Implications of coral harvest and transplantation on reefs in northwestern Dominica

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Abstract: In June, 2002, the government of Dominica requested assistance in evaluating the coral culture and transplantation activities being undertaken by Oceanographic Institute of Dominica (OID), a coral farm culturing both western Atlantic and Indo-Pacific corals for restoration and commercial sales. We assessed the culture facilities of OID, the condition of reefs, potential impacts of coral collection and benefits of coral transplantation. Coral reefs (9 reefs, 3-20m depth) were characterized by 35 species of scleractinian corals and a live coral cover of 8-35%. Early colonizing, brooders such as *Porites astreoides* (14.8% of all corals), *P. porites* (14.8%), *Meandrina meandrites* (14.7%) and *Agaricia agaricites* (9.1%) were the most abundant corals, but colonies were mostly small (mean=25cm diameter). *Montastraea annularis* (complex) was the other dominant taxa (20.8% of all corals) and colonies were larger (mean=70cm). Corals (pooled species) were missing an average of 20% of their tissue, with a mean of 1.4% recent mortality. Coral diseases affected 6.4% of all colonies, with the highest prevalence at Cabrits West (11.0%), Douglas Bay (12.2%) and Coconut Outer reef (20.7%). White plague and yellow band disease were causing the greatest loss of tissue, especially among *M. annularis* (complex), with localized impacts from corallivores, overgrowth by macroalgae, storm damage and sedimentation. While the reefs appeared to be undergoing substantial decline, restoration efforts by OID were unlikely to promote recovery. No Pacific species were identified at OID restoration sites, yet species chosen for transplantation with highest survival included short-lived brooders (*Agaricia* and *Porites*) that were abundant in restoration sites, as well as non-reef builders (*Palythoa* and *Erythropodium*) that monopolize substrates and overgrow corals. The species of highest value for restoration (massive broadcast spawners) showed low survivorship and unrestored populations of these species were most affected by biotic stressors and human impacts, all of which need to be addressed to enhance survival of outplants. Problems with culture practices at OID, such as high water temperature, adequate light levels and persistent overgrowth by macroalgae could be addressed through simple modifications. Nevertheless, coral disease and other stressors are of major concern to the most important reef builders, as these species are less amenable to restoration, collection could threaten their survival and losses require decades to centuries to replace. Rev. Biol. Trop. 58 (Suppl. 3): 111-127. Epub 2010 October 01.

Key words: coral mariculture, fragmentation, restoration, coral health and disease, transplantation.

A land-based coral farm was established by Associated Marine Technologies (AMT, later renamed Oceanographic Institute of Dominica) off the northwest coast of Dominica, near Portsmouth in 1998. This farm was interested in growing corals to supply the aquarium trade, and also proposed to restore neighboring reefs using corals collected from local waters and propagated on the farm. The farm was initially established with brood-stock imported from Indonesia, including hundreds of soft and stony corals and colonial anemones. Caribbean species were introduced to the facility after receiving permission to harvest corals from surrounding reefs, with the agreement that 10 corals would be transplanted back to the reef for each colony that was harvested. As of 2002, AMT was primarily growing stony and soft corals in shallow outdoor tanks from small fragments and clippings removed from wild-harvested colonies, using natural seawater piped in from Prince Rupert Bay. These were fragmented and attached with adhesive to small (8cm) cross-shaped discs and exported to the United States for the aquarium trade. Following a shift in management, the owner undertook an extensive review of existing practices and future options for mariculture, including a proposed shift for coral culture from IndoPacific specimens to Caribbean corals. The primary goal of this effort was to grow corals for use in coral reef restoration, with a secondary goal of producing second or third "generation" corals for international trade, to supply aquarium hobbyists in the U.S. and other locations. The owner also wanted to support local communities by employing individuals from Portsmouth and neighboring towns.

In June, 2002 the authors undertook a site visit to AMT to evaluate the sustainability of wild harvest, adequacy of husbandry practices, and the need for the proposed restoration efforts. There were reports that Indo-Pacific species propagated by AMT were used in restoration efforts conducted off the island of Mustique and Jamaica, and in several locations off the west coast of Dominica. Because the facility uses water from the bay, and this water is returned to the bay after being circulated through the coral propagation tanks, there was also a high potential for introduction of invasive Pacific species into the Caribbean through effluent from the culture facility. An additional problem regarding illegal permits for coral exports was identified by USFWS law enforcement agents in Miami following inspection and confiscation of a shipment of corals from AMT. This shipment contained falsified Convention on International Trade in Endangered Species (CITES) documentation and permits, along with discrepancies with species identification, and the origin of the corals. The shipment contained mixed species of Caribbean and Indo Pacific corals, while paperwork reported these solely as a re-export of Philippines corals. This immediately was flagged as a problem by U.S. law enforcement because the Philippines had prohibited the export of stony corals since the 1970s.

In response to the confiscation, the Dominican fisheries agency requested assistance from U.S. experts in explaining how the Convention applied to cultured corals and what would be required to issue permits for export. There were also questions whether harvest of corals from Dominican waters was sustainable and whether proposed restoration activities would compensate for losses associated with coral harvesting. To address these questions, an evaluation of practices undertaken by OID in Dominica and the potential benefits of and need for the proposed restoration activities was undertaken. Field surveys were undertaken to 1) assess the diversity, abundance and condition of these organisms; 2) determine whether certain species could be collected without impact to source populations and 3) assess the benefits of the proposed restoration activities. This study included an examination of the population dynamics of corals, the extent of mortality, and the major threats affecting them. An evaluation of existing technologies and species used in coral propagation at OID was also undertaken as steps to address environmental concerns surrounding captive coral propagation and provide recommendations on the optimal strategies for harvest, culture and transplantation of corals. Information on CITES requirements for international commerce in corals and implications of these requirements for OID and the Dominican authorities are discussed. Recommendations are presented on possible harvest guidelines for corals and biological restoration approaches.

MATERIALS AND METHODS

Study site: Dominica is a mountainous volcanic island in the Eastern Caribbean. The island is fairly small in size (754sq km) with

148km of coastline surrounded by a narrow coastal shelf that drops rapidly into deep water. Total reef area is estimated at less than 100 km^2 with the most well-developed reefs on the south, west and northwest coasts, and limited reef development on the exposed, Atlantic coast (Spalding *et al*. 2001). The island has a low population density (approx. 70 000 inhabitants; population growth rate of -0.98%) and limited industrial development. While most people reside in Roseau, small communities are located on coastal areas within embayments that are surrounded by rugged, forested hillsides and mountains. The economy is largely based on agriculture, although artisanal fishing is important (UNEP/WCMC 1988). Inshore fisheries are fully exploited by local fisherman and local demand for fish exceeds supply more than two-fold (Goodwin 1985). The marine environment was first reported to have suffered from overfishing of lobsters, conch, finfish and turtles 20 years ago (UNEP/WCMC 1988), and coral diseases have been reported (Borger 2003). There is one marine protected area on the west coast (Cabrits National Park; CNP) where fishing is still permitted.

Field surveys: Baseline data on the condition of reef-building corals were obtained for 8 reefs (Toucarie, Douglas Bay, Cabrits North, Cabrits West, Cabrits South, Black Coral Gardens, Coconut Outer, Coconut Inner, Pointe Rounde (Table 1, Fig 1) off the west coast of Dominica using the benthic protocol from the Atlantic and Gulf Rapid Reef Assessment (AGGRA) Version 2 (http://www.coral.noaa.gov/agra/index.html) assessment methodology, with minor modifications. At each site, 10m transects were extended parallel to depth contours, and all corals 5cm in diameter and larger that touched or lay directly below the transect tape were recorded to species, measured (maximum diameter and height, to nearest 1cm). For each coral an estimate of the amount of live tissue, recently killed tissue and condition (s) causing coral mortality was recorded. Live coral cover was determined by calculating the total number of centimeters of live coral tissue located directly under each 10m transect. In addition to corals, other benthic invertebrates including corallimorphs, octocorals, anemones, gorgonians and sponges were counted within 1 m of either side of the line. All stony corals were identified to species. Colonies of *Montastraea annularis* complex were separated according to Weil and Knowlton (1994) as *M. annularis, M. faveolata* or *M. franksi*. Forms or morphotypes of *Agaricia agaricites, Colpophyllia natans, Meandrina meandrites* and *Porites porites* were combined under the respective species.

Recent mortality was defined in this study as any tissue loss occurring within approximately the last 30 days, using signs that

TABLE 1
Coral community composition at eight reefs in northwestern Dominica

Site	Location	Depth (m)	Number of: transects	Corals	coral species	Coral density
Toucari Bay	15° 36’ 38” N 61° 28’ 02” W	11-18	8	135	18	1.73
Douglas Bay	15°36’ 17” N 61°27’ 59” W	16.5-17.5	6	74	14	1.45
Cabrits North	15°35’ 26” N 61° 28’ 35” W	14.8-18	10	101	25	1.01
Cabrits West	15°34’ 59” N 61°28’ 44” W	13-15	9	99	25	1.10
Cabrits South	15° 34’ 54” N 61° 28’ 32” W	13-15	9	100	26	1.10
Black Coral	15°33’ 11” N 61°28’ 7” W	22-26	3	41	22	1.45
Coconut Inner	15° 33’ 4” N 61°28’ 7” W	6-8	10	85	20	0.89
Coconut Outer	15° 33’ 3” N 61° 28’ 14” W	9-12	8	130	24	1.63
Pointe Ronde	Coordenada???	6-7.5	8	146	22	1.83
All Sites		6-26	71	911	35	1.28

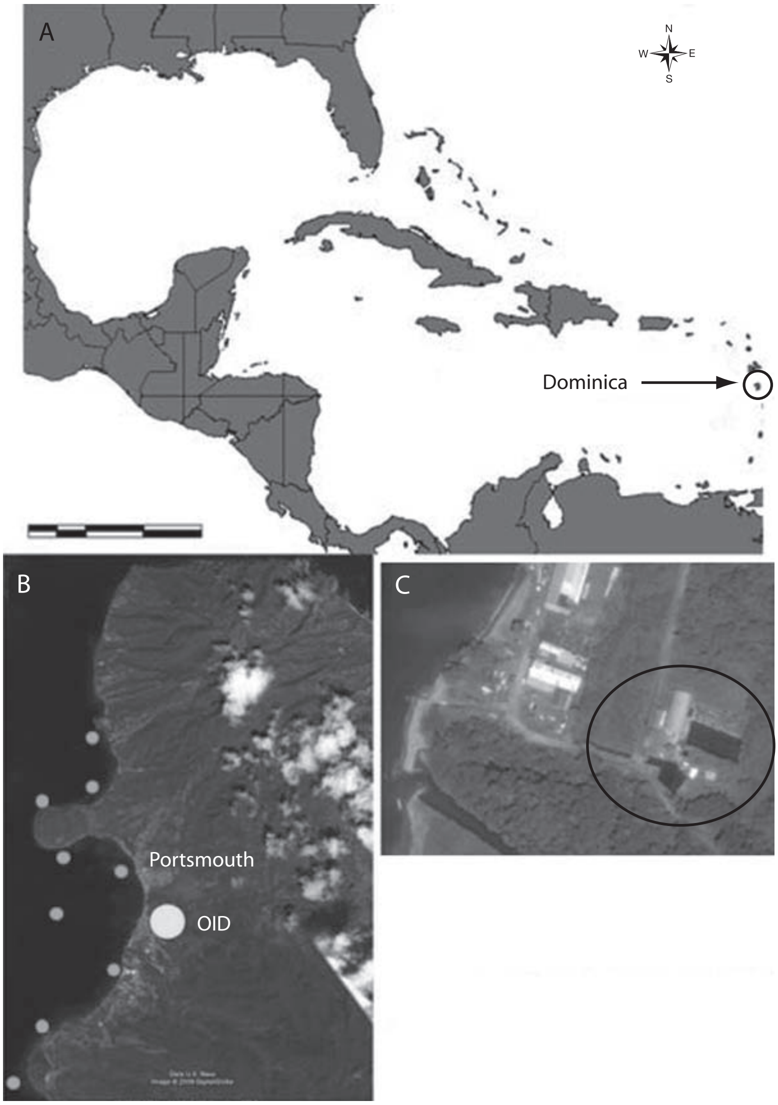


Fig. 1. Study sites and the Oceanographic Institute of Dominica. A. The wider Caribbean, showing the location of Dominica. B. The northwest end of Dominica near Portsmouth. The nine reefs examined in this study are indicated. C. Aerial photograph of OID showing its location with respect to Prince Rupert bay.

included: (1) white coral skeleton that lacked algae (surfaces denuded of tissue within the last 5-7 days); (2) skeletal areas with readily recognizable corallites that had not been substantially eroded but were colonized by fine green filamentous algae or (3) white, exposed skeletal surfaces, or eroded skeletal surfaces with fine filamentous algae, that had been physically abraded by fish or other agents but had not yet been colonized by epibionts. Old mortality was defined as areas on a colony that were dead for longer than 30 days and included exposed skeletal surfaces with eroded corallites, and denuded areas on a colony colonized by crustose coralline algae, macroalgae or encrusting invertebrates; in most cases the cause of mortality could not be definitively determined. Causes of recent mortality were identified as disease (separated into black band disease, white plague, yellow band disease, dark-spots disease, or other disease), corallivory [parrotfish bites, damselfish (primarily *Stegastes planifrons*) algal lawns, fireworm (*Hermodice carunculata*) or snail (*Coralliophila abbreviata*) predation], overgrowth by algae or invertebrates (cnidarian, sponge or tunicate), sedimentation or storm damage, based on the key identification features described in Bruckner (2001). In the event that a cause of mortality could not be determined, it was recorded as unknown. The following abbreviations are used throughout this manuscript: BBD (black band disease), WP (white plague), YBD (yellow band disease), DSD (dark spots disease), PB (focused parrotfish biting), snails (*Coralliophila abbreviata* snails and scars), sponge (overgrowth by *Cliona* spp. and *Siphonodictyon* spp.), cyano (mats of cyanobacteria smothering parts of colonies) and algae (dense mats of macroalgae, especially *Dictyota* and *Lobophora*).

Data analysis: Data were first examined by combining all coral measurements from all sites, and then by examining individual sites or species groups. Coral species were lumped into the following groups based on colony abundance, mean colony size, susceptibility to disease or predation, colony morphology or sexual reproductive character: 1) massive corals including *C. natans, S. siderea, Diploria spp., Montastraea cavernosa, Stephanocoenia intersepta*; 2) the *M. annularis* complex and 3) all other species, especially small branching and plating corals that brood planula larvae (primarily *P. porites, P. astreoides, M. meandrites, Eusmilia fastigiata, Madracis spp., Agaricia spp., Mycetophyllia* spp., *Mussa angulosa*).

Assessment of coral husbandry practices: A tour of the facility was undertaken to collect information on the size of the facility, methods of water circulation and decontamination, coral fragmentation, and culture and husbandry practices. OID employees provided demonstrations of the technique used to fragment corals and attach them to bases for grow-out, and efforts to maintain the health of the corals, including removal of algae and corallivores. A survey of the species, numbers of fragments, and condition of the fragments on hand was undertaken, along with general observations on culture facilities including water quality, water flow, exchange between tanks, quarantine practices, and light and temperature levels.

Efficacy of restoration efforts: Two sites with pilot restoration projects were examined. Transect surveys as described above were conducted within these sites to provide an indication of the community composition, structure and condition. Transplanted corals were located and assessed in terms of survival and growth and effects on the surrounding reef.

RESULTS

Reef Condition: A total of 71 transects, each 10m in length, were examined on 9 reefs near Portsmouth, Dominica in June, 2002; reefs ranged in depth from 6-26m (Table 1). Transects contained 911 stony coral colonies (mean density=1.28 corals/m^2) consisting of 35 species, with up to 26 species at one site. The dominant scleractinian corals observed on these reefs were *Porites porites* (14.8%), *Meandrina meandrites* (14.7%), *Porites astreoides* (14.3%), *Montastraea annularis* (10.5%), *Montastraea faveolata* (10.3%), *Agaricia agaricites* (9.1%), *Montastraea cavernosa* (7.1%), *Madracis mirabilis* (6.3%), *Siderastrea siderea* (5.6%) and *Colpophyllia natans* (2.7%)(Fig. 2). Stony corals (all species pooled from all sites) had a mean diameter of 42.2cm and a mean height of 22.4cm. There was an overall dominance at all sites by small colonies less than 20cm diameter consisting primarily of early colonizing, brooding coral species such as *P. astreoides, A. agaricites* and *M. meandrites*. Colonies of *M. annularis* and *M. faveolata* were significantly larger than all other species,

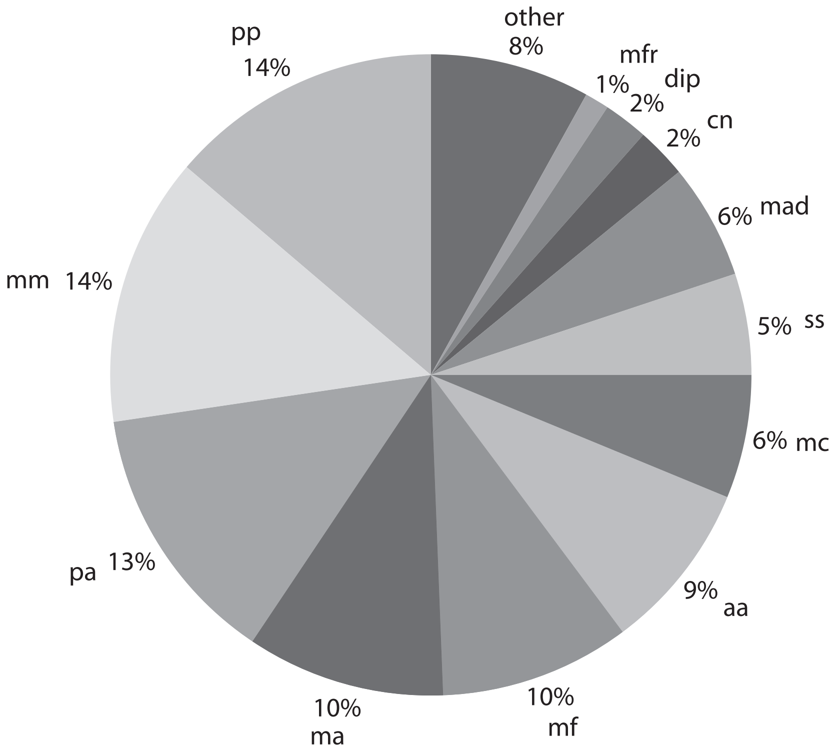


Fig. 2. The composition of reef building corals identified on nine reefs in northwestern Dominica. ma=*Montastraea annularis*, mf=*M. faveolata*, mc=*M. cavernosa*, pp=*Porites porites*, pa=*P. astreoides*, mm=*Meandrina meandrites*, aa=*Agaricia* spp., mad=*Madracis* spp., **ss**=*Siderastrea siderea*, ds=*Diploria* spp., cn=*Colpophyllia natans*, other= 20 other species.

with exception of *Madracis mirabilis* and *P. porites* which formed large, low-relief mounds up to 7m in diameter (Fig. 3).

Extent and causes of mortality: Most corals examined on these reefs had experienced partial mortality, except for colonies that were small in size (20cm or less). Mean old mortality for all corals combined was 20.4% compared to 1.4% recent mortality. Recent mortality was attributed to coral diseases (6.4% of all colonies), predation (3.6%), overgrowth by algae (6.1%), invertebrate predation (0.8%), storm damage (0.8%; Hurricane Lenny, 1999) and sedimentation (0.5%). While most colonies of *M. annularis* (90%) had experienced partial mortality in the past, only 20% of the other massive broadcast spawning corals and 10% of brooding corals showed signs of old mortality. In contrast, a larger proportion (60%) of brooding corals showed signs of recent mortality, compared to about 40% of the *M. annularis* complex and 10% of other massive corals (Fig. 4). The mean amount of recent mortality (tissue loss) among all corals (n=911) was low (1.4%). However, 160 (17.5%) corals exhibited signs of recent mortality and these colonies had lost a mean of 8.9% of their tissue within the last 1-14 days. The highest percentage of recent mortality was observed in Cabrits National Park. Overall, recent mortality among all colonies at Cabrits West was 4.9% (all species pooled), while 20 colonies (5% of the total examined) had 32% recent mortality, including many of the largest and oldest corals on this reef.

Disease and predation: A number of coral diseases were observed along transects,

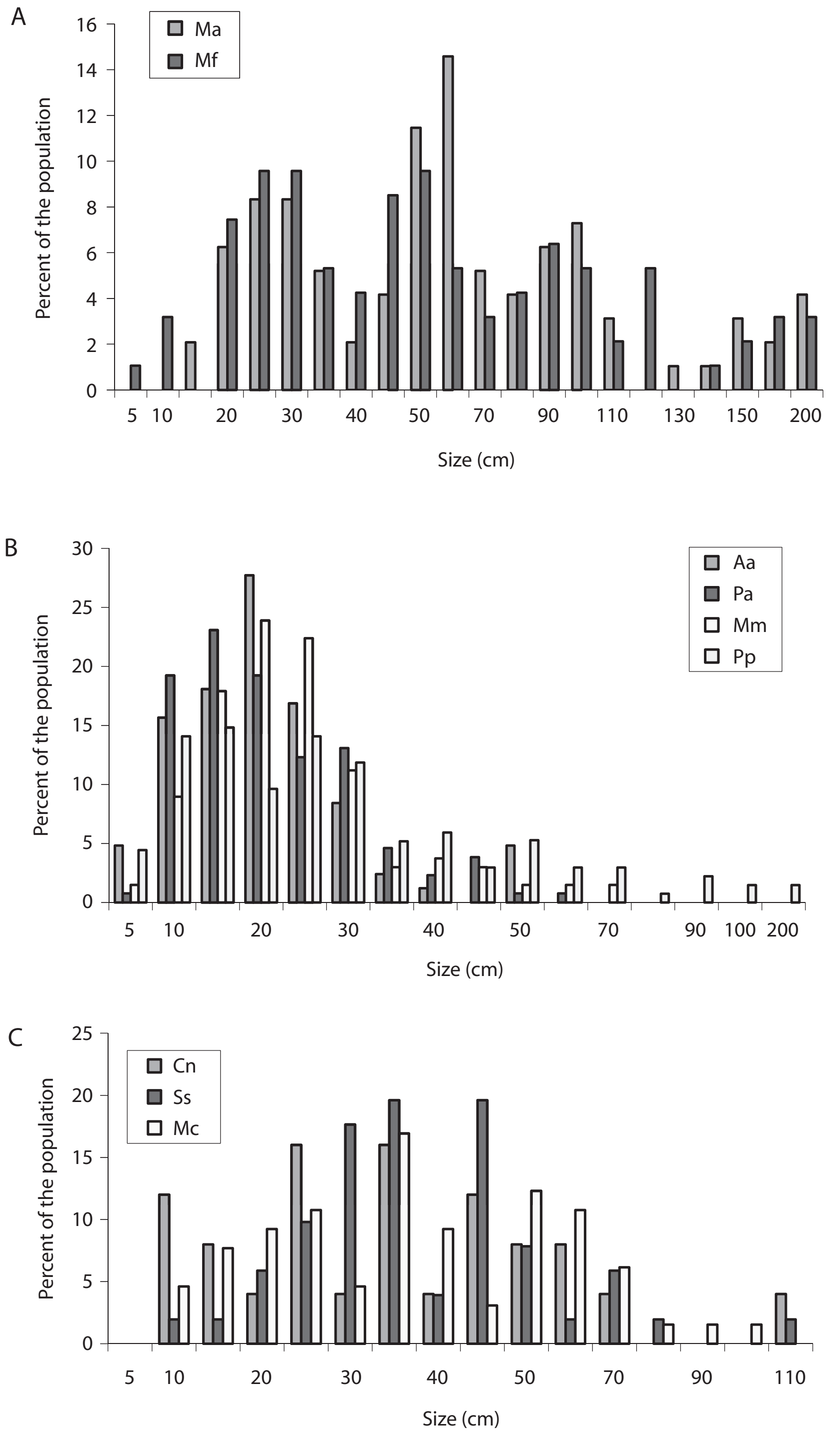
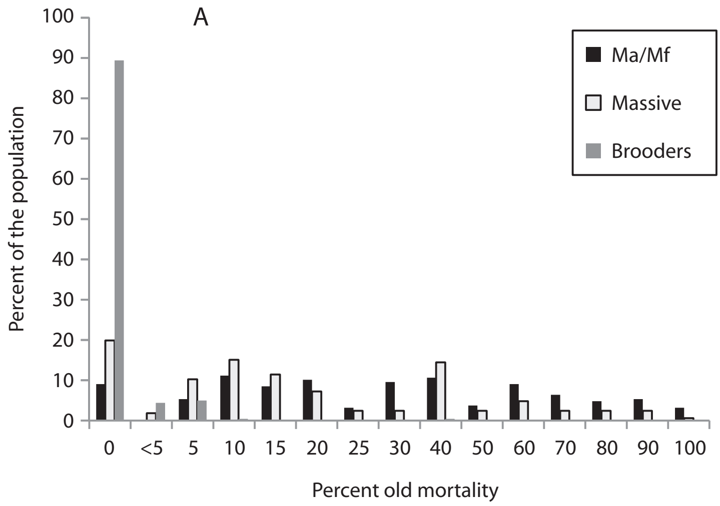


Fig. 3. The size structure (maximum diameter in cm) of major reef building corals on reefs off the west coast of Dominica. A. Size frequency distribution of *M. annularis* and *M. faveolata*. B. Size frequency distribution of other massive corals. C. Size frequency distribution of *Porites* spp. and *Agaricia* spp.



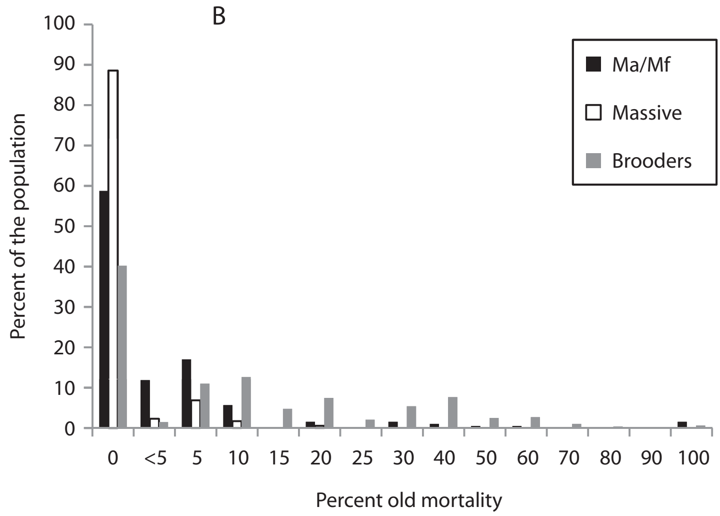


Fig. 4. Total amount of partial mortality for the three groups of reef building corals. M. annularis and M. faveolata are black bars, other massive species are white bars and brooding corals are the gray bars. A. Percent old mortality for the three groups of corals. B. Percent recent mortality for the three groups of corals.

including white plague, black band disease, Caribbean yellow band disease, and dark spots disease. White plague was observed on all reefs, while other diseases were restricted to specific locations and generally occurred at a low prevalence (<5%). The highest prevalence of disease overall was recorded at Cabrits West (11.0%), Douglas Bay (12.2%) and Coconut Outer (20.7%) (Table 3). In addition, corallivores including coral-eating snails (*C. abbreviata*), fireworms (*H. carunculata*) and stoplight parrotfish (*Sparisoma viride*) were prominent, and in some locations had caused substantial mortality. Coconut Outer was dominated by large (1-5m diameter), very old colonies of *M. annularis* and *M. faveolata*, many of which had signs of recent mortality (colonies were missing a mean of 45% of their tissue).

TABLE 2

Condition of the reef building corals examined on nine reefs off the west coast of Dominica

Coral Species	No.	BBD	WP	YBD	DSD	PB	Snails	Sponge	Cyano	Algae
						No. (%)				
Pa	130					5 (3.8)		1 (0.8)	9 (7.0)	1 (0.8)
Pp	135					4 (2.9)			1 (0.7)	4 (2.9)
Mm	134		1 (0.7)				1 (0.7)			5 (3.7)
Mf	94		29 (30.8)	3 (3.1)				3 (3.1)	2 (2.1)	2 (2.1)
Ma	96		17 (17.7)	2 (2.1)		16 (16.6)	3 (3.1)		1 (1.0)	1 (1.0)
Aa	83		2 (2.4)				1 (1.2)		4 (4.8)	1 (1.2)
Mc	65	1 (1.5)					2 (3.0)	1 (1.5)		1 (1.5)
Ss	51	1 (1.9)			5 (10.0)				1 (1.9)	7 (13.7)
Cn	50	1 (1.9)								
All	911	3 (0.3)	53 (5.8)	5 (0.6)	5 (0.6)	26 (2.8)	10 (1.1)	6 (0.6)	20 (2.1)	35 (3.8)

Notes: The total number of each species are presented for *Porites astreoides* (Pa), *P. porites* (Pp), *Meandrina meandrites* (Mm), *Montastraea faveolata* (Mf), *M. annularis* (Ma), *Agaricia agaricites* (Aa), *M. cavernosa* (Mc), *Siderastrea siderea* (Ss), and *Colpophyllia natans* (Cn). All corals include the nine dominant species and also all other species. The number of colonies and the percent affected by each condition (in parenthesis) are shown for BBD (black-band disease), WP (white plague), YBD (yellow band disease), DSD (dark spots disease), PB (focused parrotfish biting), snails (*Coralliophila abbreviata* snails and scars); sponge (overgrowth by *Cliona delitrix* and *Siphonodictyon*), Cyano (mats of cyanobacteria smothering parts of colonies), and algae (dense mats of macroalgae, especially *Dictyota*).

TABLE 3

The size structure and health metrics of reef building corals (all colonies over 5cm diameter) and condition at each reef examined off the west coast of Dominica

	Diameter (cm)	Height (cm)	Old mortality	Recent mortality	disease	algae	sponge	predation	Damsel fish lawns
Toucarie	30.6	15.9	13.0	0.9	3.7	2.2	2.0	1.5	0.7
Douglas Bay	37.3	19.6	17.8	1.9	12.2	13.5	0	1.4	4.1
Cabrits N	34.2	17.7	25.9	1.3	4.0	12.9	1.0	2.0	13.0
Cabrits W	33.7	17.7	14.4	4.9	11.0	8.0	1.0	1.0	0
Cabrits S	32.2	18.9	12.2	0.4	2.0	8.0	1.0	0	1.0
Black Coral	44.2	19.4	20.1	0.5	1.6	6.3	1.0	0	0.7
Coconut Inshore	74.4	25.6	26.7	0.1	1.2	12.9	0	1.2	10.0
Coconut Outer	75.7	49.8	34.6	2.1	20.7	3.0	3.0	12.0	28.0
Point Round	33.9	17.3	17.6	0.7	2.7	2.1	0.7	8.3	0
All sites	42.2	22.4	20.4	1.4	6.4	6.1	0.8	3.6	6.9

Data are presented as the mean size (maximum diameter and height) and mean percent mortality (old and recent mortality). The cause of recent mortality includes the percent of colonies with active coral disease, overgrowth by cyanobacteria or macroalgae, overgrowth by *Cliona* spp. sponges, focused biting by stoplight parrotfish and feeding scars from the snail *Coralliophila abbreviata* (predation), and colonies with damselfish algal lawns.

Fig. 5. The Oceanographic Institute of Dominica. A. Coral propagation tanks. B. Top view of an individual propagation tank. C. Sea water table for fragmenting corals. D. Water filtration system and settling tank. E. Multiple Indo-Pacific soft corals in culture. F. Shade cloth covering propagation area. G. Indo-Pacific corals in display tank. H. Pacific *Fungia* in culture at OID. I. *M. annularis* fragment that is partially bleached. J. Typical algal colonization of fragments and underlying substrate within OID facility. K. Branching gorgonian attached to a cross-shaped disc and placed in the field at a restoration site. L. *Porites porites* fragment attached to the reef. Note the dead, algal covered branch on the left. M. Live rock in quarantine tank.

White plague affected 19.2% of all corals and 30% (n=23) of the *M. annularis* (species complex). In addition, 13% of all *M. annularis* colonies exhibited recent lesions created by *Sparisoma viride* (focused biting); 26% also had older lesions that were either colonized by damselfish algal lawns or were showing signs of tissue recovery.

Damselfish algal lawns: *Stegastes planifrons* territories were observed on all reefs except Cabrits West, affecting 6.9% of all corals, but they were of particular concern in three locations, Coconut Inner (10% colonies affected), Coconut Outer (28% colonies affected) and Cabrits North (13%). In these locations, fish established territories among massive and plating corals and had created extensive lesions on corals.

Storm damage: Coconut Inner, a shallow patch reef (5-8m depth) within Prince Rupert's Bay, was dominated by fields of *M. mirabilis* and large mounds of *P. porites*. Although this site had a low prevalence of disease and very little recent mortality, coral cover was very low and much of the reef consisted of dead *M. mirabilis* and *P. porites* rubble, possibly as a result of damage from Hurricane Lenny (1999). Piles of coral rubble also accumulated in the sand flat landward of the patch reef.

Coral mariculture: The Oceanographic Institute of Dominica (OID) was primarily culturing corals in 2002, along with limited experimentation with other aquaculture products. The facility had a large quarantine tank, a deeper (50 000L) tank and 160 shallow (0.5m deep, 1.5m diameter) plastic circular tanks for coral propagation (Fig. 5). An indoor, shallow flowing-seawater table was used for fragmenting corals and attaching them to a substrate. All outdoor tanks were located under dense shade cloth which reduced ambient light by 50-60%. Sea water was pumped from several hundred meters offshore in Prince Rupert's Bay from about 30 m depth. The water was pumped to the 50 000L tank, which serves as a settling tank and then into each smaller propagation tank before being circulated through the quarantine tank and returned to the sea. The water was reported to be UV-sterilized and ozonated before discharge, but this sterilization system was not working properly during the site visit. Each individual coral propagation tank was self-contained; water was not exchanged among those tanks.

In June, 2002, the main propagation area contained stony corals and gorgonian (soft) corals, all originally obtained from waters surrounding Dominica, along with a small number of tanks with Pacific soft corals and stony corals. Each tank was subdivided with PVC pipe into six pie-shaped sections, with each section holding 55 coral fragments (330 corals/tank; approx. 52 000 corals on hand) of one to three species of corals. One group of six tanks in a separate location contained Indo-Pacific soft corals, including genera such as *Clavularia*, Pacific *Briareum* (formerly *Pachyclavularia)*, *Sarcophyton*, *Xenia*, *Sinularia, Tubipora, Actinodiscus, Lobophytum*, and other species. The facility also had one display tank that contained seven gorgonian species, 3 corallimorph species, 2 zoanthid species, and 21 species of stony corals including 3 Indo-Pacific genera (*Fungia*, *Caulastrea* and *Leptoria*). The holding (quarantine) tank contained a few large colonies of stony corals, including *M. faveolata*, *M. cavernosa*, *P. astreoides* and gorgonians (*Pseudopterogorgia*), as well as a large pile of live rock. The main settlement tank (50 000L tank formerly used for tourist-related helmet diving) had a large central pile of reef rock with a few isolated corals and numerous Caribbean reef fishes, including angelfish, doctorfish, wrasses and parrotfish.

For coral propagation, fragments or pieces of colonies averaging 2-5cm across or in length were used. These included small clippings taken from mature gorgonian colonies using clippers; fragments from branching corals; and square, rectangular, or irregular "plugs" (explants) from massive and plating corals removed with a rotary tool and a cutting wheel. The explants were attached to a base using an adhesive. The base was shaped like a cross and made of resin and sand with one small hole for attachment and a separate hole for attachment to the reef or other substrate (Fig. 5). Second and third "generation" clippings were marked using colored bands.

Mariculture issues: Coral fragments were generally in good condition. However, many fragments exhibited signs of bleaching, and recent tissue loss was observed on approximately 5% of the corals. In addition, colonies were being stressed by macroalgal overgrowth. Several staff worked full time maintaining the corals, which included meticulously removing the algae from the fragments and the disc (which was scraped off the substrate and dumped back into the culture tanks, further propagating the algae). Other problems included elevated water temperatures and low light. The water flow had been reduced in attempt to limit transport and growth of algal spores and thalli into the tanks which subsequently led to elevated temperatures. Attempts to reduce water temperatures by shading reduced light to suboptimal levels.

Restoration efforts: The former owner of AMT had used fragments propagated at this facility for a reef restoration effort in Mustique, and in experimental trials on reefs in Dominica. In Dominica, fragments at different locations were attached to Reef Balls (Reef Ball Development Group, LTD, Doraville, Georgia) and also anchored directly onto the reef. The initial pilot study involved 443 propagules of 26 species, consisting of 1) ten stony corals in the genera *Montastraea, Porites, Eusmilia, Mycetophyllia, Diploria, Agaricia* and *Meandrina*; 2) two colonial anemones in the genera *Palythoa* and *Zoanthus*; and 3) eleven gorgonians in the genera *Eunicea, Pseudopterigorgia, Muricea, Plexaura, Pseudoplexaura, Erythropodium, Muriceopsis* and *Pterogorgia*. Outplants (27) were identified and assessed in one location. This included 18 that had died, including all of the (12) massive corals, four gorgonians, and two brooding corals (*Agaricia*). Two fragments, both gorgonians (*Psuedopterogorgia bipinnata*) exhibited substantial upward growth (colonies were 15-20cm in height) while two encrusting *Erythropodium caribaeorum* colonies and one colony of the colonial anemone *Palythoa* had expanded off the base and were overgrowing and smothering adjacent corals. Two other survivors were stony corals (*P. porites*) that appeared healthy, but remained small (5-15cm) with little evidence of new growth and dense mats of algae encircling the base of the colony (Fig. 5). A thorough search of the restoration site, examination of a reef ball placed at a second site, and examination of the substrate surrounding the outflow pipe did not reveal any Indo-Pacific stony corals or soft corals.

DISCUSSION

Production of corals for home aquaria: The Oceanographic Institute of Dominica was established originally as a for-profit coral farm with the goal of producing corals and other cnidarians from fragments taken from wild-harvested specimens to supply international markets with home aquarium specimens. The facility started with Indo-Pacific corals obtained from Indonesia, with exports of several shipments of 'second generation" fragments to the U.S. These were supplemented with, and eventually replaced by western Atlantic corals harvested from waters in Dominica.

Over the last decade there has been a 10-30% annual increase in the export of live stony corals (primarily scleractinian corals) for home aquaria, with over 98% taken from the wild and more than 1.5 million corals in trade during 2007 (Bruckner 2005, unpubl data). Most of these are from Indonesia, as well as several other southeast Asian and Pacific Island nations, with less than 1% from western Atlantic reefs; over 80% are destined for the U.S. Because of the increasing threats to coral reefs, including recent climate-induced bleaching events, and worldwide declines in living coral cover, there are growing concerns of the sustainability of the wild harvest of corals.

Concurrently, there is recognition of the importance of this trade as a source of revenue for developing countries and potential educational value of aquarium displays. In recent years, there has been a move to switch from wild harvest to *in situ* coral production facilities, especially in the Indo-Pacific. Most of these efforts involve the fragmentation and grow-out of corals on racks placed in shallow lagoonal environments. While there are economic risks associated with this practice, especially losses due to storm damage, bleaching events and other stressors, this approach supports entire communities and can be much less detrimental to wild populations if done in an environmentally friendly way. Further improvements to coral mariculture practices, to the point it can replace wild harvesting for the ornamental trade, is a priority measure to enhance conservation of reefs while still allowing trade in corals for home aquaria.

Nevertheless, there is a critical need to develop internationally recognized environmental standards, criteria for certification in best practices, and improved reporting guidelines for coral farms to minimize impacts to the wild associated with collection of brood stock, and reduce potential risks of introductions of non-native species. For instance, it is possible to take only a portion of an individual colony for each preferred species and color variety, and use this as the donor colony to produce first generation fragments. These fragments could be allowed to grow up beyond marketable size, with periodic removal of small branches or fragments that are grown to market size and exported. This would minimize the need to supplement production with additional specimens removed from the wild. Other standards regarding the sizes of fragments and the amount of time for grow-out prior to export need to be established, possibly including the use of some sort of pit tag to allow rapid verification that the corals were in fact produced following recognized mariculture standards. In addition, coral farms should only use locally harvested corals as source colonies to reduce potential introductions of pathogens, diseases and non-native species. Utilization of sexual reproduction, especially for brooding species, is also possible.

CITES requirements: There are specific international requirements that must be addressed to legally export of all stony corals (but not currently for soft corals) associated with their Appendix II listing in CITES. CITES requires that any export of a listed specimen must be authorized with an export permit based on a management program implemented by the country's CITES scientific authority, and administered by its CITES management authority. The management plan should include a variety of control measures such as quotas for wild harvest, which are based on the abundance and population dynamics of the species in trade (Armstrong & Crawford 1998; Green and Hendry 1999). CITES permits can be issued for export only if they address three criteria: 1) the specimens were acquired legally, in accordance with the country's laws and regulations; 2) the export will not be detrimental to the survival of the species or its role in the ecosystem; and 3) live specimens will be prepared and shipped so as to minimize the risk of injury, damage to health or cruel treatment. One of the difficulties for corals has been a lack of baseline data on the status and trends of CITES listed corals and a simple approach to determine what constitutes sustainable levels of harvest. An approach to manage coral fisheries was proposed for Indonesia, which relied on a determination of the total amount of habitat occupied by the species of interest, the abundance and size structure of the species within its preferred habitats, and the coral life history (Bruckner 2003, Bruckner & Borneman 2006).

Ensuring sustainable harvest: At the time of this study, the government of Dominica had not yet implemented many of the CITES requirements and it lacked the information necessary to make a determination that exports are non-detrimental. OID was the first western Atlantic-based coral farm intending to produce corals for international markets.

Other Caribbean nations, as well as the United States, currently ban the wild harvest of stony corals because of the importance of these as reef builders, habitat for other species, sources of food, and important sources of primary productivity (Bruckner 2005). Furthermore, western Atlantic reefs have experienced widespread declines in living coral cover, and additional collection may severely compromise the health and resilience of these reefs. Dominica's reefs are affected by many of the same stressors observed throughout the region, including threats from overfishing, coastal development, land based pollution, sedimentation and effects from climate change. Benthic reef surveys were conducted on the west coast of Dominica in the early to mid 1980s by Goodwin (1985) to assess the potential value of artificial reefs. The fringing reefs of Toucarie Bay and Douglas Bay were considered at the time to be the finest in Dominica, with high coral species diversity and living coral cover, although some algal overgrowth of corals was observed and macroalgae were conspicuous between corals (Putney *et al*. 1983; Goodwin 1985). In addition, west coast reefs were reported to be affected by industrial/urban activity and river input, with considerable turbidity and silt observed on reefs in northern Prince Rupert's Bay, Scott's Head, and in areas between Layou and Pte. Tarou (Goodwin 1985). During the present surveys, coral cover was moderate to low and it appeared to be declining. A high prevalence of disease and other biotic stressors were recorded, which had also been previously reported (Borger 2003), and corals exhibited high levels of recent mortality and ongoing degradation.

The extensive and ongoing decline of Caribbean reefs emphasizes the need to limit harvest of corals. In Indonesia, recommendations were developed that included a conservative harvest of no more than 5% of the population of the target species for fast growing species with high recruitment, with 1-2% allowable take of other slow growing species provided their populations exceeded some minimal baseline abundance and there was evidence of recruitment (Bruckner & Borneman 2006). More conservative estimates need to be adopted for the Caribbean and certain species from the Caribbean should be completely avoided. This includes a ban on the collection of *Acropora palmata* and *Montastraea annularis* (complex) due to unusually low levels of recruitment, widespread losses experienced over the last two decades, and an ongoing regional decline of these species due to disease and bleaching (Bruckner & Hill 2009).

Reef restoration: The benefits of the pilot restoration experiments conducted by AMT need to be carefully evaluated before additional restoration efforts are undertaken. OID initially obtained a permit from the government of Dominica to harvest over 3 000 colonies from local reefs, with agreement that they would replace each colony that was removed with 10 new corals. There were few details on the types or sizes of corals that would be harvested and returned to the reefs, sites for collection, or the approach used to identify sites for restoration and implement and monitor restoration efforts. Before allowing additional harvest and restoration efforts, a thorough analysis of the benefits from a conservation perspective should be undertaken. This should include an evaluation of existing threats and the likelihood that these threats will impact the survival of transplanted corals, the condition of reefs and their need for restoration, optimal species and sizes for transplant and methods/substrates for attachment. For instance, one of the primarily sites for the pilot restoration project, Toucari Bay reef, was in good condition. This site contained a high diversity and cover of stony corals and a low prevalence of disease and recent mortality; coral restoration was likely to have minimal benefits at this site. Corals transplanted onto the Reef Balls at other sites included many different coral species with vastly different life histories, and these corals were planted within 5-10cm of each other, suggesting the possibility of competition and potential mortality of the weaker competitor in the near future. Furthermore, benefits and limitations of natural substrates versus artificial substrates such as a Reef Ball need to be carefully considered before more of the structures are placed into the marine environment.

While pilot efforts may provide some useful biological information in terms of growth rates and survivorship of various species exposed to different environmental conditions on Dominica's reefs, it is unlikely that these efforts will contribute to true ecological or geological "restoration" of these reefs, since the transplanted corals consisted of a large number of non preferable species. Soft corals are generally of little value in reef restoration efforts in terms of creating habitat for other species or in continued reef building. In fact, some species such as the colonial anemone *Palythoa* and the encrusting gorgonian *Erythropodium* may negatively impact reefs by monopolizing reef substrate, outcompeting reef-building corals and preventing recruitment of other species. Furthermore, branching gorgonians may shade slow-growing understory stony corals. The fast growing genera, such as *Agaricia* and *Porites,* have relatively short life spans and appear to be recruiting on these reefs at high rates in the absence of human intervention. In addition, these species were least affected by current stressors, and the need for outplanting of these taxa is questionable. A small number of long-lived, slow growing massive corals such as *M. faveolata, M. cavernosa* and *S. siderea* were also transplanted onto the reef, but these exhibited very low survival. These are likely to be the most important corals for restoration projects, yet they will require 25 or more years to reach sexual maturity and provide habitat and other functions. Furthermore, stressors affecting these reefs, including overfishing, sedimentation, lack of herbivory, disease and other factors, have not been mitigated and these important species are also the ones particularly susceptible to some of the most virulent diseases observed on these reefs. In other restoration efforts, near total loss of coral fragments has occurred over time largely due to the conditions of the site and stressors unrelated to the restoration approach (Bruckner & Bruckner 2006, Bruckner *et al*. 2009).

Invasives: While it does not appear that AMT purposely introduced Pacific corals to Dominica's reefs, the onshore culture of Pacific corals presents a significant threat because the facility is not sufficiently isolated from the sea. Although AMT had systems of filtration and UV sterilization in place, Dominican officials should be permitted to inspect the system in detail to ensure the filtration method is adequate to treat effluent water and not subject to failure. In addition to the danger that imported species will spatially outcompete indigenous corals, there is the danger of introducing exotic diseases. The risk of growing Indo-Pacific corals in a Caribbean-based facility with direct connection to the ocean is unacceptable, even in situations where filtration and UV sterilization of water is undertaken before release into the sea, due to a high potential for accidental release (e.g. if the filtration system is not functioning properly or the facility is hit by a hurricane).

CONCLUSIONS

OID had a large number of corals in their production facility in June 2002, mostly consisting of species removed from local reefs with a small number of Indo-Pacific corals. These corals were growing under suboptimal conditions of water temperature (too high), water flow (too low) and light (too low), and macroalgae were outcompeting and overgrowing the substrate and fragments. OID had transplanted corals to surrounding reefs and Reef Balls, including species that are not ideal candidates for restoration due to their invasive nature, competitive dominance and limited contribution to reef structure and growth. No Pacific corals were identified at any sites during these surveys. Most of the long-lived massive corals transplanted to the reefs showed limited growth and low survival, possibly due to poor environmental quality and various anthropogenic and natural stressors. Given the declining state of Dominica's reefs and the high number of stressors that need to be mitigated, further harvest of key reef building corals is not likely to be sustainable in its current form. Future restoration efforts require a thorough evaluation to select appropriate sites and species and identify best practices, and improvements of the culture system at OID need to be undertaken to maximize the health and survival of the corals. Over the longer term, OID's activities could contribute to conservation and recovery of these reefs if management measures are implemented and are successful at addressing human stressors that are contributing to reef decline.

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RESUMEN

En junio del año 2002 el gobierno de Dominica solicitó asistencia para evaluar el Instituto Oceanográfico de Dominica (OID), una operación de cultivo de corales del océano Atlántico y del Indo Pacifico para propósitos de restauración y comercio. Evaluamos las facilidades de cultivo del OID, la condición de los arrecifes y el impacto potencial de la recolección de corales y los posibles beneficios del transplante de colonias. Los arrecifes de coral (9 arrecifes de profundidades entre 3 y 20m se caracterizaban por 35 especies escleractíneos y una cobertura viva de coral entre 8 y 35%. Las especies que liberan larvas tales como *Porites astreoides* (14.8 % de todos los corales), P. porites (14.8%), *Meandrina meandrites* (14.7%) y *Agaricia agaricites* (9.1%) fueron los más abundantes, pero sus colonias eran pequeñas (promedio de 25cm de diámetro). El complejo de *Montastraea annularis* fue otro grupo dominante (20.8% de todos los corales) y sus colonias eran mayores (promedio de 70cm de diámetro). Entre todas las especies los corales habían perdido el 20% de sus tejidos, con un promedio de 1.4% por mortandad reciente. Las enfermedades de coral afectaron 6.4% de todas las colonias, con la incidencia mayor en Cabrits Oeste (11%), Bahía Douglas (12.2%) y el arrecife de Coconut Afuera (20.7%). Plaga blanca y la enfermedad de la banda amarilla causaron la mayoría de la pérdida de tejido vivo, especialmente en el complejo de *M. annularis*, con impactos localizados por caracoles coralívoros, sobre crecimiento por macroalgas, impactos de tormentas y sedimentación. Mientras los arrecifes parecen estar declinando substancialmente, los esfuerzos de restauración de OID no parecen entablar su recuperación debido a que las especies escogidas para transplantar con las mayores tasas de sobrevivencia incluyen especies que liberan larvas (*Agaricia* y *Porites*) que fueron abundantes en las restauraciones, al igual que los organismos potencialmente parasíticos (*Palythoa* y *Erythropodium*) que pueden monopolizar el sustrato y sobre crecer a los corales. Las especies de mayor valor para la restauración (corales masivos de liberación de gametos) tuvieron baja sobrevivencia, sufrieron mas de las enfermedades u otros impactos biológicos e impactos antropogénicos los cuales deben ser atendidos para garantizar la sobrevivencia de los corales transplantados. Algunos problemas con la operación de cultivo de OID tales como temperaturas e irradiación altas al igual que sobre crecimiento de algas podrían ser controladas con algunos cambios en los sistemas de irrigación, iluminación y mantenimiento. Sin embargo los altos niveles de enfermedades y otros impactos (macroalgas, ausencia de herbívoros, evidencia de sobre pesca, sedimentación y eutrofización) son de mayor preocupación por sus impactos sobre los corales que proveen el armazón del arrecife ya que estas especies reciben menos beneficio de la restauración, su colección puede amenazar la sobrevivencia de sus poblaciones y la recuperación de estos corales podría tomar siglos

Palabras claves: maricultura de coral, fragmentación, restauración, enfermedad y salud de coral, transplantes.

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