Seagrass ecosystem as fish larvae habitat and its biomass algorithm from Sentinel-2A Satellite at Kemujan Island, Karimunjawa, Indonesia

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Abstract. Seagrass ecosystem is one of the important coastal habitats for the protection, feeding and survival of fish larvae. The density of seagrass in a coastal area will influence the abundance of fish larvae. The larval stage is the initial phase of fish growth. The application of satellite data is increasingly developing with the addition of new satellites that can be used for better efficiency and accuracy for more diverse coastal and marine uses. This study aims to identify seagrass species, seagrass density, abundance of fish larvae and develop an algorithm for field seagrass biomass using Sentinel-2A. Field observations identified the seagrass species of *Cymodocea rotundata, Enhalus acoroides,* and *Thalassia hemprichii*. Seagrass biomass algorithm is Y = 51.657 x (Band 4/Band 2)^2 – 83.853 x (Band 4/Band 2) + 36.544, with r=0.873, for *Cymodocea rotundata*. The seagrass biomass algorithm is Y = 1.7958 x (Band 3/Band 2)^2 – 11.82 x (Band 3/Band 2) + 14.787, with r=0.815, for *Enhalus acoroides*. Y = -24.984 x (Band 3/Band 5)^2 – 50.755 x (Band 3/Band 5) + 21.59, with r=0.799, is the algorithm for *Thalassia hemprichii*. Overall, the three species of seagrass had biomass values ranging from 13.44 to 231.44 g m^{-2}, with a RMSE value 0.162. Fish larvae from 11 families were identified, dominated by the Gobiidae with an abundance of 580 ind 1000 m^{-3}. The results showed a strong correlation of field seagrass density with independent variables of the abundance of fish larvae, sediment organic matter, water temperature and current velocity, with a correlation coefficient (r) of 0.988.
Key Words: *Cymodocea rotundata*, density, digital number, Gobiidae.

Introduction. Seagrass ecosystems are one of the main ecosystems in coastal areas, with an essential role in maintaining the balance of the sea water ecosystem. It is also a productive natural ecosystem, with high economic and ecologic values for marine life, including fish larvae. The existence of fish larvae in seagrass beds is closely related to their function as nurseries for larvae and juveniles of many species of fish and other biota (Ara et al 2011; Riniatsih 2016). Fish larvae interact with their ecological environment, being inseparable (Wulandari et al 2019). The life cycle from eggs to larvae of some fish finds good development in seagrass ecosystems. The characteristics of seagrass beds can affect the abundance and distribution of fish larvae, and environmental conditions affect the suitability of the habitat for fish larvae (Nastiti et al 2016). Several oceanographic parameters are influencing the growth of seagrass and the life of other marine organisms. These parameters include water temperature, current velocity, salinity and substrate characteristics (Muskananfola et al 2020). Bottom substrate contains nutrients for seagrass growth. The seagrass absorbs the nutrient through its root system. According to Riniatsih (2016), there is a strong relationship between seagrass density and water quality in the Karimunjawa Islands. Seagrass growth is influenced by the substrate fraction, and by the chemical conditions of th substrate nutrients, among others (Christon et al 2012).

Kemujan Island is one of the islands of Karimunjawa Island National Park, with seagrass beds areas. Kemujan Island is also used as a residential area. In this regard, the anthropogenic activity could inflict damage to the seagrass ecosystem, if not appropriately managed. This condition, in turn, could affect the life of fish that are living in the seagrass. There has been some research carried out in this region regarding seagrass density and species (Gunawan et al 2019; Zulfikar et al 2016), benthic organisms community (Wowor et al 2016), fish larvae (Simanullang et al 2016; Aditya et al 2013; Christon et al 2012), and sediment characteristics and oceanographic factors (Satriadi 2012; Gemilang et al 2018; Suryantini et al 2011; Muskananfola et al 2017).

The Sentinel-2A satellite carries medium-resolution multispectral bands with 13 bands. The satellite is designed for terrestrial observation in support of forest monitoring, detection of land cover changes, and natural disaster management (Putri et al 2018; Nurmalasari & Santosa 2018). It is important to develop the use of the correct wavelengths of satellite bands for coastal and marine algorithms (Hartoko et al 2019). The present study aimed at investigating seagrass species and associated fish larvae, and to create an application of satellite remote sensing data for seagrass biomass using Sentinel-2A satellite data. The findings could contribute to the coastal management of Kemujan Island and nearby coastal regions.

Material and Method. The study was conducted from September to November 2019, in Kemujan Island, Karimunjawa, with 4 sampling points (Figure 1). Visual observation field surveys determined the position of sampling points for seagrass ecological conditions. Station 1 is in the east coast of Kemujan Island, nearby Legon Bajak Harbor. Station 2 is located in the west coast of Kemujan Island, with two sub-stations: 2A, near the jetty; and sub-station 2B, at Batu Pengantin beach. Station 3 was at Ujung Pandean coast, south of Kemujan Island. Three seagrass stations were assumed as potential sites for fish larvae or nursery grounds for several families of fish, which are affected by tidal water. The coordinates of each field sampling point were recorded using GPS, and processed into spatial data.

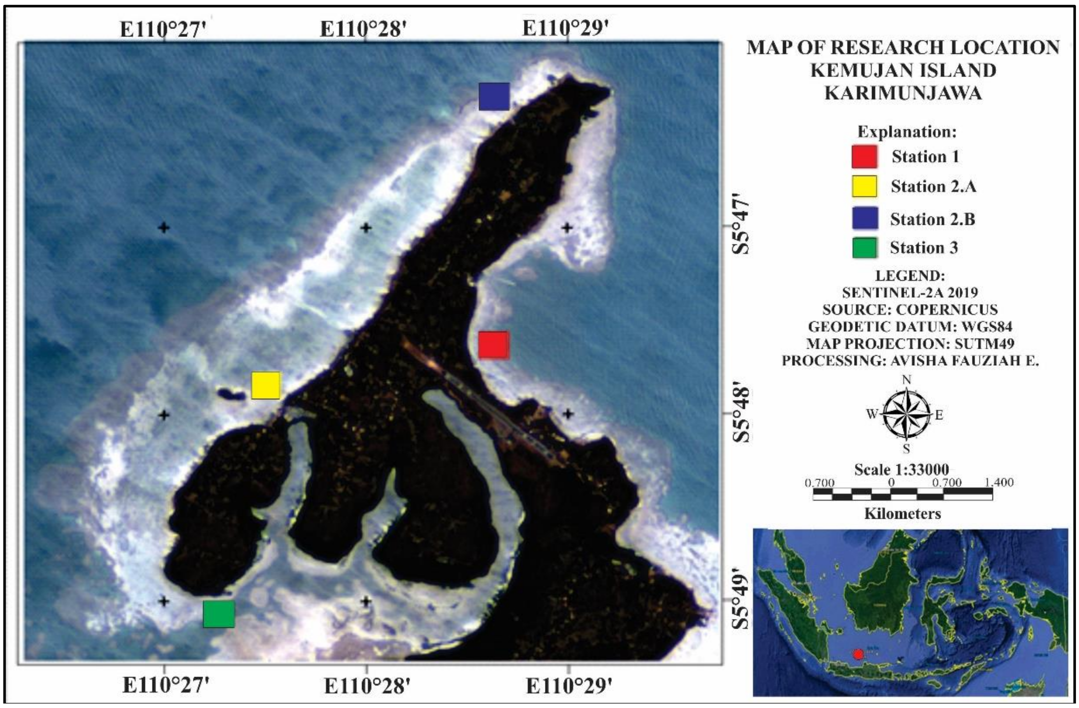

Figure 1. Study location in Kemujan Island.

Field observation of seagrass was based on the Seagrass Watch Manual by McKenzie (2003) and the Guidebook from Coremap LIPI (2017) with the modification of quadrant position. Field observations include seagrass species identification, density and percentage of seagrass cover. Seagrass density was determined as the number of seagrass (ind) in a unit area (m^2). Seagrass cover is calculated at every m^2, on each line with a length of 100 m. There was a distance of 50 m between lines. Sampling observation was conducted using 1x1 m quadrants, divided into 8 equal parts for obtaining representative data. Transect quadrant plots were based on the depth contour of each line. They were repeated each 5 meters to obtain 4 quadrant plots that represent fish larvae habitats and every seagrass condition at the stations. Seagrass sampling was carried out to calculate seagrass biomass values. Seagrass biomass values were divided into above ground and below ground biomass in grams dry weight per square meter (gdw m^{-2}). Seagrass samples were collected from each transect quadrant (Irawan 2017) and should represent the dominating species in the transect quadrant (Graha et al 2015).

Sample collection of fish larvae was carried out using a 4x1 m larvae net (seine net), with a mesh size of 1 mm, a diameter of 50 cm and a length of 1 m. The seine net was operated by two people, along 50 m, parallel to the coastline and with two hauls. Samples of fish larvae were collected in containers with 4% formalin solution for laboratory identification (Subiyanto et al 2008). 3 sediment samples were collected at each station. Sediment samples were collected along a 50 m transect line perpendicular to the sea with three quadrant transects of 5x5 m. Sediment sampling was conducted using sandpits at seagrass surface sediments to a depth of 10-15 cm. Samples were collected into plastic bags and labelled for each sampling point. Sediment samples were tested for grain size (Hartati et al 2017) and sediment organic content.

The correlation analysis on the primary variable of seagrass density with the environmental variables of the abundance of fish larvae, sediment organic material, and grain size was done using Principal Component Analysis (PCA). The next analysis was used to determine the linear relationships between seagrass density (independent variable) with abundance of fish larvae, sediment organic content, seawater temperature and current velocity (dependent variables) using Multiple Linear Regression analysis (MLR). The first step in the spatial analysis was an unsupervised classification of seagrass biomass with the Sentinel-2A satellite digital number values. The seagrass biomass algorithm was developed based on polynomial regression of field biomass for the digital number of selected chlorophyll-a wavelength band of Sentinel-2A (Hartoko et al 2015). The regression equation obtained shows the relationship between satellite data and field data (Zulfikar et al 2016). Then the working algorithm was be selected after exploring a series of polynomial regressions between field data and the satellite band combinations based on the highest value of the correlation coefficient (r). The spatial accuracy of the algorithm was tested using Root Mean Square Error (RMSE) analysis (Hartoko et al 2015). RMSE values less than 1 or values closer to 0 show better accuracy (Parmadi & Sukojo 2016).

Results and Discussion

Density and percentage of seagrass cover. The seagrass species identified at the study sites are *Cymodocea rotundata*, *Thalassia hemprichii* and *Enhalus acoroides*. The percentage of seagrass cover in a quadrant, seagrass density and cover are presented in Table 1. The highest density was found for *C. rotundata* at quadrant 3 of Station 1, with 126 ind m^{-2}. The lowest density was observed at quadrant 9 of Substation 2B, with 51 ind m^{-2}. The highest density of *T. hemprichii* was observed in quadrant 2 of Station 1, 108 ind m^{-2}, while the lowest density was observed in quadrant 13 of Station 3, 26 ind m^{-2}. The highest density of *E. acoroides* was in quadrant 2 of Station 1, 40 ind m^{-2}, and the lowest density was in quadrant 11 of Station 3, 23 ind m^{-2}.

Seagrass biomass. Field data of seagrass biomass (Figure 2) show that below ground biomass values are higher than above ground biomass values. The highest total seagrass biomass value is in quadrant 1 at Substation B, with 231.44 gdw m^{-2}. The lowest biomass is in quadrant 4, with the biomass value of 12.6 gdw m^{-2}.

Table 1

Seagrass density and cover in each sampling point

Station	Point	*Cymodocea rotundata*		*Thalassia hemprichii*		*Enhalus acoroides*	
		D (ind m^{-2})	C (%)	D (ind m^{-2})	C (%)	D (ind m^{-2})	C (%)
1	1	87	38.28	-	-	-	-
	2	-	-	108	42.97	-	-
	3	126	48.44	-	-	-	-
	4	97	39.84	-	-	-	-
	5	-	-	102	40.63	-	-
2	6	-	-	-	-	40	57.03
	7	-	-	-	-	28	36.72
	8	-	-	60	50.78	-	-
	9	51	60.16	-	-	-	-
	10	-	-	75	55.47	-	-
3	11	-	-	-	-	23	25
	12	-	-	-	-	36	31.25
	13	-	-	26	25	-	-

Note: D - density; C - cover; ind - individual.

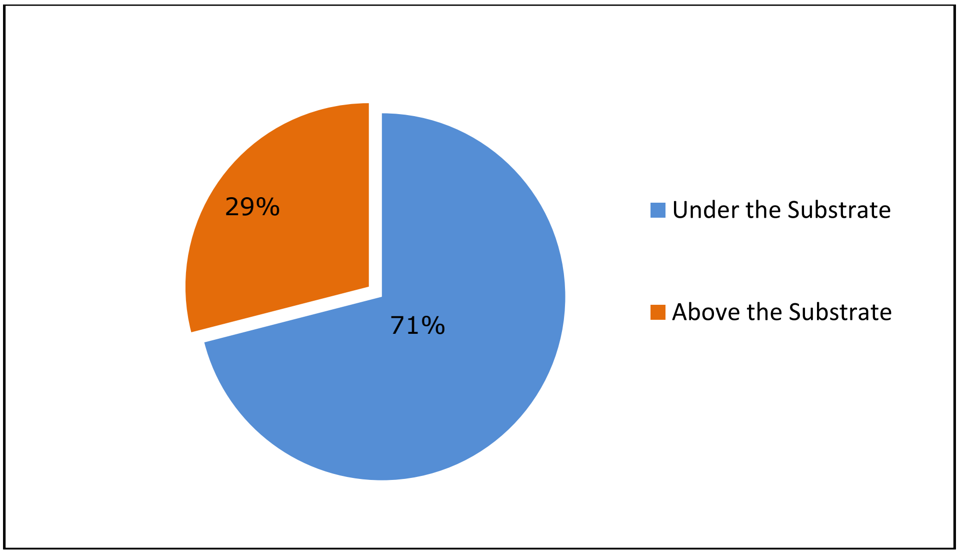

Figure 2. Percentage of seagrass biomass above and under the substrate.

Composition and abundance of fish larvae. A total of 11 fish families with larvae specimens were identified during the study, with 571 individuals, including 4 unidentified species of fish larvae due to damage (Figure 3). The 11 families of fish larvae are Monachantidae, Nemipteridae, Hemiramphidae, Mugilidae, Belonidae, Blennidae, Apogonidae, Atherinidae, Oryziatidae, Labridae and Gobiidae. The most dominant family was Gobiidae, with an abundance value of 580 ind 1000 m^{-3}. The least dominant is the Labridae family, with an abundance of 55 ind 1000 m^{-3} (Figure 4). Environmental conditions influenced the distribution of larvae in seagrass ecosystems of Kemujan Island. One crucial ecological factor is the availability of natural food for fish larvae. Based on routine life, larvae are classified as planktonic and passive types following water currents and other conditions.

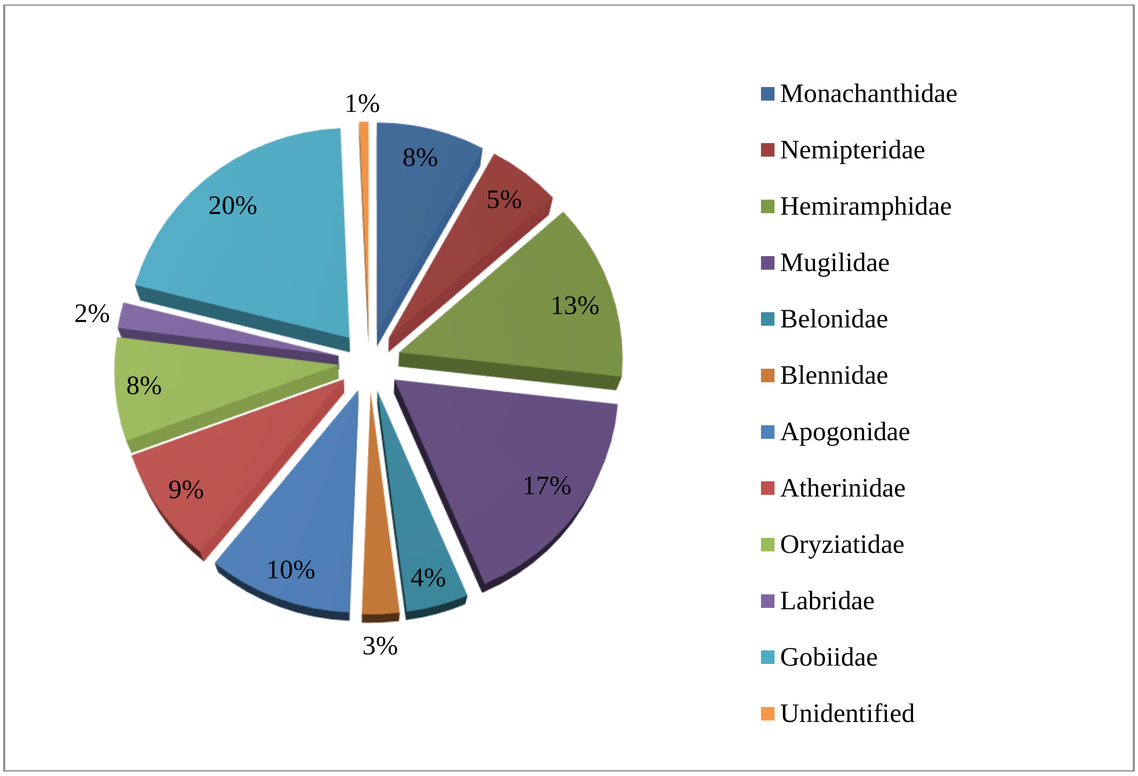

Figure 3. Fish larvae percentages from seagrass ecosystems, Kemujan Island, Indonesia.

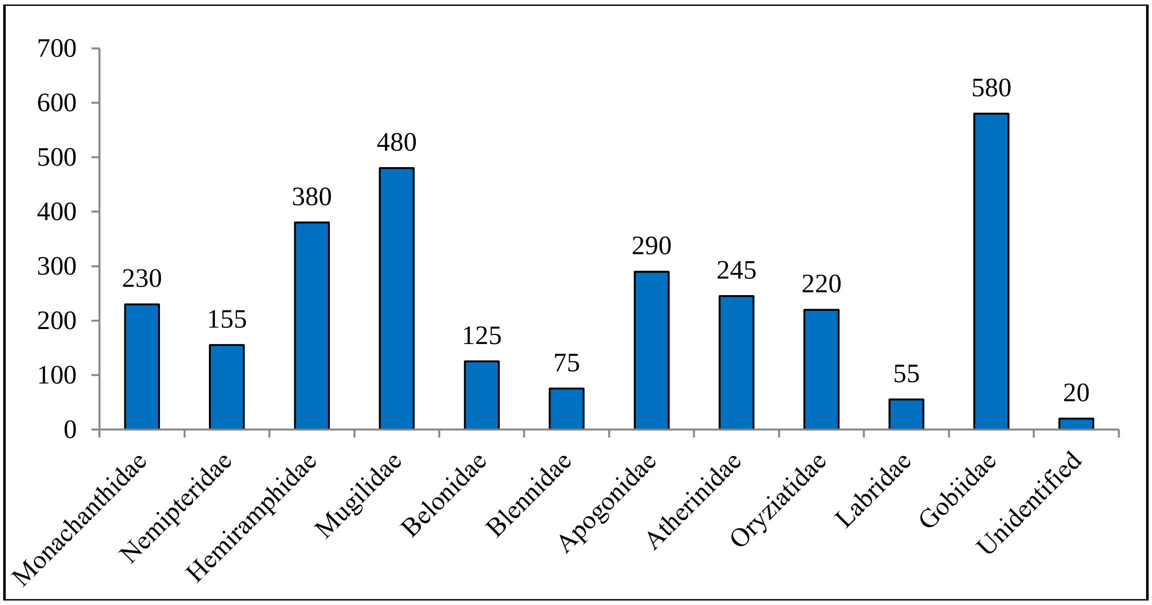

Figure 4. Abundance of families of fish larvae.

Seagrass biomass algorithm development based on field and Sentinel-2A satellite data. Some polynomial regression for algorithm development was based on the seagrass chlorophyll-a reflectance using a band combination of Band 5, Band 4, Band 3 and Band 2 (Figures 5, 6 and 7). The polynomial regression with the highest correlation coefficient (r) will be used for the algorithm, to calculate seagrass biomass and its spatial distribution on the level of seagrass species at each study site.

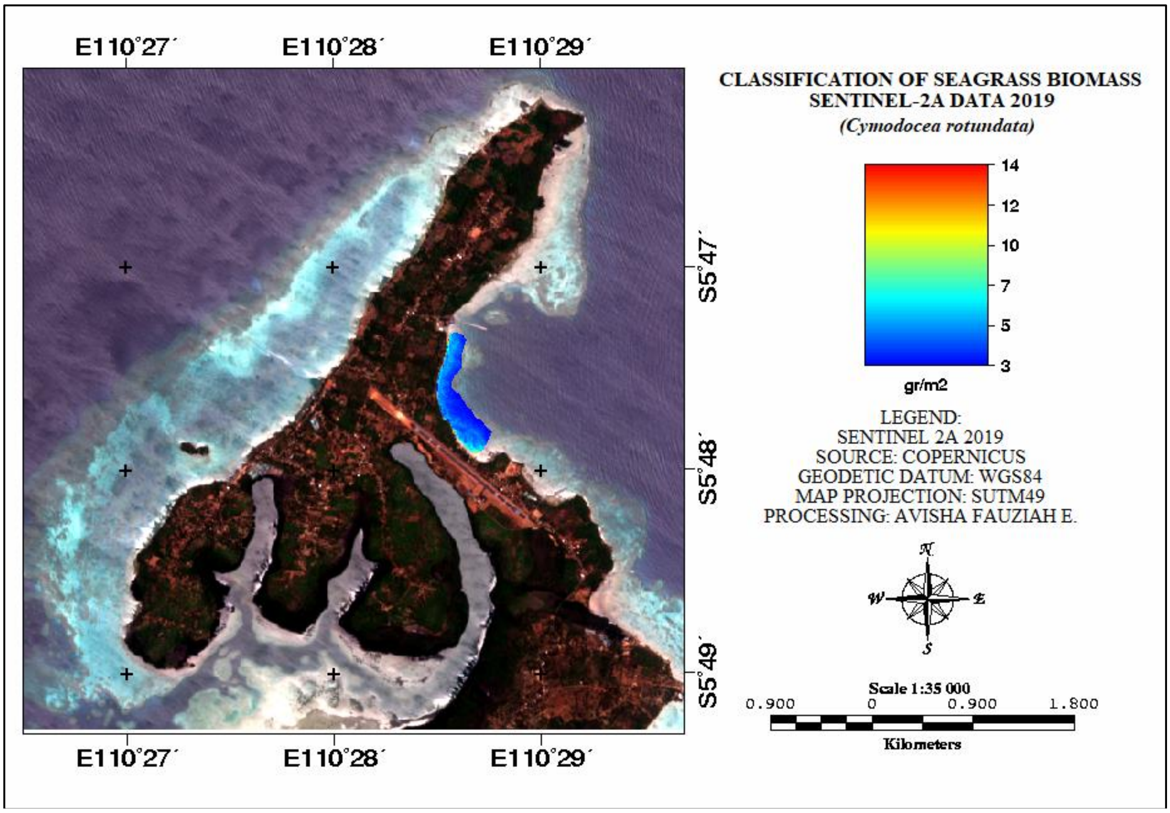

Figure 5. Classification of seagrass biomass of *Cymodocea rotundata* using Band 4/Band 2 rationing of Sentinel-2A satellite data.

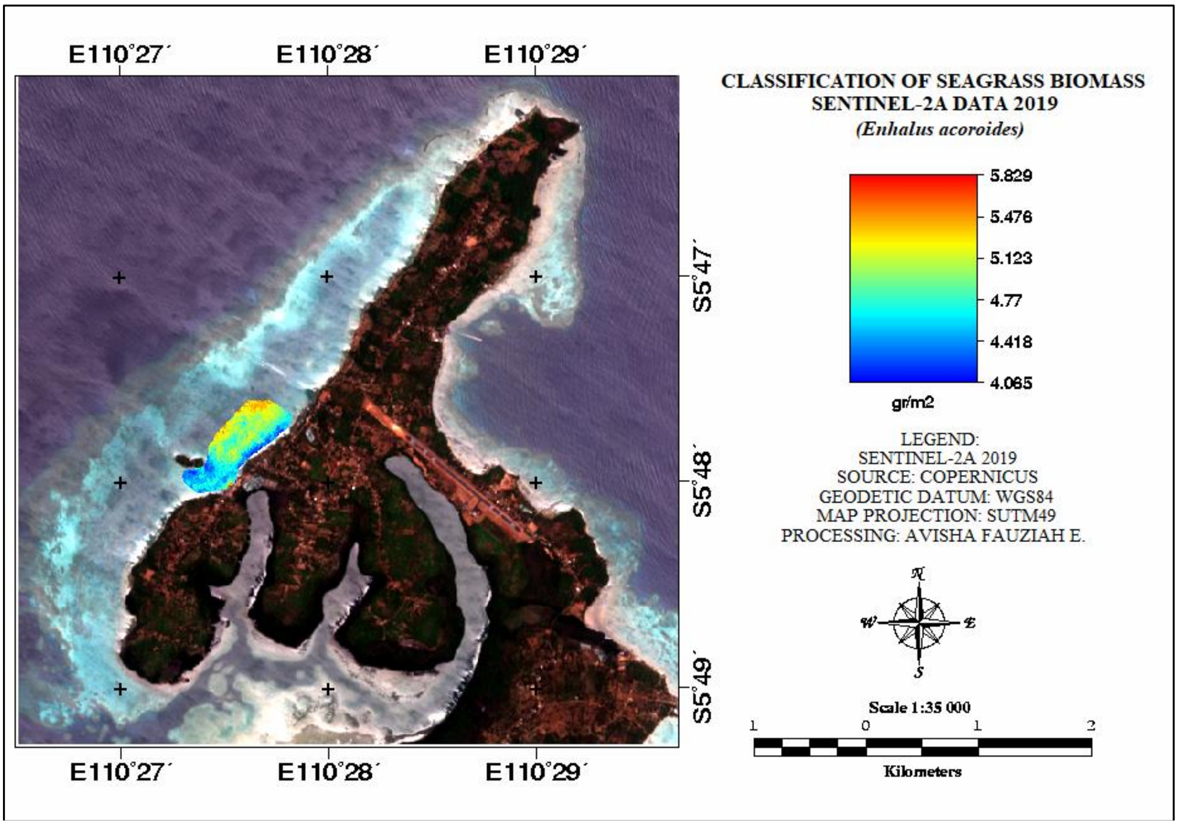

Figure 6. Classification of seagrass biomass of *Enhalus acoroides* using Band 3/Band 2 rationing of Sentinel-2A satellite data.

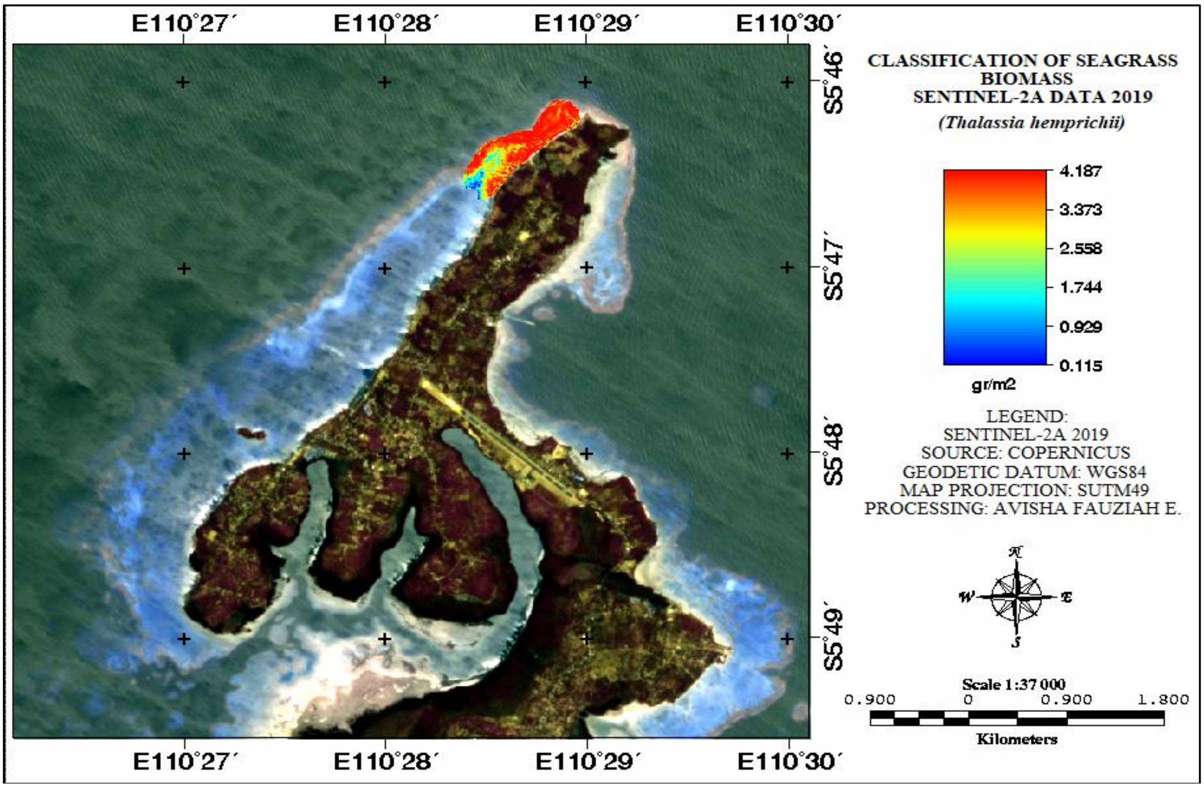

Figure 7. Classification of seagrass biomass of *Thalassia hemprichii* using Band 3/Band 5 rationing of Sentinel-2A satellite data.

Grain size analysis. In general, sediment characteristics in seagrass ecosystems in the study site were dominated by coarse to fine sand (Table 2). The difference in grain size is related to the origin of the sediment source. Sediment grain facing the open sea has a more coarse size. The most dominant sediment was sand, with a weight percent range from 7.41 to 56.05%. Sediment samples enter the organic calcareous category, being dominated by mollusc, coral and other marine organism remains.

Table 2

Percentage weight of grain size

Station	*Sediment grain size*						*Dominant*
	G (%)	VC (%)	CS (%)	M (%)	FS (%)	S (%)	
1 (Q1)	5.61	6.48	7.41	8.72	56.05	14.68	Sand
1 (Q3)	6	10.58	16.61	25.21	34.27	7.27	Sand
1 (Q5)	6.34	11.63	15.63	19.64	35.52	10.87	Sand
2 (Q1)	9.56	27.78	15.68	10.5	16.2	19.85	Sand
2 (Q3)	4.6	5.96	9.31	15.75	33.6	30.35	Sand
2 (Q5)	7.01	9.19	8.57	25.08	26.16	16.07	Sand
3 (Q1)	7.77	12.12	14.46	16.73	26.68	12.25	Sand
3 (Q3)	7	4.21	13.96	10.88	23.31	16.67	Sand
3 (Q5)	9.77	8	15.18	29.54	31.18	5.6	Sand

Note: Q - quadrant; G - gravel; VC - very coarse sand; CS - coarse sand; M – medium coarse sand; FS - fine sand; S - silt.

The sediment in the study area is dominated by sand to fine sand (Table 2). Hydrodynamically, these results represent a high energy environment, indicated by coarse sand, and a moderate energy environment indicated by fine sand (Muskananfola et al 2020). Sediment particle movement occurs when the fluid force exceeds gravity force and friction force acting on sediment grains at the seabed. In this regard, current velocity is a crucial factor in determining sediment dynamics and characteristics in a marine environment. Current velocity functions as a factor of sediment transport, where a sediment grain size of 1 mm will move if the minimum current speed is 0.5 m s^{-1} (Satriadi 2012). Sediments will settle when oceanographic factors at the location are no greater than the gravitational force. Besides being influenced by environmental and oceanographic factors, the force acting on the sediment particles could also be affected by the size and constituent material of the sediment particles, including biogenous factors (Muskananfola et al 2017). The size of sediment grains will determine the ability of the deposition processes that occur in the waters. The smaller the size of the sediment is, the time for settlement is longer, and vice versa (Gemilang et al 2018).

Seagrass density is the number of seagrass individuals in a given area (Gunawan et al 2019). The present study revealed that three species of seagrass were found at Kemujan island, i.e. *C. rotundata, T. hemprichii* and *E. acoroides* (Table 1). According to Zulfikar et al (2016), *E. acoroides* is the dominant species at the west coast of Kemujan Island. Seagrass at each station have different characteristics due to their environmental conditions. Station 1 is dominated by *C. rotundata* and *T. hemprichii*. The highest density of *C. rotundata* is 126 ind m^{-2}. The seagrass cover at Station 1 ranged from 38.28% to 42.97%, and can be included in the medium category of coverage. At this station, the seagrass size tends to be small, but dense in some places. Seagrass at Station 2 tends to be taller and thicker, with less individuals. Seagrass cover at Station 2 ranged from 50.78% to 57.03%, being in the dense category. Seagrass at Station 3 was close to the mangrove ecosystem. The substrate in this area was represented by a mix of sand with a low level of mud. Riniatsih (2016) stated that the density of seagrass species is highly dependent on the substrate, especially on the chemical conditions of substrate nutrients.

There were fish larvae from 11 families identified during the study period, with a total of 571 individuals (Figure 3). The pattern of marine organisms distribution is influenced by several factors, including substrate, the availability of food in the form of detritus and suspended particles, ecological factors, adaptation strategies and biological interactions between populations in the community (Wowor et al 2016). The substrate functions as a protection, feeding and growth habitat for fish larvae. Simanullang et al (2016) stated that coastal waters and estuaries are characterised by tidal fluctuations, mangroves, seagrass beds, and coral reefs. Sandy beaches function as nurseries for various species of fish. The fish larvae hatched in the offshore area migrate to coastal habitats that act as nurseries, and will affect recruitment. The abundance of fish larvae in the study area ranged from 90 to 335 ind 1000 m^{-3} in each station. It was dominated by the Gobiidae family with 580 ind 1000 m^{-3}. The lowest abundance is presented by the Labridae family, with 55 ind 1000 m^{-3}. Gobiidae representatives have a transparent and elongated body, with two dorsal fins. Labridae larvae have a clear colored body, so that the streaks on the sides of the body are visible. The tail is truncated. Labridae includes the Napoleon fish and the coral fish. Aditya et al (2013) stated that, in general, the larvae of Labridae use seagrass beds as a spawning ground and when they mature, they migrate to mangrove ecosystems, coral reefs and even deeper water.

The algorithm for seagrass biomass was based on polynomial regression obtained from Sentinel-2A satellite data of digital number values for each seagrass species and the field biomass value. Exploration of several band combinations has been carried out for the highest correlation coefficient value. Seagrass biomass algorithm of *C. rotundata* is $Y=51.657 \times (Band\ 4/Band\ 2)^2 - 83.853 \times (Band\ 4/Band\ 2) + 36.544$, with $R^2=0.7622$ and r=0.873, with a very strong correlation. The seagrass biomass algorithm for *E. acoroides* is $Y=1.7958 \times (Band\ 3/Band\ 2)^2 - 11.82 \times (Band\ 3/Band\ 2) + 14.787$, with $R^2=0.6652$ and r=0.815, with a very strong correlation. Seagrass biomass algorithm for *T. hemprichii* is $Y=-24.984 \times (Band\ 3/Band\ 5)^2 - 50.755 \times (Band\ 3/Band\ 5) + 21.59$ with $R^2=0.639$ and r=0.799, with a strong correlation. The color scale-bar depicted on the map indicated the biomass value of each species of seagrass. The RMSE values ranged between 0.162 and 0.226. According to Nurmalasari & Santosa (2018), regression is a statistical calculation used to determine satellite data that should be used to describe conditions in the field. The relationship between regression correlation is expressed in the correlation coefficient (r) and the coefficient of determination (R^2). The correct wavelength bands of any satellite data can be used to develop accurate spatial algorithms based on field data verifications, i. e. the use of Band 4 with 0.6 μm wavelength reflectance of chlorophyll-a (Hartoko et al 2015).

Based on the results of the PCA analysis, 4 components were obtained. The seagrass density correlated with four variables: fish larvae abundance, sediment organic content, water temperature and current velocity. The MLR test produced the coefficient of determination R^2=0.977. This explains that the contribution of the independent variables (abundance of fish larvae, sediment organic material, temperature and current) to the density of seagrass was 97.7%. Ara et al (2011) stated that another factor that will contribute to the abundance of fish larvae in seagrass ecosystems is the availability of food and shelter. The high primary productivity of seagrass beds can guarantee the availability of abundant organic material for organisms. The structure of seagrass vegetation provides physical and chemical qualities to the environment, making the area suitable for fish recruitment. Seawater temperature values in the seagrass ecosystem in Kemujan Island range from 27.9 to 33.7°C, being considered as optimal for the growth and photosynthesis of seagrass. Rawung et al (2018) note that seawater temperature has a big influence on the process of photosynthesis, and on the population related to seagrass beds. Current velocity values ranged from 0.04 to 0.25 m s^{-1}. The current velocity varied significantly from feeble currents to very strong currents. This is because several factors affect the value in each research station. Christon et al (2012) stated that tidal currents and trends affect the dissolution and distribution of nutrients in seawater for seagrass growth.

Conclusions. Three species of seagrass were found in Kemujan Island, namely *Cymodocea rotundata, Thalassia hemprichii* and *Enhalus acoroides*. The value of seagrass biomass below the substrate is higher than the amount of the biomass above the substrate. Seagrass density has a strong correlation with the abundance of fish larvae, sediment organic content, seawater temperature and current velocity. Seagrass biomass algorithm was obtained based on the polynomial regression of the Sentinel-2A digital numbers with a combination of Band-5, Band-4, Band-3 and Band-2 for the field seagrass biomass with an accuracy of 0.1–0.2 RMSE of the Sentinel-2A pixel size.

Acknowledgements. The authors would like to thanks to the Karimunjawa National Park Office for the field survey permit. A sincere thanks to the ESA Copernicus for the Sentinel-2A satellite data, also to all parties had helping the research and the manuscript.

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Received: 09 April 2020. Accepted: 16 May 2020. Published online: 17 June 2020.
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How to cite this article:
Erzad A. F., Hartoko A., Muskananfola M. R., 2020 Seagrass ecosystem as fish larvae habitat and its biomass algorithm from Sentinel-2A Satellite at Kemujan Island, Karimunjawa, Indonesia. AACL Bioflux 13(3):1511-1521.