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Coral of opportunity survivorship and the use of coral nurseries in coral reef restoration

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Abstract Coral reef damage is unfortunately becoming a common occurrence off southeast Florida, U.S.A. Reattachment of the dislodged scleractinian corals usually initiates damage site restoration. Because mortality of dislodged colonies is typically high and natural recovery in southeast Florida is typically slow, transplantation of additional scleractinian corals into a damaged area has been used to accelerate reef recovery. Donor colonies available for transplantation have been grown *in situ*, grown in laboratories, and taken from non-damaged reef areas. An alternative source of donor colonies for transplantation into damaged sites is "corals of opportunity," which we define as scleractinian corals that have been detached from the reef through natural processes or unknown events. This paper describes a project, initiated in 2001 in Broward County, Florida, that was developed to collect these dislodged colonies and transplant them to a coral nursery. Coral nurseries are interim locations that function as storage sites for corals of opportunity where they can be cached, stabilized, and allowed to grow, until needed as donor colonies for future restoration activities. This project is a partnership between a local university, county government, and a volunteer dive group. Two hundred and fifty corals of opportunity were collected, transplanted to the coral nurseries, and monitored for survival. Transplanted colony survival was similar to that of naturally attached control colonies and significantly greater than that of corals of opportunity left unattached. Results provide resource managers with information on the utility of using corals of opportunity as a source of transplant donor colonies, and the value of using coral nurseries to create a reserve of corals of opportunity for use in future coral reef restoration activities.

Keywords restoration, transplantation, coral of opportunity, coral nursery

Introduction

Coral reef damage from ship groundings and marine construction activities is unfortunately a common occurrence off southeast Florida, U.S.A. Current restoration of these damaged coral reefs generally begins with the reattachment of viable scleractinian corals dislodged from the damaged site (Jaap 2000). These colonies typically represent only a fraction of the original coral population. In addition, due to damage-caused mortality of dislodged colonies (Gilliam et al. 2000; Jaap 2000), as well as slow natural recruitment (Gilliam et al. 2000; Jaap 2000), a return to pre-impact scleractinian coral abundance, density, and cover in southeast Florida may take from several decades to a century (Jaap 2000; Pearson 1981; Harriott and Fisk 1988). Transplantation of additional scleractinian corals may accelerate the early stages of natural reef recovery by returning the damaged site to pre-impact scleractinian coral abundance, density, and cover, by promoting increased recruitment through larvae released from transplants and transplants attracting recruits, and by maintaining substrate complexity (Gilliam et al. 2000; Yap et al. 1990).

Donor colonies for coral transplantation into a damaged site are generally available from two sources: 1) planulae-larvae grown *in situ* or in the laboratory (Rinkevich 1995), and 2) adult colonies taken from existing undamaged reef surfaces (Bouchon et al. 1981). The process of rearing planulae-larvae can be time-consuming and expensive (Jaap 2000), and may result in high mortality (Oren and Benayahu 1997; Rinkevich 1995). Removing colonies from a non-damaged reef area for transplantation to a damaged site may result in no net gain (Edwards and Clark 1998; Miller 2002; Becker and Mueller 2001). As an alternative, natural (Lindahl 1998; Nagelkerken et al. 2000; Bowden-Kerby 1997) and artificially-produced (Guzman 1991; Kobayashi 1984; Becker and Mueller 2001) fragments of fast-growing, branching species have been used as donor colonies in coral transplantation; however, this limits the number of species with which one can repopulate a reef, especially in southeast Florida where most coral species are not fast-growing (both in comparison to the rest of the Caribbean, and the Pacific) (Glynn 1973) or branching (Gilliam 2004). Additionally, the free-living corals *Goniopora stokesi* Milne Edwards and Haime, 1851

(Rosen and Taylor 1969) and species in the family Fungiidae (Yap et al. 1990; Yates and Carlson 1992; Highsmith 1982) have been suggested for use as donor colonies in coral transplantation, but this is not an option in southeast Florida.

This paper introduces the utility of using "corals of opportunity" as an additional source of donor colonies for scleractinian coral transplantation. We define "corals of opportunity" as scleractinian coral colonies dislodged from the reef from unidentified causes such as bioerosion, storms, or unreported anchor damage. We do not include colonies that were dislodged from identified events (e.g., ship groundings), which usually are designated for reattachment to the damaged site as part of primary restoration activities. Also, as we define them, corals of opportunity do not include species that utilize fragmentation as a means of asexual reproduction (i.e., mainly *Acropora* spp. in southeast Florida). Unlike fragments, corals of opportunity are generally not capable of regenerating, regrowing, or reattaching to the substrate (personal observation). Dislodgement is not an adaptive, normal occurrence for the species that comprise corals of opportunity (e.g., *Montastraea cavernosa* [Linnaeus 1766]), and therefore they require reattachment in order to survive and grow (Graham and Schroeder 1996). As with colonies dislodged due to a damage event, scattering corals of opportunity over unstable substrate may retard reef recovery (Jaap 2000). Also not included in our definition are coralliths, solitary rugose corals, and spherical corals (Bolton and Driese 1990; Scoffin et al. 1985; Glynn 1974; Lewis 1989). These detached, relatively fast-growing, mobile coral colonies live in environments where bottom disturbance is normal (Glynn 1974). Thus an intact cover of live tissue around the entire colony is maintained (Scoffin et al. 1985) through rolling (Riegl et al. 1996) and/or passive self-righting (Hubmann et al. 2002). This is not the case with corals of opportunity in southeast Florida.

Corals of opportunity, as detached colonies, are susceptible to bleaching, partial mortality, disease, algal overgrowth, and may even perish (Jaap 2000) unless salvaged from the reef and reattached to a stable substrate (i.e., coral nursery). We define "coral nurseries" as secure substrates that serve as interim locations for the creation of a reserve of corals of opportunity. The purpose of coral nurseries is to provide a temporary storage site for corals of opportunity to stabilize, continue to grow, and to be readily available for transplantation to a damaged site in the future.

In 2001, this community-based project was established in Broward County, southeast Florida, U.S.A. It utilizes personnel from volunteer groups, government, and academia to search for and collect viable corals of opportunity from local reef areas, relocate them to a coral nursery, and monitor colony survivorship. The project involves local academia (National Coral Reef Institute-Nova Southeastern University Oceanographic Center [NCRI-NSU OC]), a local government (Broward County Environmental Protection Department [BC EPD]), and a local non-government dive organization (Ocean Watch Foundation [OWF]). NCRI-NSU OC and BC EPD scientists and managers developed protocols for and supervised volunteers during coral of opportunity collection, transplantation, and monitoring.

This project has three goals: 1) to establish a coral nursery in Broward County, Florida, U.S.A. composed of corals of opportunity that may perish if left unattached from the reef substrate, 2) to train and utilize a local community-based team, composed of a partnership of volunteers, scientists, and managers, in the establishment and maintenance of this coral nursery, and 3) to ultimately use the transplanted corals of opportunity as transplant donor colonies in future coral reef restoration activities. This paper discusses the success of transplanting corals of opportunity to coral nurseries, in terms of survivorship, in comparison to that of naturally attached coral colonies, and to corals of opportunity that have not been transplanted to a stable substrate.

Materials and methods

The Florida Reef Tract is a large barrier reef system. It extends from the Dry Tortugas and Florida Keys northward to Miami (Marszalek et al. 1977); however, well-developed coral reefs do exist north of Miami along this tract in Miami-Dade, Broward, and Palm Beach Counties (Goldberg 1973). Coral reefs in this area are near the northern limit for active reef accretion due to natural reductions in light and water temperatures (Lightly et al. 1978; Goldberg 1973; Jaap 1984). The high-latitude reefs off of Broward County, Florida, are composed of three increasingly deeper, shore-parallel terraces (inner, middle, and outer reefs, respectively), and a near shore ridge complex located inshore of the inner reef (Moyer et al. 2003) (Fig. 1). The inner reef of Broward County, previously referred to as the Second Reef (Goldberg 1973), was selected as the location of this project because: 1) preliminary searches indicated that corals of opportunity are available, 2) depth (8-13 m) is conducive to the amount of diving work to be done with volunteers, and 3) the benthos and environmental conditions of the inner reef are similar throughout Broward County (Moyer et al. 2003).

Corals of opportunity were collected from inner reef sites offshore Broward County at depths of between 8-13 m, and were transplanted to coral nurseries adjacent to the inner reef at 13 m depth (Fig. 1). Each field day consisted of two SCUBA dives. Corals of opportunity were located and collected by hand within search areas of approximately 1000 m^2 during the first dive by scientists, managers, and volunteers. State of Florida permit requirements restricted the collection of colony sizes to between 5 and 40 cm in diameter (long live-tissue axis), as well as prohibiting the collection of the branching colony *Acropora cervicornis* (Lamarck, 1816). Collection site depth and location were recorded. In order to correlate the original condition of a collected coral of opportunity with its survival in the coral nursery, data were recorded on the original position of the colony when found (tissue side up or down) and the substrate type the colony was resting on (hard substrate or sand).

Colonies with disease, boring sponge (*Cliona* spp.), or high partial mortality (> 60%) were not taken to the nursery.

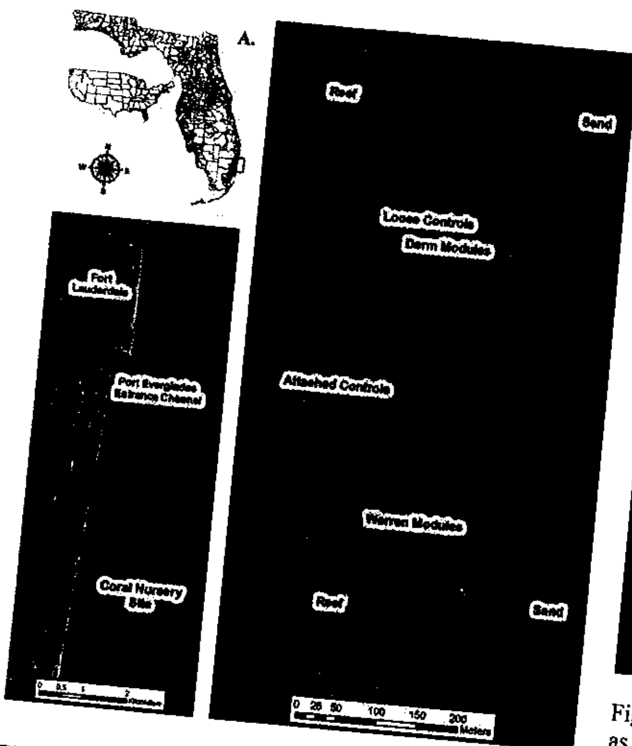

Fig. 1. Project Location. **A**, Location of Broward County, southeast coast of Florida. **B**, Laser Air Depth Sounding (LADS) sunshaded bathymetric image of the southern part of the Broward County coastline. Note the three shore-parallel terraces, inner (I), middle (M), and outer (O) reefs, and a near shore ridge complex (NSRC) located inshore of the inner reef. The Coral Nursery Site is located less than 4 km south of Port Everglades along the inner reef. **C**, LADS sunshaded bathymetric image of the Coral Nursery site which is comprised of four locations: two coral nurseries (Warren Modules and DERM Modules) and two control coral sites (Attached Controls and Loose Controls).

Collected corals of opportunity were brought to the research vessel in baskets, and transported to the coral nursery immediately after the collection dive. During transportation, additional data about each colony were recorded (species, percent mortality, percent bleaching, and incidence of encrusting organisms). Colonies were transported via the "dry method" (Becker and Mueller 2001). Corals were generally out of the water for less than two hours.

The state permit for this project did not allow for the use of natural substrate as a nursery. Funding did not allow the deployment of artificial substrate specifically designed as coral nurseries; use of two previously deployed artificial substrates in Broward County, the Warren Modules and the DERM Modules (Fig. 2), was suggested and approved by BC EPD. Both the Warren Modules and the DERM Modules were deployed in 2001 as mitigation for unrelated projects. Both modules are located at 13 m depth, approximately 350 m from each other on sand substrate offshore of and adjacent to the inner reef (Fig. 1). The Warren Modules are composed of 55 cm x 55 cm x 15 cm concrete blocks stacked in pyramid fashion (Fig. 2); three Warren Modules were used as the first coral nursery. The DERM Modules are a standard design used by Miami-Dade County Department of Environmental Resources Management (DERM) (PBS&J 1999). They are composed of 2.59 m x 1.52 m x 1.52 m concrete slabs, concrete culverts, and limestone boulders (Fig. 2), arranged in 5 sets of 6 modules each (PBS&J 2000). Thirteen DERM Modules have been and will continue to be used as the second coral nursery.

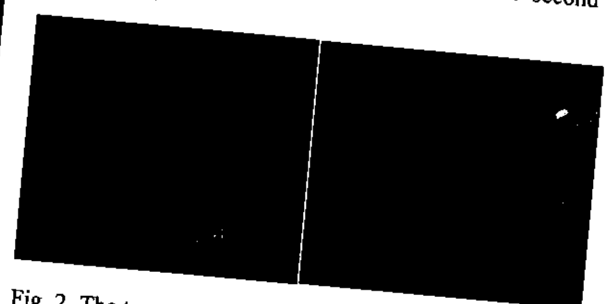

Fig. 2. The two artificial substrates utilized in this project as coral nurseries: **A**. Warren Modules, and **B**. DERM Modules.

Corals of opportunity were transplanted to the nurseries during the second dive using Portland Type II cement (Alcala et al. 1982; Auberson 1982; Harriott and Fisk 1988; Jaap 2000; Gilliam et al. 2000), which was mixed with seawater on the vessel and placed into covered buckets. The surface of the nursery was prepared by scraping off sediment and encrusting organisms to promote adhesion of the cement. All transplanted colonies were tagged.

Immediately after transplantation, planar images of the transplanted colonies were taken using a digital camera in an underwater housing attached to a 37.5 cm x 50.0 cm, scaled framer. These images were used as a visual reference of the condition of the colonies at the time of transplantation. The location of each colony within the nursery was mapped and the depth of each transplant was recorded.

In order to compare transplanted coral of opportunity survivorship to that of naturally attached scleractinian coral colonies, attached control colonies on an inner reef site near the coral nurseries were mapped, tagged, and monitored. The Attached Controls site is located approximately halfway between the Warren Modules and the DERM Modules (Fig. 1). Species and size distribution of these attached control colonies was based on the species and size distribution of the transplanted colonies. Images were taken of the attached control colonies in the same manner as the transplanted corals of opportunity for a visual reference of the initial condition of the colonies.

The survivorship of the transplanted corals of opportunity was also compared to a set of corals of opportunity not transplanted to a coral nursery. These loose control colonies were collected and transported as described earlier. Instead of being transplanted to one of the coral nurseries, these colonies were placed tissue-side up on an inner reef site adjacent to the DERM Modules (Fig. 1). The positions of these colonies were mapped with reference to a stake inserted into the substrate. Tags were secured to the undersides of the colonies. The choice of species and size distribution of these loose control colonies was based on the species and size distribution of the transplanted corals. Images were taken of the loose control corals in the same manner as the transplanted corals of opportunity to provide a visual reference of the initial condition of the colonies.

Images were taken of each coral of opportunity, attached control colony, and loose control colony when they were transplanted, tagged, and/or relocated, and subsequently quarterly, for two years. During each subsequent monitoring event, data were recorded on the condition (presence of disease, bleaching, and encrusting organisms) and stability (attached, loose, or missing) of the transplanted colonies, attached control colonies, and loose control colonies. Loose control colony movement since the previous monitoring event was also recorded. Additionally, the position (tissue side up or down) of each loose control colony was recorded. If the colony was found tissue side down it was up-righted to allow for an image of the tissue side to be taken. The colony was then placed back in the position in which it was found.

Five 2x2 contingency tables were created and tested for significance using the Chi-square test of independence at $\alpha = 0.05$ and 1 degree of freedom (Sokal and Rohlf 1995; Rohlf and Sokal 1995). Alive and dead proportions of the following treatments were compared: 1) the total number of transplanted corals of opportunity v. the total number of attached control corals, 2) the total number of transplanted corals of opportunity v. the total number of loose control corals, 3) the total number of attached control corals v. the total number of loose control corals, 4) the total number of corals transplanted to the Warren Modules v. the total number of corals transplanted to the DERM Modules, and 5) the six species of corals common to both transplanted corals of opportunity and attached control corals.

Results

A total of 253 corals of opportunity, representing 17 species, were transplanted to the coral nursery during 14 collection days between 3 June 2001 and 7 December 2002. An average of 23 corals of opportunity were collected each field day, with a maximum of 36 colonies collected. After eliminating colonies with disease, boring sponge, and high partial mortality, an average of 18 colonies were transplanted each field day. Two hundred and fifty of the colonies, representing 14 species, were monitored quarterly for survivorship from the date of transplantation to the last monitoring event in January 2004 (Table 1). The monitoring period for the transplanted corals ranged from a maximum of 31 months (colonies transplanted in June 2001) to 13 months (colonies transplanted in December 2002). In January 2004, 240 (96.0%) of the 250 monitored corals of opportunity were securely attached to the nursery substrate and alive (Table 1). Eight of the 14 species of transplanted corals of opportunity had 100% survival over the monitoring period. Of those species that contributed more than five colonies, *Dichocoenia stokesi* Milne Edwards and Haime, 1848, had the lowest survivorship (4 of 12 died). Mortality of *D. stokesi* was attributed to White Plague disease that infected the colonies during the summers of 2002 and 2003.

Fifty-eight attached control coral colonies, representing six species, were tagged and monitored quarterly for survivorship from date of tagging to the last monitoring in January 2004 (Table 1). Ten *Montastraea cavernosa* colonies and 10 *Meandrina meandrites* (Linnaeus, 1758) colonies were first assessed in June 2001 (Fahy 2003). The remaining 38 colonies were first assessed in November 2001. The monitoring period for the attached control corals ranged from a maximum of 31 months (colonies tagged in June 2001) to 26 months (colonies tagged in November 2001). Of the 58 attached control colonies, 56 (96.6%) were still attached and alive in January 2004 (Table 1). Four of the 6 species of attached control corals had 100% survival over the monitoring period. Interestingly, one attached control coral became dislodged between the August 2002 and December 2002 monitoring periods, but was still living in January 2004.

Twenty-eight loose control coral colonies, representing 9 species, were tagged and monitored quarterly for survivorship from June 2002 to the last monitoring in January 2004 (Table 1). The monitoring period for the loose control corals was 19 months. In January 2004, 19 (67.9%) of the 28 colonies remained in the mapped area and had living tissue (Table 1). None of the 9 species of loose control corals had 100% survival over the monitoring period. Eight of the 9 colonies that died during the monitoring period remained in the mapped area, while one colony has not been found since its initial assessment, and was presumed dead.

Overall, the survivorship of the transplanted colonies was statistically indistinguishable from that of the attached control colonies ($X^2 = 0.038$, df = 1, $p > 0.50$) (Table 1). The corals of opportunity that were not transplanted to the nursery (loose control corals) had a highly significantly reduced survivorship (67.9%) compared to both that of the transplanted colonies (96%) ($X^2 = 13.320$, df = 1, $p < 0.001$), and the attached control colonies (96.6%) ($X^2 = 13.939$, df = 1, $p < 0.001$) (Table 1).

Of the 250 monitored corals of opportunity, 58 colonies (23.2%), representing 12 species, were transplanted to the Warren Modules; the remaining 192 colonies (76.8%), representing 14 species, were transplanted to the DERM Modules (Table 2). The

Table 1. Overall species contribution and percentage survivorship of transplanted corals of opportunity, attached control corals, and loose control corals. * indicates six species common to both transplanted corals of opportunity and attached control corals. Percentage survivorship is from date of transplantation and/or tagging to the last monitoring event in January 2004.

Species	Transplanted Corals		Attached Control Corals		Loose Control Corals	
	# Monitored	# Survived	# Monitored	# Survived	# Monitored	# Survived
Siderastrea siderea (Ellis and Solander, 1786)*	78	78	18	17	8	7
Montastraea cavernosa (Linnaeus, 1766)*	42	42	10	10	1	0
Meandrina meandrites (Linnaeus, 1758)*	30	28	10	10	6	5
Solenastraea bournoni Milne Edwards and Haime, 1849*	26	26	6	5	3	2
Stephanocoenia michelinii Lamarck, 1816*	21	20	5	5	5	4
Dichocoenia stokesi Milne Edwards and Haime, 1848	12	8	0	0	2	1
Porites astreoides Lamarck, 1816*	11	11	9	9	0	0
Colpophyllia natans (Houttuyn, 1772)	6	5	0	0	1	0
Diploria labyrinthiformis (Linnaeus, 1758)	6	6	0	0	0	0
Porites porites (Pallas, 1766)	6	6	0	0	0	0
Montastraea faveolata (Ellis and Solander, 1786)	5	4	0	0	0	0
Eusmilia fastigiata (Pallas, 1766)	3	2	0	0	1	0
Agaricia agricites (Linnaeus, 1758)	2	2	0	0	0	0
Diploria strigosa (Dana, 1846)	2	2	0	0	1	0
Overall total	250	240	58	56	28	19
Overall % survivorship		96.0		96.6		67.9
Total for six common species	205	202	58	56		
% survivorship of six common species		96.0		96.6		

monitoring period for the corals of opportunity transplanted to the Warren Modules ranged from a maximum of 31 months (colonies transplanted in June 2001) to 29 months (colonies transplanted in August 2001). The monitoring period for the corals of opportunity transplanted to the DERM Modules ranged from a maximum of 27 months (colonies transplanted in October 2001) to 13 months (colonies transplanted in December 2002). In January 2004, 53 of the 58 (91.4%) corals of opportunity transplanted to the Warren Modules were securely attached and alive; whereas 187 of the 192 (97.4%) corals of opportunity transplanted to the DERM Modules were securely attached and alive (Table 2). Seven of the 12 species of corals transplanted to the Warren Modules had 100% survival over the monitoring period (minimum of 29 months). Eleven of the 14 species of corals transplanted to the DERM Modules had 100% survival over the monitoring period (minimum of 13 months). The five colonies that died on the Warren Modules, one of each species, are *Meandrina meandrites*, *Dichocoenia stokesi*, *Stephanocoenia michelinii*, *Montastraea faveolata* (Ellis and Solander, 1786), and *Eusmilia fastigiata* (Pallas, 1766); the five colonies that died on the DERM Modules are 1 *M. meandrites*, 3 *D. stokesi*, and 1 *Colpophyllia natans* (Houttuyn, 1772) (Table 2). Transplanted coral of opportunity survival on the Warren Modules was significantly less than that of the corals of opportunity transplanted to the DERM Modules (97.4%) ($X^2 = 4.199$, df = 1, $p < 0.05$), although still very successful with 91.4% survival.

The six species common to both the transplanted corals and the attached control corals, (*Siderastrea siderea* [Ellis and Solander, 1786], *M. cavernosa*, *M. meandrites*, *Solenastraea bournoni* Milne Edwards and Haime, 1849, *Stephanocoenia michelinii* Lamarck, 1816, and *Porites astreoides* Lamarck, 1816) contributed 205 (85.4%) of the total 250 transplanted coral colonies monitored, and all 58 (100%) of the attached control corals (Table 1). The monitoring period for these six species of transplanted corals ranged from a maximum of 31 months (colonies transplanted in June 2001) to 13 months (colonies transplanted in December 2002). The monitoring period for these six species of attached control corals ranged from a maximum of 31 months (colonies tagged in June 2001) to 26 months (colonies tagged in November 2001). The survivorship of these six species of transplanted corals of opportunity was 98.5%, while the survivorship of the same six species of attached control corals was 96.6% (Table 1). Four of the 6 species had 100% survival over the monitoring period for both the transplanted corals of opportunity, after a minimum of 13 months, and the attached control corals, after a minimum of 26 months (Table 1). In January 2004, 202 (98.5%) of the 205 monitored corals of opportunity comprising the six common species were securely attached to the nursery substrate and alive; fifty-six (96.6%) of the 58 attached control colonies (the six common species) were still attached and alive in January 2004. Survival of the six species common to both the transplanted corals of opportunity (98.5%) and the attached control corals (96.6%) was not significantly different ($X^2 = 0.0009$, df = 1, $p > 0.90$) (Table 1).

Discussion

The ultimate goal of this project (Goal #3) is to use corals of opportunity stabilized and cached in the coral nurseries for future coral reef restoration activities. In order for corals of opportunity to be a viable source of donor colonies, these colonies must: 1) be available in sufficient numbers to make collection cost-effective, 2) have a species distribution similar to that of the reefs to

Table 2. Species contribution and percent survivorship of corals of opportunity transplanted onto the two artificial substrates used as coral nurseries (Warren Modules and DERM Modules). Percent survivorship is from date of transplantation to the last monitoring event in January 2004.

Species	Warren Modules		DERM Modules	
	# Monitored	# Survived	# Monitored	# Survived
Siderastrea siderea (Ellis and Solander, 1786)	11	11	67	67
Montastraea cavernosa (Linnaeus, 1766)	9	9	33	33
Meandrina meandrites (Linnaeus, 1758)	10	9	20	19
Solenastraea bournoni Milne Edwards and Haime, 1849	4	4	22	22
Stephanocoenia michelinii Lamarck, 1816	13	12	8	8
Dichocoenia stokesi Milne Edwards and Haime, 1848	3	2	9	6
Porites astreoides Lamarck, 1816	1	1	10	10
Colpophyllia natans (Houttuyn, 1772)	1	1	5	4
Diploria labyrinthiformis (Linnaeus, 1758)	2	2	4	4
Porites porites (Pallas, 1766)	2	2	4	4
Montastraea faveolata (Ellis and Solander, 1786)	1	0	4	4
Eusmilia fastigiata (Pallas, 1766)	1	0	2	2
Agaricia agricites (Linnaeus, 1758)	0	0	2	2
Diploria strigosa (Dana, 1846)	0	0	2	2
Total	58	53	192	187
% survivorship		91.4		97.4

be restored, 3) survive the process of being detached from the reef and transplanted to the coral nursery, and 4) survive the process of being moved from the nursery and transplanted to a damaged site.

1) All coral of opportunity collections were limited to 45 minutes. In most cases there were 10 divers, six of which were volunteers, collecting in an area approximately 1000 m^2, resulting in an average of 23 colonies (range 13-36) collected per dive. Corals of opportunity are available throughout Broward County, Florida reefs, and not necessarily just at degraded or damaged coral reef sites. This indicates that corals of opportunity are a resource available in sufficient numbers and can be efficiently collected for use in restoration activities in Broward County, Florida, U.S.A.

2) Table 3 compares percent species contribution of the transplanted colonies to that of the natural scleractinian population surveyed at eight 30 m^2 inner reef sites offshore Broward County (Gilliam et al. 2004). This comparison suggests that the local species composition of corals of opportunity available for restoration will be analogous to the species composition of the colonies lost during a damage event. Using a similar species composition for restoration will promote a return of the damaged site to a state similar to pre-impact conditions. It is worth noting that there are only four species of corals surveyed on Broward County inner reef sites that were not found as corals of opportunity during this project (Table 3). Their absence as corals of opportunity does not necessarily indicate that these species of coral are impervious to the forces that cause coral to become detached from the substrate. These four species were in low abundance (8.4%) on the inner reef as naturally attached corals, so it follows that they would also be in low abundance as corals of opportunity (Table 3). The same is true for the one species of transplanted coral of opportunity in the nursery that was not surveyed within inner reef sites in Broward County (Gilliam et al. 2004) (Table 3). This is most likely an artifact of the specific sites surveyed, and not an indication that this species is only present on the inner reef as a detached coral. This species has been recorded in low abundance on different inner reef sites in Broward County (Gilliam et al. 2000).

3) Stabilizing corals of opportunity onto the coral nurseries was very successful with 96.0% survivorship of all colonies after a minimum of 13 months post-transplantation. Aside from *D. stokesi* mortality attributed to White Plague, there does not appear to be a trend between species and mortality. Attached control colonies were included in the project to evaluate processes that could affect transplant survival independent of the transplantation process (e.g., bleaching event, algal bloom, damage due to hurricanes, etc.). Overall, the survivorship of the transplanted colonies (96.0%) was indistinguishable from that of the attached control colonies (96.6%) (Table 1). Also, no significant difference was found when comparing survival of just the six species common to both the transplanted corals of opportunity and the attached control corals (98.5% and 96.6%, respectively) (Table 1). Additionally, loose control colonies were included in the project to investigate the fate of corals of opportunity left unattached. Loose control corals had a significantly reduced survivorship (67.9%) compared to both that of the transplanted colonies (96%), and the attached control colonies (96.6%) (Table 1). This suggests that loose colonies on the reef are more likely to perish than both naturally attached colonies and transplanted corals of opportunity. Hence, the use of corals of opportunity as a donor source for coral reef restoration provides a resource for the damaged reef area that has an otherwise low chance of survival. Additionally, the use of corals of opportunity as an alternative source of donor colonies for coral reef restoration may have a reduced effect on the donor reef compared to removing attached colonies.

Table 3. Abundance and percent species contribution of corals of opportunity transplanted to the coral nursery, and that of corals surveyed on inner reef sites throughout Broward County (Gilliam et al. 2004). "Other" species of scleractinian corals found during surveys of the inner reef of Broward County, but not found as corals of opportunity include: *Siderastrea radians* (Pallas, 1766), *Mycetophyllia lamarkiana* Milne Edwards and Haime, 1848, *Diploria clivosa* (Ellis and Solander, 1786), and *Scolymia cubensis* (Milne Edwards and Haime, 1849) (Gilliam et al. 2004).

Species	Transplanted Corals		Surveyed Corals	
	Number	Percentage	Number	Percentage
Siderastrea siderea (Ellis and Solander, 1786)	78	31.2	129	23.2
Montastraea cavernosa (Linnaeus, 1766)	42	16.8	84	15.1
Stephanocoenia michelinii Lamarck, 1816	21	8.4	74	13.3
Porites astreoides Lamarck, 1816	11	4.4	38	6.8
Meandrina meandrites (Linnaeus, 1758)	30	12.0	29	5.2
Dichocoenia stokesi Milne Edwards and Haime, 1848	12	4.8	21	3.8
Solenastraea bournoni Milne Edwards and Haime, 1849	26	10.4	14	2.5
Montastraea faveolata (Ellis and Solander, 1786)	5	2.0	10	1.8
Agaricia agricites (Linnaeus, 1758)	2	0.8	8	1.4
Porites porites (Pallas, 1766)	6	2.4	4	0.7
Colpophyllia natans (Houttuyn, 1772)	6	2.4	3	0.5
Diploria strigosa (Dana, 1846)	2	0.8	2	0.4
Eusmilia fastigiata (Pallas, 1766)	3	1.2	1	0.2
Diploria labyrinthiformis (Linnaeus, 1758)	6	2.4	0	0.0
Other	0	0.0	38	8.4
Total	250	100.0	455	100.0

Two coral nurseries were used in this project, the Warren Modules and the DERM Modules. Transplanted coral of opportunity survival on the Warren Modules was slightly reduced (91.4%) compared to that of the corals transplanted to the DERM Modules (97.4%). This difference may be due to several facts: 1) the corals on the Warren Modules have been transplanted longer than those on the DERM Modules (29-31 months compared to 13-27 months), 2) the Warren Modules contain fewer (less than one quarter) transplanted corals of opportunity than the DERM Modules (58 compared to 192), and 3) the Warren Modules are located slightly more offshore of the inner reef than the DERM Modules (25 m v. 1 m), and therefore may be more susceptible to sedimentation. It is also possible that the colonies that died on the Warren Modules were detached from the reef longer than the colonies that died on the DERM Modules; however, this is only speculative, as no data are available to determine coral of opportunity detachment time prior to colony collection. Regardless of the cause of death, greater than 90% survival in both coral nurseries indicates that it is possible to successfully create a reserve of donor corals composed of corals of opportunity. It is interesting to note that of the five colonies that perished on the Warren Modules, four were transplanted on the same day (and collected from the same site). These corals of opportunity were collected adjacent to the attached control coral site, so one would assume that if mortality were site-induced, it would be evident in the attached control corals as well. The day in which these colonies were collected, however, happens to be the first collection day of the project (3 June 2001); therefore it seems reasonable to expect a greater percentage of the corals that have been transplanted the longest to have perished.

4) Although this paper does not address component 4, restoration activities funded by the State of Florida associated with two recent ship groundings offshore of Broward County, Florida, U.S.A. will be using coral of opportunity colonies from the coral nurseries. When these colonies are used as transplant donors, the methods described herein will be performed again to restock the coral nursery with another supply of transplanted corals of opportunity. It is assumed that since corals of opportunity survive the process of being detached from the reef and transplanted to the coral nursery, they will also survive the process of being moved from the coral nursery and transplanted to a damaged site.

In anticipation of Goal 3 (using the transplanted corals of opportunity as donor colonies in future coral reef restoration activities), the corals of opportunity that died were subsequently removed from the coral nursery. Overall, the effort required to remove colonies was low and did not damage any colony skeleton (what would be live tissue in live colonies). The successful removal of these colonies indicates that using these corals from the nurseries at a later date for transplantation to a future restoration site will be effective.

It could be argued that coral of opportunity survivorship may be the same or even higher if colonies were transplanted directly to a damaged area instead of being transplanted to a coral nursery first. However, the goals of this project were not only to use these colonies as a new source of donor corals, but also to create a readily available cache of donor corals to be used for future restoration events. In fact, several sources have advocated a readily available source of donor colonies in anticipation of coral transplantation for restoration activities (Edwards and Clark 1998; Wheeler 1999; Jaap 2000).

The location of all coral of opportunity collection sites, both coral nurseries (Warren Modules and DERM Modules), and both control sites (Attached Controls and Loose Controls) were contiguous, either on (collection and control sites) or adjacent to (coral nursery sites) the inner reef in Broward County, Florida, U.S.A. (Fig. 1). This ensures that environmental conditions (e.g., depth, current, turbidity, etc.) at all sites are similar (Harriott and Fisk 1988; Moyer et al. 2003). Additionally, the inner reef of Broward County is most often impacted by marine activities requiring restoration (East Wind in 2004, *M/V* Alam Senang in 2003 [Marine Resources Inc. 2003], *C/V* Hind in 1998 [Gilliam et al. 2000], *M/V* Pacific Mako in 1998, *M/V* Firat in 1994 [Graham and Schroeder 1996], and U.S.S. Memphis in 1993 [Banks et al. 1998]), so environmental conditions at the final restoration site (Goal 3) will also be similar.

Conclusions

Corals of opportunity provide a viable resource for future coral reef restoration off Broward County. As a source of donor colonies for transplantation into damaged sites, these corals are sufficiently available on the reefs to be efficiently collected and transplanted; their species distribution is very likely to be similar to the distribution of species lost during a damage event; the survival of the colonies transplanted to the nursery indicates that their survival once transplanted to the damage area will also be high, and they are located on the reefs which are most often impacted. Coral nurseries provide a suitable interim substrate for corals of opportunity to be cached, stabilized, and allowed to grow. The use of corals of opportunity in conjunction with coral nurseries creates a proactive approach to coral reef restoration by having a cache of donor corals readily available for an immediate response to damage events. The assistance provided by volunteer divers in establishing and maintaining the coral nurseries not only allows for the cost-effective restoration of damaged coral reefs, but also fosters community ownership of these offshore resources. Corals of opportunity and coral nurseries can become important tools in the future of coral reef restoration, especially when combined with community outreach.

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