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Artificial cultivation of hermatypic corals on experimental frame on the reefs of Vietnam

Yu.Ya.Latypov

A.V.Zhirmunsky Institute of Marine Biology, Far East Branch, Russian Academy of Sciences, Vladivostok, 690041, (RUSSIA)

E-mail : ltpv@mail.ru

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-specificfactors 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 coralspecies, colony size, and season of transplantation. An average monthly accretion of medium and larger transplantsand 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 ratesin 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 reticulates* (Pomacentridae); the species is a common coral fish species that lives on natural reefs.

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 centers 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 deposition of 70–100 g/m^2 a day, and this estimate grows one order higher during typhoons[3,4]. Erosion processes along the coastal line at the city and port of Nha Trang, as well as developing sea farming in coastal waters of neighboring islands, aggravate the sedimentation and eutrophication impact in Nha Trang Bay[1,5,6]. An increased amount of micro particles 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[7,8,9]. As a result,

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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 coastalwaters, which reduce fish stocks, and the barbaric attitude of the residents of coastal areas towards sea inhabitants. A very harmful impact on the coral reefs is caused by collecting corals, shells and other tropical fauna. 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[5,10,11,12] 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[15,16,17,18]. Under favorable conditions, coral fragments attach to the substrate and, when recovered to the size of a colony, they reproduce sexually[19,20, 21,22].

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 aremore likely than the larvae to survive in loose (mobile) soils, owing to their larger sizes and elevated location above the substrate[23,24,25]. 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 inorder to be planted; what should the orientation of the coral fragments by during transplantation; what should the depth of planting be; and should the bottom shall be cleaned from algal growths.

MATERIALS AND METHODS

In October 2003 altogether, 35 coral fragments colonies (6 species of the genera *Acropora* and

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

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

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Porites)were selected from10 donor that were 1–1.5 m high and 2.5–4 min diameter. All but one donor colony grew at a depth of2–3 m, and a colony of *A. palifera* dwelled at 11 mdeep. Peripheral parts of coral colonies with 2 to 17branches were used for the experiment. The frames with fixed transplants were placed at a distanceof 20 to 50 m off the donor colonies at a depth ofsix–seven meters in two periods: on October 8, 2003(steel frames, 2× 1 m), and on May 21, 2004 (plasticframes, 2× 2 m).

Based on an agreement with the Institute of Technology and Applied Research of the VietnameseAcademy 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. 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 frameswas 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 1).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 oftransplantation. 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 2). The first results were recorded 6 months upon the start of the experiment.

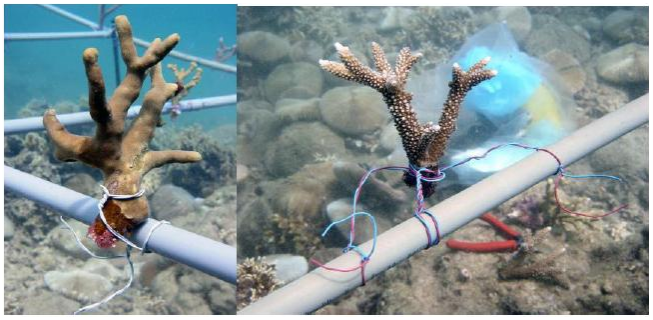

Figure 1 : Methods of attaching fragments of corals

Figure 2 : General view of frame with fragments of coral

RESULTS AND DISCUSSION

All fragments that survived after transplantationrecovered and formed new branches, and the branchesthat were intentionally injured also recovered. About60% of all fragments fused over 6–8 months with theirbases onto horizontal rods of the frames, using them asa substrate. Three fragments sized 100–110 mm diedunrecovered: of them, one fragment of *Acropora microphthalma*, transplanted in October 2003, leanedwith more than 75% of its length against the metalframe of the facility. Nodependence 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 and within 4–6 months formed basal attachments to horizontal bars of the installation and used them as a substrate. A year 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 3). 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. Mediumsized and large fragments of the species *Acropora valida, A. valenciennesi, A.*

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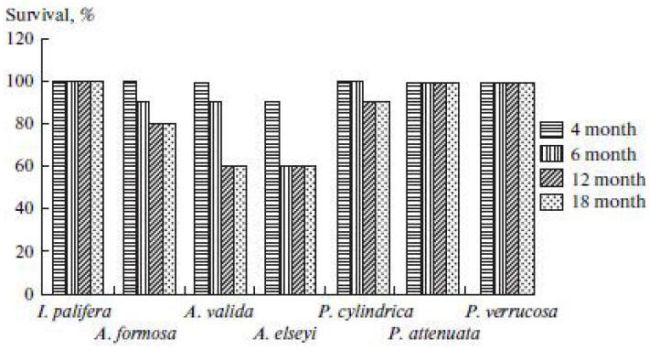


Figure 3 : Survival of transplanted fragments of various coral species.

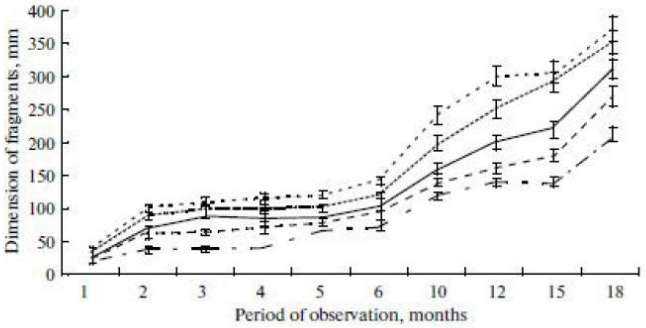


Figure 4 : The linear growth increment of coral fragments of various coral species in the experiment of 2010–2011. (*1*) *Acroporaelseyi*; (*2*) *A. valenciennesi*; (*3*) *A. formosa*; (*4*)*Porites cylindrica*; (*5*)*P.attenuata.*

florida, A. gemmifera, and *Pocillopora verrucosa, Porites attenuate,* and *P. cylindrical* regenerated most successfully. Fragments of *Isoporapalifera*had a 100% survival rate,irrespective of their orientation during transplantation.

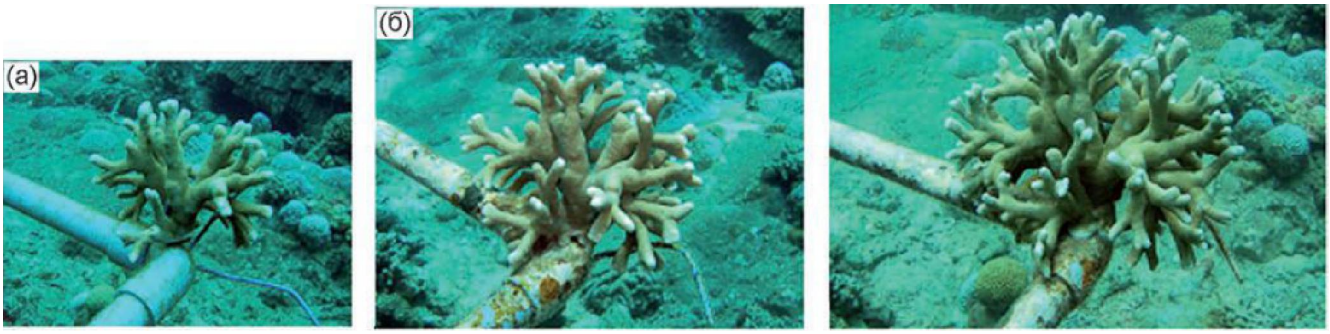
Within 2–2.5 months of the transplantation, new branches formed on the branch surfaces of all the surviving coral species, including the bottom surfaces that were damaged during the separation from donor colonies. The linear growth increment of the coral fragments of various species was 30–160 mm. This 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 (*TABLEs 1 and 2, Figure 4).

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% (Figure 5). Upon extension of the cultivation period from 1 year to 18 months, the coral fragments increased by 1.2–1.5 times. The successful growth of transplanted fragments and the formation of large colonies contributed to the invasion of the damselfish *Dascyllus reticulates* (Pomacentridae) into the new coral assemblages (Figure 6). 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 thicketsof branched corals and seldom depart by more than a distance of 1 m.

These experiments showed that cultivation of coralfragments on artificial facilities can be effective in different reef parts. Large fragments of the studied coralspecies survived better and had higher growth rates. Theyformed the greatest number of new branches and builtlarge colonies, which is consistent with the results thatwere obtained previously[15,23–26]. It is known thatlarge coral colonies that are grown from larger fragmentsalso have the greatest reproductive success[24]. Growth of corals from colony fragments is animportant natural process, at least in corals withbranched colo-

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

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



10.10. 2010, 35 branches 21.04.2011, 59 branches 21.09. 2011, 93 branches

Figure 5 : Growth increment of coral fragments and an increase in the number of branches in the colony of *Porites attenuata*.(a) transplanted fragment; (á) upon 6 months; (â) upon 12 months.

Figure 6 : Settling of fishes *Dascyllus reticulatus* on artificial settlement of corals

nies. Under natural conditions, the broken fragments of colonies first "anchor" on the bottom and then attach to the substrate through theregeneration and growth of the soft tissues and skeleton[17,20,28]. The results we obtained in our experiments agree well with the data that were reported byOcubo et al.[25], 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 withtheir 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 isthe settlement and growth of sea squirts on this artificial substrate.

CONCLUSIONS

Thus, the experiments we carried out in 2010–2011on the coral reefs of Vietnam confirmed that successful survival of coral fragments under natural conditions of coral reef is possible and depends on two mainfactors: the coral species and the size of coral fragmentto be planted. The relatively high growth rates of thefragments of all coral species can probably beexplained by their transplantation into a welllit environment that is less populated by other macrobenthicorganisms. Installation of the experimental facilitiesover the bottom keeps them from becoming buried bysandy sediments.

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

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