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The Value of Mangrove Ecosystems Based on Mangrove Carbon Sequestration in West Kalimantan

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ABSTRACT

Research on carbon storage is currently in the world spotlight along with the increasing greenhouse effect. Mangroves as one of the ecosystems play a role in blue carbon which can store more carbon than terrestrial forests. Mangroves absorb more carbon than any other forest ecosystem. This is because mangroves are included in wetlands that have the ability to store carbon when the land remains wet. An in-depth discussion was carried out by integrating various literatures on mangroves from 2011–2021 to enrich the information for this research. Mangrove area in West Kalimantan in the period 2011 - 2021 has an area of about 256,586.80 Ha which is dominated by species *Brugueira spp.*, *Rhizophora spp.*, *Sonneratia alba*, *Avicennia spp. Nypa fruticans*, *Excoecaria agallocha*, *Xylocarpus moluccensis* and *Acrostichum speciosum*. Human activities, abrasion and sedimentation have caused a decrease in the area of mangrove ecosystems in West Kalimantan. An increase in temperature has a global impact on life on the earth's surface and the environmental conditions of mangroves. The decrease in micropopulation and aboveground biomass causes a decrease in infauna species and biomass, affects nutrient cycles, destroys nurseries, and reduces mangrove ecosystem services. The results show that mangrove carbon storage in the period 2011 - 2021 is 628.10 tons $C.ha^{-1}$ which has an economic valuation of 3,410.50 US$. Efforts to mitigate global warming and trade in mangroves can be carried out through community-based restoration, restoration of forest plantings, integrated coastal ecosystem rehabilitation, and economic approaches.

Keywords: *Carbon storage, economic valuation, economic valuation of mangroves, mangroves, mangrove carbon storage.*

INTRODUCTION

Mangroves are described as coastal forest areas and tidal forests. Mangroves are generally dominated by several tree species that can grow and thrive in muddy tidal coastal areas (FAO, 1994). Mangroves provide significant benefits both ecologically, economically, and socially. Wang *et al*. (2018) stated that mangroves have various protections, including coastal protection, nutrient retention, heavy metal retention, and carbon storage.

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Studies related to carbon storage are currently in the world spotlight as the greenhouse effect increases. According to Reichle (2020), the greenhouse effect is a mechanism that keeps the earth's temperature warm and is suitable to support life. Earth will receive 30% of the radiant energy from the sun. The greenhouse effect principle is that the heat generated from reflected solar radiation energy is absorbed by water vapor and carbon dioxide raising the earth’s temperature. At some level, the greenhouse effect is required by the earth. However, anthropogenic activity increases atmospheric carbon dioxide levels (CO_2), causing an increase in temperature. The impact continues to turn to climate change which causes changes in all sectors, including human health (Hayes *et al*., 2018). Therefore, the

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quantity of CO_2 released should be controlled, for example, by defending the forest.

Forests can absorb and store CO_2 through photosynthesis. Through photosynthesis, the carbon in the atmosphere is distributed to various parts of the plant, such as seeds, stems, roots, and other organs. Therefore, the CO_2 fixation process increases global atmospheric carbon sequestration (Nogia *et al*., 2016). Sutaryo (2009) stated that mangroves can absorb more carbon than other forest ecosystems. The rate of soil decomposition in wetlands lasts a long time. Hence, the release of CO_2 from the decomposition results can be held longer.

In addition, mangroves are believed to provide another ecological benefit. They have economic value since humans can utilize them by taking the mangrove wood, fuelwood, and raw material to make charcoal. Zulkarnaini *et al*. (2017) informed that the demand for mangrove wood in the Bengkalis Regency for charcoal production is 421.69 m^3 per month. Wang *et al*. (2018) stated that the role of mangroves in ecosystem protection is around 287,993 US$ per year for 174.58 ha (around 1,650 US$.ha-1.year-1). However, the exploitation carried out is increasing along with human growth and human activities. Poor mangrove management will also have an impact on the existence of mangroves. The loss of mangroves will reduce the ability of the mangrove ecosystem to store carbon and increase the release of carbon into the atmosphere, which increases the earth's temperature. Changes that occur are global and will affect climate change and the sustainability of life on earth.

The results of this study serve as preliminary data for monitoring carbon storage in West Kalimantan. This data helps increase public awareness in preserving the mangrove ecosystem and considers . This research is also expected to be helpful as consideration for local governments in making policies for managing and utilizing mangrove areas sustainable in West Kalimantan. Entrepreneurs, the community, and the government need to work together to create harmony in managing the mangrove ecosystem.

RESEARCH METHOD

This article was a literature review that was gathered from various sources. An in-depth discussion was carried out to assess the valuation of mangrove ecosystems based on the perception of mangrove carbon storage. The study was carried out by integrating various literature and journals on mangroves from 2011 – 2021 to enrich information. Keywords in the literature search covered the economic valuation of mangroves, mangrove carbon storage, mangroves carbon storage, economic valuation, and mangroves economic valuation.

The assessment of the economic valuation of mangrove carbon storage is then calculated based on the Minister of Environment Regulation number 15 of 2012 concerning Guidelines for the Economic Valuation of Forest Ecosystems.

RESULTS AND DISCUSSION

Mangrove Ecosystem

Mangroves are coastal plant formations characteristic of tropical and subtropical sheltered coastlines that can grow and thrive in muddy tidal coastal areas. Mangrove root systems are submerged by saltwater, although they may be diluted by freshwater runoff and flooding once or twice a year (FAO, 1994). According to Ewel *et al*. (1998), mangrove ecosystems benefited as a sediment catcher, a place for processing organic matter and nutrients, exporting organic matter, storing nutrients, improving water quality, animal habitat, environmental aesthetics, protecting against floods and production plants.

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Mangrove growth is influenced by environmental factors such as temperature, pH (degree of acidity), salinity, tides, and human activities (FAO, 1994). According to Duke and Allen (2006), the optimum temperature range for mangrove growth is 0ºC – 38ºC. The temperature affects physiological periods such as photosynthesis and evaporation. It also affects salinity around mangroves. Hastuti *et al*. (2012) pointed out that the salinity range requirements for the best mangrove growth are 5 – 30 ppt. The salinity of more than 35 ppt has an adverse effect due to the negative impact of osmotic pressure (Dinilhuda *et al*., 2018). In their study, Irsadi *et al*. (2019) suggested several mangrove growth factors. For instance, the water pH in mangrove growth sites tends to be acidic to alkaline (6.6 – 8.4), while soil pH ranges from 4.8 – 7.3 (acid to normal). The soil where mangroves grow is an area with a good frequency of tidal currents because soils often submerged in water will make the soil pH tend to become acidic. The ebb and flow that occurs in the mangrove ecosystem results in the zoning of mangrove plants. In addition, human activities also affect the existence of mangroves. The loss of mangroves due to humans is exemplified by urban development, aquaculture, agricultural conversion, urbanization, immigration, and conversion to oil palm plantations (excessive timber exploitation (Rasyid *et al*., 2016; Romañach *et al*., 2018; Worthington *et al*., 2020)

Mangrove growth is influenced by many factors, causing mangroves to grow differently depending on environmental conditions. Lugo and Snedaker in FAO (1994) identified and classified mangroves into six community types based on their appearance-related to geology and hydrological processes. Each type has some characteristics influenced by environmental variables such as soil type, soil salinity, and flushing rate. Each mangrove community has a characteristic range of primary production, litter decomposition, and carbon conversion with different nutrients and community components. The mangrove classification is Overwash mangrove forests, Fringe mangrove forests, Riverine mangrove forests, Basin mangrove forests, Hammock forests, and Scrub or dwarf forests. Mangrove zoning can be seen in Figure 1.

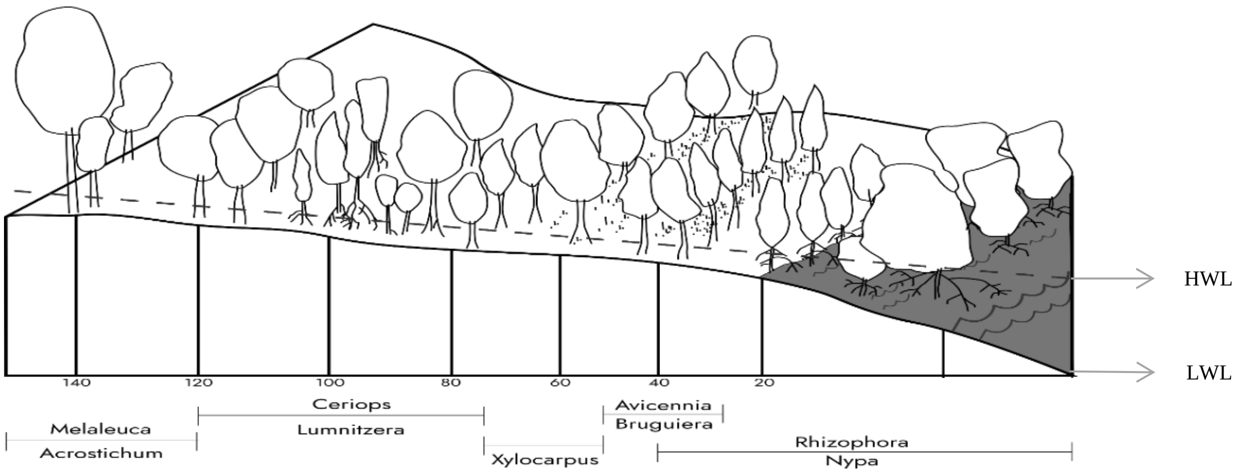

Figure 1. Distribution and zonation of mangrove vegetation (FAO, 1994)

Mangroves in West Kalimantan can be found on the west coast of the island of Borneo. The distribution of mangroves includes the districts of Sambas, Singkawang, Bengkayang, Mempawah, Kubu Raya, North Kayong and Ketapang. The area of mangroves in West Kalimantan is 286,485.28 Ha in the span of 2011 – 2020. The largest mangrove area is in Kubu

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Raya Regency, 256,586.80 Ha. Meanwhile, the area with the lowest mangrove area is in Bengkayang Regency, which is 13.04 Ha (Table 1).

Table 1. Mangrove area in West Kalimantan

No.	County/City	Mangrove Area (Ha)	Source
1	Sambas	11,170.00	Ari et. al. (2016)
2	Bengkayang	13.04	Bunting et. al. (2018)
3	Singkawang	101.51	Jumaedi (2016)
4	Mempawah	739.31	Khairuddin *et al*. (2016)
5	Kubu Raya	256,586.80	CFCRRD-FORDA and CIFOR (2013)
6	Kayong Utara	17,780.00	IFACS (2014)
7	Ketapang	94.62	BPS (2020)
	Total	**286,485.28**	

Mangrove growth in West Kalimantan is supported by environmental conditions that are influenced by tides, the substrate in the form of mud, high salinity, and waves (Khairunnisa *et al*., 2020). The coastal stretch of the western part of the island of Borneo causes various mangrove species to grow. Mangrove species in West Kalimantan are dominated by *Brugueira spp., Rhizophora spp., Sonneratia alba, Avicennia spp. Nypa fruticans, Excoecaria agallocha, Xylocarpus moluccensis* and *Acrostichum speciosum* (Table 2).

Table 2. Mangrove dominance in West Kalimantan

No.	County/city	Mangove species	Source
1	Sambas	*Brugueira cylindrica, Brugueira gymnorhiza, Rhizopora mucronata* dan *Sonneratia alba.*	Habdiansyah et. al. (2015)
2	Bengkayang	*Avicennia marina, Avicennia alba, Avicennia officinalis, Rhizopora mucronata, Rhizopora stylossa, Bruguiera cylindrica, Bruguiera gymnorhiza* dan *Nypa fruticans*	Nurrahman et. al. (2012)
3	Singkawang	*Avicennia alba, Sonneratia alba, Rhizophora mucronata* dan *Excoecaria agallocha.*	Jumaedi (2016)
4	Mempawah	*Bruguiera cylindrica* dan *Rhizophora apiculata*	Muharamsyah et. al. (2019)
5	Kubu Raya	*Rhizophora apiculata, Bruguiera cylindrica, Sonneratia alba* dan *Xylocarpus moluccensis*	Heriyanto and Subiandono (2016)
6	Kayong Utara	*Avicennia marina* dan *Rhizophora apiculata*	Khairunnisa et. al. (2020)

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No.	County/city	Mangove species	Source
7	Ketapang	*Rhizopora apiculata*, *Bruguiera gymnorrhiza* dan *Acrostichum speciosum*	Padli et. al. (2019)

Mangrove Ecosystem Damage

Mangrove damage is currently caused by anthropogenic activities, climate change, and weak integrity in mangrove management. Overall, mangrove cover decreased 5.4% over 36 years from 76,250 ha to 72,169 ha in 2017 in Belize, Central America (Cherrington *et al*., 2020). Romanach *et al*. (2018) revealed that about 50 – 80% of the causes of mangrove damage are caused by the growth and development of human populations in the coastal zone. Mangroves are used for urban development, aquaculture, land conservation, timber exploitation. Shrimp culture production is also responsible for reducing mangrove cover. Shrimp exports only generated US$ 30.7 million in 2004.

Meanwhile, environmental degradation costs are up to 6.1 billion US$ or around 15,000 US$.ha-1 (Ferreira and Lacerda, 2016). In Vietnam, Veettil and Quang (2019) informed that damage to mangroves due to herbicides during the Vietnam war and land-use change reached 38%. Uncontrolled aquaculture development has produced compounds that have worsened mangrove cover in Vietnam.

The diverse and changing natural conditions of the environment contribute to mangrove loss. According to Sippo *et al*. (2018), mangrove loss reached 70% due to natural disturbance of mangroves in nature, such as low forest frequency and high-intensity weather phenomena, including tropical cyclones and extreme climates. The increased frequency, intensity, and extent of cyclone damage and climate extremes, including low and high sea-level events and heat waves, can affect mangrove mortality and recovery, especially in mid-latitudes. Servino *et al*. (2018) claimed that climate change causes sustainable physiological stress such as hail and el Nino during 2014 – 2016. Further, satellite image measurement results reveal that mangrove loss has reached 500 ha after the 2016 hail. The economic loss from mangrove ecosystem services, including food provision, climate regulation, raw materials, and nurseries, is estimated to reach at least 792,624 US$ per year. The loss of economic value to climate change and fishing efforts is around 27.78 million US$ – 31.72 million US$ per year (Ngoc, 2019).

Knowledge and failure of management practices in mangrove ecosystem management as a restoration effort contribute to maintaining the existence of mangroves in the world. According to Vettil and Quang (2019), some factors make the efforts of forest restoration fail. These factors include inadequate knowledge of the sedimentary and hydrological environment, poor species selection, incorrect planting density, lack of local stakeholder involvement, and administrative conflicts at the government level. The results of Owuor *et al*. study (2019) showed that 12% of their respondents considered mangroves to be “degraded” while 40% considered mangroves to be ”somewhat degraded”. The low knowledge is then misused in policy-making, which causes conflict between the community and policymakers. In their research, Phong *et al*. (2017) found that ineffective management in the field makes the mangrove transplantation program in Brebes Regency ineffective and inefficient. Incorrect mangrove species selection practices, improper transplantation techniques, insufficient coastal protection, and inadequate continuous monitoring and evaluation contributed significantly to this limited success.

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The failure of the mangrove management program was exacerbated by conflicts of interest in field implementation and inaccurate data. For instance, Dharmawan *et al*. (2016) stated that the management has resulted in conflicts of interest ranging from excessive exploitation and environmental degradation. These conflicts are commonly caused by poor communication and ambiguity between the government and the community in developing the conservation. The increased desire to conserve mangroves is not accompanied by easy current management processes and a lack of communication between villages and the national government (Arumugam *et al*., 2020). Moreover, the community does not receive external support (e.g.wages or replacement of plantation costs).

Additionally, the restoration efforts spread over a more extended period (Ranjan, 2019). Therefore, the implementation of its management in the community was not effective. Worthington *et al*. (2020) stated that current data on mangroves global in nature have not explicitly defined mangroves. The existing data only define vegetation more than 5 meters and does not include degraded mangroves less than 5 meters high. This inaccurate data then leads to an error in choosing correct policies taken by the policymakers.

Based on the literature study that has been carried out, it is known that mangroves in West Kalimantan have decreased in the area due to human activities, abrasion, and sedimentation. This is following the research of Akbar, et. al., (2017) The shrinkage of the mangrove area of West Kalimantan is caused by the reclamation of mangroves into coconut plantations and abrasion which exacerbates the shrinkage of the area.

Impact of Mangrove Damage

Today, the growth of the human population and their activities increase the concentration of emissions in the atmosphere. According to Zhong and Haigh (2013), solar radiation occurs when it enters the earth and is reflected into space by clouds. Some other radiation will reach the ground, heat up, and emit hot rays. When the emission in the atmosphere is high, solar radiation reflected from the earth's surface cannot pass through the atmosphere. Most of the radiation will be absorbed by the atmosphere's gas and clouds, leading to increased heat radiation. When the earth starts to heat up, greenhouse gases are produced. One of the emissions that causes greenhouse gases is CO_2.

Excessive CO_2 in the atmosphere can increase the average surface temperature of the earth (global warming) and global climate change. The temperature increase can rise between 1.1^{o}C – 6.4^{o}C (Samimi dan Zarinabadi, 2011). It will have a global impact on the life of the entire earth's surface and the environmental conditions of mangroves. Based on Walden *et al*. (2019), an increase in seawater temperature of 1.2°C causes homogenization and flattening of the mangrove root epibiont community.

Mismanagement of mangroves will also increase salinity by three times or 300% (Dharmawan *et al*., 2016). The looming threat of eutrophication adds reduced nutrient flux to the sustainability equation, requiring adequate sewage treatment and wetland restoration (McDougall, 2017). Hence, it will affect the biomass of an ecosystem. A decrease in micro-population and aboveground biomass can decrease infauna species and biomass, affect the nutrient cycle, damage the nursery function, and reduce mangrove ecosystem services (Nordhaus *et al*., 2019)

Valuation of Mangrove Carbon Stock Ecosystem

The economic value of carbon storage can be estimated by calculating the amount of biomass. Biomass is derived from living plants, including tree trunks, twigs, leaves, and other residues

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(Peng *et al*., 2016). Nogia *et al*. (2016) revealed that a large amount of biomass is obtained from photosynthesis. Alexander Pérez *et al*. (2018) added that the amount of biomass in the mangrove ecosystem is influenced by activities in the upstream ecosystem, such as urban development and deforestation.

Based on Sutaryo (2009), the biomass estimation method generally can be grouped into sampling with harvesting in situ (destructive sampling), sampling without harvesting with forest data collection in situ (non-destructive sampling), modeling, and remote sensing. According to Dung *et al*. (2016), mangrove carbon storage is based on the mangrove growth zone, namely 102 ± 24.7, 298.1 ± 14.1, and 243.6 ± 40.4 mgC.ha-1 for peripheral, transitional, and interior mangrove forests, respectively. Dinilhuda *et al*. (2020) reported that the mangrove of Karimunting Bay, with a density of 177,480 individuals, have carbon storage by 99,231 mgC.ha-1 in 2019.

Based on the results of a literature study, mangrove carbon storage in West Kalimantan in the 2011-2021 range is around 682.10 tonsC.ha^{-1} (Table 3). The value of carbon storage in each district is different in West Kalimantan, which is influenced by the extent of the mangrove landscape, administrative area and the type of substrate that supports mangrove growth. This carbon storage value can be used to estimate the economic valuation of mangrove carbon stores in West Kalimantan.

Table 3. Mangrove carbon sequestration in West Kalimantan

No.	County/city	Carbon sequestration (tonC.ha^{-1})	Source
1	Sambas	53.26	Mulyadi *et al*. (2017)
2	Singkawang	No data	No data
3	Bengkayang	0.00010938345 (99,231 mgC.ha-1)	Dinilhuda *et al*. (2020)
4	Mempawah	3.37	Lestari *et al*. (2020)
5	Kubu Raya	438.79	Heriyanto and Subiandono (2016)
6	Kayong Utara	No data	No data
7	Ketapang	186.68	Kusmawati *et al*. (2021)
	Total	**682.10**	

The ability of Indonesia's forests has been recognized worldwide as the world's largest carbon sink. West Kalimantan is a province with a coastal area that makes West Kalimantan a province that contributes to maintaining blue carbon in the world. The economic valuation price for mangrove carbon storage services in Indonesia is regulated in the Minister of Environment Regulation no. 15 of 2012 concerning Guidelines for the Economic Valuation of Forest Ecosystems of 5 US$/Ha. So it is known that the economic value of mangrove carbon storage in West Kalimantan in the 2011-2021 range is US$ 3,410.5.

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 ISSN: 2354-5844(Print)
ISSN: 2477-5223 (Online)

Tabel 4. Economic valuation of mangrove carbon sequestration services

Carbon sequestration (tonC.ha^{-1})	Carbon selling price (US$/Ha)	Economic valuation of mangrove carbon sequestration services (US$)
682.10	5	3,410.50

Mangrove Ecosystem Protection Efforts

Carbon storage affects global warming and carbon trading. A more significant loss of mangroves will increase the impact on world change and the mangrove carbon trade. Thus, mangrove conservation attempts to maintain mangroves to mitigate global warming and mangrove trade through community-based restoration, forest-planting restoration, integrated rehabilitation of coastal ecosystems, and an economic approach.

The mangrove land clearing can be prevented by increasing the involvement of local communities in the mangrove rehabilitation process. The participation of local communities can make mangrove forest management effective and in an integrated manner (Ferreira and Lacerda, 2016). In addition, the community approach also aims to consider the needs of local communities living in mangrove areas (Romañach *et al*., 2018). Andrieu *et al*. (2020) stated that Senegalese Mangroves, affected by environmental fluctuations, can regenerate after years of disappearance. This success is assisted by local communities living around mangroves. The community is considered the primary knowledge holder about mangroves because of the sustainable interaction and utilization through cultural traditions (Pearson *et al*., 2019). Apart from that, Aheto *et al*. (2016) disclosed that local customary rules are enforced, and institutional arrangements are put in place to mediate exploitation and mangrove regeneration rates.

Mangrove replanting is an effort to restore mangroves. The replanting will gradually improve stand conditions, introducing native species saplings to facilitate their formation (Peng *et al*., 2016). Mangrove planting has been shown to increase functional diversity and restore the ecological function of macrobenthic communities, depending on the season (Leung and Cheung, 2017). According to Datta and Deb (2017), vegetation growth zones, soil parameters, and environmental conditions (Dinilhuda *et al*., 2018) are factors for the success of mangrove management. Nusantara *et al*. (2015) stated that local communities play an essential role as nursery supervisors in planting mangroves. The right environmental conditions and good management supervision will restore a good carbon cycle.

Activities in the upstream ecosystem cause part of the damage to mangroves. Perez *et al*. (2018) revealed that the mangroves position downstream causes the mangroves to accumulate sediment that drops due to deforestation and urban development activities. In addition, tides also affect the impact accumulated by mangroves (Kusumaningtyas *et al*., 2019). Restoration of mangrove environmental conditions should be carried out by a multi habitat approach around the mangrove ecosystem. Milbrandt *et al*. (2015) stated that a multi-habitat approach (mangroves, coral reefs, and seagrasses) helps increase planted seeds colonies, strengthen mangrove structures, and increase coral reefs habitat. Multi habitat restoration impacts increase the number of fish, invertebrates and stabilize the coastline (Milbrandt *et al*., 2015). Saudamini (2017)

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revealed that the contribution of nurseries and mangrove habitats planted to the fisheries sector in Gujarat is worth US$ 0.57 billion annually.

Other conservation efforts can be planned to reduce the rate of exploitation and maintain mangrove carbon storage capacity with an economic approach. According to Dinilhuda *et al*. (2018), climate change and global warming are increasing. Therefore, a REDD (Reducing Emission from Deforestation and Degradation) mechanism deals with international carbon trading.

In addition, policies to prevent exploitation in mangrove ecosystems cause local communities to lose income. Aheto *et al*. (2016) stated that livelihoods and economic benefits are the main factors motivating the participation of local stakeholders in mangrove restoration and management. The mangrove restoration is expected to reduce the failure of community-based restoration programs (Ranjan, 2019). Karlina *et al*. (2016) revealed that the management of protected mangrove forests in Batu Ampar Regency combines economic and ecological benefits in a zoning system divided into a biodiversity conservation or protection zone and a limited use zone. Akbar *et al*. (2017) added that a wave breaker could rehabilitate the mangrove ecosystem. The level of coastal protection with the addition of a wave removal structure prevents 70% of coastal erosion and increases the distribution density of R*hizophora sp.* and *Avicennia marina* colonization.

CONCLUSIONS

Mangrove area in West Kalimantan in the period 2011 - 2021 has an area of about 256,586.80 Ha which is dominated by species *Brugueira spp., Rhizophora spp., Sonneratia alba, Avicennia spp. Nypa fruticans, Excoecaria agallocha, Xylocarpus moluccensis* and *Acrostichum speciosum*. Human activities, abrasion and sedimentation have caused a decrease in the area of mangrove ecosystems in West Kalimantan. An increase in temperature has a global impact on life on the earth's surface and the environmental conditions of mangroves. The decrease in micropopulation and aboveground biomass causes a decrease in infauna species and biomass, affects nutrient cycles, destroys nurseries, and reduces mangrove ecosystem services. The results show that mangrove carbon storage in the period 2011 - 2021 is 628.10 tonsC.ha^{-1} which has an economic valuation of 3,410.50 US$. Efforts to mitigate global warming and trade in mangroves can be carried out through community-based restoration, restoration of forest plantings, integrated coastal ecosystem rehabilitation, and economic approaches.

This study does not include data on mangroves in several districts in West Kalimantan. So that periodic monitoring is needed to determine the dynamics of the mangrove ecosystem in West Kalimantan in the future.

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