The fungus *Paecilomyces* from Leang Pettae in Maros karst area and the suggestions for rock art preservation

Jamur *Paecilomyces* dari Leang Pettae di kawasan karst Maros dan saran pelestarian gambar cadasnya

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Kata Kunci: Jamur *Paecilomyces*; Leang Pettae; gambar cadas; pelestarian

ABSTRAK

Tulisan ini mengkaji mikroorganisme penyebab kerusakan gambar cadas di Leang Pettae, Kawasan Karst Maros, Sulawesi Selatan. Mikroorganisme ini tumbuh subur pada kondisi gua yang lembab dan basah. Bentuk kerusakan ditunjukkan dengan lapisan endapan putih pada dinding gua dan gambar cadas. Penelitian ini mengidentifikasi mikroorganisme penyebab kerusakan sebagai upaya pencegahan serta pelestarian gua dan gambar cadas. Sampel mikroorganisme diambil dari sekitar gambar cap telapak tangan dan babirusa yang mengalami kerusakan. Pembiakan sampel dilakukan pada media PDA (*Potatoes Dextrose Agar*) di Laboratorium Biologi Balai Konservasi Borobudur. Analisis berhasil mengidentifikasi sampel berupa jamur dari genus *Paecilomyces*. Jamur jenis ini menghasilkan enzim protease dan dapat mempengaruhi unsur organik gambar cadas yang menyebabkan kerusakan pada banyak gambar cadas. Berdasarkan karakteristik jamur, saran untuk pelestarian gambar cadas di Leang Pettae yakni, mengontrol suhu dan kelembapan, mencegah polusi udara, dan membatasi aktivitas manusia di dalam ruang gua.

Keywords: Fungus *Paecilomyces*; Leang Pettae; rock arts; preservation

ABSTRACT

This paper examines microorganisms causing damage to rock arts in Leang Pettae, Maros Karst Area, South Sulawesi. The damage is indicated by a layer of white sediment on the cave walls and rock arts. This research aims to identify the microorganisms that cause the damage and to determine the preservation strategy for the rock arts. Microorganism samples were taken from the area around the damaged hand stencils and figurative paintings of babirusa (*Babyrousa*). The samples were cultured on PDA (Potatoes Dextrose Agar) medium at the Biology Laboratory of the Agency for Borobudur Conservation. The analysis identifies fungus from the genus *Paecilomyces*, which thrives in humid and wet conditions, and produces protease enzymes that affect the organic elements of the rock arts. To preserve the rock arts in Leang Pettae, it is suggested to control temperature and humidity, prevent air pollution, and limit human activities inside the cave.

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INTRODUCTION

Rock arts or also known as prehistoric cave paintings are cultural products that are universal because they are found almost all over the world, in Africa, Europe, America, Asia, and Australia. The findings of rock arts are generally in the form of hand stencil, animal (zoomorphic), human (anthropomorphic), geometric, and abstract motifs. Prehistoric rock arts in Indonesia are mostly found in South Sulawesi, Southeast Sulawesi, East Kalimantan, Maluku, and West Papua (Permana, 2014). The existence of rock art evidence shows that humans have been active in that place. Rock arts in Indonesia are also a cultural product achieved during a period of advanced hunting and gathering (Soejono & Leirissa, 2009).

The rock art culture in Indonesia is one of the oldest in the world, parallel to the rock arts on a famous cave site in Europe, namely El Castillo (Spain). Research on prehistoric rock arts carried out in the Maros-Pangkep karst area (South Sulawesi) in 2019 shows that the rock arts at the Leang Bulu Sipong 4 Site are 44 thousand years old, while those at the El Castillo Site are less than that age. Rock arts at the Leang Bulu Sipong 4 Site show scenes of animal hunting and depictions of therianthropes (half human and half animal creatures) (Aubert et al., 2019). The 2019 research is a strengthening of previous research, namely the research conducted in 2014 at the Leang Timpuseng Site. The chronology of rock arts on the Leang Timpuseng Site using the same method (uranium series) is among the oldest, which is 39,900 years old for the hand stencils motif and 35,400 years old for the babirusa (*Babyrousa*) motif (Aubert et al., 2014).

The dating of the rock arts is known to be incredibly old, so it is only natural that many rock arts are damaged and are in danger of being lost. Bednarik suggests that the rock arts in the natural environment have now reached a high equilibrium point. The balance is shown by rock arts that are tens of thousands of years old, found in good condition. If there is damage to the rock arts, generally it is mostly caused not by the art itself, but due to external factors. The factors that cause damage are due to natural weathering of the art media. Besides, the damage is also caused by human activities such as settlements, agriculture, tourism, industry, and vandalism (Bednarik, 2003).

Site conditions and rock arts in Maros-Pangkep (South Sulawesi) can represent the general geographical condition of the karst of prehistoric cave sites in the world. Karst clusters were formed as a result of the lifting process in the post-Holocene Glacial era. Karst clusters have their own character, namely the remains of marine species, the presence of karst towers, and cracks in the rock. Based on these characteristics, the Maros-Pangkep karst area can be included in the karst topography type. The karst morphology unit stretches eastward to the limestone cluster of Bulu Ballano which is a limestone hill area. This is evidenced by the presence of stalactites and stalagmites in caves, natural bridges, and karst towers (Suhartono et al., 2008).

The Maros-Pangkep Karst Mountains have unique characteristics due to the dissolving rocks (karstification) process. As a result of this process, karst hills that resemble towers are formed (karst tower). At the foot of the karst hills, there are natural holes (caves) which the local people call *leang* (Said et al., 2007). The karst cluster that stretches along Maros Regency and Pangkep Regency is the second largest in the world after China. In a number of *leangs*, there are many remains of ancestral civilizations from prehistoric times. Maros-Pangkep

karst cluster based on Minister of Forestry Decree No. 398/Menhut-11/2004 is included in the Bantimurung-Bulusaraung National Park area (Said et al., 2007).

Research on rock arts in South Sulawesi has been carried out since 1950 but was stopped for several years. Research activities started back in 1969, organized by the National Research Center of Archaeology in collaboration with the Australian National University's Department of Prehistory. The results of the ^{14}C analysis in the joint research are the dating 1030+275 AD (ANU-392), 870+210 BC (ANU-391), and 1470+400 BC (ANU-390) (Mulvaney & Soejono, 1970). Cave occupation in South Sulawesi is based on Glover's research at Ulu Leang 1 and Leang Burung 1 sites in the context of Toalean cultural strata dating from 8,000–3,500 years ago (Glover, 1976). Glover's further research at the Leang Burung 2 site suggests a time frame of 35,000-24,000 years ago (Glover, 1981). The timeframe of rock art culture in South Sulawesi is getting older with joint research conducted by the National Research Center of Archaeology with the University of Wollongong Australia. The sample from the Leang Timpuseng (Maros) site shows an age of 39,900 years, while the sample from the Leang Bulu Sipong 4 site shows an age of 44,000 years (Aubert et al., 2014, 2019).

A long period of time has resulted in many cave rock arts in the karst area of South Sulawesi, particularly in the Maros-Pangkep region, which are found to be in damaged condition. The research of rock arts in South Sulawesi related to damage and conservation began in the 1980s. This research focused on activities to conserve damaged rock arts or cave paintings. Initial efforts to preserve Indonesian rock arts were first carried out at the Leang Sumpang Bita and Leang Petta Kere sites by the Restoration and Maintenance of Historical and Archaeological Relics Project (Samidi, 1986). About 20 years later, an evaluation of conservation activities in the 1980s was carried out. The results of the evaluation by the Agency for Borobudur Conservation concluded that the conservation that had been carried out previously had many negative impacts on rock arts. Conservation activities carried out at that time used chemicals for cleaning damaged parts and reforming rock arts (Permana, 2009; Suhartono et al., 2008).

Different from the 1980s era, in the 2000s era, the research shifted its focus to the shape and process of rock arts damage. This research sought to find the factors that cause damage and efforts to treat them (Suhartono, 2012). Referring to the definition that prehistoric rock art images are still attached to natural source rock, rock arts attached to karst rocks are very susceptible to damage if the rock art media is disturbed. According to research conducted by Robert Bednarik, an Australian rock art conservation expert, disturbance in rocks as a result of natural processes is generally in the form of weathering. Weathering in rocks is usually caused by moisture due to capillary seepage of water in the rock or hydrologically through the rock structure (Bednarik, 2003).

Furthermore, Bednarik explained that high rainfall or water flow due to gravity can make water seep through and wet the surface of the rock arts media. Water moving through rocks either by gravity or capillaries, carries dissolved substances in the form of cation salts, chlorides, and carbonates. These salt substances will experience deposition in certain zones. The zone of salt deposition (sub florescence) expands several millimeters parallel to the rock surface and below the rock surface where it dries. This process occurs repeatedly until it forms a "*drummy*" layer. The "*drummy*" layer is then lifted and finally peels off. The process of rock weathering occurs more rapidly in areas

that are usually exposed to direct rain or water seepage on cave walls (Bednarik, 2003).

Research related to microorganisms as the cause of damage to rock arts in Indonesia have not been carried out. Outside Indonesia, for example in Europe, research of microorganisms on rock arts have been carried out. Researches on microorganisms from this type of fungus have been carried out at the Lascaux Cave site in a cave complex in the Dordogne region (France) (Bastian et al., 2010). In addition, researches on bacterial microorganisms have also been carried out at the Magura Cave site (Bulgaria) (Mitova et al., 2015).

This paper examines the damage to rock arts at the Leang Pettae site caused by microorganisms. Administratively, the Leang Pettae site is located in Leang-Leang Village, Bantimurung District, Maros Regency, South Sulawesi Province. The Leang Pettae site is in The Leang-Leang Prehistoric Park complex in the Karst Mountains of Maros-Pangkep. Geologically, the karst mountainous area is included in the Tonasa Formation. The Leang-Leang Site Complex is easily accessible, located ± 35 km north of Makassar City, and can be reached by two-wheeled or four-wheeled vehicles (Nur, 2017).

The Leang Pettae site is located at the foot of a karst hill with an altitude of 50 meters above sea level. The Leang Pettae site is a small rockshelter and has ornaments in the form of stalactites and stalagmites. The mouth of the cave faces west to be precise N 290^{o} E. The width of the mouth of the cave Leang Pettae is ±3 m and it has a height of ±5–6 m. The floor of the cave has a slope of ±3^{o}. There is a fence at the mouth of the cave that functions to close the cave. The surface of the Leang Pettae walls is mostly rough textured and there are many protrusions. Meanwhile, on the roof of the cave, there are stalactite ornaments. The intensity of the light that entered the cave is not that great so that the inside of the cave was dim. In the frontal part of the cave, there are shells that are thought to have been food waste from the ancient inhabitants of the cave (see Figure 1).

The archaeological remains found at the Leang Pettae site are rock arts in the form of babirusa motifs and hand stencils. The rock art on the Leang Pettae wall, which was first discovered by Heeren Palm on February 26, 1950, is seven

Figure 1. Leang Pettae site.
(Source: R. Cecep Eka Permana)

hand stencils with red background. All of the hand stencils depict the left hand with complete and slender fingers. The hand stencils that are still clearly visible now are only four. Right next to the hand stencils group, there is a portrait of babirusa that was discovered by Van Heekeren the day after the discovery of the hand stencils. Babirusa paintings are depicted in a naturalist manner using brush strokes to form the head, body, tail, and legs (see Figure 2).

The current condition of the babirusa motif has suffered damage similar to the condition of the hand stencils, the art image is faded, becomes less clear, and experiences peeling. Besides, there is a layer of white sediment that is close to the right of the art image. Observations on the conditions of the Leang Pettae Site show that the indoor temperature and condition are low, humid, and wet. This condition makes it easier for microorganisms to reproduce. Conditions in the floor, walls, and spaces in the cave are wet with the air temperature being lower than the mouth of the cave. Small amounts of stalactites still dripping water and traces of water are found at the ends. More water droplets will appear during the rainy season. This condition causes some of the art images to experience quality changes due to developing microorganisms.

This research conducted at the Leang Pettae site aimed to identify the microorganisms that cause rock arts damage. Identification needs to be done to identify the type of microorganism and its specific characteristics. This research also aimed to provide suggestions for controlling damage caused by microorganisms in the context of cave and rock arts conservation.

METHODS

As mentioned above, the humid and wet conditions of the Leang Pettae site cause microorganisms to multiply rapidly. This causes many parts of the cave walls, including the rock arts there, are damaged. A number of stages of research are carried out to identify the types of microorganisms that cause damage including data collection, data analysis, and research results. The results of the research are in the form of control suggestions in the context of cave and rock art conservation at the Leang Pettae site.

Data collection in July 2019 was carried out through sampling of microorganisms from the cave walls which have a white sediment layer. The sample taken was between the babirusa painting and the hand stencil which are close together. The sample was taken using a spatula by carefully scraping. sample is put into a small sterile glass bottle, which is about 25 mg, considering that it can represent the two image objects. The bottle containing the sample was closed with a rubber cap, wrapped in aluminum foil, and put in a cooler box. The sampling process was carried out by researchers wearing rubber

Figure 2. Rock arts of hand stencils and babirusa stamp motif, as well as the threat of damage. *(Source: R. Cecep Eka Permana)*

gloves and masks to prevent contamination (see Figure 3), accompanied by staff from the Regional Office for Cultural Properties Preservation in South Sulawesi Province and local site maintenance staff.

The sample analysis activity was carried out at the Biology Laboratory of the Agency for Borobudur Conservation (see Figure 3). There are two types of methods carried out in the laboratory, namely purification and culture, and identification of the types of microorganisms. The method of purification and sample culture was carried out on PDA (Potatoes Dextrose Agar) media. Each plate went through an incubation stage for 5-7 days in the Mold Fungus Incubator. The culture of pure culture was carried out with an Ose needle. Before the needle was used, first the needle was burned until the wire was glowing. After burning, the needle was cooled for ±8-10 seconds. The Ose needle is a tool for inoculation. Usually, the straight tip of the Ose needle rod is used for inoculation by means of a scratch technique on the media. The sample for inoculation was taken from the culture site as much as one Ose, it was then put into a tube containing agar media. The inoculation tube was labeled and underwent an incubation process in an incubator with a temperature of 27^0C for 5-7 days. After obtaining pure isolates, each isolate was planted on a plate containing agar media. Furthermore, just like in the inoculation tube, the plates were also labeled and were subjected to the incubation process in an incubator with a temperature of 27^0C for 5-7 days. After experiencing this process, the growth of microorganisms was visible, thus their characteristics are ready to be identified.

Figure 3. Sampling (left) and microorganism sampling inoculation process on PDA media (right).
(Source: Moh. Habibi)

Figure 4. Leang Pettae's microorganism appearance in microscope (400x).
(Source: Moh. Habibi)

After the growth of microorganisms was seen, the next step was to transfer the microorganisms to a new medium (inoculation). Inoculation of microorganisms was carried out by smearing the sample on PDA (Potatoes Dextrose Agar) media. Incubation of microorganism cultures in the incubator was carried out with RH 70-80% and a temperature of 25^{0}C. After three days, observations of the growth of microorganisms were carried out under the microscope. Initially, samples from the Leang Pettae site were difficult to grow (see Figure 4). However, after experiments on several media, microorganisms began to grow on the PDA media. Microorganisms that started growing in October 2019 are classified as very slow, hence they take a long time to grow.

Based on the results of the isolation of microorganisms, only one isolate was able to grow in PDA media. The growing isolates were then analyzed to determine more specific species identification. The identification results lead to the characteristics of the microorganisms to be used as suggestions for the conservation of cave and rock arts.

RESEARCH RESULTS

Research on microorganisms that cause damage to prehistoric cave rock arts in Indonesia in general and in South Sulawesi in particular, have not been widely carried out. Therefore, there is not yet an adequate reference to make comparisons between this research and other research. In addition, through several experiments in the laboratory, the isolation of fungi from the Leang Pettae wall only produced one isolate that was able to grow on PDA media. Related to these conditions, other types of fungi might be identified if using more sophisticated methods and technology. The focus of this paper is to discuss the types of fungi that have been identified in the effort to preserve rock arts at the Leang Pettae site.

The identification results of the obtained isolate showed the type of fungus (fungi) of the genus *Paecilomyces*. Fungi identification has not yet reached the species level, due to limited facilities, infrastructure, funds, and available samples. Classification of the genus *Paecilomyces* according to (Barnett & Hunter, 1972) is:

Kingdom : *Fungi*
Division : *Deuteromycota*
Class : *Hyphomicetes*
Order : *Moniliales*
Family : *Moniliaceae*
Genus : *Paecilomyces*

Samson corrected the classification. The classification that then applies until now is (see also on page: drfungus.org) (Samson, 1974):

Kingdom : *Fungi*
Division : *Ascomycota*
Class : *Euascomycetes*
Order : *Eurotiales*
Family : *Trichocomaceae*
Genus : *Paecilomyces*

Classification based on morphological characteristics carried out on fungi from the genus *Paecilomyces* to the species level is often difficult. Difficulties occur due to fungi belonging to this genus which are mostly mutated products from cultivation such as plants, food, and cosmetics. Another difficulty arises

when using traditional or non-DNA identification methods (Inglis & Tigano, 2006).

The results of the identification of fungi at the Biology Laboratory of the Agency for Borobudur Conservation from the Leang Pettae site show the general characteristics of the *Paecilomyces* genus, namely having conidia and hyphae. The visible morphological feature is that chains of single-celled phialoconidia (amerconidia) are produced in a basipetal succession of phialides. The conidia are formed in chains with the youngest age located at the base called the basocatenate (see Figure 5).

Observations in the laboratory show that the development of fungal colonies is fast and has a powder or starch form. At the beginning of the growth, the fungal colonies are white, but when they reach the sporulation stage, they are greenish yellow. The phialides, the cells that produce the conidium, enlarge at the base of the colony and taper to the neck. Meanwhile, hyaline is dark, smooth or rough, and is ovoid to fusoid conidia. Nucci and Anaissie in the book of Clinical Mycology also describes the growth of fungi as happened in experiments in the laboratory (Nucci & Anaissie, 2009).

The genus *Paecilomyces* was first described by G. Bainier in 1907, as a genus closely related to *Penicillium* and consists of only one species, namely *Paecilomyces variotii Bainier*. Fifty years later, the description of this genus was revised by AHS Brown and G. Smith. A revision was also carried out by SA Samson in 1975, thus it was recorded as having 31 species. This genus has now registered as many as 145 species (Moreno-Gavira et al., 2020).

DISCUSSION

The characteristics of *Paecilomyces* fungi are described as being cosmopolitan and usually living in the soil. *Paecilomyces* fungus is often found in rotting plant debris, food products, and cosmetic products. The *Paecilomyces* fungus is contradictory and inhibits growth (antagonistic) against other fungi. This fungus is also commonly used as a biological agent that is effective in controlling nematodes, which are a type of worm-shaped thread that inhibits plant root growth (Moreno-Gavira et al., 2020; Nucci & Anaissie, 2009). In general, this fungus can grow quickly in humidity over 65%. When the relative humidity reaches 75-95%, fungal spores develop into mycelium. The optimum temperature required for fungi is in the range of 20^0-35^0C, although there are some species that thrive at temperatures of 50^0-60^0 C (Nucci & Anaissie, 2009).

Based on the characteristics mentioned, it is only natural that many types of *Paecilomyces* fungi are found in caves, including prehistoric cave sites. In

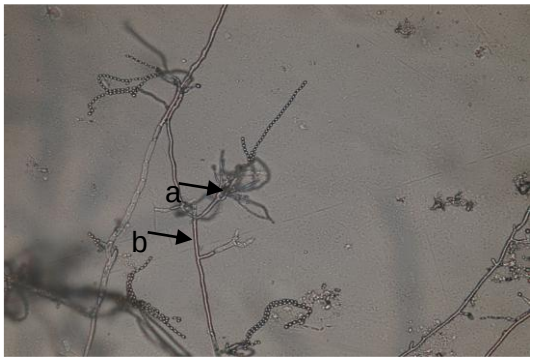

Figure 5. *Paecilomyces* fungi isolated from Leang Pettae; (a) *conidia* and (b) *hyphae.* *(Source: Moh. Habibi)*

connection with the preservation of caves and rock arts, this fungus produces protease enzymes that can damage the organic elements of the rock arts and its surroundings. This assumption is also based on the layers where the fungal samples were taken that dominate the Leang Pettae walls, including those covering the rock arts.

Paecilomyces fungus is also known to degrade and convert metal elements in rock art pigments into other forms. Rock arts that are generally made using ocher contain the iron oxides or oxyhydroxides elements such as hematite (Fe2O3), goethite (FeOOH), magnetite (Fe3O4), and limonite (FeO.nH2O). The results of the reaction of these metal elements with fungi species *Paecilomyces* produce a salt in the form of a white precipitate (MacDonald et al., 2019).

Based on the characteristics obtained from the type of fungi analysis stage, a preventive step as a suggestion that can be done or given to minimize the effect of fungi on rock arts is to control the environment, such as temperature and humidity. The result of temperature measurement at the time of sampling at Leang Pettae was 29.3^{0}C, while the humidity reached 74.7%. Based on the results of these measurements, it can be said that the fungi found in the Leang Pettae site live comfortably. The room temperature in Leang Pettae which ranges from 29^0 C-30^{0}C is still included in the optimum temperature for fungal growth. Efforts that can be recommended are to keep the humidity below 65% so that fungus does not grow rapidly. Therefore, artificial ventilation engineering that does not violate archaeological principles is needed.

Almost the same conditions also occur in various prehistoric caves, for example in caves which are included in the UNESCO World Heritage, namely, Altamira in Spain and Lascaux in France. The inside of the cave which is far from the mouth of the cave has a low temperature; hence the colony of microorganisms such as fungi can breed well. Maintaining the temperature is one of the efforts made in these caves (Jurado et al., 2009).

Another environmental factor that needs to be maintained so that fungi do not reproduce – or so that their growth is minimized – is air pollution. Air pollution occurs mainly in the form of dust. Dust in nature is actually solid chemical particles formed due to natural or mechanical forces of objects or materials, both organic and inorganic (Suma'mur, 2009). Dust containing various chemicals enters the cave space through gusts of wind and then becomes contaminated with fungi at humidity between 25-75%. In this humid condition, there is an increase in fungus growth (Fitria et al., 2008). In the context of prehistoric cave sites, dust can form deposits on cave walls and become a source of nutrition for fungal growth.

Air pollutants that affect the Leang Pettae site come from cement and marble factories, chicken farms, bat droppings, and bird droppings. Cement industrial pollutants contain hazardous chemicals, such as nitrogen oxides, sulfur oxides, carbon monoxide, and particulates (Duppa et al., 2020). Pollutants generated by the industry are dominated by dust which affects the air quality in the surrounding environment. Pollutants also have the potential to cause silicosis in humans, which is a disease with symptoms of shortness of breath accompanied by coughing without phlegm, even at a severe stage it can cause heart failure (Hasibuan et al., 2015). Meanwhile, pollutants from chicken farms, bat droppings, and bird droppings contain harmful chemicals such as nitrogen and phosphate (Rosa & Elvrida, 2017; Sari et al., 2016).

Pollutant dust particles from industry and animals can enter the wind and stick to the surface of the cave walls. The dust that adheres to the cave walls will

feed the fungus and cause damage to the rock arts. Preventive efforts that need to be done by related agencies are enforcing regulations to move or prohibit the cement and marble industries around the rock art sites. Likewise, the chicken farming business, which is widely available in villages close to the site, needs to be reorganized. Besides, efforts also need to be made to move the colony of bats and birds that live in the cave or prevent bats and birds from entering the cave. Based on field observations, many bats and birds stop by at the Leang-Leang Prehistoric Park complex, especially Leang Pettae, because the surrounding environment is still well preserved. Meanwhile, many caves or other habitats in the vicinity have changed with the expansion of settlements, farming, and rice fields. Efforts to prevent bats and birds from entering the Leang Pettae cave space can be done by installing nets in front or at the mouth of the cave.

A condition that needs to be watched out for– for the fungus of the genus *Paecilomyces* is its ability to survive even in conditions of dry space and stationary air. If there are factors from the environment outside the cave that cause increased humidity such as rain or humid air, then fungus growth will also increase. Likewise, if there is air moving both inside the cave and air coming from outside the cave. This is because fungi are heterotroph organisms that require organic material from outside for their nutritional needs. Dust in the cave that contains animal waste or decay of plants, which is lifted by the moving air in the cave, will stick to rock arts and become a source of food for fungi.

Considering that the Leang Pettae cave is one of the main tourist destinations in the Leang-Leang Prehistoric Park, it also needs special attention from related agencies such as Regional Office for Cultural Properties Preservation in South Sulawesi Province and the Maros Regency Tourism Office. The visitor activity factor, namely, the movement of the steps at the bottom of the cave, the sweat dripping, the hands touching the cave walls and art images, and the breath that emits carbon dioxide, have the potential to contribute to the rapid breeding of fungi.

The things mentioned above have also happened in prehistoric caves of Altamira in Spain and Lascaux in France. It is known that there was an increase in the growth of microorganisms on the cave walls and the rock arts in them after the cave was opened as a public tourist attraction. The arrival of the visitors or the tourists causes cave wall rocks to tend to accept any microorganisms coming in from visitors including air spores from outside, all arthropods (various types of insects, spiders, and centipedes), dust, and soil sediment carried on shoes. Microorganisms undergo biogeochemical processes which then cover or attack the rock arts on the walls of prehistoric caves. The most recent experiment, carried out in 2007, demonstrated the rapid development of microorganisms, particularly fungi on the walls, ceilings, and galleries of caves (Jurado et al., 2009). According to research by Bastian et al., the types of fungi that attack prehistoric caves in Spain are from the species Fusarium solani. The same type of fungus has also been reported in the sediments of prehistoric caves in Slovakia, England, America, and India (Bastian et al., 2010).

Based on the results of monitoring fungal growth at the Leang Pettae site from July to October 2020 (a year since sampling), the damage process was not clearly visible. The results of the observations show that the condition of the rock arts and the damage is still the same as when the sample was taken. This can be due to the impact of pollution and severely reduced human contact.

During the Covid-19 pandemic since around March 2020, there was a disruption in mining production activities, the cessation of chicken farming activities near the site, and the closure of the Leang-Leang Prehistoric Park. The results of this monitoring may not show definite results. Apart from the short observation period, a more in-depth research is also needed. Nevertheless, it is hoped that conditions like the end of 2020 can be a positive indicator in the context of efforts to preserve rock arts at the Leang Pettae site.

CONCLUSION

Microorganisms are one of the causes of rock arts damage at the Leang Pettae site, Maros. The cause of the damage is seen in the form of a white sediment layer around and on the rock arts. The research succeeded in identifying microorganisms originating from the white sediment layer, namely fungi from the genus *Paecilomyces*. Damage to rock arts occurs because fungi of this genus are fast-growing, especially in humid environmental conditions, and are very susceptible to outside pollutants. This type of fungus also produces protease enzymes which can affect the organic elements of the rock arts and its surroundings.

Controlling suggestions regarding the preservation of cave and rock arts are to control the environment at micro and macro scales such as temperature, humidity, wind, rain, and sunshine. Another factor that can be suggested for conservation is preventing air pollution from the cement industry, marble industry, livestock, and animal waste in the cave. Besides, based on the experience of preserving prehistoric caves in Spain, it is necessary to consider creating a policy that prohibits visitors from entering the cave, considering that the space inside the Leang Pettae site is not large. Making replacement media, for example in the form of a complete information board outside the cave or in a special information room, can be done without reducing the adventure aspect for visitors.

Research on fungi in general and the genus *Paecilomyces* in particular, need to be further developed with more sophisticated methods. Based on comparisons with research on fungi at other prehistoric cave sites, such as in China and in Europe, the findings of fungi are not only from the genus *Paecilomyces*. In fact, a number of research have shown that the genus *Paecilomyces* can be identified by species. Detailed research is needed for the formulation of a more comprehensive policy for cave and rock art conservation and of course, requires a lot of facilities, infrastructure, and funds.

AUTHOR DECLARATION

All authors contributed to the creation of this manuscript as primary contributors. R. Cecep Eka Permana contributed on the analysis of the rock arts and the previous studies di South Sulawesi, Moh. Habibi contributed on the microbiology analysis, and Edy Gunawan contributed on the preservation study of the Cultural Conservation. The manuscript has been read and approved by all authors. The order of authors listed in the manuscript has been approved by all named authors. This manuscript is a publication of the "Preservation and Conservation of Indonesian Rock Arts, Study Case Prehistoric Caves in Maros-Pangkep Karst Area, South Sulawesi", one of the Prominent Tertiary Education Applied Research DIKTI 2019 and 2020, contract number: NKB-1697/UN2.R3.1/HKP.05.00/2019. All authors confirm that there

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