The use of high resolution satellite imagery to identify coral reef cover and its correlation with the abundance of reef fish in Nias Island, North Sumatera, Indonesia

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Abstract. Indonesia is located in the Southeast Asia region, which is famous for its coral biodiversity. It formed the well-known Coral Triangle Initiative with other six countries in the region. Coral reefs, as the most fertile and diverse ecosystem, with massive biogenic structure, are prone and vulnerable to several stressors and changes. Fishery resources, especially reef fish, are associated with coral reefs, with a significant correlation with coral reef communities. The study was conducted in Soma Islands, Nias District, and used the remote sensing technique in maximizing Pleiades satellite imagesvcombined with the Lyzenga algorithm and *in situ* observation. The Diversity Index, Uniformity Index, and Dominance Index were used to identify coral reefs in Soma Islands. Coral reefs were dominated by fringing reefs, where the coverage of the live coral in the islands was categorized as very good, ranging from 67.8 to 92.28%. The total extent of live coral reefs observed from satellite images was 5.8 ha or almost 47% from the total seafloor substrate. There was a positive correlation between live coral reefs and reef fish abundance, with 676 individuals 250 m^{-2} in Soma Sebua Island, 595 individuals 250 m^{-2} in Soma Sideide Islands, and 1107 individuals 250 m^{-2} in Soma Shoal.
Key Words: Pleiades satellite imagery, prediction, reef fish abundance, small islands.

Introduction. Southeast Asia is known as the region with the highest coral biodiversity in the world, while the Philippines and Indonesia together own around 77% of Southeast Asia coral reefs, with almost 80% of them are threatened and poorly managed (Burke et al 2011). The coral reefs of Indonesia have the highest diversity in the world (Veron et al 2009), and are included in the country forming coral triangle located along the equator (Roberts et al 2002). More than 75% of world coral reefs species were found in this coral triangle region (Veron et al 2009), with more than 3000 species of live fish (Green et al 2011). Around 13% of the region is considered to have high biodiversity importance (Asaad et al 2018).

Coral reefs are one of the most fertile and diverse ecosystems with massive biogenic structure, being also endangered (Mumby & Steneck 2008). Coral reefs are prone and vulnerable to several stressors such as coral bleaching and acidification caused by climate change (Hoegh-Guldberg 1999) and fishing (McClanahan et al 2014), especially destructive fishing (Pet-Soede et al 1999), which directly affects the ecological response (Walther et al 2002). Reef fish are the dominant biota in coral habitats (Rembet et al 2011) and correlate with coral reefs, affecting interactions, ecological processes and production in the ecosystem (McClanahan 2002).

Coral reefs are highly valuable ecosystems, known for the variety of marine flora and fauna within (Xin et al 2016). The fisheries sector is often associated with coral reefs. Coral reefs give significant economic value for the fisheries industry in Indonesia (Arini 2013). Coral reefs and fisheries are important resources for some countries around the world (FAO 2016), with a high potential for ecosystem services

(Sumadhiharga et al 2006). The existence of reef fish in coral reefs is essential in its role and natural function for the ecosystem and human livelihood (Rondonuwu 2014).

Changes in coral reef ecosystems by monitoring and management were continuously studied in the past decades (Xu & Zhao 2014; Hedley et al 2016; Ampou et al 2017). The most effective and efficient method to monitor the coral reefs is the utilization of high-resolution satellite imagery (Anggoro et al 2015; Green et al 2000). Remote sensing can be used to detect coral reef changes in shallow water and mapping the geomorphic zone of coral reefs (Andrefouet et al 2001; Phinn et al 2012). Monitoring the distribution dynamics and extent of coral reefs can examine the reef fish diversity, which has a positive relationship with the coral reefs (Longo et al 2014).

Studies on coral reefs associated with reef fish using remote sensing in Indonesia are limited. This study aims to identify the diversity of reef fish distribution and the extent of live coral reef habitats obtained through satellite imagery interpretation.

Material and Method

Research sites. The research sites are located in Soma Islands, Nias Regency, and included Soma Sebua Island, Soma Sideide Island, and Soma Shoal (Figure 1). The field survey was conducted in September 2015.

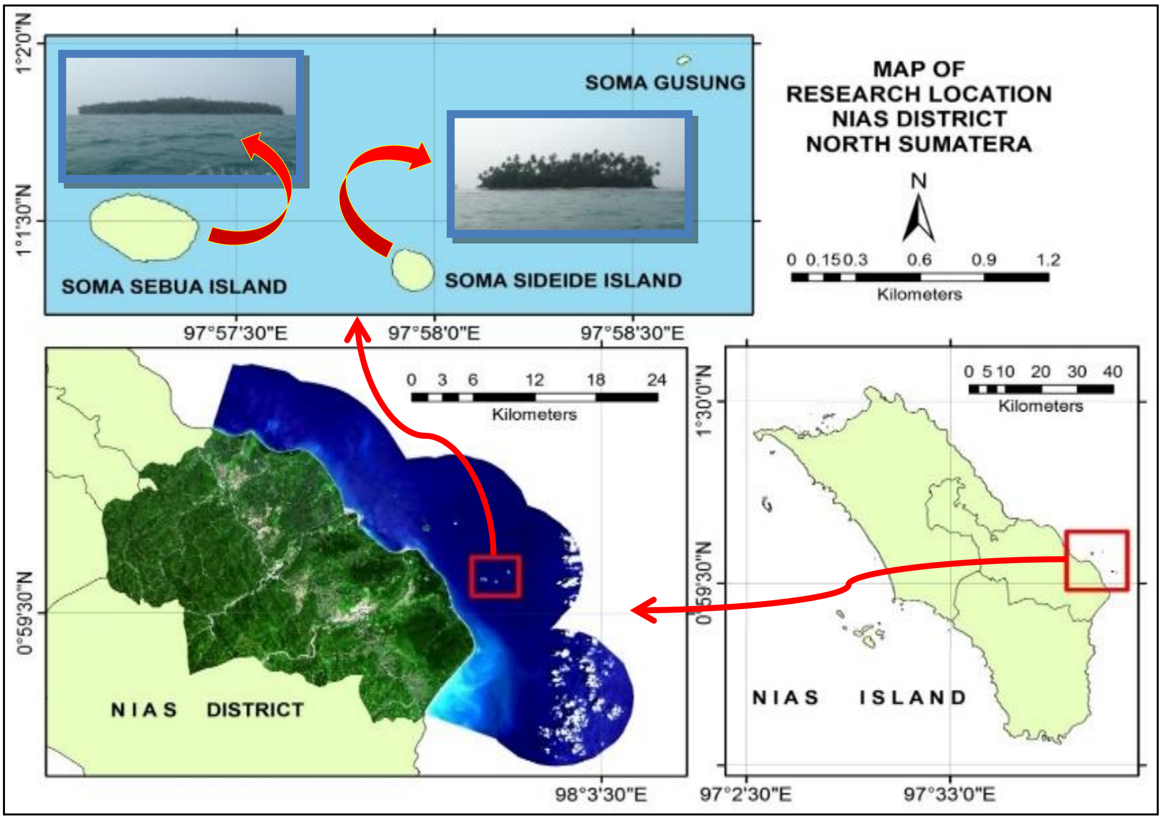

Figure 1. Nias coastal waters.

Data collecting. The two Pleiades satellites, Pleiades 1A (2011) and 1B (2012), known as passive remotely sensed satellites with high resolution, providing regular monitoring and fast response, were used for data collection. Pleiades satellites have 4 multispectral bands with a 2 m spatial resolution, a panchromatic band with 0.5 m spatial resolution (Table 1) and a swath width of 20 km. The characteristics are presented in Table 1. Band combinations in Pleiades satellites are capable to detect coastline changes, and can be used in bathymetry studies, marine surveillance, and identification of underlying aquatic objects (Collin et al 2018).

Table 1

Specification of Pleiades satellites

Channel	*Wavelength (μm)*	*Resolution (meter)*
Band 1 - Blue	0.43-0.55	2
Band 2 - Green	0.49-0.61	2
Band 3 - Red	0.60-0.72	2
Band 4 – NIR	0.75-0.95	2
Panchromatic	0.48-0.83	0.5

Note: NIR - near infrared; source: USGS (2017).

Data analysis. There are several steps in satellite image processing, such as image restoration, enhancement, and classification (LAPAN 2015), where commonly an initial image contains object information and noises caused by the imaging system that need to be processed with geometric corrections, image corrections, masking, Lyzenga algorithm and classification.

Geometric correction is used to transform the satellite images to have the same properties as a map in form, scale, and projection (LAPAN 2015). Fundamental geometric transformation consists in re-positioning pixels until the transformed digital image can be seen as the earth surface recorded by the sensor (Hakim et al 2012). This technique improves distortions, so the image has an appropriate appearance, as the actual conditions on the earth surface and can be used as a map (Nurandani et al 2013).

In this study, geometric correction refers to geospatial data such as the RBI map scale of 1:50000 produced by Bakosurtanal, and the image data from Google maps. The correction process was carried out by image rectification using polynomial (control point) or linear geocoding to rectify images with Ground Control Points (GCP) (LAPAN 2015).

Radiometric correction aimed to improve pixel values by considering atmospheric disturbance factors as the source of error, using the histogram shift technique, while image improvement was used for better visual quality and spectral variability (LAPAN 2015). Pseudo-color composite technique was conducted after the image correction process to familiarize with the object recognition, especially underwater objects, while the identification process was carried out by comparing images to separate land and water objects.

Masking technique was used to separate the terrestrial and water bodies by giving the zero value to the digital number value for terrestrial radiance (Bobsaid & Jaelani 2017), so the radiance in the classification process is not affected by the terrestrial radiance (Musliadi et al 2014). This method created a binary image (0 and 1) based on its pixel values in band 4 (near infrared). Images were created using the binary combination between water and terrestrial radiance applied to each band, so the terrestrial radiance was left out for the next analysis (Musliadi et al 2014).

The Lyzenga transformation was used to identify coral reefs and extract information based on its reflectance value from underwater (Lyzenga 1981). Water column correction was extracted from an identified object in the area for the same substrate with a different depth before the image transformed and regression calculated (Wahidin et al 2014), as follows:

$$Y=\ln(B1)-[ki/kj \times n(B2)]$$

The value of the regression slope (ki/kj) was calculated based on the depth invariant index as following equation:

$$ki/kj = a+\sqrt{(a^2+1)}$$

$$a = [var(B1)-var(B2)]/[2 \times cov(B1 \times B2)]$$

Where: Y - underwater information extraction; B1 - blue band reflectance value; B2 - green band reflectance value; ki/kj - blue and green coefficient ratio.

The combination between passive satellite images and *in situ* observations covers more information related to the depth and underlying substrate by developing an algorithm that represents the underwater habitat (Nurkhayati & Manik 2016).

The classification was performed on cropped and corrected images (Wahidin et al 2014). The classification process is generally divided in two: visual classification, which is carried out by the interpretation and delineation of the image directly, and digital classification, also known as the supervised/unsupervised method (Gibson & Power 2000).

Coral reefs were observed using Line Intercept Transect (LIT) method with a 50 m length and 6-10 m depth aligned to the coastline to identify transition length, growth form and coral reef genus. Coral reefs were photographed and recorded for the validity of the census (English et al 1997). Tools and materials used in this research were basic scuba diving gear, slate, roll-meters, Global Positioning System (GPS), and underwater camera. The observed parameters are the bottom substrate cover, the coral mortality index (CMI), and coral reef types.

Bottom substrate biota and length transition coverage along transects were grouped based on life form, while the life form coverage was assessed individually (English et al 1997):

$$Li=ni/L \times 100$$

Where: Li - percentage of biota coverage in i; ni - total length of base habitat biota; L - total length of line transect (50 m).

The State Minister of Environment, Republic Indonesia (2001) established the criteria for coral reef condition based on the percentage of live coral coverage: poor, if live coral coverage ranges from 0-24.9%; medium - 25-49.9%; good - 50-74.9%; and very good - 75-100%. In addition, there is also an assessment of the coral mortality ratio, which shows the magnitude of changes from living corals to dead corals. The ratio is calculated by the Coral Mortality Index formula (CMI) (English et al 1997):

$$IMK=A/(A+B)$$

Where: IMK - coral mortality index (CMI); A - dead coral coverage; B - live coral coverage.

Reef fish data collection was conducted using the visual census method, where in each station a transect of 50 m was placed at a 5 m depth as a benchmark, combined with the LIT (English et al 1997). The data obtained includes reef fish assemblages at different sites, with abundance categories, species counts, and individuals (Allen et al 2005), as presented in Figure 2.

Underwater Visual Census (UVS) was used to determine the index values associated with reef fish communities, namely diversity index (H’), uniformity index (E), dominance index (D) and dice equality index (Di). Shanon-Wiener diversity index was used to examine the diversity of fish communities or fish species (Odum 1996):

$$H'=- \sum(Pi \ln Pi)$$

Where: H’ - Shannon-Wiener Diversity Index; Pi - (ni/n); ni - total number of individuals type i; n - total number of individuals of all types.

The uniformity index (E) was calculated to examine the type or the community (Ludwig & Reynolds 1988):

$$E=H'/Hmax$$

Where: E - evenness uniformity index; Hmax - ln S; S - number of taxa/species/type; H′ - Shannon Diversity Index.

The range of uniformity index (Ludwig & Reynolds 1988) can be in the following categories: $0<E\leq0.5$ - depressed community; $0.5<E\leq0.75$ - labile community; $0.75<E\leq1$ - stabile community.

The dominance index was used to examine the domination of a type or a community (C):

$$C=\sum(Pi)^2=(ni/n)^2$$

Where: Pi - probability of the individual existence; C - Dominance Index; ni - number of individuals of type i; n - number of individuals in all types.

The dominance index value ranged from 0 to 1. If the dominance index value is close to 1, there is one species dominating the community. Otherwise, if the dominance index value is close to "zero", it means that the communities are varied (Odum 1996).

The regression analysis performed to see the correlation between two variables has a causal or functional relationship. A general equation, with a simple linear regression was used (Abebe et al 2001; Sugiyono 2012):

$$Y=a+bX$$

Where: Y - subjects in predicted dependent variables (abundance of reef fish); X - subjects in independent variables that have a certain value (percentage of live coral coverage); a - value Y when X = 0 (constant value); b - direction or regression coefficient, showing the increase or decrease of a dependent variable number.

Results and Discussion. The composite images from the 321 RGB bands combinations showed the islands in natural coloration or visually more natural (Figure 2A). The result of the Lyzenga transformation provides precise information and classification coverage of shallow water substrate, resulting in the red color of the sand, green of the damaged coral, orange of the algae or seagrass, and cyan for living coral. The masking technique eliminated the land object and focused on the aquatic object classification.

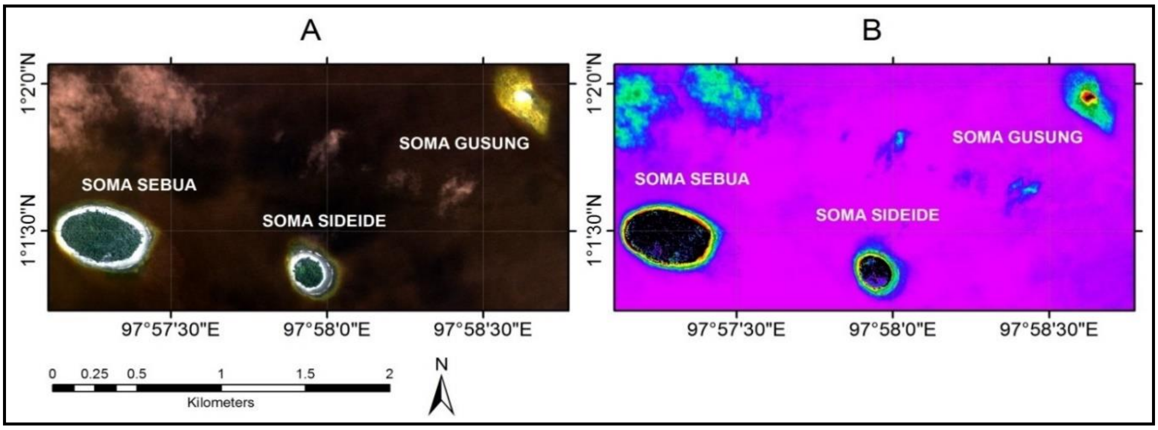

Figure 2. Pseudocolor composite image 321 RGB (A), and Lyzenga transformation (B).

Figures 2A and 2B showed the objects of the seafloor in shallow water, describing the distribution of live coral reefs evenly along the coastline, fringing and barrier reefs, with an average depth ranging from 2 to 15 m, drastically decreasing to the brink. Unsupervised classification technique was performed with 15 classes, a minimum iteration of 30 times, and a convergence threshold 0.95 (Figure 3).

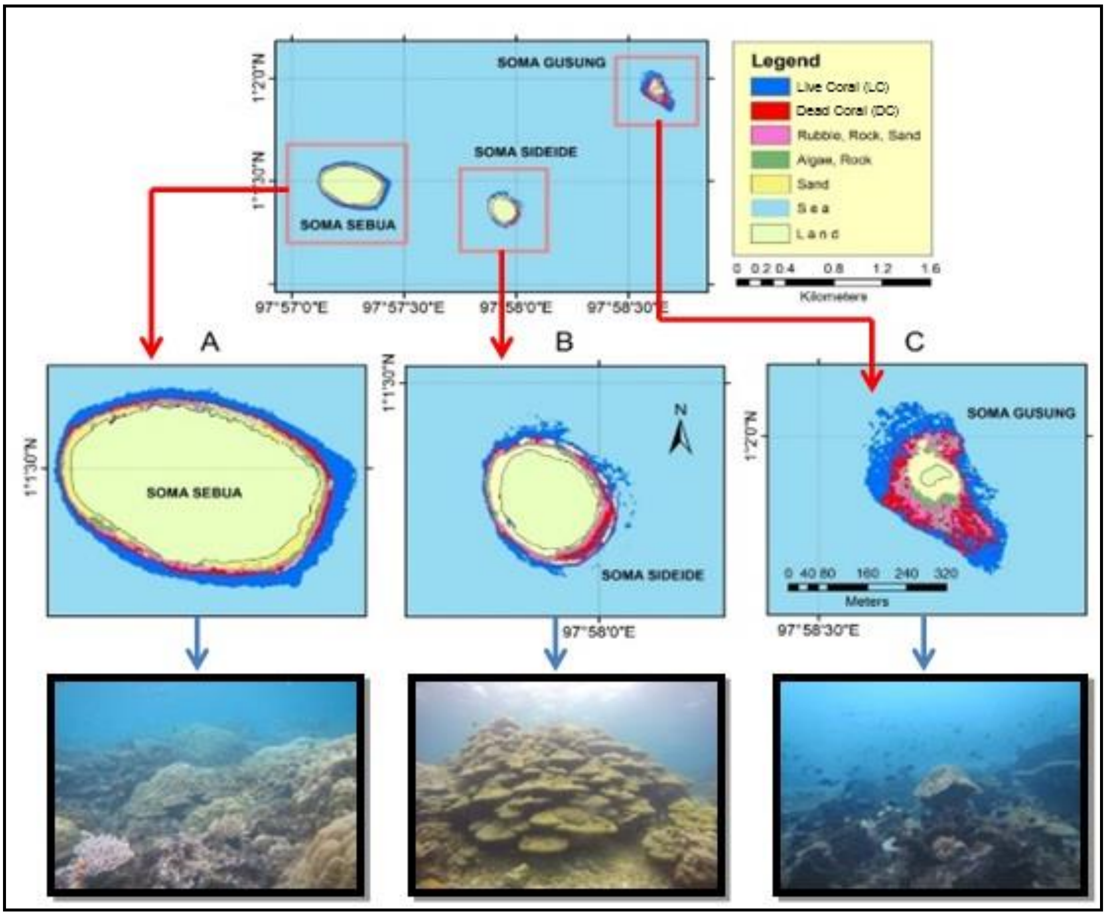

Figure 3. Coral reefs and other substrate distribution in Soma Island.

The classification results were regrouped based on Lyzenga transformation and ground truth, then narrowed down based on the shallow-seabed substrate in 5 classes: live coral; damaged coral; dead coral and algae; coarse sand, rubble, coral fragments; and fine sand. Validation and verification with field data were needed for accuracy in classification, to fulfill a more advanced processing and analysis. The area calculation and coverage of shallow water benthic habitat (Table 2) showed that all islands were dominated by live coral. Soma Shoal had the highest percentage of live coral, while Soma Sebua Island shows the highest percentage of damaged coral.

Table 2

Benthic habitat type and conditions in study area

No	*Habitat Benthic*	*Soma Sebua Island (Ha)*	*%*	*Soma Sideide Island (Ha)*	*%*	*Soma Shoal (Ha)*	*%*
1	Live coral	1.919	27.12	1.21	34.94	2.674	46.69
2	Damaged coral	1.594	22.53	0.478	13.80	1.119	19.54
3	Dead coral	1.419	20.05	0.458	13.23	0.716	12.50
4	Coarse sand, rubble, coral fragments	0.668	9.44	0.453	13.08	0.542	9.46
5	Fine sand	1.476	20.86	0.864	24.95	0.676	11.80
	Total	7.076	100	3.463	100	5.727	100

Figure 4A shows the composition of coral coverage at the dive sites in Soma Sebua Island, during ground check, while the Soma Sideide Island composition is presented in Figure 4B, where the percentage of live corals was high (76.54%), while the dead coral coverage was less than 6.08%, and coral fragments had a proportion of 16.08%. Based on satellite image analysis, the total coral reef coverage in this region area was 34.94%.

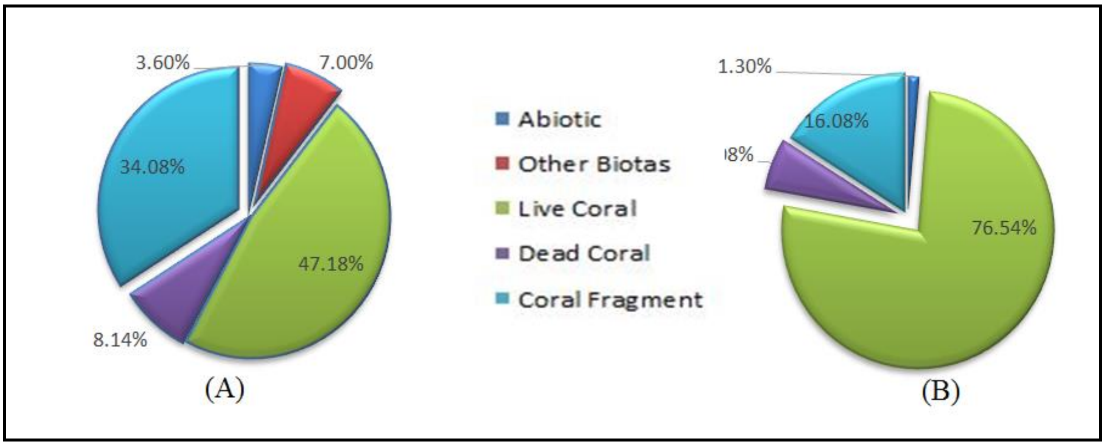

Figure 4. Coral reef coverage in Soma Sebua Island (A), and Soma Sideide Island (B).

The Diversity Index (H') of reef fish in Nias district waters ranged from 1.35 to 2.89. The Uniformity Index (E) ranged from 0.72 to 0.91, and the Dominance Index (D) value was between 0.07 and 0.40 (Figure 5).

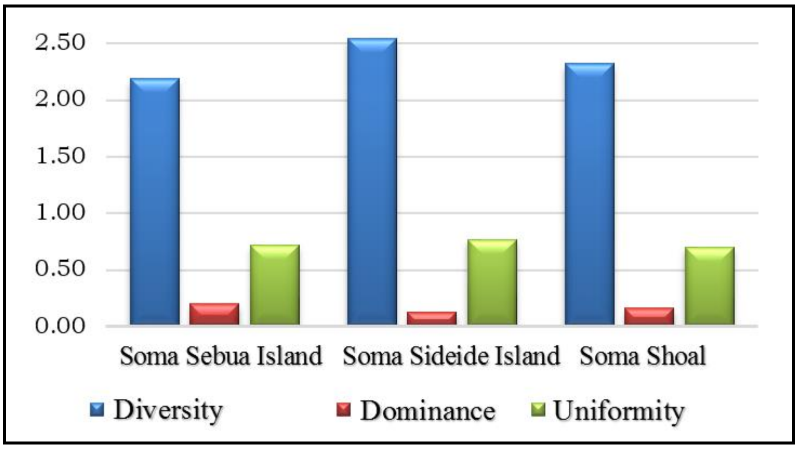

Figure 5. Diversity (blue), Dominance (red), and Uniformity (green) Index of reef fish in the study sites.

The 321 RGB composite images were not able to detect the underlying aquatic objects, due to the influence of the water column affecting the electromagnetic wave ability to capture the object. The algorithm needed to alter the influence of the water column is also known as the Lyzenga algorithm (1981). The result is not final after applying the algorithm; there are times when the result is not entirely the same as the actual conditions in the field. Coloration using the Lyzenga transformation is sometimes different from *in situ* reality, where the object is not the same, or the dominant factor of an object in a specific area determines the coloration. Overall, the coral reef condition at the study sites was in a medium category, ranging from 30% to 75%. There were 17 species of corals in the region, mostly dominated by branching coral/Acropora. Fish associated with coral reefs can be categorized in the target fish group, major fish group, and indicator fish group.

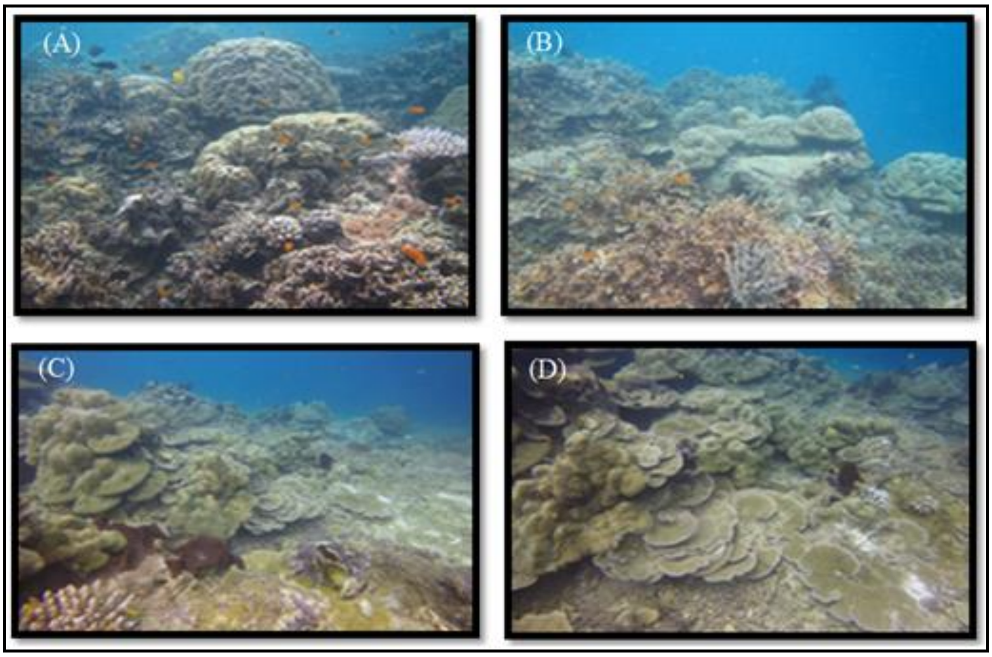

Figure 6. Coral reefs in Soma Sebua (A and B), and Soma Sideide (C and D).

The coverage of live corals (Figure 6) in Soma Sebua Island is about 47.18% of the 5 groups. It enters the medium category (State Minister of Environment 2001), and it is spread around the island with a total area of 1919 ha. The percentage of coral fragments in the region reached 34.08%, dead coral was 8.14%, sand reached 3.6%, and other biotas about 7%. The number of dead and damaged corals (about 3 ha) indicates the effect of human activity in Soma Sebua Island, due to the proximity to the mainland. There were 56 types of reefs fish from 14 families: Acanthuridae, Pomacentridae, Pomacanthidae, Labridae, Balistidae, Zanclidae, Casionidae, Chaetodontidae, Carangidae, Nemipteridae, Scaridae, Lutjanidae, Phempherididae and Haemulidae. Several reef fish besides the 14 families were found outside the observation transect such as: Lutjidae (*Lutjanus kasmira*), Carangidae (*Carangoides orthogrammus*), and Haemulidae. The abundance of reef fish found in each station ranged between 595-1107 individuals 250 m^{-2}. The lowest abundance was in Soma Sideide Island (595 individuals m^{-2}), while the highest was in Soma Shoal (1107 individuals 250 m^{-2}), as presented in Figure 7.

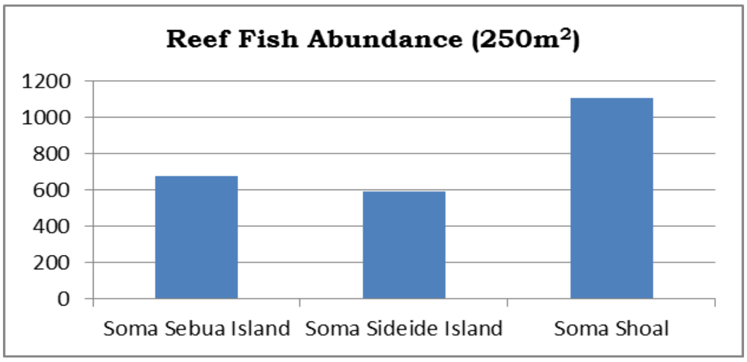

Figure 7. Reef fish abundance in Soma Islands.

Reef fish distribution in Soma Sebua Island waters varied and were dominated by fish from the Pomacentridae family, which are categorized as major fish, and occupy coral reefs for feeding, nursery, protection, and spawning. Indicator fish discovered include Chaetodon familiy, *Heniochus pleurotaenia*, *Forcifiger longirostris*, *Heniochus* *singularius*, and *Chaetodon trifascialis*. The abundance of indicator fish is associated with the quality of waters, since most of the fish tend to live in clear and clean waters (Hutomo et al 1991). Reef fish and live corals have a positive correlation with the equation y = 10.24x + 339 and a coefficient determination of 0.819, which means that the abundance of reef fish is influenced by live coral coverage as high as 81.9%. This condition strengthens the correlation between reef fish and coral reef health (Figure 8), being in line with coral reef diversity and symbiosis among species (Mardasin et al 2011).

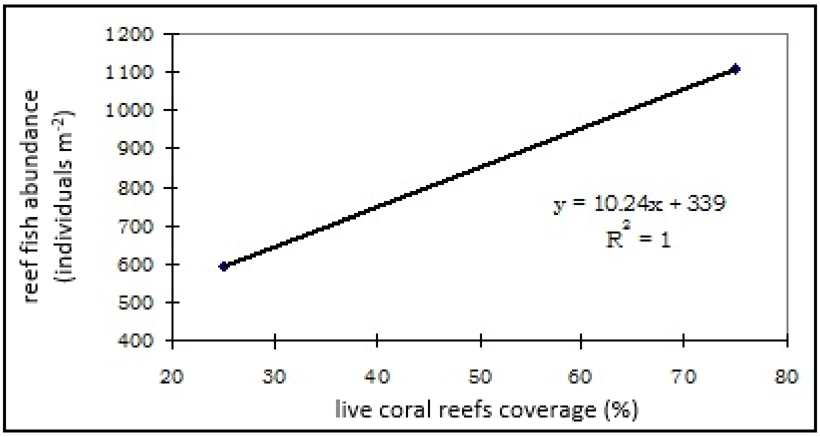

Figure 8. Correlation between reef fish and live coral reefs

Coral reef coverage resulted from Pleiades satellite interpretation was used for the prediction the total individual of reef fish based on reef fish in study sites (Table 3).

Table 3

Reef fish abundance in study sites

No	*Island*	*Live coral coverage (Ha)*	*Abundance (Individuals 250 m^{-2})*	*Total prediction of coral reef fish*
1	Soma Sebua	1919	676	51889.76
2	Soma Sideide	1210	595	28798
3	Soma Shoal	2674	1.107	118404.72

All study sites had a Diversity Index of reef fish included in the low category (2.19 - 2.54), which means that the diversity of reef fish is relatively small, with low environmental pressure indication. The Uniformity Index is categorized as high, ranging from 0.7 to 0.77 in all study sites, which shows the stability of the reef fish community in study sites, with a relatively equal distribution. According to Krebs (1972), the ecosystems dominated by particular species caused by environment instability will have a Uniformity Index near zero, while if it approaches 1, it is assumed the ecosystem is stable and distribution is equal. The Dominance Index (D) is categorized as low, ranging from 0.13 to 0.20, which shows no domination among species in study sites.

Conclusions. Coral reef coverage in Soma Sebua Island, Soma Sideide Island, and Soma Shoal entered the categories of good to excellent, based on its live coral coverage, ranging from 67.80% to 92.28%. The total extent of live coral reefs observed from the satellite images was approximately 5.8 ha or almost 47% of the total seafloor substrate. There is a positive correlation between the existence of live coral reefs and reef fish abundance. Based on Pleiades satellite images interpretation, the reef fish abundances in Soma Sebua Island, Sideide Island and Soma Shoal are

676 individuals 250 m^{-2}, 595 individuals 250 m^{-2}, and 1107 individuals 250 m^{-2}, respectively.

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