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# Physicochemical characteristic, nutrient, and fish production in different types of mangrove forest in North Sumatra and Aceh Provinces of Indonesia

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## Abstract

Mangrove forests are highly productive ecosystems that sustain marine life, including fish communities. This study aimed to analyse mangrove characteristics, physicochemical parameters, nutrient and primary production derived from mangrove litter and estimate the fish production. The study was conducted at five mangrove sites in North Sumatra and the Aceh Provinces, Indonesia. Two sites represented natural forest at North Sumatra and Aceh (Jaring Halus and Langsa). In comparison, two sites were mangroves converted into oil palm plantations (Pulau Sembilan and Pulau Kampai, North Sumatra). The fifth site was a mangrove forest converted into aquacultural ponds (Percut Sei Tuan, North Sumatra). The study displays the dissemination of mangrove species in five different mangrove sites showing diversity. *Avicennia* spp found in estuarine near a coastal area, *Rhizophora* spp spread across the sites, and *Sonneratia* spp were more likely to occur in the mouth of the upstream river. Litter production at the present study site was dominated by *Rhizophora* spp., followed by *Avicennia* spp. This finding was very closely related to the nutrients resulting from litter decomposition in the mangrove ecosystem. The primary production value of 870-1,747 g C $m^{-2}$ year had a significant role as the beginning of the estuary food chain. Our results show a close association between fish productivity and mangrove management, and conservation status. The highest fish production was found in the well-preserved forests (Jaring Halus and Langsa), followed by the sites converted to palm oil plantations (Pulau Sembilan and Pulau Kampai). At the same time, the least fishing productivity was identified at the fishing ponds (Percut Sei Tuan). The present study provides further evidence of the significant role of mangrove ecosystems for fisheries and calls for effective restoration programs to support local food security along the coast of Indonesia.

**Keywords:** Fish production; leaf litter; mangrove restoration; nutrient; primary production.

## 1. Introduction

The conservation of mangrove ecosystems has been closely associated with their productivity and human social wellbeing (Zaldívar-Jiménez *et al*., 2010; Barbier *et al*., 2011; Sheaves *et al*., 2017).

Mangrove forests produce nutrients that nourish marine waters, playing an important role in nutrient cycling (Thatoi *et al*., 2013) and sustaining highly commercially important species in local and wider market fisheries (i.e., fish, shrimp, crabs and bivalves), providing a relevant source of livelihoods, especially along the coast and river estuaries. However, mangroves remain one of the most threatened ecosystems worldwide by land-use change and the aquaculture farming industry (Valiela *et al*., 2001; Aburto-Oropeza *et al*., 2008; Barbier *et al*. 2011). This has urged restoration efforts worldwide (Ellison, 2000) and called for a more comprehensive understanding of environmental drivers of productivity, as well as for the identification of environmental indicators that can inform on the success of restoration activities and management policies (Ellison, 2000; Barbier *et al*., 2011; Vovides *et al*., 2011a).

A relevant indicator of restoration success could be provided by linking vegetation structure and litter production with fish biomass. Litter production is a major source of organic matter in estuarine sediments (Davis *et al*., 2003), and litter decomposition processes provide (1) detritus for microfauna and (2) essential nutrient elements for plant growth (Crawshaw *et al*., 2019). Hence litter production, along with stand and faunal biomass calculations, can provide valuable information on mangrove productivity, decomposition rates, and nutrient cycling (Hutchison *et al*., 2014a). For instance, the nutrient composition of the litter can indicate the efficiency of the nutrients used and which nutrients are limiting within the system, providing key elements of productivity (Ananda *et al*., 2007).

While vegetation provides refugee for fish and detritus supports the food chain, fishing productivity can be closely linked to vegetation structure and litter dynamics (Nagelkerken *et al*., 2008, Hutchison *et al*., 2014b). From the moment of litter production, detritivores and bacteria actively participate in leaf decay, recycling nutrients (i.e., Carbon, Nitrogen, and Phosphorus). The faster the litter decay occurs, the more likely it is that nutrients will be maintained within the ecosystem (Li & Ye, 2014) and create a positive productivity loop. A more abundant and diverse community of detritivores will contribute to faster litter decay, higher nutrient availability, and productivity (Middleton & McKee, 2001). However, if decay rates are slow, the probability of nutrient export through the eater column is higher (Nagelkerken *et al*., 2008). Primary productivity can ultimately determine fish stock within mangroves (Friedland *et al*., 2012; Hutchison *et al*., 2014a). Although litter decay and nutrient cycling have been well studied in the context of nutrient availability and ecosystem productivity (Middleton & McKee, 2001; Davis *et al*., 2003; Ananda *et al*., 2007; Nagelkerken *et al*., 2008; Contreras *et al*., 2017), and from a restoration context (Nagelkerken *et al*., 2008; Vovides *et al*., 2011a; Marquez *et al*., 2017), and that mangrove vegetation has been positively associated with fishing productivity (Aburto-Oropeza *et al*., 2008, Fitri *et al*., 2018), relevant information quantifying fish biomass with litter production and associated nutrient release rates remains limited. Furthermore, studies comparing management conditions (or status of restoration), notably from Indonesian mangroves, are currently unavailable, despite the important role of mangroves to support sustainable fisheries and aquatic organisms. This study aimed to assess the changes in fish productivity in response to mangrove forest structure and litter decay under different management scenarios:

1. Well conserved mangroves without significant disturbance.
2. Mangrove restoration from fishing ponds, and
3. Mangroves restored from the previous conversion to palm oil plantations. We estimated the primary productivity of phytoplankton from nutrients released by mangrove litter and related it to fish production within these management conditions.

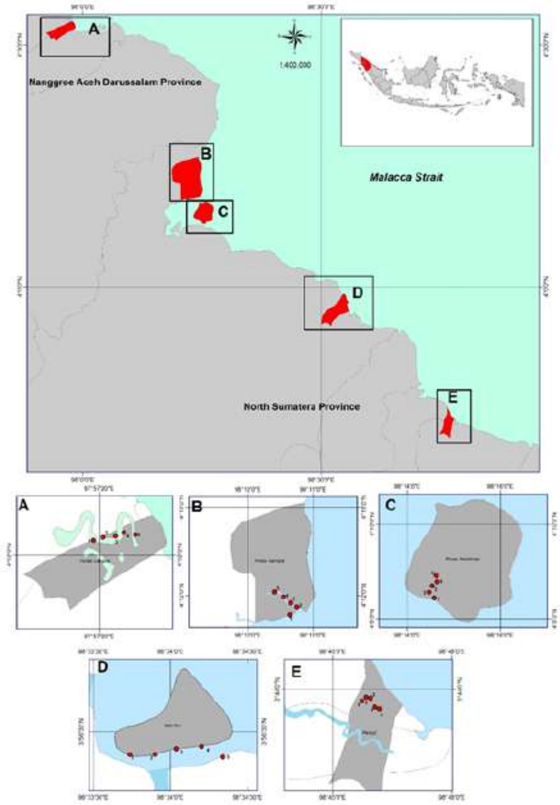

**Fig. 1.** Study area at five locations spread in North Sumatra and Aceh Province, A: Langsa, B: Pulau Kampai, C: Pulau Sembilan, D: Jaring Halus, dan E: Percut Sei Tuan.

## 2. Materials and Methods

### 2.1 Study area

This study was conducted within five mangrove forests of North Sumatra and Aceh Provinces, Indonesia (Table 1 and Figure 1). The sites were selected with their management condition; natural mangroves (Langsa and Jaring Halus), mangroves converted into the aquacultural ponds (Percut Sei Tuan), and mangroves shifted into oil palm plantation (Pulau Kampai and Pulau Sembilan).

### 2.2 Forest structure

Mangrove forest structure was assessed by establishing five sampling stations to monitor mangroves adjacent to the sea (stations 1 and 2, Table 1) and upstream mangroves (stations 3-5, Table 1). Three 10 x 10 m quadrats were delimited within each station, and the following parameters accounted for: tree species, number of trees, stem diameter, height (Fitri *et al*., 2018). The collected data were used to estimate: Stand density (tree ha$^{-1}$) for stands and each species, importance value index (IVI), and the Shannon-Wiener diversity index (H′) was calculated as previously reported (Fitri *et al*., 2018).

### 2.3 Measurement of physical and chemical parameters

At each sampling plot, three samples of sediment were collected at random points to assess substrate type. Three samples were collected from surface and sub-surface water to measure temperature, salinity, dissolved oxygen (DO), pH, current velocity, and humidity as previously described (Fitri *et al*., 2018; Al-Enezi *et al*., 2019). DO was measured using a DO meter (LutronDO-5510), pH was measured using a pH meter (EcoTestr pH2), the humidity was measured using a humidity meter (HTC-2), salinity was measured using a hand-refractometer (Atogo Master S28 M), and current velocity was measured manually using a stopwatch.

**Table 1.** Description of sample locations in North Sumatra and Aceh provinces

| Location | East longitudes (º) | North latitudes (º) |
|---|---|---|
| Langsa 1 | 4° 32' 47.51" | 97° 58' 29.56" |
| Langsa 2 | 4° 32' 46.79" | 97° 58' 8.38" |
| Langsa 3 | 4° 32' 46.48" | 97° 57° 44. 97" |
| Langsa 4 | 4° 32' 45.04" | 97° 57' 20.37 |
| Langsa 5 | 4° 32' 44.67" | 97° 57' 9.44" |
| Pulau Kampai 1 | 4° 8' 35.55" | 98° 14' 28.56" |
| Pulau Kampai 2 | 4° 8' 37.20" | 98° 14' 22.83" |
| Pulau Kampai 3 | 4° 8' 41.64" | 98° 14' 25.08" |
| Pulau Kampai 4 | 4° 8' 45.80" | 98° 14' 28.69" |
| Pulau Kampai 5 | 4° 8' 51.40" | 98° 14' 27.15" |
| Pulau Sembilan 1 | 4° 11' 34.09" | 98° 14' 54.09" |
| Pulau Sembilan 2 | 4° 11' 48.32" | 98° 15' 0.08" |
| Pulau Sembilan 3 | 4° 11' 50.70" | 98° 14' 51.06" |
| Pulau Sembilan 4 | 4° 11' 57.70" | 98° 14' 38.08" |
| Pulau Sembilan 5 | 4° 12.5' 44" | 98° 14' 28.18 |
| Jaring Halus 1 | 3° 56' 22.67" | 98° 33' 43.89" |
| Jaring Halus 2 | 3° 56' 22.62" | 98° 33' 51.92" |
| Jaring Halus 3 | 3° 56' 21.98" | 98° 34' 0.58" |
| Jaring Halus 4 | 3° 56' 22.12" | 98° 34' 9.97" |
| Jaring Halus 5 | 3° 56' 20.36" | 98° 34' 15.06" |
| Percut Sei Tuan 1 | 3° 45' 22.59" | 98° 44' 5.18" |
| Percut Sei Tuan 2 | 3° 45' 35.32 | 98° 44' 3.06" |
| Percut Sei Tuan 3 | 3° 45' 44.51" | 98° 43' 48.65" |
| Percut Sei Tuan 4 | 3° 45' 38.05" | 98° 43' 39.96" |
| Percut Sei Tuan 5 | 3° 45' 29.36" | 98° 43' 37.45 |

Location numbering is also described as a station

### 2.4 Mangrove litter production

Production of mangrove litter was estimated by placing five 1 × 1 $m^2$ litter traps made of fishing nets mounted on squared frames and placed under tree canopies (Liu *et al*., 2017; Fitri *et al*., 2018) at an altitude of 1-1.5 m above ground level in each plot. Trapped litter was collected every 14 days for a total period of two months. The collected samples of litter were then separated by component (leaves, twigs, and fruits), weighted before (fresh weight) oven drying at 105 °C until a constant weight measurement was achieved, and dry weight was recorded.

### 2..5. Relation between forest structure and physicochemical parameters

The relationship between mangrove characteristics and environmental parameters was analyzed using agglomerative hierarchical clustering (AHC) to be grouped in classes with similar or adjacent characteristics (Dasgupta & Long 2005; Fitri *et al*., 2018). Thus, analysis helps classify research stations by similarity of attributes and aided in recognizing mangrove classes as a function of their litter.

### 2.6 Fish productivity in response to primary productivity

Fish productivity was estimated by computing potential nutrient release into the water, which would then be available to phytoplankton for photosynthesis as primary production (Fitri *et al*., 2018). The total potential nutrient release was calculated as:

$\Sigma$ Nutrient (g $m^{-2}$) = $\Sigma$ (LLx× RNx) + (LLx × RPx) (Eq. 1)

where LL is the litter production, RNx denotes N release (RN) potential for species x, and RPx is the potential release of phosphorus (RP) for species x.

A C: N ratio (carbon: nitrogen), the ratio for protein production, was taken as 17:1 (Gil-Weir *et al*., 2011). The amount of nitrogen that changes to dry weight (g C) is 1 g C = 2 g of dry biomass weight (Gil-Weir *et al*., 2011). Phytoplankton (g) C: Nutrient (g) N ratio = 17: 1.

Primary productivity (PP) was then estimated is determined through the litter nutrient release estimations (Eq. 1, Fitri *et al*., 2018) as:

$\Sigma$ PP = $\Sigma$ Nutrient × 2 × 17. (Eq. 2)

Finally, herbivore fish production (g wet weight of fish $m^{-2}$) was calculated from Eq. 2 by computing the primary productivity conversion efficiency Beveridge, 1984, as follows:

fish (HF) = 10 × (b × $\Sigma$PP) (Eq. 3)

where HF is the production of herbivore fish, b is the percentage value of conversion into grams of fish carbon per square meter per day (g C-fish $m^{-2}$). While carbon content in fish is 10% of the weight of the fish, or on the other hand, the wet weight of the fish is equal to 10 times the carbon content of the fish.

Production of carnivore fish (CF) was further estimated assuming a 10% efficiency in the energy flow; CF was derived from 10% of HF (Fitri *et al*., 2018).

Total fish production was calculated as

$\Sigma$FB = HF + CF. (Eq. 4)

### 2.7 Statistical analysis

Data were analyzed by one-way analysis of variance (ANOVA) followed by Duncan's multiple range test for location comparisons. The value of $P < 0.05$ was selected as a limit of statistical significance. All statistical analyses were constructed using the IBM SPSP Statistics ver. 22 (IBM Cooperation, Armonk, NY).

## 3. Results and Discussion

### 3.1 Mangrove forest structure

Table 2 summarizes mangrove species found in the study sites. The highest species-specific mangrove density was seen for A. marina with a density between 2-24 trees $m^{-2}$, while the lowest (between 1-28 trees $m^{-2}$) was observed for *Sonneratia* spp. which was not found in the Langsa and Percut sites. The present study displays the dissemination of mangrove species in five different mangrove sites showing different densities and diversity.

*Avicennia* spp. is mainly found inside the estuaries, near the coastal area. This is consistent with its pioneer nature on sheltered coastal lands, where they can colonize salty mudflats (Borkar *et al*., 2011; Fitri *et al*., 2018). It is interesting to note that *Rhizophora* spp. was evenly represented across all sites, especially R. apiculata. This condition may be due to the high adaptation to the surrounding environment (Dangremond *et al*., 2015; Phuphumirat *et al*., 2016). Also, *Rhizophora* spp. has a shorter and slender hypocotyl than other species that allow it to be carried by seawater and disperse further distances (Phuphumirat *et al*., 2016). The existence of *Sonneratia* spp. found in almost all stations indicated that this species could grow on the part that gets freshwater input, primarily on the species of S. caseolaris (Aznan *et al*., 2018). Furthermore, in the species of S. alba,

**Table 2.** Mangrove species found in the study sites.

| Location | Species | Station 1 | Station 2 | Station 3 | Station 4 | Station 5 |
|---|---|---|---|---|---|---|
| Langsa | A. marina | 0 | 2 | 10 | 12 | 22 |
| | R. apiculata | 10 | 14 | 4 | 2 | 2 |
| | R. stylosa | 8 | 6 | 2 | 0 | 0 |
| | A. alba | 0 | 0 | 0 | 14 | 4 |
| Jarin Halius | R. apiculata | 8 | 16 | 4 | 16 | 4 |
| | R. stylosa | 4 | 0 | 0 | 16 | 0 |
| | R. mucronata | 8 | 4 | 0 | 0 | 0 |
| | A. marina | 4 | 12 | 15 | 24 | 8 |
| | S. alba | 0 | 0 | 0 | 0 | 28 |
| Pulau Kampai | R. apiculata | 9 | 3 | 8 | 5 | 7 |
| | R. stylosa | 0 | 4 | 0 | 2 | 1 |
| | A. marina | 8 | 5 | 7 | 0 | 0 |
| | S. alba | 1 | 4 | 1 | 0 | 0 |
| Pula Sembilan | R. apiculata | 4 | 5 | 7 | 3 | 9 |
| | R. stylosa | 3 | 2 | 5 | 4 | 7 |
| | A.alba | 4 | 0 | 0 | 2 | 1 |
| | A. marina | 6 | 8 | 5 | 5 | 3 |
| | S. alba | 1 | 2 | 0 | 4 | 6 |
| | S. caseolaris | 3 | 0 | 1 | 1 | 0 |
| Percut | R. apiculata | 1 | 0 | 0 | 0 | 2 |
| | R. mucronata | 2 | 1 | 0 | 0 | 0 |
| | A. marina | 5 | 3 | 3 | 7 | 1 |
| | A. alba | 3 | 2 | 4 | 2 | 1 |
| | R. stylosa | 0 | 0 | 1 | 2 | 0 |

**Table 3.** Physical and chemical parameters in the location sites.

| Parameter | Unit | Langsa | Jaring Halus | Pulau Kampai | Pulau Sembilan | Percut |
|---|---|---|---|---|---|---|
| Air temperature (At) | ºC | 39.00±3.1a | 33.90±2.6bc | 33.98±4.2bc | 35.75±5.8b | 32.11±1.4c |
| Seawater temperature (Swt) | ºC | 31.88±1.5a | 29.26±1.3c | 30.03±1.1b | 30.08±1.7b | 28.09±1.2c |
| Salinity (S) | ‰ | 36.90±1.3a | 18.40±2.5d | 34.55±1.4b | 34.30±1.0b | 24.80±2.8c |
| DO | mg/l | 4.07±0.7c | 7.72±0.1a | 6.46±0.3b | 6.54±0.4b | 3.60±0.4d |
| pH | - | 6.73±0.4a | 6.80±0.6a | 6.80±0.6a | 6.04±0.8b | 5.20±0.6c |
| Current velocity (Cv) | m/s | 0.13±0.0a | 0.10±0.0ab | 0.08±0.0b | 0.10±0.0ab | 0.08±0.0b |
| Humidity (H) composition | % | 88.40±3.4b | 87.20±1.9b | 93.50±2.2a | 92.40±1.5a | 84.30±2.0c |
| Sediment | % | | | | | |
| - Sand | | 58.00±7.7a | 41.20±3.5b | 48.20±9.7ab | 62.33±9.0a | 50.60±7.7ab |
| - Silt | | 30.00±6.8ab | 37.20±4.5a | 31.60±7.3ab | 21.67±5.9b | 33.60±3.8ab |
| - Clay | | 12.00±2.4a | 21.60±5.2a | 20.20±9.3a | 16.00±4.4a | 15.80±6.8a |
| Sediment texture | | Sandy clay | Silty | Sandy silty | Sandy clay | Sandy silty |
| C-organic | % | 7.93±1.4ab | 2.42±0.3d | 5.51±2.2bc | 11.03±1.4a | 4.03±0.6cd |

Data are represented as mean ± SD. Means with the same superscript are not significantly different for each other ($P < 0.05$) using Duncan's test.

it is often found in more salty areas and gets more seawater intake (Whitfield, 2017; Fitri *et al*., 2018). During the field observed, *Sonneratia* spp. were detected more likely to grow in the mouth of the upstream river.

### 3.2 Physical and chemical parameters

Table 3 shows the physical and chemical parameters measured in the research areas of aquatic temperature ranged from 28.14 to 31.88ºC with oxygen levels in all sites statistically were significantly different, ranging from 3.60 to 7.72 mg/l. Furthermore, pH ranged from 5.20 to 6.80.

The current speed is very slow to moderate, ranging from 0.07-0.12 m/s. The range of DO in this study was within the range of DO reported in intertidal water for other mangroves (Al-Bader *et al*., 2014). Other physicochemical parameters, salinity ranged between 18.40-36.90 ‰, and humidity ranged between 84.30-93.50%. Sediment composition was dominated by sandy substrate ranged 41-62%, with the highest in Pulau Sembilan and the lowest sandy was Jaring Halus. In the case of C-organic, the highest, as shown in Pulau Sembilan, and the lowest in Jaring Halus (Table 3). Salinity was significantly different among the sites.

It has been reported that the lower salinity of the upper river might be caused by more significant freshwater input compared to seawater (Chambers *et al*., 2013).

Therefore, Langsa, Pulau Kampai, and Pulau Sembilan have relatively high significant salinity and a significant decrease in salinity value upstream of Jaring Halus. Salinity levels ranging from 10-30 ‰ are also appropriate salinity concentration in mangrove survival varies according to the species (Dangremond *et al*., 2015; Mendez-Alonzo *et al*., 2016; Kodikara *et al*., 2018). Mangrove species often depict growth stimulation at low salinity (25% seawater/5 ‰ salt concentration) and moderate salinity (50% seawater/15 ‰ salinity) and then a decline in growth with further increases in salinity (Basyuni *et al*. 2014, 2019; Mendez-Alonzo *et al*., 2016; Kodikara *et al*., 2018). This study suggested

**Table 4.** A location classified based on the agglomerative hierarchical clustering (AHC) analysis

| Group | At (ºC) | Swt (ºC) | S (‰) | DO (mg/l) | pH | Vc (m/2) | H (%) | Td cm) | Th (m) | Ns |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 37.38 ± $4.5^{a}$ | 30.98± $1.6^{a}$ | 35.60± $1.2^{a}$ | 5.23± $0.6^{b}$ | 6.38± $0.6^{ab}$ | 0.11± $0.0^{a}$ | 90.4± $2.4^{ab}$ | 16± $4.0^{b}$ | 4± $0.6^{b}$ | 6± $0.8^{a}$ |
| 2 | 33.90± $2.6^{ab}$ | 29.26± $1.3^{a}$ | 18.40± $2.5^{c}$ | 7.72± $0.1^{a}$ | 6.80± $0.6^{a}$ | 0.10± $0.0^{a}$ | 87.2± $1.9^{c}$ | 27± $3.0^{a}$ | 8± $1.2^{a}$ | 5± $0.2^{a}$ |
| 3 | 33.04± $2.8^{b}$ | 29.08± $1.2^{a}$ | 29.68± $2.1^{b}$ | 5.03± $0.4^{b}$ | 6.00± $0.6^{a}$ | 0.08± $0.0^{a}$ | 88.9± $2.1^{c}$ | 13± $2.0^{c}$ | 4.8± $0.3^{c}$ | 5± $0.1^{a}$ |

Data are represented as mean ± SD. At= air temperature, Swt= sea water temperature, S= salinity, Do= dissolved oxygen Vc= velocity current, H= humidity, Td=tree diameter, Th= tree height, Ns= number of species. Means with the same superscript are not significantly different for each other ($P < 0.05$) using Duncan's test.

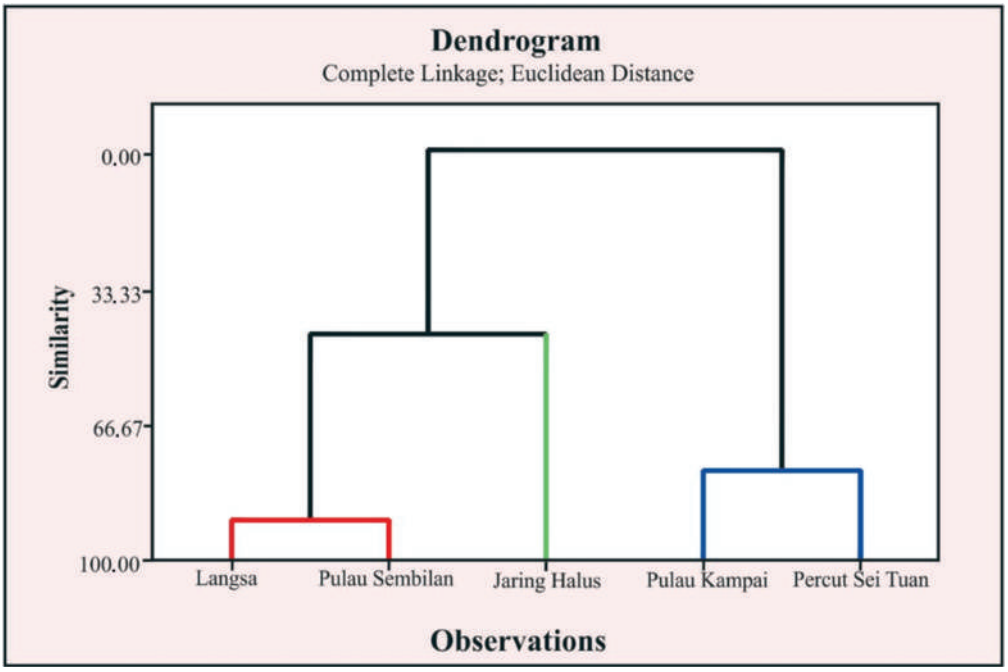

**Fig. 2.** Agglomerative hierarchical clustering (AHC) analysis. Mangrove sites were clustered by site attribute similarity, clustering Langsa, and Pulau Sembilan within group 1 (red lines), Jarin Halus (green line) more related to group 1 than to 3 (blue lines), which includes Mangroves at Pulau Kampai and Percut. The variables with more weight in the clustering were physicochemical parameters and stand density.

that several mangrove species tolerated to adapt either in saline or freshwater stress.

### 3.3 Relation of mangrove characteristics and physical and chemical parameters analysi

Based on agglomerative hierarchical clustering (AHC) analysis, mangrove individual observation locations are grouped into three groups based on existing physical and chemical parameters, as shown in Figure 2. The first group consists of locations in Langsa and Pulau Sembilan. This group was dominated by R. apiculata and A. marina with medium density, high salinity and humidity, and a sandy-clay substrate (Table 4).

The second group consisted of Jaring Halus only with mangrove R. apiculata, A. marina, and S. alba, which has very high density, the lowest salinity, and high mud. It has been demonstrated that there is a relationship between soil characteristics and mangrove species (Hossain & Nuruddin, 2016).

Soils are made up of sand, silt, and clay in different combinations, and mud refers to a mixture of silt and clay, both of which are rich in organic matter (detritus) (Hossain & Nuruddin, 2016), as represented in Jaring Halus. Group three consisted of locations in Pulau Kampai and Percut overgrown with vegetation type with low density and medium salinity. This grouping data is based on the object's concentration of the dendrogram (Figure. 2).

### 3.4 Importance value index and diversity index analysis

The calculation of the importance value index (IVI) showed that the highest value was in group 1 on *Rhizophora* spp. of 164.37% and the lowest in group 3 for *Sonneratia* spp. they were subjected to 29.02%.

Based on the result of a Shannon–Weiner diversity index value (H'), mangrove forests in group 1 had high diversity (3.02), followed by group 2 (2.97) and group 3 (1.73). In the present study, species diversity was higher than previous studies in Lubuk Kertang, North Sumatra, Indonesia. As for restored mangroves

**Table 5.** Importance value index and diversity index of study sites

| Group | Species | Relative Density (%) | Relative Frequency (%) | Relative Dominance (%) | IVI (%) | H' |
|---|---|---|---|---|---|---|
| 1 | *Avicennia* spp. | 22.82 | 35.90 | 14.38 | 73.09 | 3.02±0.1a |
|  | *Rhizophora* spp. | 65.10 | 46.15 | 53.12 | 164.37 |  |
|  | *Sonneratia* spp. | 12.08 | 17.95 | 32.50 | 62.54 |  |
| 2 | *Avicennia* spp. | 36.84 | 33.33 | 36.58 | 106.75 | 2.97±0.1a |
|  | *Rhizophora* spp. | 46.78 | 60.00 | 45.55 | 152.34 |  |
|  | *Sonneratia* spp. | 16.38 | 6.67 | 17.87 | 40.91 |  |
| 3 | *Avicennia* spp. | 48.57 | 46.67 | 46.57 | 141.81 | 1.73±0.1b |
|  | *Rhizophora* spp. | 45.72 | 43.33 | 40.13 | 129.17 |  |
|  | *Sonneratia* spp. | 5.71 | 10.00 | 13.30 | 29.02 |  |

Data of H' are represented as mean ± SD (n= 3). Means with the same superscript are not significantly different for each other (P < 0.05) using Duncan's test.

(H' = 0.27-1.09, Fitri *et al*., 2018), mangrove species in Sungai Haji Dorani and Kuala Selangor with a Shannon–Weiner Index (H') value of 0.91 and 0.55, respectively (Zhila *et al*., 2014), and compared to the natural mangrove forest in Palawan, Philippines (H'= 0.99) (Abino *et al*., 2014). This study indicated that natural mangrove forests in Langsa and Jaring Halus had considerable high species diversity (Table 5).

### 3.5 Fish biomass and production estimation

This finding was very closely related to the nutrients resulting from litter decomposition. The primary production value had a significant role as the beginning of the estuary food chain. In this circumstance, the highest fish productivity from Jaring Halus can be derived not only from its high productivity but can also be related to lower sediment salinity related to surrounding rivers and rainfall (Hutchison *et al*., 2014b, Méndez-Alonzo *et al*., 2016), and a potential higher litter decay rate, promoted by a well-established herbivore community, characteristic of mature preserved mangroves (Middleton & McKey, 2001; Ananda *et al*., 2007, Whitfield, 2017). In contrast, degraded mangroves, often hyper-salinized due to vegetation cover loss and excess insolation (Vovides *et al*., 2011a; Vovides *et al*., 2011b), lose not only their detritivore community and thus their ability to contribute to the food chain. The lower fish productivity observed for the conserved site Langsa can be attributed to the relatively high salinity compared to Jaring Halus. Salinity reduces detrital decomposition (Contreras *et al*., 2017). However, its fish productivity was still >50% higher than the restoring site within its group (Pulau Sembilan), suggesting litter decay might be more closely related to fish productivity than salinity.

The estimation of fish biomass in the mangrove ecosystem was done using the approach of nutrient release from mangrove litter. To the evaluation, the significant highest average fish production was in Jaring Halus (3,063.05) kg ha$^{-1}$ year, and the significant lowest average fish production was in Percut (231.37) kg ha$^{-1}$ year. The fisheries production found for Jaring Halus is much higher than the reported for Lubuk Kertang 1,248.76 kg ha$^{-1}$ year (Fitri *et al*., 2018). Litter production at the present study site was dominated by *Rhizophora* spp., followed by *Avicennia* spp as displayed in Table 6. The high production of *Rhizophora* litter is probably related to the high density of the species as compared to the other

**Table 6.** Fish biomass estimation in five different sites.

| Site | Species | Weight (g) | N (%) | P (%) | Nutrient total (gm$^{-2}$) | PP (g C m$^{-2}$) | HF (gm$^{-2}$) | CF (gm 2) | Fish Total (g m$^{-2}$) | Fish Production (kg ha$^{-1}$ year) |
|---|---|---|---|---|---|---|---|---|---|---|
| Langsa | *Rhizophora* spp. | 5.29 | 0.12 | 0.007 | 0.116 | 3.932 | 0.397 | 0.040 | 0.437 | 1,012.73±54.7b |
| | *Avicennia* spp. | 6.26 | 0.11 | 0.012 | 0.105 | 3.560 | 0.360 | 0.036 | 0.396 | |
| | *Sonneratia* spp. | 0.00 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | |
| Jaring Halus | *Rhizophora* spp. | 9.42 | 0.21 | 0.030 | 0.206 | 6.992 | 0.706 | 0.071 | 0.777 | 3,063.05±161.0a |
| | *Avicennia* spp. | 11.10 | 0.19 | 0.105 | 0.186 | 6.315 | 0.638 | 0.064 | 0.702 | |
| | *Sonneratia* spp. | 11.73 | 0.28 | 0.009 | 0.275 | 9.353 | 0.945 | 0.094 | 1.039 | |
| Pulau Kampai | *Rhizophora* spp. | 1.37 | 0.03 | 0.006 | 0.030 | 1.017 | 0.103 | 0.010 | 0.113 | 448.74±59.8c |
| | *Avicennia* spp. | 1.32 | 0.02 | 0.000 | 0.022 | 0.753 | 0.076 | 0.008 | 0.084 | |
| | *Sonneratia* spp. | 1.94 | 0.05 | 0.000 | 0.046 | 1.550 | 0.157 | 0.016 | 0.172 | |
| Pulau Sembilan | *Rhizophora* spp. | 2.41 | 0.05 | 0.000 | 0.053 | 1.791 | 0.181 | 0.018 | 0.199 | 465.89±38.4c |
| | *Avicennia* spp. | 1.29 | 0.02 | 0.000 | 0.022 | 0.733 | 0.074 | 0.007 | 0.081 | |
| | *Sonneratia* spp. | 1.16 | 0.03 | 0.000 | 0.027 | 0.922 | 0.093 | 0.009 | 0.102 | |
| Percut | *Rhizophora* spp. | 0.75 | 0.02 | 0.000 | 0.016 | 0.558 | 0.056 | 0.006 | 0.062 | 231.37±40.7d |
| | *Avicennia* spp. | 2.03 | 0.03 | 0.000 | 0.034 | 1.153 | 0.116 | 0.012 | 0.128 | |
| | *Sonneratia* spp. | 0.00 | 0.00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | |

Data of Fish production are represented as mean ± SD (n= 3). Means with the same superscript are not significantly different for each other ($P < 0.05$) using Duncan's test. N = nitrogen, P = phosphorus, PP = primary productivity, HF = herbirorous fish, CF= carnivorous fish.

species, as tree density is positively correlated with litter production (Chen *et al*., 2019).

Mangrove forest, through its litter production, significantly influenced fish production within the sites studied here. The increase of N at the early stage of decomposition is quite common due to immobilization (Nordhaus *et al*., 2017). Both N and P are actively involved in translocation, microbial growth, and metabolites, increasing levels during decomposition (Jiang *et al*., 2017). This result is positively linear correlated in most of the sites of our present study.

Within the mangrove ecosystem, there is at least one life cycle of various fish species and invertebrates in utilizing mangrove ecosystems as feeding places. The abundance of food is produced through litter production. The understanding of the carrying capacity of the mangrove ecosystem is the ability of the mangrove ecosystem as the area where to find food and or shelter in supporting the amount of biomass of fish through the transfer of energy that begins the production of organic materialderived from mangrove litter (detritus) (Saifullah *et al*., 2016). The Leaves and detritus form a crucial part of marine food chains supporting fisheries.

Our results support previous positive relationships between estuarine mangrove forests and fishery resources (Aburto-Oropeza *et al*., 2008, Whitfield, 2017; Fitri *et al*., 2018) and add insight into the quantitative interaction between nutrient release and fish biomass. Mangrove forests in the Gulf of California have been reported to increase fishery yields up to 32% for small-scale fisheries (Aburto-Oropeza *et al*., 2008). On the other hand, high fishery productivity in natural mangroves is likely to be fully supported by adjacent estuaries (Raoult *et al*., 2018). It has been reported that the loss of one hectare of mangrove to a fish pond causes a loss of 480 kg of offshore fish and shrimp ha$^{-1}$ year$^{-1}$ (Ahmed *et al*., 2017). This study also implied the importance of mangrove conservation to protect the existing mangroves and restore degraded areas due to mangrove conversion. Further studies are needed to investigate the broader impact of mangrove conversion and mangrove loss on the fishing communities and production, particularly in Pulau Sembilan, Pulau Kampai, and Percut Sei Tuan.

## 4. Conclusion

Jaring Halus, as a natural mangrove forest, had the highest average fish production, and the lowest average fish production was found at the abandoned aquaculture ponds in Percut Sei Tuan, confirming that conservation and management affect mangrove productivity from primary productivity to secondary. The highest fish production followed the order of Jaring Halus > Langsa > (conserved mangroves), followed by Pulau Sembilan > Pulau Kampai (palm oil plantations) and Sei Tuan Percut (aquaculture ponds), which is following their mangrove status and habitat zones. The present study provides information for the significant role of mangrove ecosystems for fisheries and calls for effective restoration from a perspective of food security.

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