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The Effect of Temperature on *Goniastrea aspera* Polyp Degradation and the Post-bleaching Resistance

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ABSTRACT

Coral recovery from bleaching depends not only on the intensity and continuity of some influencing factors but also on the cellular condition of the coral itself. The relationship between coral recovery and bleaching can be studied from the loss process of zooxanthellae from a polyp and the tissue profile changes. This research focused on the degradation of polyp tissue due to temperature stressors and the potential recovery after bleaching in artificial media. It was conducted at Coastal Eco-development Laboratory of FPIK-UNDIP Jepara and natural waters of coral reef ecosystem in Southern of Panjang Island Jeparafrom April to September 2021. Four levels of temperature: 40°C, 36°C, 32 °C 28 °C were used to expose the sample organisms. The objectives of this research are, therefore, to (a) investigate the effect of temperature on the zooxanthellae density in the polyp tissues, (b) investigate the effect of temperature on process change of polyp tissues and (c) analyze the survivability of coral after bleaching. The results show that: (a) the optimum temperature and exposure that zooxanthellae can resist in the polyp histology of *Goniastrea aspera* is 36 °C for 6 hours, (b) Higher temperature and longer incubation time degrade the tissue of the *Goniastrea aspera* polyp, influence the zooxanthellae release and cause coral death, (c) The recovery of the *Goniastrea aspera* still occurs after partial bleaching and (d) Coral recovery is characterized by the *zooxanthellae* regulation process in the polyp tissues and reaches perfect condition and to achieve perfect arrangement after week 12.

Key words : *Coral Bleaching, Coral Polyp, Panjang Island, Temperature, Zooxanthellae*

Introduction

Coral reefs ecosystem is an essential endangered ecosystem in the world. Its role in providing ecological services such as food supply, livelihoods, carbon sequestration and extreme weather buffers to millions of people is needed to be preserved (Cinner *et al.,* 2016; Woodhead *et al.,* 2021). The large-scale human dependency on this marine resource in Southeast Asia has led to the over-exploitation, resulting in the degradation of coral reefs, particularly near densely populated human settlement centres. These centres have put the coral reefs in danger due to overfishing, improper fish farming using damaging methods, sedimentation, pollution, and marine development (Hughes *et al.,* 2017). In addition, climate change has also exposed this vital resource to dangers.

The increasing global temperature of seawater is the leading cause of the lowering quality of coral reefs from bleaching (Leinbach *et al.,* 2021). Coral bleaching is described because of the lack of colour, partial or overall lack of *Symbiodiniaceae dinoflagellates* and the discount in their photosynthetic pigments, which exposes the white calcium carbonate to the coral skeleton. Bleaching is a generalized

strain reaction to environmental perturbations, i.e. aerial publicity, sedimentation, eutrophication, exposure to heavy metals, excessive UV radiation, and intense adjustments in salinity and temperature (Carballo Bolaños *et al.*, 2020). The increasing sea temperatures can cause substantial coral mortality and threaten the persistence of corals as ecologically relevant framework builders (Hughes *et al.*, 2017). In the short term, the increasing temperature of seawater influences the multi-function of the algae photosystem of the coral reefs (Goulet *et al.*, 2017). Several studies have identified some effects of sea temperature increase on coral reefs, such as the decrease of primary production (Lewandowska *et al.*, 2012; Kim and Kim, 2021); respiration change (Rädecker *et al.*, 2021) which eventually causes the bleaching of the corals (Brown *et al.*, 2019); lowering fecundity (Paxton *et al.*, 2016) and classification (Schmidt *et al.*, 2016). In the long term, the bleaching of the corals due to the increased temperature can cause the decline in coral growth rate and classification, reproduction impairment and polyp tissue necrosis of coral reef (Brown and Phongsuwan, 2012). The recovery process of coral reefs depends not only on the intensity and continuity of the influencing degradation factors but also on the availability of coral reefs in the environment through the recruitment process. Given the slow growth and long lifespan of most coral species, it's essential to understand the mechanism of coral recovery (Adjeroud *et al.*, 2018).

The coral bleaching process is caused by the breakdown of the photosynthetic machinery (Photosystem II or PSII) of Chlorophyll a (Chl a) of the endosymbiotic dinoflagellate. This case can lead to the loss of pigments and *zooxanthellae*, leading to subsequent paling or whitening of corals. The cellular processes or mechanisms for the expulsion of *zooxanthellae* during bleaching are still unclear (Moorgawa *et al.*, 2018).However, the change in the cellular conditions of the coral polyp is one of the crucialindicators of the continuing degradation or recovery potential. Therefore, the relationship between coral recovery and bleaching can be studied from the loss process of *zooxanthellae* from polyp and changes in the tissue profile (Osborne *et al.*, 2017). As the temperature is one of the leading causes of bleaching, it is then taken as the determining factor in the degradation of coral reefs.

Degradation and recovery test of coral polyp tissue is one of the steps taken to study zooxanthellae translocation. The criteria applied are the minimum conditions for the degraded organisms to survive. The objective of this study is, therefore:

1. To study the effect of temperature on the change of zooxanthellae on coral polyp tissue.
2. To study the effect of temperature on the change of coral polyp tissue
3. To evaluate the ability of coral to recover after bleaching

Materials and Methods

Research Time and Location

In situ experiments were conducted at the coral reef areas in Southern Panjang Island, Jepara, from April to September 2021.

Procedures

Field Manipulation

The research adopted 4-level single heat treatments to assess the roles of temperature stress and bleaching on the samples of *Goniastreaaspera*:

1. S-1 temperature exposure of 40^{o}C (± 2^{o}C)
2. S-2 temperature exposure of 36^{o}C (± 2^{o}C)
3. S-3 temperature exposure of 32^{o}C (± 2^{o}C)
4. S-4 temperature exposure of 28^{o}C (± 2^{o}C)

In addition to the above treatments, cross temperature heat shock treatment (36^{o}C, 32^{o}C and 28^{o}C) on the *Goniastreaaspera*. During the 4-level temperature exposure of the coral colony, sample management of *Goniastreaaspera* was conducted for every repeat treatment, as shown in Table 1.

Coral submersion was carried out in an aerated 1 m^3 conical. The primary variable measured is the concentration of *zooxanthellae* and the tissue analysis. The measurement of *zooxanthellae* density was conducted at the beginning of the experiment, hours 4, 6, 8, 12, 24, 30 and 36. Tissue analysis was conducted at the beginning and at certain times by the density data of *zooxanthellae* during the heat shock periods. The organisms were returned to nature for the recovery stage, and measurement was carried out after two weeks.

Zooxanthellae Density

The density of the zooxanthellae polyp was measured utilizing the decalcification by first collecting a *Goniastreaaspera* coral specimen (an area of 10-15 cm^2) and then decalcifying the specimen in the 5% high concentration HCL solution for 48 hours

Table 1. Research Colony Management.

Sampling Time (hour)	Temperature 28°C		Temperature 32°C		Temperature 36°C		Temperature 40°C	
	Incub. Tank	Sea	Incub. Tank	Sea	Incub. Tank	Sea	Incub. Tank	Sea
0	2	0	2	0	2	0	2	0
4	2	3	2	3	2	3	2	3
6	2	3	2	3	2	3	2	3
8	2	3	2	3	2	3	2	3
12	2	3	2	3	2	3	0	0
18	2	3	2	3	0	0	0	0
24	2	3	2	3	0	0	0	0
30	2	3	2	3	0	0	0	0
36	2	3	2	3	0	0	0	0
Number per treatment	18	24	18	24	10	12	8	9

(Nordemar *et al.*, 2003). The process was completed by homogenization in 10 ml distilled water using a centrifuge for 20 minutes under the rotational speed of 2,500-3,000 rpm. Further analysis was carried out on the supernatant using a hemocytometer.

Polyp Histology

The collection of coral polyps is carried out by decalcification, where a certain mass of coral specimen was removed, fixated, dehydrated and infiltrated using alcohol before it is sliced into sections using a microtome. *Hematoxylin eosin* (HE) was then used in the colouring process of the sections.

Water Quality

Water quality variables measured are temperature, salinity, dissolved oxygen and pH, measured daily based on the incubation tank and weekly-based at sea. In contrast, ammonia and nitrite are measured weekly in the tank or at sea.

Data analysis

A statistical analysis using linear regression is utilized to analyze the density change of *zooxanthellae*, while a descriptive study is adopted for analyzing the degradation pattern and coral resistance.

Results

The density measurement of *zooxanthellae* in *Goniastreaaspera* corals is shown in Figure 1.

The resistance analysis indicates that *zooxanthellae* in *Goniastreaaspera* polyp tissue show a high response to low temperature (t = 28°C). In higher temperatures, however, the resistance of *zooxanthellae* in

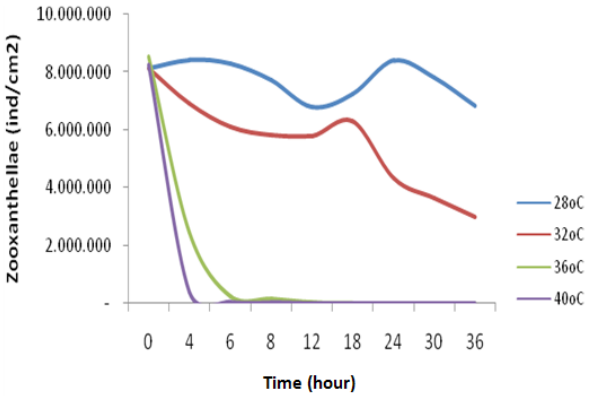

Fig. 1. The density of *Zooxanthellae* in *Goniastreaaspera* at different levels of temperatures

the coral polyp tissue declines. With exposure to 28°C and 32 °C in the media, *zooxanthellae* remain until the end of the experiment. The temperatures of 36°C and 40°C in the media decrease the number of *zooxanthellae* linearly under the relationship of: Y = 5.879.590,72 – 631.102,28 t (R = -0,68) dan Y = 6.467.176,15 – 986.679,73 t (R = -0,74) where Y = density of *zooxanthellae* (individuals/cm^2) and t = temperature (°C). Therefore, the model suggests that theoretically, the corals in both temperature environments will die after 9 hours and 6.5 hours. The change in the coral tissue pattern due to the different temperature levels is shown in Figures 2A to 2D.

A survival test was conducted to obtain the number of colonies that survive aftershock heat temperatures. Analysis was carried out based on 2-week monitoring of the ability of the test organisms to survive in the natural coral reef marine environment after being submersed in the incubation tank. The

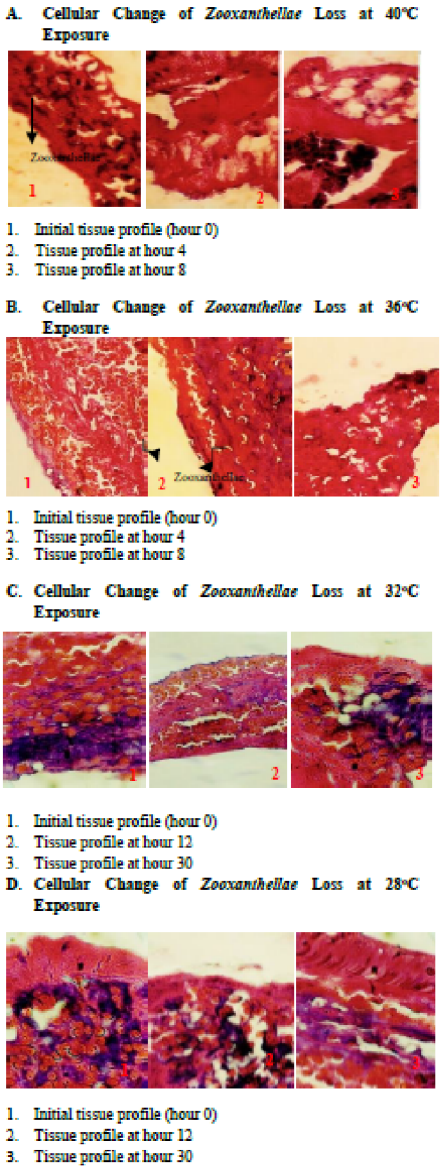

Fig. 2. The profile of coral polyp tissue during different levels of temperatures

test organisms' survivability results are presented in Figure 3.

Water quality measurement in the submersion water indicates that the water temperature is relatively stable with a range of 28.1 – 29.7°C. The salinity ranges from 31.3 to 32.6°/$_{oo}$ can be expected to support the coral organisms as at the salinity of 30 °/$_{oo}$ to 33 °/$_{oo,}$ beaching does not occur. The level of Ammonia and Nitrite in the coral reef ecosystem of the incubation location is relatively low. The high oxygen level supports the pH in the base condition.

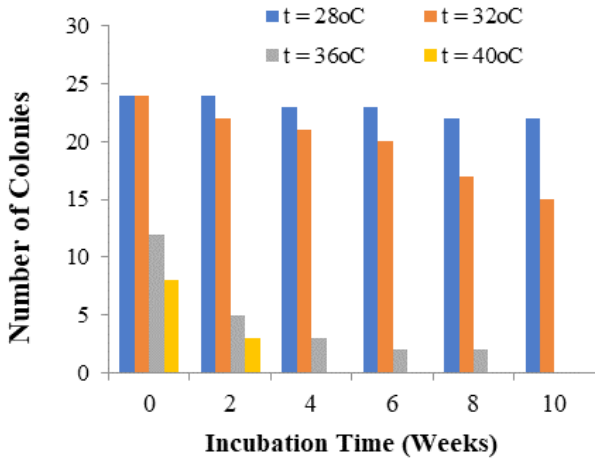

Fig. 3. Survivability of *Goniastrea aspera* after bleaching

Discussion

The relationship between *zooxanthellae* and coral is mutual (*Mutualistic symbiosis*) at the physical interdependency and the physiological level. These relationships are so strong that coral polyp colonies can only complete their biological life cycle by coexisting with algae. When the functional relationship between the animal cells of the polyp and the algae is broken, the polyp dies (Titlyanov and Titlyanova, 2020). In general, *zooxanthellae* can be massively found in every polyp living symbiotically in energy transfer. *Zooxanthellae* have chlorophyll for photosynthesis and accessory pigments (e.g., other chlorophylls, carotenoids, phycobilins) and provide the products of photosynthesis to their host corals (Hasanah *et al.*, 2018). *Zooxanthellae* contribute 90% of polyp needs for carbon through photosynthesis (Hughes and Grottoli, 2013), while *zooxanthellae* needs are supplied almost 100% by the polyp (Pang *et al.*, 2020). Therefore, except *Astrangiadanae* and possibly *Madracis* Sp that can live facultatively, coral polyps cannot survive without *zooxanthellae* (Shapiro *et al.*, 2016).

The results also indicate that the declining growth of zooxanthellae characterizes partial temperature exposure as in the experiment in the 36°C and 40 °C media. At the shock heat temperature exposure, both show total bleaching of *Goniastrea aspera* coral during 12 hours submersion at the 36°C media and 8 hours at the 40 °C media. The application of 28 °C media shows that the growth of *zooxanthellae* fluctuates, whilst the application of 32 °C media shows slow and relatively declining growth.

This finding is in line with Fitt *et al*. (2000), who expressed that at 26 °C media, *zooxanthellae* grow fast. At the temperature of 30 °C, *zooxanthellae* show slow growths and no indication of growth at 32 °C. The experimental results of various temperatures effects are shown in Figure 4.

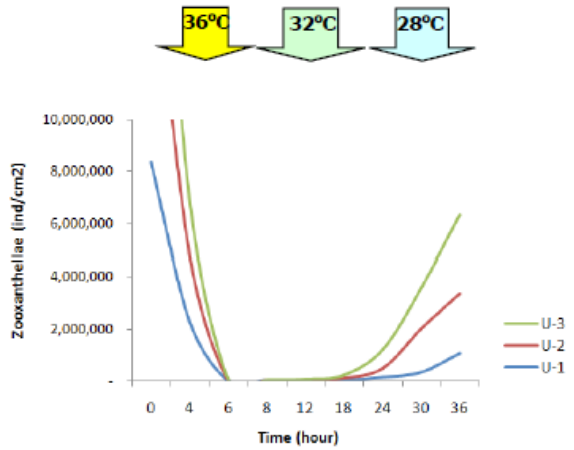

Fig. 4. The growth of *Zooxanthellae* in *Goniastrea aspera* at cross temperature media

Figure 4 shows that the placement of *Goniastrea aspera* coral at the temperature of 36°C for 6 hours causes the *zooxanthellae* to decline exponentially. During the 6 hour adaptation period, *zooxanthellae* shows continuing adaptability and grow on the cellular tissue of *Goniastrea aspera* coral polyp and continues to reach $2.1x10^6$ individuals/cm^2 as a result of submersion period in the media.

The above phenomenon is similar to the results of large-scale recovery study by Pratchett *et al.* (2013) and Heron *et al.* (2016). It is stated that the bleaching of the corals occurs alternately within a year, causing the life pattern to fluctuate. The condition where the corals survive despite the high temperature of the external environment is characterized by: (a) incomplete bleaching (partial bleaching) where *zooxanthellae* remain normal in the living polyp tissue in terms of its position and number (Bara'langi *et al.,* 2021); repopulation of *zooxanthellae* occurs fast (Morishima *et al,* 2019; Sammarco *et al,* 2013). On the other hand, total bleaching significantly causes the deaths of corals (Sully *et al.,* 2019).

Incomplete bleaching was shown in histological experiments. In this case, coral *Goniastrea aspera* as tested animals were placed at medium with different temperatures. Optimum temperature until these organisms can stand at 36 °C, kept for 6 hours. At this condition, some normal polyp cells were found and inhabited by zooxanthellae, then were adapted natural waters environment. It has survival rates of upto 85% of the total number of adapted corals. Furthermore, laboratory and naturally repopulation of zooxanthellae occurred faster.

This is in accordance with statement of Leinbach *et al.* (2021) and Rodgers *et al.* (2021) that partial bleaching still enables coral polyp recovery. In this regard, there are free cells with the perfect content of *zooxanthellae*. This research also shows that even though *Goniastrea aspera* got stress at temperature 36 °C still can recover in 6 hours after it was returned to natural waters, it has a slight possibility compared with pressures at a lower temperature.

The structural formation of cell tissue on the initial stage will occur in similar columns, either in ectoderms, mesoglea or endodermis. In development conditions, three polyp strata have occurred ideally; therefore, it will enable transfer between strata where the movement of cells from ectoderm to mesoglea, then to endoderm tissues and vice versa. This movement pattern was enabled by the similarity of cell structure which builds all polyp tissue. Parisi *et al.* (2020), and Sebe-Pedros (2018), stated that there is four mechanisms category of cell in cnidaria, which are : (a) Cell reproduction, in this case contact between cells due to activities in gastro cavity caused hydrostatic pressure on one polyp, forming longitudinal organization at basic tissue strata which are called *teaniolae*. (b) Mesoglea cell reproduction, a process of cell reproduction at *taeniolae* so that it will tie up the system on every tissue in ectoderm, mesoglea and endoderm. (c) Arrangement of cell between strata in polyp tissue which is a process of cell arrangement between tissues. These three processes will occur in synergy with placement process of *zooxanthellae* and growth process of *zooxanthellae*. (d) Reproductive cell process, is a normal condition in formation of mature polyp recovery followed by reversible correlation between coral and its symbiont.

Recovery mechanisms shown in this research are expressed as a chemical adhesive of cells and involve nervous mechanisms on the cnidaria group. Association between protein and tissues connected with carbohydrate at adhesive cell processes is generally very complicated. This is not only an adhesive relationship but also followed by the formation of muscular nervous system bonding, which is called

the nervous organization of epithelium cells of cnidaria (Watanabe *et al.,* 2009). A study conducted by Rodrigues and Grottoli (2006) found that n *M. annularis* and *A. lamarcki* were depleted of total lipids, proteins and carbohydrates by 39-73% after 5 months of recovery, indicating that all three reserves may be utilized while bleaching. In cell compression to form *teaniolae,* nervous tissue also will develop following the formation process of *teaniolae*. This pattern was revealed in this research as shown in Figure 5.

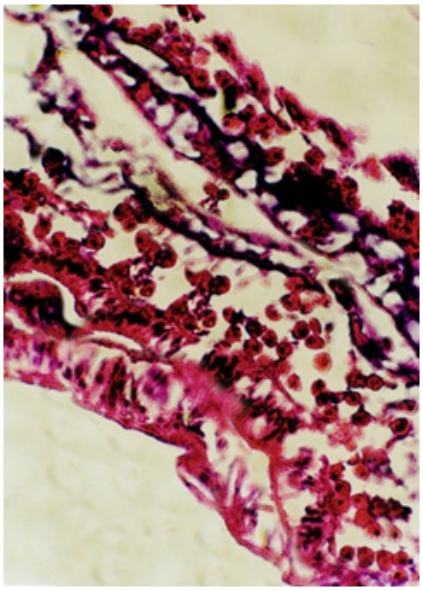

Fig. 5. Cell addition process during a period of coral polyp recovery

- Mesoglea cell addition, a process of cell compressio natteaniolaeso that it will tieup system on every tissues in ectoderm, mesogleaand endoderm.
- Arrangement of cell between strat a in polyp tissue which is a process of cell arrangement between tissues. The processes will occur in synergy with placement process of zoo xanthellae and growth process of zooxan the llae.

Based on that mechanism, the nervous system is associated not only in one stratum but also between various stratum of polyp tissues, which is longitudinal from ectoderm to endoderm. Leclère and Röttinger (2017) stated that cells movement between stratum could occur through an effective nervous system of cnidaria *ephitel cell*.

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