Coral Culture and Transplantation: Methods for Use in Coral Reef Restoration, Fisheries Enhancement, and Commercial Coral Aquaculture

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Progress report to the University of Puerto Rico Sea Grant Program.

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August 1999

I continue to focus on publishing data and follow-up of the newer sites and experiments. The reef restoration and coral aquaculture sites in Solomon Islands were revisited in May '99, with a travel grant to the Solomons and Papua New Guinea supplied by Counterpart International. The Solomon Islands Development Trust sponsored a community training on low-tech coral reef restoration and coral aquaculture in Malaita in May. From information gathered during the recent trip to these countries, a conservative estimate of 30-60 million kg of lime is calculated as being consumed each year, chewed with betel nut. Much of this lime is produced by killing and burning staghorn *Acropora* coral. Sites in this region are now focusing on replanting lagoonal areas denuded by the lime trade with staghorn corals and developing sustainable coral culture methods for the lime trade.

An new grant for US$10,800. was received from New Zealand this past May '99, for additional experimental and community training sites in Fiji, and more follow-up in the Solomons. This grant was matched by another $10,000., by Counterpart International in July, and again in August, another $10,800., plus $5,000. in-kind was donated by the Fijian Shangri-La Resort, in support of community training and coral reef restoration in Cuvu Tikina, Nadroga, Fiji. The Cuvu reefs experienced a widespread freshwater kill this past January. There is a receptivity at the community level for conservation, restoring reef habitats, the establishment of marine reserves, etc, and this activity is welcomed by the tourism industry. The plan is to establish a community-based marine reserve around the existing resort, and to train the community in coral reef restoration and fisheries management, with coral aquaculture for the aquarium trade as a project incentive. The reefs of this area present a good model applicable to fringing reefs of the region (Samoa, Vanuatu, Solomons, etc.). This site compliments other sites which mimic atoll-type conditions of calm and sandy lagoons, and the more challenging silty mangrove-backed lagoon sites.

The Foundation for the Peoples of the South Pacific International has determined to identify major funds (1.25 million US dollars) to be able to expand the initial work into a five-year regional project, and a GEF concept paper is in the approval stage by the Fiji Government, for submission to UNDP. Other submissions include MacArthur Foundation, Packard Foundation, and NZODA. Counterpart International, the USA affiliate to FSPI, flew me to Washington DC in November '98 and April '99 to meet with potential funding sources, and for further discussions with NOAA, the State Department, and World Bank officials.

The Fiji Minister of Agriculture, Forests, and Fisheries recently appointed me to a special task force to study the controversial coral trades in Fiji. I have been active in raising awareness at the governmental level of the negative impact of these trades on Fiji's reefs. According to the US Department of State, Fiji is currently the supplier of 81% of the worlds coral harvest by weight. I was visited last month by the US First Secretary for Political and Economic Affairs from the US Embassy about the trades, as the US is considering a ban on imports. I was interviewed by two newspapers, one local and two international: the Associated French Press, and the New Zealand Herald. Two radio interviews were aired during the past month on Radio New Zealand as well, one on the coral reef restoration project, and the other on the coral trades. I am working with two of the six companies on sustainable methods and standards for the industry. The rapidly expanding live rock trade is a special concern that I am gathering new data on, seeking a sustainable solution to the current destruction.

I continue collaborating with IUCN in UK, The Cnidarian Foundation in LA, and with Andy Bruckner of NOAA in DC on statistics for the coral trade into the USA from Fiji, the major global importer/exporter. Several thousand corals have been sold by the women I trained in Marau Sound, Solomons to the aquarium industry in the USA, and the first cultured corals for the bleached curio trade have been harvested in Fiji, and will be sent once a CITES exemption is issued (later this week) to "Just World Trading", the marketing wing of UK-FSP, for a marketing study.

Since January, I presented two papers and two posters at major conferences, at the International Conference on Scientific Aspects of Coral Reef Assessment, Monitoring, and Restoration (NCRI), Fort Lauderdale, April, 1999, and in Sydney, Australia, at the World Aquaculture Society meetings this past May, in the session entitled "Island and Indigenous Aquaculture". The abstracts are enclosed. The paper I presented at the ICRI conference has been accepted for publication in the *Bulletin of Marine Science*. I presented a paper entitled the *"The Coral Gardens Initiative: Island communities planting corals for coral reef management, conservation, and resource restoration"* at the UN-Funded International Workshop on Fisheries Management in Suva, Fiji, June 30-July2, 1999. Three abstracts have recently been accepted for oral presentation at the World Aquaculture Society conference: *Marine Ornamentals '99,* taking place in November in Hawaii, and the papers are being prepared for publication in the conference proceedings. University of Hawaii Sea Grant is being contacted about potential funding to attend the meetings.

In addition to presentations at scientific meetings since January, I have presented slide shows on coral reef restoration and sustainable coral aquaculture at Sea Grant in DC in April, at meetings of FSPI in Papua New Guinea, twice at marine studies classes at the

University of the South Pacific, in Fiji, and eight times to traditional leaders and communities around Fiji.

I was involved in the formation of the **"Low-Tech Action Group for Coral Reef Restoration"**, at the NCRI meetings in April. The vision statement of this group, has aroused much interest and support and is also attached at the end of this report.

In Puerto Rico, work discontinued on restoration sites subsequent to Hurricane Georges in September of last year. A collaborative study was begun in the months prior to that time, with Dr. David Ballantine, studied the extensive yet undescribed rhodolith beds (rounded coralline algae cobbles) that I discovered at several of my sites. These beds are ideal sites for coral culture, with high survival of fragments. We drafted a joint publication, which has now been accepted to the journal *Coral Reefs*. Counterpart International is investigating the application and extension of the "Coral Gardens Initiative" into the Caribbean islands, and will be writing a proposal to this effect. The *Coral Gardens* concept involves the establishment of marine reserves, with the enhancement of coral cover and fish habitat within these reserves, so that the reserve recovers coral cover quickly, which in-turn begins impacting fisheries recovery and accelerating the process of positive change brought about by the reserves.

Co-investigator Antonio Ortiz has deployed several more "reef ball" structures in the past few months, and he continues his work using these structures as foundations for coral transplants and for fisheries enhancement. In September, 1998, during Hurricane Georges, the "reef balls" survived without damage or displacement.

I plan to return to my sites in Puerto Rico sometime in October or November, to hopefully defend my dissertation at that time.

Abstract of paper presented at NCRI meeting, International conference on *scientific aspects of coral reef assessment, monitoring, and restoration*, Fort Lauderdale. April, 1999, paper to be published in a special issue of Bulletin of Marine Science. The abstract was published in the proceedings as *The "Johnny Coral Seed" approach to coral ref restoration: new methods appropriate for lower energy areas*. Title changed in response to non-Americans not understanding American folklore.

LOW-TECH CORAL REEF RESTORATION METHODS MODELED AFTER NATURAL FRAGMENTATION PROCESSES

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A low-cost and environmentally sustainable coral reef restoration method modeled after natural coral reef recovery processes and appropriate for use in developing

countries is described. This method involves scattering coral fragments in lower energy back reef areas of unstable rubble substrate where natural recovery processes are inhibited, using sustainably obtained transplants.

Experiments focus on the post-fragmentation processes important to coral reef recovery, quantifying site-specific, species-specific, size-specific, and substrate-specific survival, growth, and self-attachment of coral fragments. Two coral species were used for the studies, *Acropora cervicornis* and *A. prolifera*, with distinct morphotypes of each species obtained from high and low energy environments. Coral fragments from axial and basal regions of colonies were tested to determine if senescence affects fragment survival.

Results indicate that the mortality and growth of unattached coral fragments is strongly size, substrate, site, species, and morphotype dependent. Coral fragments from axial regions have significantly lower mortality than fragments of similar size obtained from inner colony portions. Back reef and reef front morphotypes of *Acropora cervicornis* grown together in the back reef for one year continued to differ significantly in branch diameter, relative growth, and self-attachment ability, indicating a genetic basis to morphology and adaptation to specific reef environments.

Abstract of paper presented at the World Aquaculture Society meetings in Sydney this past May, in the session entitled "Island and indigenous aquaculture", abstract published in *World Aquaculture 99.*

CORAL AQUACULTURE BY PACIFIC ISLAND COMMUNITIES

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Coral aquaculture in South Pacific Island communities has recently reached the level of successful production (ie. thousands of coral colonies). This article reports on growth trials of scleractinian reef corals in the Caribbean and South Pacific, and reports on coral aquaculture being carried out by coastal communities in Fiji and in the Solomon Islands. Corals are being cultured for sale in the aquarium and ornamental coral trades, for use in the production of betel lime, and for enhancing coral reef fisheries habitat.

Corals are being grown from 3-5cm fragments for the aquarium trade in six months, and for the ornamental coral trade and for lime production in nine months to two years, with higher growth rates than predicted from the literature and with low mortality. The reef-flat and lagoonal culture and transplantation methods are described in detail, and growth and mortality rates are given.

The demand for stony reef corals is high, and this demand is being met almost exclusively by wild harvest. About four metric tons of corals per day are currently being removed from the reefs of Fiji for the international trade in bleached ornamental corals. The aquarium trade removes several hundred thousand juvenile corals per year from South Pacific reefs as well. Traditional coral harvesting in the Solomons and other islands, for the production of betel lime and for use as fill material, has had a major negative impact on many reef areas, and branching *Acropora* corals have been wiped-out from extensive lagoonal areas. Branching corals are important shelter habitat, and coral harvesting has contributed to fisheries decline in these areas.

The "coral reef rehabilitation and sustainable marine farming project" focuses on the rehabilitation, protection, and sustainable management of coral reef resources by Pacific Island communities. An integral part of the project involves replacing the destructive harvest of corals in project communities with a sustainable coral aquaculture industry. The goals of the project are being accomplished by working to establish community-based marine protected areas, developing local resource recovery plans, and by the introduction of simple reef restoration and coral planting methodologies. Corals are being grown for replanting damaged reef areas and for enhancing reef fish habitat within marine reserves. Commercial coral aquaculture for the aquarium and ornamental coral trades, and for the production of betel lime is being introduced in project communities, and will help offset the initial economic burden of discontinuing the wild coral harvest, establishing no-fishing areas, and increasing fishing regulations. The initial work has demonstrated that communities and traditional leaders are responsive to the participatory methods, becoming more environmentally aware as they eagerly participate in the coral aquaculture and coral reef restoration and conservation aspects of the project.

ANNOUNCING THE FORMATION OF:

THE LOW-TECH ACTION GROUP FOR CORAL REEF RESTORATION (LTAG)

Purpose/Aim:

To develop and disseminate inexpensive, low-tech, coral reef restoration and coral cover enhancement methods appropriate for use in "third world" nations and for use by rural fishing communities.

Rationale:

Some 70% of the planet's coral reefs are owned and controlled by rural fishing communities, not by national or state governments. These rural fishing communities are primary stewards of the planet's coral reef biodiversity, and are a chief force of destruction as well. The future of coral reefs is very much in the hands of coastal village communities, but this fact is under-recognized by researchers and the international community at present.

Most coral reef restoration research focuses on repairing damage due to ship groundings, or attempts to enhance the recruitment of coral larvae. While important in situations of the developed world, these methods do not address the needs of most of the planet's coral reefs due to their high-tech and expensive nature.

Many fishing communities are already acutely aware that there is severe problem with declining coral reef resources, being directly impacted by overfishing and habitat destruction. Many of these communities are becoming increasingly receptive to understanding the reasons for fisheries demise/coral reef decline. In areas where destructive fishing methods have been discontinued, the application of low-tech methods to restore coral reefs within traditional fishing areas becomes possible.

Founding members:

Ulf Lindahl, Sweden (working in Tanzania and the Indian Ocean) *ulindahl@kmf.gu.se*
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Austin Bowden-Kerby (working in Fiji, S. Pacific and Caribbean) *bowdenkerby@is.com.fj*

Those of similar research focus and concern, please join us!
Please direct inquires to each of the above members.

The first LTAG general meeting is tentatively planned to be associated with the ICRS meetings in Bali, Indonesia, 2000.

Work of Co-Investigator, Antonio Ortiz
Antonio presented a poster at the NCRI conference, and informed me of his recent work with the reef ball experiment in Guanica and La Parguera. Antonio is actively involved and is making progress in the project.

From my earlier report, you should get an update directly from him:

Concrete "reef ball" molds were obtained from the local NGO, Corallations, and with the assistance of five students from UPR Aguadilla, Antonio Ortiz constructed four "reef balls". Three of these were deployed at three backreef sites in La Parguera. These structures were planted with juvenile massive corals (*Diploria, Montastrea, Calpophyllia*), and results indicate a very successful method. A problems was encountered in that the reef balls are considerably heavier than expected (500-700 pounds each), and this problem needs to be solved if more of this reef ball work is to be carried out. Antonio has since been conducting trials of transplantation methods which affix *Acropora palmata* branches in both erect and prone positions on smaller concrete frames before transplanting. Survival has been good, and many survived the recent hurricane. Antonio is on a year of educational leave from his job at UPR Aguadilla, and is focused intensely on field work, and on writing his dissertation proposal. He plans to undergo new experiments to study the natural population structure of A. palmata, involving electrophoretic studies with assistance from Dr. Fernando Bird, a member of his graduate committee. Understanding the natural clonal structure and natural levels of coral diversity is important in restoring coral reefs following destruction.

WORKING TOWARDS SUSTAINABLE AND ENVIRONMENTALLY SOUND "GREEN" METHODS OF CORAL AQUACULTURE

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Low-tech field culture methods for Scleractinian and other stony corals for the aquarium and curio coral trades have been tested successfully in Fiji, the Solomon Islands, and Puerto Rico. These trials have met with success in all locations, and are in the second phase of refinement. Commercial production of aquarium corals has been reached in Marau Sound, Solomons, and initial marketing trials are proceeding from Kaba, Fiji, for both the aquarium and curio coral trades. This paper provides the details of the culture methods as well as key characteristics essential for certification of cultured corals as "green" products.

The "Coral Gardens" Method involves the low-tech culturing of small 2-3cm coral nubbins into colonies of sufficient size for sale at six months (generally a >500% biomass increase). The method involves planting coral fragments onto small concrete disks or bivalve shell bases. The fragments are not glued onto the bases, but rely on natural self-attachment and overgrowth processes. To hold the coral fragments securely to the bases so that self-attachment can occur, both are woven securely onto wire mesh with 30 lb. test mono-filament line. Simple "culture tables" are constructed to elevate the planted mesh frames over the substrate, made of bent iron bars held together with baling wire, of the type ICLARM uses for *Tridacna* clam culture. Initially coral nubbins are collected as seed from "mother colonies", corals located on the reef with desirable characteristics of color and form. The initial growth trials have identified coral strains (genotypes) with superior characteristics (color, form, growth rates, survivability, etc.), and these colonies are being cultured into mother colonies, to be used in two-three years as coral seed sources, bypassing the need to rely heavily on wild harvested seed.

Corals grown by the "Coral Gardens method" are easily identifiable as properly cultured corals by overgrowth onto a base, as well as by the presence of deeply ingrown monofilament line. The suggestion by some that alizarin dye be used as an indicator, that corals have been cultured for a long enough period to qualify as aquacultured corals, is considered redundant.

Personal experience has shown that aquaculture of corals does not guarantee sustainable or environmentally benign methods. In an effort to plant corals as an income-generating venture, the coral farming women of Marau Sound planted some 30,000 corals within three months of a single workshop, causing moderate reef damage at several sites. Greenhouse culture of corals in cold climates burns fossil fuels and produces volumes of Co_2 gas, and therefore should not be considered a "green" practice. The exploitation of coral reef biodiversity by greenhouse culture of corals in developed countries effectively bypasses the indigenous owners of the parent material, and thus may be considered a violation of certain UN conventions on indigenous rights.

The *Coral Gardens Initiative* encourages a sustainable ornamental industry and involves indigenous communities in the culture of corals as an incentive to the establishment of marine reserves, low-tech coral reef restoration, and community-based resource management plans.

CAN DESTRUCTIVE REEF FLAT MINING PRACTICES OF THE "LIVE ROCK" TRADE BE HARNESSED FOR BIODIVERSITY ENHANCEMENT AND CLIMATE CHANGE MITIGATION?

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Fiji is the current leader in the "live rock" trade, with some 1.8 million kg exported in 1998. The methods of live rock extraction range from very bad to that of minimal impact. The worse case scenario and exceptional example of the live rock industry is the smashing of abundant living corals to get to a base layer of coralline algae-covered rock. The second-worse but widespread impact is the removal of important dead coral shelter habitat and physical attachment structure from the reef. The least-damaging removal of "live rock" appears to be from areas of the intertidal zone which experience periodic exposure, drying, and frequent freshwater kills of organisms such as corals. In this later case, tidal pools have been created by live rock mining, and these pools show promise as a habitat enhancement measure. This study explores the potential beneficial effects of creating a series of tidepools in low biodiversity reef flat biotopes.

Modifications associated with the live rock harvest in the reef flat zone were studied at several sites in Nadroga, Fiji. Tidepools were observed to be significantly more diverse in both plant and animal life than the exposed reef flat rock, regardless of whether they were naturally or artificially created. However, for reef flats with a distinct algal rim on the reef crest. which serves to entrain water on the reef flat during low tide, the mining of live rock appears to endanger the wider reef flat area, as breaking the algal rim during mining can result in draining this entrained intertidal water during low tide, causing extensive drying of the reef flat and the mortality of organisms.

An additional factor, the ability of various types of reef flats to slow wave-generated currents was studied. Results using a flow meter indicate that a series of tide pools on the outer reef flat serves as a baffling system, slowing wave-generated currents.. The redirection of reef flat mining for live rock, and the re-mining of tidepool depressions once the desired coralline algae regrow over the dead rock surfaces, would result in the deepening of the tidepools, and could allow for the construction of a series of tidepools on the outer reef flat zone. These reef flat modifications could potentially dissipate waves and slow wave-generated currents, helping decrease beach erosion during storms. The potential thus exists for the development of procedures and methods to channel the live rock trade towards specific reef flat modifications as a workable climate change and storm wave mitigation measure. Presently the practices of the live rock trade by no means approach this standard.

THE CORAL GARDENS INITIATIVE: CORAL AQUACULTURE AS AN INCENTIVE FOR COMMUNITY-BASED CORAL REEF CONSERVATION AND RESTORATION

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Coral reefs are vital providers of protein-rich food for island communities and provide needed income in the form of fisheries and tourism resources. Unfortunately, coral reefs are rapidly declining due to increasing development pressures and negative human impacts.

Coral is the primary shelter habitat for reef fish, thus a decline in coral cover results in a decline in reef fish. Coral cover is declining regionally. Fiji has become the global leader in the trade in corals, with over 80% of the global trade by volume: live rock, curio corals, and aquarium corals. Coral, live rock, and ornamental fish collection practices in Fiji are at present unmonitored, and range from relatively minor to blatantly damaging in their impacts to the reefs of Fiji. The FSP Coral Gardens Initiative seeks sustainability for these industries based on the development of sustainable procedures, community-based monitoring, resource management, and coral aquaculture as a realistic alternative to the destructive coral harvests.

The *Coral Gardens Initiative* recognizes the important role fishing communities play as the primary stewards of Pacific Island coral reef resources. The initiative combines a consultative planning approach with practical action, building upon the traditional knowledge base of island fishing communities. Coal Gardens involves communities in environmental awareness, marine resource management, proven conservation and low-tech reef restoration techniques, and sustainable coral aquaculture as an income-generating project incentive. The overall objective of the project is the development and testing of a community-based marine resource management model with widespread global applicability. Fiji was chosen as a testing ground for the project based on the importance of the coral trades, the fact that Fiji is the regional leader in tourism, as well as the fact that Fiji has all of the major reef types found in the Indo-Pacific region.

The Foundation for the Peoples of the South Pacific International is an experienced international network of non-government agencies, with metropolitan offices in the UK, USA and Australia, and with independent national affiliates in PNG, Fiji, Tonga, Kiribati, the Solomon Islands, Vanuatu, Tuvalu, and Samoa. The Fiji model will be applied during phase two of the project throughout this network. The project will focus on community-based management and restoring coral reef health throughout the region. Various national focuses are envisioned as well, such as the replanting and aquaculture of staghorn corals in the Solomon Islands and Papua New Guinea, harvested for the production of lime to chew with betel nut. In Kiribati, Tuvalu, and Tonga, the planting of new reefs on lagoonal sand flats for fisheries enhancement and for mitigation of the impact of sea level rise will be a special focus of the project.

TRANSFORMATION OF ARTIFICIAL CONCRETE "REEF BALL" STRUCTURE INTO LIVING CORAL HEADS THROUGH THE USE OF IMPLANTS OF JUVENILE MASSIVE CORALS

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Key Words: reef restoration, implants of massive corals, reef balls, artificial reefs, back reef,

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TRANSFORMATION OF "REEF BALL" STRUCTURE INTO LIVING CORAL HEADS

Abstract

Implants of massive corals over long lasting artificial reefs, like concrete reef balls (a coral-like dome) have proven to be useful for the restoration or development of a small patch reef on back reef area. The potential ability of some massive corals to spread over an artificial reef structure can reduce the time of colony development while enhancing vertical stratification of coral microhabitats. Three concrete "reef balls" were deployed at three back reef sites in La Parguera, southern Puerto Rico. These structures were planted with juvenile massive corals (< 20 cm diameter) of several species (*Diploria spp.*, *Montastraea spp.*, *Colpophyllia spp.* and *Siderastrea siderea*) using marine cement. Dead coral heads observed near reef balls were also planted with juvenile massive corals. Jeopardized coral populations from shallow reef flat zones were used as a source for transplants (n=62 colonies). Overall survivorship of corals one year after transplantation was 90 % (93 % for reef balls (n=42), 85% for dead coral heads (n=20)). In addition, coral colonies overcame the impairment of the wave action, which occurred during Hurricane Georges. These preliminary results indicate a very successful rate for the methodology employed.

Introduction

There is a general thought that natural reefs cannot rebuild themselves fast enough to meet human demands (Hughes, 1994; Grigg and Dollar, 1990). Thus, there is a concern to identify management options to protect and restore coral communities. One of those management options proposed is the establishment of effective methodologies for coral propagation through human activities. Transplantation of corals for the recovery of degraded reefs has been extensively discussed by several authors (Alcala et al., 1982; Birkeland et al., 1979; Bowden-kerby, 1996; Clark and Edwards, 1995; Guzman, 1991; Harriot and Fisk, 1988; Hudson and Diaz, 1988; Hudson et al., 1989; Kojis and Quinn, 1981; Maragos, 1974; 1992, Plucer- Rosario and Randall, 1987; Yap and Gomez, 1985). The basic approach is to introduce new colonies of fast growing species into the reef. The establishment, growth, development and maturating of these colonies may increase larvae production and recruitment locally or the increase the number of colonies by the establishment of broken off fragments from transplanted colonies (Bowden-Kerby, 1996). There is a widespread use of branching species for restoration plans because of their high survival rate, fast growth rate, aesthetic appeal and increased vertical stratification (Bowden-Kerby, 1996; Harriot and Fisk, 1988).
Massive corals also have the ability to reproduce asexually by the propagation of broken fragments of individual colonies. This provides enhanced colony survival, propagation, and dispersion of the genet. However, massive corals are limited by their slow growth rate. To increase coral cover by transplantation of fragments or juvenile massive colonies (without transplantation of very large colonies) requires long-term survival studies. Thus, this limitation may repress our willingness to actively transplant massive corals to increase coral cover and vertical stratification of reef microhabitat.
Reef ball structures are long lasting artificial reefs, which are being used increasingly worldwide for fisheries enhancement. To a certain extent, reef balls mimic large, eroded, massive, corals heads, a commonly found formation on Caribbean reefs, this provide important fish habitat. As previously accomplished by Hudson et al. (1989), we suggest that these artificial structures be implanted with several massive coral colonies. These implanted structures are useful for restoring the reefs appearance and creating a small reef patch on sandy back reef areas. The potential ability of some massive corals to spread over artificial reef structures may reduce colony development time while enhancing vertical stratification of reef microhabitat. The objective of this study was to investigate the possibility of transforming artificial reef ball structures into living coral heads with small, massive coral colonies. The goal of this experiment is to test survivorship, attachment, and permanence of massive coral species on concrete reef ball structures.

Methodology

Study sites

Three back reef sites in La Parguera, southern Puerto Rico were selected for this study: 1) East of Enrique Reef; 2) West of Enrique Reef; and 3) Mario Reef. In March 1998, one concrete reef ball was deployed over sandy bottom at each site (10-15 feet depth) (Figure 1).

Reef ball construction and transportation

Reef balls (1.2 m height x 1.2 m width, and weighing 250 Kg) were constructed on land, using molds loaned from Coralations Inc., and following a modified protocol provided by Reef Ball Company. Two modifications to the protocol were implemented: 1) no silicate compound was used in the mix in order to reduce the recruitment of algae over the ball; and 2) we attached Styrofoam wheels over the inner part of the mold to create small holes (9 cm diameter) over the surface of the ball to affix coral colonies. Reef balls were transported to the study sites by using floats and towing with a small boat.

Collection sites

Juvenile or small massive corals (< 20 cm diameter) of several species (*Diploria spp.*, *Montastraea spp.*, *Colpophyllia spp.* and *Siderastrea siderea*) were collected from two shallow (0.5 m) reef flat zones on the west side of Laurel Reef and from the east side of Enrique Reef.

These were transported in buckets with seawater to the transplantation sites. Most of those colonies collected have been found unattached over sandy bottom or coral rubble.

Planting corals

Colonies were attached to the reef balls using underwater cement. Cement was prepared by mixing, five parts per volume of Portland type I cement to 1 part of molding plaster. After mixing with enough water (approximately 3 parts), a small ball was applied immediately into the small holes created using Styrofoam on the reef ball. Once the cement was in place the colony was affixed as soon as possible to the reef ball. The same method was used to affix coral colonies onto a dead coral structure.

Results

Sixty-two colonies were transplanted in the three study areas (Tables 1 and 2). One year after transplantation the overall survivorship of transplanted corals in colonies affixed onto reef balls and colonies on dead coral heads was 90% (93 % for reef balls (n=42), 85% for dead coral heads (n=20)). These preliminary results indicate a very successful rate for this methodology, also considering that coral colonies overcame the storm surge wave action, which occurred during Hurricane Georges and widespread bleaching that occurred during this year.
The omission of silicate, which reduces the pH of the cement mix, did not restrict coral growth over the surface of the ball. Ten colonies representative of each species have been observed growing and spreading over the reef ball. Besides, we observed a recruitment of five coral species and other invertebrates over and within the reef ball (Table 3). The inner part of the reef balls are covered with encrusting sponges, bryozoans and some other organisms not reported in the Table 3.

Discussion

One of the major problems of past transplantation studies (Birkeland et. al, 1979; Clark and Edwards, 1995; Plucer-Rosario and Randall, 1987) is the loss of coral colonies. The preliminary results of this pilot study reflect that the methods used are efficient for coral colony transplantation, since no colonies were lost. High survival of coral transplants and the stable substrate provided by reef balls for long periods of time (10-15 years) will promote coral establishment and growth. Long term observations of similar studies were conducted by Hudson et al. (1989). They built a small patch reef using 23 hollow concrete domes (similar to reef balls) which were implanted with 32 hard corals of 10 species. Ten years after inmersion the dome showed no signs of deterioration and the overall survivorship was 87.5 %. Both Hudson et al. (1989) and the present study indicate that this methodology has widespread application potential for enhancing the recovery of damaged coral reefs and the creation of small patch reefs in suitable areas.

Another consideration is the collection of colonies for transplantation and its effects on natural populations. Preliminary observation in Puerto Rico have identified numerous juveniles or small massive coral species recruiting to areas of extremely shallow depths (< 0.5 m). Long-term survival to adulthood for these colonies may be lessened in this shallow zone, many of these corals are unattached or weakly attached to the substrate and could therefore be transported by storm currents to deeper sandy areas. These jeopardized coral populations offer a potential source for transplants.

Conclusion

Currently reef balls are being used to construct artificial reefs, it is surprising that these have not been implanted in order to reduce the establishment time of coral species. A possible cause of this may be the companies (Reef Ball, Inc.) suggestion that reef balls have the capacity to recruit corals. After one year of observation, a total of 36 hard coral colonies have recruited on 3 reef balls (Table 3). Hudson et al. (1989) reported 45 scleractinian corals comprising 7 species and a total of 89 octocorals comprising 15 species recruited in ten years. Even though these structures are able to recruit coral colonies this methodology may select particular coral species and reduce time required for their successful establishment. This may also be of practical use in the establishment of small patch reefs in areas unsuitable for coral recruitment.

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APPENDIX

Table 1. Number of colonies of each coral species planted on each reef ball at the start of the investigation and number of colonies dead after one year.

Corals species	**Reef Ball at Enrique Reef (East)**		**Reef Ball at Enrique Reef (West)**		**Reef Ball at Mario Reef**	
	planted	dead	planted	dead	planted	dead
Diploria strigosa	4	0	4	0	6	0
Diploria clivosa	1	0	2	1	1	0
Diploria labyrinthiformis	1	0	3	1	5	0
Colpophyllia natans	2	0	4	0	1	0
Montastraea annularis	1	0	3	1	3	0
Siderastrea siderea	1	0	0	0	0	0
Total	10	0	18	3	16	0

Table 2. Number of colonies of each coral species planted to dead coral heads at two study sites at the start of the investigation and those dead after one year.

Corals species		**Enrique Reef West**		**Mario Reef**	
		planted	dead	planted	dead
Diploria strigosa		4	1	4	1
Colpophyllia natans		2	1	2	0
Montastraea annularis		4	0	4	0
	Total	10	2	10	1

Table 3. Number and classification of organisms recruited on each reef ball.

Observed Organism	Enrique Reef East	Enrique Reef West	Mario Reef
Hard Corals			
Favia fragum	7	2	16
Colpophyllia sp.	2	0	0
Porites astreoides	0	0	5
Agaricia sp.	0	0	2
Diploria strigosa	0	0	2
Polychaetes			
Spirobranchus giganteus	3	2	0
Crustaceans			
Panulirus argus	2	0	0
Stenopus hispidus	2	2	0
Percnon gibbesi	3	0	1
Echinoderms			
Diadema antillarum	8	3	0
Lytechinus variegatus	0	3	0
Echinometra lucunter	0	0	8
Tunicates			
Ascidia nigra	5	1	0
other	12	3	0
Total	44	16	34

Figure 1. Map of La Parguera, southern Puerto Rico.
Number indicate the back reef sites selected for this study.