Tampere University of Applied Sciences

The status of coral reefs in Vietnam sea region: Compare commercial & traditional transplantation methods to coral rehabilitation

Base on case studies in Okinawa (Japan) and Nha Trang bay (Vietnam)

Chi Pham Lan

BACHELOR'S THESIS

September 2021

Environmental Engineering

ABSTRACT

Tampereen ammattikorkeakoulu
Tampere University of Applied Sciences
Environmental Engineering

CHI PHAM LAN:
The Status of Coral Reefs in Vietnam Sea Region: Comparison commercial & traditional transplantation methods to coral rehabilitation
Based on case studies in Okinawa (Japan) and Nha Trang bay (Vietnam)

Bachelor's thesis 30 pages, 1 appendices page
September 2021

In recent years, with the rapid development of technology and industry, the modernization and industrialization of people have greatly affected the natural living environment. As a result, environmental and climate conditions are changing markedly, which is gradually becoming the most noticeable issue today. Many environmental changes are causing people to look back: The coral reefs in the world are disappearing. The disappearance of coral reefs leads to consequences affecting the ecosystem. In an effort to restore the coral reefs, many transplantation method have been applied. The main purpose of this thesis is to create a literature review and conduct a comparison between two coral transplantation methods: the traditional and the commercial way. By analyzing the two case studies in Nha Trang bay (Vietnam) and Okinawa (Japan), the comparison was made based on a SWOT analysis and 4 different criteria: Effectiveness, Time efficiency, Cost and Social impact.

The results that the traditional transplantation method has outstanding performance in effectiveness since the research base provides it an opportunity to track and modify the condition for coral fragments. However, with three other criteria, the commercial way has proved its great progress in time efficiency, cost effectiveness and high social impact.

In conclusion, these two transplantation methods with different in operation and funding ways have both pros and cons. Nevertheless, the commercial transplantation method has proved to be feasible as a coral restoration solution for a sustainable future. Although commercializing coral transplantation in Vietnam sea region is promising, there are many challenges that need to be identified and resolved, especially in manging the private associations from exploiting coral and educating people in coral protection. For further understanding and improvement of commercial transplantation, extra experiences and studied need to be conducted in the future.

Key words: coral reefs, transplantation, coral rehabilitation

CONTENTS

ABBREVIATIONS AND TERMS

GNP	Gross National Product
FIF	Flat Iron Frame (method)
CSR	Corporate Social Responsibility
APTs	Artificially Produced coral Transplants
MPA	Marine Protected Area
SWOT	Strengths, Weaknesses, Opportunities, Threats
NGOs	Non-governmental organizations
ENSO	El Niño–Southern Oscillation

1 INTRODUCTION

The primary purpose of the thesis is to compare different transplantation methods in coral reefs rehabilitation, which are traditional transplantation and commercial transplantation. The thesis is an applied study as it is based on the actual knowledge of the related research results, books and scientific reports to examine the cost-effectiveness and sustainable coral reefs transplantation method. Analysis and improvements of coral reefs transplantation or combination of two methods will be discussed.

Furthermore, by analyzing the actual case studies in Okahoma and Nha Trang bay that use these two transplantation methods, another objective of the thesis is to examine the local adaptability and feasibility of commercial transplantation methods in Vietnam sea region, evaluate the pros and cons and conclude what can be done and improved for further development.

2 THEORY

2.1 Coral Reefs

Despite being animals, coral reefs are often mistaken for shaped rocks or plants. They are large underwater structured masses composed of skeletons of colonial marine invertebrates called coral. Each individual coral is known as a polyp. Coral polyps live on the exoskeleton of their own ancestors, adding their own exoskeleton to the existing coral structure.

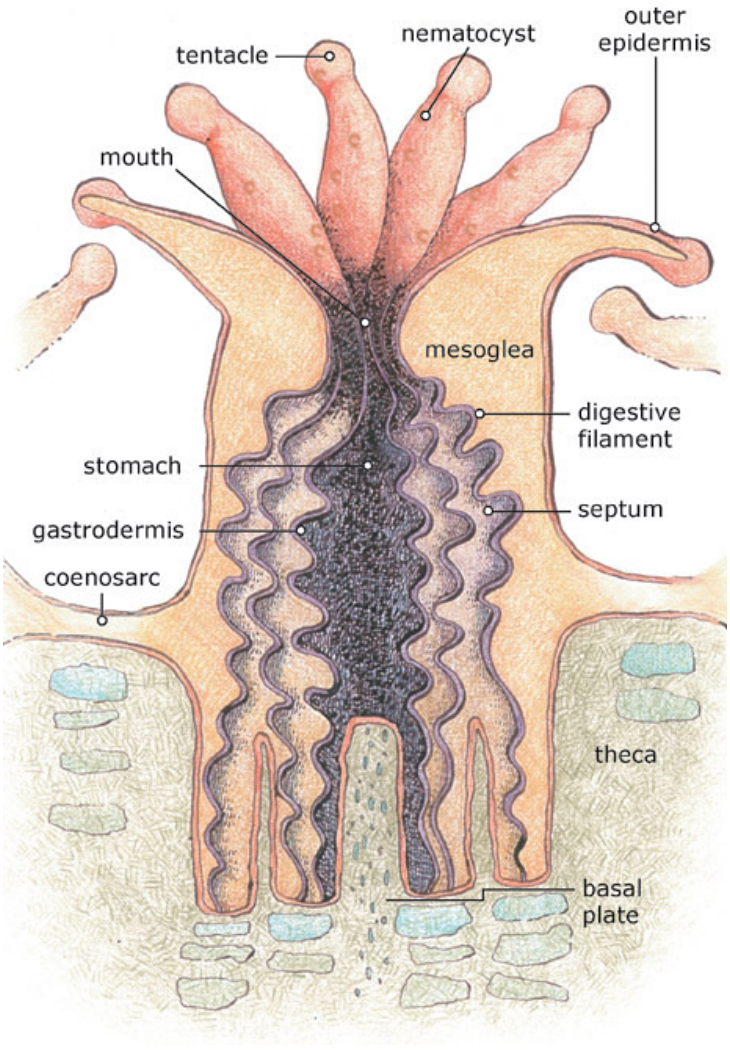


FIGURE 1. Anatomy of coral polyp (Source: Wikipedia)

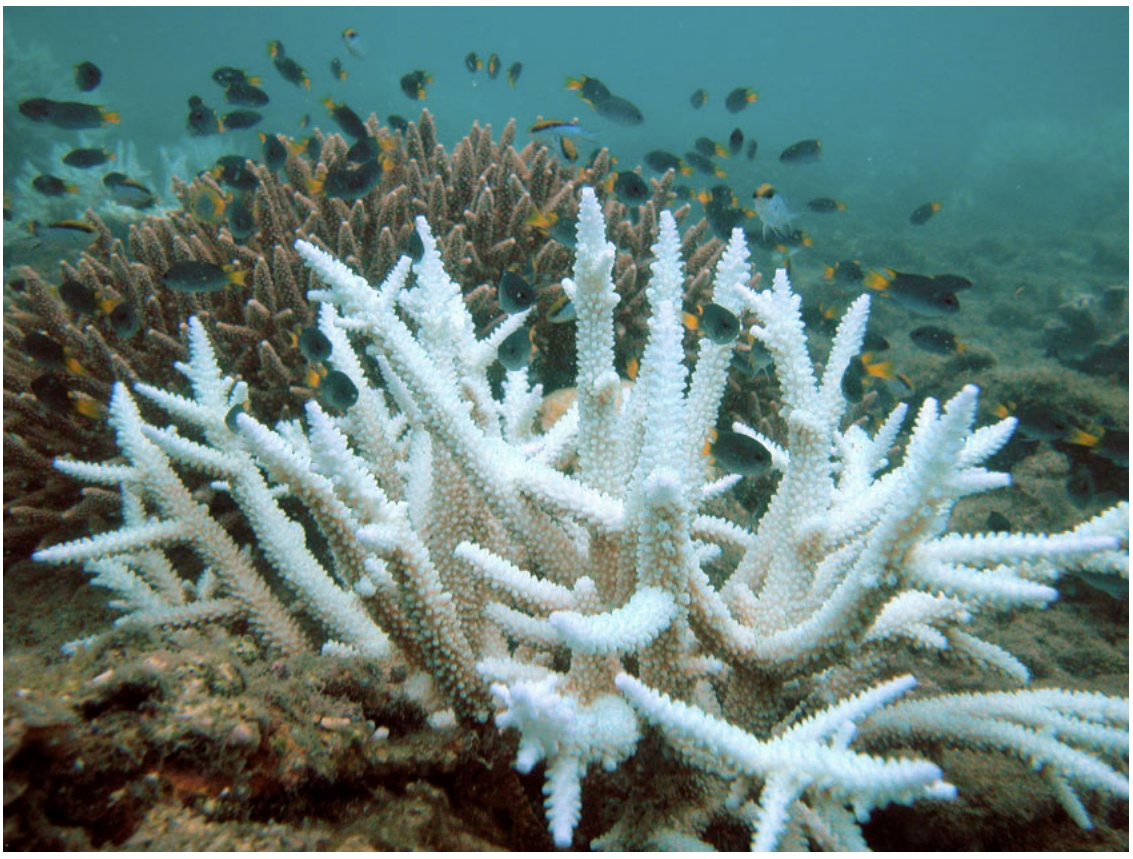
There are two types of coral, soft coral and hard coral. Whereas soft corals are not involved in the process of reef building, hard corals extract calcium carbonates from seawater and contribute to the construction of coral reefs by forming thick composition which is known as colonies.

Even though the entire of coral species can consume taken prey with their stinging tentacles, most corals in tropical region acquire the majority of their nutritions from an exceptional symbiosis. There are thousands of microscopic algae named zooxanthellae that photosynthesize sunlight for energy (Burke, L., Selig, E. & Spalding, M. 2002). In exchange for energy, coral provides zooxanthellae with protection from their predators. This coexisting relationship is tremendously effective which allows corals to continue to live and thrive even in waters with lack of necessary nutrient. Coral reefs in good condition are considered as the most biodiversity source of all known marine ecosystems than any other ecosystem on the planet with a vast number of life forms. Coral reefs thrive in the shallow waters of tropical seas with optimum temperatures between 26°C and 27°C. Coral reefs are considered the most productive ecosystems in the world. They cover about 0.1% of the earth's surface, but fisheries directly or indirectly related to coral reefs are estimated to account for about 10% of the world's fisheries production (Vo, T. et al. 2018).

Southeast Asia is the center of this amazing diversification, making up more than 77 percent of the total 800 species of reef-building corals that have been discovered. In Southeast Asia, the history between human and coral reef ecosystem have lasted for many centuries. Coral reefs play a crucial role in both the local communities' cultures and the economies of the region. Coral reef fisheries bring an invaluable source of nutrition and commercial benefit. The fishing industry generates billions of dollars each year through live fish trade, ornamental aquatic trade and regional subsistence economies. It is estimated that the sustainable coral reef fisheries bring US$ 2.4 billions for the Southeast Asia region per year. Not only do coral reefs bring natural resources for fishery, and are attractions for the travel industry, coral reef formations also act as natural breakwaters, which reduce the impact of waves from storms such as cyclones, hurricanes or typhoons, preventing catastrophes to both human and nations alike. Corals also hide within themselves an immeasurable amount of biochemical material for pharmaceuticals and other products (Cooper, et al. 2014). Many marine species live in habitat creating by coral structures. Moreover, corals also act as a shield to the shoreline from erosion (Burke, L., Selig, E. & Spalding, M. 2002).

2.2 Coral Bleaching Phenomenon

Coral bleaching is defined as a state where some or all of their symbiotic zooxanthellae and photosynthetic pigments are kept away from the coral, resulting in their skeleton becoming apparent through the translucent tissue layer. It is a common phenomenon that has happen in the recent decades, resulting from a series of environmental pollution events (e.g., low salt level in seawater, unusual water temperature, pollution).



PICTURE 1. Bleach coral with normal coral in the background (Source: Wikipedia)

In the earlier days, only small scales of this phenomena were detected due to localized stresses. From the 80s onwards, coral bleaching has been related to the effect of global warming due to human activities. It happens on substantial scales and has frequency increasing at an alarming rate, where the entire reef systems are affected. Noticeable events have happened at the Great Barrier Reef, Australia (2002), the Caribbean (2005) and Western Australian reefs (2011). The world had witnessed a global-scale coral bleaching event that

damaged coral reefs in 1997-1998, which happened again in 2010 and from 2014 to 2017. Some regions such as Hawaii and the Great Barrier Reef have gone through ongoing years of coral bleaching with an alarming rate (van Oppen & Lough. 2009).

2.3 The status of coral reefs in Vietnam

Vietnam has a long coastline that stretches along the length of the country, crossing more than 15° of latitudinal variation. Over 300 species of hard corals have been discovered in Vietnamese sea regions. In the south, reefs possess the most diverse characteristic, with 277 species of coral that constitute fringing as well as platform reefs. In the north, fringing reefs generally have low diversity level with only 165 species. It is estimated that 1100 square kilometers of coral reefs are coming up against varieties of threats, especially in dense human-inhabited areas.

In Vietnam's seas, there are approximately 500 species of identified coral reef fish. In Truong Sa (Spratly) islands, the reef fish biomass was estimated at 114 tons per square kilometer, equivalent to US$ 78,000-105,000 per square kilometer of reef (Vo and Nguyen [26]). Apart from fish, coral reefs are also home to many other high economic value species such as crustaceans, mollusks, sea urchins, abalone, pearl, sea cucumber, etc. The fishing methods are diverse, including hooks and lines, gill net or diving. Vietnam is well known for traditional marine fisheries, with many local communities counts on resources provided by coral reefs to make a living. In recent years, population increases, lower income of small-scale fishers and the appearance of illegal, foreign harvesters from China and Hong Kong have had a great impact on marine fisheries. In present days, coral reefs of central Vietnam are being negatively affected and degraded. According to research conducted in 1999, overfishing and marine resources declines are the main contribution factors to the bleaching of many coral reefs along the coastline of Vietnam.

Like many other coral reefs in the coastal area of Vietnam and other countries in the world, they also share similar benefits, such as possessing medicinal materials, providing material for handicraft, boosting tourism, and especially for a

tropical country that focusing on exporting food, coral reefs have brought a variety of different marine species. Marine species with aesthetic values are exploited and sold to tourists. The affected species are: snails with beautiful shapes, puffer fish, lobsters, green sea turtle, Hawksbill sea turtle etc. Due to high demands from tourists for handicrafts and souvenirs, many of the species are becoming endangered and even in risk of extinction.

Mekong and Red rivers depositing sediments throughout the country is the main pressure on Vietnam's reefs. Coastal development only adds more to this pressure. Algal blooms have been discovered nearby Binh Thuan province, Khanh Hoa province, and Ho Chi Minh City along with marine pollution in the northern areas of Hai Phong and Quang Ninh. It has witnessed a slow acceleration in rehabilitation process from the destruction caused by the El Niño–Southern Oscillation (ENSO) event from 1997 to 1998. Due to the adversely impact from human activities and coral bleaching, there is a decreasing trend in coral coverage, and the coral loss caused by sedimentation in Ha Long bay and Cat Ba island, with the exception of reefs around Binh Thuan. Coral bleaching also leads to a decrease in marine resource diversification, especially among butterfly fishes.

PICTURE 2. Damaged coral reefs in Nha Trang bay in 2019 (Source: Konstantin Tkachenko)

Surveys done between 1994 and 1997 from more than 142 sites presented a harsh reality. The amount of coral reefs in Vietnam that are in healthy condition is only 1% (with more than 75% of live coral coverage). Of the remaining coral coverage, 41% were discovered to be in acceptable state (with 25-50 percent coral coverage), and 31% in poor state (with under 25% coral coverage).

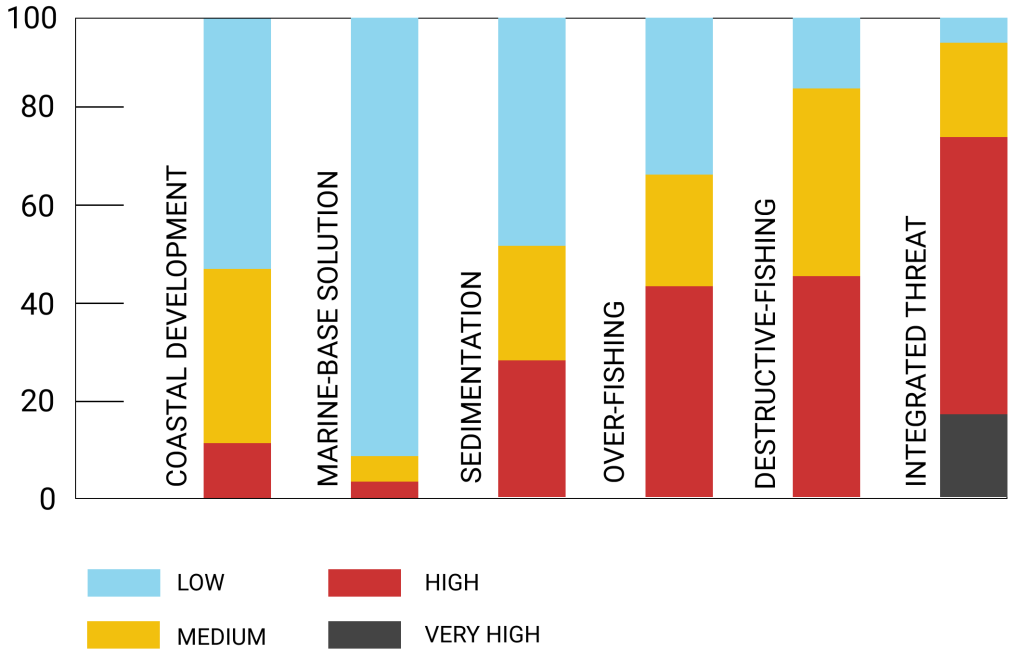


FIGURE 2. Reefs at risk in Vietnam (Source: Burke, Selig & Spalding 2002)

Destructive fishing is the main factor that causes damage for coral ecosystems, which causes 85% of the reefs at medium or higher threat. Overfishing is the biggest factor, estimated to put 60% of coral reefs in Vietnam in danger. It is followed by sedimentation, which accounted for 50% of the country's reefs threats. Other factor is coastal development, which is the threat for 40% of the reefs (Figure 2).

Fisheries and tourism are the two national strategic schemes that are focus on when Vietnam clarifying the problems. Contributing estimatedly 6% of Gross National Product (GNP) in 2000, tourism is expected to increase to 12 % by 2010.

Sustainable tourism is expected to develop in Vietnam in the near future, especially in Con Dao, Ha Long bay National Park and Cat Ba, through land planning and formation of natural reserves and classified area. Although Vietnam has 20 Marine-Protected Areas (MPAs), only 3 of them have coral reefs. Thus, with the additional proposal suggests adding 30 MPA, the reefs-protected areas are expected to grow from 1528 hectare to 3118 hectare (Burke, Selig & Spalding 2002).

2.4 Transplantation methods

2.4.1 Traditional transplantation

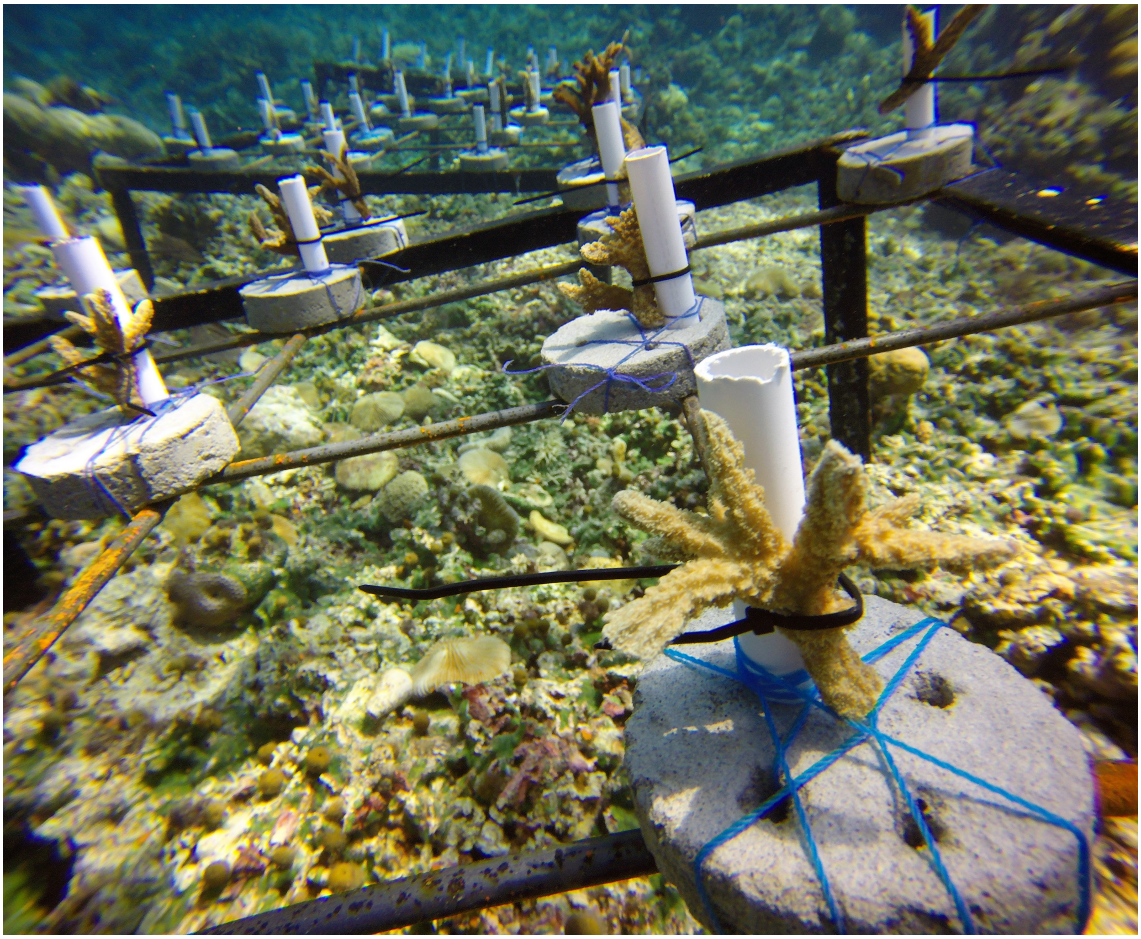
Coral transplantation is a method where the coral is moved from a hostile environment to a more favorable one. This method has been used in coral rehabilitation for several decades (Ferse, Hein & Rölfer 2021). Improving the quality of live coral reefs is the main purpose of coral transplantation. Therefore, this method is often applied for live coral in danger of eradication or in an attempt to rebuild a damaged site by relocating coral from an undamaged site to the site that needs help.

There are two sources of transplant: Corals of opportunity and corals from donor colonies. “Corals of opportunity” are parts cut off from their colonies due to natural causes, such as storms, fish, etc., and usually found in the seabed. These fragments are hard to survive alone; thus their survival possibility can be increased significantly by attaching them to healthy coral colonies. Another type of coral of opportunity is the eroded coral colonies which are already detached and grow with unnatural size. The rescuing method applied for them is to eliminate the dead and unhealthy parts, be nurtured in nurseries before being transplanted in the rehabilitation site. The second transplant source is corals from donor colonies, which are always cut out by hammers and chisels carefully to prevent the donor colonies from being dislodged or causing large wounds that can become a place for algae and boring sponges. After that, these fragments are instantly put into the seawater for transplantation. When applying this method, transplant material collecting activity should not unfavorably impact the

generative ability or the survive ability of colonies in the source reef (Edwards 2010).

Choosing the coral species for the restoration project is crucial for the whole project's success. The species that live in restoration site or fairly prevailing on nearby the promising source reefs are the most reasonable choice in terms of coral species selection. Applying this method can eliminate a lot of guesswork as to whether the coral would be able to adapt to its surroundings in the restoration site. Nevertheless, the selected corals that share the same species but differ in the living condition, such as depth, can not be completely adjusted to the rehabilitation site. Therefore, to ensure the adaptability and survival of transplanted corals, not only the species should be considered, but also the analogous level of the surrounding environment should be kept as high as possible.

There are several transplantation methods that can be used in coral rehabilitation: flat iron frame, thread hanging, plastic net and cement table (Zhang et al. 2016). However, in this thesis, we will focus on the method that was used in a case study at Nha Trang bay: Flat iron frame (FIF) method. In this method, the iron frames are placed and nailed onto the bottom of the sea as a form of a fishing net. The coral fragments are settled by cable ties on each FIF. The distance between each fragment is defined case by case, which often range from 20 to 30cm (Zhang et al. 2016). Usually, the time to decide whether the coral branch after transplanting is successful or not is in the first 2-3 weeks. If it is not strong enough to survive, the coral branch will change color and then die. However, the time for a coral fragment to continue to grow and regenerate into a new coral cluster is very long. The average time for a coral branch to live and grow on the substrate at the nursery is about two years. During this time, the technical staff must check them regularly. After two years, the healthy coral fragments are removed from the nursery site and are planted permanently in the damaged coral reefs. The time for the coral individuals to take root and officially become a new "resident" in the seabed takes about three more years.



PICTURE 3. Flat iron frame with coral fragments. (Source: commons.wikimedia.org/)

2.4.2 Commercial transplantation

Since transplantation is considered an expensive method, there is another way to reduce the cost, even bring more economic benefits: commercial transplantation. While this method is not popular, it was applied in several regions, and in this thesis, we will focus on the case study on Okinawa, Japan. In Okinawa, the transplantation is commercially carrying out rehabilitation, where tourist divers and the associations operating Corporate Social Responsibility (CSR) are responsible for the transplantation expense. Based on ecotourism model, a transplantation method was developed with a commercial direction, in which a diving tour is established where tourist divers are the ones who conduct services to transplant coral fragments on the seabed voluntarily as there is no financial compensation for them to do the transplantation work.

3 METHOD

3.1 Method and Scope of work

The thesis is written as a literature review, which is a search and assessment of scholarly information through books and scientific journals. All the information related to the topic was gathered and critically analyzed to answer the main research question of the thesis: Which method between the traditional and commercial coral transplantation is more optimal for Vietnamese sea region. The data sources of all the information that has been used in this thesis come from various search engines, such as ScienceDirect, TuniLib (Library of Tampere University), and Google Scholar.

The project's scope covers the use of traditional and commercial transplantation methods, benefits, and potential applications in Vietnam sea regions. Although coral transplantation is applied for several decades, the commercial approach has not yet been popular and utilized widely as well as is still a controversial topic; the examination and comparison of these two methods for coral restoration will be discussed based on the particular case studies that are researched, conducted, and established in the world.

3.2 SWOT analysis

SWOT stands for “Strengths, Weaknesses, Opportunities, Threats.” It is an analytical tool for evaluating the strengths and weaknesses of a matter, determining the opportunities it might have and threats it can confront. Although this tool is usually used in business, the popularity and efficiency of SWOT has made it a widely-used method in different areas. SWOT has two aspects: internal (strengths & weaknesses) and external (opportunities & threats). Since this method is mostly used for strategic planning, we can determine the strengths and opportunities that the matter has to reach the goals and be aware of the weaknesses as well as the challenges that the stakeholders might face and prevent from the undesirable results (SWOT analysis. ScienceDirect).

3.3 Evaluation criteria

3.3.1 Effectiveness

Considering the effectiveness of the transplantation method, the process efficiency is the most critical aspect, including operational efficiency, coral growth rate, and survival rate. Furthermore, the external factors such as weather, water temperature, etc., that can impact the whole process also need to be examined. Finally, scalability is another factor covered in this thesis: is there any limit when applying these transplantation methods on a global scale, or do they need any special requirements for the location.

3.3.2 Time efficiency

When it comes to time efficiency, the time for setting up a project and for the corals to be fully adaptable with their new colonies will be identified and compared between two transplantation methods.

3.3.3 Cost

The cost analysis must be taken into account since it is a crucial practical aspect of every project. It is a decisive factor when considering the scalability of the method and its attractiveness to investors. This cost includes the setting up and operation cost as well as the maintenance and development costs.

3.3.4 Social impact

Raising awareness about saving the coral reefs' ecosystem is a critical mission that we cannot overlook. The higher level of the social impact is, the more attractive and efficiency the method is. Which method can promote environmental awareness better will be examined in the thesis.

4 ANALYSIS OF CASE STUDIES

4.1 Traditional transplantation: case study in Nha Trang bay, Vietnam

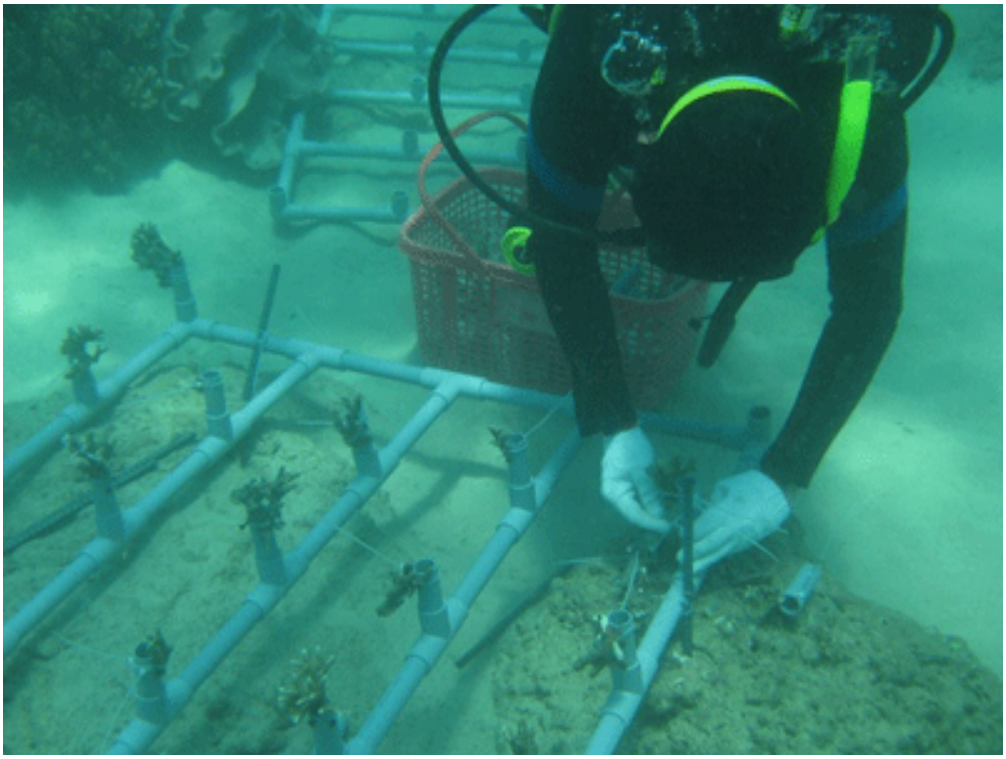
Nha Trang is one of the 29 most beautiful bays in the world, with a water surface area of about 12,200 hectares, including 14 large and small islands with a coastline of over 15 km long. This place's conditions are pretty ideal for the distribution of coral reefs. Studies show that the total area of coral reefs in Nha Trang Bay is 731 ha, distributed around most of the islands in the bay and Granband area (Latypov 2006). However, due to the economic development activities on the bay's islands as well as the increasing demand for marine tourism, it is inevitable that the coral reefs here have been under a lot of pressure and are likely to change in different directions. The case study in Nha Trang bay is a research experiment on coral reef restoration techniques that were carried out at Mun Island, Nha Trang Bay. The site chosen for the research on coral restoration techniques is in reef slopes of Mun Island. This area has many advantages as the mountains in the south of Mun island prevent the reefs from the strong wave's effect, and the northern part of the reefs is protected from the wind and rough sea by Tre island. Furthermore, the light condition, which is a significantly crucial factor, in this area is ideal for coral growth. Water turbidity and sedimentation rate in here are also quite low when comparing with other locations. In general, the experimental area for coral restoration in Mun island had ideal natural conditions for the research on coral restoration techniques as environmental factors in here were pretty stable, it's near the source of coral donor colonies that provided for the experiment planting; the management and protection of the experimental area are also an advantage (Nguyen 2005).

4.1.1 Method

Six hard coral species were selected to conduct the coral reef restoration experiment: Acropora austera, Stylophora pistillata, Galaxea fascicularis, Seriatopora caliendrum, Pocillopora verrucose and a hydra coral species Millepora tenella. The source of transplant in this case is coral from donor colonies. A total of 169 colonies of coral species were transplanted and restored. The transplantation method was used in this research experiment is FIF method.

The coral fragments were attached to the different types of frame: on iron rods that were driven directly on the sandy bottom and crushed coral, on the concrete pillars, and on the dead coral base.

PICTURE 4. The concrete base frame with fixed coral fragments in Mun island (Source: Vung Nguyen).



PICTURE 5. The iron frame with fixed coral fragments in Mun island (Source: Nguyen Quang Viet).

Colonies with three hard coral species (Stylophora pistillata, Acropora austera and Seriatopora caliendrum) were fixed on concrete bases and placed in two zones with different depths: Shallow zone with a depth of about 3 meters; deep zone with a depth of about 6 to 6.5 meters with an average tidal level. The fragments were transplanted and checked in two periods. The first one is from April to August 2003. This is the dry season with high temperature. The second period is from October 2003 to March 2004. This is the rainy season time, with the northeast monsoon: rain, low temperature, and windy) (Nguyen 2005).

4.1.2 Results

After two months of transplantation, the growth rate of corals in the two zones with different depths was significantly different. The growth rate of these corals was higher in the shallow zone than in the deep one. As we all know, different depths receive different light radiation intensities. The higher the depth is, the lower the intensity of light radiation is. Therefore, the difference in the growth rate of coral species in the two different depth zones is closely related to the photosynthesis intensity of the corals. This also leads to the conclusion that the transplanted coral species in this study are suitable for environments with lots of light.

In addition to light intensity, the type of frame also has a significant influence on the growth rate of corals (Nguyen 2005). The data in Appendix Table 1 show that corals transplanted on concrete substrates had the highest growth and survival rates. Conversely, corals transplanted on iron rods driven directly on the sandy bottom had the lowest growth and survival rates; the Seriatopora caliendrum coral species even entirely died during the researched period. It was observed that coral colonies attached on iron rods driven on sandy bottoms were tightly close to the bottom. Therefore, in the process of water movement due to currents and waves, it often displaces and ripples the sediment in the water near the bottom, making it difficult for corals to develop. As a result, many coral fragments died, the survival rate was remarkably low.

Seasons also play a vital role in coral rehabilitation. The results show that during 4 months of transplantation in dry season, the general survival rate of transplanted fragments was 71.43%. Meanwhile, in the rainy season with the impact of Northeast monsoon, the survival rate of transplanted corals during 5-month period was 86.71%. From the experimental results of research on rehabilitation techniques of corals in Mun island during the rainy season (from October 2003 to March 2004), it has been presented that all coral species in this research had the same survival rate as well as growth rate usually higher than transplanted corals in the dry season. Despite being affected by waves, the water temperature from October 2003 to March 2004 is lower than in summer and autumn, so it was more favorable for the development of coral species (Nguyen 2005).

4.2 Commercial transplantation: case study in Okinawa, Japan

There are 200 coral species in Okinawa, Japan out of a total of 800 species of coral existing in the world. In recent decades, it is witnessed the deterioration of coral reefs in Okinawa as a result of coral bleaching, red soil pollution from extensive construction, eutrophication and sediment pollution (Wilkinson 2002). In 1998, global sea temperature hikes caused a catastrophe through coral bleaching. Coral lives in warm water, but many of them die when the sea temperature stays 2 degrees above the summer maximum for 2 weeks. The coral reefs in Okinawa also did not avoid that bleaching event. 80% to 90% of corals in Okinawa died because of high sea temperatures in 1998. The coral reefs scenery changed completely because many organisms significantly declined with corals. There was a transplantation project that was conducted from 2012 to 2016 by using artificially produced coral transplants (APTs) technique. This technique is similar to propagate a tree from a branch by adopting asexual production; and it is also applied for coral rehabilitation in some countries. According to Okinawa prefecture, the budget for this project was about 6.25 million USD. Although there was an increasing trend in the number of rehabilitation activities, the project development state was still in the initial phase. The reason for this tardy progress in specific and for inefficiency conservation policies in general is because of the involvement of too many stakeholders, including fishermen, farmers, land developers, diving shop owners and animal husbandry. Therefore, the new way

of conducting coral transplantation was introduced in Okinawa – a commercial transplantation (Okubo 2014).

4.2.1 Method

In an attempt to restore the coral reef in Okinawa, coral aquaculture was carried out under the model of ecotourism, also known as commercial transplantation, and using the APT technique. In this ecotourism model, tourist divers participated in the coral transplantation process voluntarily. Each diving tour costs around 150 USD, which includes the insurance and the expense for boat and tank. In another word, the operators do not have to pay for the APT cost and this cost will be transferred to the diving tourist as a fee. Providing free labor as a voluntary work to improve the environment is seen in many projects. However, in Okinawa, the contributor need to pay the APT cost but also at the same time receive utility with regard to personal amusement. The fragments are broken off from donor colonies after receiving Okinawa prefecture's approval. They must be nurtured for at least 6 months until they grow to the size of 6-8 cm APTs (Okubo 2014).

At least two shops in Japan provide the producing and transplanting APTs service. Moreover, the requests to transplant APTs from companies are sent to these shops as a section of CSR activities. Since all the transplantation process is conducted by these shops, the companies pay the cost for them with the price is 35 USD for each APTs transplant. The companies concerned can use transplantation activities for advertising as a part of their CSR program. As stated in an interview with an operator who began commercial transplantation in 2005, 60,000 coral fragments were transplanted in 9 years for several companies. However, due to the fact that the operator only takes charge of the nurtured part and does not supervise the further steps after delivering the transplanted fragments, there is not enough data to analyze either commercial transplantation has devoted to the improvement of coral reefs situation in Okinawa or not (Okubo 2014).

4.2.2 Results

According to Okinawa prefecture, in Okinawa the total revenue from tourist in 2009 was 6.6 billion USD. Although the precise number of how coral-related tourism activities contribute to the total revenue were not published, it was estimated that coral reefs-based tourist accounted for 43.4% of the total tourist from 2003 to 2007. Applying the commercial APTs transplantation minimized the cost for not only the transplantation process itself, but also for the local economy (create more jobs for local people) as well as promote the ecological awareness in community.

Although the data of transplanted coral from commercial transplantation was hard to track, according to the research in Onna village in Okinawa, the survival rate of coral in farm which used the iron frame was higher than the one that plant on the natural ground substance and natural colonies, especially in the mass bleaching event in 2016 (Higa et al. 2017). This state can be affirmed through the table 1, 2 and 3.

TABLE 1. Survival rate of coral on farmed colonies during summer 2016 (Higa et al. 2017)

Aquaculture place	Number of colonies	Number of death colonies	Survival rate	Observation date
Onna fishing port destination	9424	20	99.7%	Nov 15th 2016 Nov 17th 2016
Maekaneku fishing port (North)	347	139	59.9%	Nov 13th 2016
Maekaneku fishing port (South)	997	114	88.5%	Mar 20th 2017

TABLE 2. Survival rate of coral on natural substrates at Onna Village coral nurseries during summer 2016 (Higa et al. 2017)

Species	Number	Survive	Death	Survival rate
Acropora valenciennesi	100	100	0	100%
Usueda midoriishi	267	231	36	87%
Acropora donei	216	103	116	47%
Nanyo midoriishi	48	12	36	25%
Total	634	446	188	70%

TABLE 3. Survival rate of acroporid coral at 3 natural coral communities near Maeganeku fishing port during summer 2016 (Higa et al. 2017)

Point	L1	L2	L3
Coordinate (WGS84)	N 26. 440222 E 127. 790000	N 26. 443611 E 127. 789306	N 26. 441833 E 127. 792028
Water depth	1.3	1.5	2.3
Lateral line distance	60m (20m x 3)	100m (30m x 2, 20m x 2)	150m (50m x 3)
Survival • Death	Survival Death	Survival Death	Survival Death
Colonies number	50 58	50 73	0 107
Survival rate	46%	41%	0%

5 DISCUSSION

5.1 Comparison

5.1.1 SWOT analysis

To better understand the challenges and opportunities for different coral transplantation methods and progress from the strengths as well as minimize the weaknesses for the future development, a SWOT analysis is conducted and is presented in table 1 and table 2 below.

TABLE 4. SWOT analysis of traditional transplantation method

Strengths • Easy to modify the process: base on the characteristic of each coral species, operators can decide the suitable season and depths for transplantation process. • Variety sources for coral fragments: coral of opportunity, coral from donor colonies	**Weaknesses** • The cost of coral reef restoration is very expensive. For example, to restore 1 hectare of coral reefs in Vietnam, the cost is about 3980 USD.
Opportunities • Improve the growth and survival rate of coral fragments • Diversity in the coral species for transplantation • The restoration and management of coral reefs provide the potential for marine tourism.	**Threats** • Hard to scale widely due to the high cost of this method

TABLE 5. SWOT analysis of commercial transplantation method

Strengths • High effective cost as tourist dive is the one that pay the APTs cost. • Bring more jobs for local people • Increase social awareness in coral rehabilitation	**Weaknesses** • The source of fragments is from natural coral colonies • The operators do not monitor the whole process. Thus, it's hard to keep track the coral fragments condition. • Lack of diversity in genetic and coral species as mostly the chosen species for transplantation was Acropora because of its attractive look and speedily growth rate.
Opportunities • High potential widely-scale the model. This method can be applied in many tourist attractions. • Create more business opportunity for local community • Attract tourists and investors/ firms by promoting ecological awareness through transplanting diving tours. Using this method can be more cost-effective than developing a formal program of saving the environment, which can cost a lot.	**Threats** • Coral reefs in Okinawa are already in bad condition. Using natural coral colonies as a source for coral transplantation in wide-scale can make it worse. • Depend on tourist, which is unstable factor, especially in pandemic era. • If the survival rate of fragments decreases, the cost will not be high effective anymore. • Lack of diversity in genetic and species can lead to mass fatality because of bleaching and diseases.

5.1.2 Comparative study

Throughout the analysis of two different methods used in coral reefs rehabilitation, the general comparison of two methods is analyzed based on four evaluation criteria and is demonstrated in the table below.

TABLE 6. General comparison between traditional and commercial transplantation

	Effectiveness	Time efficiency	Cost	Social impact
Traditional	++++	++	+	++
Commercial	++	+++	++++	+++++
+ Very bad; ++ Bad; +++ Moderate; ++++ Good; +++++Excellent				

Firstly, since traditional transplantation has been used for several decades, it has proved its effectiveness through many case studies, such as in Maldives or Philippines. The main reason is that this method is a research-based model: the operators can monitor the whole process of transplantation; thus, it is easier to adjust and check the condition of fragments from the start to the end of cultivation. Meanwhile, in commercial transplantation, the operators only supervise the transplantation process and do not monitor further steps. Moreover, the selected coral species in traditional transplantation are more diverse than commercial transplantation since, in this method, they only choose the colorful species and have a fast growth rate. Therefore, traditionally transplanting coral has more outstanding points in terms of effectiveness than the commercial way.

Time efficiency is an important factor that need to be defined when comparing these two methods. In general, the time it takes for coral fragments to be nourished and take root in a new colony is very long; usually, the average time is five years. Traditional transplantation has bad performance because of the limited people that can participate in the project. Therefore, it would take longer time for operating and maintaining the transplantation process. On the other hand, by taking advantage of resources from tourists who want to participate in a scuba diving tour and are willing to volunteer for coral culture activities, the coral culture process will be much faster and more efficient. In addition, the cost that tourists

pay for the diving trip already covers the cost of transplantation, so there will be no shortage of budget as well as the project has not to stop halfway to ask for more funding.

Considering the cost-effective of the coral rehabilitation methods, the commercial transplantation outperforms the traditional way. Due to the small number of healthy coral reefs in Vietnam, the collection of fragments from the donor colonies is limited. Therefore, the cost was calculated based on the density of replanted corals with only 1 group of corals/m^2. In other word, there are 10,000 replanted coral colonies per hectare and the cost for 1 hectare is about 3980 USD. This cost does not include infrastructure investment, farm establishment, management fee, and protection fee. The expensive cost can be a burden for developing countries since most of the fund has come from government and non-governmental organizations (NGOs). Thus, this can become an obstacle for coral restoration activities. In contrast, with a new approach to define the budget for transplantation (the cost is shouldered by diving tourists), there is a huge potential for the location to develop the project in larger scale. This approach attracts companies and firms to cooperate and invest as it can be advertised to be one of CSR activities. However, the cost per APTs can be increased if the fatality event happens because the colonies get diseases or bleaching.

The main reason for the devastation of coral reefs is human activities (destructive fisheries, tourism, marine litter, coral exploitation, etc.). Thus, raising ecological awareness becomes a crucial part of coral conservation and protecting marine biodiversity. Commercial transplantation represents its excellent performance by attracting more and more people to participate in coral reservation activities voluntarily when it comes to social impact. Furthermore, this activity would help educate ocean lovers on the importance of coral reefs to our marine ecosystem and what we can do to protect them. Many people are concerned about the environment but do not know how to contribute. By giving them the way to get involved, transplanting coral commercially would spread its influence more powerful. For traditional transplantation, the scale is only limited in a group of operators, which mostly are researcher, marine biologists and fisherman. Therefore, the impact of this method is only limited in academic environment and fisher community.

5.2 The feasibility of applying the commercial method in Vietnam sea region

Coral reef-related tourism such as scuba diving and other sightseeing activities play a crucial role in the economies of many countries. With being recognized as one of the 29 most beautiful bays in the world since 2003, tourism services in Nha Trang Bay are increasing significantly, and scuba diving is one of the activities attracting many tourists to travel here. With favourable conditions that the sea has fewer waves and the distance is not too far (about 10 km from Cau Da port), Mun island's coral reef has become an attractive diving spot of Vietnam. Compared to the areas that have been put into operation for scuba diving tourism, this place has many different diving spots with many coral species and colorful fishes. According to the people who do diving service at Mun island, this activity started in 1995 and developed gradually over time. According to current regulations, activities can be held in protected areas (MPA) with a certain fee (2,90 USD). Except on rough sea days due to bad weather, scuba diving service is organized all year round (Nguyen et al., 2019).

With such great tourism potential, it is quite feasible to apply commercial coral transplantation in Vietnam sea region. In fact, since 2015, Khanh Hoa Department of Natural Resources and Environment, together with Nha Trang Institute of Oceanography and three enterprises, including Yen Sao Ltd, Vinpearl Nha Trang Co., Ltd, and Tri Nguyen Tourism Company, have started to implement the business model of participating in the management of coral reefs for the purpose of ecotourism at 3 points close to Mun island: Sau Sao - Vinpearl, Nam Hon Tam and Bai San - Mieu island. The results of the assessment for the period 2015 - 2018 show that in the study area, coral coverage increased significantly in the period 2015–2017 but decreased suddenly from 56.8% in July 2017 to 12.5. % (decreased by nearly 80%) in December 2017 due to being severely affected by typhoon No. 12/1997. Along with this situation is the low density of reef fish, especially the group of fish with a size of 20 cm or more, which is very rare. This indicates that state management is still inadequate. The exploitation of resources happens anytime, anywhere, and cannot be controlled (Vo et al., 2018). Besides, the supply-side also need to be considered. A proper guideline and a strict regulation are necessary to mitigate the coral exploitation.

To receive the approval and start to promote their business, companies should meet all the ecological requirements in a specific period. Another challenge when commercializing the transplantation process in Vietnam is to educate the diving tour guides and tourists to not harm the coral fragments when visiting. There are many people who work as scuba diving guides, but in fact, they have not been properly trained, so they are not equipped with enough knowledge about environmental protection. Even many people who have not been granted scuba diving certificates also take guests to dive.

6 CONCLUSION

In conclusion, these two coral transplantation methods with different scale and model have both pros and cons. Nevertheless, commercialize the transplantation process still demonstrates its remarkable ability and effectiveness, especially in term of cost and social impact. Developing the commercial method to be more sustainable is an ideal direction and can mitigate most of its weaknesses and threats. This maybe achieve by introducing an ecological friendly consideration stage before starting the whole transplantation process. In particular, this can begin from selecting suitable coral species for transplantation but still meet the biodiversity requirements, or opening with other source of fragments, such as coral of opportunity, to reduce the burden on donor colonies. Encouraging supply-side to keep track and monitor the survival rate of fragments after the tour is also help preventing the mass coral rate. In fact, some diving shops are applying the monitor process after delivering fragments to companies.

Overall, more research and experiments need to be conducted for further improvement. It also required closely coordination between the government, private companies and the supply-side. The government needs to issue transparent and specific policies in the exploitation and culture of coral for private businesses, to ensure sustainability and not affecting the local coral ecosystem. In addition, measuring and managing the coral culture facilities should also be fully and regularly implemented by the government. When applying this model in Vietnam, in addition to the above requirements, the government also needs to manage scuba tourism businesses to ensure that the scuba instructors have the required certificates and proper knowledge about corals, ensuring a safe diving process as well as not harming the coral's environment.

REFERENCES

Burke, L., Selig, E. & Spalding, M. 2002. Reefs at Risk in Southeast Asia. 1st edition. United States: World Resources Institute.

Lough, J. M. & van Oppen, M. J. H. 2018. Coral Bleaching: Patterns, Processes, Causes and Consequences. 2nd edition. Switzerland: Springer.

Okubo, N. & Onuma, A. 2015. An economic and ecological consideration of commercial coral transplantation to restore the marine ecosystem in Okinawa, Japan. Ecosystem Service 11.

Coral transplantation. Coral Digest. Read on 03.09.2021. https://www.coraldigest.org/index.php/CoralTransplantation

Edwards, A. 2010. Reef Rehabilitation manual. Coral Reef Targeted Research & Capacity Building for Management Program: St Lucia, Australia. ii + 166 pp. Read on 04.09.2021. https://ccres.net/images/uploads/publications/3/reef_rehabilitation_manual_web.pdf

Ferse, S., Hein, M. & Rölfer, L. 2021. A survey of current trends and suggested future directions in coral transplantation for reef restoration. Read on 05.09.2021. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0249966

Bayraktarov, E. Stewart-Sinclair, PJ. Brisbane, S. Boström-Einarsson, L. Saunders, MI. & Lovelock, CE. 2019. Motivations, success, and cost of coral reef restoration. Restoration Ecology.

Ferse, S., Nugues, M., Romatzki, S & Kunzmann, A. 2013. Examining the Use of Mass Transplantation of Brooding and Spawning Corals to Support Natural Coral Recruitment in Sulawesi/Indonesia. Restoration Ecology.

Zhang, Y., Huang, H., Huang, J., You, F., Lian, J., Yang, J. & Wen, C. 2016. The effects of four transplantation methods on five coral species at the Sanya bay. Acta Oceanologica Sinica 35(10), 88-95.

SWOT analysis. ScienceDirect. Read on: 06.09.2021. https://www.sciencedirect.com/topics/economics-econometrics-and-finance/swot-analysis

Latypov, Y. 2006. Transplantation and Cultivation of Fragments of Coral Colonies of Various Scleractinian Species on a Reef in Vietnam. Russian Journal of Marine Biology 32 (6), 375-381.

Nguyen, A. 2005. Nghiên cứu các giải pháp bảo vệ, phục hồi các hệ sinh thái rạn san hô, cỏ biển và khắc phục ô nhiễm môi trường biển tự sinh. Viện Khoa Học và Công Nghệ Việt Nam.

Vo, T. et al. 2018. An assessment on the effectiveness of coral reef management by tourism sector in Nha Trang bay, Vietnam. Collection of Marine research works 23, 73-80.

Nguyen, B. & Le, T. 2019. An assessment of Hon Mun coral reef basing on foreign scuba-diving tourist survey. Journal of Fisheries Science and Technology.

Wilkinson, C.R. 2002. Status of coral reefs of the world: 2002. Australian Institute of Marine Science. Australia.

Higa, Y, et al. 2017. Restoration efforts for coral reefs by fishery cooperatives – A case in Onna Village, Okinawa. Journal of the Japanese Coral Reef Society 19, 119-128.

Cooper, E, et al. 2014. Corals and their potential applications to integrative medicine. Evidence-based Complementary and Alternative Medicine.

APPENDICES

Appendix 1. Survival rate of recovered corals on different frames (Source: Nguyen 2005)

Type of frame	Survival rate (%)		
	5-9/2003	9/2003-4/2004	4-7/2004
Concrete	100 (3)	71.4	92.0
Death coral	95.5 (2)	60.5	88.5
Concrete in the frame	40.3		
Iron rods	3.7		