Ecological risk of coastal ecosystem: A perspective of mangrove ecological sensitivity in small islands, case in Anambas Archipelago District at Natuna Sea

Yonvitner\textsuperscript{1,2,*}, G Rakasiwi\textsuperscript{3}, Y Wahyudin\textsuperscript{4} and Kamsari\textsuperscript{3}

\begin{itemize}
  \item \textsuperscript{1} Department of Aquatic Resources Management, Faculty of Fisheries and Marine Science, IPB University. Email: yonvitr@yahoo.com
  \item \textsuperscript{2} Centre for Disaster Studies (CERDAS), IPB University
  \item \textsuperscript{3} Centre for Coastal and Marine Resources Studies (CCMRS), IPB University
  \item \textsuperscript{4} Faculty of Agriculture, Juanda University Bogor
\end{itemize}

\textsuperscript{*}E-mail: yonvitner75@gmail.com

Abstract. The ecosystem sensitivity in the coastal and small islands is dependent on the vulnerability and resilience level of that ecosystem. Mangroves are one of the primary ecosystems in coastal areas, also high vulnerability and sensitivity due to natural factors such as waves, pollution, and due to the impact of human activities. Based on this reason, the study of vulnerability and sensitivity was needed for mitigation plans and other actions in reducing the risk due to the pressure by a coastal manager. This study was carried out around small islands in Anambas District, especially in Matak Island. The results showed that the level of mangrove vulnerability was relatively high at all locations; the condition of the ecological status was classified as moderate. The status of the social and economic index was classified as medium to high vulnerability. The assessment of the sensitivity level, known as the condition of mangrove ecosystems, is moderate to very sensitive. The areas with the highest sensitivity level are Peninting and Ayerbadong. The high sensitivity in both locations is due to the influence of the economic index, which indicates that the region is economically sensitive and potentially vulnerable.

1. Introduction
Matak Island and surrounding areas are groups of small tropical islands characterized by small embayments, estuaries, sandy and rocky beaches, mangroves, and coral reefs and considered biodiversity highly in terms of ecosystems and habitats. The Matak Island area is also in the middle of a massive economic development, which makes this area economically sensitive. Then also position in the Natuna Sea and Archipelagic Sea Lanes I potential to increase the impact of vulnerability and sensitivity in the coastal area.

The Environmental Sensitivity Index (ESI) study is an important program which can be further used as input for environmental management. Any activity on coastal and offshore of Matak Island, potential to increase the hazard, vulnerability, sensitivity, and risk to mangrove ecosystem. Overall, at the long time potential to reduce the carrying capacity of the coastal area.

Sensitivity determined as the potential impact on a system from perturbations, including shocks and stress [1]. The issue of sensitivity usually close relation to the topic of sustainable development. The sensitivity concept is one of the sustainability constraints together with, for example, the concept of...
minimum safety standards, quality standards, carrying capacity, eco-capacity, maximum sustainable yield, critical loads, environmental utilization space, etc. [2]. All such concepts may be useful for policy analysis and operations planning.

The sustainability ecosystem express at least from four attributes [3] such as: (1) it is expressed in one or more measurable parameters; (2) these parameters are linked to sustainability targets; (3) the parameters have proper geographical scale; and (4) these parameters also have a relevant time dimension. It is also stated that ideally, these parameters should be mapped out as quantitative factors, but in reality, it is often confronted with qualitative, fuzzy and incomplete information [2]. In this context, therefore, a better understanding of the habitats and ecosystems and their sensitivity of the Matak Supply Base and surrounding areas in the western and northern parts of the Matak Island environment can be derived through the development of the Environmental Sensitivity Index (ESI).

The objectives of the study are to identify the sensitivity level of changes in both ecological and social conditions of coastal ecosystems, particularly mangrove ecosystem and human impact that cause the sensitivity area.

2. Materials and Method

2.1. Research area

The research area is in Matak Island, Anambas District, at the Natuna Sea (see figure 2). The sampling sites were selected by the team, along with the coastal areas that are inhabited by mangrove ecosystems. The survey activities cover four main divisions, i.e.: (i) Matak Jetty; (ii) Matak Strait; (iii) Peninting Strait; (iv) Ayerbandong and Mandilang Strait. The field survey and data collection were conducted on June 19th – 26th in 2014 ago. The kind of data that was collected at that location as follows: 1) Identification of the mangrove species in the study areas and its geographical position; 2) Estimation of density and other ecological function; 3) Sensitivity area map of the mangrove ecosystem. The type of data was collected in the location shown in the Table below.

| No | Type of Data       | Collection procedures     | Equipment    |
|----|--------------------|--------------------------|--------------|
| 1  | Mangrove species   | In-situ identification   | Reference    |
| 2  | Number of species  | Direct counting          | Counter      |
| 3  | Diameter of tree   | In-situ measurement      | Roll meter   |
| 4  | Coverage           | Coverage estimation      | -            |
| 5  | Type of substrate  | Visual Survey            | -            |

Data collection was conducted in each habitat of mangrove found in the study area. On each site, the transect grid applied for species identification and density counting. Type of sediment, substrate, and associated fauna living in the mangrove was observed as well directly while sampling process.

2.2. Data analyses

2.2.1. Vulnerability index (VI)

The vulnerability value of the mangrove ecosystem is high because it grows in sensitive habitats that are vulnerable to pollution and the influence of rivers and oceans. Mangrove ecosystem was also known as a habitat for fish, crocodiles, migratory birds, fish nursery, and other resources. We have any sensitive ecosystem such as mangroves, brackish swamps, tidal areas, floodplain areas that classified as very high vulnerability areas by [5]. Therefore, the vulnerability index (VI) criteria of the mangrove ecosystem have a score value at 5 (very high).
Vulnerability score also refers to the sensitivity level of each species is according to its response against pollution, debris, or other pollutants on the mangrove area. Crude oils and sea waves can pool onto sediment surfaces and are highly persistent. These heavy oils and emulsified oil can be trapped in thickets of aerial roots (pneumatophores) by mangrove, especially on species \( \textit{Avicennia} \) sp. While in a location, we found a susceptible species (\( \textit{Avicennia} \) sp), can state as a highly vulnerable site. Based on the ability to recover from oil spill pollution, mangrove species can be divided onto five-level sensitivity such as Table 2.

**Table 2. Sensitivity level and score based on species of mangrove [6]**

| Score | Sensitivity Level     | Genus                  |
|-------|-----------------------|------------------------|
| 1     | Not sensitive         | \( \textit{Bruguiera} \) |
| 2     | Less Sensitive        | \( \textit{Lumnitzera, Xylocarpus, Scyphiphora} \) |
| 3     | Moderate              | \( \textit{Rhizophora, Ceriops} \) |
| 4     | Sensitive             | \( \textit{Sonneratia, Excoeceria} \) |
| 5     | Very sensitive        | \( \textit{Avicennia} \) |

2.2.2. **Mangrove ecology index (EI)**
The first activity of analysis mangrove ecology is identified of mangrove species, through in-situ observation according to the book of mangrove identification [7,8]. Data analysis of mangrove ecology consists of species diversity, density, the status of protection, wildlife habitat, and tidal exposure to mangrove habitat.

2.2.3. **Mangrove Species Diversity**
Species diversity was calculated on each site of mangrove area based on occurrence mangrove species in each habitat mangrove. The higher number of species found, also increasing mangrove diversity. Value and score of mangrove diversity shown in Table 3.

2.2.4. **Mangrove Species Density (Di)**
The species density (Di) is the number of a mangrove tree in a specific area:

\[
D_i = \frac{n_i}{A} \tag{1}
\]
Where, \( D_i \) is species density of species-\( i \); \( n_i \) is the total number of the tree of species-\( i \), and \( A \) is a sample area where data collected.

2.2.5. **Protected of Mangrove area**

Protected area mangrove means showing the status of the mangrove area, whether as a protected area or not. If it is a protected area, the area level was classified as a regional or national protected area.

2.2.6. **Wildlife habitat**

Wildlife habitat means whether the mangrove area is a habitat for wild biota or not, and have functioned as preservation endanger species. Therefore, information or recording about wildlife in mangrove forests needed to set a protection program. The increasing number of endanger or endemic species in the mangrove ecosystem show that an increase of sensitivity. The higher number of wildlife criteria shows a critical habitat and sensitivity score value higher too.

2.2.7. **Tidal exposure**

Tidal exposure defined as the potential impact from the tidal process to coastal or mangrove are and also wave and sea current. While in an extreme wave, the mangrove area potential has an abrasion or rob flood in the terrestrial area. The important thing mangrove function is as coastal protection from wave, rob, and tidal dynamic. The higher tidal frequency or extreme wave on the mangrove area means increasing sensitivity on the mangrove ecosystem and score value high.

The next step environmental sensitivity index (ESI) is scoring parameters in each criterion above. The score value range from 1-5 (low-grade to high-grade). [5] Categorized the vulnerability value for mangrove into five scoring criteria. The scoring criteria for the ecological indicator on mangrove parameter as described above shown in Table 3 and 4.

**Table 3. Score and Criteria of Each Variable in Ecological Value (Ev) for Mangrove**

| Score | Diversity (Number of Species)* | Mangrove Density (and/ha)* | Protected**) | Wild Life Habitat (NoS)** | Tidal exposure *** |
|-------|-------------------------------|---------------------------|--------------|--------------------------|------------------|
| 1     | 1                             | < 500                     | Not protected | Not Exist                | Low exposure     |
| 2     | -                             | -                         | -            | 1-2                      | -                |
| 3     | < 3                           | 501-1000                  | Locally Conserved | 3                       | Medium exposure  |
| 4     | -                             | -                         | -            | -                        | -                |
| 5     | > 3                           | > 1000                    | Nationally Conserved | > 3                    | High exposure    |

Sources: *) Developed from [9,10]; **) Developed from [11]; *** Developed from [11,12]

The criteria for ecological values of mangrove ecosystem is presented in Table 4. The range of value in each description score determined based on the potential record of data and any judgment related to mangrove research. The traceability score in each criterion, there are also remark or a reference by the researcher to expand.
### Table 4. Criteria for Ecological Values of Mangrove Ecosystem.

| Criteria                              | Weight | Score | Description                                      | Remark                                                        |
|---------------------------------------|--------|-------|--------------------------------------------------|---------------------------------------------------------------|
| Diversity*)                           | 0.3    | 1     | One mangrove species was recorded               | The number of species found in the study area ranges from 1 to 5 species |
|                                       |        | < 3   | Two mangrove species were recorded              |                                                                |
|                                       |        | > 3   | More than three mangrove species were recorded  |                                                                |
| Mangrove*) Density                    | 0.15   | < 500 | Less than 500 trees/ha                          | Mangrove density in the study area ranges between 300-1400 trees/ha (offshore) and between 1000-1500 trees/ha (onshore) |
|                                       |        | 501-1000 | Between 500 to 1000 trees/ha                     |                                                                |
|                                       |        | > 1000 | More than 1000 trees/ha                         |                                                                |
| Designated Protected Area**)          | 0.1    | Not   | The mangrove area was not protected             | Part of mangrove ecosystems in the River Division 4 (onshore barging) area is nationally protected by law |
|                                       |        | protected | The mangrove area is locally protected (green belt area) |                                                                |
|                                       |        | LC (Locally Conserved) | |                                                                |
|                                       |        | NC (Nationally Conserved) | |                                                                |
| Wildlife Habitat**)                   | 0.25   | NE (Not Exist) | The protected wildlife is not found | The protected species were commonly found in Division 4 (onshore barging) |
|                                       |        | 1-2   | 1-2 protected wildlife species found             |                                                                |
|                                       |        | 3     | Three protected wildlife species found           |                                                                |
|                                       |        | >3    | More than three protected wildlife species found |                                                                |
| Tidal Exposure***)                    | 0.2    | Low Exposure | Not influenced by the tide                        | Whole mangrove area in the offshore and onshore (Division 4) are commonly highly influenced by the tidal |
|                                       |        | Medium Exposure | Moderately influenced by the tide              |                                                                |
|                                       |        | High Exposure | Highly influenced by the tide                   |                                                                |

Sources: *) Developed from [9], [10]; **) Developed from [11]; *** Developed from [11], [12]

2.2.8. Socio-economic index

Socio economy data that relate to mangrove are cover demographic structure and its parameters, sensitive area (in the perspective of socio-economy), and mapping. Socio economy data analyses are comprised of, i.e., age structure, population income and expenditure, socio-economic valuation, and development of environmental sensitivity index of the local communities socio-economic at the Matak Supply Base and surrounding areas in the western and northern parts of Matak Island. As mentioned, socio-economic value is similar to the Social Values Index (SI), which comprises the economic value index (ESV) and the social value of resource uses (SV). The formula of the Social Values Index (SI) as follows [13].
$SI = \sum (SV, EcV)$ ................................................................. (2)

Where, SI is the social value index; SV is the social value of the resources component, and ESV = economic value component of the resources.

### 2.2.9. Social value

Social value for the mangrove ecosystem is calculated based on criteria such as (i) tourism development potential area, (ii) fishing ground, and (iii) other mangrove utilization such as for construction/housing materials.

**Table 5. Criteria for Social Values of Mangrove Ecosystem**

| No. | Description          | Criteria                                      |
|-----|----------------------|-----------------------------------------------|
| 1   | Potential tourism development area | Very potential = 5; Potential = 4              |
|     |                      | Moderate = 3; Less Potential = 2              |
|     |                      | Not potential = 1                             |
|     |                      | Very intensive = 5; Intensive = 4             |
| 2   | Fishing ground       | Moderate = 3; Rare = 2                        |
|     |                      | None = 1                                       |
| 3   | Other utilisation    | Moderate = 3; Less utilized = 2               |
|     |                      | None = 1                                       |

Source: Adopted and modified from [14]

The social value is calculated through a geometrical average as described in the following formula:

$SV_j = \frac{1}{3} \left( \frac{S_{j1} \times S_{j2} \times S_{j3}}{E_{cV}} \right)$ ................................. (3)

Where; $SV_j$ is the social value of j site; $S_{ji}$ is score value criteria of i-social value at j-site.

### 2.2.10. Economic value

The economic value of mangrove resource is calculated based on the geometrical average of social value and ecological value multiplied by the standardized economic value of mangrove resource /ha/year issued by (Ministry of Environment KLH 1999) , i.e. USD 15,877.42/ha/year. This value was taken from similar research in Barelang and Bintan Island, which is an assumption to be identical to the recent study [13].

$EcV_j = \frac{1}{4} \left( \frac{S_{j1} \times S_{j2} \times S_{j3}}{E_{cV}} \right) \times 15,877.42$ ................................. (4)

Where, $S_{ji}$ is score value criteria of i-economic value at j-site; it was then justified to result in the weighted score through the following formula [13]:

$EcV_j = \frac{EcV_{j_1}}{EcV_{j_{max}}} \times 5$, ................................. (5)

$EcV_i$ is the economic value of mangrove resource at i-site; $EcV_{ji}$ is shown the economic value of mangrove of 1...n; $EcV_{j_{max}}$ is the maximum economic value of mangrove resource observed.

### 2.2.11. Social Economic Index (SI)

The economic value of mangrove resource calculated through the following formula [13]:

$SI = \sum (SV, EcV)$ ................................................................. (2)
\[ SI_j = \sqrt[3]{SV_j \times EcV_j}, \] ................................................................. (6)

Where, \( SI_j \) = socio-economic value of \( j \)-site, \( SV \) = social value, and \( EcV \) = economic value.

### 2.2.12. Environmental sensitivity index analysis (ESI)

An Environmental Sensitivity Index (ESI) value describes the relative environmental sensitivity of each area was calculated and displayed on the spatial profile. The area to be outlined on the sensitivity maps represents an integration of three main components of the ESI, namely Vulnerability Index (VI), Ecological Index (EI), and Social Index (SI). The integration of these values can be represented in a composite equation, as described in Equation [5].

\[ CESI_i = VI_i \times EI_i \times SI_i \] ................................................................. (7)

Where, \( CESI_i \) is the composite ESI of area \( _i \); \( VI \) is the vulnerability index; \( EI \) is the ecological index; and \( SI \) is social values index (SI), which comprises economic value index (EcV) and social value of resources use (SV) with formulas as below.

\[ VI_i = (\sum_{j=1}^{n} VC_j)^{-n} \] ................................................................. (8)

\[ EI = (\sum_{j=1}^{n} EC_j)^{-n} \] ................................................................. (9)

\[ SI = (\sum_{j=1}^{n} SC_j)^{-n} \] ................................................................. (10)

Where, \( VC \) is vulnerability components (shoreline values); \( EC \) is ecological components (ecosystem value and species value), and \( SC \) is social components (economic values and social-uses values). Each component, i.e., vulnerability, ecological and social, has a value between 1 (minimum = the least sensitive) to 5 (maximum = the most sensitive). Since the composite ESI (CESI) is a multiplication among these components, hence the CESI values range from 1 (the least sensitive) to 125 (the most sensitive). This formula is developed by [15] which is inspired by ESI guidelines [11]. Therefore, the composite environmental sensitivity index (CESI) has a value between 1 – 125 and is categorized as follows (Table 6).

**Table 6. Level of Sensitivity Based on CESI Values [15]**

| CESI Value | Sensitivity Level |
|------------|-------------------|
| 1          | Not Sensitive     |
| 2 – 8      | Less Sensitive    |
| 9 – 27     | Moderate          |
| 28 – 64    | Sensitive         |
| 65 – 125   | Very Sensitive    |

### 3. Results and Discussion

The reduction of mangrove coverage is a common cause of human settlements or other conversions such as at Antang and Butun. However, the mangrove ecosystem in Payalaman relatively stable, and no significant changes was observed, while Mangrove in Batu Ampar and Mandilang naturally grow and slightly expand in height and width of the tree.
Mangrove ecosystems in the western and northern part of Matak Island and the surroundings have a significant ecological function, environment and socio-economic functions which include: 1) to maintain coastal water quality; 2) to reduce the severity of impact from the coastal storm, wave, and flood damage; 3) as nursery areas and feeding grounds for commercial fisheries; and 4) as important habitat and feeding grounds for benthic and birds. The mangrove ecosystem found in the study area has unique characteristics since it is located on rocky islands with a minimum supply of freshwater, indicated by a lack of major estuary. A similar condition is also observed in the western and northern coastline of Matak Island and other surrounding small islands.

3.1. Vulnerability and ecological index
The ESI value of the mangrove ecosystem is calculated based on vulnerability value, ecological value, and social value. Based on CESI criteria, the vulnerability index of mangrove towards oil spills is the highest (the most vulnerable) while it was located in the intertidal area with a muddy substrate.
Table 7. Ecological Variable Status of Mangrove Ecosystems

| No Unit Analysis | Unit Analysis          | Diversity | Density | Protected/Unprotected | Wildlife | Tidal Exposure |
|------------------|------------------------|-----------|---------|-----------------------|----------|----------------|
| Division 1. Matak Jetty |                        |           |         |                       |          |                |
| 4A               | Batu Ampar A           | 3         | 600     | Unprotected           | Not Exist| Full Exposure  |
| 4B               | Batu Ampar B           | 2         | 800     | Unprotected           | Not Exist| Full Exposure  |
| 6A               | Payalaman A            | 2         | 800     | Unprotected           | Not Exist| Full Exposure  |
| Division 2. Matak Strait |                  |           |         |                       |          |                |
| 9A               | Durian A               | 4         | 1000    | Unprotected           | Not Exist| Full Exposure  |
| 10B              | Butun B                | 3         | 400     | Unprotected           | Not Exist| Full Exposure  |
| Division 3. Peninting Strait |                |           |         |                       |          |                |
| 11A              | Sedak A                | 2         | 400     | Unprotected           | Not Exist| Full Exposure  |
| 11B              | Sedak B                | 3         | 500     | Unprotected           | Not Exist| Full Exposure  |
| 12               | Telayan                | 1         | 100     | Unprotected           | Not Exist| Full Exposure  |
| 14A              | Peninting A            | 2         | 700     | Unprotected           | Not Exist| Full Exposure  |
| 15A              | Dusun A                | 3         | 700     | Unprotected           | Not Exist| Full Exposure  |
| 15D              | Dusun B                | 3         | 700     | Unprotected           | Not Exist| Full Exposure  |
| 17A              | Antang A               | 1         | 100     | Unprotected           | Not Exist| Full Exposure  |
| 17B              | Antang B               | 3         | 500     | Unprotected           | Not Exist| Full Exposure  |
| Division 4. Ayerbandong – Mandilang |             |           |         |                       |          |                |
| 21A              | Mandilang A            | 3         | 600     | Unprotected           | Not Exist| Full Exposure  |
| 21B              | Mandilang B            | 3         | 700     | Unprotected           | Not Exist| Full Exposure  |
| 21C              | Mandilang C            | 3         | 700     | Unprotected           | Not Exist| Full Exposure  |
| 22A              | Ayerbandong A          | 3         | 900     | Unprotected           | Not Exist| Full Exposure  |
| 22B              | Ayerbandong B          | 4         | 800     | Unprotected           | Not Exist| Full Exposure  |

Remarks: NoS = Number of Species

It means that the mangrove ecosystem is easily exposed to the oil spill and absorbs oil at the event of an oil spill. Mangrove is vulnerable since this plant is biologically sensitive to oil exposure considering its habitat for many aquatic biotas such as fish, crustaceans, echinoderms, mollusks, benthic animals, plankton and terrestrial wildlife. Besides, the mangrove ecosystem also plays a significant role in supporting local fisheries, as they are functioned as a nursery ground, feeding ground, and spawning ground [16]. Mangrove ecosystem as the most sensitive area to oil spill since this ecosystem has a complicated physical configuration and muddy substrate, which is difficult to clean up while spilling event [11].
The maximum number of mangrove species that have been observing in the study area are 4 (four) species, with density ranges from 200 – 1,000 ind/ha. Mangrove areas were not explicitly categorized as a protected area (i.e., Nature Reserve and Nature Conservation Areas). However, based on Indonesian law, mangrove is categorized as a protected area as stipulated in Presidential Decree No. 32/1990 regarding Protected Area Management. As a small island ecosystem, the most of mangrove ecosystems in the study area were exposed to tidal wave except at Dusun Sedak. The mangrove ecosystem in Dusun Sedak relatively protects by rubble and stone. This research also found some changes in mangrove coverage were observed and mostly causes by conversion into human uses mainly as settlements. However, it is also found increasing of mangrove width and tree height at Ayerbandong. An ecological variable of mangrove ecosystem in the study area is described in Table 7. In addition, the ecological value for the 2014 survey in each component then determined by the above data and presented in Table 8.

Table 8. Ecological Score of Mangrove Ecosystem

| No Unit Analysis | Unit Analysis | Score |
|------------------|---------------|-------|
|                  |               | Diversity | Density | Protected | Wildlife | Tidal Exposure |
| Division 1. Matak Jetty |               |       |       |       |       |       |
| 4A               | Batu Ampar A  | 3     | 3     | 1     | 1     | 5     |
| 4B               | Batu Ampar B  | 3     | 3     | 1     | 1     | 5     |
| 6A               | Payalaman A   | 3     | 3     | 1     | 1     | 5     |
|                  |               |       |       |       |       |       |
| Division 2. Matak Strait |           |       |       |       |       |       |
| 9A               | Durian Bay A  | 5     |       | 1     | 1     | 5     |
| 10B              | Butun B       | 3     | 1     | 1     | 1     | 5     |
|                  |               |       |       |       |       |       |
| Division 3. Peninting Strait |         |       |       |       |       |       |
| 11A              | Sedak A       | 3     | 1     | 1     | 1     | 5     |
| 11B              | Sedak B       | 3     | 3     | 1     | 1     | 5     |
| 12               | Telayan       | 1     | 1     | 1     | 1     | 5     |
| 14               | Peninting A   | 3     | 3     | 1     | 1     | 5     |
| 15A              | Dusun A       | 3     | 3     | 1     | 1     | 5     |
| 15B              | Dusun B       | 3     | 3     | 1     | 1     | 5     |
| 17A              | Antang A      | 1     | 1     | 1     | 1     | 5     |
| 17B              | Antang B      | 3     | 3     | 1     | 1     | 5     |
|                  |               |       |       |       |       |       |
| Division 4. Ayerbandong – Mandilang |       |       |       |       |       |       |
| 21A              | Mandilang A   | 3     | 3     | 1     | 1     | 5     |
| 21B              | Mandilang B   | 3     | 3     | 1     | 1     | 5     |
| 21C              | Mandilang C   | 3     | 3     | 1     | 1     | 5     |
| 22A              | Ayerbandong A | 3     | 3     | 1     | 1     | 5     |
| 22B              | Ayerbandong B | 5     | 3     | 1     | 1     | 5     |

Each criterion of each mangrove site is then weighted to know its ecological index, as shown in the Table 9.
Table 9. Ecological Index of Mangrove Ecosystem

| No Unit Analysis | Unit Analysis  | Score | Diversity | Density | Protected | Wildlife | Tidal Exposure | EI |
|------------------|----------------|-------|-----------|---------|-----------|----------|----------------|----|
| Division 1. Matak Jetty | | | | | | | | |
| 4A | Batu Ampar A | 0.9 | 0.45 | 0.1 | 0.25 | 1 | 2.7 |
| 4B | Batu Ampar B | 0.6 | 0.45 | 0.1 | 0.25 | 1 | 2.7 |
| 6 | Payalam A | 0.9 | 0.45 | 0.1 | 0.25 | 1 | 2.7 |
| Division 2. Matak Strait | | | | | | | | |
| 9A | Durian Bay A | 1.5 | 0.45 | 0.1 | 0.25 | 1 | 3.3 |
| 10B | Butun B | 0.9 | 0.15 | 0.1 | 0.25 | 1 | 2.4 |
| Division 3. Peninting Strait | | | | | | | | |
| 11A | Sedak A | 0.6 | 0.15 | 0.1 | 0.25 | 1 | 2.4 |
| 11B | Sedak B | 0.9 | 0.45 | 0.1 | 0.25 | 1 | 2.7 |
| 12 | Telayan | 0.3 | 0.15 | 0.1 | 0.25 | 1 | 1.8 |
| 14 | Peninting A | 0.9 | 0.45 | 0.1 | 0.25 | 1 | 2.7 |
| 15A | Dusun A | 0.9 | 0.45 | 0.1 | 0.25 | 1 | 2.7 |
| 15B | Dusun D | 0.9 | 0.45 | 0.1 | 0.25 | 1 | 2.7 |
| 17A | Antang A | 0.3 | 0.15 | 0.1 | 0.25 | 1 | 1.8 |
| 17B | Antang B | 0.9 | 0.45 | 0.1 | 0.25 | 1 | 2.7 |
| Division 4. Ayerbandong – Mandilang | | | | | | | | |
| 21A | Mandilang A | 0.9 | 0.45 | 0.1 | 0.25 | 1 | 2.7 |
| 21B | Mandilang B | 0.9 | 0.45 | 0.1 | 0.25 | 1 | 2.7 |
| 21C | Mandilang C | 0.9 | 0.45 | 0.1 | 0.25 | 1 | 2.7 |
| 22A | Ayerbandong A | 0.9 | 0.45 | 0.1 | 0.25 | 1 | 2.7 |
| 22B | Ayerbandong B | 1.5 | 0.45 | 0.1 | 0.25 | 1 | 3.3 |

3.2. Socio-economic index
The economic value of a mangrove ecosystem is defined by the function of a mangrove ecosystem in supporting economic activities and the daily life of the local people living nearby. The social benefits of the mangrove ecosystem can be classified as direct and indirect benefits. The direct benefit is defined by the use of mangrove trees for firewood (Tancang or *Rhizophora* sp.), traditional rooftop or thatching (*Nypa fruticans*), and construction materials (*Sonneratia* sp. and *Rhizophora* sp.). The indirect benefit defined as protection and conservation function of mangrove area as well as a nursery ground for larvae and juveniles of fishes and crustaceans and feeding ground for some marine biota. Mangrove functions also as a spawning ground for some marine biota. The Social Index of Mangrove in the study area ranges from 1.82 to 4.15. The highest index was found in the north of Peninting, and the lowest index at the estuary of Antang river. The detail of the socio-economic parameters was shown in Error! Not a valid bookmark self-reference.10.

3.3. ESI for mangrove ecosystem
ESI for mangrove was defined as a composite calculation by vulnerability index, ecological index, and social-economic index. The multiplication of those indexes is a composite ESI, as listed in. The ESI classes were varied from moderate to very sensitive. Mangrove ecosystem at West of Batu Ampar A, and Peninting A are classified as very sensitive, while Mangrove in Antang and Mandilang B are
categories as moderate, and other areas categorized as sensitive. Based on survey ESI class from moderate to very sensitive. The moderate areas are Telayang and Antang Cape, and the very sensitive area is Ayerbandong A and Ayerbandong B.

Table 10. Social-economic Index for Mangrove Ecosystem

| No.  | Unit of Analysis         | Tourism potential | Fishing activities | Other use of mangrove | SV     | Biomass | Quality (%) | Resource economic value (USD ha/year) | EcV | SI   |
|------|--------------------------|-------------------|-------------------|-----------------------|--------|---------|------------|--------------------------------------|-----|------|
|      |                          |                    |                   |                       |        |         |            |                                      |     |      |
|      | Division 1. Matak Jetty  |                    |                   |                       |        |         |            |                                      |     |      |
| 4A   | Batu Ampar A             | 4                  | 4                 | 4                     | 4      | 1,312.82| 49.58      | 31,488.48                           | 3.00| 3.46 |
| 4B   | Batu Ampar B             | 4                  | 4                 | 4                     | 4      | 1,956.98| 73.91      | 46,938.90                           | 4.00| 4.00 |
| 6A   | Payalaman A              | 3                  | 3                 | 4                     | 3.3    | 1,905.50| 71.96      | 34,278.10                           | 3.00| 3.15 |
|      |                          |                    |                   |                       |        |         |            |                                      |     |      |
|      | Division 2. Matak Strait |                    |                   |                       |        |         |            |                                      |     |      |
| 9A   | Durian Bay A             | 3                  | 3                 | 4                     | 3.3    | 2,647.85| 100.00     | 47,632.26                           | 4.00| 3.63 |
| 10B  | Butun B                 | 3                  | 3                 | 4                     | 3.3    | 1,779.10| 67.19      | 32,004.29                           | 3.00| 3.15 |
|      |                          |                    |                   |                       |        |         |            |                                      |     |      |
|      | Division 3. Peninting Strait |                |                   |                       |        |         |            |                                      |     |      |
| 11A  | Sedak A                 | 4                  | 4                 | 4                     | 4      | 984.04  | 37.16      | 23,602.57                           | 2.00| 2.83 |
| 11B  | Sedak B                 | 4                  | 4                 | 4                     | 4      | 769.32  | 29.05      | 18,452.43                           | 2.00| 2.83 |
| 12   | Telayan                  | 5                  | 3                 | 4                     | 3.91   | 429.44  | 16.22      | 10,859.49                           | 1.00| 1.98 |
| 14A  | Peninting A             | 4                  | 5                 | 5                     | 4.64   | 2,397.52| 90.55      | 61,945.84                           | 5.00| 4.82 |
| 15A  | Dusun A                 | 4                  | 5                 | 4                     | 4.31   | 2,030.66| 76.69      | 52,467.10                           | 5.00| 4.64 |
| 15B  | Dusun D                 | 4                  | 5                 | 4                     | 4.31   | 753.36  | 66.22      | 45,302.38                           | 4.00| 4.15 |
| 17A  | Antang A                | 3                  | 3                 | 4                     | 3.3    | 984.04  | 37.16      | 17,701.93                           | 2.00| 2.57 |
| 17B  | Antang B                | 3                  | 4                 | 3                     | 3.3    | 492.02  | 18.58      | 9,741.75                            | 1.00| 1.82 |
|      | Division 4. Ayerbandong – Mandilang |          |                   |                       |        |         |            |                                      |     |      |
| 21A  | Mandilang A             | 3                  | 4                 | 4                     | 3.63   | 1,753.36| 66.22      | 34,715.64                           | 3.00| 3.30 |
| 21B  | Mandilang B             | 3                  | 4                 | 4                     | 3.63   | 1,476.06| 55.75      | 29,225.24                           | 3.00| 3.30 |
| 21C  | Mandilang C             | 4                  | 4                 | 4                     | 4      | 764.39  | 66.63      | 42,319.56                           | 4.00| 4.00 |
| 22A  | Ayerbandong A           | 4                  | 4                 | 5                     | 4.31   | 1,590.12| 60.05      | 38,139.63                           | 4.00| 4.15 |
| 22B  | Ayerbandong B           | 4                  | 4                 | 5                     | 4.31   | 1,716.52| 64.83      | 41,171.38                           | 4.00| 4.15 |

Remarks: SV = Social Value; EcV = Economic Value; SI = Social-economic Index
Table 11. Environmental Sensitivity Index for Mangrove Ecosystem

| No. Unit Analysis | Unit Analysis | ESI Component | ESI | ESI Class 2014 | ESI Class 2012 | ESI Class 2009 |
|------------------|--------------|---------------|-----|----------------|----------------|----------------|
|                  |              | VI | EI | SI |                |                |                |
| Division 1. Matak Jetty |              | 5  | 2.7 | 3.46 | 46.71 | Sensitive | Sensitive | Very Sensitive |
| 4A               | Batu Ampar A | 5  | 2.7 | 4.00 | 54.00 | Sensitive | Sensitive | Sensitive |
| 6A               | Payalaman A  | 5  | 2.7 | 3.15 | 42.53 | Sensitive | Sensitive | Sensitive |
| Division 2. Matak Strait |              | 5  | 2.7 | 3.63 | 59.90 | Sensitive | Sensitive | Sensitive |
| 9A               | Durian Bay A | 5  | 2.7 | 3.63 | 59.90 | Sensitive | Sensitive | Sensitive |
| 10B              | Butun Bay B | 5  | 2.4 | 3.15 | 37.80 | Sensitive | Sensitive | Sensitive |
| Division 3. Peninting Strait |            | 5  | 2.4 | 3.15 | 37.80 | Sensitive | Sensitive | Sensitive |
| 11A              | Sedak A      | 5  | 2.7 | 2.83 | 33.96 | Sensitive | Sensitive | Sensitive |
| 11B              | Sedak B      | 5  | 2.7 | 2.83 | 38.21 | Sensitive | Sensitive | Sensitive |
| 12               | Telayan      | 5  | 1.8 | 1.98 | 17.82 | Moderate | Moderate | Moderate |
| 14A              | Peninting A  | 5  | 2.7 | 4.82 | 65.07 | Very Sensitive | Very Sensitive | Very Sensitive |
| 15A              | Dusun A      | 5  | 2.7 | 4.64 | 62.64 | Sensitive | Sensitive | Very Sensitive |
| 15D              | Dusun D      | 5  | 2.7 | 4.15 | 56.03 | Sensitive | Sensitive | Sensitive |
| 17A              | Antang A     | 5  | 1.8 | 2.57 | 23.13 | Moderate | Moderate | Sensitive |
| 17B              | Antang B     | 5  | 2.7 | 1.82 | 24.57 | Moderate | Moderate | Moderate |
| Division 4. Ayerbandong – Mandilang |          | 5  | 2.7 | 3.30 | 44.55 | Sensitive | Sensitive | Sensitive |
| 21A              | Mandilang A  | 5  | 2.7 | 3.30 | 44.55 | Sensitive | Sensitive | Sensitive |
| 21B              | Mandilang B  | 5  | 2.7 | 3.30 | 44.55 | Sensitive | Sensitive | Sensitive |
| 21C              | Mandilang C  | 5  | 2.7 | 4.00 | 54    | Sensitive | nad    | nad    |
| 22A              | Ayerbandong A| 5  | 2.7 | 4.15 | 56.03 | Sensitive | Sensitive | Sensitive |
| 22B              | Ayerbandong B| 5  | 3.3 | 4.15 | 68.48 | Very Sensitive | Sensitive | Sensitive |

Remarks: VI = Vulnerability Index; SI = Social-economic Index; EI = Ecological Index; ESI = Environmental Sensitivity Index; Nad = Not available data

Table 11 shows the values ESI and sensitivity levels of each unit of analysis in the study area. It shows that based on the 2012 study, the mangrove ecosystem in the study area have a sensitivity level ranges from moderate to very sensitive. Compare to the distribution of sensitivity levels in the 2009 study, and it can be seen that there are changes in sensitivity level at Batu Ampar A, Telayan, Antang B and Mandilang B. Significant difference of ESI in 2014 is observed at Ayerbandong B due to increasing of mangrove width and tree diameter species of Rhizophora sp. and Bruquiera sp.

The sensitivity level in Matak Jetty division ranges from less sensitive to very sensitive. The less sensitive is found along the rocky shoreline with low economic activities. In contrast, the sensitivity level is located in the mangrove area, which is highly essential both from an ecological and economic point of view. The Sensitive level is the mangrove ecosystem in Batu Ampar. The waters area of the bay is classified as a moderate level to sensitivity, while local people utilized the area as a fishing
ground. The fishing activities of local people consider as the main economic factor which determined the moderate level of sensitivity.

ESI status in Matak Strait Division, the dominant level of sensitivity is Moderate. The Sensitive level is only limited to a small area of mariculture activity of Butun Bay and Pian Pasir. The waters site of this division is classified as moderate in level of sensitivity since the area is ecologically and economically important but at a moderate level of intensity. The area is also used by local people as fishing ground but not at an intensive level.

ESI value in Peninting strait division, the sensitivity level range is moderate to very sensitive. Most of the shoreline types are categorized as less sensitive since they are dominated by the rocky substrate. The sensitive levels are found in Tarempa, Momong Cape, Tebu Cape, Antang, and Sedak. The very sensitive level is found in Tebu Cape for its tourism site, in an area between Dusun to Mabay bay, where a combination of sandy and muddy substrate inhabited by mangrove and coral reef ecosystems; Peninting, for its mangrove ecosystem and Tarempa A for its settlements.

The last ESI Ayerbadong and Mandilang division, the sensitivity level range from moderate to sensitive. This result shows changes of ESI for Ayerbadong B from a sensitive to very sensitive due to the increase of mangrove biomass. Locations that have the highest ESI value are those with the highest ecological risk. The area must be given the earliest priority in efforts to protect against various potential pollution. Locations with a lower index indicate low environmental risk and low impact on the ecosystem.

4. Conclusions
Typically for islands in the north part of Matak Island, they are characterized by rocky shoreline since they directly face the open sea of South China Sea. No mangrove ecosystem has been found in this division due to the rough hydrodynamics environment. Open waters in this area are part of the South China Sea, which is habitat for protected wildlife, i.e., the bottlenosed-Dolphin (Tursiops sp.) and Hawksbill sea turtle (Eretmochelys imbricata); hence the area is classified as very sensitive. The mangrove sensitivity range from moderate to very sensitive in two sites in which the highest are in Peninting and Ayerbadong. The other site show as sensitive dan moderate. The highest percentage of the sensitive area shows that this ecosystem potential to have an impact on human or other failure activity in offshore or nearshore. To avoid and decease of sensitivity needed a strategic plan and mitigation of pollution impact on the mangrove ecosystem.

References
[1] Kasperson. 2001. International Workshop on Vulnerability and Global Climate Changes : Workshop Summary. Stockholm Environmental Institute. Stockholm, Sweden.
[2] Nijkamp, P. and Ron Vreeker. Sustainability Assessment of Development Scenarios: Methodology and Application to Thailand. Ecological Economics, 2000; 33: 7-27.
[3] Van Pelt, J., Uylings, H. B., Verwer, R. W., Pentney, R. J., & Woldenberg, M. J. (1992). Tree asymmetry—a sensitive and practical measure for binary topological trees. Bulletin of mathematical biology, 54(5), 759-784.
[4] PKSPL-IPB dan KLH. 1999. Valuasi Ekonomi Sumberdaya Pesisir dan Lautan Barelang dan Bintan. Kementerian Lingkungan Hidup Republik Indonesia.
[5] Sloan, N.A. 1993. Effects of Oil on Marine Resources, Literature Study from the World Relevant for Indonesia. EMDI Project, Indonesia Ministry of Environment.
[6] Jupiter S, S Phinn, N Duke, D Poots. 2006. Changing mangrove distribution in the pioneer estuary (Quesland, Australia) evaluation a technique for monitoring mangrove health. Proceeding of 10th International Coral Reef Symposium. 1727-1731.
[7] Bengen, DG. 2000. Teknik Pengambilan Contoh dan Analisis Data Biofisik Sumberdaya Pesisir. Pusat Kajian Pesisir dan Lautan. Fakultas Perikanan dan Ilmu Kelautan, Institut Pertanian Bogor. Bogor. 88 hlm.
[8] Noor, Y.R., M. Khazali, dan N.N. Suryadiputra. 1999. Panduan Pengenalan Mangrove di
Indonesia. Wetlands International Indonesia Programme, Bogor

[9] Kathiresan, K. 2007. Important of Mangrove Ecosystem. P.136-168 Centre of Advanced Study in Marine Biology Annamalai University.

[10] Fabiyi, O. 2008. Mapping Environmental sensitivity index of the Niger delta to oil spill; the policy, procedures and politics of oil spill response in Nigeria. Paper on Department of Geography, University of Ibadan Seminar. Nigeria. P 1-20.

[11] NOAA. 1997. *Environmental Sensitivity Index Guidelines, Version 3.0*. NOAA Technical Memorandum NOS ORCA 115. Seattle: Hazardous Materials Response and Assessment Division, National Oceanic and Atmospheric Administration. 79 pp. + appendices.

[12] Klein, A.H.F. Petermann, R.M.; Araujo, R.S.; Silva, A.F.; Oliveira, T.C.R.; Menezes, J.T. & Sperb, R.M. 2003. Environmental Sensitivity Index (ESI) Maps for The Shorelines of the State of Santa Catarina, Southeastern Brazil.

[13] Wahyudin, Y., Damar, A., Rustandi, Y., Afandy, A., Rakasiwi, G., & Rikardi, N. (2019). Coastal and River Basin Environmental Sensitivity Area Mapping (CARBESAM). *Journal on Marine and Fisheries Social Ecological System (JoMFiSES–1 (August 2019) 1-28).

[14] Grigalunas, T.A. and R. Congar. 1995. Environmental Economics for Integrated Coastal Area Management: Valuation Methods and Policy Instruments. UNEP Regional Seas Reports and Studies No. 164. UNEP.

[15] PKSPL-IPB & Kabupaten Maluku Tenggara Barat. 2005. *Kajian Daya Dukung Lingkungan Pulau Kecil di Pulau Wetar*. Joint Program of PKSPL-IPB and Kabupaten Maluku Tenggara Barat.

[16] Nybakken, J. W. 1982. *Biologi Laut, Suatu Pendekatan Ekologis*. Terjemahan : Koesoebiono, D. G. Bengen, M. Eidman, M. Hutomo, dan S. Sukardjo. PT Gramedia Pustaka Utama. Jakarta. 168-184 h.