Reef fish stocks assessment around the islands in the Banda Sea for supporting local community livelihood

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Abstract. Located in the Indonesian fisheries management area (WPP) 714, the Banda Sea has a high potential of fisheries resources. However, information about reef fish resources is limited. This study aims to assess the Banda Sea reef fish diversity, abundance, and stocks. The diversity, abundance, and density of three reef fish groups (indicator, target, and major) were assessed using underwater visual census (UVC) from 287 sites. A stock assessment was done by multiplying fish habitat areas and fish density. There were 287, 42, and 301 species of target, indicator, and major groups recorded respectively. High abundances were found in Banda Islands and the Southeast region, while the lowest abundance was in the Kendari waters. The average density of indicator and major groups were 0.251 and 4.519 individuals.m⁻², with estimated stocks of 2,883×10⁶ and 51,899×10⁶ individuals (ind.) respectively. The density of target group fish which has economic values was 1.976 ind.m⁻², equivalent to the biomass of 599.6 ton.km⁻² with stocks of 4,214,468 tons. Despite huge reef fish resources supporting the local livelihood, the stock tended to decrease in 2009-2012 and 2015-2016 in Flores and Banda Islands. Therefore, conservation and sustainable use of reef fishes of the Banda Sea is required.

Keywords: Reef bathymetry, Reef fishes, Diversity & Abundance, Stocks, Banda Sea

1. Introduction

The Banda Sea is a portion of the western South Pacific Ocean and one of the inner seas in the Indonesian territory. It is bounded by the islands of the Maluku Province (Watubela, Kai, Tanimbar, Wetar, Babar, Islands) on the east, East Nusa Tenggara (NTT) Province (Lembata and Flores Islands) on the south; the islands of Southeast Sulawesi Province (Watobi Islands and Islands around Kendari waters) on the west, and Sulu, Buru and Seram Islands of the North Maluku and Maluku Province on the north [1]. Two deep basins are located in this sea; the north and south basin with the depth of 5,800 m and 5,400 m respectively. A volcanic ridge further divides the southern South Banda Basin from the Weber Basin where the deepest area reaches 7,440 m. An active volcano, Mount Api, rises from the floor of the southern basin at depth of 4,500 m to 670 m above sea level. The clear waters surrounding many islands provide a perfect habitat for spectacular coral reefs [1].

Ekman in 1953 divided the Banda Sea into two regions on the basis of the realm of marine biogeography, the West Indo Pacific Regions and the East Atlanto Pacific. The West Indo Pacific is a huge areas spread from Southeast Asia to Papua New Guinea (PNG) consisted thousands of coral islands that have the highest of marine biodiversity [2]. On the other hand, Spalding developed a global system that divided the marine and coastal ecosystems in the world into 232 ecoregions. Those
ecoregions were divided based on the homogeneity of marine biodiversity and the presence of the small ecosystems, or the existence of difference oceanographic or topography conditions [3]. Regarding those criteria, Indonesian waters were divided into 12 ecoregions in which the Banda Sea was grouped into ecoregion no.131 [4]. The Banda Sea is surrounded by other inner seas e.g. the Flores Sea (west side), Sawu Sea (southwest), Timor Sea (south), Arafura Sea (southeast), Seram and Maluku Seas (north). Furthermore, the Ministry of Marine Affairs and Fisheries (MMAF) manages the Banda Sea under two regulations: PerMen 01 2009 and PerMen 18 2014 where it was categorized as Fisheries Management Area (WPP) no 714.

There are about 533 coral species found in the Banda Sea, making it a part of the coral triangle system (coral diversity > 500 species) [5], as well as reef fishes that comprised about 1,760 species in which 3 species are endemics [4]. This accounts for about 30 % out of 6,000 of the world’s reef fishes, or about 44% from the total of 4,050 reef fish species in the Indo-Pacific region [6,7]. Since the Banda Sea is also located in the eastern part of Indonesia, it is thought to have the highest diversity of reef fish in the world for the families of Pomacentridae (Damselfishes) and Chaetodontidae (Butterflyfishes) with 128 species and 83 species, respectively [8]. This high diversity of Banda Sea was very contrast with the total of reef fishes in the Hawaiian waters, which has only about 420 species [9].

The richness of coral reef ecosystems provides direct or indirect goods and environmental services for the local community, especially in fisheries and marine tourism sectors [10]. However, the information about the coral reef resources, particularly the reef fishes, in the Banda Sea are still lacking since the data and information are very limited [11]. Those data, if any, are scattered over a vast geographic area of the Banda Sea. Therefore, it is difficult to establish a sustainable reef fish resources management.

Concerning the reef fish management, several obstacles exist, i.e. the lack of information on stocks of various reef fishes in the Indonesian fisheries statistics compared to pelagic and demersal fish. Thus, the existing reef fish stock data is inadequate to be used for management purposes [12]. Furthermore, apart from the available methods in estimating stock pelagic and demersal fish, there is still no practical standard method available to estimating stocks of the reef fish [13] rather than underwater visual census (UVC) which is time-consuming and requires expertise to identify species of reef fish during conducting an underwater census. In addition, most reefs are located in remote areas and in shallow waters with irregular shapes, making it difficult to access and perform acoustic surveys to estimate the stocks of reef fish [14].

Considering the importance of supporting the livelihood of local communities, this resource is facing threats of overexploitation and unsustainable fishing practices such as blasting/poisoning [15-17]. Therefore, stock assessment and sustainable management on reef fish in all Indonesian waters using effective and efficient ways are important and must be prioritized. This study aims to describe the diversity, abundance and to estimate the stocks of reef fish of the Banda Sea (WPP 714) as a part of supporting sustainable management of reef fish resources.

2. Methodology
Fish stock is defined as a group of fish belongs to a taxonomy unit such as species or sub-species that occupy in a certain geography region [18]. Fish stock assessment is the activity to get information on how much the fish stocks in a certain water body. This important information is then used to give guidance to the decision maker for managing and utilizing the fish resources properly [18-20]. Principally, reef fish stock assessment is simple, although there is no standard method available for assessing the stock rather than UVC [13]. Two parameters are needed, the estimated of shallow areas (A, ha or km²) of reef fishes habitat and density of reef fish (D, ind.m⁻² or ton.km⁻²) [13].

2.1. Study sites and shallow water bathymetry mapping of coral reefs
This study was conducted in 9 locations surrounding the Banda Sea that were partitioned into 8 regions i.e. Ambalau (1) and Lease (2) Islands as north region; Watubela Islands (3) as northeast
region; Banda Islands (4) as mid-region, Kai Kecil Islands (5) as east region; Southwest Maluku Islands (6) as south region-Maluku; Lembata, Flores, Alor Island (7) as south region - NTT, Wakatobi Islands (8) as southwest region and the islands in the Kendari waters (9) as west region (figure 1).

The first step in reef fish stock assessment was the determination of the shallow water on the range 0-20 m derived from bathymetry map to define the coral reef areas as the habitat of reef fishes. The bathymetry of shallow coral reefs can be mapped using remote sensing technique by utilizing satellite data such as Landsat (resolution 30 × 30 m). However, it needs at least 30 scenes of Landsat data (figure 2), which is impractical and time-consuming for deriving shallow reef bathymetry. As the alternative, available bathymetry data from the general bathymetric chart of the oceans (GEBCO) provided by the British Oceanographic Data Center (BODC) were used. This data has a resolution of 30 arc-second grid (926 m × 926 m) [21]. The image processing software of IDRISI Sevla (Ver. 17) was used to extract the bathymetry values. Depth range of 0-20 m was selected by assuming most of the reef fishes were abundance at that depth. The size area (A, km²) on that depth was calculated afterward.

2.2. Reef fish diversity, abundance, and density estimation
The second step was the estimation of the density (D) of reef fishes using UVC method (figure 3). This method was developed and introduced in the Asian-Australia project in 1986 [22] and applied for the first time in Indonesian waters. This method has become a standard operating procedure (SOP) for monitoring reef fishes in the Great Barrier Reef, Australia [23] and then well used in some other tropical countries.
The UVC was performed simultaneously with the coral observation. A 50 m long plastic ruler tape was placed parallel to the coastline on the reef slope at depths between 3 and 10 m [22, 23]. The person who performing census dived using SCUBA equipment along this transect line and recorded all fish at the distance of 2.5 m to the left and 2.5 m to the right. This observation generated an observation area of 250 m² (figure 3). Reef fishes were identified using several fish identification books [24-28]. Each species was classified into three different groups; target, indicators and major groups [29]. The density of each species (D, ind.m⁻²) was counted. Target group fishes are the consumable fishes, which have economic values, so they become a target by the fishers; Indicator group fishes are the fishes that strongly associated with coral reefs. All butterfly fishes (Family Chaetodontidae) belong to this group. The major group, the fishes that are not included in those two groups have small size, beautiful colour and well known as ornamental fishes [29].

2.3. Data collection and analysis

Two types of data were used; first, data collected from the field (primary data), and secondly, data collected from various sources, such as research reports originated from individual and/or NGOs or published journals (secondary data). Most secondary data used the same UVC method even though some sources needed to be standardized or adjusted or recalculated in order to have the same format as primary data format. Variables used in the primary/secondary data were reef fish diversity (number of species), abundance (number of fishes in each species), the density of each species (number of fish per area), date, and location per coordinates of census.

The standing stock (S) of each group of reef fish was estimated using the equation:

\[ S = A \times D \]  

where stock (S) is the total number of individual fish within each species of indicator and major groups (individual), A is the size area (m² or km²) and D is the density of each species (ind.m⁻²). For the target group, since all species in this group have economic value, then S was expressed in the total biomass, rather than numbers of individual fish. The weight-length relationship:

\[ W = a \times TL^b \]  

was used for the conversion, where W denotes fish biomass (tons) and TL is the fish total length in cm, while a and b are fish growth coefficients obtained from available references [30-35]. Equation 2 was multiplied afterwards with the total number of specific species counted during the census to obtain the total biomass of the aforementioned species. The fish length was estimated mostly using the following equation:

\[ TL = (TL_{min} + TL_{max})/2 \]  

where TL_{min} is the minimum TL and TL_{max} is the maximum one. If there is no information available on TL_{min} and/or TL_{max} for specific species to be calculated using equation 3, we used the information of common/mean TL of fishes from previous literatures (eg. [30,33]), as well as the information of TL_{max} [33] to estimate the species TL (TLₗₜ₆):

\[ TLₗₜ₆ = 0.65 \times TL_{max} \]
The multiplication factor used in the equation 4 (0.65) was based on approximation and field experience.

In order to ensure whether any influence of the upwelling phenomenon to the stock of reef fishes, both data chlorophyll-a concentration and sea surface temperature (SST) derived from Aqua-MODIS satellites images (2003-2017) were used in the analysis. These data were obtained from Giovanni online data system web (Geospatial Interactive Online Visualization ANd aNalysis Infrastructure) developed and maintained by the NASA GES DISC.

3. Results and Discussion

3.1. Bathymetry map of the Banda Sea
Figure 4 shows the bathymetry map of the Banda Sea derived from GEBCO and was processed using IDRISI Selva software. The depth of the Banda Sea ranges from the shallowest waters of the coral reefs to the deepest of the Banda Trench (> 7,000 m). The total areas of the Banda Sea for a depth range 0 to >7,000 m was approximately 591,024.1 km². The sampling area of shallow waters in the depth range 0-20 m was 11,484.6 km². This depth range was used to assess the reef fish stocks of indicator and major group. For target group reef fish, the depth started at 2 meters. Therefore, the estimated total area for the standing stock of target group at depth of 2-20 m was 7,028.8 km².

3.2. Reef fish diversity, abundance and density
Table 1 shows the diversity (numbers of species), the abundance (number of fishes of each species) and the average density (D, in ind.m⁻² or gram.m⁻²) for the target, indicator and major groups respectively. These data were originated from both the primary and secondary data from 287 UVC sites. The primary data consisted of quantitative data of all group of reef fishes collected directly in the field mainly from COREMAP (Coral Reef Rehabilitation and Management Project) phase-1 (1998-2004, Initiation stage) [36], COREMAP Phase-2 (2004-2008) [37], and COREMAP CTI (2014-2020) [38]. The secondary data reported mainly only for the target group reef fishes. Since most of this data was qualitative data, thus they were not listed in the table 1. Data in the table 1 was grouped following the 8 regions as shown in the figure 1.

![Figure 4. Bathymetry map of the Banda Sea derived from BODC data with the ranges of depth (m) and its areas (km²) from the deepest of Banda Trench to the shallowest of coral reefs ecosystems.](image-url)
Table 1. Diversity (number of species), abundance (number of fish in each species) and density (ind.m$^{-2}$, gram.m$^{-2}$) of reef fishes in some regions of the Banda Sea.

| Location         | Year   | N  | Location | Year   | N  | Location | Year   | N  | Location | Year   | N  |
|------------------|--------|----|----------|--------|----|----------|--------|----|----------|--------|----|
|                  |        |    |          |        |    |          |        |    |          |        |    |
|                  |        |    | Diversity (Number of Species) |        |    | Abundance (Number of Fish) |        |    | Average Density |        |    |
|                  |        |    | Target  | Indicator | Major | Total | Target  | Indicator | Major | Total | Target  | Indicator | Major | Data Type and Sources |
| 1. North region  |        |    |         |         |        |        |         |         |        |        |         |         |        | Primary, (Authors data) [39] |
| Lease Islands,   | 1993   | 12 | 57      | 27      | 98   | 182   | 1,072  | 300     | 4,239  | 5,701  | 0.858   |         |        |             |
| Ambon Island,    | 2008   | 5  | 85      | 28      | 112  | 225   | 7,824  | 840     | 9,861  | 18,525 | 6.259   | 1166.2  | 0.672  | Primary, (Authors data) |
| Nusakarta,       | 2010   | 6  | 44      | 24      | 97   | 165   | 604    | 188     | 2,838  | 3,630  | 0.403   | 114.7   | 0.125  | Primary, (Authors data) |
| Ambon, 2011      |        | 18 | 93      | 26      | 208  | 327   | 3,521  | 646     | 9,849  | 14,016 | 0.782   | 149.3   | 0.144  | Primary (Authors data) |
| Pombo Islands,   | 2014   | 2  | 66      | 18      | 112  | 196   | 557    | 104     | 2,646  | 5,557  | 0.557   | 183.5   | 0.104  | Primary, (Authors data) |
| Total Stations   |        | 31 |        |         |        |        |        |         |        |        |         |         |        |             |
| 2. Northeast region |      |    |         |         |        |        |         |         |        |        |         |         |        | Primary, (Authors data) |
| Watubela Islands, 2007 | 10 | 126 | 29      | 144     | 299  | 14,261| 473    | 16,936  | 31,670 | 5.093   | 726.9   | 0.169  | 6.049 |
| Watubela Islands, 2017 | 4  | 101 | 21      | 88      | 212  | 8,204 | 165    | 5,842   | 14,117 | 5.793   | 870.5   | 0.118  | 4.076 |
| Total Stations   |        | 14 |        |         |        |        |        |         |        |        |         |         |        |             |
| 3. Mid region    |        |    |         |         |        |        |         |         |        |        |         |         |        | Primary, (Authors data) |
| Banda Islands,   | 2012   | 20 | 198    | 32      | 178  | 408   | 22,668 | 2,276   | 18,204 | 43,148 | 4.534   | 1,930.0 | 0.455  | 7.504 |
| Banda Islands,   | 2015   | 12 | 98      | 29      | -    | 127   | 4,575  | 843     | -      | 5,418  | 1.089   | 19.17   | 0.201  | -   |
| Total Stations   |        | 32 |        |         |        |        |        |         |        |        |         |         |        |             |
| 4. East region   |        |    |         |         |        |        |         |         |        |        |         |         |        | Secondary, [40] |
| Keli kecil,      | 2015   | 37 | -       | -       | -    | -     | -      | -       | 0.736  | 885.6  | -       | Secondary, [41] |
| Total Stations   |        | 37 |        |         |        |        |        |         |        |        |         |         |        |             |
| 5. South region  | Maluku |    |         |         |        |        |         |         |        |        |         |         |        | Secondary, [42] |
| Southwest Maluku,2014 | 20 |  -   | -       | -       | -    | -     | 2.409  | 1.030.3 | -       | -       | -       | -       | -   |
| Total Stations   |        | 20 |        |         |        |        |        |         |        |        |         |         |        |             |
| 6. South region  | NTT    |    |         |         |        |        |         |         |        |        |         |         |        |             |
| Lembata, 2009    |        | 8  | 52      | 20      | 129  | 201  | 1,699  | 319     | 8,112  | 10,130 | 0.850   | 189.9   | 0.160  | 4.056 |
| Lamalera, 2013   |        | 8  | -       | 27      | -    | 27    | -      | 1,047   | -      | -      | -       | Secondary, [43] |
| East Flores, 2009 | 10    | 10 | -       | 20      | -    | 20    | 1,230  | 286     | 13,795 | 15,311 | 0.492   | 100.2   | 0.105  | 5.518 |
| East Flores, 2014 | 19    |  - | -       | -       | -    | 1,473 | -      | 1,473   | -      | 0.310  | 54.2    | -       | Secondary, [42] |
| Alor, 2014       |        | 25 | -       | -       | -    | 3,600 | -      | 3,600   | -      | 0.626  | 166.7   | -       | Secondary, [42] |
| Total Stations   |        | 73 |        |         |        |        |        |         |        |        |         |         |        |             |
| 7. Southwest region |    |    |         |         |        |        |         |         |        |        |         |         |        |             |
| Watobabi Islands, 2001 | 15 |  - | 29      | -       | 30   | 1,318 | -      | -       | -      | 0.239  | -       | Secondary, [44] |
| Watobabi Islands, 2006 | 15 |  - | 30      | -       | 30   | 14,700 | 1,590 | 39,210  | 55,500 | 3.000  | -       | Secondary, [45] |
| Watobabi Islands, 2007 | 15 | 106 | 32     | 161     | 299  | 7,290 | 4,125 | 21,940  | 33,375 | 1.389  | 532.3   | 1.493  | 4.193 |
| Watobabi Islands, 2015 | 15 | 127 | 28      | 155     | 8,313 | 1,535 | 9,848  | 1583    | 200.4  | 0.279  | -       | Primary, (Authors data) |
| Total Stations   |        | 75 |        |         |        |        |        |         |        |        |         |         |        |             |
| 8. West region   |        |    |         |         |        |        |         |         |        |        |         |         |        | Secondary, [46] |
| Kendari, 2012    |        | 5  | 30      | 17      | 63   | 110   | 320    | 276     | 4,009  | 4,513  | 0.256   | 79.1    | 0.123  | 0.535 |
| Total Stations   |        | 5  |        |         |        |        |        |         |        |        |         |         |        |             |
| Overall Total Stations | 287 |        |        |         |        |        |        |         |        |        |         |         |        |             |

Note: N: Number of fish; Total: Total number of fish; Target: Target number of fish; Indicator: Indicator number of fish; Major: Major number of fish.
In terms of reef fish diversity, a total of 630 species consisting of 287 target, 42 indicator, and 301 major species were recorded during UVC survey. The rank of reef fish diversity from the highest to the lowest are the mid-region (Banda Islands), followed by the same rank of northeast region (Watubela Islands) and the southwest regions (Wakatobi Islands), then the north regions (Ambalau Island), the south region (Lembata Island, NTT), and the lowest rank is the east region (islands around Kendari waters), with total species of 408, 299, 299, 225, 201 and 110, respectively (table 1). It seems that the diversity of reef fish in each region correlated with the distance between UVC observation sites to the relatively highly human populated region. For example, the low diversity of reef fish (110 species) was found in the Kendari waters which have a high human population. In contrast, the high diversity of reef fish was found in the region that has low human population such as the Banda Islands, Watubela and Ambalau Islands. The human population number has a linkage with the community activity pressures on coral reef resources.

The diversity of reef fish in the Banda Sea (WPP 714) are about five times higher compared with another location in the Cendrawasih Bay, Papua (WPP 717), such as in the Arui Islands (116 species), south of Biak (105 species), lower Padaido Island (97 species), Upper Uperi Padaido (72 species), and Numfor Island (62 species) [48-50], even perhaps in other WPPs. The richness of reef fish in the Banda Sea is in line with the opinion which states there are about 1,760 species, 3 of which are endemic species [4].

It is somewhat surprising that reef fish from the target fish group in the Banda islands (mid-region of the Banda Sea) have higher biodiversity (198 species) than the major fish group (178 species), because the later ones were often more diverse than target and indicator groups such as in all of other regions in the Banda Sea (table 1) as well as in WPP 717 [48-50]. The reasons are not yet known precisely, but it is likely that overfishing or unfriendly utilizaton of target group fish such as the use of explosives or fish poisoning in this region is not as severe as other regions, either in other regions of Banda Sea or in other Indonesian waters.

In term of abundance, the pattern has almost the same with the reef fish diversity in which the highest abundance was found in the Banda Islands with a total of 43,148, followed by Watubela Islands with a total of 31,670. However, in the other regions, the abundance of reef fishes were less than 20,000, while the lowest was in the islands around the Kendari waters with a total of only 4,513.

With regard to the fish density (D) estimation, it tended to be different than the diversity and abundance patterns. Pointing to the specific sites, the highest average density of the target group reef fish was found in several locations such Ambalau Island (6.3 ind.m⁻²), followed by the Watubela Islands (5.8 ind.m⁻²), the Banda Islands (4.5 ind.m⁻²) and the islands in the southwest of Maluku (2.4 ind.m⁻²). Lower density (D < 2.0 ind.m⁻²) was found in other locations and the lowest was in the Kendari waters (0.3 ind.m⁻²). However, the average D for each region was different than sites with the high D of > 2.0 ind.m⁻² in the Northeast region, the Mid-region, the South regions of Maluku, the North region, while the rest other regions has D of < 1.0 ind.m⁻², except the Southwest region with D of 1.5 ind.m⁻². The overall average D of target group of reef fishes in the all Banda Sea (WPP 714) was nearly 2.0 ind.m⁻² (table 2), which is 1.6 higher than in the all Cendrawasih Bay (WPP 717) [50].

Concerning the target group fishes with economic values, Indonesian fisheries statistics authority expressed the stock of commercial fish in the biomass unit (ton) instead of number of individual fish unit. Therefore, the reef fishes belonged to the target group should be expressed in biomass unit as well. The sites with the highest D in biomass unit (D_{biomass}) was noted in the Banda Islands, followed by the Ambalau Island, the islands in the southwest Maluku, Kei Kecil Islands, Watubela Islands, and Wakatobi Islands. However, the average D_{biomass} in each region was different compare to specific site. Mid-region and South region of Maluku have higher D_{biomass} of > 1000 gram.m⁻². The East and Southwest regions has D_{biomass} of > 500 gram.m⁻², while the rest were < 500 gram.m⁻², with the west region (Kendari waters) has the lowest D_{biomass} of 79.1 gram.m⁻². The overall average D_{biomass} of Banda Sea was 600 gram.m⁻² (table 2).

The density (D) pattern of the target fish in the Banda Sea differed, both in the individual fish units (D_{fish}) and biomass units (D_{biomass}). Reef fishes that have high species diversity and/or high
abundance or high \( D_{\text{fish}} \) may not necessarily have high \( D_{\text{biomass}} \), because the species composition of target fishes and their size in each region varies greatly. For example, fish in Ambalau Island with an abundance only 7,824 has a higher \( D_{\text{biomass}} \) (1,166.2 gram.m\(^{-2}\)) compared to those of high abundance fishes in the Watubela Islands in 2007 (14,621) and 2017 (8,205) and in the Wakatobi Islands in 2015 (8,313). However, the latter two islands waters had a lower \( D_{\text{biomass}} \) of 726.9, 870.5 and 290.4 gram.m\(^{-2}\) respectively (table 1). Thus, it indicated that the reef fishes of the target group in Ambalau Island (north region) were dominated by species with the larger size. A *Naso unicornis* with length of 35 cm and body weight of 904 grams in the Ambalau Island was equal to 11 *Pterocaesio tile* with length of 19 cm and body weight of 85 grams or 6 *Caesio teres* with length of 20 cm and body weight of 154 grams in other regions.

The indicator group fish consists of one family (Chaetodontidae). The Banda and Wakatobi Islands have the highest diversity (33 species), followed by Watubela Islands (29 species), Ambalau Islands (28 species), Lease and Lamarela Islands (27 species), while other regions less than 27 species with the lowest one is in the islands around Kendari waters with only 17 spesies (table 1). In case of the abundance divided by the number of UVC sites, it showed that Wakatobi Islands has the highest average abundance (136 ind.UVC site\(^{-1}\)) followed by the Banda Islands (98 ind.UVC site\(^{-1}\)), islands around the Kendari waters (55 ind.UVC site\(^{-1}\)), and Ambalau-Lease Islands (51 ind.UVC site\(^{-1}\)). Some sites were less than 50 ind.UVC\(^{-1}\) site such as Wakatobi (46 ind.UVC site\(^{-1}\)) and the lowest ones was in the east Flores, NTT (23 ind.UVC site\(^{-1}\)). The average \( D_{\text{fish}} \) of indicator group also showed that the Wakatobi Islands has the highest followed by the Banda Islands, Lease Islands and Watubela Islands with \( D_{\text{fish}} \) of 0.389, 0.328, 0.261 and 0.143 ind.m\(^{-2}\), respectively, while Islands around Kendari waters as the lowest of 0.123 ind.m\(^{-2}\). The overall average \( D_{\text{fish}} \) of this group in the Banda Sea was 0.278 ind.m\(^{-2}\) (table 2), which was slight higher compare to Cendrawasih Bay, Papua (0.212 ind.m\(^{-2}\)).

### Table 2. Standing stocks estimation of reef fish in the Banda Sea (WPP 714) for target, indicator and major groups.

| Location / UVC survey sites | N | Target (ind.m\(^{-2}\)) | Indicator (gr.m\(^{-2}\)) | Major (ind.m\(^{-2}\)) |
|-----------------------------|---|--------------------------|--------------------------|------------------------|
| 1 North region              | 31| 2.000                    | 405.7                    | 0.261                  | 3.403                  |
| 2 Northeast region          | 14| 5.443                    | 798.7                    | 0.143                  | 5.062                  |
| 3 Mid region                | 32| 2.811                    | 1,060.9                  | 0.328                  | 7.504                  |
| 4 East region               | 37| 0.736                    | 885.6                    | -                      | -                      |
| 5 South region (Maluku)     | 20| 2.409                    | 1,030.3                  | -                      | -                      |
| 6 South region (NTT)        | 73| 0.569                    | 127.7                    | 0.232                  | 4.787                  |
| 7 Southwest region          | 75| 1.486                    | 411.3                    | 0.523                  | 5.826                  |
| 8 West region               | 5 | 0.256                    | 79.1                     | 0.123                  | 0.535                  |

**Total UVC sites** 287

| Overall Average Density (D) | 1,964 | 599.6 | 0.268 | 4,519 |
|-----------------------------|-------|-------|-------|-------|
| Shallow areas (0-20 m) of the Banda Sea (A) | 7,028.8 km\(^{2}\) | 11,484.6 km\(^{2}\) |
| Standing stocks (S) of reef fish | 13.805 × 10\(^{6}\) individuals | 4,214,468 tons | 3.078 × 10\(^{9}\) individuals | 51.899 × 10\(^{9}\) individuals |

* The reef areas for the target group (2-20 m) with the assumption that the fish distribution starts to occur from 2 meters depth.

* The reef areas for indicator and major group (0-20 m) with the assumption that the fish distribution starts to occur from the surface layer.

Fishes belong to the indicator group were used as an indicator of coral reefs health. The more diverse and abundance within this group, the more healthy the coral reefs monitored [51]. Many studies show strong correlation between the diversity of indicator fish and the percentages cover of
living corals, such as in the Biak and Padaido Islands, Cendrawasih Bay, Papua [52]. Similar results also showed in the southwest coast of Madagascar [51], as well as in Noumea, New Caledonia ([53 and references therein]). Therefore, it is no doubt that the fishes classified in the indicator group are very important components to the reef ecosystem.

The diversity of the major group fish in each region of the Banda Sea ranged from 63 (west region, Kendari waters) to 208 species (north region, Ambon Islands) (Table 1). However, the total fish diversity of the major group was 301 species consisted of 26 families, in which Pomacentridae was the most dominant family with 90 species (29.9%) followed by Labridae 75 species (24.9%), Apogonidae 16 Species (5.3%), and Balistidae 15 species (5%), while the rest of each family within 22 families have species diversity less than 5%. The family Pomacentridae (Damselﬁsh) in the eastern Indonesia waters has the highest species diversity with 123 species, which is the highest in the world [8]. Thus, the Banda Sea represented 73.2% of the world's Pomacentridae.

Meanwhile, the average abundance of major group fish showed that waters of Wakatobi Islands has the highest abundance (2,039 ind.UVC site\(^{-1}\)), followed by Watubela Islands (1,629 ind.UVC site\(^{-1}\)), south region (NTT) (1,217 ind.UVC site\(^{-1}\)), Ambalau-Lease Islands (950 ind.UVC site\(^{-1}\)) and surprisingly, the Banda Islands was the lowest (910 ind.UVC site\(^{-1}\)). The overall average abundance for the Banda Sea was 1,349 ind.UVC site\(^{-1}\), which was 20, 8 and 12 times higher than the Upper Padaido Islands, Lower Padaido Islands and the south coast of Biak Islands, respectively [50].

The density (D\(_{\text{fish}}\)) of major groups ranged from 0.535 (west region, Kendari waters) to 7.889 (north region, Ambalau Island). However, the highest average D\(_{\text{fish}}\) were in the mid-region, southwest and northeast regions with D\(_{\text{fish}}\) of around 7.0 ind.m\(^{-2}\), while the south region-NTT and the north region have D\(_{\text{fish}}\) of 3.0 to 4.0 ind.m\(^{-2}\) (table 2). The average D\(_{\text{fish}}\) of major group of the Banda Sea again was 1.4 to 2.0 times higher than that of Cendrawasih Bay waters.

About 70% of fishes belonging to the major group can be classiﬁed as ornamental ﬁshes. Despite their generally small size, most of them have economic values. According to the Indonesian Ministry of Marine Affairs and Fisheries (MMAF) data, 70% of ornamental ﬁshes in Singapore market were imported from Indonesia. Furthermore, the data from Indonesia’s Statistics Central Agency suggested that Indonesia’s ornamental ﬁsh export reached US$13 million in 2011 and it is predicted to increase around 30-40% in 2012 [54]. Thus, it is clear that the major group ﬁshes play important roles (as well as target and indicator groups), not only due to their commercial values as ornamental ﬁsh but also due to their function in the reef ecosystem. Their high diversity and abundance can also support marine tourism sector. Unfortunately, the COREMAP CTI program has been discontinued to monitor major group ﬁsh since 2015 for unknown scientiﬁc reasons.

### 3.3. Reef ﬁsh standing stock

The reef ﬁsh standing stocks (S) estimation for the Banda Sea (WPP 714) (table 2) was the result of the multiplication of each target, indicator and major groups ﬁsh density (D) on each UVC survey site (Table 1) and the areas (A) of shallow water reefs derived from the bathymetry map (ﬁgure 4). For target group ﬁsh, S was also expressed in ﬁsh biomass unit (tons). The S for target, indicator and major groups were 13,805 \(\times 10^5\), 3,078 \(\times 10^6\) and 51,899 \(\times 10^6\) individuals respectively, while the biomass stock of target ones was 4,214,468 tons. This S was rather underestimated especially for the indicator and major group ﬁsh, because there is no data available for the west region (Kei Kecil Islands) and the south region Maluku (Southwest Maluku Islands). For target group ﬁsh, as explained in the methodology section (cf. section 2.3), we used equations 3 and 4 to estimate TL and used it to convert the number of individual ﬁsh to their biomass. The estimated ﬁsh TL used here were likely to be shorter than the actual size of the ﬁsh during UVC survey. Thus, the target ﬁsh stocks were also underestimated from the real ones. Therefore, in terms of reef ﬁsh diversity, this study shows that UVC was able to estimate only about 35.8% out of 1,760 species of reef ﬁsh in the Banda Sea [4].

In addition, the bias in the standing stock estimation could probably due to the depth where the UVC was carried out (average depth of 5 m), due to equipments constraint. Whereas reef ﬁshes are generally higher in number and larger in size at depths greater than 10 m. The reef ﬁsh census cannot
always be done at the best of times, when the fish is most visible. Other than that, many nocturnal fishes that can only be seen active at night time as well as planktivorous fish that only appear when the currents carry food particles were less visible during UVC survey [55]. These things show that there are quite a number of limiting factors in the estimation of reef fish stocks by using UVC surveys, which need to be considered for any future monitoring purpose. Nevertheless, UVC survey is a technique that can provide the best available data of the reef fish stocks currently. The availability of these data facilitate the sustainable management of reef fish resources. Moreover, concerning the exploitation management, the underestimated of reef fish stocks can be useful too for conservation purposes.

Table 3 and figure 5 display the list and some photos of reef fishes, which have high standing stocks (S) of the target, indicator, and major groups fish based on the average Density (D) for the whole of Banda Sea. The target group fish in table 3 represents only 12.5% (38 species) of the total diversity target fish (287 species), but account for 61.6% (2,597,052 tons) of the total S (4,214,468 tons). The fish families representing 62.3% S of target group fish starting from the highest S were Acanthuridae (in Indonesian ikan Butana and ikan Kulit pasir) which consisted of Acanthurus fowleri, A. xanthurus, A. thompsoni, Naso hexacanthus, N. unicornis and N. Lituratus with total S of 1,004,640 tons, followed by Family of Caesionidae (ikan Pisang-pisang and Ekor Kuning) with Pterocaesio tile, Caesio caerulaurea, C. teres, C. cuning, Caesio lunaris and Caesio sp. with total S of 645,645 tons.

Other families with species ranging from 25,000 to <100,000 tons are Lutjanidae (or ikan Kakap in Indonesian) consisting of Lutjanus fulvus, L. bohar, L. gibbus, L. malabaricus, L. argenticulatus, Macolor macularis and M. niger with estimated total S of 326,097 tons; Family Scaridae (or ikan Kakatua in Indonesian) with species Scarus ghobban, S. dimidiatus, Scarus sp. and Chlorurus bleekerii with total S of 145,829 tons; Family Kyphosidae consisted of Kyphosus cinerascens, K. vaigiensis and K. bigibbus with total S of 102,477 tons; Carangidae with species of Caranx melampygus and Seriola lalandi have S of 66,457 tons. Other individuals species were Cheilinus undulatus (Family Labridae), Lethrinus miniatus (Lethrinidae), Gymnosarda unicolor (Scombridae) which is not a reef fish, but a pelagic fish that recorded during UVC, Mullloidichthys vanicolensis (Mullidae), Plectorhinchus chaetodontoides (Haemulidae) and Platax teira (Ephippidae) with S of 82,762; 61,388; 57,180; 50,930; 28,597 and 25,050 tons, respectively. Cheilinus undulatus, commonly known as Humhead Wrasse (or ikan Maming in Indonesian) is one of the species already listed in The IUCN Red List as Threatened due to its D rarely exceed 20 fish per hectare (0.0020 ind.m$^{-2}$), but heavily exploited. Even if only moderately exploited, the D of this fish quickly declines to 25% or less of peak densities recorded at no fishing areas [56].

From 11 families listed in table 3, five families (Acanthuridae, Scaridae, Labridae, Kyphosidae, and Ephippidae) are herbivorous fishes with a big stock (1,360,758 tons) of more than one third (32.8%) of total S of target group fish, excluding the family of Siganidae (ikan Baronang in Indonesian). A ratio pattern between herbivorous and carnivorous fish of 30:70%, indicating a balance in the reef fish population has been reported by the COREMAP-LIPI research team in the Wakatobi Islands, with similar result to this study [46]. Herbivores fishes are known recently to play an important role in maintaining reef ecosystems health. They may help to control and reduce the abundance of certain competitively superior macroalgae from the coral habitat. These superior macroalgae can impede reef resilience if allowed to grow [57,58], particularly when coral reefs were heavily impacted by large scale acute and chronic environmental changes such as El Niño. El Niño caused global coral bleaching in 2016, which makes many reefs in the world collapsed [59] including Indonesian reefs [60]. Thus, a long-term maintenance of reef habitat quality, which underpins fisheries, requires sufficient herbivory stocks [57,58]. However, as many larger species of herbivores fish, such as parrotfish (Scaridae) and surgeonfish (Acanthuridae) are heavily exploited, then it is possible that algae will increase in abundance, start to dominate benthic systems and bring about a decrease in reef biodiversity [59, 61, 62].
| No | Target Group Fish | D (tons) | S (tons) | Indicator Group Fish | D (ind.) | Major Group Fish | D (ind.) |
|----|------------------|---------|---------|----------------------|---------|------------------|---------|
| 1  | Acanthurus forsteri de Beaufort, 1951 | 50.8    | 356.89  | Chaetodon kleinii Bloch, 1790 | 0.034   | Pseudoanthias huchti Bleeker, 1857 | 0.342   |
| 2  | Pterocaesio tatei Cuvier, 1830     | 44.7    | 314.41  | Hemirussiriphus polyepis Bleeker, 1857 | 0.031   | Chromis xanthalus Cuvier, 1830 | 0.337   |
| 3  | Naso hexacanthus Bleeker, 1855     | 39.9    | 280.132 | Heniochus varius Cuvier, 1829 | 0.015   | Pseudoanthias squamipinnis Peters, 1855 | 0.312   |
| 4  | Naso tomentosus Forster, 1801     | 21.0    | 147.493 | Chaetodon trifasciatus Park, 1797 | 0.014   | Odonus niger Ruppell, 1856 | 0.302   |
| 5  | Caesio caerulea Lacepede, 1801    | 15.3    | 107.826 | Chaetodon trifasciatus Quoy & Gaimard, 1825 | 0.012   | Chromis viridis Cuvier, 1830 | 0.293   |
| 6  | Acanthurus xanthopterus Valenciennes, 1835 | 14.0  | 98.153 | Heniochus chrysomelas Cuvier, 1831 | 0.012   | Amblyglyphidodon cuncazo Bloch, 1787 | 0.178   |
| 7  | Caesio teres Seale, 1906          | 12.5    | 87.703  | Chaetodon vagabundus Linnaeus, 1758 | 0.012   | Abudefduf vaigiensis Quoy & Gaimard, 1825 | 0.163   |
| 8  | Cheilinus undulatus Ruppell, 1835  | 11.8    | 82.762  | Chaetodon melanopterus Schneider, 1801 | 0.012   | Chromis amblyrhynchos Bleeker, 1873 | 0.112   |
| 9  | Liujunus fulva Schneider, 1801   | 11.4    | 79.808  | Chaetodon hamorua Cuvier, 1831 | 0.011   | Melichthys niger Bloch, 1796 | 0.104   |
| 10 | Caesio cupreus Bloch, 1791       | 9.8     | 68.570  | Forcipiger flavissimus Jordan & McLeay, 1899 | 0.008   | Chromis weberi Fowler & Bean, 1928 | 0.099   |
| 11 | Liujunus bokhar Forskål, 1775   | 9.3     | 65.507  | Forcipiger flavissimus Jordan & McLeay, 1899 | 0.008   | Chromis weberi Fowler & Bean, 1928 | 0.099   |
| 12 | Liujunus gibbus Forskål, 1775    | 9.3     | 65.363  | Chaetodon rafflesii Bennett, 1830 | 0.008   | Chromis solorensis Cuvier, 1853 | 0.088   |
| 13 | Leithrinus miniatus Forster, 1801 | 8.1     | 61.388  | Chaetodon punctatofasciatus Cuvier, 1831 | 0.008   | Melichthys stiphon Solander, 1804 | 0.082   |
| 14 | Gymnosarda unicolor Ruppell, 1836 | 8.1     | 57.180  | Chaetodon meyeri Bloch & Schneider, 1801 | 0.007   | Dascyllus reticulatus Richardson, 1846 | 0.077   |
| 15 | Naso unicornis Forskål, 1775     | 7.5     | 52.601  | Chaetodon lemu Lacepede, 1803 | 0.006   | Chromis margaritifer Fowler, 1946 | 0.077   |
| 16 | Mullidoichthys vanicolensis Valenciennes, 183 | 7.2     | 50.950  | Heniochus singularis Smith & Radclife, 1911 | 0.006   | Chromis cyanomelas Bleeker, 1851 | 0.073   |
| 17 | Scarus ghobban Forskål, 1775    | 7.2     | 50.272  | Chaetodon octofasciatus Bloch, 1787 | 0.006   | Pomacentrus lepidoglyptus Fowler & Bean, 1928 | 0.071   |
| 18 | Acanthurus acanthurus Forster, 1838 | 6.0    | 42.330  | Chaetodon ocellatus Cuvier, 1831 | 0.006   | Pseudoanthias taka Herre & Montalban, 1927 | 0.062   |
| 19 | Scarus sp                 | 5.6     | 39.206  | Chaetodon unimaculatus Bloch, 1787 | 0.005   | Pseudoanthias dispers Herre, 1955 | 0.062   |
| 20 | Kyphosus cinereus Forskål, 1775 | 5.5     | 38.819  | Chaetodon alacensis Cuvier, 1831 | 0.005   | Chromis xanthosomus Allen, 1991 | 0.058   |
| 21 | Caesio lunaris Cuvier, 1830    | 5.5     | 38.533  | Chaetodon auriga Forskål, 1775 | 0.005   | Chromis auriga Forskål, 1775 | 0.058   |
| 22 | Seriola lalandi Valenciennes, 1833 | 5.3    | 36.980  | Chaetodon ephippium Cuvier, 1831 | 0.004   | Chromis solorensis Cuvier, 1853 | 0.058   |
| 23 | Kyphosus vaigai Quoy & Gaimard, 1825 | 5.2    | 36.432  | Chaetodon speculis Quoy & Gaimard, 1825 | 0.004   | Pomacentrus sp. | 0.058   |
| 24 | Macolor maculatus Fowler, 1931  | 4.7     | 32.924  | Chaetodon citrinellus Cuvier, 1831 | 0.004   | Amblyglyphidodon leucogaster Bleeker, 1873 | 0.051   |
| 25 | Chlorurus bleekeri de Beaufort, 1940 | 4.4    | 30.947  | Chaetodon hamrini Cuvier, 1831 | 0.003   | Megalops cyprinoides Forster, 1801 | 0.049   |
| 26 | Cirrhitus maculatus Cuvier, 1833 | 4.2     | 29.477  | Chaetodon maculatus Cuvier, 1831 | 0.003   | Pomacentrus acutirostris | 0.049   |
| 27 | Caesio sp               | 4.1     | 28.599  | Chaetodon loricatus Cuvier, 1831 | 0.003   | Pomacentrus acutirostris | 0.049   |
| 28 | Plectorhinchus chabotiodae Lacepede, 1801 | 4.1    | 28.597  | Heniochus ephippium Linnaeus, 1758 | 0.003   | Pomacentrus acutirostris | 0.049   |
| 29 | Liujunus malabaricus Bloch & Schneider, 1801 | 4.0    | 28.439  | Chaetodon adspersus Seales, 1910 | 0.003   | Pomacentrus acutirostris | 0.049   |

**Table 3.** List of some fishes with high average Density (D) and Standing stocks (S) of target (tons), Indicator and major (Ind number × 10^6) fish groups in the Banda Sea.
Figure 5. Illustration of predominant target (1-8), indicator (9-16) and major (17-24) fish groups of reef fish stocks of the Banda Sea (see also table 3). Target: 1. Acanthurus fowleri, 2. Pterocaesio tile, 3. Naso hexacanthus, 4. Naso thynnoides, 5. Caesio caerulaurea, 6. Acanthurus xanthopterus, 7. Caesio teres, and 8. Cheilinus undulatus; Indicator: 9. Chaetodon kleinii, 10. Hemitaurichthys polyplepis, 11. Heniochus varius, 12. Chaetodon trifasciatus, 13. Chaetodon trifascialis, 14. Chaetodon baronessa, 15. Forcipiger longirostris, and 16. Chaetodon rafflesi; Major: 17. Pseudanthias huchti, 18. Chromis ternatensis, 19. Pseudanthias squamipinnis, 20. Odonus niger, 21. Chromis viridis, 22. Amblyglyphidodon curacao, 23. Abudelfduf vaigiensis, and 24. Melichthys niger. Photos were made available by Randall J E, Johnson J, Greenfield J and Mayer T and downloaded from [33].

The indicator group fish consisted of one family (Chaetodontidae) dominated by 10 species i.e. Chaetodon kleinii, Hemitaurichthys polyplepis, Heniochus varius, C. trifasciatus, C. trifascialis Heniochus chrysostomus, C. vagabundus, C. melanotus and C. baronessa which has a standing stock \((S) > 100 \times 10^6\) ind. (figure 5). Thus, the total S only for these 10 species was \(1,872 \times 10^6\) ind.
or composed 60.8% of the total indicator group fish. For stock ranged from 50 to $100 \times 10^6$ ind. consisted of 14 species with the total stock $919 \times 10^6$ (29.8%). While for the stock less than $50 \times 10^6$ ind. consisted of 18 species with the total of $S$ $346 \times 10^6$ ind. (11.2%), including six species that were not listed in table 3 i.e. Coradion chrysozonus, C. xanthurus, Parachetodon ocellatus, C. melanopus, C. pelewenesis and lowest C. altivelis.

C. kleinii has high abundance and D not only in the Banda Sea but also widely distributed in all Indonesian waters [36, 63-65]. It seems that this fish is a cosmopolitan fish [43, 47]. In addition, the presence and high density or abundance of C. kleinii as shown in table 3 can be considered as the indicator for a good condition of coral reef [43]. On the contrary, the high abundance of C. octofasciatus indicates that the coral reefs in a degraded condition because of low water transparency, sedimentation or low salinity [43]. Table 4 showed clearly the evidence that waters with relatively good reef conditions such as in the Lamalera, Lembata, East Flores, Wakatobi, Banda, Lease and Watubela Islands had a high abundance of C kleinii, but low on S. octofasciatus. The opposite condition was found in the Kendari waters with coral conditions that were not as good as those mentioned above with the low abundance of C. kleinii, but have a very high abundance of C. octofasciatus (about 32 times higher).

Furthermore, as an indicator of coral health, the bright and beautiful colors of family Chaetodontidae make them also classified as ornamental fish, like the major fish group. Some species that are often used or sold as ornamental fishes are Chelmon rostratus, Heniochus diphreutes, Forcipiger flavissimus, F. longirostris, Chaetodon lunula, C. punctatofasciatus, C. mertensi, C. unimaculatus, C. rafflesii, C. ulietensis, C. falcata, C. auriga, C. Raffles dan C. Semilarvatus [67]. However, most of these species have low S, except F. Longirostris and F. Flavissimus with S of 113.1 and $95.2 \times 10^6$ ind., respectively (table 3).

The major fish group (mostly ornamental fish) consisted of 26 families with the total S of $50,027 \times 10^6$ ind. However, only four families dominated in this group i.e. Serranidae, Pomacentridae, Balistidae, and Labridae. Species of these families with S ranging from 1,000 to $>3,000 \times 10^6$ ind. were Pseudanthias huchti, Chromis ternatensis, P. Squamipinnis, Odonus niger, C. viridis, Amblyglyphidodon curacao, Abudefduf vaigiensis, C. amboinensis, Melichthys niger and Abudefduf sexfasciatus (table 3) with the total of $S$ $22,210 \times 10^6$ ind., composing 44.4% of the total major fish group. Major fish with S ranged from $500$ to $<1,000 \times 10^6$ ind., 250 to $<500 \times 10^6$ ind., and $<250 \times 10^6$ ind. (not listed in table 3) were 9,576 $\times 10^6$ ind. (19.1%), 5,499 $\times 10^6$ ind. (11%), and 12,757 $\times 10^6$ ind. (25.5%) respectively. From table 3, 19 species of Pomacentridae dominated the stocks followed by species of Serranidae, three species of Balistidae and five species of Labridae with the total S of each family were $21,474 \times 10^6$ ind. (42.9%), 8,225 $\times 10^6$ ind. (16.4%), 4,824 ind. (9.6%) and 2,764 ind. (5.5%), while the rest composed of 230 species belonging to 26 families with the total S of 12,757 ind. (25.5%).

Table 4. Density and abundance of C. kleinii and C. octofasciatus as indicators of coral reefs condition.

| Region (locations) in the Banda Sea | C. kleinii | C. octofasciatus |
|-------------------------------------|------------|-----------------|
|                                    | D (ind.m$^{-3}$) | Abundance (ind.) | D (ind.m$^{-3}$) | Abundance (ind.) |
| North Region (Ambalau-Lease Islands)| 0.025       | 287,115,000      | 0.001           | 11,484,600       |
| Northeast Region (Watubela Islands)| 0.019       | 218,207,400      | 0.000           | -               |
| Mid region (Banda Islands)         | 0.028       | 321,568,800      | 0.000           | -               |
| South Region, NTT (Lamalera, Lembata, east Flores) | 0.060 | 689,076,000 | 0.001 | 11,484,600 |
| Southwest region (Wakatobi Islands)| 0.059       | 677,591,400      | 0.000           | -               |
| West Region (Kendari waters)       | 0.015       | 172,269,000      | 0.032           | 367,507,200      |
The major fish group is likely to have much higher stocks, but available data are limited. There was no available data for the major fish in the east region (Kei Kecil Islands) and south region of Maluku (table 2) except for the total number of fish belonging to this group that already calculated from each family, such as in the west region or Islands in the Kendari waters [49]. In other regions, only qualitative data were available for major group fishes by showing the presence of each species and the total number of this group [47]. It appears that the major fish group data was more negligible than the target and indicator ones. This drawback may be one of the main reasons to stop the major fish census on the CTI COREMAP program. Thus, until now the role of this group of fish on the health of coral reefs is still not known clearly.

Further, the average density (D) of reef fish in the Banda Sea was compared with the density in the Cendrawasih Bay, Papua (WPP 717) which has similar geographical conditions of many small islands surrounded by deep seas such as Numfor, Biak, Padaido Islands (Biak-Numfor District) and the Arui Islands (Supiori district). The average density of reef fish in the Banda Sea was about 1.62, 1.29 and 1.88 times higher for the target, indicator and major fish group respectively than those in the Cendrawasih Bay (appendix 1). This was due probably to the influences of seasonal upwelling phenomenon monitored using long-term (2003-2017) multi-temporal of average seasonal data of Chlorophyll-a concentration (Chl-a) and sea surface temperature (SST).

Satellite image of Aqua-MODIS was used to describe this phenomenon (figure 6). During east monsoon (June-July-August, JJA), Chl-a ranged from 0.2 to 1.5 µg.l\(^{-1}\) or 2-6 times higher which indicated a high productivity of the Banda Sea (figure 6) than to Chl-a on west monsoon (December-January-February, DJF) and transitional-I season (March-April-May, MAM). The distribution of sea surface temperature (SST) in JJA was dominated by low SST (< 28.0°C), indicating an upwelling, but very high during DJF and MAM seasons where SST ranged from 30 to more than 31.5°C. During transitional-II season (September-October-November, SON), upwelling starts to be low indicated by a decrease of Chl-a (0.2-0.5 µg.l\(^{-1}\)), while SST starts to increase (29-30°C).

This upwelling phenomenon during JJA season was due to a regional wind which drives a motion associated with the monsoon climate [66]. This indicator could be observed by Aqua-MODIS satellite as similar with this study [67]. Upwelling event was also well studied by using the indicators of low sea temperatures and dissolved oxygen (DO), but high in salinity, nutrients and Chl-a concentration at near surface layer [68] followed by high phytoplankton and zooplankton abundance [69-71]. The abundance of zooplankton was higher just after upwelling season or during SON [72]. Once phytoplankton and zooplankton are abundant, it will support the reef fishes of the Banda Sea with many foods in the food chain, as well as the formation of fishing ground for larger fish, i.e Skipjack and Yellowfin Tuna [73].

The results of this study indicated that reef fish stocks in the Banda Sea (WPP 714) were high, so it can support the livelihood of small island communities around the Banda Sea. However, sustainable management of reef fish stocks is required to preserve them. Thus, the communities must exploit the reef fish resources in a more sustainable way. Unsustainable fishing practices such as the commonly used explosives, poisons or bad fishing gears in many small islands all around Indonesian waters (such as in the Padaido Islands, Papua, WPP 717) [50] will make the stocks of reef fishes lower than in the Banda Sea (WPP 714) and thus must be avoided. In recent decades, the spearfishing activities using a harpoon and scuba gear, particularly at night in many reefs in the world tend to increase. These activities are focused more on herbivorous (i.e. Acanthuridae, Labridae, and Scaridae) fish catches [74], especially the big size ones. This is alarming to the coral ecosystem scientists because it leads to not only the reduction of the reef fish stocks but also to the declining health of coral reefs [55,75].

Looking back at table 1, there was a tendency of reef fishes stock depletion over time. For example, in the north region of the Banda Sea, the average density (D) of the target group fish of Lease Islands (Ambon, Haruku, Saparua and Nusa Laut Islands), decreased from 0.858 ind.m\(^{-2}\) in 1993 to 0.403 (Nusalaut Island, 2010), 0.782 (Ambon Island, 2011) and 0.577 ind.m\(^{-2}\) (Pombo Island, 2017). In the northeast region, the average density of indicator and major fish groups of the Watubela islands decreased from 0.169 to 0.118 and from 6.049 to 4.070 ind.m\(^{-2}\) during 2007 to 2017.
respectively. The same pattern was found for the target and indicator fish groups of the Banda Islands where it decreased from 4.534 to 1.089 ind.m\(^{-2}\) and from 0.455 to 0.201 ind.m\(^{-2}\) during 2007 to 2017. While in the south region of the east Flores Islands (NTT), the target fish group decreased from 0.492 to 0.310 ind.m\(^{-2}\) from 2009 to 2014. These tendencies were similar with the reef fish stock condition in the most of Biak, Numfor and Padaido Islands, and Arui Islands of Cendrawasih Bay, Papua (WPP 717) [50]. Therefore, the management of fish resources needs to be done seriously where one of the applicable methods is the establishment of a marine protected area (DPL).

Figure 6. Mean seasonal chlorophyll-a concentration (µg.l\(^{-1}\)) (left) and SST (°C) (right) in the Banda Sea acquired from Aqua-MODIS Satellite, 2003-2017.

Results of the study on the effectiveness of three types of DPL in Indonesia and Papua New Guinea (PNG), namely: National Park (TN), co-managed DPL and traditional DPL showed that the traditional DPL type in Muluk, Ahus (PNG) and Kakalotan Island (North Sulawesi, Indonesia) were the most effective in conserving the reef fish resources. This was indicated by higher biomass and fish
size of target group fish inside DPL than outside DPL [76]. Those DPLs were small in size (33-58 ha), managed by local communities and periodically closed following local wisdom rules (e.g., Sasi in Maluku and Papua). Similar results were found on 20 DPLs established by Coremap LIPI in 2008 in the south coast of Biak Island (4 DPLs), lower Padaido (8 DPLs) and upper Padaido islands (8 DPLs), which were traditional DPL [65] with small areas of 15-20 ha (length ± 500m, width ± 400 m). It seemed that these DPLs were more effective in conserving the reef fishes. The average density (D) of target, indicator and major groups fish within these DPLs were 2.8-3.6, 1.5-3.0 and 1.8 - 4.4 times higher than the fish outside the DPLs respectively [77].

In the Kei Kecil Islands, several NGOs, local governments and universities are working together to set up a co-managed DPL called "Small Island Park". They monitor the condition of fish in the DPL. The DPL consists of 3 zones: 1) utilization zones, 2) no-take zones and 3) outer zones. Results showed that herbivorous (Acanthuridae, Scaridae, and Siganidae) and some carnivorous (Serranidae, Lethrinidae and Nemipteridae) fishes in the no-take zone area have the highest fish density (ind. ha⁻¹) and biomass (kg. ha⁻¹), although the overall of total fish were more abundant in the utilization zone [41]. Therefore, regarding the previously cited references [76,77], it is clear that the establishment of DPLs, particularly no-take zones in many locations around small islands in the Banda Sea is highly recommended, to ensure that reef fish populations remain at a sustainable level.

4. Conclusion
The estimation of reef fish stocks for Indonesian waters is still very rare due to a highly fragmented data. The data is almost not recorded in Indonesian fishery statistics, except for a certain species only. In this study we have conducted stock assessments of reef fishes for the most islands around the Banda Sea representing Indonesian fisheries management region of WPP 714. The advantage of this study is that we have estimated reef fish stocks to the species level, where this has not been done before for a wide area on a WPP region level. Given the availability of this data, it will support the fisheries decision makers in managing reef fish resources, such as the stock of a species or group of fish (yellowtail/banana fusilier, grouper, snapper and other fishes) in order to be exploited sustainably.

The small islands in the Banda Sea have a high diversity of reef fishes. There were at least 630 species comprised of 287, 42 and 301 species of the target, indicator and major groups, respectively including the estimated stock data of each species. Moreover, the fish stocks of indicators and major groups that also have potentials as ornamental fish to support marine tourism with its own market share.

The stock assessment of reef fish of Banda Sea was conducted using UVC survey. The results of this study tends to underestimate the reef fish stocks and there are also some limitations to be considered. Nevertheless, this method has at least provided the best reef fish stocks data that can be used for the sustainable management of reef fish resources. In the near future, the use of this method is needed to be improved.

All the reef fish resources will support the livelihoods and the welfare of the local community. As a consequence, the local community should use the reef fish resources in a more sustainable and eco-friendly way. Furthermore, in order to make the fish stocks to be available and sustainable, many DPLs need to be established. The co-management of DPLs as has been done in the Kei Kecil Islands and/or traditional DPLs that are supported by local people (traditional one) has proven effective in conserving fish resources. Thus, DPL establishments should be constantly proposed and developed to the entire small islands in the Banda Sea.

Considering the vast area of Indonesian waters (11 fisheries management area, WPP), this study has initiated fish stocks assessment in the Banda Sea (WPP 714) using the best available data. Some data were also available for the Cendrawasisn Bay (WPP 717) although limited. There are still nine WPPs that are still unknown. Therefore, the stock assessment of reef fish in other WPPs must be started immediately by using available secondary data. Thus, the estimation data of reef fish stocks abundance will be a needed important addition to the Indonesian fisheries statistics comprising only
the pelagic and demersal fish stocks so far. The existence of reef fish stocks data throughout Indonesia
then can be used for the sustainable reef fish management purposes.

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Appendix 1. Standing stocks of reef fish in the Cendrawasih Bay (WPP 717) for target, indicator and
major groups as a comparison to the Banda Sea (WPP 714).

| Location (UVC sites).Year¹ | N  | Target (ind.m²) | Indicator (ind.m²) | Major (ind.m²) | Ref. |
|--------------------------|----|----------------|--------------------|---------------|-----|
| Biak-Numfor District     |    |                |                    |               |     |
| - Numfor Island 2011-2012| 31 | 0.71           | 0.07               | 0.57          | [78]|
| - Biak Island, 1995      | 4  | 1.53           | 0.49               | 6.37          | [48]|
| - Biak Island 2008, No-Take Zone (NTZ) | 4 | 1.78 | 0.79 | 2.23 | [79]|
| - Biak Island, 2010-2012 | 21 | 0.56           | 0.17               | 1.06          | [50]|
| - Lower Padaido Islands, 2001 | 6 | 1.30 | 0.48 | 3.22 | [49]|
| - Lower Padaido Islands, 2010-2012 | 25 | 0.32 | 0.09 | 1.25 | [61]|
| - Lower Padaido Islands, 2008, NTZ Area | 8 | 1.27 | 0.40 | 4.35 | [79]|
| - Upper Padaido Islands, 2001 | 6 | 0.93 | 0.19 | 2.65 |     |
| - Upper Padaido Islands, 2010-2012 | 31 | 0.23 | 0.05 | 0.70 | [50]|
| - Upper Padaido Islands, 2008, NTZ Area | 8 | 0.67 | 0.17 | 2.12 | [79]|
| Supiori District         |    |                |                    |               |     |
| - Aruri Islands, 1995    | 6  | 1.22           | 0.16               | 1.96          | [48]|
| - Aruri Islands, 2009    | 20 | 3.56           | 0.29               | 4.16          | [80]|
| - Aruri Islands, 2013    | 25 | 2.70           | 0.17               | 2.96          | [81]|
| - Average               |    | 2.49           | 0.21               | 3.03          |     |
| Total UVC survey sites   | 209|                |                    |               |     |
| Overall Average Density  |    | 1.212          | 0.212              | 2.378         |     |

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