ORIGINAL PAPER

Growth Rates of Coral Micro-Fragments from a Coral Restoration Project at Koh Larn, Chonburi Province, Thailand

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Abstract. The development of coral reef restoration techniques is very important to the success of large-scale coral reef restoration projects, especially for those having low operating costs and easy implementation. This study aimed to examine growth rates of micro-fragments of the massive coral *Porites lutea* from a pilot coral restoration project for a new technique of coral restoration using coral micro-fragmentation and coral colony fusion. The results showed that the coral micro-fragments of three different sizes (1, 2 and 3 cm.) in the coral nursery plots exhibited significant growth within two months, eventually forming a large colony within nine months. The monitoring of coral micro-fragment growth rates revealed that the micro-fragments with an initial diameter of 1 cm showed the highest growth rate (51.32%). Significant differences in mean growth rates between coral micro-fragments with an initial diameter of 1 cm and those with initial diameters of 2 or 3 cm were detected. This study provides insight into the optimal size of coral micro-fragments for coral reef restoration projects and can be applied for developing effective coral restoration strategies in Thailand.

Keywords: Growth rate, Micro-fragmentation, *Porites lutea*, Coral restoration, Conservation

1. Introduction

Coral reefs are very important ecosystems in tropical seas because of their high biodiversity and high economic value to the world's population. They especially provide food sources, employment, tourism coastal defense, pharmaceutical and cosmetic products and cultural significance. (Kittinger et al. 2012; Costanza et al. 2014; Fisher et al. 2015; Spalding et al. 2017; UN Environment Programme et al. 2018; Morrison et al. 2019; Dyshlovoy and Honecker 2020; Knowlton et al. 2021). The global economic value of coral reefs could be as much as THB 300 trillion per year (Costanza et al. 2014)

However, coral reefs and their ecosystem services have deteriorated over the past several decades (Knowlton 2001; Pandolfi et al. 2003; Hoegh-Guldberg et al. 2019). Coral reefs are among the most threatened marine ecosystems. (McCauley et al. 2015; IPCC 2019). The vulnerability of coral reefs arises from their sensitivity to the local impacts of human activities such as overfishing and pollution as well as the global impacts, especially emissions of carbon dioxide into the atmosphere causing ocean warming and acidification (Sutthacheep et al. 2022a).

The concept of passive and active restoration is adapted from forest restoration (Bradshaw 1996). Passive restoration is an attempt to improve natural recovery and ecosystem function by reducing and/or eliminating human impacts. However, active restoration needs direct human efforts to help the ecosystem restored to healthy conditions (Bradshaw 1996; Yeemin et al.

2006: Holl et al. 2011; Rinkevich 2019; Vaughan 2021; Klinthong et al. 2022; Sutthacheep et al. 2022a, 2022b; Yeemin et al. 2022). Many activities are recognized as active restoration, such as coral transplantation, coral gardening, establishing electric reefs, and enhancing the artificial reef structure in harmony with nature. Managing reef substrates to enhance coral recovery processes by stabilizing coral rubbles to help coral larval settlement, removing macroalgae to reduce competition for space with coral larvae, and coral propagation through sexual reproduction by enhancing the rates of larval production and increasing the rates of coral recruitment. (Edwards 2010; Rinkevich 2019; dela Cruz and Harrison 2020; Hein et al. 2020; Hein et al. 2021; Ligson and Cabaitan 2021; Rinkevich 2021; Vaughan 2021).

The development of coral reef restoration techniques and methods is critical to the success of current and future large-scale coral reef restoration projects, particularly, methods with low operating costs and easy of implement. Coral micro-fragmentation is a new technology that helps coral fragments to grow at a high rate, especially coral species that have a low growth rate in nature (Page et al. 2018; Broquet 2019; Steinberg 2021). When coral micro-fragments that have grown to a certain degree are connected (coral colony fusion), large coral colonies can produce gametes faster (Forsman et al. 2015; Vaughan 2021).

The Department of Marine and Coastal Resources emphasizes coral reef restoration. The Coral Reef Restoration Plan of Thailand has therefore been formulated, focusing on measures to prevent coral reef degradation from human activities such as wastewater, sediment, fishing and tourism impacts (Suraswadi and Yeemin, 2013).

Coral reef restoration is, therefore, an important issue in Thailand to enhance the health of marine and coastal ecosystems, which is the conservation of natural capital and promoting the country's ocean health index. Coral restoration methods require research and development using novel and innovative technologies, especially new techniques for coral restoration using coral micro-fragmentation and coral colony fusion. This new technique will increase the growth rate of the coral fragments and make coral colonies reproduce faster to support a sustainable blue economy. This study aimed to examine growth rates of coral micro-fragments from a pilot coral restoration project to support the development of a new technology for coral restoration using the technique of coral micro-fragmentation and coral colony fusion.

2. Materials and Methods

2.1 Study site

The study site is located at Ko Larn, Chonburi Province, Thailand (Figure 1). The coral nursery plot was installed at Ao Nuan, southeast of Ko Larn. It was constructed from welded steel into a square frame with 0.5 meter in width, 1 meter in length, and 0.7 meter in height. The frame was painted with anti-rust paint and attached with a plastic net on top to secure round cement sheets (Figure 2). The steel frame was situated approximately 50 centimeters above the sand to prevent sediment diffusion and protect against large marine benthic animals from scraping. The coral nursery plot was positioned on a coral reef slope and had a suitable water depth, ranging between 3-5 meters (Figure 3). The environmental conditions are suitable for coral growth, and a few large marine benthic invertebrates and reef fish may affect the survival rates of coral micro-fragments. Additionally, the coral nursery plot has the potential as an eco-tourism destination.

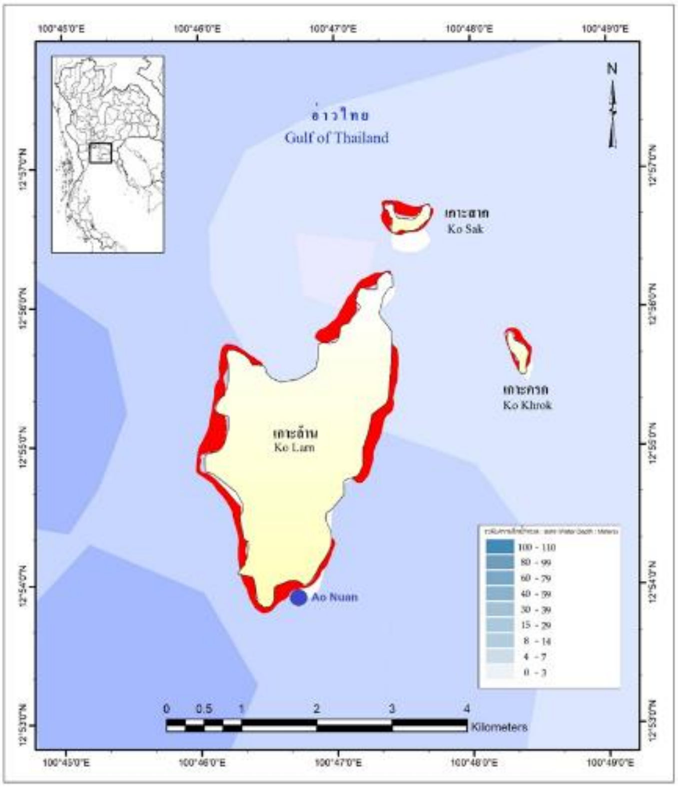

Figure 1. Location of study the site at Ko Larn, Chonburi Province, Thailand

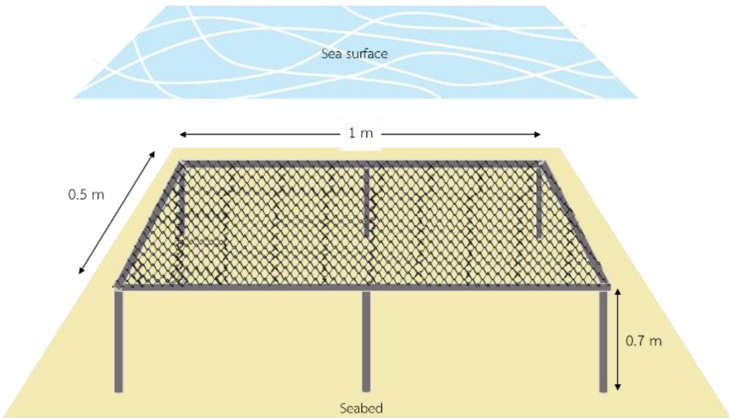

Figure 2. The nursery plot model

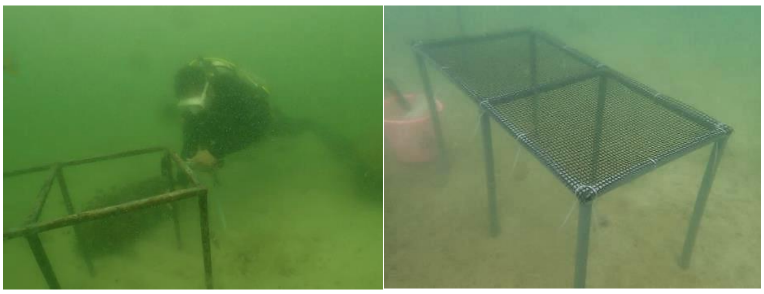

Figure 3. The Installed nursery plots on a coral reef at Ko Larn

2.2 Micro-fragmentation method

The selection of coral colonies, *Porites lutea*, was based on specific criteria, i.e., the absence of partial mortality, bleaching, invasive organisms, and coral diseases (Figure 4). Ten suitable colonies were selected and acclimatized in a pond in the nursery area for at least 24 hours. Subsequently, coral fragments of approximately 10x10 cm were cut and transferred to a culture pond equipped with an aeration system and seawater circulation. Micro-fragments were generated by cutting the coral fragments into diameters of 1, 2, and 3 cm using an electric cutter while being cooled by seawater. The researchers wore rubber gloves to avoid direct contact with the coral tissue during handling, and the coral micro-fragments were placed in a container with swirling seawater to reduce stress and mucus production after cutting (Figure 5).

Figure 4. *P. lutea* colonies that can be used as a donor

Figure 5. The coral micro-fragments in a container with swirling seawater after cutting

The coral micro-fragments were affixed to circular cement plates with a radius of 5 cm, which were pre-soaked in seawater for 48 hours to acclimate them. The epoxy glue was used to attach four micro-fragments per plate, with 1 cm of space between each micro-fragment (Figure 6). A SCUBA diver then attached the plates with coral micro-fragments to the nursery plot using a plastic net and cable tie. Each nursery plot contained a total of 15 cement plates in five rows, spaced approximately 10 cm apart and numbered for monitoring the growth rate of the coral micro-fragments (Figure 7).

Figure 6. A cement plate is used as the base for attaching coral micro-fragments.

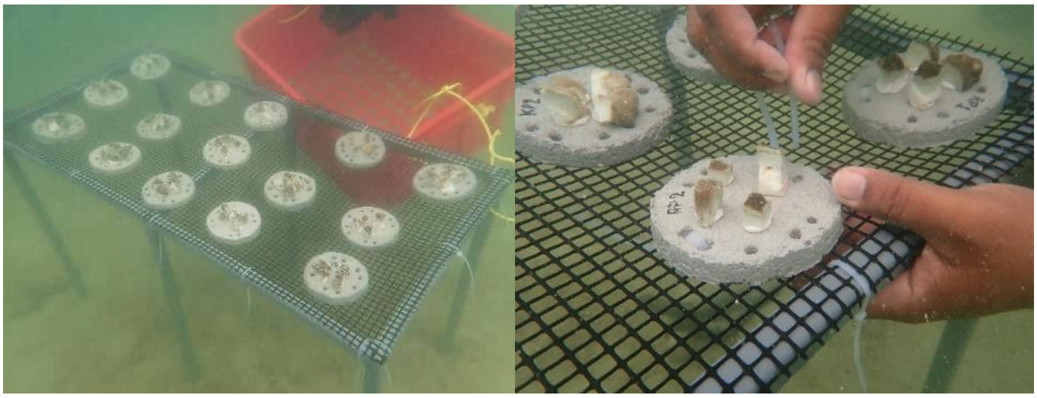

Figure 7. Installing cement plates in coral nursery plot

2.3 Data collection

In the coral nursery plots, various environmental factors were monitored, including seawater temperature, light intensity, salinity, pH, dissolved oxygen (DO), oil or grease, suspended solid content, and sedimentation rate (Figure 8). The growth rate of coral micro-fragments was monitored from June 2022 to February 2023 by measuring changes in the area of coral micro-fragments (Figure 9).

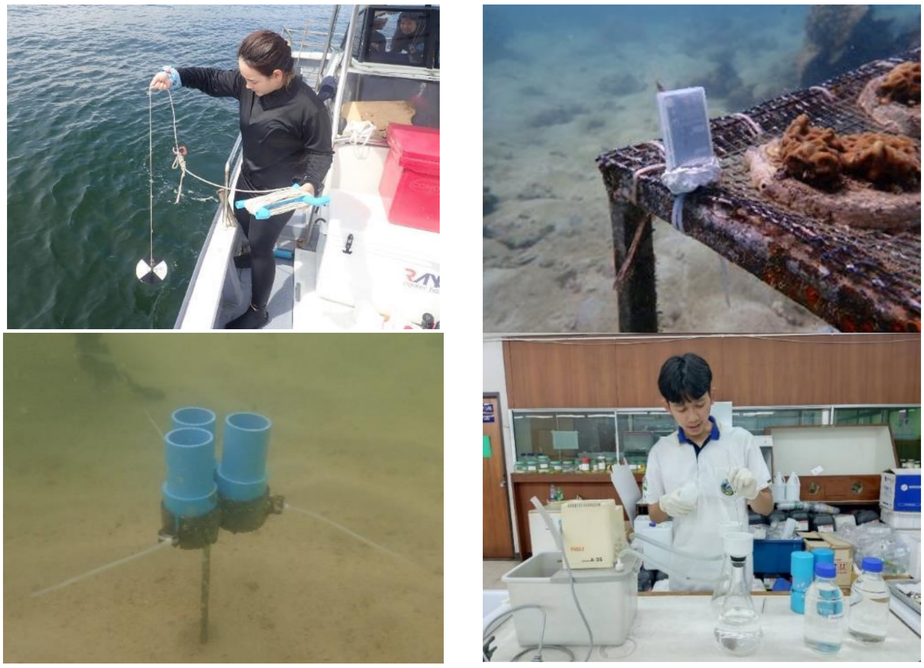

Figure 8. A study of environmental factors in coral nursery plots

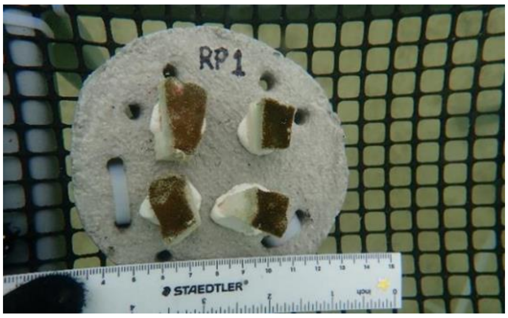

Figure 9. Measurement of coral micro-fragment size in a nursery plot to monitor growth rate of coral micro-fragments

2.4 Statistical analyses

The growth rates of the coral micro-fragments were analyzed using a one-way ANOVA to determine if there were any differences between the groups. To identify which groups differed significantly from each other in terms of growth rate, Tukey's Honestly Significant Difference (Tukey's HSD) test was applied to the coral micro-fragments.

3. Results

3.1 Environmental factors

The effects of various environmental factors on the growth rate of micro-fragments of *P. lutea* were investigated in the nursery plots on a coral reef. The environmental factors were monitored, including seawater temperature, salinity, pH, dissolved oxygen (DO), oil or grease, suspended solid content, and sedimentation rate, over nine months from June 2022 to February 2023.

The results showed that seawater temperatures ranged from 28.76 to 30.12 °C, with the highest temperature recorded in July 2022 and the lowest one in January 2023 (Figure 10). Light intensity was in the range of 14-11,920 lux, with the highest luminous intensity in January 2023 and the lowest one in July 2022 (Figure 11). Salinity ranged from 28.50 to 33.21 ppt, with the highest salinity recorded in July 2022 and the lowest one in August 2022. pH ranged from 7.95 to 8.40, with the highest value recorded in September 2022 and the lowest one in February 2023. Dissolved oxygen content ranged from 5.65 to 6.95 mg/l, with the highest level recorded in June 2022 and the lowest one in February 2023. Transparency ranged from 1-2 meters, with the highest level in July 2022 and the lowest one in September and October 2022. Neither oil nor grease was detected during the study period. Suspended solid contents ranged from 17.00 to 20.56 mg/l, with the highest level recorded in June 2022 and the lowest one in August 2022. Sedimentation rates ranged from 5.37 to 15.64 mg/cm^2/day, with the highest rate recorded in June 2022 and the lowest one in November 2022.

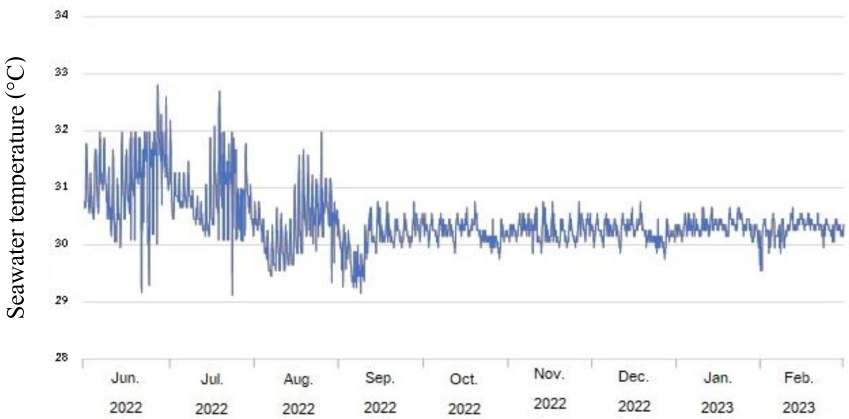

Figure 10. Seawater temperatures recorded from a data logger during June 2022 - February 2023

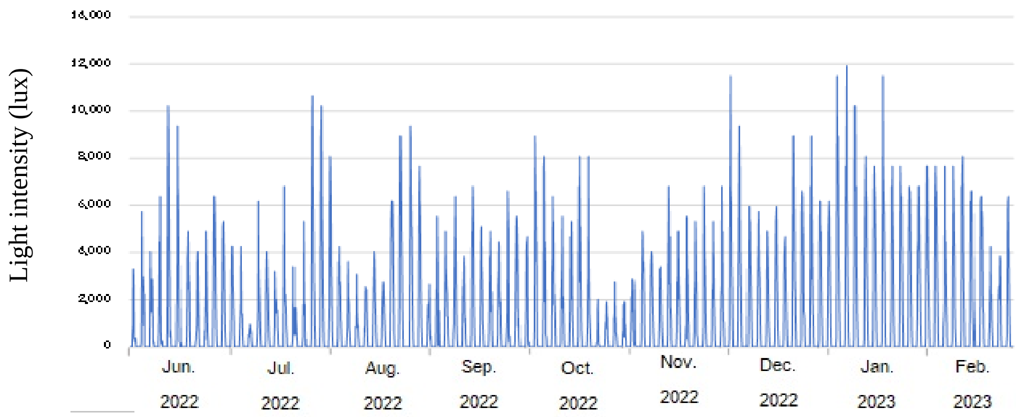

Figure 11. Light intensity recorded from a data logger during June 2022 - February 2023

3.2 Growth rate of coral micro-fragments in coral reef nursery plot

The results showed that the coral micro-fragments of three different sizes in the coral nursery plots exhibited significant growth within two months, eventually forming a large colony within nine months (June 2022 - February 2023) (Figure 12). The monitoring of coral micro-fragment growth rates revealed that the micro-fragments with an initial diameter of 1 cm displayed the highest growth rate of 51.32%, while the micro-fragments with initial diameters of 2 cm exhibited a growth rate of 31.24%. The coral micro-fragments with an initial diameter of 3 cm exhibited the lowest growth rate of 29.54% (Figure 13).

Figure 12. The coral micro-fragments successfully fused together after 9 months.

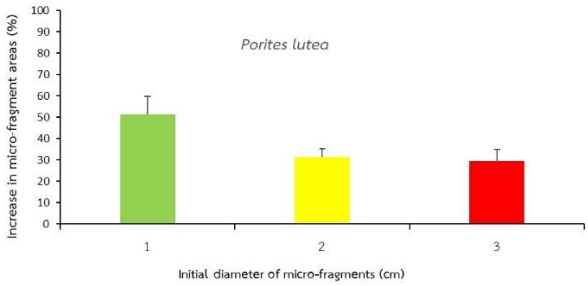

Figure 13. Growth rates of various sizes of coral micro-fragments

The growth rates of micro-fragments in coral reef nursery plots were analyzed using one-way ANOVA to compare the mean growth rates of three different sizes of coral micro-fragments. The results revealed a significant difference in the mean growth rates between the coral micro-fragments of different sizes. Tukey's Honestly Significant Difference (Tukey's HSD) test was then employed to compare all possible pairs of groups and determine if their differences in means were statistically significant. The analyses showed significant differences in mean growth rates between coral micro-fragments with an initial diameter of 1 cm and those with initial diameters of 2 or 3 cm, but not between those with initial diameters of 2 and 3 cm. Based on these findings, it can be concluded that the coral micro-fragments with an initial diameter of 1 cm had the highest growth rate compared to the other sizes in this study. Our data provide insight into the optimal size of coral micro-fragments for coral reef restoration projects and can be used to inform the development of more effective coral restoration strategies.

4. Discussion

Porites lutea is the most abundant coral species in the coral reefs surrounding Ko Larn, Chonburi Province. These coral communities are affected by freshwater and sedimentation influenced by the main rivers that flow into the Inner Gulf of Thailand, resulting in high sedimentation and low salinity levels (Pengsakun et al. 2019). Additionally, environmental stresses such as coastal development, garbage, wastewater, tourism, and coral bleaching further contribute to the challenges faced by these coral communities. Therefore, selecting *P. lutea* as a breeder for coral restoration is a cost-effective approach to restoring damaged coral reefs (Morikawa and Palumbi, 2019).

Environmental variability in coral nursery plots on coral reefs is crucial for the adaptation of corals to survive under highly stressful conditions. Coral adaptation can increase the resilience of corals in nursery or restoration areas. A previous study suggested that corals exposed to high temperatures exhibit less bleaching when subjected to heat stress (DeMerlis et al. 2022).

The results of this study indicate that coral micro-fragments of different sizes exhibit various growth rates in coral nurseries. Coral micro-fragments with an initial diameter of 1 cm at Ko Larn had the highest growth rate (51.32%). Our findings were consistent with previous studies showing higher coral growth rates in smaller coral fragments (Harrington et al. 2004; Lirman et al. 2016; Steinberg 2021).

The slower growth rates observed for coral micro-fragments with initial diameters of 2 and 3 cm may be due to competition for space, light, and nutrients, as well as susceptibility to predation (Kojis et al. 2001; Baird et al. 2002). Page et al. (2018) examined coral micro-fragmentation in the slow-growing massive corals *Orbicella faveolata* and *Montastrea cavernosa* from nearshore and offshore locations of the Florida Keys. Their results from excluding plots with over 40% predation at the nearshore site revealed that *O. faveolata* micro-fragments grew 10 times more than bigger coral fragments. It is suggested that if predators are reduced, some coral micro-fragments can grow very fast and have a high potential for coral restoration projects.

This study highlights the potential of coral nurseries for restoring damaged coral reefs as coral micro-fragments can be fused to a large colony within 9 months. Our finding is consistent with previous studies that demonstrated the effectiveness of coral nurseries in promoting the growth and survival rates of coral fragments (Young et al. 2012; Schopmeyer et al. 2017). The significant difference in growth rates observed between the different sizes of coral fragments suggests that small coral fragments should be selected for coral restoration projects. It is emphasized that coral species having slow growth rates in nature should be used in coral restoration efforts. Their micro-fragments that grow faster can be fused, resulting in large coral colonies that can sexually reproduce faster (Forsman et al. 2015; Vaughan 2021). Our findings have important implications for coral restoration efforts in Thai waters.

Acknowledgments

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