



Artificial Cultivation of Hermatypic Corals on Experimental Frame on the Reefs of Vietnam

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Abstract

In 2003-2005 and 2010-2011, experimental commercial cultivation of 14 species of hermatypic corals was carried out using the method of donor colony fragmentation. The transplants successfully survived on experimental frame installations. The coral colonies that were recovered from the fragments became attached to the frame installations in a similar way to their attachment on natural substrata. The research has established species-specific factors and others affecting regeneration of fragments and growth of new colonies in these coral species. The accretion of donor fragments and new branches averaged from 40 to 160 mm per year, depending on the coral species, colony size, and season of transplantation. An average monthly accretion of medium and larger transplants and growth of new branches were 1.2-1.3 times higher at spring cultivation than at autumn transplanting. When transplanted, coral fragments of medium and larger sizes survived well and showed higher growth rates in all species studied. After 1-1.5 year, the size of the transplants was found to have increased by 220-275%. The newly formed artificial coral community was colonized by the damselfish *Dascyllus reticulatus* (Pomacentridae).

Keywords: Coral fragments; Cultivation; Reefs; Vietnam

Introduction

The economy of Vietnam is developing rapidly. The coastline of Vietnam has become a site of intense house- and road-building; dozens of new hotels and diving centres have recently appeared here, and sea farming is developing extensively. This intensification has become a cause of increased terrigenous effluent into waters of local bays [1,2]. Local coral reefs are subjected to particulate sediment deposition of 70-100 g/m² a day, and this estimate grows one order higher during typhoons [3,4]. Erosion processes along the coastal line the city and port of Nha Trang, as well as developing sea farming in coastal waters of neighbouring islands, aggravate the sedimentation and eutrophication impact in Nha Trang Bay [1,5,6]. An increased amount of by particulate sediment of different origins increases water turbidity caused by deposition, leads to impairment of photosynthetic abilities of reef building corals and other benthic organisms, and reduces physical and biological processes in the sea [7-9]. As a result, coral cover of the substrate reduces to 20-40%, while the portion of substrate cover by macrophytes *Chnoospora* and *Halimeda* grows to 60-80%. General reduction of the area of coral reefs has recently been documented (Latypov, 2006). We welcome the care of science and the government of Vietnam to make every effort in the search for possibilities of preservation and reconstruction of reef ecosystems.

According to the Global Coral Reef Monitoring Network (GCRMN), 20% of all coral reefs have been destroyed by human activities. The main causes of coral reef devastation are general global problems: climate warming and increasing acidity of oceanic waters through carbon dioxide emissions to the atmosphere, increased eutrophication and sedimentation of coastal waters, which reduce fish stocks, and the barbaric attitude of the residents of coastal areas towards sea inhabitants. Collecting corals, shells and other tropical

fauna cause a very harmful impact on the coral reefs. The income of all countries through just the sale of corals is estimated at 30 million U.S. dollars annually. The world scientific community and civil society are concerned with these sad, and even threatening, circumstances. Special workshops are held; the results of research on the problems of conservation and restoration of coral reefs [5,10-12] and the results of experiments on artificial breeding of reef building corals are regularly published [8,13,14]. It is shown that the transplantation of coral fragments is the most successful method for restoring reefs [15-18]. Under favorable conditions, coral fragments attach to the substrate and, when recovered to the size of a colony, they reproduce sexually [19-22].

Many publications are available on transplantation and cultivation of coral fragments; they cover various methodical, physical and biological problems connected with coral cultivation [8,13,23-26]. A majority of researchers believe that the attention of those engaged in the matter should be focused on the size of coral fragments, the season of their transplantation, orientation in the place of transplanting, and selection of substrate. These factors are most important for restoration of reproductive abilities of new coral colonies reared from fragments [27-30].

Earlier, a detailed analysis was performed on the theoretical works and the experimental data on artificial cultivation of corals and the "framework" method was recognized as most appropriate for Vietnam; it has given good results [14]. It is known that coral fragments are more likely than the larvae to survive in loose (mobile) soils, owing to their larger sizes and elevated location above the substrate [28,31,32]. The reproduction of coral communities through the fragmentation of colonies seems to be a reasonable and effective method. But before intervention into the reef ecosystem (in order to assess all the critical situations connected with the use of the method) we shall experimentally determine the procedures that would allow us to obtain the greatest number of surviving transplanted fragments

with the least damage to live colonies. For this, we must elucidate the following important questions: what coral species can give a larger number of viable fragments? In what parts of the donor colony shall we select the fragments for transplantation? What should the size of the fragment be in order to be planted? What should the orientation of the coral fragments be during transplantation? What should the depth of planting be; and should the bottom shall be cleaned from algal growths?

This paper reviews conditions driving the need for restoration, and the questions that must be considered to identify the type of restoration necessary or possible. Artificial reefs around the world, their uses, social and economic impacts, liability, the use of novel technology approaches in artificial reefs and future applications were also reviewed. Artificial reefs can have positive economic impacts which are significant and may be several hundreds of million dollars per year.

Materials and Methods

In October 2003 altogether, 35 coral fragments colonies (6 species of the genera *Acropora* and *Porites*) were selected from 10 donor that were 1-1.5 m high and 2.5-4 m in diameter. All but one donor colony grew at a depth of 2-3 m, and a colony of *A. palifera* dwelled at 11 m deep. Peripheral parts of coral colonies with 2 to 17 branches were used for the experiment. The frames with fixed transplants were placed at a distance of 20 to 50 m off the donor colonies at a depth of six-seven meters in two periods: on October 8, 2003 (steel frames, 2×1 m), and on May 21, 2004 (plastic frames, 2×2 m).

Based on an agreement with the Institute of Technology and Applied Research of the Vietnamese Academy of Science and Technology and the “Sanest” Company, in April 2010 we set three installations of plastic frames near the protected Hon Nai Island, which were 1×2 m in size and were elevated 50-70 cm above the bottom (Figure 1). Coral fragments (115 pieces) of 14 species of the genera *Acropora*, *Isopora*, *Pocillopora*, and *Porites* were attached to the frames (Table 1). The frames were installed at a distance of 70–80 m from the water’s edge at a depth of 3-4 m in sand corallogenic hollows among dense growths of reef building coral colonies. Transplantation of fragments was performed without removing the corals from water. Fragments with 2 to 17 branches were taken out of the periphery of the donor colony, placed into individual plastic bags and transported from the nearest assemblages of donor corals to an installation at a distance of 30-50 m at a depth of 2-3 m. The fragment length in all frames was measured with a caliper and three size groups were identified: 4-7, 11-12, and 20-21 cm. Coral pieces were attached to the frames with a copper wire in a plastic sheath; their contact with the framework was avoided to the extent possible (Figure 2). The survival and growth rates of coral fragments were investigated in terms of the coral species, the fragment size and its orientation at attachment, as well as of the season of transplantation. The installation with coral fragments was raised above the bottom to prevent it being covered by sedimentation and possible attacks by the predatory gastropod *Drupella rugosa*. The state of the facilities and the attached coral fragments were checked in a week (Figure 3). The first results were recorded 6 months upon the start of the experiment.

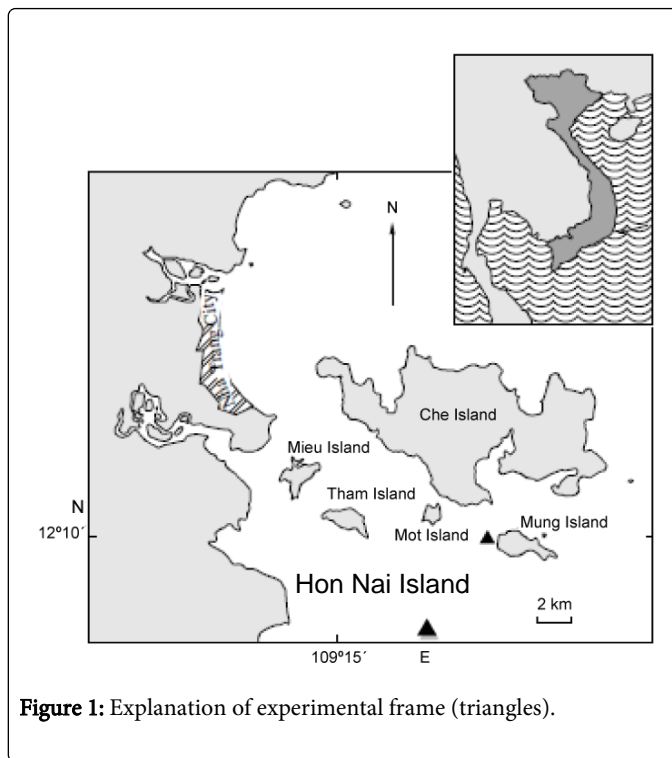


Figure 1: Explanation of experimental frame (triangles).

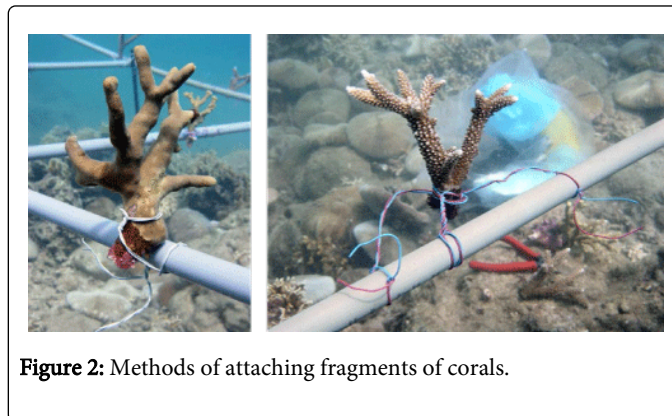


Figure 2: Methods of attaching fragments of corals.

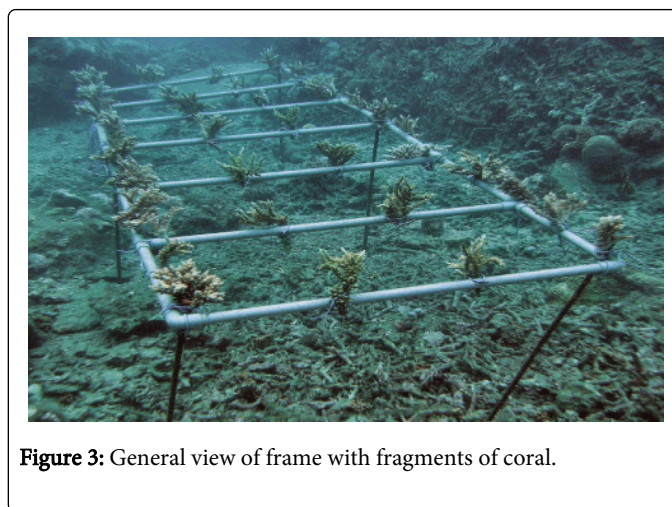


Figure 3: General view of frame with fragments of coral.

Species	Period observations of (month)	Number of branches on the fragment	
		Beginning of the experiment	End of the experiment
<i>Acropora valida</i>	12	12	57
<i>A. valenciennesi</i>	12	7	47
<i>A. microphthalma</i>	18	4	37
<i>A. formosa</i>	18	17	42
<i>A. robusta</i>	12	4	16
<i>A. elseyi</i>	12	12	83
<i>A. cerealis</i>	12	12	79
<i>Isopora palifera</i>	18	4	7
<i>Pocillopra verrucosa</i>	12	20	40
<i>P. eydouxi</i>	12	12	26
<i>P. woodjonesi</i>	12	5	15
<i>Porites cylindrica</i>	12	5	65
<i>P. nigrescens</i>	12	7	18
<i>P. attenuata</i>	12	32	75

Table 1: The number of branching's on the transplanted fragment in terms of the species and the size of coral fragments at the beginning and at the end of the experiment.

Results and Discussion

All fragments that survived after transplantation recovered and formed new branches, and the branches that were intentionally injured also recovered. About 60% of all fragments fused over 6-8 months with their bases onto horizontal rods of the frames, using them as a substrate. Three fragments sized 100-110 mm died unrecovered: of them, one fragment of *Acropora microphthalma*, transplanted in October 2003, leaned with more than 75% of its length against the metal frame of the facility. No dependence was detected among the number of surviving fragments, their orientation at planting, and the season of transplantation. About 60% of the fragments overgrew the wire connecting them to the frame, within 4-6 months formed basal attachments to horizontal bars of the

installation, and used them as a substrate. Years after the transplantation, all successfully surviving fragments were found attached to the frame of the installations and had the size of a small colony. The survival of the fragments was 100-86.2% and depended on the coral species, fragment size and duration of the experiment (Figure 4). In the first size group, 20-30% of transplanted fragments died within 8-10 months from the beginning of the transplantation. Small and medium sized fragments of *Acropora valida* and *A. microphthalma* had the lowest survival. Medium sized and large fragments of the species *Acropora valida*, *A. valenciennesi*, *A. florida*, *A. gemmifera*, and *Pocillopora verrucosa*, *Porites attenuate*, and *P. cylindrical* regenerated most successfully. Fragments of *Isopora palifera* had a 100% survival rate, irrespective of their orientation during transplantation.

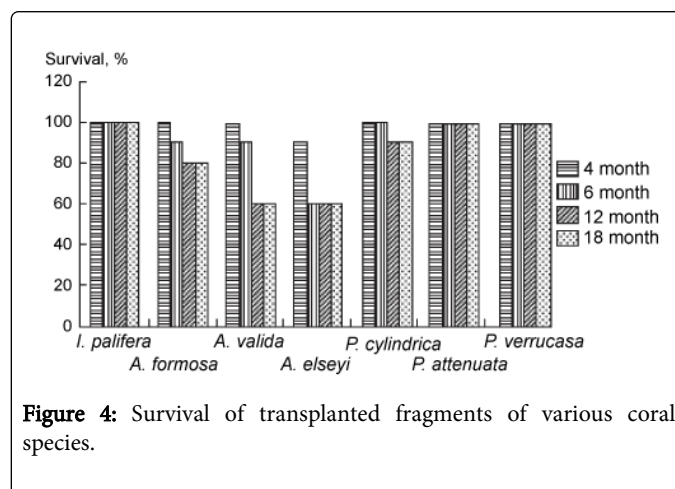


Figure 4: Survival of transplanted fragments of various coral species.

Within 2-2.5 months of the transplantation, new branches formed on the branch surfaces of all the surviving coral species, including the bottom surfaces that were damaged during the separation from donor colonies. The linear growth increment of the coral fragments of various species was 30-160 mm. This parameter depended on the species and size of the fragment. Morphologically different fragments of *Acropora valida*, *A. valenciennesi*, *A. formosa*, *P. attenuate* and *P. verrucosa* were characterized by different growth rates. A high linear growth increment was typical of the most extensively branched fragments of *A. valida* and *P. attenuate* (Figure 5, Tables 1 and 2).

Species	Period of observation (month)	Beginning of the experiment, mm	End of the experiment, mm
<i>Isopora palifera</i>	18	40	120
<i>I. palifera</i>	18	70	140
<i>A. valenciennesi</i>	12	40	120
<i>A. valenciennesi</i>	18	70	200
<i>Porites cylindrica</i>	12	40	110
<i>P. attenuata</i>	12	18	39
<i>A. formosa</i>	12	120	240
<i>A. formosa</i>	18	220	320
<i>A. elseyi</i>	12	140	242
<i>A. elseyi</i>	18	210	370

Table 2: The linear growth increments in terms of coral species and sizes of the fragments in the 12 and 18 month experiments.

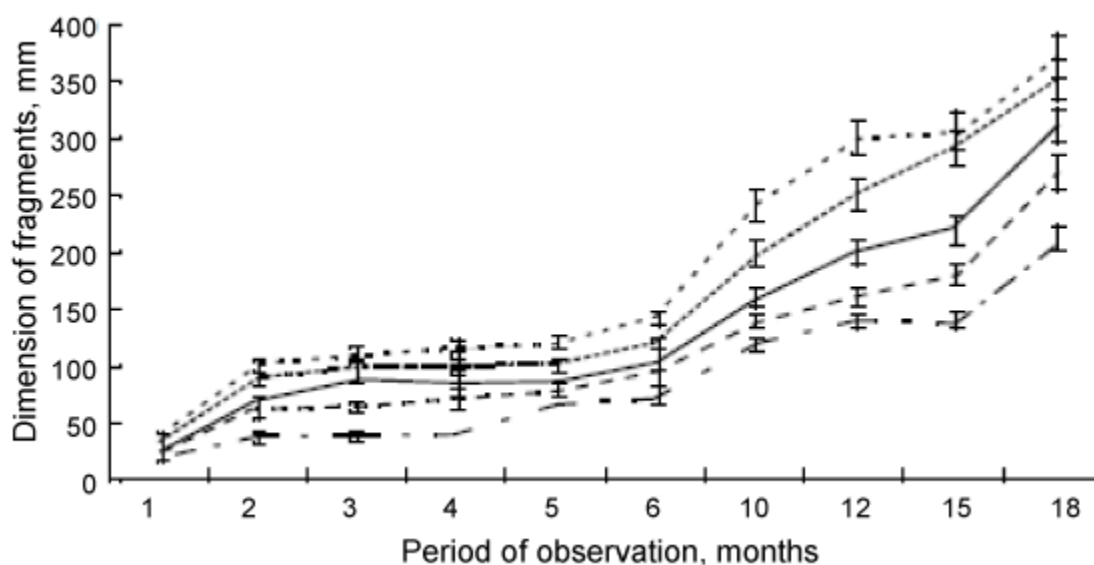


Figure 5: The linear growth increment of coral fragments of various coral species in the experiment of 2010–2011. (1) *Acropora elseyi*; (2) *A. valenciennesi*; (3) *A. formosa*; (4) *Porites cylindrica*; (5) *P. attenuata*.

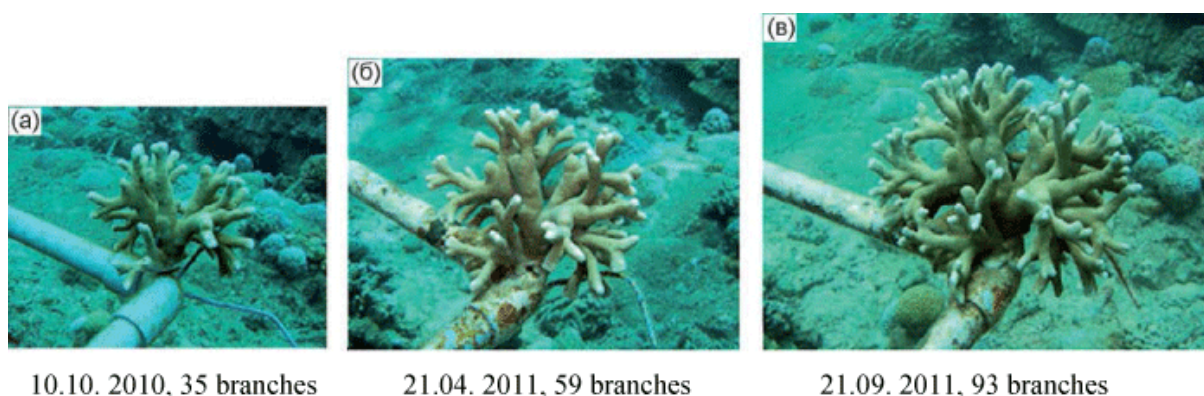


Figure 6: Growth increment of coral fragments and an increase in the number of branches in the colony of *Porites attenuata*. (a) transplanted fragment; (b) upon 6 months; (B) upon 12 months.

Large fragments were also characterized by a higher growth rate. The more ramified were the donor colonies, the more new branches appeared on the transplanted fragments. During the first 6 months of 2010, the size of the fragments and the number of new branches on them increased generally by 150-165%; in a year, it increased by 210-275% (Figures 5 and 6). Upon extension of the cultivation period from 1 year to 18 months, the coral fragments increased by 1.2-1.5 times. Similar values of growth of new branches showing a Taiwanese *Acropora* [8]. The successful growth of transplanted fragments and the

formation of large colonies contributed to the invasion of the damselfish *Dascyllus reticulatus* (Pomacentridae) into the new coral assemblages (Figure 7). This coral reef fish demonstrates a pronounced homing behavior in the formed coral reefs, similar to that in the natural reef, where adult fish usually live in groups in thickets of branched corals and seldom depart by more than a distance of 1 m. Catch rates of fish around artificial reefs are often higher than catch rates in surrounding non-reef areas, leading to the perception of “enhanced” fisheries [34,35].



Figure 7: Settling of fishes *Dascyllus reticulatus* on artificial settlement of corals.

These experiments showed that cultivation of coral fragments on artificial facilities can be effective in different reef parts. Large fragments of the studied coral species survived better and had higher growth rates. They formed the greatest number of new branches and built large colonies, which is consistent with the results that were obtained previously [15,30-33]. It is known that large coral colonies that are grown from larger fragments also have the greatest reproductive success [32]. Growth of corals from colony fragments is an important natural process, at least in corals with branched colonies. Under natural conditions, the broken fragments of colonies first “anchor” on the bottom and then attach to the substrate through the regeneration and growth of the soft tissues and skeleton [17,20,33]. The results we obtained in our experiments agree well with the data that were reported by Ocubo et al. [28], who believe that attachment of fragments to the substrate is a prerequisite for the successful completion of the long process of transplantation. In an experiment in 2010-2011, all the surviving fragments became rooted to the frame and attached with their base parts to the horizontal bars of the installation. A direct proof of the formation of the coral settlement is its invasion by reef fish and an indirect proof is the settlement and growth of sea squirts on this artificial substrate. These artificial reefs can be designed for different purposes like: tourism (SCUBA diving, recreational angling, surfing and beach enhancement), fisheries, nature conservation and science [14,36-39].

Conclusions

Thus, the experiments we carried out in 2010-2011 on the coral reefs of Vietnam confirmed that successful survival of coral fragments under natural conditions of coral reef is possible and depends on two main factors: the coral species and the size of coral fragment to be planted. The relatively high growth rates of the fragments of all coral species can probably be explained by their transplantation into a well-lit environment that is less populated by other macrobenthic organisms. Installation of the experimental facilities over the bottom keeps them from becoming buried by sandy sediments.

The data that were obtained in our experiments can be used for restoring natural coral settlements or for the cultivation of corals for aquariums and oceanariums. A chain of facilities installed on the bottom of sandy areas along or around a reef contributes to an increase in the area of the reef within 2 to 4 years and to the protection of the shore from wave action.

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