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EFFECT OF ENVIRONMENTAL PARAMETERS ON THE VALUE OF HUE SAND DOLLARS IN KARIMUNJAWA ISLANDS CENTRAL JAVA INDONESIA

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ABSTRACT

Sand dollar is one among many echinoid groups with unique habitat preferences in the coastal waters. The hue (color) of sand dollar is one of the unique aspects, but currently, the information is still very limited. The purpose of this study is to investigate the value of hue sand dollar in Karimunjawa waters and investigate the condition of environmental parameters in Karimunjawa waters so that it can further analyze the environmental effect on hue sand dollar levels descriptively. The research was carried out in Karimunjawa islands, including Karimunjawa, Menjangan Kecil, and Cemara Kecil islands in June – July 2019. Sampling was carried out using line-transect with the transect length of 25 m. Four sampling stations were occupied at each island. The observation parameters were including sea surface temperature, pH, DO, organic matter, and seafloor coverage such as coral, rubble, and sand. Hue value was analyzed with Haphazard sampling method, using Adobe Photoshop. Data analysis was conducted with ANOVA and regression. The result showed there were variations in environmental parameters, including the significant difference of pH, organic matter, and rubble coverage. The hue of sand dollar has also differed significantly among islands. Regression analysis showed significant effect from pH, coral coverage and rubble coverage on the hue value of sand dollar with the formula: ln (Y) = 20.867– 2.364(X1) + 6.608e^{-5}(X2)+ 1.271e^{-4}(X3); while the determination coefficient was 0.849 (p = 0.001). The effect of environmental parameters on the hue value of sand dollar might occur indirectly, but due to the change of pigment composition and concentration.

Keywords: hue; pigmentation; sand dollar; substrate; Karimunjawa Islands

INTRODUCTION

Sand dollar (Echinoid: Clypeasteroida) is one of the most diverse marine organisms. Sand dollar consists of approximately 150 extant species and 750 fossil species (Lopes, 2011). It is distributed between the intertidal and sublittoral areas and is a deposit-feeder. Sand dollar is commonly found in sandy substrates from the intertidal area to the depth of 20 meters (Guilherme *et al*., 2015). However, at a certain location, it is also found in the depth of 800 m (Christian *et al*., 2010). Sand dollars have short skin covered in cilia (small hair) so they can move along the sand and grass that can function to breathe (Morris *et al*., 2015).

Sand dollar is not commercially traded. However, in certain fields sand dollar is used for commercial purposes. Sand dollar, such as another Echinoid species, is a marine organism that produces quinone pigment, such as echinochrome and spinochrome (Ageenko *et al*., 2014). Both pigments are an important source for pharmaceutical and industrial substances. The improvement of the production of both pigments had been carried out for various medicine production.

Sand dollar can be found in the intertidal area to the depth (approximately 20 m). However, the distribution of sand dollar is affected by various factors, such as depth, hydrodynamics, substrate, size of sand particle, and food availability[2]. The distribution of sand dollar can be found in the uniform or clumped pattern based on species (Suryanti *et al*., 2016).

Sand dollar is an important biotic component for the sea shelf. Sand dollar plays a role in controlling the composition of microorganism community on the soft sea bottom (Christian *et al.*, 2010). The role is possibly carried out through two methods, including the direct effect by consuming the microorganism, or indirect effect by reducing the availability of organic matters. Sand dollar feeds on various prey, such as plankton, algae, remnants of living organisms, as well as organic matters and trapped microorganisms in their spines (Suryanti *et al*., 2016). Thus, its feeding activity would cause a change in the community of microorganisms directly or indirectly.

Sand dollar is also known as the host of microscopic crabs such as *Dissodactylus crinitichelis* and *Clypeasterophilus stabbing* (Martinelli-Filho *et al.*, 2014). However, both species are considered parasitic to the sand dollar. The occurrence of both crabs in abundant numbers on the sand dollar indicates that the immunity of sand dollar is weakened.

Sand dollar also acts as a bioindicator for heavy metal contamination in the sediment (Christian *et al.*, 2010). However, the capability is limited to a low contamination level, since sand dollar can not live in the highly contaminated habitat. The only sediment with minimum contamination level can be inhabited by sand dollar. The bioindicator function is related to the ecological role of sand dollar which includes the bioremediation of coastal water, especially in the bottom area.

To marine organisms, color has several important roles for its survival, such as camouflage and attraction (Williams, 2016). Certain marine species also utilize colors to obtain protection from environmental threats, such as the UV light (Camargo-Sosa *et al*., 2018). The color variation in the same species also indicates the health condition, spawning stages, and the infection of the parasite (Johnson and Fuller, 2015). Thus, understanding the coloration in animals is important to understand its condition as well as the state of the environment.

The color of marine animals is determined by the combination of several pigments. Generally, Echinoids has bright colors with red and orange as the most frequent color (Kennedy, 1979). The color in the echinoid species is determined by the combination of carotenoids and naphthoquinone compounds (Ageenko *et al*, 2011). In san dollar, the color variation results from the change in the number of pigment cells and the lucent fluorescent cells (Takata and Kominami, 2011). During the embryo stage, sand dollar contains a lot of pigment cells. Generally, there are several pigments contained in the echinoids, such as β-carotene, cryptoxanthin, echinenone, astaxanthin, ketocarotenoids, and xanthophylls (Kennedy, 1979). However, among those pigments, only the echinochrome and spinochrome pigments are exploited for commercial use (Ageenko *et al*., 2014). In the adult sand dollar, the pigments are found in the epidermis (Drozdov *et al*., 2017).

The livelihood of an organism is definitely related to its habitat condition. Environmental factors define the various aspects of an organism, such as survival rate, growth, reproduction, and it's health. In echinoid species, the color (hue) intensity is related to the concentration of pigment, such as spinochrome (Hou, 2018). However, the number of pigments in sand dollar itself is affected by the environmental condition (Ageenko *et al*., 2014). Thus, there is an indirect relationship between the environmental factors to the color intensity of echinoid species.

Karimunjawa is an archipelago district located in Jepara Regency with Karimunjawa islands as the center. The dominant substrate that existed in the archipelago is sand, making it suitable for various Echinoidea species. There are more than 10 sand dollar species identified in the Karimunjawa area. Previous research showed there were 11 species in Cemara Kecil Island alone (Suryanti *et al*, 2016).

The role of sand dollar in the ecosystem had been much studied. However, the response of sand dollar to various environmental conditions is not well understood, especially related to its hue intensity. This research aims to observe the environmental condition of the coral ecosystem in Karimunjawa island and its nearby islands, identify the hue value of sand dollar in the Karimunjawa island and nearby islands, and to analyze the effect of environmental quality on the hue value of sand dollar.

RESEARCH METHODS

The research was carried out in Karimunjawa and surrounding islands, such as Menjangan Kecil and Cemara Kecil Islands (Figure 1). The observation was carried out to collect data for environmental quality and the samples of sand dollar. The research was carried out in June – July 2019. Line transect was utilized as a research instrument, including a length of 25 m. Twelve observation spots were occupied, including four spots for each island.

The environmental parameters observed in this research were including surface temperature, salinity, pH, DO, organic matter, as well as coral, rubble, and sand coverages. The samples of sand dollars collected from the observation spots were then analyzed for its hue value. Hue value was measured in the photo laboratory. Measurement was carried out from a distance of 20 cm. Haphazard sampling method was carried out in the sampling of hue value. Haphazard is a method where the observer tries to create randomized sampling from the selected materials to obtain correct randomness. The image obtained from the sand dollar was then analyzed in Adobe Photoshop for its hue value.

Data analysis was carried out with ANOVA and regression. ANOVA was carried out to analyze the difference of environmental conditions as well as the hue intensity of sand dollar obtained from each location. Regression analysis was carried out to analyze the effect of environmental factors on the hue intensity of sand dollar obtained from the Karimunjawa area. Regression analysis was carried out through backward stepwise, thus a significant parameter was automatically removed.

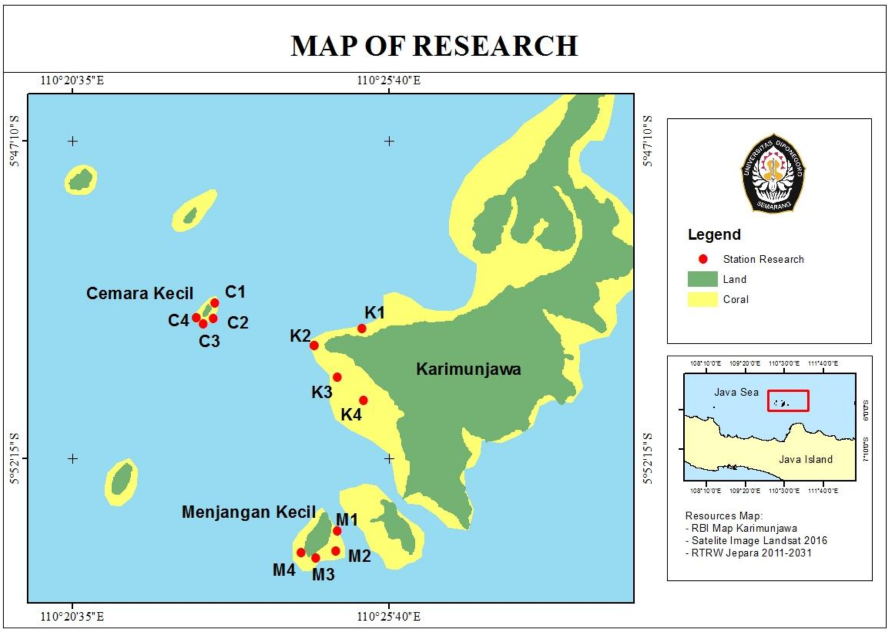

Figure 1. Map of the Research Location

RESULT AND DISCUSSION

Result Sand dollars were found at each location there were 11 species namely *Laganum Laganum* , *L. depressum, L. Depressumtonganense, L. fudsiyama, L. fudsiyamaafricanum, L. retins, L. europacificus,, L. centrale, L. joubini, L. decagonale, L. decagonale.* the special features of different species are indicated by the style of sand dollars and different cilia colors. The types of sand dollars found at the research location are presented in Figure 1. Observation on the environmental quality showed that there was variation among the sampling stations. The observation was carried out for the physical, chemical, and habitat conditions. **Error! Reference source not found.** shows detailed observation results on the condition of environmental parameters.

Table 1. Environmental Quality In Research Location

Parameters	Location		
	Karimunjawa	Menjangan Kecil	Cemara Kecil
Water temperature (°C)‡	30.8 ±0.5	30.0 ± 0.0	29.8 ± 0.5
Salinity (ppt)⸎	30.0 ± 0.0	33.0 ± 0.0	35.0 ± 0.0
pH	6.9 ±0.01[b]	6.9 ± 0.02[a]	7.0 ± 0.03[c]
DO ($mg.l^{-1}$)‡	5.4 ±0.2	6.4 ±0.1	6.5 ±0.0
Organic matter ($mg.l^{-1}$)	3.8 ±0.1[a]	4.2 ±0.2[b]	4.8 ±0.1[c]
Coral coverage (cm/50 m)	1.735.5 ±179.6[a]	2.649.5 ±467.0[a]	2.360.5 ± 842.6[a]
% of coral coverage	34.7 ±3.6[a]	53.0 ± 9.3[a]	47.2 ±16.9[a]
Rubble coverage (cm/50 m)	1.855.8 ±377.6[b]	1.291.0 ±267.4[a]	1.019.0 ±312.2[a]
% of rubble coverage	37.1 ± 7.6[b]	25.8 ±5.3[a]	20.4 ±6.2[a]
Sand coverage (cm/50 m)	798.3 ±329.8[a]	574.8 ±452.8[a]	963.5 ±739.1[a]
% of sand coverage	16.0 ± 6.6[a]	11.5 ±9.1[a]	19.3 ±14.8[a]
Hue value of sand dollar	135.9 ±12.6[b]	150.1 ± 13.3[b]	111.4 ±8.0[a]

Notes: ‡data distribution is not normal; ⸎data contains no variance
Different letters in the same line indicate a significant difference

Error! Reference source not found. shows that among the environmental parameters, there were some noticeable differences among locations, such as temperature, salinity DO, organic matter, and substrate coverage. Based on the observation result, the water temperature in Karimunjawa was warmer than in two other islands. There was approximately 1°C of temperature difference, which is quite significant to affect the aquatic community.

Another noticeable difference was the salinity. For some reason, the salinity in Cemara Kecil island was much higher than in Menjangan Kecil and Karimunjawa. Moreover, the salinity in the Menjangan Kecil island was also higher than in Karimunjawa island. The concentration of DO in Karimunjawa island was lower than in the Menjangan Kecil and Cemara Kecil islands.

Statistical analysis with ANOVA showed that there was significant difference on the pH ($p = 0.001$), organic matter ($p = 0.000$), rubble coverage ($p = 0.015$), and hue value of sand dollar among location ($p = 0.003$). However, statistical analysis for temperature, salinity, and DO was not conducted due to data abnormality or lack of variance. Detailed differences for respective parameters are presented in **Error! Reference source not found.**.

Further analysis was carried out with regression to understand the statistical significance effect of environmental parameters on the hue value of sand dollar. The analysis result is presented as the following equation:

$$\ln(Y) = 20.867 - 2.364(X1) + 6.605e^{-5}(X2) + 1.271e^{-4}(X3) \quad (1)$$

$R^2 = 0.849$; probability = 0.001 ………………… (2)

Notation: Y = hue value of sand dollar; X1 : pH value; X2 : coral coverage; X3 : rubble coverage

The result of the regression analysis showed that three environmental parameters had a significant effect on the hue intensity of sand dollar, including pH, coral coverage, and rubble coverage. According to the analysis result, pH has a negative effect on the hue of sand dollar, while coral and rubber coverage have positive effects.

Discussions

Within the habitat, environmental factors have a strong contribution to the livelihood of the organisms. Different organisms may require different environmental conditions. However, generally, there are some dominant environmental variables which act as the main factors affecting the distribution of organisms, such as soil/sediment texture, temperature, salinity, and light intensity. Particular environmental variables may affect the certain condition of the organism.

The distribution of sand dollar is mainly driven by the favorable food source during its larval stage (Hodin *et al.*, 2018). However, recent studies also indicate that echinoid species also consider the environmental condition such as light, sediment texture, hydrodynamics, and sound waves in the selection of settlement areas. For example, the concentration of Na and Mn in sand dollar *Dendraster excentricus* are affected significantly by water temperature (Harriss and Pilkey, 1966). Water temperature along with the wet weight significantly increases the metabolism rate of sand dollar which causes the increase of oxygen uptake and release of ammonia (Li *et al*, 2013). The reduction of photosynthetic rate by microphytobenthos is noticeable as the bioturbation impact of sand dollar.

Environmental stress such as increased water temperature and reduced oxygen concentration stimulate the changes in the metabolism of sand dollar (Olivares *et al*., 2014). The change in metabolism is considered as the adaptation effort of sand dollar to the changing environmental condition. Environmental factors, especially salinity has a significant effect on the reproduction process of sand dollar. Sand dollar obtains great fertilization and cleavage performance at salinity above 30 ppt. However, failure on fertilization is obtained at the salinity below 15 ppt, while cleavage failure was obtained at salinity below 18 ppt (Allen and Pechenik, 2010). Instead of salinity pH also has a noticeable effect on the fertilization of sand dollar, however, the effect is not significant and inconsistent toward salinity gradient (Allen *et al*., 2017).

According to the obtained data, the environmental condition of the sampling stations was varied, especially for temperature, salinity, DO, and ecosystem coverage. The variation of the environmental condition among stations was caused by the altering disturbance of anthropogenic activities such as tourism (Sulardiono *et al*., 2018). The difference in the temperature distribution among stations may have a particular impact on sand dollar. Various impact of temperature increase includes the inhibition of reproduction, survival, growth rate, size of larvae as well as its behavior (Pankhurst and Munday, 2011). However, the organism will only achieve a serious impact while the temperature increase exceeds the optimum limit and will cause mortality when it exceeds the tolerance range (Storch *et al*., 2014). The prefered temperature range for some echinoid species is suggested between 22-25°C (Díaz *et al*., 2017).

The fluctuation of DO in marine ecosystem is related to the temperature. Increasing temperature will cause a decrease in DO concentration (Storch *et al*., 2014). The observation on the environmental quality also showed a similar pattern of temperature – DO fluctuations. Thus, the temperature change has a direct and indirect effect on marine biota. Specifically, in echinoderms, the increasing temperature is incorporated with an increase of skeletal Mg content, resulting in a higher weight/volume ratio (Smith *et al*., 2016).

Another important aspect of marine animal distribution, especially for benthic organisms is habitat preferences. Sandy substrate is considered as favorable for hard-bodied animals such as sea urchin, sand dollar and mollusk since it may provide suitable protection against the water current (ADB, 2017). The variation of ecosystem coverage in the research stations was the impact of various anthropogenic activities, such as destructive fishing and tourism. Both kinds of activities exist in Karimunjawa area and are the most dominant drivers of ecosystem degradation (Hafsaridewi *et al*., 2018; Prasetya *et al*, 2018) . Referring to the obtained data, it can be suggested that Karimunjawa Island obtained the most severe impact of the activities, shown by the significantly higher rubble coverage.

The color variations in plants and animals are the result of various pigment combinations. In sand dollar, the color is mainly related to the concentration of pigment contained in the skeleton. The more pigment concentration leads to the higher hue intensity of the sand dollar. However, since the pigment concentration is related to the gastrulation process, it is less visible in adult individuals. For some marine animals, the pigment cells would stay dormant during adulthood and reactivated during metamorphosis (Camargo-Sosa *et al*., 2018).

The number of pigments in the animal is varied to species. Some marine animals may only consist of several pigments, but generally fish, reptiles, and amphibians have more types of pigments (Camargo-Sosa *et al*., 2018).Sand dollar contains some types of pigments, such as fluorescent (Takata and Kominami, 2011), echinochrome, spinochrome (Ageenko *et al*., 2014). The fluorescent pigment is the pigment which is capable of absorbing the light and illuminate it (Tomčíková *et al*., 2017). However, only lights with certain wavelengths can be absorbed. Echinochrome is a substance that provides red pigment to the sand dollar (McClendon, 1912), while spinochrome has the color from red to purple (Brasseur et al., 2017).

Sand dollar has various colors, such as green, red, yellow, brown, and even grey (Kitazawa *et al*., 2016). There are also other colors, such as black and purple (Blatama *et al*., 2016). Color variations in sand dollar species are caused by habitat, food, depth, and genetic distribution areas as well. Furthermore, the distribution area also affects the color pattern of sand dollar. The heterogeneity of environmental conditions is considered as the main driver of the diversity in the colors and patterns. This also indicates that the effect of environmental conditions on the diversity of sand dollar's color occurs in a long period.

Until now, the discussion concerning the coloration of sand dollar is mostly focused on the gastrulation process, which is related to pigmentation (Ageenko *et al*., 2011; Takata and Kominami, 2011; Drozdov *et al*., 2017). However, the pigmentation which implicates the coloration of the adult sand dollar is not much studied. In echinoids, the gastrulation process involves serial mechanisms, such as the change of cell's shape, cell rearrangement, and cell pushing up and towing (Kitazawa *et al*., 2016). Thus, the pigmentation of sand dollar during its development is related to the processes. Echinochrome and spinochrome are the most dominant pigments in echinoid species. Both pigments are distributed in the whole organ of sea urchin (echinoid) (Brasseur *et al*., 2017). Thus, the color of sand dollar is mostly determined by both pigments.

Currently, the correlation between pigment content in sand dollar to the environmental factors is not well understood[15]. However, there is an indication that the pigment content in Echinoidea is related to the gastrulation process (Takata and Kominami, 2004). Thus, there might be a possibility that the hue intensity of sand dollar is related to its age rather than the effect of environmental conditions.

Pigments concentration is related to the various elements, such as metal. Research for the marine snails indicated that the pattern of pigment distribution is similar to the distribution of trace metal elements (Suryanti *et al.,* 2016). Another research showed that the concentration of anthocyanin pigment in plants tends to decrease as the pH increase (Jamei and Babaloo, 2017).

According to the result of this research, pH has a negative impact on the hue value of sand dollar, while coral and rubble coverages have a positive impact. Unfortunately, the pigment concentration was not analyzed in this research. Thus, the effect of pH, coral coverage, and rubble coverage on the pigment concentration, as well as the correlation of pigment concentration and hue intensity could not be analyzed.

The effect of pH on pigment was shown in sorghum. The anthocyanins pigment in sorghum fluctuates with the change of pH (Devi *et al*., 2012). A similar result was shown in blueberry (Jamei and Babaloo, 2017). However, the effect of pH on the pigment concentration may vary toward species. The fluctuation is related to the variation of the optimum pigmentation range. Optimum pigmentation of each organism occurs at a specific range of pH. For example, the ligneous fungi have the optimum pigmentation pH range from 4.5 to 5 (Tudor *et al*., 2013).. Some echinoderm species are vulnerable to low pH (Smith *et al*., 2016). Acidification could cause the delay of larval development in echinoids (Wangensteen *et al*., 2013)

The positive effect of coral and rubble coverage on the hue of sand dollar is suggested as the effect of food availability. Some animals can not synthesize certain pigments, thus they obtain pigments from their prey (Lindstedt *et al*., 2010). Coral reef and rubble provide various types of microalgae as the food source for sand dollar. However, the compositions provided by both substrate may be differently indicated by the different impacts of the hue value of sand dollar. According to the analysis result, the effect of rubble on the hue value of sand dollar is nearly twice that of the coral reef.

Sand dollar feeds on various types of food, such as diatoms, filamentous algae, and organic debris (Hilber and Lawrence, 2009). Microalgae develop a microbial film on the surface of sand grains (Challener et al., 2009). The plankton on the sand surface may be originated from the surrounding habitat, such as coral reef and rubble. However, since the coral reef is covered by zooxanthellae, the population of plankton which acts as the source of sand dollar's feed is lower. Moreover, since rubble is a non-living substrate, it may be covered by a similar plankton composition as the sand grain. Thus, it acts as the source of plankton which develop the biofilm on the sand substrate as the food of sand dollar.

Since the hue intensity in sand dollar is related to pigment concentration, while pigment concentration is related to the gastrulation process and tends to decrease along with its growth, it can be suggested that the hue intensity is related to the age of sand dollar. Further research needs to be carried out to analyze the changes in sand dollar's hue related to its development as well as the change of pigment composition. Another aspect that requires further understanding is the impact of environmental dynamics on the pigmentation process and pigment composition in the adult sand dollar. Thus, the color diversity of sand dollar in an area can be understood.

CONCLUSION

In conclusion, variations in the hue value of sand dollars observed on the islands of Karimunjawa, Menjangan Kecil and Cemara Kecil are indirectly affected by the substrate base, salinity, pH, coral cover, and coral fragments through pigmentation processes. Changes in environmental conditions in the study area due to anthropogenic activities such as fisheries and tourism are suggested as important factors that encourage variations in pigmentation.

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