra Island with an area of approximately 12,660 ha, which is also experiencing anthropogenic pressure. The conversion of mangrove forests to coconut plantations, oil palm plantations, ponds, agriculture, ports and settlements has destroyed approximately 63% of primary and secondary forests in the area by 2020 (Eddy et al. 2017; Eddy et al. 2021a). This has led to a very high increase in carbon emissions in the period 2000-2020 in this region, where more than 50% of emission sources are generated from primary forest destruction (Eddy et al. 2021b).

Changes in land cover and disturbance of forest vegetation structure will have an impact on habitat conditions and food supply for biota (Eddy et al. 2021c). A comprehensive study of the damaged condition of mangrove forests and their impacts can be carried out by analyzing the forest structure and composition of plant species (Eddy et al. 2019; Basyuni et al. 2021); for example, the invasion of certain plants such as *Nypa fruticans* is an indicator of mangrove forest degradation (Eddy and Basyuni 2020). The composition and structure of mangrove vegetation can form patterns of adaptation, association, and zoning to the potential for biodiversity in an ecosystem (Bathmann et al. 2021; Steibl et al. 2021).

Our research specifically examines the structure and composition of mangrove species and changes in land cover in the ATPF area. The results of this study are important to explain the existing condition of mangrove forests which are degraded due to anthropogenic activities. In addition, through this ecosystem monitoring, policies related to the restoration of degraded mangrove forests will be formulated.

MATERIALS AND METHODS

Study area

This research was conducted in the Air Telang Protected Forest (ATPF) area which is one of the mangrove forest areas located in Banyuasin District, South Sumatra Province, Indonesia (Figure 1). ATPF has an area of approximately 12,660.87 ha. The ATPF area has been degraded and converted into coconut plantations, oil palm plantations, ponds and ports which have resulted in a reduced area of mangrove forest (Eddy et al. 2017; Eddy et al. 2021a).

Imageries data collection

The image data used is sourced from Landsat 8 Oli in 2021. The Landsat 8 image is then identified as a mangrove forest using the normalized difference vegetation index (NDVI). Location sampling is done to check the accuracy and precision of the identification results. The coordinates of the sampling point were taken using the Geographical Positioning System (GPS).

Vegetation data collection

Vegetation sampling was carried out from April to May 2021 using the purposive sampling method in shrubs and secondary forests based on the results of the survey of the research site (Figure 2). Meanwhile, data on primary natural forests that have not been disturbed are taken from the secondary data from the 2015-2016 research (Eddy et al. 2019). Plant vegetation data samples were taken using a line transect method made from east to west or vice versa along 100 m. The number of transects made was 8 transects consisting of 3 transects in the secondary forest and 5 transects in the shrubs (Figure 3). Each transect made 5 plots for each level of tree growth, saplings and seedlings; with a size of 10 x 10 m for the tree level, 5 x 5 m for the sapling level, and 1 x 1 m for the seedling level (Mueller-Dombois and Ellenberg 1974). The plant data obtained were recorded on a tally sheet and pictures of the plants were taken using a camera to identify the species. Each documented plant species was identified using several plant species identification books according to the Lembaga Biologi Nasional (1980), Andrews (1990), Noor et al. (2006) and Giesen et al. (2007).

Data analysis

Landsat data analysis

We used six classifications of land cover types consisting of primary forest, secondary forest, coconut plantation, open area, fishpond and waterbody. The image classification method we use is the supervised classification method (visual interpretation) which is an effective method for identifying land cover types (Butt et al. 2015). The steps in Geographic Information System (GIS) analysis consist of four stages, namely pre-processing, processing, image classification and field survey (Eddy et al. 2017).

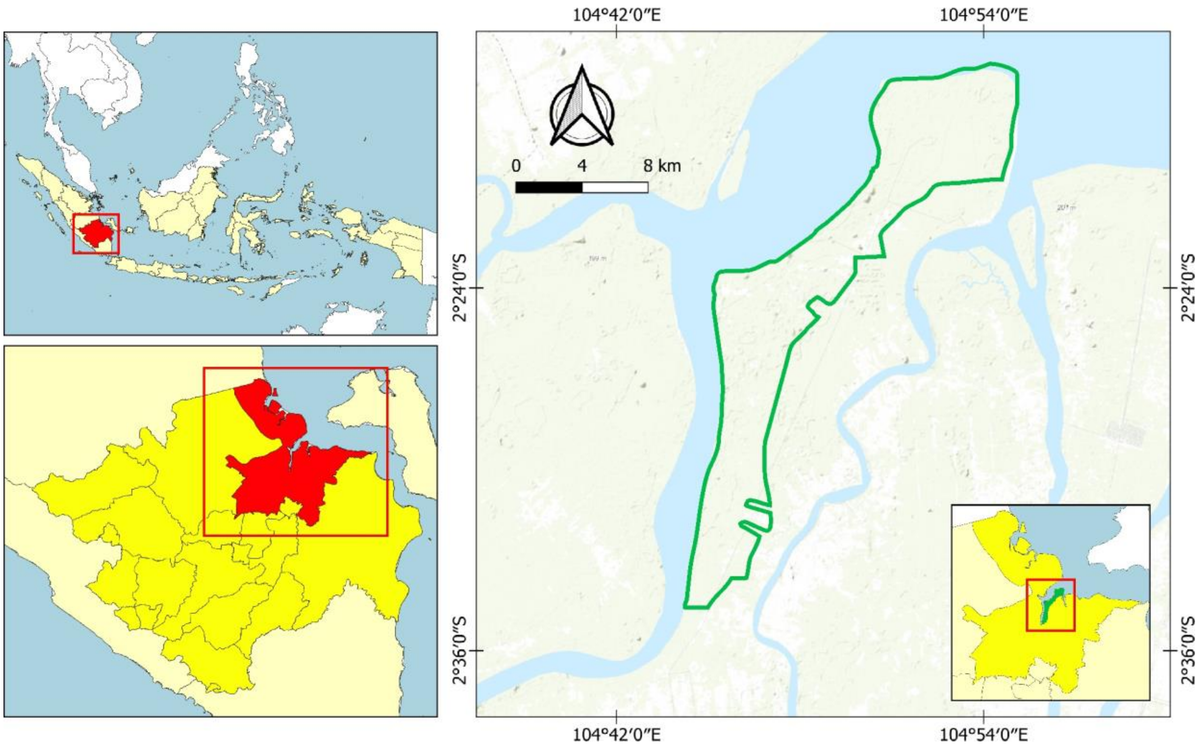

Figure 1. The study site is in the Air Telang Protected Forest (ATPF), Banyuasin District, South Sumatra Province, Indonesia

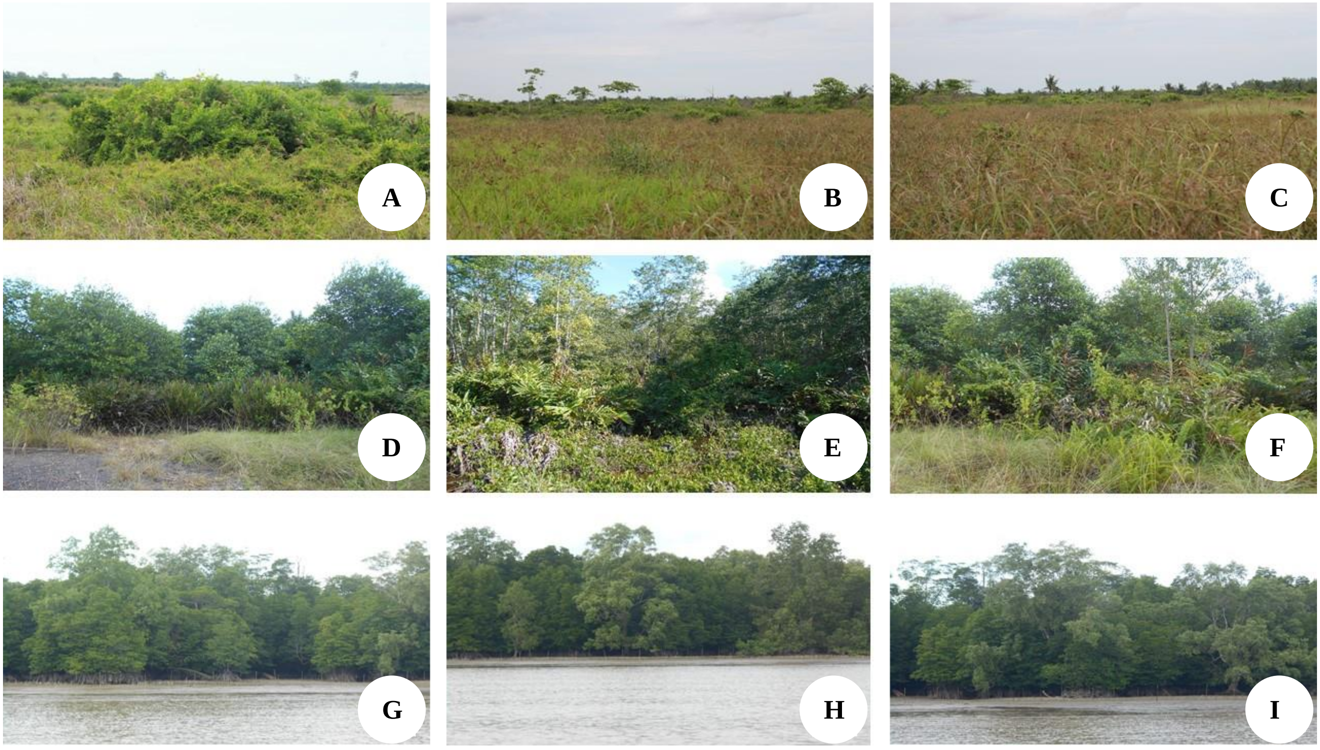

Figure 2. Conditions of sampling locations in ATPF (A, B and C are shrubs; D, E and F are secondary forests; G, H and I are primary forests)

Vegetation data analysis

The analysis of vegetation data used in this study is quantitative analysis, namely by calculating the Important Value Index (IVI) and the Shannon Diversity Index (H'). For each plant species at the tree level obtained in each plot, the number of trees and basal area was calculated, while the number of seedlings and saplings was only counted. This data is used to determine the value of density (individuals/ha), frequency (%) and dominance (m^2/ha) of each plant species; so that the relative values of density, frequency and dominance are obtained which are used to calculate IVI (Kent and Coker 1992; Neelo et al. 2015). H' was used to calculate the plant species diversity index (Krebs 1989; Odum 1998; Magurran 2004), with categories very high (H'≥4), high (4≥H'≥3), moderate (3≥H'≥2), low (2≥H'≥1) and very low (H'≤1) (Barbour et al. 1999; Djufri et al. 2016).

RESULTS AND DISCUSSION

Land cover and land use

The land cover identification in 2021 that we use is based on the NDVI vegetation index algorithm, whose overall accuracy is very good (Reddy & Prasad 2018; Sun et al. 2018; Meroni et al. 2019; Spadoni et al. 2020). Based on the NDVI analysis, we divided the land cover types into five types, namely primary forest, secondary forest, coconut plantations, open area and fishpond (Figure 3). The open area has the largest area, followed by secondary forest, coconut plantations and primary forest. The existence of open areas occurs due to the clearing of primary and secondary forests by the community and companies to be used as plantation areas. The largest forest conversion is in the form of coconut plantations, while the conversion to fishponds is only slightly.

The ATPF area is designated as a protected forest based on SK.822/Menhut-II/2013 concerning the Determination of Forestry Areas in South Sumatra Province, with an area of approximately 12,660.87 ha. When this area was designated as a protected forest in 2013, the area of the primary forest and the secondary forest was around 8,974.8 ha (Eddy et al. 2017). The condition of primary and secondary forests until 2021 continues to occur, reaching 4,725.8 ha of deforestation so that the remaining area of primary and secondary forests is only about 4,249 ha (33.6%) (Table 1).

Long before being designated as a protected forest, this area consisted of almost half of the primary forest in 1985 and a slight decline after 15 years was around 7.4% or 0.49% per year (Table 1). The decline in primary forest area continues to occur in the 2000-2020 period, which is around 18.8% or around 0.94% per year. The decline in primary forest area occurred significantly, namely in the 2020-2021 period, namely 8.9% per year or only 1,804.6 ha remained. This decline occurs because deforestation is increasingly massive in this area, especially when the Tanjung Api-api Special Economic Zone (SEZ) is built in this area.

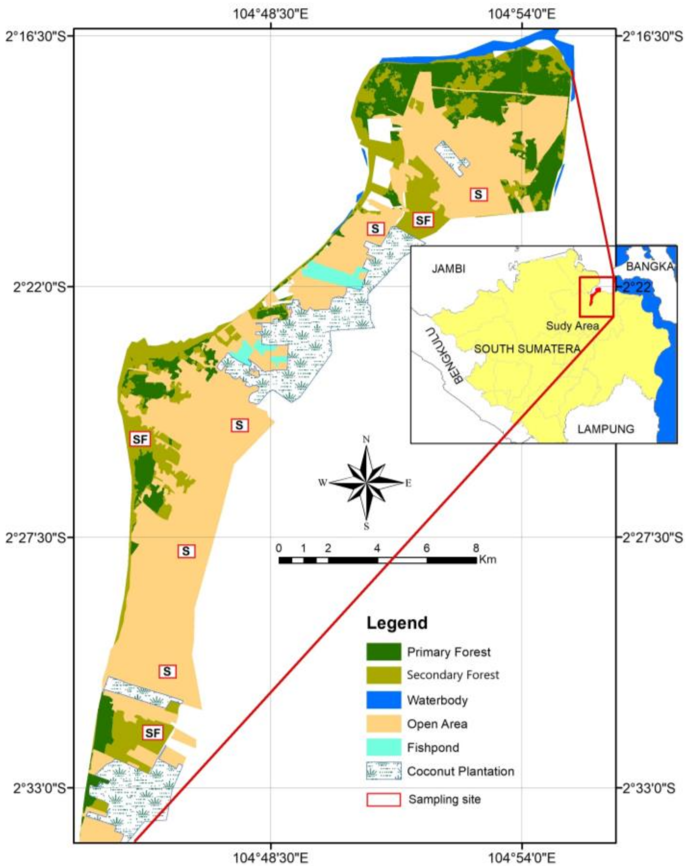

Figure 3. Map of land cover and land use in the Air Telang Protected Forest (ATPF) 2021 and location of sampling sites for secondary forests (SF) and shrubs (S)

Table 1. Land cover change in ATPF in 1985, 2000, 2020 and 2021. Land cover data for 1985, 2000 and 2020 were obtained from Eddy et al. (2021)

Land cover types	Area in 1985		Area in 2000		Area in 2020		Area in 2021	
	ha	%	ha	%	ha	%	ha	%
Primary forest	6,257.0	49.4	5,321.4	42.0	2,936.1	23.2	1,804.6	14.3
Secondary forest	4,628.8	36.6	2,563.8	20.3	1,123.0	8.9	2,444.4	19.3
Coconut and oil palm plantation	1,074.9	8.5	3,713.4	29.3	1,834.6	14.5	1,834.6	14.5
Open area/deforested area	22.8	0.2	495.0	3.9	6,334.2	50.0	6,145.3	48.5
Fishpond	-	-	93.7	0.7	189.9	1.5	188.9	1.5
Waterbody	677.4	5.4	473.5	3.7	243.1	1.9	243.1	1.9
Total	12,660.9	100.0	12,660.9	100.0	12,660.9	100.0	12,660.9	100.0

Vegetation composition

The number of plant species obtained in ATPF in this study was 20 species consisting of 14 families (Table 2). There are as many as seven true mangrove species and 13 associated mangrove species. The true mangrove species consist of *A. alba, N. fruticans, E. agallocha, S. alba, X. granatum, B. cylindrica,* and *R. apiculata*. All true mangroves were found in primary forests or secondary forests and some were found in both. Meanwhile, all associated mangrove plants grow in shrubs.

There are as many as seven species found in primary forests, of which only one species is included in the associate mangrove, namely *A. aureum* while the others are included in the true mangrove; and there are as many as six species found in secondary forests, where only one species is included in the associate mangrove, namely *Nephrolepis* sp while the others are included in the true mangrove. Meanwhile, the plants obtained in the shrubs vegetation type were 12 species, all of which were included in associate mangrove plants.

Vegetation structure

The highest number of species, including tree life-forms, were found in primary forests, sapling life-form species were mostly found in secondary forests, while seedling life-form species were mostly found in shrubs (Table 3). This result affects the Shannon diversity index value (H') where primary forest, secondary forest and shrubs have the highest H' values at tree, sapling and seedling life-forms, respectively. The highest density for tree life-form is in primary forest, while for sapling and seedling life-forms, secondary forest and shrubs have the highest density, respectively.

Tree life-forms were found in primary and secondary forests, which consisted of only three species (Table 4). *N. fruticans* and *R. apiculata* dominated primary and secondary forests, respectively, with the highest IVI in both areas. Likewise, sapling life-form is only found in primary and secondary forests. The dominant plants in the sapling were *R. apiculata* and *E. agallocha* in the primary forest and secondary forest, respectively. Meanwhile, plants for seedling life-form were found in all study areas, where *A. aureum, R. apiculata* and *C. rotundus* predominated in primary forest, secondary forest and shrubs, respectively.

Table 2. Species composition of plants obtained in primary forest (PF), secondary forest (SF) and shrubs (S) in ATPF. Natural primary forest species were taken from secondary data from Eddy et al. (2019)

Familia	Species	Local name	Species type	Location found
Acanthaceae	*Avicennia alba*	Api-api	True mangrove	SF, PF
Amaranthaceae	*Amaranthus* sp	Bayam Hutan	Mangrove associate	S
Arecaceae	*Calamus* sp	Rotan Cacing	Mangrove associate	S
Arecaceae	*Nypa fruticans*	Nipah	True mangrove	SF, PF
Asteraceae	*Ageratum conyzoides*	Bandotan	Mangrove associate	S
Cyperaceae	*Cyperus rotundus*	Rumput Teki	Mangrove associate	S
Euphorbiaceae	*Excoecaria agallocha*	Buta-buta	True mangrove	SF, PF
Fabaceae	*Mimosa pudica*	Putri Malu	Mangrove associate	S
Lomariopsidaceae	*Nephrolepis* sp	Paku	Mangrove associate	S, SF
Lythraceae	*Sonneratia alba*	Pedada/Perepat	True mangrove	SF
Meliaceae	*Xylocarpus granatum*	Boli	True mangrove	PF
Myrtaceae	*Rhodomyrtus tomentosa*	Karamunting	Mangrove associate	S
Poaceae	*Bouteloua dactyloides*	Rumput Kerbau	Mangrove associate	S
Poaceae	*Cynodon dactylon*	Rumput Gerinting	Mangrove associate	S
Poaceae	*Ottochloa nodosa*	Rumput Kawat	Mangrove associate	S
Poaceae	*Paspalum scrobiculatum*	Rumput Ketih Belalang	Mangrove associate	S
Pteridaceae	*Acrostichum aureum*	Paku laut	Mangrove associate	PF
Pteridaceae	*Adiantum* sp	Suplir	Mangrove associate	S
Rhyzophoraceae	*Bruguiera cylindrica*	Tomok	True mangrove	PF
Rhyzophoraceae	*Rhyzophora apiculata*	Bakau	True mangrove	SF, PF

Table 3. A number of species (N), Shannon diversity index (H') and density (ind./ha) for all life-forms (tree, sapling and seedling) in the study area. Primary forest data are taken from sources Eddy et al. (2019)

Study site	Tree		Sapling		Seedling		Density (ind./ha)		
	N	H'	N	H'	N	H'	Tree	Sapling	Seedling
Primary forest	6	0.62	3	0.42	4	0.45	767	1,867	53,333
Secondary forest	1	0.00	5	0.59	2	0.30	224	3,924	24,286
Shrubs	0	0.00	0	0.00	12	0.58	0	0	275,714

Table 4. Importance value index (IVI) of dominant species at each life-forms in primary forest, secondary forest and shrubs. Primary forest data are taken from sources Eddy et al. (2019)

Study site	Tree		Sapling		Seedling	
	Species	IVI (%)	Species	IVI (%)	Species	IVI (%)
Primary forest	*N. fruticans*	150.9	*R. apiculata*	107.1	*A. aureum*	106.3
	R. apiculata	63.6	*X. granatum*	53.6	*A. alba*	47.9
	A. alba	14.0	*A. alba*	39.3	-	-
Secondary forest	*R. apiculata*	300.0	*E. agallocha*	97.2	*R. apiculata*	104.8
	-	-	*R. apiculata*	30.4	*Nephrolepis* sp	95.2
	-	-	*S. alba*	27.5	-	-
	-	-	*A. alba*	27.5	-	-
Shrubs	-	-	-	-	*C. rotundus*	98.3
	-	-	-	-	*C. dactylon*	17.5
	-	-	-	-	*A. conyzoides*	13.1
	-	-	-	-	*Nephrolepis* sp	12.8

Discussion

Anthropogenic is a factor that triggers degradation

Deforestation of protected forests in Indonesia has occurred as much as in ATPF Areas (Brun et al. 2015; Elz et al. 2015; Enrici & Hubacek 2016; Austin et al. 2019). Deforestation of mangrove forests is mostly caused by anthropogenic factors (Giri et al. 2015; Eddy et al. 2021a). The ATPF area is administratively part of the Banyuasin II Sub-sub-district, with a population in 2021 of 29,480 people with a population growth rate of 1.2% (BPS Banyuasin District 2022). The increasing number of residents has pushed the need for space to live and meet the needs of the community, one of which is by converting protected forests into ponds and plantations as well as illegal logging (Fokeng et al. 2020; Walker et al. 2020). In addition, forest and land fires also trigger deforestation in various areas, such as the major fires that occurred in Indonesia in 2015 which scorched approximately 2.6 million ha of land (Purnomo et al. 2017; Budiningsih et al. 2022; Utomo et al. 2022).

Massive land clearing to build plantations, agriculture and fishponds has caused degradation in ATPF to only leave around 14.3% of primary forest in 2021. Meanwhile, deforestation (open area) reaches almost half of the ATPF area. Massive anthropogenic activity in this region is the main cause of deforestation and the destruction of primary forest ecosystems (Basyuni et al. 2022). The main causes of damage to mangrove forests in Indonesia are land conversion into fishponds, plantations and agricultural (Laulikitnont 2014); these three factors are also the cause of deforestation of mangrove forests in several countries in the world (Ilman et al. 2011; Bryan et al. 2013; Li et al. 2013; Nfotabong-Atheull et al. 2013; Jones et al. 2014; Komiyama 2014).

Coconut plantations and oil palm plantations are the dominant factors causing damage to mangrove forests in ATPF (Eddy et al. 2017; Eddy et al. 2019). This can be seen from a large amount of open area that is immediately used by the community and the company. This open area is used by communities and companies for the development of coconut plantations, oil palm plantations and agricultural (Eddy et al. 2021a). Coconut plantations have been around since 1972 which were introduced by the Bugis people from Sulawesi Island who migrated to this area, while oil palm plantations began to exist after 2000.

Vegetation analysis

The massive and continuous deforestation of ATPF areas requires fast and appropriate action to maintain its sustainability. Analysis of vegetation structure and composition is very important to provide information regarding existing and dominant plant species in the area for the purpose of efficient and sustainable forest management.

There are five true mangrove species that grow in secondary forests, namely *A. alba*, *N. fruticans*, *E. agallocha*, *S. alba*, and *R. apiculata* (Table 2). Their presence in the secondary forest is very important because they will be the main driver of the regeneration and succession of mangrove forests. Meanwhile, the presence of dominant tree species in primary and secondary forests such as *N. fruticans*, *R. apiculata* and *A. alba* (Table 4) is very important in providing propagules to support the regeneration and succession of mangrove forests. In addition, the high density of mangrove vegetation at the tree and sapling levels in primary and secondary forests is also very important in providing propagules and in assisting regeneration (Table 3). Anthropogenic pressures that massively reduce the amount of primary forest can disrupt the distribution of mangrove propagules, making it difficult to regenerate. According to Di Nitto et al. (2008), the distribution of mangrove propagules can be disrupted due to the loss of root mass of mangrove trees. In addition, the limited number of propagules due to the lack of mature trees and the invasion of lower plants that hinder the distribution of propagules are two factors inhibiting regeneration and succession (Biswas et al. 2012).

Rhizophora apiculata is the most dominant mangrove plant in primary and secondary forests because it is found in all life-forms (Table 4). The research results of Eddy et al. (2019) in this area showed the presence of *R. apiculata* in all life-forms in primary and secondary forests. This plant can grow well in the middle zone on muddy substrates that are often traversed by tides and it is able to live in conditions of high water salinity and waves crashing (Priosambodo et al. 2019; Rafiq and Mukhtar 2020; Irawan et al. 2021; Miryeganeh and Saze 2021). In addition, this plant has a very high growth rate and very good adaptability (Guo et al. 2017) and it includes true mangroves that grow 90% in mangrove habitats (Prasetya and Purwanti 2017).

Avicennia alba is a codominant species in primary forests, where this species is found in all life-forms. This plant is generally found around the edge of fishponds which aims to prevent abrasion (Harini et al. 2019). It is also commonly found planted on riverbanks which is useful for preventing landslides on riverbanks. It usually grows in the leading zone (the zone closest to the tide) as well as along the estuary (Martuti et al. 2019; Triest et al. 2021).

The vegetation structure of shrubs is only covered with cover plants, which are presented in Table 4. *C. rotundus* dominates this area with the highest IVI because this plant is found in every plot. This plant is a grass plant that is commonly found in open areas. This plant is also a weed that is commonly found growing wild in grassy fields, roadsides and agricultural land; it has become a serious threat to agriculture because it is difficult to control and has high adaptability and can grow on various types of soil, especially in dry tropical areas (Kraehmer et al. 2016; Peerzada 2017; Khan et al. 2020).

The value of H' for all life-forms, both in primary forest, secondary forest and shrubs, ranges from 0.00 to 0.62 which is included in the low category (Table 3). The criteria for the size of the species diversity index are based on the Shannon-Wienner criteria, namely if the value of $H'>3$ is high, $1\leq H'\leq 3$ is moderate and $H'<1$ is low (Omayio & Mzungu 2019; Strong 2016), while according to Barbour et al. (1999) and Djufri et al. (2016) the value of $H'<1$ is very low. The high and low diversity index in a plant community depends on the number of species and the number of individuals found in the community. This result is in accordance with the research results of Eddy et al. (2019) which obtained a low H' value for all life-forms in primary forest, secondary forest and shrubs. This happens because the value of H' does not only depend on the number of species obtained but also depends on the number of individuals in each species.

The number of mangrove plants, especially trees, is decreasing in this area due to disturbances that cause damage, so the number of mangrove stands decreases (Duke et al. 2021; Peereman et al. 2022). Mangroves are one of the coastal ecosystems that have experienced a fairly high degradation due to the pattern of utilization by the community, which tends not to be oriented to the aspect of sustainability. Most of the ATPF area has been converted into coconut and oil palm plantations, fish and shrimp ponds, agricultural land and into community settlements (Eddy et al. 2018). In addition, the community also utilizes various species of mangrove plants to be used in various things such as building materials for houses, firewood and other benefits. Local communities have long used mangroves for various purposes, such as building materials, firewood, use fruit, seeds and roots as food, fodder and medicine (Eddy et al. 2021b).

The ATPF area has experienced deforestation of 8,411.9 ha or 66.4% until 2021, most of which is converted to coconut plantations, oil palm plantations and open areas. The number of plant species obtained was 20 species consisting of 14 families, with seven true mangrove species and 13 associated mangrove species. There were two important species obtained in this study, namely *R. apiculata* and *A. alba* which were obtained in primary forest sand secondary forests which grew in all life-forms. The highest species diversity index value is 0.62 which is included in the low category.

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