Biodiversity in the coastal ecosystems of small islands and its conservation status

Suyadi1*, D A Nugroho1, A Irawan2, D Pelasula2, F Ruli2, M M Islami2, R Alik2, D J. Tala2, L Pay2, C Matuankotta2, A S Leatemia2, and I Naroli2

1Research Center for Biology - Indonesian Institute of Sciences (LIPI), Jl. Raya Bogor km 46, Cibinong 16911, Bogor, Jawa Barat, Indonesia
2Research Center for Deep Sea - Indonesian Institute of Sciences (LIPI), Jl. Y. Syaranamual, Guru-guru, Poka, Ambon, Maluku, Indonesia

*E-mail: suya009@lipi.go.id, yadi_pdt@yahoo.com

Abstract. Around 77% of Indonesian islands is small islands and Indonesia known as mega biodiversity center, but coastal biodiversity of small islands was not well documented. The objective of this study is to assess coastal biodiversity in small islands and its conservation status.

The study indicated that small islands provide complex biodiversity ranging from ecosystem to species. Diversity index of mangrove: 1.4–1.8, seagrass: 1.5–1.9, coral: 1.7–2.3. Ecosystem condition in urban small island was poor and in rural small island was healthy. The islands also provide fauna diversity i.e mollusc (110 species), crabs (52 species), and coral fish (261 species). Diversity of mollusc and crabs in rural island was higher than in urban island, χ² (1) = 1.3, p< 0.001 and χ² (1) = 4.3, p< 0.002, respectively. Diversity index of coral fish range from 2.14 to 4.27 (mean: 3.4). Most of the biodiversity located outside protected area and main threats were ecosystem degradation, pollution, overexploitation, and sedimentation. In conclusion, small islands are important coastal biodiversity spots, but it faces tremendous threats. The study recommends better management of coastal biodiversity i.e. establishing coastal protected areas in small islands, building marine corridor, and public awareness to ensure biodiversity conservation.

1. Introduction

Indonesia is known as archipelago country (17,504 islands) which 77% of the islands categorized as small islands (< 2.000 km²) [1,2]. Indonesia is a tropical country located between Asia and Australia Continent, between Indian and Pacific Ocean, and on the pacific ring of fire [3]. These geographic positions make Indonesia rich in biodiversity, therefore it is also known as mega biodiversity centre [3]. Based on the biogeography of flora and fauna, Indonesian territory was grouped into seven bioregions of biodiversity which each bioregion has their own unique characteristics and high number of endemic species [3]. There are three types of biodiversity: ecosystems, species, and genetic biodiversity. Indonesian biodiversity is complex and varied ranging from sea to mountain including marine, coastal, freshwater, and terrestrial. Coastal ecosystem includes mangroves, coral reefs, and seagrass. Indonesia has the largest mangrove area in the world (23%) and habitat for 67% of global mangroves [4-6]. Around 450 species of various coral (soft coral, stone coral, and gorgonian) can be found in Indonesia. The estimation of coral reef area in Indonesia varies ranging from 51.000 km² to 85.000 km² [3]. Coral define as calcareous skeleton secreted by certain marine polyps characterized as
hard and bright various colour underwater structure grow in warm water [7]. Coral reef is shallow water habitat or marine ecosystem characterized by both physical structure (dead corals) and living corals/organism [7]. Indonesia is also rich with other marine fauna, such as crustaceans with 309 species, and fishes with 3,476 species [3].

Biodiversity provide wide range benefits for human life such as ecological values and economical values. For example, biodiversity is important raw material for many products including drugs, food, craft, energy, and textile. Many species are known as bio-indicator for environmental health and play important role in ecosystem balance. However, biodiversity faced various threats due to human activities that caused ecosystem degradation, over exploitation, pollution, sea level rise, and rising seawater temperature. Many of ecosystems are degraded, for example 40% of mangrove was loss [8] and 71% of coral reef was in poor condition [9]. It is estimated that 84–94% of Indonesian endemic species decreased [3]. The biodiversity degradation caused various direct and indirect impacts for human life such as carbon emission (climate change), disaster due to environmental degradation and ecosystem unbalance, and zoonosis outbreak [8,10,11].

Indonesia has the second longest coastline (99,093 km) in the world with large area of coastal especially in small islands [12-14]. The majority of small islands in Indonesia located in eastern Indonesia such as Maluku which most of this region is small islands (1,411 islands) including Ambon and Moa [15]. Maluku especially Banda Sea is one of important Indonesian Through Flow (ITS) connected Indian and Pacific Ocean [16,17]. This region has important rule for regional and global climatic regulation and also known as one of coral triangle sites with high biodiversity [14,18-21]. A study based on model approach showed eastern part of Indonesia is biodiversity spot for marine biota [22]. Banda Sea provides a lot of biological resources such as commercial fishes and mineral resources that important to support economic development [23]. However, attention on the coastal biodiversity of small islands and its conservation status were low, consequently, many research gaps on this area should be filled.

Although Indonesia has high number of small islands and coastal areas, study on biodiversity and it conservation status in coastal area of small islands is still limited. The objective of this study is to determine the biodiversity (mangrove, seagrass, coral reef, mollusc, crabs, and fish) in coastal area of two small islands and its threats. This study is to help government, local conservation manager, and local decision maker to develop integrated coastal management and conservation.

2. Methodology
The study was undertaken in Ambon (3°40’12.4’S and 128°10’57.4”E) and Moa (8°12’45.4’S and 127°50’33.7”E), located in Maluku Province, Indonesia (figure 1). Ambon and Moa situated in Banda Sea and Timor Sea that connected Indian and Pacific Ocean. Ambon (804 km²) is an urban small island with tidal range 0.23–2.12m, current ranging from 0.13–1.1 m sec-1, wave up to 2m, temperature (27.20°C–31.10°C), mean precipitation is 456 mm, and mean salinity is 34.22 ‰ [24,25]. Moa (960 km²) is rural small island in the southern of Maluku with tidal range 0.9–2.4 m, current ranging from 0.13–1.31 m sec-1, wave up to 4m, temperature (24–48°C), mean precipitation is 412 mm, and mean salinity is 35.3‰ [26]. Ambon and Moa are subject of two seasons: northwest monsoon (November to March) and southeast monsoons (May to September) with the transitional season occurred in October and April [23,25].
GIS/Remote Sensing and transect were applied to achieve the objectives (figure 2). Landsat Operational Land Imager (OLI) images year 2019 was used to estimate the area of mangrove, seagrass, and coral reef. The images were downloaded from the US Geological Survey (USGS) Website (https://earthexplore.usgs.gov). The integrated Maximum Likelihood Classification and Knowledge-Based Classification (Improved Image Analysis) were applied for image classification and Sagawa water column correction was used to minimize the water column effects [27].

Transects were applied in Ambon (Suli, Waiheru, Passo, Negeri Lama) and Moa (Moa 1/Tiakur, Moa 2/Patti, Moa 3/Klis, Moa 4, Moa 5/Kaiwatu, Moa 7/Siota, and Leti) to collect data of mangrove, seagrass, coral reef, mollusc, crabs, and coral fishes. A purposive random sampling was applied to select the location of transect to represent variation of ecosystem and local environment conditions. Mangrove data were collected from a total 66 plots (10m × 10m) located along seven transects in Ambon and Moa. Data collected from the plots were species of mangrove, stem diameter (DBH = 1.3m aboveground), tree height, canopy coverage, number of cut trees, and coverage of plastic debris. Nine photos of mangrove canopy in nine locations inside each plot were taken, then processed using ImageJ software (downloaded from http://imagej.nih.gov/ij/download.html) to calculate the canopy coverage.

Figure 1. Study area of Ambon and Moa, Maluku Province, Indonesia.
Figure 2. Flowchart of methods: GIS-Remote sensing, Transects, and Quadrates.

Quadrates (50 × 50cm) were placed along total 14 transects in seagrass areas of Ambon and Moa with the distance among quadrates was 10m. Data of seagrass includes species, diversity, coverage, and density of seagrass were collected in the quadrates. Underwater Photo Transect (UPT) was applied in Ambon and Moa [28-30]. A total of 15 transects were placed on coral reef perpendicular of coastline in Ambon and Moa. Data were collected using underwater camera to capture coverage of coral reef at the ground size of 50 × 50cm. Around 1,750 photos of coral reef coverage were analysed using Coral Point Count Excel developed by Nova University, Davie, FL, USA [31] to analyse reef benthic coverage and then used to assess diversity index and coral reef health.

Data of mollusc and crabs were collected along the transects. Sample of mollusc and crabs then preserved in alcohol 70% and identified in a lab based on Wye [32] and Dharma [33] for mollusc and based on Naderlou [34] and Rahayu & Setyadi [35] for crabs. Data of coral fishes were collected using Underwater Visual Census (UVC) developed by Dartnall & Jones [36] and Hourigan et al. [37]. The UVC was conducted along the coral reef transects (2.5 m on each side of transects). We also took photos and videos using underwater Camera (Canon Power Shot G.15). The fishes were identified based on Allen [38], Allen et al. [40], and Froese and Pauly [40]. Following English et al. [41], Coral fishes were classified as target fish, indicator fish, and major fish.

Data were analysed to assess diversity index using Shanon-Weaver diversity index, important value index, and vegetation health [42-45]. Following the national standard of mangrove health published by Ministry of Environment Republic Indonesia No. 201 Year 2004 [46], parameters used to assess mangrove vegetation health were tree density and canopy coverage. Criteria developed by Wilkinson et al. [47] were applied to assess coral reef health based on coverage: poor (0–24.9%), moderate (25–49.9%), good (50–74.9%), and very good (75–100%). Density and equability index of coral fishes was calculated using method described in Odum [44]. Kruskal-Wallis and a Bonferroni post-hoc test were applied to determine if significant differences in biodiversity occurred between Ambon (urban small island) and Moa (rural small island). Hierarchical cluster analysis was used to assess the similarity of mollusc and crab biodiversity between the islands.
3. Result and discussion

3.1. Coastal ecosystem (mangrove, seagrass, coral reef)
Coastal areas of small island of Ambon and Moa have three main coastal ecosystems: mangrove, seagrass, and coral reef. The spatial analysis in this study revealed that mangrove area in Ambon was 58 ha, mostly located in Ambon Bay few in Baguala Bay and in the north of the island (figure 1). Mangrove area in Moa was 6 ha mainly located in the north and east of the island. However, this estimation possibly underestimated due to the exclusion of small patches of mangrove because small patches cannot be detected using Landsat images. Mangrove in both islands was characterised as small patches of mangrove (mean patch sizes 3 ha). Mangrove zonation and hydrological categories of mangrove (delta mangrove, riverine mangrove, and estuarine mangrove) were not clear due to most of mangrove in these small islands grow along the coastline. The spatial characteristics of mangrove in small islands as described above are different from large islands such as Weda Bay, in Halmahera Indonesia, or Auckland, New Zealand which typically have larger patches, form zonation, and can be categorized as delta, riverine, and estuarine mangrove [48].

This study found 15 species of mangrove in Ambon and 5 species in Moa. The diversity index of mangrove in Ambon was 1.8 (moderate diversity) and in Moa was 1.4 (low diversity). Previous study showed that the number of mangrove in Moa was 11 species [26]. The most common species of mangrove in Ambon and Moa was Rhizophora apiculata, with important value index was 87.9 and 71.5, respectively. Some mangrove species such as Xylocarpus moluccensis and Camptostemon schultzii are listed in the IUCN as endangered species [49]. Mean diameter of mangrove trees in Ambon and Moa were 19cm and 16cm, respectively, ranging from 5cm to 36cm. The mean tree height in Ambon and Moa were 8m and 7m, respectively, ranging from 3m to 10m. Compare to mangrove in large islands such as in Sundarbans, India and Segara Anakan, Indonesia [50,51], the size of mangrove in these islands are smaller. However, mangrove in these small islands are much higher than mangrove located in temperate region [48]. Following the national standard of mangrove health in Indonesia described in KLH RI No. 201 Year 2004 [46], mangrove vegetation (Table 1) in Ambon was categorized as poor or unhealthy (canopy coverage < 50 and density < 1000) and mangrove in Moa was categorized as moderate (canopy coverage > 50 and density > 1000). Mangrove in Ambon was degraded due to some tremendous threats such as mangrove conversion to infrastructure development, pollution (plastic, oil), and sedimentation [52].

This study found 6 species of seagrass in Ambon (diversity index was 1.5; low) and 10 species in Moa (diversity index: 1.92: moderate). The number of species found in this study was higher than previous studies which reported only 6 species of seagrass in Moa [26]. The dominant species in Ambon was Enhalus acoroides and in Moa was Thalassia hemprichii. Species of E. acoroides known as cosmopolite species grow in wide range of habitat while T. hemprichii grows in sandy and gravel area [53,54]. An endemic species of seagrass, Thalassodendron ciliatum, was found in Moa, but it was not found in Ambon. This species is found only in eastern Indonesia especially in Maluku and Nusa Tenggara [55].

The density of seagrass in Ambon and Moa ranging from 0.4–386.2 stand/m² (mean: 243.7 stand/m²). This density is fall within the range observed in some other small islands in Maluku Barat Daya [26]. However, it is much higher than density of seagrass in small island of Lirang, Maluku, 139.6 stand/m² [45]. The coverage of seagrass ranging from 0.7 to 91% (mean coverage for Ambon: 48% and Moa: 67%). The density and coverage indicate that seagrass in Moa was healthier than in Ambon. Compare to seagrass in another small island such as Lirang, seagrass in Ambon was less healthy and seagrass in Moa was healthier than in Lirang Island. Although overall condition of seagrass in Moa relatively healthy, we found that seagrass in some sites such as Tiakur /Moa 1 (54.55%), Kaiwatu / Moa 5 (47.14%), and Pati/Moa 2 (49%) were unhealthy.
Table 1. Characteristics of coastal ecosystem (mangrove, seagrass, and coral reef).

|                      | Ambon | Moa |
|----------------------|-------|-----|
| **Mangrove**         |       |     |
| Number of species    | 15    | 5   |
| Mangrove area (ha)   | 58    | 6   |
| Diversity index* / H’| 1.8   | 1.4 |
| Tree density (ha y\(^{-1}\)) | 846  | 523 |
| Canopy coverage (%)  | 43    | 56  |
| Mean tree diameter (cm) | 19   | 16  |
| Mean tree height (m) | 8     | 7   |
| **Seagrass**         |       |     |
| Number of species    | 6     | 10  |
| Diversity index* / H’| 1.5   | 1.92|
| Seagrass area (ha)   | 258   | 783 |
| Coverage of seagrass (%) | 48   | 67  |
| Mean length of seagrass bed (m) | 75   | 70  |
| **Coral reef**       |       |     |
| Number of species    | 210   | 124 |
| Diversity index* / H’| 2.3   | 1.7 |
| Coral reef area (ha) | 416   | 2164|
| Coverage of coral reef (%) | 20   | 72  |
| Mean length of coral reef (m) | 78   | 58  |

*Shannon-Weaver diversity index

Coral reef ecosystem was distributed in many locations around Ambon and Moa. The study found 210 species (17 families) of coral in Ambon and 124 species (15 families) in Moa. Other studies conducted in small islands of Maluku Barat Daya found 216 species from 16 families of coral [26]. The dominant species of coral was *Porites cylindrica* followed by *Hydnophora rigida* and *Acropora hyacinthus*. The diversity index of coral in Ambon was moderate (H’ = 2.3) and in Moa was low (H’ = 1.7). The coverage of coral in Ambon was lower than in Moa (table 1) with coverage of life coral between 10.7 and 85.3%. Substrate was dominated by hard coral (mean 38%) and soft coral (27%). The diversity index and coverage of life coral indicate that coral in Moa was healthier than in Ambon, but further studies are required to ensure the health level of coral. Coastal ecosystem degradation happened in the last decade due coral mining, coastal development, and pollution [26].

3.2. Fauna biodiversity (mollusc, crabs, and fishes)

In this study, 33 species (19 families) of mollusc were found in Ambon and 100 species (45 families) in Moa. Most of molluscs in Ambon are associated with mangrove ecosystem. Gastropod was the most dominant in Ambon and Moa with 23 species (12 families) and 89 species (37 families), respectively. Bivalve was the co-dominant mollusce with 10 species (7 families) in Ambon and 11 species (8 families) in Moa. Neritidae (6 species) was the most common family in the study area, followed by Nassariidae (3 species). Although there were only two species of Potamidiidae, *Cerithidea obtusa* and *Terebralia sulcata*, these species were the most abundant with 98 and 95 individuals, respectively. The hierarchical
cluster analysis (Figure 3a) showed that diversity of mollusc in Ambon and Moa has similarity around 40%. Diversity of mollusc in Moa was significantly higher than in Ambon ($\chi^2(1) = 1.3, p < 0.001$).

About 25 species (16 genera, 9 families) of crabs were found in Ambon, which *Austruca triangularis* (Ocypodidae) and *Parasesarma indiarum* (Sesarmidae) were the most dominant crabs. Crabs in Ambon were mostly associated with mangrove. High diversity of crabs in Ambon occurred between Ambon Bay (Negeri Lama, Passo, and Waiheru) and Baguala Bay (Suli) which the similarity was less than 50% (Figure 3b). Ambon Bay is a closed bay with low tide and wave, and low current, mostly mangrove area, and most of the habitat is muddy substrate, in contrast, Baguala Bay is an opened bay directly connected to Banda Sea has high tide, wave, and current with sandy substrate [23,25]. The study found 40 species (31 genera, 16 families) of crabs in Moa. Some species of Xanthidae (*Atergatis floridus*, *Etisus sp.*, *Actaeodes sp.*, and *Lachnopodus sp.*) were the most dominant species in Moa. Crabs in Moa were mostly associated with seagrass and coral reef. The dendogram of cluster analysis (Figure 3b) showed that the similarity of crabs in Moa 1 (Tiakur) was less than 30% to other sites in Moa. Our visual observation showed that environment disturbance in Moa 1 (Tiakur) was more prominent than other sites. This is due to this site is close to the most developed and populated area in Moa island.

![Dendogram of hierarchical cluster analysis for similarity of mollusc (a) and crabs (b) diversity in Ambon (urban small island) and Moa (rural small island).](image)

This study showed that Moa was inhabited by 261 species (27 families) of coral fishes. This number of species was higher than reported previously, range 93–165 species in Moa [26,42]. The most common species of fish in Moa was *Pterocaesio tile*, followed by *Caesio lunaris*, *Caesio pisang*, and *Caesio teres*. The most abundant were *Chromis ternatensis* and *Melichthys niger*. About 49% of fish was categorized as major fish, 42% was target fish, and 9% was indicator fish. Major fish is relatively small and many of them used as ornament (ornamental fish), target fish is known as economically important fish for consumption, and indicator fish is ecologically important because it is associated with coral reef
and known as bio indicator of coral reef health [26,42]. The diversity analysis (table 2) showed that the diversity index of coral fish in Moa ranging from 2.14 to 4.27 (mean: 3.4), the equability index was between 0.02 and 0.23 (mean: 0.10), and the density of fish was 61 individu ha$^{-1}$ to 92 individu ha$^{-1}$ (mean: 73 individu ha$^{-1}$). These mean that the diversity and density of coral fish in the study area were high, but the population was not distributed equally, possibly due to unstable conditions or pressure in some areas. This finding is supported by Arief & Edrus [42] and Estradivari et al. [26] that the diversity and the density of coral fish in small islands such as in Maluku Barat Daya was high, but they face tremendous threat due to blast fishing and habitat destruction [26,42].

### Table 2. Diversity and density of coral fishes.

| Sampling sites | Diversity index | Equability index | Density (indv. ha$^{-1}$) |
|----------------|-----------------|-----------------|--------------------------|
| Leti           | 3.92            | 0.06            | 83                       |
| Moa 1.         | 3.12            | 0.15            | 63                       |
| Moa 2.         | 4.19            | 0.02            | 85                       |
| Moa 3.         | 3.12            | 0.11            | 67                       |
| Moa 4.         | 4.30            | 0.02            | 92                       |
| Moa 5.         | 3.25            | 0.08            | 65                       |
| Moa 7.         | 2.14            | 0.23            | 61                       |
| **Mean**       | **3.41**        | **0.10**        | **73**                   |
| **Min**        | **2.14**        | **0.02**        | **61**                   |
| **Max**        | **4.30**        | **0.23**        | **92**                   |

### 3.3. Challenges of biodiversity conservation

The major threats of coastal biodiversity in Ambon and Moa were overexploitation (e.g. blast fishing, potassium, and coral mining), coastal ecosystem conversion and mangrove deforestation, pollution (e.g. plastics and oil spill), illegal logging, and sedimentation. Some threats such as plastic and oil pollution, coastal ecosystem conversion and mangrove deforestation, and sedimentation were more prominent in Ambon than in Moa. Blast fishing, potassium, and bore (akar tuba) were the most common practices of fishing caused coastal biodiversity degradation particularly coral fishes and coral reef. Coral mining, sedimentation, and plastic pollution were other threats of coral. Spatial competition of coral and sponge was the most dominant caused of coral damaged (4.15%), followed by sedimentation (2.86%) and ulcerative white spots (0.02%) [26]. It is predicted that these biodiversity threats will increase up to 75% [14]. Our study found that plastic coverage on the coral reef in Ambon was 1.68% and in Moa was 0.02%. Plastic debris was found in the digestive system of fish in Ambon and it is caused imposex for gastropod [56]. Around 60% of coral reef in the world was degraded due to anthropogenic activities such as over exploitation, coastal development, upland pollution, and marine pollution [57].

Ecosystem conversion into coastal infrastructure such as modern market, port, and housing were tremendous threats of mangrove and seagrass in Ambon. In the last decade, the annual mangrove deforestation rate in Ambon was 3 ha y$^{-1}$ [58]. Plastic pollution was also occurred in mangrove ecosystem and caused mangrove degradation because plastic covered seedlings and prevent photosynthesis [59,60]. Pollution was not only degraded coastal ecosystem and drive biodiversity loss, but also directly affects human health. For example, in 2004, around 30 people get sick and four of them died in Ambon after consuming mollusc collected in mangrove ecosystem [61,62].

Marine resources exploitation such as illegal fishing, coastal development, and pollution in small islands of Maluku was high [26]. It is more challenging because most of people in this region did not aware to these threats of biodiversity [26]. In 2015, the government of Indonesia declare seven protected areas in Maluku with total area 173,172 ha [26]. However, this protected area was not effective yet,
because it covers only 1% of the total area of marine environment in Maluku. Therefore, the functions of the protected areas for biodiversity and habitat protection were not optimal [63]. More marine protected areas especially in small islands which have high biodiversity and flagship species are crucial to ensure the conservation and sustainable use of marine resources for human well-being. Building corridors especially in the migration routes are good strategy to connect protected areas and to conserve the migratory species. Consideration to the biodiversity richness, flagship and migratory species, and local wisdom such as sasi for the selection of protected area and its management is important to ensure the effectiveness of the protected areas. Some small islands in Maluku Barat Daya are potential protected areas because it have high biodiversity and habitat for at least 15 flagship species such as whales (e.g. *Balaenoplera borealis*, *Balaenoplera musculatus*, *Megaptera novaeangliaei*, *Orcinus orca*, *Physeter catodon*), dolphins (e.g *Delphinus capensis*, *Globicephala macrorhynchus*, *Pseudorca crassidens*, *Tursiops truncatus*), Dugong (*dugong dugon*); sea turtles (e.g. *Chelonia mydas*, *Eretmochelys imbricata*) [26]. In addition, establishment of protected areas in Maluku Barat Daya is not only ecologically important, but also geopolitically and economically important because this region located in outer territory of Indonesia and to accelerate sustainable development in this new district region. Another strategy is providing public awareness for society living in small islands. It is important to improve knowledge and perception about biodiversity and habitat conservation.

4. Conclusions

Small islands are important coastal biodiversity spots due to the high biodiversity and provide wide range of biodiversity ranging from ecosystem to species diversity. Small islands were not only rich of biodiversity, but also habitat for many flagship species, and migration routes for many species of marine mammals, fishes, and turtles. Coastal biodiversity in small islands varied depend on local environmental conditions and threats. The main threats of biodiversity were coastal conversion into infrastructure development, pollution (plastic and oil spill), biodiversity overexploitation, and sedimentation. The threats and its impacts on biodiversity were more prominent in developed or urban small island (e.g. Ambon) than in rural small island (e.g. Moa). Most of biodiversity spots in small islands were located outside of protected areas. Some strategies to strengthen biodiversity and habitat conservation are recommended such as establishing more coastal protected areas in small islands, building marine corridor in migration routes to connect among protected areas, and public awareness for local communities. These strategies are required to ensure the conservation of biodiversity and sustainable used of this resources for human wellbeing now and for next generation.

Acknowledgments

All authors declare that Suyadi is the main contributor of this article and the others are member of contributor. This research was supported by DIPA Fund of Research Center for Deepsea – Indonesian Institute of Sciences (LIPI). We would like to thank Francy Nendissa, Kena Tamnge, Syaiba Ohoirenan, and Arman Uar for their assistance during fieldwork and labwork. Thanks also due to Dr. Nugroho Dwi Hananto (Acting Director of Research Center for Deepsea) and Dr. Augy Syahailatua (former Director of Research Center for Deepsea) for facilitate the research.

References

[1] Purba N P and Harahap S A 2016 *Kondisi Awal Perairan Pulau Gosong, Indramayu-Jawa Barat*. FPIK Universitas Padjadjaran Bandung Indonesia
[2] Undang-Undang Republik Indonesia Nomor 27 Tahun 2007 tentang Pengelolaan Wilayah Pesisir dan Pulau-Pulau Kecil Jakarta Indonesia
[3] Darjati W S, Pratiwi E, Herwinda A D, Radiansyah V S, Nalang B, Nooryanto J S, Rahajoe R, Ubaidillah I, Maryanto R, Kurniawan T A, Prasetyo A, Rahi J, Jefferson and Hakim F. 2016 *Indonesian biodiversity strategy and action plan* 2015–2020. Kementrian Perencanaan Pembangunan Nasional BAPPENAS Jakarta Indonesia
[4] Giri C, Ochieng E, Tieszen L L, Zhu, Z, Singh, A, Loveland, T and Duke, N 2011 Glob. Ecol. Biogeogr. 20(1) 154-159
[5] Noor Y R, Khazali M and Suryadiputra I N N 2006 Panduan Pengenalan Mangrove di Indonesia
[6] Thomas N, Lucas R, Bunting P, Hardy A, Rosenqvist A and Simard M 2017 PloS One 12(6)
[7] Spalding M, Spalding M D, Ravilious C and Green E P 2001 World atlas of coral reefs Prepared at the UNEP World Conservation Monitoring Cevter Univ of California Press Berkeley USA 15-18 pp
[8] Murdiyarso D, Purbopuspito J, Kauffman J B, Warren M W, Sasmito S D, Donato, D C and Kurnianto, S 2015
[9] Johnson P Dutton I, Murdiyarso D, Purbopuspito J, Kauffman J B, Warren M W, Sasmito S D, Donato, D C and Thomas Noor Y Giri C, Ochieng E, Tieszen L L, Zhu, Z, Singh, A, Loveland, T and Duke, N 2011 Glob. Ecol. Biogeogr. 20(1) 154-159
[10] Aldrian E 2008 Meteorologie Laut Indonesia Badan Meteorologi dan Geofisika Jakarta Pp 1 -20
[11] Wood C L and Lafferty K D 2013 Trends Ecol. Evol 28(4) 239-247
[12] Setiawan A, Agustiadi T, Abida R F, Theoyana T A, Annisaa T A, Sukadana G P, BIG / Badan Informasi Geospasial 2013 Laporan Tahunan PPKLPP BIG Bogor
[13] Pandey V K and Pandey A C 2006 Journal India Geophysical 10(4) 273-277
[14] Perner H, McConachy T, Priadi B, Parr J, Hananto N, Burhanuddin S and Sultan 2008 Jurnal Geologi Kelautan 69(2) 20-35
[15] Troa R, Sarmili L, Perner H and Triarso E 2013 Jurnal Geologi Kelautan 1(2) 11 - 26
[16] Asaad I, Lundquist C J, Erdmann M V and Costello M J 2018 Biol. Conserv. 222 (198-211)
[17] Suyadi, Gao J, Lundquist C J, Scwhendennmann L 2020 Estuaries Coast
[18] Suyadi, Gao J, Lundquist C J, Schwendennmann L 2020 Estuarine Coast and Shelf Science 222 (198-211)
[19] Gemilang WA, Rahmawan GA and Wisita UJ 2017 Kualitas perairan Teluk Ambon I. Enviro Scienteae 13(1) 79-90
[20] Ondara K, Wihsa U J and Rahmawan G A 2017 Jurnal Kelautan 10(1) 66-77
[21] Estradivari B Sumiono and Kikilily A (eds.) 2016 Status Ekologi, Sosial, Pemanfaatan dan Tata Kelola Sumber Daya Laut Kabupaten Maluku Barat Daya WWF-Indonesia Kementerian Kelautan dan Perikanan, Dinas Kelautan dan Perikanan Kabupaten Maluku Barat Daya Universitas Pattimura, Institut Pertanian Bogor Wildlife Conservation Society Jakarta Indonesia
[22] Suyadi, Gao J, Lundquist C J and Scwhendennmann L 2018b Int. J. Remote Sens. 39(1) 17-36
[23] Giyanto, Iskandar B H, Soedharma D and Suharsono 2010 Effisiensi dan akurasi pada proses analisis foto bawah air untuk menilai kondisi terumbu karang Oseanologi dan Limnologi di Indonesia 36(1) 111-130
[24] Giyanto 2012 Penilaian kondisi terumbu karang dengan metode transek foto bawah air Oseanologi dan Limnologi di Indonesia 38(3) 377-389
[25] Giyanto 2012 Kajian tentang panjang transek dan jarak antar pemotretan pada penggunaan metode transek foto bawah air Oseanologi dan Limnologi di Indonesia 38(1) 1-18
[26] Kohler K E and Gill S M 2006 Comput Geosc. 32(9) 1259-1269
[27] Wye K R 2000 The Encyclopedia of Shells Quarto Publishing Company London 288 p
[28] Dharma B 2005 Recent & Fossil Indonesian Shells ConcBooks Hackenheim 424 p

[34] Naderloo R 2017 Atlas of Crabs of the Persian Gulf
[35] Rahayu D L and Setyadi G 2009 Mangrove estuary crabs of the Mimika Region-Papua, Indonesia. PT Freeport Indonesia Papua 154pp
[36] Dartnall A J and Jones M 1986 A Manual of Survey Methods Living Resources in Coastal Area ASEAN-Australia Cooperative Program on Marine Science Handbook Australian Institute of Marine Science Townsville 167 pp
[37] Hourigan T F, Tricas T C and Reese E S 1988 Coral Reef Fishes as Indicators of Environmental Stress in Coral Reefs. In Soule D F and G. S. Kleppel (Eds) Marine Organisms as Indicators. Springer - Verlag New York Inc p 107-135
[38] Allen, G R 2000 Marine Fishes of South – East Asia. A Field Guide for Anglers and Divers Periplus edition
[39] Allen G R Steene R Humann P and Deloach N 2003 Reef Fish Identification Tropical Pacific New World Publication, Inc. Jacksonville, Florida USA
[40] Froese R and Pauly D 2000 Fish Base 2000, Concepts, design and data sources ICLAR, Los Banos Laguna Philippines
[41] English S C Wilkinson and Baker V 1994 Survey Manual for Tropical Marine Resources ASEAN-Australia Marine Science Project: Living Coastal Resources. Australian Institute of Marine Science Townsville
[42] Arief, S and Edrus IN 2010 Struktur komunitas ikan karang di perairan Kabupaten Maluku Barat Daya Jurnal Penelitian Perikanan 16(3) 235-250
[43] Dharmawan, I. W.E. & Pramudji 2017 Panduan Pemantauan Komunitas Mangrove. Edisi 2. Coral Reef Rehabilitation and Management Program (COREMAP). Pusat Penelitian Oceanografi – LIPI.
[44] Odum E P 1983 Basic ecology Vol Saunders College Pub, Philadelphia: Saunders.
[45] Saputro M A, Ario R and Riniatsih I 2018 Sebaran Jenis Lamung di Perairan Pulau Lirang Maluku Barat Daya Jurnal Penelitian Perikanan 7(2) 97-105
[46] Wilkinson C R, Chou L M, Gomez E, Ridwan A R, Soekarno S and Sudra S 1993 Status of coral reefs in Southeast Asia: Threats and Responses. Colloquium on Global Aspects of Coral Reefs: Health Hazards and History 5 – 11 June 1993 University of Miami Miami USA
[47] Suyadi, Gao J, Lundquist C J and Scwhendennmann L 2018c Estuar. Coast. Shelf Sci.
[48] Polidoro B A, Carpenter K E, Collins L, Duke N C, Ellison A M, Ellison J C, Farnsworth E J, Fernandez E S, Kathiresan K, Koedam N E, Livingstone S R, Miyagi T, Moore G, Nam V N, Ong J E, Priamvara J H, Salmo S G, Sanciangco J C, Suardjo S, Wang Y and Yong J W H 2010 The loss of species: Mangrove extinction risk ad geographic areas of global concern PLoS ONE 5(4) e10095
[49] Joshi H and Ghose M 2003 Forest structure and species distribution along soil salinity and pH gradient in mangrove swamps of the Sundarbans Tropical Ecology 44(2) 197-206
[50] Pramita S B 2018 Kajian kerusakan lingkungan ekosistem mangrove akibat aktivitas pemanfaatan lahan di Ujung Alang Kabupaten Cilacap Postgraduate Master Degree Thesis.Gadjah Mada University
[51] Suyadi and Manulang C Y 2020 Distribution of plastic debris pollution and it is implications on mangrove vegetation Marine Pollution Bulletin. DOI: 10.1016/j.marpolbul.2020.111642.
[52] Broun JJWM 1985 A preliminary study of the seagrass Thalassodendron ciliatum (Forsk.) and Hartog from Eastern Indonesia. Aquatic Botany 23 249- 260
[53] Tomascik T, Mah A J, Nontji A and Moosa M K 1997 The Ecology of Indonesian Seas Part Two Periplus Edition
[54] Nainggolan P 2011 Distribusi Spasial dan Pengelodi Teluk Bakau, Kepualauan Riau. Skripsi. Institut Pertanian Bogor
[56] Evans SM Dawson M Day J Frid CL Gill ME Pattisin and LA Porter J 1995 Domestic waste and TBT pollution in coastal areas of Ambon Island (Eastern Indonesia) Marine Pollution Bulletin 30(2) 109-115

[57] Burke L, Reytar K, Spalding and Perry A 2012 Reef at Risk Revisited in the Coral Triangle. Washington USA: World Resource Institute

[58] Rotua P J 2017 Kajian vegetasi mangrove di Teluk Ambon Dalam dengan menggunakan teknik penginderaan jarak jauh Skripsi Sarjana pada Program Sumberdaya Perairan Universitas Pattimura Ambon, Indonesia

[59] Ivar do Sul J A, Costa F M, Silva-Cavalcanti JS and Araujo M C B. 2014 Mar Poll Bull 78 252–257

[60] Martin C, Almahasheer H and Duerte CM 2019 Environ. Pollut 247 499-508

[61] Sapulete D, Mudjiono and Pelasula (Editor) 2007 Laporan Monlloring Teluk Ambon 2007,5-15 Konservasi Biota Laut Ambon-Lembaga Pengetahuan Indonesia, Ambon

[62] Suyadi 2009 The Condition of Mangrove Forest in Ambon Bay: Prospect and Challenges. Berita Biolog 9(5) 481 – 490

[63] Handayani C N N, Daniel D, Estradivari and Musthofa A 2016 Hasil Kajian Jejaring Kawasan Konservasi Perairan di Provinsi Maluku Jakarta: WWF-Indonesia