Key success factors and problems in coral transplantation: A review

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Abstract. The coral reef is one of the important coastal ecosystems in the tropic and sub-tropic regions, serving as a feeding area, spawning location, as well as habitat for many marine biotas. This ecosystem is highly productive, providing a habitat for more than one million species of marine organism. In addition, it also supplies ecosystem services for hundreds of millions of people across the tropic and subtropical regions. Despite its integral role, coral reef is undergoing rapid degradation. Rehabilitation or restoration of damaged coral reefs is a very significant program that must be carried out by various stakeholders, including coastal communities. This paper aimed to systematically review relevant works related to the rehabilitation or restoration of coral reef ecosystems, with an emphasis on the propagation or transplantation of coral reefs. The review contains several specific issues such as coral reef rehabilitation, restoration, remediation, and transplantation, and the development of methods and media, as well as limiting factors of transplantation activities.
Key Words: coral reef, rehabilitation, transplantation, remediation, limiting factors.

Introduction. Coral reef is an important type of coastal ecosystem, functioning as temporary or fixed habitat for many marine species, as feeding, spawning, and nursery area (Pelasula et al 2021). This ecosystem also acts as the harbor for biological processes as well as for chemical and physical cycles, globally attaining a high productivity (Losos & Leigh 2004). Coral reefs act as a barrier for coastal areas against the waves and is a major source of construction materials (Branderet et al 2004; Kench & Brander 2009; Pascal et al 2016). Coral reefs provide suitable grounds for supporting coastal fishery activities, such as marinculture areas and tourist activities (including snorkeling and diving), as well as for educational purposes (aș a natural laboratory) and for protection of rare marine biota (Pelasula et al 2021). In addition, it also provides important ecosystem services (e.g. food supply, coastal protection) for hundreds of millions of people across the tropic and subtropical regions. Despite its role, the coral reef is undergoing a rapid degradation (Hughes et al 2003). The degradation is caused by extensive fishing, coastal development, pollution, and the rise in sea temperature (Hughes et al 2003). Those factors continue to decrease the abundance of coral reefs, which leads to a decline in biodiversity and ecosystem services (Cinner et al 2012; Pendleton et al 2016). Coral reef could be used to record all earthquakes that occurred in the past (Himakelunsoed 2020). By observing the presence of coral reefs, a record of an earthquake could be obtained, in order to find patterns that could be used to predict future earthquakes (Coremap-LIPI 2017).

The global population continues to grow. The majority of the human population lives in coastal areas, and the coral reef ecosystem becomes a source of life for such communities. Ironically, even though the community benefits from the existence of the coral reef ecosystem, continued pressure has adverse effects on the sustainability of the coral reef ecosystem (Pandolfi et al 2003). The latest data and information from several previous studies show that more than 37% of coral reef areas in the world have been degraded or damaged. It is estimated that 30% of other areas will suffer the same fate within the next 10-30 years (Burke et al 2002). Coral reefs area in Indonesia is equivalent to 18% of the total area of coral reefs in the world (Spalding et al 2001). Furthermore, according to this data, only 30% of coral reefs belong to the good status category, 37% belong to the moderate status category and the remaining 33% belong to the damaged category. The data was obtained from the results of a survey in 77 sites, from Sabang in Sumatra Island to Raja Ampat Islands in West Papua. The percentage of damaged coral cover is increasing due to the coral bleaching phenomenon (Hughes et al 2003). This condition will be further exacerbated by the presence of coral diseases. Some experts concluded that coral diseases are closely related to global climate change and environmental degradation, as they are associated with the ability of the corals to adapt to climate change and global warming. However, further study is needed to demonstrate this hypothesis (Hughes et al 2003). There is another opinion that in the short term, corals can adapt to environmental changes by changing the type of their algal symbiont or the composition of their bacterial community (Hughes et al 2003). However, if climate change and environmental damage due to human activities continue, the adaptability of corals to survive will become very limited (Reshef et al 2006).

As it is already known, the productivity of coral reefs is very high due to the relationship between coral animals (polyps) and the single-cell microscopic algae genus Symbiodinium called zooxanthellae that lives in the coral tissues (Douglas, 2003; Grimsditch & Salm 2006; Eakin et al 2008). Thus, corals depend on zooxanthellae as the symbiont because they can produce 90% of the energy that corals need. The relationships between corals and their symbionts will deteriorate if sea temperatures increase by about 1 to 2°C over ≥4 weeks, such as during the El-Ninō events. This condition causes stress to corals so that the density of zooxanthellae decreases, and then the corals release their symbionts, which makes the beautiful color variations of coral turn white or pale, similar to the color of limestone ($CaCO_3$), the coral skeleton (Douglas 2003). This phenomenon is defined as coral bleaching (Brown 1997; Fitt et al 2001; Douglas 2003; Marshall & Schuttenberg 2006). If the coral bleaching event (CBE) continuously occurs with an anomaly water temperature of 1-2°C for >8 weeks (degree heating weeks or DHW>8), it will damage bleached corals and often leads to high levels of coral mortality (Brown 1997; Hoegh-Guldberg 1999; Coles & Brown 2003; Douglas 2003; Donner et al 2005; Hoegh-Guldberg at al 2007; Eakin et al 2008; Barron et al 2010).

The first CBE was recognized about 75 years ago, but over the past 20 years, CBE's appearance has become more frequent and its distribution wider, resulting in dramatic changes to the reefs leading to coral extinction (Hoegh-Guldberg 1999). Results on coral bleaching modeling show that if corals cannot withstand an increase in sea temperature of 0.2-1.0°C/decade, then in the next 30-50 years this phenomenon will occur every two years or even every year (Donner et al 2005). Baker et al (2008) showed that CBE occurred every two years since the early 1980s.

The CBE with the worst impact in almost all of the world's tropical waters occurs at the same time as El-Ninō years. Four significant CBEs due to the global warming induced by El-Ninō have been reported all over the globe, including in the Indonesian waters. Between 1982-1983, CBE killed 95% of the coral in the Galapagos Islands (Glynn 1984; Berkelmans et al 2004), while the increase in global ocean temperature of about 2°C in 1997/1998 wiped out 16% of the world's corals (Hoegh-Guldbergat al 2007; Baker et al 2008; Oliver et al 2009). A mild El Niño in 2010 elevated sea temperatures caused mass bleaching of reefs in many parts of the world (Heron et al 2016). The strong El Niño in 2015/2016 was the longest and the most extensive CBE recorded impacting some reefs in consecutive years (Huges et al 2017; Eakin et al 2019,2022). The first CBE in Indonesia occurred in 1982-1983 in Pari Island, the Seribu Islands. The other impacted areas were the Karimun Jawa Islands, the Sunda Strait of Java Sea, and the South China Sea. Coral mortality in Seribu and Karimun Jawa Islands, reaching 90% (Suharsono & Kiswara 1984; Brown & Suharsono 1990). Significant big CBE in 1997/98 occurred again in various Indonesian seas such as in Sumatra, Jawa, Bali, Lombok Islands, east of Kalimantan Island, the National Marine Park of Bunaken, north of Sulawesi Island and surrounding waters that lead to 60-70% coral mortality (UNEP-WCMC 2013). At the same time, in the waters of West and South Sumatra, 90% of coral mortality occurred not because of temperature rising, but due to a decrease in temperature below 26°C (Coremap-LIPI 2017). At that time, El-Ninō occurred concurrently with the Indian Ocean Dipole (IOD).

Figure 1 shows the mild CBE and strong and extensive CBE due to El Niño that occurred again all over the Indonesian seas in 2010 (Wouthuyzen et al 2015) and 2015/2016 (Wouthuyzen et al 2018), respectively. Generally, the CBE of 2010 and 2016 had the same pattern that started, developed and finished in the same periods of March to June, as well as the impacted areas. However, the coral bleaching strength was higher in 2015/2016 than in 2010 (Table 1) (Wouthuyzen et al 2018). The CBE areas occur along the west coast of Sumatra Island and in some small islands of the west mainland of Sumatra, and the southern Jawa, Bali Lombok, and the islands of East Nusa Tenggara Islands, which are under the influences of the Indian Ocean water masses. Other areas are inner Indonesian seas such as Malaka, Karimata straits, and a part of Makassar Straits, Java and Flores Seas, Spermonde and Wakatobi Islands, and Tomini Bay. On the contrary, in the east Indonesian waters, under the influences of the Pacific Ocean as in some sites of the Sulawesi Sea (Bunaken Island, site 15; Gorontalo site 18), Halmahera Sea (Morotai, Sangihe-Talaud Islands, site 14), Cendrawasih Bay (Supiori, Biak, Numfor, Padaido Islands of Papua, site 13). Raja Ampat Islands (site 12), Ambon, except in 2010 (site 11), and Aru Islands (site 11) CBE did not occur (Figure 1).

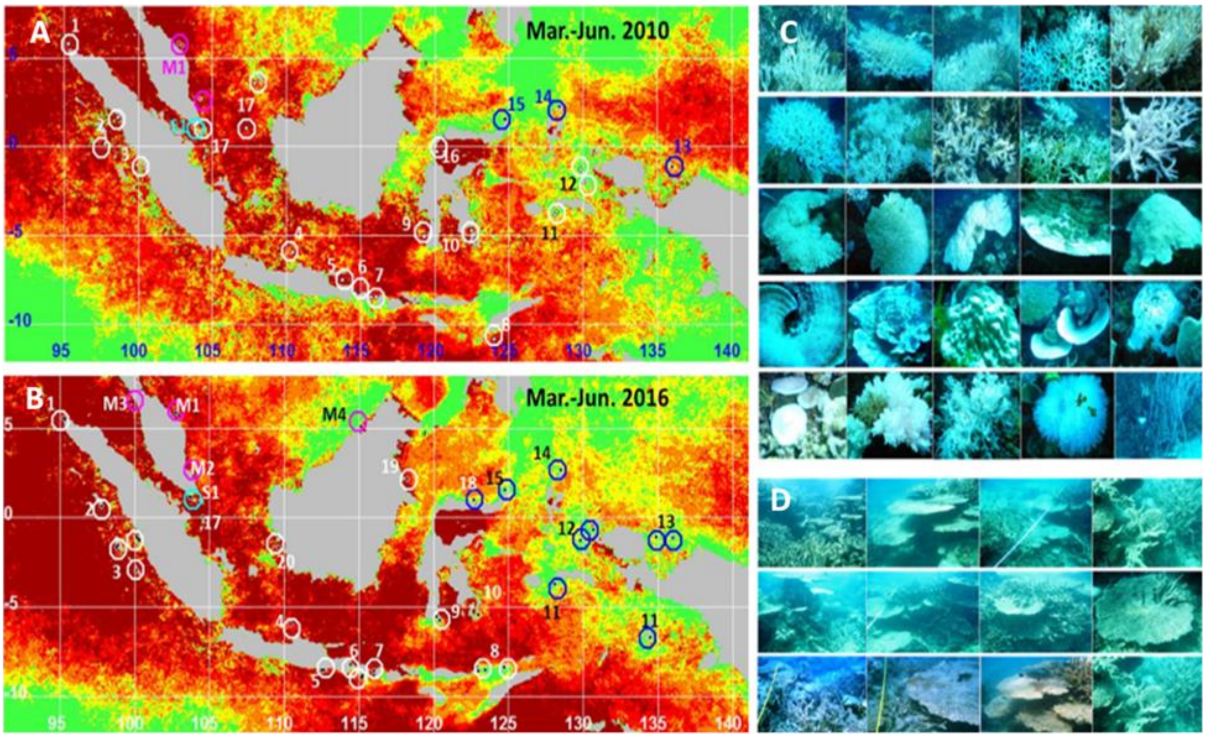

Figure 1. Degree Heating Weeks (DHW) maps showing coral bleaching severity sites of March-June 2010 (A) and 2015/2016 (B) analyzed using Sea Surface Temperature (SST) data derived from Aqua MODIS Sattellite and field observations. White circles-the occurences of coral bleaching in the Indonesian waters; magenta and cyan circles-neighboring countries of Malaysia and Singapore; blue circles- sites where coral bleaching did not occur. The right panel shows an example of coral bleaching in Spermonde Islands, South Sulawesi (C) and in Natuna and Riau Islands (D) in 2010. HS=Hot Spot=Anomalous SST–Normal SST. Green: HS≤0°C, No thermal stress on corals; Yellow: HS 0-1°C, low thermal stress; Orange: HS>1°C, DHW≤4 weeks, thermal stress accumulated; Red: DHW 4-8 weeks, Allert Level-1, Strong thermal stress, which may results in Partial bleaching; Dark Red: DHW >8 weeks, Alert Level-2, Severe thermal stress, which may results in spread beleaching with likely corals mortality (INCOIS 2011; Wouthuyzen et al 2015,2018,2020).

Table 1 displays the CBE in Indonesian waters in 2010 and in 2016 categorized by bleaching intensity. The total percentage of coral bleaching in Warning, Alert-1 and Alert-2 categories in 2010 and 2016 were 49.3% and 56.2%, respectively. The Alert-2 (severe thermal stress, which may result in spread bleaching with likely corals mortality) in 2010 was 14.1%, while in 2016 was 24%. These data indicated that the CBE magnitude in 2015 was higher than in 2010 (Wouthuyzen et al 2018).

Table 1

Percentage of monthly HS and DHW areas of CBE during 2010 and 2016 in Indonesian waters

Category	*Coral bleaching events of 2010*					*Coral bleaching events of 2016*				
	Mar.	*Apr.*	*May*	*Jun.*	*Mar.-Jun.*	*Mar.*	*Apr.*	*May*	*Jun.*	*Mar.-Jun.*
HS≤0°C; No thermal stress	31.2	18.0	15.3	29.1	18.9	28.3	15.9	11.9	18.8	11.9
HS 0-1°C; Watch	38.8	51.5	49.6	28.4	13.9	28.1	43.0	48.5	38.8	14.0
HS>1°C; DHW<4, Warning	12.1	12.5	16.9	23.4	18.0	23.9	22.8	20.4	23.8	16.8
HS>1°C; DHW 4-8, Alert-I	0.1	0.2	1.2	1.2	17.2	1.7	0.5	1.3	0.8	15.4
HS>1°C; DHW>8, Alert-II	0.0	0.0	0.0	0.0	14.1	0.0	0.0	0.0	0.0	24.0
Land	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8
Total	100	100	100	100	100	100	100	100	100	100

In Indonesian seas, the massive CBE period showed a tendency for coral bleaching to become shorter and shorter i.e, it needs 14-15 years from CBE in 1982/1983 to 1997/1998, 12 years from 1997/1998 to 2010, and only six years from the CBE in 2010 to 2015/2016. The coral reefs decrease due to coral bleaching would have direct consequences, especially for the local communities that depend on their livelihoods on a part or the whole coral reefs' goods and environmental services, such as coastal protections, food security/fishes, and tourism (Ompou et al 2017; Cesar et al 2013).

Besides the factors mentioned above, there is another factor that also contributes to coral mortality, namely fishing, using non-environmentally friendly equipment (Johan 2006; Pelasula et al 2021). Coral damage is getting worse due to the intensive trading of ornamental fish and fish for food (Muswar & Satria 2011). On the other hand, restoration/rehabilitation of coral reef ecosystems takes a relatively long time (Bowden-Kerby 2008; Edwards & Gomez 2008). The low level of public awareness and knowledge of the importance of sustainable management of coral reef ecosystems is a key factor that contributes to the increasing level of coral reef damage (Johan 2006; Pelasula et al 2021). By observing the current condition of coral reefs, in order to predict their condition in the future, the Global Coral Reef Monitoring Network's (GCRMN) report estimates in the Status of Coral Reefs of the World that approximately 20% of coral reefs in the world have been destroyed (Wilkinson 2004). Furthermore, in the short term, it was estimated that 24% of coral reefs in the world will be destroyed due to human activities, while 26% are at risk in the long run (Burke et al 2011).

Figure 2A displays the global percentage of living coral cover estimation from 1980 to 2020 quoted from the report of The 2020 World Coral Reef Status Report based on comprehensive global data from approximately 2 million observations collected from 12,000 observation sites over 40 years in 73 countries (Souter et al 2020). In 1997/1998, a CBE wiped out 16% of the world's corals (Hoegh-Guldbergat et al 2007; Baker et al 2008), which caused a decline in the percentage of living coral cover from 32.5 to 30% (Souter et al 2020). However, from 2002 to 2009, the living coral cover percentage recovered and increased to pre-1998 levels of 33.3%. This condition demonstrates that in the absence of global disturbances, such as the El Niño phenomenon, many of the world's coral reefs remain resilient and capable of recovery, despite there are some influences of regional or local stressors, such as tropical storms, crown-of-thorns (CoT) starfish outbreaks, coral diseases, over fishing, destructive fishing, poor water quality due to land-based pollution (Souter et al 2020). In 2010 and 2016, the CBE reoccurred (Heron et al 2016; Huges et al 2017; Wouthuyzen et al 2018; Eakin et al 2022), which caused the percentage of live coral cover to decrease again from 33.3 to 28.8%, indicating a loss of 13.5% of the world's hard corals (Souter et al 2020). Although few data are available for 2019, the global average coral cover shows the first signs of recovery with an increase of 0.70% (Souter et al 2020). This sign is similar to the study results on the small island of the marine protected area of Pieh Island and surrounding islands, Indonesia, which is under the influence of the Indian Ocean after being exposed to CBE twice in 2010 and 2016, as reported by Wouthuyzen et al (2019).

Coral reef health indicators expressed as a percentage of live hard coral cover are now globally accepted and used universally. Furthermore, the percentage cover of macroalgae (algae) relative to corals recognizes as an indicator of the ecological changes in corals (Souter et al 2020). Thus, healthy coral reefs will have low algae cover and vice versa. Figure 2b shows the global percentage of macroalgae cover estimation from 1980 to 2020. According to Souter et al (2020), the average live coral cover percentage in the world before 1998 was twice that of algae cover. However, the CBE in 1997/1998 caused the living coral cover to decrease, followed by an increase in the algae cover until the coral cover recovered to initial levels in 2011. Thus, before 2011, the estimated global mean algal cover was low at ~16% and stable for 30 years. However, the CBE in 2010 and 2016 led to an increase in a global algal cover percentage to around 20% (Figure 2B), which reflects a decrease in live coral cover (Figure 2A).

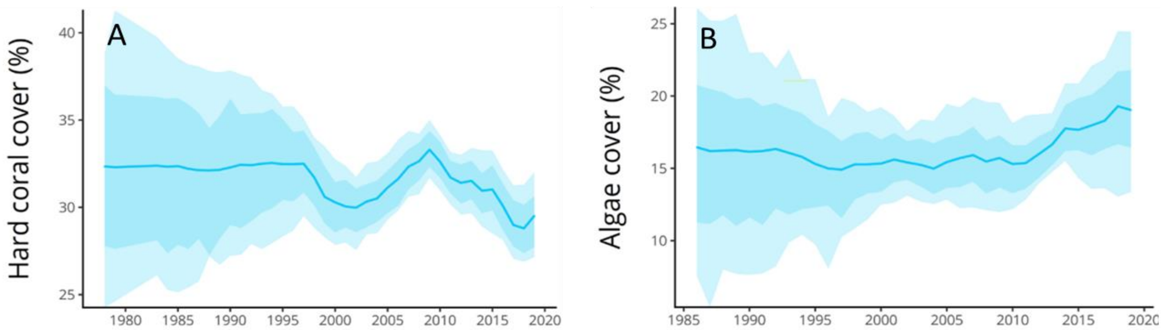

Figure 2. Estimated global average of living hard coral cover (A), and algae cover (B) indicated by solid blue line and associated 80% (darker shade) and 95% credible intervals, which represent levels of uncertainty (lighter shade) (Adapted from Souter et al 2020).

If the global estimation of living hard coral cover and algae cover percent in figures 2A and 2B are divided into ten regions, the difference among the regions in the periods 2005-2009 and 2015-2020 (Table 2) is understandable. From these two periods, the percentage of living coral cover decreased in all regions in the range of 0.1 to 8.7%, with a total decline of 24.2%, except in the Brazilian and the Caribbean seas, where the percentage of living coral cover increased by 1.6 and 3.0%, respectively. The regions with the highest decline in living coral cover were South Asia (8.7%), followed by Australia (6.0%), and the Pacific regions (4.3%), while others had coral cover declines <4.0%. Meanwhile, the increase in algae cover in those regions ranged from 3.1 to 13.4%, with a total increase of 53%, except for the East Asian Seas and Western Indian Ocean regions, where the percentage of algal cover decreased by 2.9 and 1.1%, respectively. Regions with the highest increase in algae cover were ROPME (West Asia) area (13.4%), followed by Australia (10.2%) and Brazil (9%), but In the other regions, the increase in algae cover was <7%.

Of the ten global coral reef regions located throughout the Global Coral Reef Monitoring Network (GCRN), the region of the East Asian Seas, which includes the Coral Triangle and has 30% of the world's coral reefs, and is the center of global hard coral diversity (Souter et al 2020), has its peculiarities that shows a very different trend from all other GCRMN regions (Table 2). This region is the only region where the coral cover was substantially higher in 2019 (36.8%) than in 1983 (32.8%), which was the earliest data collected when the GCRMN program started.

Table 2

Mean absolute change in percent living hard coral and algae covers in each region between the period of 2005-2009 and 2015-2019

No	*Region*	*Live hard coral (%)*	*Algae cover (%)*
		2005-2009 and 2015-2020	*2005-2009 and 2015-2020*
1	Australia	-6.6	10.2
2	Brazil	3.0	9.0
3	Caribbean	1.6	6.7
4	East Asian Seas	-2.8	-1.1
5	Eastern Tropical Seas	-1.4	3.1
6	Pacific	-4.3	5.9
7	Red Sea and Gulf of Eden	-1.7	4.8
8	ROPME (West Asia) Area	-3.2	13.4
9	South Asia	-8.7	3.9
10	Western Indian Ocean	-0.1	-2.9
	Total	-24.2	53.0

Figure 3A shows a high percentage of living coral cover percentage. On the other hand, Figure 3B shows low algae cover percent, so the ratio of live coral cover to algae cover is five times higher in this region (Souter et al 2020). This region is the same as the nine other regions that experienced pressure from high sea surface temperature (SST) anomalies triggered by the El Nino phenomenon in 2010 and 2016. The East Asian Seas region appears to be less affected. The possibility of these conditions indicates a hypothesis that the high diversity and the high coral covers in this region are very significant since they can provide a natural level of resistance to increasing SST (Souter et al 2020). However, such a hypothesis needs to analyze in more detail in years to come.

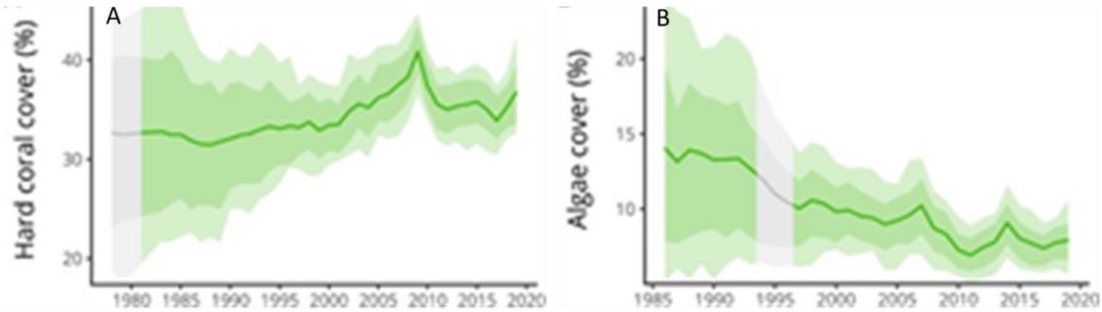

Figure 3. Estimated average of living hard coral cover (A), and algae cover (B) for the region of the East Asian Seas indicated by solid green line and associated 80% (darker shade) and 95% credible intervals, which represent levels of uncertainty (lighter shade) (Adapted from Souter et al 2020).

In addition, the biggest threats to coral reefs that have been identified are sedimentation (resulting from land clearing and watershed management), disposal of household and industrial waste directly into the sea, use of nutrients and eutrophication from agricultural activities, coral mining for building projects, and overfishing of marine biota (Gomez et al 2010; Pelasula 2008). Results from the previous studies have shown that coral reefs under severe stress will recover in a minimum of 5-10 years. It means that coral reefs are "resilient" because they can return to their original condition. However, coral reefs that are constantly being stressed will be less likely to recover

(Gomez et al 2010). After observing the estimated level of destruction in the present and future, both in the short and long terms, a fundamental question comes to mind: are coral reefs still important for the sustainability of human life and other creatures? The discussion above shows that humans are heavily dependent on coral reefs (Rani 2003). Coral reefs are a source of food and livelihood for hundreds of millions of coastal residents from 100 countries, also attracting tourists (Edwards 2010). Coral reefs are also used as raw/basic materials in the pharmaceutical sector for treating various diseases such as cancer and AIDS (Gomez et al 2010). On the one hand, the sustainability of human life depends on coral reefs, on the other hand, damage to the coral reefs keeps piling up. Efforts to increase public awareness of coral reef preservation must be encouraged (Rani 2003). Furthermore, rehabilitation or restoration of damaged coral reefs is crucial and must be carried out by various stakeholders including coastal communities (Edwards & Gomez 2008).

This paper aimed to review systematically all findings and information from the previous works, related to the rehabilitation or restoration of coral reef ecosystems, with an emphasis on the propagation or transplantation of coral reefs in several countries, including Indonesia. It analyses topics that have been heavily researched, while avoiding bias. It gauges when, how, and by whom the research has been conducted, in order to support the formulation of future strategies for strengthening the research capacity (Djalante 2018). Coral reef propagation or transplantation in the future seems to be a large challenge, therefore the purpose of this review was to find out the success and failure rates of coral transplantation in various places, the conditions of transplantation sites, the successfully transplanted types and forms of coral colonies, as well as the commonly-used methods and limiting factors in transplantation activities. The structure of this review is as follows: this first section describes the rationale, purpose, and objectives of the study; the second section describes the methods used; the third section discusses some findings from previous works, and the last section comprises conclusions and recommendations which can benefit the stakeholders.

Sources of data and information. To find relevant publications, the authors gradually collected relevant publications using Scopus as the main search engine alongside Google Scholar and Gray Literature. Scopus became the primary option since it has a larger number of publications, a structured database, and a citation record that is older than the database of the Institute of Scientific Information (Leydesdorff 2010). Meanwhile, Google Scholar was used to meeting the targets of publications and gray literature that have not been published in a newsletter. In Systematic Literature Review (SLR) studies, gray literature can be in the form of research reports, technical reports of project activities, as well as academic papers in the form of theses, dissertations, and ongoing research that has not been published (Paez 2017), and studies on coral reef restoration, carried out by Government Agencies and Non-Governmental Organizations (NGOs) in various places, that are uploaded on a website. Scopus was used as the authors' first choice in finding publications related to the topic. The initial keywords used were transplantation, coral, and reef, which yielded a total of 263 documents. The next step was filtering the documents based on the year of publication, from 2005 to 2021 (17 years), which narrowed the result to 206 documents. The next step was inserting more keywords related to the topic, namely Anthozoa, coral reef, transplantation, coral, ecological restoration, coral transplantation, growth rate, survival, conservation of natural resources, coral gardening, coral restoration, coral reef restoration, methodology and predation, resulting in 124 documents. After that, the documents were downloaded in the XML format and then imported into Microsoft Excel to be checked manually by the research topic, narrowing the result even further to 110 documents. Finally, 30 documents were obtained from Google Scholar, along with 6 grays literatures. Summary of data and information could be seen on Table 3.

The data or documents that had been collected were divided into topics and sub-topics to identify and achieve the main objectives, as follows:

a. Definition of rehabilitation, restoration, remediation, and transplantation/propagation;

b. Factors influencing the success and failure rate of coral transplantation in various places;
c. Algae and competing biota in transplantation;
d. Types and development of methods and media in transplantation activities (Types of corals commonly used in transplantation activities, commonly-used methods and media, and Ideal fragment sizes that can be used in transplantation activities);
e. Limiting factors in transplantation activities;
f. Recommendations related to future coral rehabilitation and restoration activities.

Table 3

Summary of literature cited for this review

No	*Sources*	*Indonesian*	*English*	*Total*
1	Books	5	11	16
2	Notes	2	5	7
3	Reports	-	9	9
4	Review articles	-	8	8
5	Technical articles	-	4	4
6	Review articles	-	8	8
7	Riset articles	27	86	110
8	Website (http)	2	-	2
	Total amount	36	131	167

Definition of rehabilitation, restoration and transplantation or propagagation. Restoration of damage to coral reef ecosystems is often related to the term’s rehabilitation, restoration, remediation, transplantation, or propagation. Narratives around these words often appear in scientific, popular, or semi-popular articles. The terms that appear in the narratives certainly have definitions and meanings that may be similar but are different (Precht 2006). Therefore, it is necessary to conduct a review to obtain the meaning and scope of these terms about the restoration of coral reef conditions.

Rehabilitation and restoration. Rehabilitation is an act of replacing part or all the structural or functional characteristics of an ecosystem that has been lost or substituting them with a better alternative, with the assumption that after being rehabilitated, the coral reef ecosystem will have better social, economic, or ecological value. As such, rehabilitation can be interpreted as the act of replacing part or all of the structural or functional characteristics of an ecosystem that has been damaged (Edwards 2010). On the other hand, a coral reef restoration is an act of restoring a degraded ecosystem to a state similar to its original condition (Edwards & Gomez 2008). Restoration of coral reef ecosystems, as defined by Baird (2005), is an activity designed to restore degraded ecosystems to a better condition even if not exactly the same as the original one. Restoration of the structural function of an ecosystem will take place naturally (Livingston 2005; Yeemin et al 2006). According to Donald (2016), in the Society for Ecological Restoration International Science & Policy Working Group (SER), restoration is “the process of assisting the restoration of ecosystems that have been degraded, damaged, or destroyed”, and “restoration seeks to return the ecosystems to their historical trajectories". Restoration can be carried out passively or actively. Passive restoration refers to recovery or regeneration that occurs naturally or indirect restoration carried out by eliminating or minimizing damaging factors without replanting. Meanwhile, active restoration is conducted by replanting (Donald 2016). Ecological restoration is the process of restoring coral reef ecosystems that have been degraded, damaged, or destroyed. An ecosystem is successfully restored if the biotic and abiotic components can maintain themselves structurally and functionally (Gann et al 2019; Sebastian et al 2021; Ferse et al 2021). Restoration interventions are made to assist the natural recovery processes of coral reefs. If natural restoration processes do not work, recovery can be carried out actively or with direct interventions (Edwards & Gomez 2008).

Remediation and transplantation. In addition to the definition of rehabilitation and restoration, there is still a term related to polluted environment, which in turn is associated with damaged coral reef, namely remediation. Remediation is defined as an act or process of repairing damage to the ecosystem (Edwards & Gomez 2008). The principle of remediation is to restore environmental conditions that have been affected by pollution. There are several opinions from experts regarding the definition of transplantation or propagation, which is the keyword of this article review. Some are similar, while others are broader in scope. Transplantation is an effort to remove live coral and reimplant it in other places that have been degraded, thus addressing the destruction of ecosystems and fishery production (Sadarun et al 1999; Prameliasari et al 2012). Another opinion suggests that coral transplantation is a rehabilitation technique carried out by planting corals with the fragmentation method, where coral seeds are taken from certain parent colonies and planted in various media or module models such as frames, poles, ropes, nets, and spider webs. In other aspects, some experts argue that transplantation is a method of planting and growing a coral colony in the form of fragments. However, generally, transplantation is carried out using the whole colony (Omori & Fujiwara 2004; Edwards 2010; Wijayanti et al 2015). Transplantation is widely regarded as a useful instrument for restoring damaged coral reef habitats (Rinkevich 2005; Edwards & Gomez 2008; Yap 2009). On the other hand, transplantation is considered successful if the structure of the habitat formed is similar to the structure that occurs naturally (Yap 2009). Coral transplantation is also a technique of increasing coral colonies by utilizing asexual reproduction through fragmentation. Several experts also use the term propagation as another word for coral transplantation (Munoz & Chagin 1977). It is hoped that coral transplantation could increase the recruitment of new corals in the recipient area, either by "seeding" from the surrounding area or through asexual and sexual reproduction (Edwards & Clark 1999; Gleason et al 2009; Shaish et al 2010a; Sebastian et al 2013). Transplantation is a model of a resilience-based approach aimed at overcoming the rate of coral reef degradation. This model is carried out by identifying and reducing the sources of damages to fuel the rapid recovery of coral reefs (McLeod et al 2019; Hein et al 2020; Ferse et al 2021). Recently, MPAs have improved four times in terms of protecting coral reef areas. Yet, this is not effective to reduce coral reef degradation (Rinkevich 2008). In contrast, the transplantation of corals, an ''active'' approach that has been employed as the primary management tool for reef restoration (Edwards & Clark 1999; Rinkevich 2005), is now regarded as one of the major conservation measures (Rinkevich 2008). Coral transplantation is useful in increasing biodiversity of the coastal areas serving as a tourist zone for diving, fishing and surfing, and creating new fishing and commercial opportunities. Colonial structures of fish and invertebrates in artificial coral reefs can have a significant economic impact, which may amount to several hundred million dollars per year. Coral transplantation will not be effective if the factors causing coral reef degradation are not addressed seriously or eliminated (Ammar et al 2013). Seen from the aspect of time, transplantation is a coral rehabilitation effort carried out for a long period of time, as it requires maintenance to yield maximum results. (Subhan et al 2014). A successful coral transplant will result in a healthy coral reef ecosystem that provides a place for foraging and acts as a shelter for marine organisms. In addition, a healthy coral reef ecosystem provides microhabitats to support biological and ecological processes, such as reproduction, recruitment, and protection of larvae from predators (Rani 2003).

Factors influencing the success and failure rate of coral transplantation. The success and failure of coral transplantation depend on factors related to the environment, waves, sedimentation, source and initial size of coral colony fragments, methods and media used, competing biota, treatment, management, the experience of executors/practitioners, and funding (Omori & Fujiwara 2004; Raymundo & Maypa 2004; Edwards & Gomez 2008; Baird 2005; Wijayanti et al 2015). Other factors that also determine the success of coral transplantation are the reproduction rate of coral fragments, the time of seed collection, and the minimum colony size for transplantation (Birkeland et al 1979; Plucer-Rosario & Randall 1987; Guzman 1991; Clark & Edwards

1995; Lindah 1998; Yap et al 1998; Ammar et al 2013; Bowden-Kerby 2001; Bruckner & Bruckner 2001; Epstein et al 2001; Guest et al 2011). Furthermore, other factors are the technical and design aspects as well as skills of the staff management, environmental aspect, involvement, support and awareness of the community, level of education and knowledge, as well as the aspect of periodic monitoring. These factors determine the success of transplantation (Ferse 2021). Several studies have suggested that transplantation activities cause or reduce fecundity or reduce the rate of gonadal development, even though the studies have only been conducted on a limited scale (Zakai et al 2000; Okubo et al 2007; Ammar et al 2013). Other studies suggest that if the environmental parameters of the donor site are the same as those of the recipient site, the success rate will be much better. On the other hand, if the environmental parameters are not the same, the success rate will be low (Auberson 1982; Marine Parks center of Japan 1995; Rex et al 1995; Palomar et al 2009; Ammar et al 2013). Other studies have also found that there are three main factors in the stabilization phase of the reef fragments that determine the success rate, namely (1) physical damage caused by waves/storm, (2) predators, and (3) competition for space with algae and other competitors such as sponges, bryozoans, tunicates and other competing biota (Franklin et al 2006; Bowden-Kerby 2009; Wells et al 2010; Young et al 2012). Regarding the placement of coral fragments, it is necessary to avoid areas with strong waves to reduce the level of physical damage (Johnson et al 2011). The loss and destruction of transplanted coral colonies due to waves also happened in Guam (Birkeland et al 1979; Plucer-Rosario & Randall 1987).The type of coral and the size of coral colony fragments also determine the success rate of coral transplantation (Yap et al 1992; Bowden-Kerby 1996; Bowden-Kerby 2009). Larger size coral fragments (>5 cm) will result in a higher growth rate or a high survival rate (Edward & Gomes 2008; Edwards 2010; Yong 2012; Ammar et al 2013; Wijayanti 2015). Coral colony fragments from aquariums and natural healthy coral fragments are recommended for coral transplantation to overcome degradation, preserve coral species, and avoid high mortality risk (Ammar 2001; Ammar et al 2013; Rojas et al 2008; Teplitski & Ritchie 2009; Shaish et al 2010b). The treatment factor determines the success rate of coral transplantation. Treated and untreated corals have different growth rates. Transplanted corals that are treated yield better results. Meanwhile, nubbins whose basal corallites are not treated have decreased size. Such phenomenon is related to the concentration of minerals like Ca^{2+}, Na^{-}, Mg^{2+}, CO_3^{2-}, Cl^{-}, OH^{-}, and HCO_3 (Ammar et al 2013). Systematic or routine treatment of transplanted corals is carried out every few months or intensively every 2-4 weeks. The treatment can reveal the issues experienced by transplanted corals and the causes of death or disturbance of the coral growth. Therefore, preventive action can be taken more quickly (Edwards & Gomez 2008). Ow & Todd (2010) stated that light is the main limiting factor of coral growth. In addition, the presence of symbiotic algae and a sedimentation rate of more than 100 mg cm^{-2} day^{-1} (Philipp & Fabricius 2003) causes a decline in the photosynthesis process. A sedimentation rate of 250 mg cm^2 day^{-1} can cause coral mortality (Cooper et al 2009). The size of a coral colony is an important determinant of coral survival, as it affects the rate of coral growth (Omori et al 2008). A small colony tends to be more susceptible to stress when injured at the beginning of the coral transplantation/planting process, as there is no recovery in this phase, which makes it more vulnerable to predators (Raymundo & Maypa 2004). The results of other studies also found that in diseases of *Acropora muricata*, there is a relatively higher abundance of pathogenic bacteria compared to coral species growing on basic substrates, especially massive corals. Bacteria greatly affect the survival of corals in coral transplantation activities (Jordan et al 2015). To ensure successful coral transplantation, the recipient site should have the same environmental conditions as the donor site (Edwards & Gomez 2008). The brightness and water quality of the recipient site should be comparable to the donor site. Furthermore, the nutrients, sediment, waste, temperature, depth, and current should be about the same (Edwards & Gomez 2008; Hofstede et al 2016). A recipient site is considered good if there is low stress from human activities (Shafir et al 2006), as corals transferred to different environments have a reduced survival rate (Plucer-Rosario & Randall 1987). In addition to factors related to environmental parameters, the aspect of ecologically healthy transplant management must be considered by monitoring survival rates, since the growth rate and health of transplanted corals are improved in conditions of reduced stress levels (Soong & Chen 2003; Abelson 2006; Edwards & Gomez 2008). Transplantation is an effort to rehabilitate corals for the long term. Thus, to get maximum results, treatment activities are essential (Subhan et al 2014).

Algae and competing biota in coral transplantation. Coral reef ecosystems are very fragile. Damage to coral reefs can reduce fishery productivity as it will affect the reproductive system, composition, and ability of the community to propagate (Grimsditch & Rodney 2006). Threats to coral reefs can be caused by anthropogenic and natural factors (Luthfi & Januarsa 2018). Anthropogenic threats can be derived from pollutants on land, which may cause eutrophication. Meanwhile, natural threats include waves, wind, storms, tsunamis, and others. The bioerosion process of several types of marine biota and the competition with organisms living in coral reef ecosystems are natural processes that can lead to the dominance of one species, which can disrupt the balance of an ecosystem (Birkeland & Lucas 1990). Algae is a benthic component eaten by herbivores that functions as a growth controller. Reduction in herbivorous fish due to overfishing and a high level of nutrient concentration will help the growth of algae, which in turn will compete for space with other benthic components. The interaction between corals and algae in competing for space and light results in one species' supremacy (Birkeland & Lucas 1990; Szmant 1997; McManus et al 2000; McCook et al 2001; Littler & Littler 2007; McClanahan et al 2011; Luthfi & Januarsa 2018). Due to its increased growth and predation ability, *Drupella* has the potential to dominate coral reef ecosystems. It poses a threat as the growth of algae causes the death of coral tissues and colonies (Cumming 1999). Results of studies conducted by several researchers showed that direct contact between mature algae and live corals caused tissue abrasion or erosion, individual or total coral mortality as well as it inhibited the upward growth of corals during the branching process (McCook et al 2001; Diaz-Pulido & McCook 2004; Quan-Young & Espinoza-Avalos 2006). Algal growth occurs on both dead and live corals (Jompa & McCook 2002; Reid et al 2012). Other studies have also found that algal populations tend to be resilient, thereby inhibiting the growth of mature corals (Birrell et al 2005; Kuffner et al 2006). High or excessive algal growth is one of the main problems and inhibiting factors for the success of coral restoration efforts, as it leads to low growth or high mortality rates (Yap & Molina 2003; Dizon & Yap 2006; Palomar et al 2009; Shaish et al 2010b; Yap et al 2011). When a coral dies, it will generally be covered by algae, regardless of the cause of death, whether from storms, bleaching, or the crown-of-thorns starfish. The growth and abundance of algae are the results of coral mortality. Competition between corals and algae will spread among benthic biota (Miller 1998; Mc Cook et al 2001). *Diadema*, a type of sea urchins, is an algae eater (Steneck & Dethier 1994). In the Caribbean and other areas, the presence of *Diadema* indicates a relatively high percentage of coral cover (Bellwood et al 2004; Mumby et al 2007). Manuputty et al (2006) suggest that the abundance of *Diadema* may signify the poor coral conditions in a location. In addition to algae and *Diadema*, there are other benthic biotas whose abundance also threatens coral reefs, namely (the crown-of-thorns starfish) and *Drupella*. Both of them are two types of benthic biota generally found in coral reef ecosystems. They act as natural competitors or predators as they both eat coral polyps (Pratchett 2001). Acanthaster planci can eat 5-6 m^2 coral polyps per year (Moran 1990). It poses a threat to coral reefs if there are 10-20 *Acanthaster planci* in an area of 1 m^2 (Supono & Arbi 2012). In addition to being a competitor and pest, *Acanthaster planci* also functions as a natural ecological controller, as it will prey on fast-growing coral polyps (Zamani 2015). The population explosion of *Acanthaster planci* and *Drupella* in some waters is caused by a decrease in fish populations and water quality (Reid et al 2012). Coral-eating predators, such as *Coralliophila abbreviata*, *Hermodice carunculata* and territorial damselfish, are also considered as the main causes of coral mortality. The majority of studies believe that the removal of predators to limit coral mortality during the seeding and coral planting phase is necessary (Hernandez-Delgado et al 2001; Miller et al 2010).

Types of corals commonly used in transplantation activities. The success of coral reef transplantation activities is largely determined by the technical and design aspects. However, it is also related to staff management; environmental aspect; involvement, support, and awareness of the community; level of education and knowledge; as well as the intensity of the monitoring of rehabilitation activities (Sebastian et al 2021). Technical aspects related to the selection of the right type and method in accordance with environmental conditions will determine the success rate of coral transplantation. Citing the results of a study by Sebastian et al (2021), out of 362 case studies on coral restoration, which comprises 221 scientific literature, 78 gray literature, and 63 responses to survey results of restoration projects in 56 countries, 59% studies that used branching corals showed a fast growth. Almost three-quarters of the studies or 72% used more than one type of coral, while 28% used one type of coral. Out of the 59% of studies using branching coral, 30% of them used the *Acropora* genus, and of that percentage, 9% used *Acropora cervicornis* (Anthony et al 2015; Goergen et al 2020; Westoby et al 2020; Sebastian et al 2021). The branching coral species are the primary choice in these studies, especially the Acroporidae family (Sadarun et al 1999). For the coral transplant research concerning the growth of hard corals in Malalayang, North Sulawesi, Indonesia, *Acropora* sp. and *Pocillopora damicornis* were used in several transplantation activities. Those were chosen due to their ability to adapt to the environment (Clark & Edward 1995; Prameliasari et al 2012). In general, the duration of the mucus secretion phase also become a subject of research. The observations result from a study by Kambey (2013) showed that the duration of mucus secretion in *Acropora austera* and *A. Hyacintus* is 3 days, in *Acropora tenuis* it is 3-4 days, in *A. formosa* and *A. nasuta* it is 4-5 days, and in *A. divarivata*, *A. yongei*, *A. aspera, A. digitifera* and *A. valida* it is 5 days (Richmond & Jokiel 1984; Clark & Edward 1995). The type of coral used in a study related to growth (measured as the linear extension) was *Pocillopora damicornis* (Kinzie & Sarmiento 1986). Clark & Edwards (1995) found that a significant radial extension of colony diameter was found in the genus *Acropora*. Edward & Gomez (2008) stated that massive, sub-massive, and laminar coral colonies are rarely used in transplantation activities even though they have a high tolerance for climate change. This is because those coral species generally have a slow growth rate (Veron 2000). Based on the results of a study related to a slightly undulating environment with relatively strong tidal currents, 3 out of 7 types of coral have a high growth rate, namely: *Pocillopora eydouxy*, *A. formosa*, and *Cyphastrea serailia* (Okubo et al 2007). It has been shown that *Acropora nobilis* and *A. formosa* showed a better growth at a depth of 3 meters, compared to 10 meters (Yarmanti 2001). Clark & Edwards (1995) studied the growth of 12 coral species, namely *Acropora cytherea*, *A. hyacinthus A. Divaricata*, and *Acropora humilis* (from the family *Acroporidae*), *Favia Sp*. and *Favites Sp*. (from family *Favidae*), *Pocillopora verrucosa* (from family P*ocilloporidae)*, and *Porites lobata, P. Lutea* and *P. Nigrescens* (from family *Poritidae).* Four out of the 12 species have fast growth, namely *Acropora cytherea*, *A. hyacinthus, A. divaricata,* and *Pocillopora verrucosa* (Nurcahyani 2018). According to a study on *Acropora secale* in Serangan Beach and Geger Beach, Bali Indonesia, it has a high growth rate and survival rate. Omori & Okubo (2004) created a list of coral species used for transplantation of coral fragments from 1982-2000, which was obtained from the results of a literature review. The list includes 71 coral species from 23 genera and 12 families. The list is dominated by the family *Acroporidae* with 26 species, followed by the family *Favidae* with 15 species.

Method and media. The coral transplantation technology was introduced by ecologists in 1975 (Lindahl 1998). The coral transplantation methods and techniques continue to develop and vary. According to Subhan et al (2014) and Saputra (2020), the determination of the techniques and methods used should be based on local conditions, costs, availability of materials, resources, and the objectives to be achieved. The development and improvement of coral transplantation methods continue to be carried out to achieve both spatial and temporal enhancement. One of the biggest driving factors is climate change. Thus, many restoration projects tried to overcome it by planting coral species that are resistant to changes in temperature using various media and methods

(Edwards & Clark 1999). Based on the results of 20 literature reviews, it can be seen that there are approximately 5 methods and media of coral transplantation used in all kinds of forms. The methods and media are as follows:

Concrete conblock media. Concrete conblocks are made from a mixture of cement. They are made in various forms and sizes, such as resembling a multi-story pyramid with 4 levels, where the distance between the levels is 30 cm. The planting media is placed on the base (Prayoga et al 2019). The concrete conblock developed by Hermanto (2015) was created by molding substrates from a mixture of cement and PVC pipes to bind coral fragments. Taufina et al (2018) created conblock in the form of a cube with a size of 60 x 60 x 10 cm. There are holes on each side of the cube, and 4 PVC pipes are placed on top for coral fragments to attach. Rahmania (2016) used a concrete conblock as a substrate of coral reefs. The conblock was made of cement and sands with a size of 50 x 70 x 60 cm. PVC pipes were also used to bind coral fragments, Ramses et al (2019) developed a rectangular concrete conblock that was placed directly on the coral substrate as they believed that cement media is known to be very good for coral growth (Harriot & Fisk 1987). Saputra (2020) found indications of optimal attachment of juvenile coral to andesite stone and concrete blocks with a rough and hard surface.

Rack method and media with several modifications. The rack media, used as a table for substrate or a base for planting media, is created in several different types and sizes as well as with different materials. Mustahal & Rahmawati (2011) made a concrete iron rack with a size of 1 x 1 m, as a table for transplantation and planting media from a mixture of sand and cement. Prameliasari (2012) and Nurcahyani (2018) developed a square transplantation rack made of iron with a size of 2 x 1 x 0.5 m, as a base for the substrate made of cement. Haris et al (2017) created a rack from iron bars with a size of 120 x 80 cm. Wire mesh with a size of 120 x 80 cm was used as a base for substrate or square planting media with a diameter of 7-8 cm and a height of 2-3 cm. As a base for substrate, Efendi et al (2020) used an iron rack made of a mixture of sand and cement with a diameter of 10 cm and a thickness of 5 cm. They also planted poles made from ¾ inch PVC pipes with a height of 20 cm. The poles were used to bind coral fragments. Olii et al (2021) developed a spiderweb-like planting medium, adopted from Willam et al (2019). Meanwhile, Iqbal et al (2021) developed a rack whose base for planting media was made from nets. Aziz et al (2011) and Saputra (2020) used Hexadome Coral as a transplantation medium. This method facilitates the process of natural coral growth. It was observed that a considerable number of corals were attached naturally. Saputra (2020) developed a medium made of iron bars assembled to resemble a table with a size of 100 cm x 100 cm. The medium was covered with 6 mm of woven concrete metal. The medium served as a base for a substrate made of a mixture of cement and sand. The size of the substrate was 10 cm with a thickness of 5 cm, 3/4-inch PVC pipe with a height of 20 cm was placed in the middle of the substrate, to bind coral fragments.

Off-bottom method and floating method. Like the development of the rack method and media, the off-bottom method has also been developed in various ways. Kambey (2013) planted coral fragments directly in dead coral areas by looking for natural holes or creating new holes. The holes that will be planted were cleaned. After that, coral fragments were planted and hardened with epoxy glue. Coral transplantation was carried out at a depth of 3, 6, and 9 m. Tafina et al (2018) placed a media in the form of a concrete cube with a size of 60 x 60 x 10 cm. Then, they made a pyramid-shaped configuration that was also used as a dwelling by fish. Edwards & Gomes (2008) developed a concrete conblock with a size of 1 x 1 m. Each side was hollowed for water and oxygen circulation. It also served as a habitat for fish and other organisms. The hexadome coral is an effective method and medium for coral transplantation. It is prepared at the seabed to form a strong and stable coral reef cluster. Aziz et al (2011) found that many juvenile corals take the form of a hollow dome, which served as a habitat for coral reefs and various marine biota. Fujiwara (2004) discovered that hollow media with many pores is very easy for coral larvae to attach to. Hexadome coral also has a direct positive impact on the existence of phytoplankton, algae, and other aquatic plants serving as oxygen producers for the lungs of the earth (Saputra 2020). Reef fragments are directly attached to the seabed substrate and then covered with nets so that they do not get swept by the current (Subhan et al 2014; Gomez et al 2010). The bioreeftek media is primarily made of coconut shells. This media is considered to be a growing medium for coral larvae, as corals need other organisms as a source of nutrients, especially aquatic microorganisms. Therefore, the presence of coconut shells can increase the population of microorganisms in the water column (Saputra 2020). The concept of the floating method is planting coral fragments without touching the base. The media used can be in the form of PVC pipe, steel wire, and fishing line (monofilament) (Gomz et al 2014). The hang and attach planting method was developed by Yunus et al (2013), where coral fragments are tied with cable ties on a small rope with a diameter of ±7.5 mm. In this method, the installation on a rectangular transplantation rack with a size of 1 x 2 x 1 m is optimal. This is because sedimentation will have a negligible impact on coral growth as the construction of the media allows the process of sediment particle cleaning to run well.

Biorock method. The Biorock method is one of the most widely used coral reef rehabilitation methods to accelerate coral growth in damaged areas and restore coral reef habitats (Saputra 2020). The Biorock method was developed by Prof. Wolf Hilbertz & Dr. Thomas J. Goreau. Biorock technology uses a low electric voltage (direct current) of 1.2 Volts. The Biorock process is also referred to as an electrolysis process that occurs between two electrified steel rods that are placed in seawater, enabling the mineral accretion process, which causes minerals dissolved in seawater to crystallize above the structure and grow to form white limestone similar to the structure that forms coral reefs naturally. There are several alternative sources of electricity used to run this system, such as solar cells, tidal power plants, generators, batteries or household electricity. The power used is 1-24 Volts of DC current. Some studies used a voltage of 6-12 Volts. The density used to produce the best results is about 3 amperes on the cathode surface (Furqan 2009; Sabater & Yap 2002) experimentally investigated the effects of linear electrochemical deposition of $CaCO_3$ on the growth, survival, and skeletal structure of *Porites cylindrica*. The underwater transplantation of coral nubbins with 18 volts of electrical current and 4.16 A of direct current to induce dissolved mineral deposits went well.

Ideal fragment sizes for transplantation activities. Standardization of coral fragment size in transplantation activities related to length, width, height, and the number of branches is one of the requirements for measuring the success of coral transplantation. However, in practice, this is often ignored. Several researchers recommend a larger fragment size to reduce the mortality rate (Okubo et al 2005; Forsman et al 2006). The survival advantage applies to sizes ranging from 1 mm to 10 cm. Several studies have also shown that fragments whose size is above 10 cm have a better success rate (Edwards 2010). In a study conducted by Okubo et al (2005), it was found that *A. formosa* fragments with a height of 20 cm showed a high survival rate (100%), while fragments with a size of 5 cm had a success rate of 29.0%. Predators and competing biota are potential inhibiting factors that also determine the success rate of transplantation (Epstein et al 2001; Shafir et al 2001, 2003, 2006; Vijayavel & Richmond 2012; Shafir & Rinkevich 2013). Larger specimen sizes are better suited to tolerate algal competition and are able to withstand predators and sedimentation effects (Epstein et al 2001; Okubo et al 2005; Latypov 2006; Lirman et al 2010). In the Caribbean, Lirman et al (2010) observed that the mortality rate of *Acropora cervicornis* with a small branch size of 2.5 cm was 87%, while those with a fragment branch size >3.5 cm had a mortality rate of only 13%. A larger fragment size will prevent disengagement from the substrate due to hydrodynamic forces, currents and waves (Shafir & Rinkevich 2013). Another thing that needs to be considered in restoration activities is the collection of coral fragments in the donor area. The collection of fragments of more than 10% of donor colony branches will increase stress and cause the risk of death of the entire colony. In addition, it will also reduce the level of coral fecundity. Such phenomena occurred during the observation on *Stylophora pistillata* (Lirman et al 2010).

Limiting factors of coral growth. Physical, chemical, and biological factors that limit the existence and growth of coral reefs, are water temperature, sunlight (depth), salinity, water clarity, dissolved oxygen, substrate (base) condition, and predation (Barnes 1980; Nybakken 1992; Berwick 1983). If the environmental parameters of the donor site are the same as the recipient site, then the success rate is better (Auberson 1982; Marine Undersea Park Center 1993, 1994, 1995). The general conditions of environmental parameters greatly affect coral growth. High brightness is supported by small waves and slow wind speeds. Brightness is related to sunlight penetration, which in turn is related to the process of photosynthesis of zooxanthellae, that needs sunlight. Without sufficient sun, the formation of calcium carbonate will decline (Dahuri 2003). Temperature affects coral growth: an increase in temperature of even one or two degrees can affect the concentration of Zooxanthellae in coral tissue. If the increase in temperature is too high, the coral tissue will shrink and the Zooxanthellae will come out. As such, the photosynthesis process will not occur, and in the long term, the coral will die. The effect of temperature change will also result in a decreased response to the feeding process. Besides, it will decrease reproduction, result in excessive mucus secretion by corals, and reduce the rate of photosynthesis/respiration process (Brown & Bytell 2005). Warm water temperature will increase coral mortality (Yap & Gomez 1984). An increase and decrease in temperature can result in stress on corals. An increase in temperature of 0.5°C in subtropical areas can cause coral bleaching and expel the symbiotic algae found in coral colonies (Wilkinson 2008). The increase in sea surface temperature occurs due to the El Niño process. According to Arman et al (2013), the increase in temperature in the Caribbean region caused by sea-level anomalies occurred in 1983-2000. Coral bleaching can transpire due to temperature changes (Dedi et al 2016). Salinity has a significant effect on coral growth. The suitable salinity range for coral growth is 25-40‰. According to Eliza (1992), the ideal salinity for coral growth and development ranges from 25-40‰. Sudiarta (1995) stated that corals have a salinity tolerance ranging from 27-40‰. The Ministry of Environment (KLH) (2004) established a natural salinity of 33-34‰ for coral reefs. Changes <5% are allowed. Nontji (2002) revealed that salinity in the sea is influenced by various factors, such as patterns of water circulation, evaporation, rainfall, and river flow. Banjarnahor (2000) stated that differences in seawater salinity could be caused by a mixing, which in turn is caused by ocean waves or water mass movement due to wind. Another factor that also affects coral growth is sunlight. Zooxanthellae require sufficient sunlight to carry out photosynthesis (Rani et al 2004). Without enough light, the rate of photosynthesis will decrease, which will reduce the ability of corals to produce calcium carbonate and form reefs. The decrease of light that penetrates the waters can be caused by sedimentation, depth, and rise of sea level. Based on a study conducted by Kuhl et al (1995), the light waves required by zooxanthellae for photosynthesis are in the range of 550-600 nm. Fachrurrozie et al (2012) conducted a study on the effect of differences in light intensity on the abundance of zooxanthellae on branching corals using a linear regression test. The results have a positive correlation with the value of $Y = 11664.693\ X + 551857.923$. This shows that the abundance of zooxanthellae is directly proportional to the increase in light intensity.The depth of the waters is closely related to variations in the pH of seawater, which can be used to identify seawater quality. The pH in normal waters ranges from 8.0 to 8.3. According to Salm (1984), the pH in waters is influenced by various factors. Rainfall, terrestrial influences, and the oxidation process can cause a low pH (Edward & Tarigan 2003). The pH parameter for coral growth can generally be above 7-8.5, which is the tolerance limit for organisms. If the pH is less than 7, the acidity of seawater can affect the presence of phytoplankton associated with corals and other marine plants (Moira et al 2020; Ministry of Environment 2004). Dissolved oxygen (DO) is an important parameter of seawater chemical systems and marine biological processes, as dissolved oxygen is needed in the bacterial decomposition process to decompose organic matter. The decrease in dissolved oxygen will also affect coral life through the respiration process and oxidation-reduction reactions of chemical compounds in water. According to Romimohtarto & Thayib (1982), dissolved oxygen is one of the limiting factors for coral life. Changes in dissolved oxygen concentration have a direct effect on coral mortality, as dissolved oxygen is needed for metabolic processes within the body as well as for reproductive processes. According to Da'i (1991), oxygen levels in Nanwan Bay, Taiwan, where coral reefs grow and develop well ranged from 4.27-7.14 mg L^{-1}. In short, environmental parameters, both environmental changes as well as the duration and level of environmental disturbances, greatly affect coral ecosystems. A prolonged disturbance will cause partial or complete mortality of not only individual colonies but also coral reefs in general (Coles & Brown 2003).

Conclusions. Coral transplantation activities in various areas continue to be improved, as a form of concern for the increasing coral damage or degradation caused by development activities, the increasing economic needs of coastal communities that depend on marine resources, and exploitation of marine resources by entrepreneurs in the fisheries sector using non-environmentally friendly fishing equipment. Damage to coral reefs is also caused by natural factors such as waves, storms, rain, and high sedimentation in the sea. Therefore, based on the results of the review, several important points for transplantation activities to be carried out in the future for preventing damage to coral reefs are:

1. Protecting and maintaining the remaining coral reefs is more important than carrying out coral reef restoration activities, as such activities will take time, money, and effort.
2. Transplantation activities should be conducted by beginning with a study related to the percentage of coral cover, both for the recipient and donor sites, to the environmental parameters and to the willingness of the community to participate in transplantation activities.
3. The success rate of transplantation activities will be largely determined by the objectives to be achieved, cost-related planning, location, time, methods, human resources, as well as monitoring and treatment plans.
4. It is necessary to conduct training by experts so that the human resources who will participate will have the same standard of knowledge.
5. Creating an SOP or activity guideline as a guide and evaluation tool for all activities starting from planning, processing, and final evaluation is necessary.
6. Transplantation activities need to be published in scientific journals, as semi-popular articles, or in printed and electronic media so that they become public knowledge. Such publications will greatly assist the transfer of knowledge process and raising awareness on maintaining the sustainability of the coral reef ecosystem for future generations.

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