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AN ECOLOGICAL ASSESSMENT OF NUDIBRANCH DIVERSITY AMONG HABITATS RECEIVING DIFFERENT DEGREES OF SEDIMENTATION IN JEPARA COASTAL WATERS, INDONESIA

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Abstract

Nudibranchs are a prominent part of coral reef fauna that changes in their abundance and diversity due to environmental changes. The present study was carried out to assess the relative abundance and diversity of nudibranch among habitats receiving different degrees of sedimentation. A rapid assessment of nudibranch species was conducted by using the Roving Diver Visual Method on 20-27 August 2020. The sedimentation rate data were achieved by measure the number of sediments in traps that are placed in the sea bottom near coral habitats. Results of the present study recorded 256 individuals representing 6 species of Nudibranchia, which fall into 4 families namely, Discodorididae, Chromodorididae, Polyceridae, and Phyllidiidae. Of the four sampling locations, abundance and species richness was no significantly different. The nudibranch Jorunna funebris species was the most abundant species. Statistically, there were no significant different on sedimentation rates among site locations. No correlations between levels of sedimentation rate and nudibranch abuncance were found either. Jepara coastal waters are still feasible to support the survival of nudibranch life. However, monitoring is needed periodically to screen the condition of the nudibranch fauna. This study provides basic information for future monitoring due to the increasing sedimentation rate and tourism.

Keywords*: Nudibranchia; relative abundance; diversity index; turbidity; Java Sea*

Introduction

The nudibranchs are commonly known as *sea slug* or poetically sometimes called *butterfly of the sea* are a group of shell-less marine mollusks with their beauty in colors and shapes [1, 2]. They have a high variety of species with multivarious morphological characters that are attractive to be observed on their abundance and diversity. Nudibranchs are exotic representatives of the Opisthobranchia subclass of mollusk gastropods, ordo Nudibranchia [3, 4]. In the sea, nudibranch could be recognized very simply because of their body characters that consist only of skin, muscle, and organ due to lost their shells in the course of their evolution [5]. Many articles have been published to date to discover their bioactive metabolites [6-8] and to investigate the ecology of nudibranchs [9, 10]. In contrast, only a few studies have been conducted on the diversity and abundance of sea slug nudibranchs [3].

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Agricultural intensification and deforestation are the main factors that cause increasing the amount of sediment moving from land-based sources to coastal waters worldwide [11, 12]. These alterations have led to increased sediment loading in riverine systems and the water column, which subsequently gets transported to the coast [13]. It is well known that sedimentation is the main factor cause of coral reef degradation worldwide [14, 15]. Several studies showed that sedimentation can cause coral mortality by smothering or burial, decreasing adult coral growth, reducing coral reproduction, larval settlement, and early survival [16-18]. Nudibranchs are one of among components of sessile benthic communities in the coral ecosystem [19]. Even there no publication reported on the effects of sedimentation on nudibranchs. However, with coral reefs suffering all over the world, nudibranchs, which rely heavily on the reefs for food and protection, are no exception to the deadly effects.

Jepara, a coastal city in the northeast of Central Java Province, is bordered by the sea in the western and northern parts with a coastline length of 72km. Geographically, in the eastern part of the district is a mountainous area with several tributaries of small rivers flow to the west of Jepara coastal waters, Java sea [20]. This region is characterized by several badly environmental and anthropogenic conditions, such as high precipitation rates, coastal population density, and urban land use that may support coastal eutrophication. Trophic status classification of Jepara coastal waters by several researchers was classified as a eutrophic category [21, 22]. Consequently, the reefs near Jepara coastal areas are under serious stress which subjects to intense anthropogenic activity. *E.N. Edinger, M.J. Risk* [23] reported that the high sedimentation rate is the primary threat the coral ecosystem of Jepara coastal waters because of flooding and river flows. Besides, they are facing increasing nutrient and sediment inputs as a consequence of urban growth and tourism. Sedimentation from the land enters into the sea, might be, poses many challenges to the existence of marine invertebrate diversity including corals, soft corals, sponges, nudibranch, and others.

Researchers have been alarmed because more than a decade of habitat destruction, pollution, overfishing from the wild, and other human activities lead to the extinction of some species [24]. The majority of nudibranchs are benthic invertebrates relying on abiotic conditions in their environment for geographic dispersal [25]. The abiotic factors that influence nudibranchs include temperature and current, while the biotic factors are the presence of settlement hosts, chemical cues from prey items, and abundance of food [26, 27]. To date, no information was found on the effect of sedimentation on nudibranch diversity and abundance. These basic data are urgently required to conserve these species legally. Therefore, the goal of this research was to assess the effects of sedimentation on the diversity and abundance of nudibranch fauna on the Jepara coast.

Experimental

Characteristic of study area

The survey was carried out in Jepara coastal waters from August 20-27, 2020. Four sampling site locations were established in the study area included Awur Bay, Kartini Coast, Panjang Island, and Bandengan Coast as shown in Figure 1. The Awur Bay (S 06^0 36' 58.6'', E 110^0 38' 18.8'') as the name implies, has the characteristic of a beach that extends into the mainland in a semicircular shape. This location is a beach characterized by the number of mangrove trees, scrubs, and grasses that function as shade and an abrasion barrier. In this place, there are many inns, villas, hotels, and student dormitories. Panjang Island (S 06^0 34' 20.4'', E 110^0 37' 36.4'') is a small, non-inhabitant island characterized by namely white sand surrounded by shallow and clear waters and beautiful coral reefs. In the center of the island, there is a tropical forest that is dominated by tamarind, dadap, randu trees, and pine trees, shrubs, and grass as a place for seabirds to breed. Kartini coast (S 06^0 35' 08.5'', E 110^0 38' 24.8'') is a strategic area because it serves as a sea transportation route to the tourist attraction

of Karimunjawa National Marine Park and Panjang Island. There is also an agricultural farm with small rivers dominated by paddy-rice fields and brackish waters.

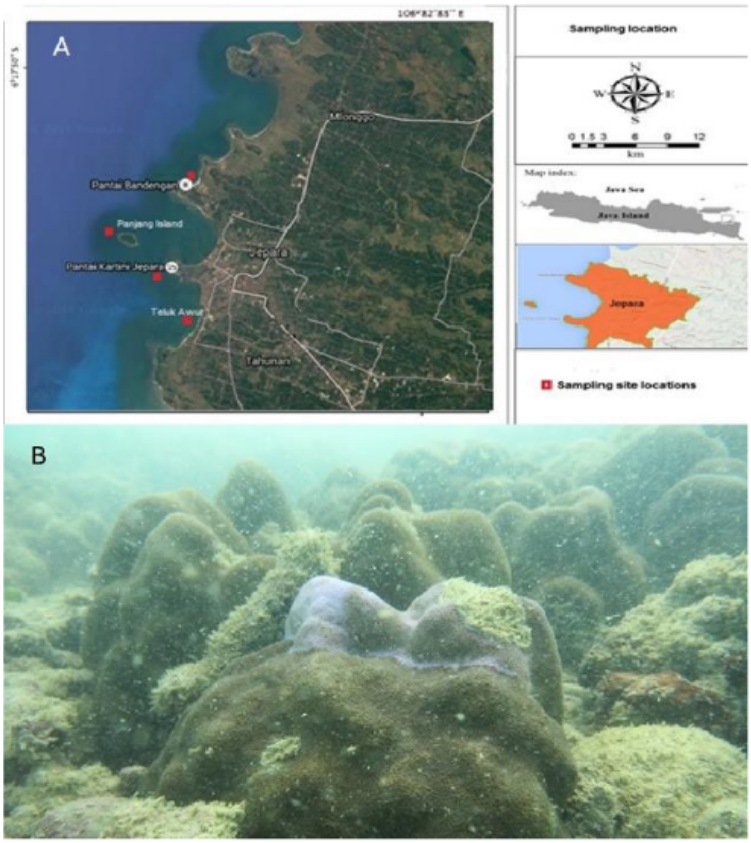

Fig. 1. Sampling site locations of Jepara coastal waters marked with red dot (A) and the reefs are continuously under serious stress from high sedimentation rate (B)

Bandengan Coast (S 06^0 33' 36.3'', E 110^0 38' 35.3''), similar to Kartini Coast condition, a tourist area with a white sand beach and mostly overgrown with pandanus trees and seagrass. This site location is an agricultural farm dominated by paddy-rice fields and is relatively grassy and has shrubby vegetation. It also has a relatively high-density settlement and some hotels, inns, and villas along the seashore.

Methods

Nudibranch diversity

It is very important to have the ability to carry out rapid species assessments as a conservation tool. The Roving Diver visual survey method was used to record data on species composition, and abundance of all nudibranchs [28]. This technique was used in this study due to the low abundance, scattered distribution, and their uncertain occurrence of nudibranch in this region. Besides, no previous studies were published from this site regarding nudibranch abundance and diversity. Specimens were documented directly from the substrate in the field by Scuba diving at each site from 20-27 August 2020. Totally 16 dives with 2 dives in every sampling site were involved. The roving diver survey technique involved four divers

investigating reef vicinity for about 45min to record all nudibranch species observed. There is no sample collection or physical disturb the habitat conducted in this study.

Coral habitats and their vicinity were observed for nudibranchs in the depth of 3-15 m from the west to east of Jepara coastal waters, namely Awur Bay, Kartini Coast, Panjang Island, and Bandengan Coast. These sites have a similar depth range (5-15m). Data recorded include serial photographs on each specimen of nudibranch species using Olympus Tough TG-6, navigational site coordinates, water temperature, and salinity. After finishing the dive, each diver records data to a NoteBook computer, and preliminarily identified it by using identification book [29] and scientific publications [30]. All individuals were identified to species level. The validity of species names was checked with the help of the World Register of Marine Species (WoRMS). Relative abundance(*pi*), the diversity index (H'), dominance index (D), and evenness (*J'*), were analyzed according to *D. Sulistiawati et al* [31].

Sedimentation rate measurement

Data on sedimentation rates are needed to understand its impact on nudibranch diversity. This species is susceptible to sedimentation. The sedimentation rate data were achieved by measure the number of sediments in traps that are placed in the sea bottom. A total of 12 sediment traps were placed on each location. The PVC pipe with a diameter of 5 - 25cm in height was used as material to make sediment traps [32]. The sediment trap was left behind for 20 days. The sedimentation rate is expressed in units of mg cm^{-2} day^{-1} [33].

Results and Discussion

Nudibranch identification

The diversity of Indonesian nudibranchs is difficult to be exactly reported due to underexplored and very poor data documented. The results of some previous studies are published mostly from the eastern part of Indonesia such as Sulawesi, Maluku, and West Papua [34-38]. Sadly, only a few articles were revealed from Google Scholar search related to the nudibranch diversity from the western parts of Indonesia, such as Sempu strait, East Java [39], Sabang Island, Aceh [40].

In the sea, nudibranch could be recognized very simply because of their body characters that consist only of skin, muscle, and organ due to lost their shells in the course of their evolution [5]. Even easier, however, the study of Jepara nudibranch diversity and biogeography had not been ever studied at all in the past. There is almost no information about these species' population dynamics in the localities they inhabit. In this first assessment, fortunately, there are still some nudibranch species that survive living in this contaminant area. Identification of these photographic records has resulted in 6 species being reliably recorded from Jepara coastal waters namely, *Jorunna funebris, Gymnodorisrubropapulosa, Doriprismatica atromarginata*, *Discodoris boholliensis*, *Chromodoris lineolate,* and *Phyllidiella sp. nov*. (Table 1 and Fig. 2).

The results of this study provide for the first time evidence that at least a small part of nudibranch species still exist in the Jepara coastal waters. Habitat destruction, pollution, sedimentation, and other human activities have pushed these species to the edge of extinction that radical need for conservation. Diagnostic characters of these species are described morphologically with illustrations. The following is a description of six exotic species of nudibranch fauna found in this study.

The nudibranch *J. funebris* is one of the marine, slug-like invertebrates belonging to phylum Mollusca that lacks a protective hard shell [41]. This species was found in all sites feeding on corals and well camouflaged on the host is carnivorous and feeds on sponges *Haliclona* sp. The body is characterized by white with black rings, fuzzy appearance owing to the presence of dense caryophyllidia [42].

Table 1. Nudibranch identifications from Jepara coastal waters [29]

Proposed species	The appearance of the opisthobranch	Depth (m)	Substrate	Size (mm)	Feeding on
Joruna funebris	White with black rings; fuzzy appearance owing to the presence of dense caryophyllidia.	2 - 7	Shallow water reefs	50	Sponges *Haliclona* sp.
Gymnodoris rubropapulosa	White with numerous large orange spots; red-orange pigment all over the gill and on the rhinophores	3 - 15	Shallow Polyceridae	60	Opisthobranchs
Doriprismatica atromarginata	Light yellow with a black marginal line; gill and rhinophores black; mantel edge undulating	3 - 15	Reef, sand slope, ridge	100	Sponge
Chromodoris lineolata	Dark brown to black, densely covered with fine opaque white longitudinal lines; a wide yellow-orange marginal band	5 - 10	Shallow Reefs	30	Sponges Dysidea
Discodoris boholiensis	Brown with black and white spots and white lines; body fairly flat with a central hump in the middle of the dorsum.	3 - 20	Underneath rocks	70	sponge
Phyllidiella sp. nov	White cube with black basic, rhinophores are black	2 - 7	Shallow reefs	20	Sponges

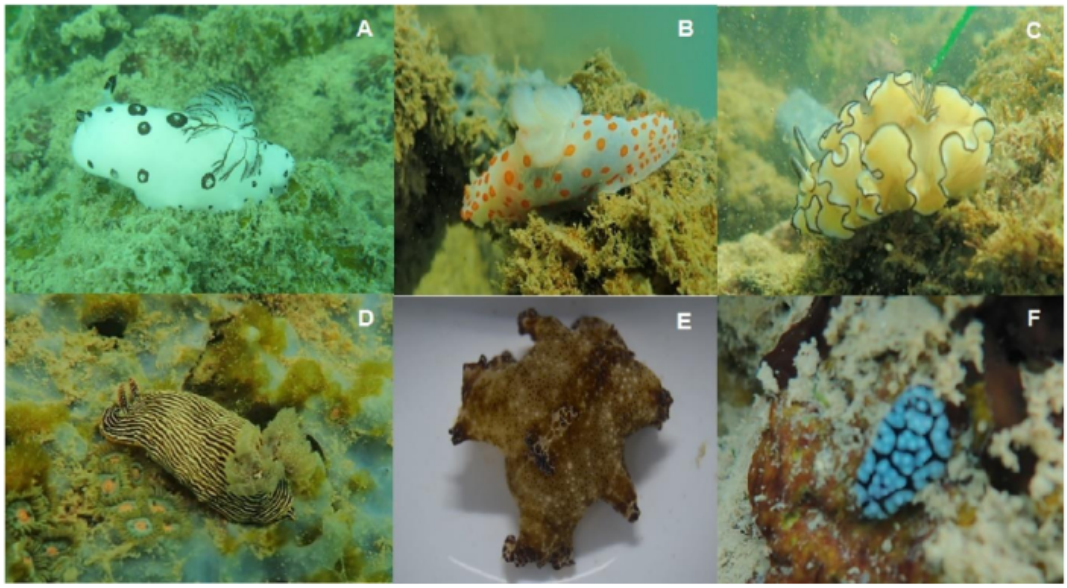

Fig. 2. Nudibranch species photo-documented at Jepara coastal waters:
A. *J. funebris*, B. *G.rubropapulosa;* C. *D. atromarginata*; D. *C. lineolate*; E. *D. boholliensis;* F. *Phyllidiella sp. nov*

The species of *Gymnodoris* sp. grows to approximately 60 mm, and the body is covered in white with numerous large orange spots; red-orange pigment all over the gill and on the rhinophores. This species is known to feed on other opisthobranchs. While *D. atromarginata* is described as light yellow with a black marginal line; gill and rhinophores black; mantel edge undulating. Body measures about 100 mm in length. The nudibranch species of *D. boholliensis* was determined to be one of the most speciose genera of nudibranchs based on a broad morphological diagnosis. This body is brown with black and white spots and white lines; the body fairly flat with a central hump in the middle of the dorsum. Nevertheless, *Y. Tibirica et al*

[43] stated that the specimens of *Chromodoris* had a soft colored body, simple pinnate branches, small tentacles, bifid jaw rodlets, and a radula with no central teeth (only a triangular thickening), with the innermost teeth having denticles on both sides but the lateral teeth having denticles only on the outer side. Genus *Phyllidiella sp. nov* is so difficult and understudied that it is not even possible to say whether this new photograph matches the recorded species. This genus is characterized as a white cube with black basic, rhinophores are black. On the other hand, *M. Domínguez et al* [44] described that yellow rhinophores and the tubercles are blue-grey at their bases and have yellow-orange apices, lack the dorsal black pigmentation. Ventrally the pedal sole has a median black longitudinal stripe. Diagnostic characters of these species are described morphologically with illustrations. Further, DNA barcode data from these species are needed to provide a supplement to morphological identifications.

Nudibranch abundance and diversity

Shannon-Weiner index was used to analyze the data due to the disorder and uncertainty of individual species in Jepara waters. The higher the uncertainty, the higher the diversity. As shown in table 2 and figure 3, there were six species of nudibranchs found in which *J. funebris* species was the largest number of individuals (156) recorded. The discovery of several nudibranch species in Jepara waters motivates our study to take comprehensive conservation measures on the part of the local community and local government to preserve and conserve nudibranch biodiversity which now is on the verge of extinction.

The Shannon-Wiener diversity index (H') is a measure of diversity that combines species richness and their relative abundances. Based on the computation results, the comparison of the diversity index (H') at four sampling sites in the Jepara coastal waters showed that the highest value found in Awur Bay (0.92), followed by Panjang Island (0.70), Bandengan Coast (0.52), Kartini Coast (0.12). According to Shannon-Weiner (1949), that H' < 2.3026 indicates a low diversity index and low community stability. Not surprisingly, the low diversity index in this sampling site because of the low number of species richness and evenness of individual distribution in the species. The stressful physical conditions, such as harbor construction, boatyard, coastal settlements, runoff and dredging, wood industries, and high-intensity agriculture were also responsible for the low species diversity in the Jepara coastal waters [45]. The relative abundance (RA) of Discodoridídae, Chromodorididae, Polyceridaeand Phyllidiidae family are 56.83%, 33.22%, 3.32%, and 1.1%, respectively (Fig. 4). Some previous studies showed different results in their abundance and dominance. *M. Ompi et al* [46] reported that Chromodorididae is the most abundant species family in Lembeh Strait, Bitung North Sulawesi.

Table 2. Relative abundance, species diversity, dominance, and evenness of nudibranchs

Family	Species	Individuals observed:							
		Awur Bay	RA (%)	Kartini Coast	RA (%)	Panjang Island	RA (%)	Bandengan Co	RA (%)
Discodoridídae	*J. funebris*	9	15.8	90	97.83	14	23.33	41	58.57
Polyceridae	*G. rubropapulosa*	5	8.8	1	1.09	1	1.67	2	2.86
Cromodorididae	*G. atromarginata*	0	0.00	1	1.09	1	1.67	0	0.00
	C. lineolata	40	70.2	0	0	44	73.33	0	0.00
	D. boholliensis	2	3.51	0	0	0	0	2	2.86
Phyllidiidae	*Phyllidiella sp. no*	1	1.75	0	0	0	0	2	2.86
Total		57		92		60		47	
Diversity index		0.94		0.12		0.7		0.52	
Dominance inde		0.53		0.96		0.59		0.38	
Evenness		0.59		0.11		0.51		0.77	

Note: Number of individuals (*N*); Relative abundance, % (RA)

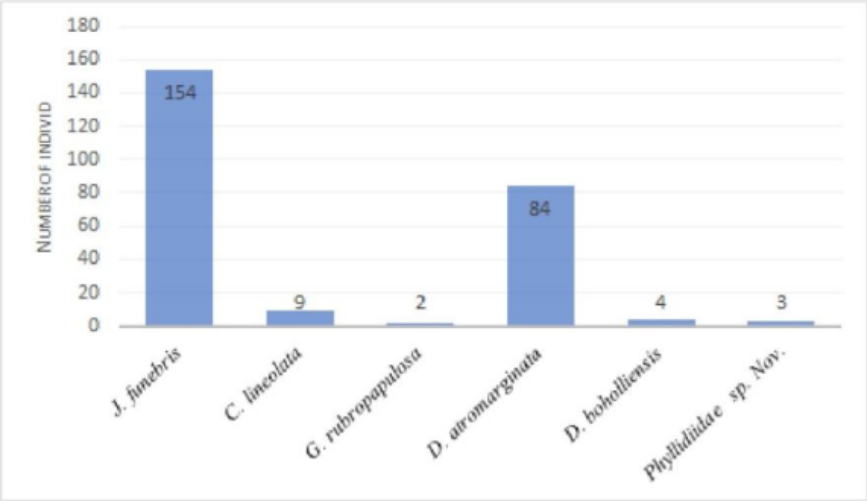

Fig. 3. The total number of nudibranch species in Jepara coastal waters

Furthermore, Papu et al [34] reported that Chromodorididae is also the most abundant in Bangka Island. On the other hand, *A. Purba et al* [47] reported that the Phyllidiidae family was the major family in the Mollucas Sea and Sulawesi Sea. Several factors that influence the diversity of nudibranchs in nature are differences in habitat, food availability, and the percentage of coral cover. These factors are related to each other because these organisms eat and live in associated with corals [48]. In this study, three species, *D.atromarginata, D. boholliensis,* and *Phyllidiidae* sp. nov were recorded with a very minimal number. Meanwhile, the species evenness is included in the distribution of individuals among locations and is not evenly distributed. Evenness index showed that the highest value was found in Bandengan Coast (0.77), followed by Awur Bay (0.59), Panjang Island (0.51), and Kartini Coast (0.12). Even the lowest species evenness is located in Kartini Coast, however, this location has a high dominance index (0.96) with the highest number of individual species *J. funebris*.

Sediment impact on nudibranch diversity

Data on sedimentation in Jepara coastal waters showed that Panjang island was the lowest sedimentation rate ($9.01\pm1.64 mg \cdot cm^{-2} \cdot day^{-1}$). While Awur Bay was the highest one ($27.31\pm1.2 mg \cdot cm^{-2} \cdot day^{-1}$) (Fig. 4).

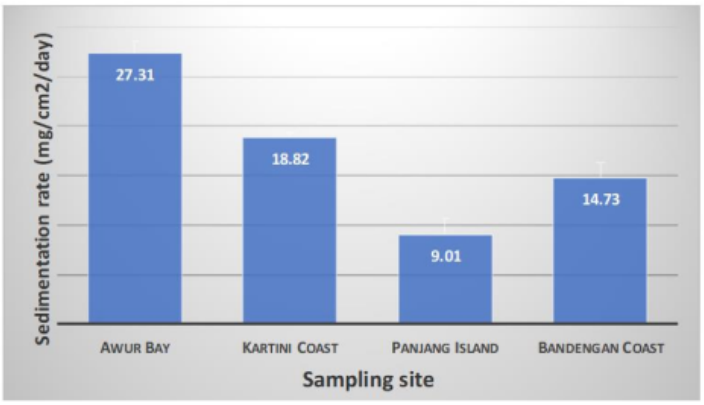

Fig. 4. Sedimentation rate (mg/cm2/day) in sampling site locations

One-way ANOVA statistical analyses showed sedimentation rates were not significantly different among habitat locations ($F_{.05(3,8)} = 2.13$, $p > 0.05$). High turbidity and sedimentation rates cause the degradation of the coral reef ecosystem due to reducing survival and coral growth, bleaching, more susceptible to diseases, and physical damage of coral tissues [49]. The high sedimentation within the Jepara coastal waters was also the main factor for the decreased number of mollusks [50]. Even limited studies have been conducted on the effect of sedimentation on nudibranchs, however, indirectly the coral degradation, nudibranchs, which rely heavily on the reefs for food and protection, will affect their life.

S. Suryono et al [51] reported that the relatively high rate of sedimentation (9.46-14.6mg/cm^2/d) might have quite a detrimental impact to planulae recruitment in Jepara coastal waters. Coral tolerance limits to turbidity in polluted areas was of 10mgL^{-1} [52]. Most publications reported that the high sedimentation rates would significantly decrease the diversity and number of species in areas [53]. *P.W. Purnomo, N. Afiati,* [54] showed that the life-form coral cover in Jepara coastal waters was in the' bad' categories (< 25%), while *S. Suryono et al* [51] reported that the coral covers of Jepara coastal waters fell into 'bad to moderate categories' (20 – 49% live of coral coverage). All four sampling sites fall into the 'low' category on the diversity index. It seems that the low species diversity in the Jepara coastal waters is thought to be primarily due to no more space provides nudibranch for their diet necessity. The increased sedimentation which have effects on the water quality and the biota resulting in decreasing coral recruitmens and growth. Besides, our field observations indicated that many coral species are becoming rare and more difficult to be found. Interestingly, a high number of *J. funebris* nudibranch species was found on Kartini coast. It suggests that each nudibranch species might respond differently to increased turbidity. This is a possibility that merits further study.

Conclusion

This study revealed that the nudibranch of Jepara coastal waters belonging to four families from which 6 species were identified. *J. funebris* Kelaart, 1859 was the most dominant species. The survival of nudibranch living in high sedimentation might probably due to providing more space for feeding. The results of this study provide basic information for future monitoring due to the increasing anthropogenic pressure, sedimentation rate, and tourism in Jepara coastal waters.

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