Leaf Damage in Segara Anakan Mangrove Forest, Cilacap

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Abstract

Segara Anakan Mangrove Forest in Cilacap is one of the most extensive mangrove forests on the southern coast of Java Island. This study aims to determine the level of herbivory and environmental conditions. The sampling technique used was purposive random sampling, which considered the different characteristics of the vegetation. Sonneratia caseolaris dominated Station 1, while Station 2 was more diverse, including Avicennia marina, Avicennia alba, Rhizophora mucronata, Sonneratia caseolaris, and Aegiceras corniculatum. Each station is spread over three points, each with five sampling plots, representing the distribution and zonal homogeneity of carrying capacity. The research was conducted in May, August, and November 2023, based on the different temporal seasons in Indonesia. The results showed biotic factors from herbivory activity and abiotic factors such as the hydrological cycle caused mangrove leaf damage. The class of leaf damage caused by herbivory at all observation stations was mainly in class I (<2.5%). The most leaf damage was found in old leaves, which is related to the optimal photosynthesis process producing carbohydrates as a food source for herbivores. Additionally, tannin content in the leaves plays a role in protection from excessive UV radiation during the dry season. This condition indicates that Segara Anakan mangrove forest is still in good condition. PCA analysis results show that mangrove leaf damage is closely related to the age of the leaves.

Keywords: *herbivory, mangrove forest, leaf damage*

INTRODUCTION

Mangrove ecosystems are unique and distinctive in the intertidal zone between land and sea. Environmental variations such as temperature, salinity, and tides allow only specific biota to thrive in this ecosystem. In 2021, Indonesia's mangrove ecosystem covered an area of 4,120,263 hectares, consisting of 3,364,080 hectares of existing mangroves and 756,183 hectares of potential mangroves. Existing mangroves are dominated by dense mangroves (93%), moderate mangroves (5%), and sparse mangroves (2%) (Direktorat Konservasi Tanah dan Air, 2021). Segara Anakan Mangrove Forest in Cilacap is one of the mangroves located on the southern coast of Central Java. This area is a natural mangrove ecosystem dominated by the families Avicenniaceae, Rhizophoraceae, Sonneratiaceae, and Acanthaceae (Kresnasari & Gitarama, 2021).

According to Koswara *et al*., (2017), the mangrove density 2009 was 2,288±1,420 ind/m² with a diversity index of 1.65 (moderate diversity). However, in 2015, there was a decline to 1,254±1,773 ind/m² for mangrove density and a diversity index of 0.68 (low diversity). The degradation of mangrove forests is suspected to be due to land-use changes and environmental pressures. This condition affects the vital role of mangroves, such as reducing carbon dioxide through photosynthesis (Zhu & Yan, 2022). The primary organ of plants involved in this process is the leaf. However, this part is vulnerable to damage and abnormal shapes caused by biotic factors from herbivorous biota and abiotic factors such as temperature, water availability, nutrient content, and environmental conditions (Menezes & Peixoto, 2009; Maldonado-López *et al*., 2019).

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Herbivores use mangrove leaves as a food source, habitat, and reproduction site. The presence of herbivores can have positive impacts, such as playing a crucial role in nutrient cycling and energy transfer at trophic levels. Nonetheless, herbivores can also have negative impacts, such as causing mangrove leaf damage, leading to incomplete leaf tissues, which affects photosynthesis, growth, vegetation development, canopy cover changes, and community structure (Trisnawati *et al*., 2019), as well as changes in mangrove ecosystem fertility originating from litter productivity (Da Silva *et al*., 2015; Pereira *et al*., 2023). Several factors influencing the level of herbivory include vegetation type, leaf age (Fadilla *et al*., 2019), leaf nutrient content, and tree height (Amalia *et al*., 2019; Laksono *et al*., 2023).

Indonesia experiences changes approximately every six months. According to Purwanto *et al*., (2021), northwesterly winds blow from the Eurasian continent to the Australian continent during December-February, bringing a lot of moisture and humidity throughout Indonesia. This season is known as the rainy season or northwest monsoon. Conversely, southeast winds blow from Australia to the Eurasian continent during June-August, bringing dry and warm air to Indonesia, known as the dry season or southeast monsoon. Environmental conditions and seasonal changes are suspected to influence leaf damage strongly. Leaf color changes and drying are some of the mangrove vegetation's responses to natural changes.

Low rainfall and high evaporation cause high salinity levels and transpiration. Plants adapt to these conditions by shedding their leaves (Rani *et al*., 2016; Lin *et al*., 2023). Increased temperature and high transpiration lead to chlorophyll disintegration. Additionally, the physiological response of plants to water deficiency is a decrease in photosynthesis rate, hindering chlorophyll synthesis (Ai & Banyo, 2011). High leaf damage due to environmental stress can reduce the nutritional quality and protective chemical compounds, making them vulnerable to herbivore attacks (Balakrishnan *et al*., 2016).

Research on leaf damage due to herbivory has been conducted in the mangrove forest of Kaliwlingi Village, Brebes District, showing that *Rhizophora mucronata* has a higher herbivory level compared to *Avicennia marina* (Widayanti *et al*., 2019). In the Kamujan Mangrove Tracking Area, Karimunjawa Islands, the herbivory level of *Rhizophora mucronata* is lower than that of *Ceriops tagal* (Laksono *et al*., 2023). In the Mamanguape River Barrier esoldry area, Brazil, it was reported that *Laguncularia racemosa* leaves have a higher damage frequency and herbivory level compared to *Avicennia germinans* (Bernini *et al*., 2021).

Research on herbivory in Segara Anakan area has been conducted by Septyaningsih *et al*., (2014), showing that the herbivory levels from highest to lowest are *Avicennia marina, Sonneratia caseolaris, Rhizophora apiculata, Avicennia corniculatum, and Ceriops tagal*. However, these results have not been correlated with environmental parameter measurements. Therefore, this research aims to determine the level of herbivory in Segara Anakan mangrove forest, Cilacap, along with its environmental conditions. The novelty of this research lies in obtaining information on the level of mangrove leaf damage and nutrient availability as indicators of habitat disturbances due to herbivory and seasonal phenomena.

MATERIALS AND METHODS

The research data collection includes primary data in the form of mangrove leaves from dominant tree species and supporting data in the form of environmental parameters, including air temperature, water temperature, soil salinity, water salinity, water pH, soil pH, organic carbon, total soil nitrogen, soil phosphorus, and leaf chlorophyll in Segara Anakan mangrove forest, Cilacap. Sampling was done using purposive random sampling, considering differences in vegetation characteristics.

The research location was based on Kresnasari & Gitarama, (2021), study: Station 1 (St. 1) was dominated by *Sonneratia caseolaris*, with soil organic carbon content of 0.48-3.019 mg/l; soil phosphorus of 0.075-0.087 mg/l; and total soil nitrogen of 0.04-0.152 mg/l. Station 2 (St. 2) had more diverse vegetation, including *Avicennia marina, Avicennia alba, Rhizophora mucronata, Sonneratia caseolaris, and Aegiceras corniculatum*. Soil organic carbon content was 1.103-3.324 mg/l, soil phosphorus 0.045-0.067 mg/l, and total soil nitrogen 0.167-0.360 mg/l. Each research station was spread into three observation points, each with five sampling plots, representing the distribution and zonal homogeneity of carrying capacity (Figure 1).

The research period was from May to November 2023, with three sampling frequencies based on the temporal seasonal approach in Indonesia. The first sampling (T1) was in May (transition from the rainy to the dry season), the second sampling (T2) was in August (dry season), and the third sampling (T3) was in November (transition from the dry to the rainy season).

The leaf sampling technique involved determining the most dominant vegetation in a 10 x 10 meter plot. Then, the leaves on one tree branch were counted. The result was multiplied by the number of branches on the tree. Subsequently, 10% of the total number of leaves on the tree were randomly sampled. The collected samples were sorted using the following criteria: leaves with a regular shape and green color were grouped as intact, and leaves with an abnormal shape and non-green color were grouped as damaged.

The average comparison of the percentage of intact and damaged leaves was calculated. The sorted leaves were placed in black plastic to avoid sunlight exposure and stored in a cool box (Fadilla *et al*., 2019; Trisnawati *et al*., 2019). Leaf samples were processed using a smartphone application, BioLeaf (Figure 2) (Machado *et al*., 2016). A smartphone was used to determine the percentage level of herbivory, i.e., the area of herbivory compared to the total leaf area. The results were classified based on the percentage level of herbivory shown in Table 1.

PCA (Principal Component Analysis) was conducted to determine the factors most influencing leaf damage. According to Mishra *et al*., (2017), PCA is a statistical test that reduces a large set of variables to a smaller one and identifies which variables are related to others.

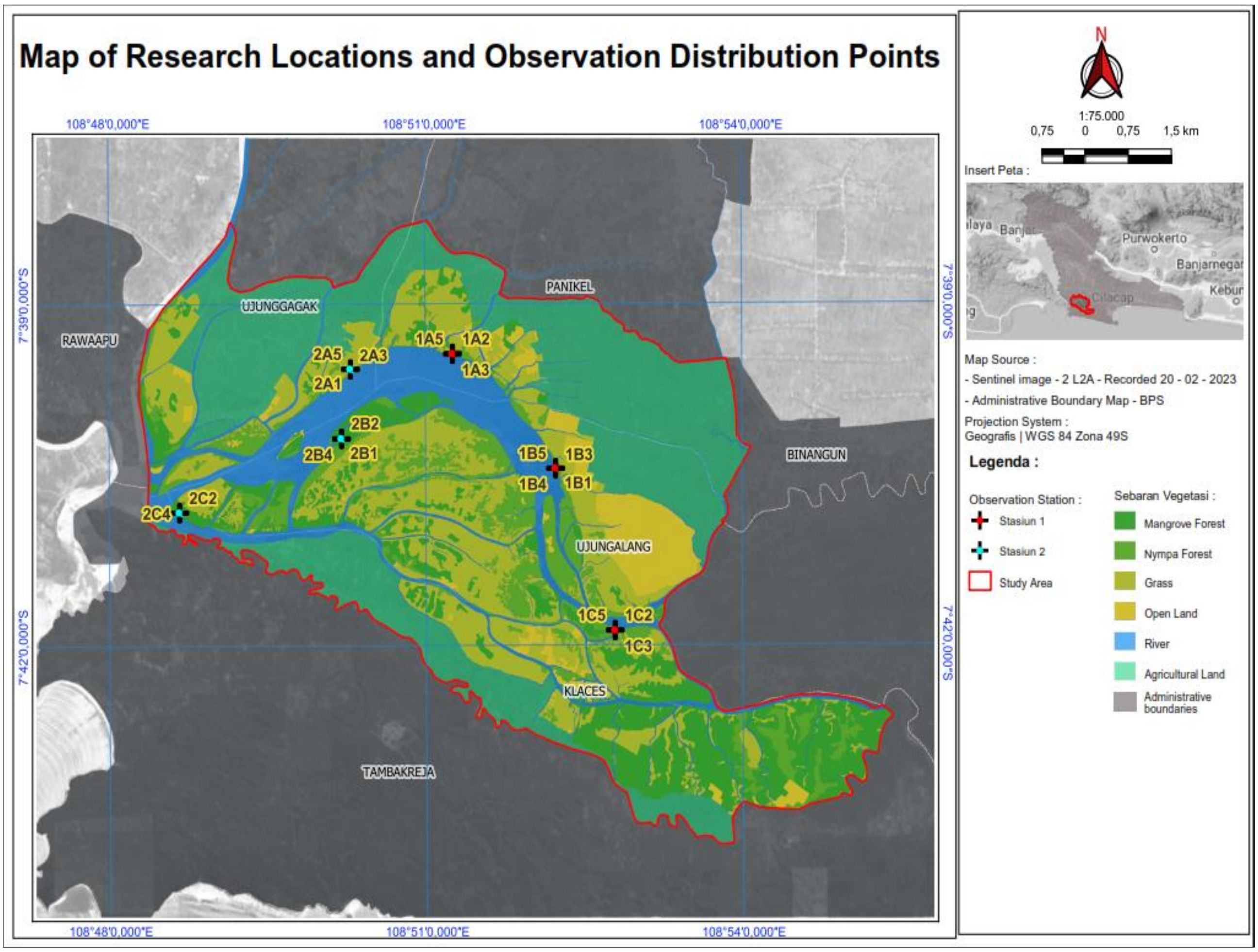

Figure 1. Research Location Map and Observation Points Distribution

Table 1. Damage Class and Herbivory Percentage

Damage Class	Herbivory Percentage
1	< 2,5%
2	2,5 %-5%
3	5,1%-10%
4	10,1 %-20%
5	20,1%-40%
6	40,1%-60%
7	60,1%-80%
8	>80%

Source: Cooke *et al*., (1984)

Figure 2. Leaf Sample Measurement in the Study

RESULTS AND DISCUSSION

The average comparison of the percentage of intact and damaged leaves is presented in Table 2. The table shows leaf damage ≥ 85%. The highest percentage of damage mainly occurred during the T2 (dry season) sampling. The causes of leaf damage include herbivory activities and the hydrological cycle. Herbivorous organisms utilize leaves as a habitat, food source, and living space. Several organisms found in the study area include Class Arachnida, Class Gastropoda, Class Crustacea, Bagworm (*Pagodiella* sp.), Green Caterpillar (*Spodoptera exigua*), Weaver Ants (*Oecophylla* sp.), Black Ants (*Dolichoderus thoracicus*), Black Cricket (*Gryllidae* sp.), Green Grasshopper (*Oxya chinensis*), Wood Grasshopper (*Valanga nigricornis*), Dragonfly (*Orthetrum sabina*), Whitefly (Hemiptera). Destructive animals such as Bagworms (*Pagodiella* sp.) use leaves for breeding, indicated by rolled leaf structures.

Whiteflies (Hemiptera) use leaves as a food source by sucking the sap, causing the leaves to dry and fall off. White powder-like substances on plant parts mark infestation by these pests (Pan *et al*., 2022). A similar condition occurs in the mangrove rehabilitation area of Gampong Baro, Aceh Jaya Regency, where pests like weaver ants, bagworms, aphids, sedge snails, small caterpillars, green grasshoppers, small snails, oysters, and spiders are found (Berutu *et al*., 2022). Herbivory and destructive animal activities damage leaf tissue, impacting photosynthesis and vegetation growth. Abulaiti *et al*., (2024), added that insect attacks begin with chloroplast destruction, followed by other organ damage, reducing nutrition and water content. During pest attacks, plants initiate defense strategies to minimize leaf tissue damage by varying biochemical leaf properties like lignin, tannin, and cellulose.

Water is crucial for plant development. Naturally, water is obtained from rainfall and temporarily stored in the soil. However, based on the hydrological cycle, rainfall amounts vary, affecting plant physiological processes. As shown in Table 2, the highest percentage of damage mainly occurred in the dry season (T2). Field measurements indicated air temperatures in May were 27.5-30.2°C, August 27-33.5°C, and November 26.5-30.5°C. Water temperature measurements in May, August, and November were 27-31.5°C, 26.5-33.1°C, and 26-31°C, respectively. According to BMKG Tunggul Wulung Cilacap, the rainfall in May was 209 mm/year with 12 rainy days, and daily sunshine averaged 7.9%. In August, rainfall was 6 mm/year with 2 rainy days, and daily sunshine averaged 8.01%. In November, rainfall was 318 mm/year with 15 rainy days, and daily sunshine averaged 6.44% (BPS Cilacap Regency, 2024). Decreased rainfall and high air temperatures increase transpiration rates. In such conditions, many stomata are close to reducing transpiration. An imbalance between absorption and excessive water evaporation causes suboptimal photosynthesis, resulting in leaf damage, shedding, wilting, and even plant death. Additionally, increased temperatures can affect herbivory activity. Herbivore metabolism increases with temperature, causing them to consume more food (Zhang *et al*., 2020). However, with suboptimal photosynthesis, herbivores seek leaves to meet their food needs.

During rainfall, water falling on leaf surfaces is not immediately absorbed. Some water evaporates into the atmosphere, and some fall to the ground or surrounding areas. However, some mangrove species can absorb water through leaves in small quantities, not as the primary water source. For example, *A. marina* can absorb water through stomata, trichomes, hydathodes, and diffusion through the cuticle. Mangrove vegetation relies heavily on roots for water needs. Mangrove roots have particular adaptations to absorb water from saline and muddy environments. Unique root structures like lenticels allow gas exchange, and water storage tissues help mangroves manage salinity (Schaepdryver *et al*., 2022). Water absorption in mangrove plants begins with soil water being absorbed through roots and transported upwards via cohesion tension driven by transpiration. Through stomatal cavities, water is transpired back into the atmosphere. Severe water shortages occur when there is an imbalance between water loss due to transpiration and soil water absorption, causing turgor loss throughout tissues and wilting. Plants have several acclimatization mechanisms with the environment and balance water loss with water absorption by regulating tissues' stomatal opening and hydraulic conductivity (Scharwies & Dinneny, 2019). Balanced water availability is crucial for maintaining optimal plant physiological functions. Water deficiency or excess, air humidity, uneven rainfall, and water quality all contribute to the risk of leaf damage.

Photosynthesis involves the absorption of carbon dioxide, nutrients, and water with the help of chlorophyll and sunlight, producing carbohydrates and oxygen. Sunlight consists of UV rays, visible light, and infrared rays. Plants use visible light with a 400-700 nm wavelength for photosynthesis. Chlorophyll can absorb red wavelengths (600-700 nm) and blue wavelengths (400-500 nm). UV rays have a wavelength of 280-400 nm, and infrared rays above 700 nm can adversely affect plants if exposed to high doses, inhibiting photosynthesis and causing tissue damage. According to Abdullah *et al*., (2018) and Pamungkas *et al*., (2019), high solar radiation can damage chlorophyll tissue, making it difficult to reproduce. Pigmentation in leaves decreases, turning yellow, orange, and red. Color changes are a response or initial symptom of physiological processes before the leaves fall.

The average percentage of young and old leaves is shown in Table 3. The results indicate more old leaves than young leaves at all observation stations. This condition indicates that Segara Anakan Cilacap mangrove forest supports photosynthesis, allowing the results to be used for growth and development. However, the leaf data of St 2.1 in August (T2) and November (T3) shows a low number. This is because the leaves of some *S. caseolaris* vegetation trees are shed during the dry season and the transition from dry to rainy season. This event occurs to reduce the rate of transpiration, which increases due to high temperatures and low rainfall. Tihurua *et al*., (2020) added that *S. alba* has no hypodermis (water storage tissue), unlike *R. apiculata*, which has the thickest hypodermis. Leaf damage due to seasonal influences also occurs in Teluk Sepetiba, Brazil, where *Laguncularia racemose, A. schaueriana and R. mangle* leaves suffer the most damage in August, September, and October (dry season), and minor damage and the emergence of small leaves in January and February (rainy season) (Menezes & Peixoto, 2009).

The study results show herbivory is higher on old leaves than on young ones. Similar findings were observed in the mangrove forests of Kaliwlingi Village, Brebes Regency (Widayanti *et* *al*., 2019), and Timbulsloko, Demak mangrove vegetation (Amalia *et al*., 2019), where old leaves had a higher percentage of herbivory compared to young leaves. Old leaves that are still dark green provide more food availability from photosynthesis (Balakrishnan *et al*., 2016; Maldonado-López *et al*., 2019). The ability of leaves to perform photosynthesis increases as they develop until they reach their maximum, then gradually decreases due to reduced chlorophyll content and chloroplast function. As leaves develop, chlorophyll content increases, indicated by the color change from light green to dark green. Dark green leaves contain 50% more chlorophyll than light green leaves (Solikhah *et al*., 2019). *A. marina* leaves with an area of 25 cm² have a chlorophyll content of 5.4 mg/L, whereas leaves with an area of 112 cm² have a chlorophyll content of 12.4 mg/L (Allifah *et al*., 2022). Fully developed (old) leaves undergo color degradation to yellow before falling. Changes in chlorophyll content will affect the ability to perform photosynthesis (Ajiningrum, 2018). Distribution of Damaged Leaves Based on Herbivory Levels at Each Station is Shown in Table 4. The table shows that the most leaf damage occurred in Class I.

Table 2. Average Comparison of Intact and Damaged Leaf Percentages

Station	Leaf Condition	Time		
		T1	T2	T3
1.1	Intact	9%	4%	7%
	Damaged	91%	96%	93%
1.2	Intact	10%	9%	4%
	Damaged	90%	91%	96%
1.3	Intact	8%	5%	7%
	Damaged	92%	95%	93%
2.1	Intact	9%	2%	0%
	Damaged	91%	98%	100%
2.2	Intact	8%	4%	7%
	Damaged	92%	96%	93%
2.3	Intact	15%	8%	4%
	Damaged	85%	92%	96%

Table 3. Percentage Comparison of Young and Old Leaves

Station	Leaf Condition	Time		
		T1	T2	T3
1.1	Young	31%	32%	26%
	Old	69%	68%	74%
1.2	Young	33%	34%	31%
	Old	67%	66%	69%
1.3	Young	34%	32%	27%
	Old	66%	68%	73%
2.1	Young	37%	9%	8%
	Old	63%	11%	12%
2.2	Young	45%	37%	26%
	Old	55%	63%	74%
2.3	Young	33%	32%	31%
	Old	67%	68%	69%

Table 4. Average Distribution of Leaf Damage Levels (Sheets)

Station	Damage Class	Time		
		T1	T2	T3
1.1	I	85	74,2	138,2
	II	25	32,2	47,6
	III	30	50	38,4
	IV	26	63,2	30,2
	V	14	61,6	16,2
	VI	2	6,6	0,8
	VII	1	0	0
	VIII	1	0,2	0
1.2	I	100,4	127,6	47,8
	II	17,8	54,2	28,4
	III	16,4	51,6	27,6
	IV	14,4	40,8	20,2
	V	5,6	17,6	8,4
	VI	0,2	0,8	1
	VII	0	0,2	0,2
	VIII	0,6	0	0
1.3	I	142,8	202	46,6
	II	38,8	65,8	20,2
	III	33,2	53,8	19,4
	IV	19,8	37	16,6
	V	13	16,2	11
	VI	1	1,8	1,6
	VII	0	0,2	0
	VIII	0,2	0	0
2.1	I	33	23,2	8
	II	18,6	13,2	7,4
	III	21,6	13,6	14,2
	IV	20,6	9,6	10,6
	V	13,6	4,8	9,4
	VI	0,6	0	1,4
	VII	0	0	0
	VIII	0	0,2	0
2.2	I	16,6	46	96,2
	II	11,4	22	36,2
	III	12,4	24,4	27,2
	IV	15,4	23	16
	V	12,6	12,6	6,4
	VI	0,6	2,2	1
	VII	0	0	0
	VIII	0	0	0,2
2.3	I	164,8	72,2	50,6
	II	39,2	20,4	31,2
	III	44,4	30,8	40,6
	IV	37,6	31,8	50,4
	V	20,4	17,6	25,6
	VI	0,6	2,2	0,6
	VII	0	0	0
	VIII	0,2	0	0

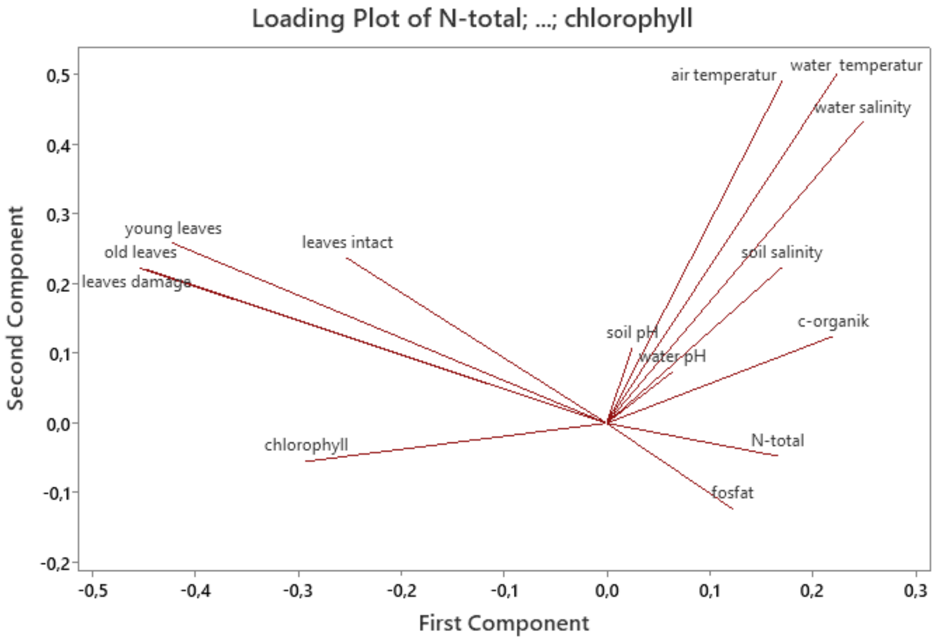

Figure 3. PCA Analysis Results

The study results show that the leaf damage class at all stations falls into Class I. The distribution illustrates that Segara Anakan mangrove forest is in good condition. The low level of leaf damage is due to the high tree density, which makes it easier for herbivores to move from one tree to another. This condition contrasts with the mangrove tracking area in Kemujan, Karimunjawa Islands, where *Ceriops tagal* and *R. mucronata* vegetation falls into Class II and III damage (Laksono *et al*., 2023). The low tree density in that area causes herbivores to have no choice but to stay and consume the leaves on the same tree. Additionally, herbivores have limited energy to disperse to other trees at a considerable distance (Septyaningsih *et al*., 2014; Fadilla *et al*., 2019). The chemical composition of leaves can influence herbivore activity. Tannins located in the epidermis can protect plants from herbivore attacks by reducing nitrogen content, thereby decreasing palatability and digestibility (Da Silva *et al*., 2015; Fadilla *et al*., 2019; Trisnawati *et al*., 2019; Lang *et al*., 2024). Tannins are phenolic compounds acting as UV protectants, preventing cell and DNA damage (Dehghanian *et al*., 2022). The concentration of phenolic compounds depends on age, species type, season, and sample location. These compounds decrease with leaf age (Widianto *et al*., 2019; Winarti *et al*., 2019). Therefore, in this study, most of the damaged leaves were mature. At station 2.2, *R. mucronata* vegetation is more resistant to herbivore attacks than Sonneratia and Avicennia leaves. This phenomenon is because Rhizophora leaves have a high tannin content. Ridlo *et al*., (2017) state that *R. mucronata* has higher phenolic compounds than *A. marina*. Balakrishnan *et al*., (2016) added that in coastal areas of India, the tannin content of *R. mucronata* and *A. officinalis* changes over time. *R. mucronata* leaves have the highest tannin content in June (twice as much as *A. officinalis*) and the lowest in November. The highest tannin content in *A. officinalis* occurs in April (slightly higher than in *R. mucronata*) and the lowest in July.

Based on PCA analysis (Figure 3), it can be seen that in quadrant I, water pH has the most significant influence. This is because water pH, being in a liquid form, has a more significant potential impact. In contrast, soil pH, being part of soil or sediment structure in solid form, is more influenced by groundwater. The following variable, soil salinity, is closer to c-organic than water salinity. Therefore, c-organic has a more significant influence than water salinity. However, c-organic is part of the carbon cycle, where several factors, including the presence of microbes, influence its degradation. Water salinity is further away than soil salinity because water's soluble nature and resuspension cause its salinity to adjust to water's properties. The farthest variables are water temperature and air temperature. Air temperature is related to humidity and interaction between air and soil in the environment, while water temperature is more stable. In quadrant II, leaf damage is closely related to old leaves. In quadrant III, only chlorophyll is present and is inversely related to air temperature. High air temperatures can cause chlorophyll levels to decrease. In quadrant IV, total nitrogen and soil phosphate have a close relationship. Total soil nitrogen and soil phosphate are inversely related to leaf damage. Leaf damage is suspected to be caused by low total soil nitrogen and soil phosphate content. Nutrients are a crucial factor in the growth and development of vegetation. Low nutrient content results in abnormal shapes and even death. The study found abnormal-shaped leaves, yellow with white spots. According to Maulida & Agustina, (2019) and Pan *et al*., (2022), some signs of nutrient deficiency in leaves include curled leaves, holes, and color changes to brown (necrosis) and yellow (chlorosis). Nitrogen deficiency causes leaves to become smaller and pale to yellowish-green. If this condition continues, the leaves will dry out and turn brownish-yellow until they evenoldlly die (Pamungkas *et al*., 2019).

The low level of herbivory can be an indicator of the fertility of the area. However, this contrasts with field measurements, where total soil nitrogen and soil phosphate values are low. The presence of bacteria is suspected to influence organic matter concentration. According to Hermansah *et al*., (2023), soil biota (bacteria and fungi) decompose plant and animal tissues. The number of soil biota has a significant correlation with nutrient availability. Therefore, the higher the number of bacteria, the higher the organic matter content, and vice versa (Mahrus *et al*., 2019).

CONCLUSION

The study results indicate that biotic factors from herbivory activity and abiotic factors from the hydrological cycle cause mangrove leaf damage. The leaf damage class caused by herbivory at all observation stations is mostly in Class I (<2.5%). The highest leaf damage occurs in old leaves. The tannin content in leaves plays a role in protection from excessive UV radiation during the dry season. This condition illustrates that Segara Anakan mangrove forest is still in good condition. PCA analysis results prove that mangrove leaf damage is closely related to the age of the leaves, with older leaves being more affected.

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