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Morphological Characteristics of Mangroves in Saltwater Lakes under Hypersaline Conditions in Gili Meno North Lombok, Indonesia

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ABSTRACT

Mangrove ecosystem is an environment formed from the interaction between land and sea waters, playing an important role as a natural protector of the coast from abrasion, tsunamis, and supporting biodiversity. This study aims to identify the types of mangroves in the Gili Meno Salt Lake Mangrove Ecotourism area, Gili Indah Village, Pemenang District, North Lombok Regency. This area has an extreme salinity level, reaching 54.00 ± 0.82 ppt, far above the average for Indonesian sea waters (33–43 ppt). The research method is qualitative through direct observation and leaf organ sampling. The identification results found five tree-type mangrove species with different root systems: respiratory roots (*Avicennia marina, Excoecaria agallocha*), supporting roots (*Rhizophora apiculata*), knee roots (*Bruguiera cylindrica*), and pencil roots (*Lumnitzera racemosa*). The five species have alternating single leaves, but show differences in leaf morphology, such as shape, size, color, and leaf position. These morphological variations are influenced by differences in habitat, environmental parameters, and nutrient sources, including substrate conditions, salinity, and temperature, which play an important role in the morphological structure of mangroves.

Keywords: hypersaline, identification, mangrove, morphology, saltwater lakes

INTRODUCTION

Indonesia is known as the country with the second longest coastline in the world, this geographical condition makes Indonesia rich in biodiversity, especially in coastal areas spread throughout the country [1]. Based on the study in the book Introduction Guide to Mangroves in Indonesia [2], Indonesia has the largest mangrove area in the world, which is about 2.5 million hectares. This area exceeds other countries such as Brazil (1.3 million ha), Nigeria (1.1 million ha), and Australia (0.97 million ha). In addition, Indonesia also has a high wealth of mangrove species, which is as many as 40 species out of a total of 52 true mangrove species [3].

Mangrove ecosystems are formed from the interaction between terrestrial ecosystems and marine waters, especially in coastal areas affected by the tides of sea water. This interaction causes the physical and chemical character of the mangrove environment to vary greatly [4]. The existence of this ecosystem has an important role in maintaining the balance of coastal ecosystems. Physically, mangroves serve as natural protectors from coastal abrasion, high waves, and tsunamis [5]. In addition, mangroves also contribute to climate change mitigation by effectively absorbing carbon dioxide from the atmosphere [6]. Chemically, mangroves are able to filter organic matter from the surrounding environment. Meanwhile, biologically, mangrove forests provide habitats, food sources, and shelters for various species, thus supporting biodiversity [7].

One of the coastal areas that has mangrove potential is North Lombok Regency. This area is known for three popular national tourist destinations, namely Gili Trawangan, Gili Meno, and Gili Air, or known as Gili Matra. One of the prominent ecotourism destinations is the Gili Meno Mangrove Ecotourism. The mangrove forests in this region have unique characteristics because they surround a pristine saltwater lake.

The saltwater lakes in Gili Meno have a very high salinity, reaching 54.00±0.82 ppt, which belongs to the extreme category. This figure is far above the salinity range of Indonesian marine waters in general, which is 33-43 ppt [8]. This high salinity is one of the factors that cause stress or abiotic stress for the organisms that live in it, including mangrove plants [9]. These extreme conditions demand high adaptability, especially for mangrove plants that have to adapt to the environment. This adaptation can be in the form of morphological adaptation, which is the adjustment of the shape and outer structure of the plant body, which is the easiest form of adaptation to observe [10]. This adaptability also plays an important role in determining the

composition of mangrove vegetation that grows in an area [11].

High salinity can decrease plant productivity, as NaCl interferes with the entry of K+ ions that are important for pH regulation and electron transport in chloroplasts. This is reinforced by Zhao et al., [12] that found that the species *Zygophyllum album* In dry and high salinity environments develop rounded leaves to minimize evaporation. Until now, the richness of mangrove diversity in the area is still maintained. Various efforts have been made to develop the potential of coastal resources, one of which is through the development of mangrove ecotourism areas. Given the many types of mangrove plants that exist, it is necessary to identify the types that grow in these extreme environments. Therefore, the purpose of this study is to identify mangrove species that grow in saltwater lakes with extreme salinity in the Gili Meno Mangrove Ecotourism area, Gili Indah Village, Menang District.

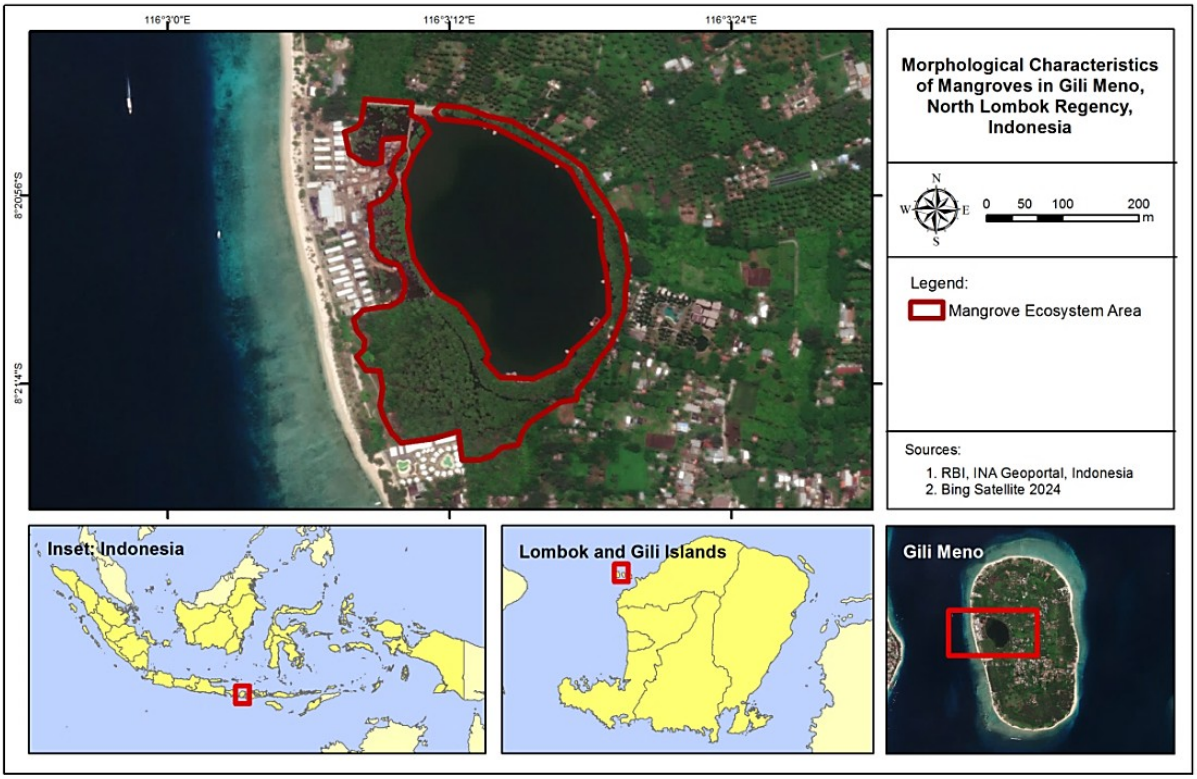


Figure 1. Research Location of mangrove ecotourism of saltwater Gili Meno lake

RESEARCH METHODS

The research flow should be presented in this section accompanied by figure captions. Image captions are placed as part of the figure caption, not part of the image. The methods used to complete the research are written in this section.

This research is a descriptive research with quantitative and qualitative approaches. This research was carried out in the April-May 2025. The location of this research was carried out in the Mangrove Ecotourism area around Gili Meno Salt Water Lake, Gili Indah Village, Menang District. North Lombok Regency, West Nusa Tenggara. At the location point - 8.349379,116.054174. Observation of the morphological structure of manrove leaves was carried out in the Integrated Laboratory of UIN Mataram.

The tools used in this study are digital cameras, plant shears, cutters, hendrafactometers, pH meters, TD and DO meters, identification books for the Introduction to Mangroves in Indonesia and stationery. Meanwhile, the materials used are millimeter block, plastic ziplock, 70% alcohol, label paper and samples of leaf species that will be specimens.

The research method used in the study is a qualitative descriptive method, by collecting data directly in the field by means of observation or direct field observation and collection of leaf organ samples to identify morphological characteristics such as, leaf shape, leaf tip, leaf base, leaf length, leaf width, leaf edge, leaf color, leaf bone and leaf position on the stem [13], [14]. and the environmental parameters taken are salinity, water pH, water temperature, biochemical oxygen deman and dissolved oxygen level.

Samples in mangrove forest areas were taken by random sampling that had the same chance and then continued to describe the morphological structure of the species. The sampling location can be seen in **Figure 1**.

RESULT AND DISCUSSION

1. Overview of Research Locations

Gili Meno is one of the three famous Gili islands in the Lombok region. Juara District includes three islands, namely Gili Trawangan, Gili Meno, and Gili Air, which are administratively included in Gili Indah Village. Among the three islands, Gili Air has the closest position to Lombok Island. These three islands are located on the west

coast of Lombok, with Juara District about 9 km from North Lombok Regency. Access to Gili Meno can be done by traveling by motorboat from Bangsal Port, which takes about 20 to 30 minutes [15]. Geographically, Gili Meno is located between Gili Trawangan and Gili Air. The uniqueness of Gili Meno lies in the existence of a saltwater lake covering an area of 6.6 hectares, which is naturally formed and still maintains its original condition at a high salinity levels, reaching 54.00±0.82 ppt, an unusual level of Indonesian marine waters in general, which is in the range of 33-43 ppt. This saltwater lake is also the only one on the island of Lombok, West Nusa Tenggara Province. In addition, Gili Meno Salt Water Lake is part of the Gili Mantra Mangrove Ecotourism Area which is visited by many local and foreign people, thanks to its well-maintained ecosystem and supporting facilities such as bridges that make it easier for visitors to explore the beauty of the mangrove.

Mangroves are classified into two main groups, namely true mangroves and mangroves sassociate (companion mangrove). True mangroves are further divided into two categories, namely major components and minor components. There are significant differences in both morphological and anatomical aspects between mangrove plants and land plants. Vegetative organs such as leaves and roots in mangroves undergo various modifications as an adaptation to specific and challenging habitat conditions [16].

The results of the environmental parameter examination in the Gili Meno Saltwater Lake Mangrove Ecotourism can be seen in **Table 1** below.

Table 1. Environmental parameters of mangrove ecotourism of saltwater Gili Meno lake.

Parameters	Unit	Value	Quality Standards*
Water Temperature	^{0}C	33,0	Natural
Water pH	-	7,66	>6
Salinity	ppt	36,6	Natural
Dissolved Oxygen (DO)	mg/l	3,00	>5
Biochemical Oxygen Deman (BOD)	mg/l	3.00	≤2

The results of the field analysis of the Gili Meno saltwater lake show that the overall visual color appears greenish from the surface of the water. This is a reflection of the color of the phytopanton that lives in these waters. said that sunlight enters the waters of the lake to a depth of 1.5 meters, which is the value of brightness. Brightness is the penetration of light in a water. Brightness also affects the process of photosynthesis in a water.

The surface water temperature is 33.0°C and this value is the normal temperature value of the lake waters. Basyuni *et al*., [17] explained that temperature variations are influenced by several factors, including the level of light intensity that the metabolic activity of organisms is at.

The degree of acidity (pH) is a negative logarithm of the concentration of hydrogen ions released in a liquid and is an indicator of the quality of the water. Variations in the pH value of waters greatly affect the biota in a water. In addition, the high pH value greatly determines the dominance of phytoplankton which affects the primary productivity level of a body of water where the presence of phytoplankton is supported by the availability of nutrients in marine waters. The pH value of the lake is 7.66 and this value is above the quality standard. The pH of lake water is relatively more stable and is usually in the range of 7.5 and 8.4, except near the coast. The ideal pH value for the waters is 7-8.5.

The results of the observation of lake water salinity of 36.6 are normal salinity for salt levels in saltwater lakes in general, this is far different from the salinity level, discussing the very high salinity of Gili Meno Saltwater Lake, which is 55 ppt and strengthened in Rahman (2022) which said that the salinity of Gili Meno Saltwater Lake reached 54.00±0.82 ppt. The condition of this decrease in salinity levels is estimated to be influenced by several factors such as the weather of the previous rainy season. High salinity is caused by the absence of washing lake water with other water, while during the rainy season rainwater that enters and mixes with lake water is diluted so that the salinity rate can change/fall.

Dissolved Oxygen (DO) is the amount of oxygen dissolved in the air. Dissolved oxygen is very important for the respiration of mangrove plant roots, the metabolic process or exchange of substances which then produces energy for growth and reproduction [18]. The dissolved oxygen value of 4.10 mg/l, the supply of dissolved oxygen has decreased compared to the results of DO observations in 2021 by Melinda, Tina *et al*., namely the dissolved oxygen value in the Gili Meno saltwater lake of 6.7 mg/l. The Biochemical Oxygen Demand value of 3.00 mg/L, this indicates that there is a load of organic material in the waters that requires oxygen in the decomposition process by microorganisms. According to the Decree of the Minister of Environment No. 51 of 1004, the BOD standard for marine conservation and tourism areas is set at a maximum of 2.00 mg/L. Meanwhile, a BOD value of ≤3 mg/L is still in

accordance with waters for the purpose of cultivating marine biota, but does not meet the standards for conservation areas. DO and BOD values can be determined by 2 factors, namely natural factors such as excessively high air temperatures, lack of aeration and dry seasons. The second factor is like humans, organic pollution from household waste and deforestation for unfriendly development such as filling lakes for tourism infrastructure development.

2. Identification of Mangrove Plant Types

The results of the identification of types of mangrove vegetation in the Gili Meno saltwater lake found that there were 4 families with 5 genera and 5 types of mangrove species found, including *Avicennia marina* L *Bruguiera cylindrica, Lumnitcera racemosa, Rhizophora apiculata* L., and *Excoecaria agallocha* (Table 2

Table 2. Types of mangroves in the Gili Meno saltwater lake mangrove ecotourism area

Familia	Genus	Kind
Acanthceae	*Avicennia*	*Avicennia marina*
Rhizophoraceae	*Bruguiera*	*Bruguiera cylindrica*
Combretaceae	*Lumnitzera*	*Lumnitcera racemosa*
Rhizophoraceae	*Rhizophora*	*Rhizophora apiculata*
Euphorbiaceae	*Excoecaria*	*Excoecaria agallocha*

These types in the "Mangrove Introduction Guidebook in Indonesia" are classified based on two ecological approaches, namely (1) classification based on habitat authenticity, the species *Avicennia marina* L *Bruguiera cylindrica, Lumnitcera racemosa, Rhizophora apiculata* L are true mangroves, namely a group of plants that are able to adapt to tidal conditions, high salinity and anaerobic substrates. Meanwhile, the species *Excoecaria agallocha* is an associated angrove that can also grow in land ecosystems that are influenced by tides. (2) classification based on dominance and role in the ecosystem, the species *Avicennia marina L, Bruguiera cylindrica,* and *Rhizophora apiculata* L are major mangroves, namely the dominant type that forms the main structure of the mangrove forest. Meanwhile, the species *Lumnitcera racemosa* and *Excoecaria agallocha* are minor mangroves, namely types that do not form structural dominance in the mangrove community.

Table 3. Morphological characteristics of *vegetative* organs, roots and stems of plants in mangrove ecotourism of Gili Meno saltwater lake

Species	Vegetative organs	
	Root *(Radix)*	**Trunk *(Cailis)***
Avicennia marina	Breath	Tree
Bruguiera cylindrica	Knee	Tree
Lumnitcera racemosa	Pneumatoforfor	Tree
Rhizophora apiculata	Supports	Tree
Excoecaria agallocha	Non-spesifik	Tree

Based on the observation results in **Table 3**, it can be concluded that the mangrove plant species in the Gili Meno saltwater lake mangrove ecotourism are all tree-like and have morphological characteristics that distinguish one type from another. These differences can be seen from the stature, roots. The results of the collection of tree-like mangrove species. The root system consists of 2 types, namely the respiratory root system in the *Avicennia marina L*. species, the supporting root system in *Rhizophora apiculata L.*, the knee roots in *Bruguiera cylindrica*, the pneumatophore roots in *Lumnitcera racemosa* and the ordinary roots (non-specific) in *Excoecaria agallocha.*

Explained by Tumangger & Fitriani [19] In his journal, there are several types of mangrove plant roots as follows:

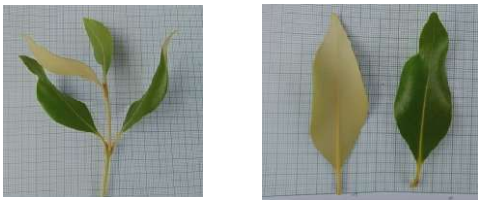
a. The root of the stem is a modification of the stem branch that is embedded in the substrate. It is shaped like a chicken claw, brown in color, and has more than two branches. Its function is to keep the tree upright when hit by wind and waves.
b. The roots of the board are roots that emerge from the bottom of the stem, grow towards the substrate and widen like a board. It functions to maintain the stability of the tree, supporting a large trunk and a wide crown.
c. Air roots, also known as hanging roots because they grow from the top of the stem that rises to the ground, function as roots absorb air gases and water vapor.
d. Knee root is a protrusion of mangrove roots that grows horizontally, then curves downward, so that the protrusion on the substrate resembles a knee, serving to help the breathing process.
e. The root of the breath is a root that rises above the ground and has many gaps as a place for air to enter, pencil-shaped/conical that protrudes upwards, similar to mangrove plants that

function for water absorption and photosynthesis.

Table 4. Morphological characteristics of plant leaves of mangrove ecotourism of Gili Meno saltwater lake

Morphological Characters (Leaf/Folium)	Mangrove Species				
	***Avicennia Marina* L**	***Bruguiera cylindrica***	***Lumnitcera racemosa***	***Rhizophora apiculata* L**	***Excoecaria agallocha***
General Leaf Shape	Oblangus	Oval	Obovate	Obovate	Obovate
Leaf tips	Accumulate	Acute	Emarginate	Obtuse	Acute
Base of the leaf	Acute	Acute	Acute	Acute	Rounded
Leaf color					
• Top surface	Light green	Dark green	Bluish Green	Dark green	Dark green
• Bottom surface	Yellowish green	Light green	Dark green	Yellowish green	Dark green
To be or not	Not	Not	Gummy	Gummy	Not
Leaf edges	Flat	Flat	Choppy	Flat	Jagged
Leaf bones	Penninervis	Penninervis	Curninervis	Penninervis	Penninervis
Leaf width	3.4 cm	3.7 cm	3.2 cm	5 cm	4.1 cm
Leaf length	9 cm	7.5 cm	8.5 cm	10.5 cm	9.1 cm
Arrangement of leaves	Single	Single	Single	Single	Single
Layout	Opposite	Opposite	Alternate	Opposite	Alternate

Table 5. Species identification of *A. marina* L.

Taxonomy			Sample Photo
Kingdom	:	Plantae	
Phylum	:	Magnoliophyta	
Class	:	Magnoliopsida	
Order	:	Lalminaes	
Family	:	Acanthaceae	
Genus	:	Avicennia	
Species	:	*A. marina* L.	

Avicennia marina is a type of mangrove that falls into the category of major mangroves with the local name of white fire [20]. Based on morphological observations that have been made on the leaves of *the species Avicennia marina* has a general shape of oblangus (elongated) leaves, with yellow leaf veins and a length:width of 9:3.4 cm, with acuminate leaf tips (tapered), acutus (pointed) base of leaves, has a light green and yellowish-green leaf surface with small white spots on the lower surface of the leaves with tightly flat and smooth edges (**Table 5**). The leaves *of Avicennia marina* have a smooth, non-gummy surface, penninervis leaf bones (pinnate leaf joints), with a single leaf arrangement and opposite leaf layout on the stem (the leaves are paired and facing on the same twig circle).

Morphology of *Avicennia marina* L leaves with single leaf shape, pinnate leaf veins, flat leaf edges and bald and elliptical leaf surfaces, blunt tips, about 7 cm long, and 3-4 cm wide. This journal also describes the habitat and adaptation of mangrove plants in the Pangarengan mangrove forest area of Cirebon Regency [21].

A. marina has several characteristics, among others having breathing roots embedded in the soil of *A. marina* has dark green leaves on the upper surface and yellowish-green. Meanwhile, the color is greenish-gray at the bottom. The leaves are simple with opposite locations and have the shape of elongated rounded leaves, inverted ovaries, or elongated rounded ellipticals.

Table 6. Species Identification of *B. cylindrica*

Taxonomy			Sample Photo
Kingdom	:	Plantae	
Phylum	:	Magnoliophyta	
Class	:	Magnoliopsida	
Order	:	Blueberries	
Family	:	Rhizophoraceae	
Genus	:	Bruguiera	
Species	:	*B. cylindrica*	

Bruguiera cylindrical is one of the relatives of *Rhizoporaceae,* The community around the mangrove forest often mentions plants *Bruguiera cylindrica* with the name of white tanjang [22]. Based on morphological observations that have been carried out on the leaves of the species *Bruguiera cylindrica* has a general shape of leaves *ovalis/elliptical,* with length:width 7.5: 3.7 cm, with

leaf tips *Acute* (pointed) base of the leaf *acutus* (pointed), having a color on the upper surface of the old leaf and light green on the lower surface of the leaf with tightly flat edges *Bruguiera cylindrica* (**Table 6**). Leaf bones *Penninervis* (pinnate leaf arrangement), with single leaf arrangement and leaf layout opposite (the leaves are paired and facing each other on the same branch circle).

B. cylindrica is characterized by black leaves on the upper surface of the leaves, has spots on the underside of the leaves with the edges of the leaves often rolled inwards. The leaves of *B. cylindrica* are elliptical with slightly pointed tips and have a simple leaf placement that grows in the opposite direction.

Table 7. Species identification of *L. racemosa*

Taxonomy			Sample Photo
Kingdom	:	Plantae	 
Phylum	:	Magnoliophyta	
Class	:	Magnoliopsida	
Order	:	Combretaceae	
Family	:	Combreta	
Genus	:	Lumnitzera	
Species	:	*L. racemosa*	

Lumnitzera racemosa famous by the local name of the fire-balah, *L. racemosa* has the general characteristics of a shrub. *L. racemosa* Likes a dense muddy substrate with waterways affected by fresh water. *L. racemosa* has many benefits, one of which is that it is durable because of its hard wood texture and is suitable for various building material needs, such as bridges, ships, furniture and so on [23]. Bark is also used as a coating material [24]. Based on morphological observations that have been carried out on the leaves of the species of *L. racemosa* has a general shape of leaves obovate (breech oval), with length: 8.5:3.2 cm wide, with leaf tips emerginate (split) base of the leaf acutus (pointed), having a dark green leaf upper surface and dark green on the lower surface, thickly fleshy and gummy, and wavy edges. *Lumnitcera racemose* has leaf bones curninervis (longitudinal leaf adventure), with single leaf arrangement and leaf layout sub-opposite (an alternate arrangement modifiet to resemble an opposite arrangement) (**Table 7**).

L. racemosa has a rounded leaf shape like a narrow egg with rounded tips, the leaf texture is slightly thick, fleshy and somewhat hard/stiff. The leaves *of L. Racemosa* grow in clumps at the tips of the branches with a simple cross-sectional position.

Table 8. Species identification of *R. apiculata* L.

Taxonomy			Sample Photo
Kingdom	:	Plantae	 
Phylum	:	Magnoliophyta	
Class	:	Manoliopsida	
Order	:	Myrtales	
Family	:	Rhizophoraceae	
Genus	:	Rhizophora	
Species	:	*R. apiculata* L.	

Rhizophora apiculata is known by the local name of oil mangrove, *R. apiculata* has a habitat to be able to grow on fine muddy soil and flooded at normal tides. Based on morphological observations that have been made on the leaves of *the species Rhizophora apiculata* has a general shape of obovate leaves (breech ovate), with a length:width of 10.5:5 cm, with the tip of the leaf obtuse (blunt), the candidate leaf that will develop is red, the base of the leaf *is* acutus (pointed), has a dark green leaf top surface and yellowish-green on the lower surface with flat edges. *Rhizophora apiculata has* penninervis *leaf bones* (pinnate leaf joints), a single leaf arrangement and opposite (the leaves are paired and facing each other on the same branch circle) (**Table 8**).

Table 9. Species Identification *of E. agallocha*

Taxonomy			Sample Photo
Kingdom	:	Plantae	 
Phylum	:	Magnoliophyta	
Class	:	Magnoliopsida	
Order	:	Euphorbials	
Family	:	Euphorbiaceae	
Genus	:	Excoecaria	
Species	:	*E. agallocha*	

Excoecaria agallocha is one of the minor mangrove groups, known by the local name blind. *E. agallocha* has a variety of benefits such as, the root can be used to treat toothache and swelling, wood used for carving materials can also be used as good quality papermaking materials. Based on morphological observations that have been made on the leaves of the species of *Excoecaria agallocha* has a general shape of *obovate* leaves (breech ovate), with a length of 9.1:4.1 cm, with *acute* leaf tips (pointed), *rounded* leaf bases, dark green and dark green on the lower surface of leaves with serrated edges and thin leaf strands. The leaves of *Excoecaria agallocha*, have a smooth, penninervis leaf bone (pinnate leaf joints), with a single leaf arrangement and opposite leaf layout on the stem (the leaves are paired and facing each other on the same branch circle) (**Table 9**).

Excoecaria agallocha has dark green leaves and will turn brick red before falling off, with finely serrated leaf margins. The leaves are simple and crossed with an elliptical shape and tapered tips. The differences in some of the morphological characteristics that are seen are estimated to be due to differences in habitat, environmental parameters, and nutrient sources, environmental factors, including substrate conditions, salinity, and temperature, play an important role in determining the morphological structure of mangroves [25].

The form of plant adaptation in the Zygophyllum album species that lives in dry areas with high salt content, the shape of the leaves is rounded to reduce the surface area so that excessive evaporation does not occur, while in the heritiera fomes species that has a dwarf stature in habitat conditions with high salt content, morphological differences can also arise as a physiological and anatomical response of plants to be able to survive in specific and changing environmental conditions.

Leaf color differences are also a physiological response to salinity stress in coastal habitats. Suarez [26] showed that increased salinity causes a decrease in the rate of photosynthesis and changes in leaf demography in *Avicennia germinans*. This means that salinity stress causes a decrease in chlorophyll content in the leaves which contributes to changes in leaf color. Suarez in his study again explained that high salinity can inhibit leaf expansion and increase leaf tissue thickness for water efficiency. This was also reinforced in tree physiology who found that in areas with high environmental pressure, mangrove leaves tend to be smaller with a lower surface for water conservation [27].

CONCLUSION

Based on the results of exploration and identification that have been carried out related to the types of mangroves in the Gili Meno Saltwater Lake Mangrove Ecotourism, North Lombok Regency, 5 species of mangroves with different morphological characteristics were obtained, namely:

1. *Avicennia marina* is a type of mangrove that is included in the category of major mangroves with the local name of white fire.
2. *B. cylindrica* is one of the relatives of *Rhizoporaceae,* the community around the mangrove forest often calls *the plant B. cylindrica* as tanjang putih.
3. *Lumnitzera racemosa* is known by its local name, Speises *L. racemosa* has the common characteristics of a shrub.
4. *R. apiculata* is known by the local name of oil mangrove.
5. *E. agallocha* is one of the minor mangrove groups, known by the local name blind-blind.

The existence of several differences in morphological characteristics that arise from the results of identification with reference is estimated to be due to differences in habitat, environmental parameters, and nutrient sources, environmental factors, including substrate conditions, salinity, and temperature, play an important role in determining the morphological structure of mangroves.

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