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Fixed and suspended coral nurseries in the Philippines: Establishing the first step in the "gardening concept" of reef restoration

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Abstract

The worldwide degradation of reef ecosystems has promoted the advocators of restoration acts to the foreground. Here, we describe the results of the first step of large-scale restoration based on the "gardening with corals" concept. During June–September 2005, two coral nurseries were established in Bolinao, the Philippines, in front of Silaqui Island, in a shallow (2 m depth) sandy lagoon. Two types of nurseries were employed: (1) suspended nursery; (2) leg-fixed nursery. The nursery held a total number of 6824 ramets, from seven coral species representing different growth forms (branching, leaf-like and sub-massive forms) and different growth rates (fast and slow growing species). Each species was represented by several genotypes. During one year, we analyzed and compared survivorship, bleaching and growth rates of fragments between the different nurseries, species and genotypes. Survivorship, which was high in both nurseries, >85%, fluctuated between the different species indicating that different species require different rearing methodologies. Mortality and detachment was subjected to environmental conditions, especially affected by the typhoons prevailing in this part of the world. The one-year nursery phase produced sizeable colonies, especially of branching forms, suitable for transplantation.
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1. Introduction

Coral reefs are of the most rich, diverse, and productive marine ecosystems (Hoegh-Guldberg et al., 2007). For countless local communities along the coasts of developing countries, this ecosystem provides livelihood and protection against strong waves and coastal erosion (Gomez, 1997; Latypov, 2006; Ahmed et al., 2007). Over the last decade, coral reefs around the world have been increasingly declining, stressed by global changes and anthropogenic impacts; that they seem unable to regenerate adequately and overcome those factors (Rinkevich, 1995, 2005a; Chadwick-Furman, 1996; Hodgson, 1999; Epstein et al., 2001; Wilkinson, 2002; Manning et al., 2006; Shafir et al., 2006a).

Unfortunately, passive rehabilitation measures and traditional management acts have proven to be insufficient or ineffective in ameliorating long-term damage and have failed to yield quantifiable returns or suitable responses to key anthropogenic threats (Edwards and Clark, 1998; Yap et al., 1998; Lindahl, 2003; Rinkevich, 2005a,b, 2006; Forsman et al., 2006; Tsuchiya, 2006). To avoid the pitfalls associated with the traditional management measures, Rinkevich (1995, 2005a,b, 2000, 2006) suggested shifting management efforts from passive conservation to active rehabilitation strategies. The proposed remediation strategy is based on the 'gardening concept' (Rinkevich, 1995, 2000; Epstein et al., 2001), a two-step restoration measure, featuring mass farming of coral nubbins, fragments and

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spats in specially designed underwater nurseries, which are transplanted onto degraded reefs upon reaching adequate size. Recently, an improved method involving the use of a floating mid-water coral nursery has been successfully tested in the northern shore of Eilat, Gulf of Eilat, Red Sea (Rinkevich, 2006; Shafir et al., 2006a,b). This nursery prototype met expectations, such as successful, cheap and fast farming of thousands of coral colonies from several coral species, with impressive rates of survivorship, fast growth and improved reproductive efforts (Bongiorni et al., 2003; Rinkevich, 2006; Shafir et al., 2006a,b; Amar and Rinkevich, 2007). Furthermore, farmed coral colonies from the Eilat mid-water nursery, which have recently been transplanted onto denuded reef sites, have yielded encouraging results in improving biological condition, such as high coral survivorship, increased conscription of reef dwelling invertebrates and fish and enhanced recruitment of coral spats (B.R., unpublished). However, in order to decide on the best applicable method for conserving reef biodiversity, prior to adopting the 'gardening concept' as an ubiquitous methodology for coral reef restoration, the newly developed methodologies should be tested and substantiated in other reef sites and on different coral species worldwide.

In Eilat, the floating mid-water nursery prototype (placed at depth of 6 m, 14 m above seafloor, in the nutrient-enriched environment of a fish farm) yielded colonies ready for transplantation within 144–200 nursery days (Shafir et al., 2006a,b). Results also revealed that a successful nursery could constitute a simple and cheap structure, built from locally available material, with little technical manipulations and extremely low maintenance costs (Shafir et al., 2006a). For example, gluing thousands of coral fragments within a few days to substrates by cyanoacrylate adhesives (super-glue) was found to be the easiest and cheapest technique for preparing new colonies by untrained workers (Shafir et al., 2006a). Since there is much more to learn about proper restoration of coral reef ecosystems, it would be inevitable to initiate similar restoration assays in other reefs worldwide for testing and comparing various aspects of both gardening concept steps; the nursery phase and the transplantation act.

This work tests the issue raised above in the Philippines where an estimated 10–15% of the total fish yield comes from coral reefs (Gomez, 1997). A 2004 Global Coral Reef Monitoring Network studies (Tun et al., 2004) found that the Philippine reefs were undergoing an annual steady decline in coral cover of 3–5%. Here we present the results of employing the first step of the ''gardening of the coral reefs'' concept (Rinkevich, 1995, 2000, 2005a), in a large *in situ* coral nursery at the eastern edge of the South China Sea, Luzon, the Philippines. Growth and survival of 6824 coral ramets prepared from seven different coral species, were observed for one year in two types of *in situ* nurseries (suspended, leg-fixed). The leg-fixed nursery model was tested for the first time because of the shallow waters at the experimental site, allowing the comparison of the two types for future reference. Cost effectiveness and invested person–months were taken into consideration.

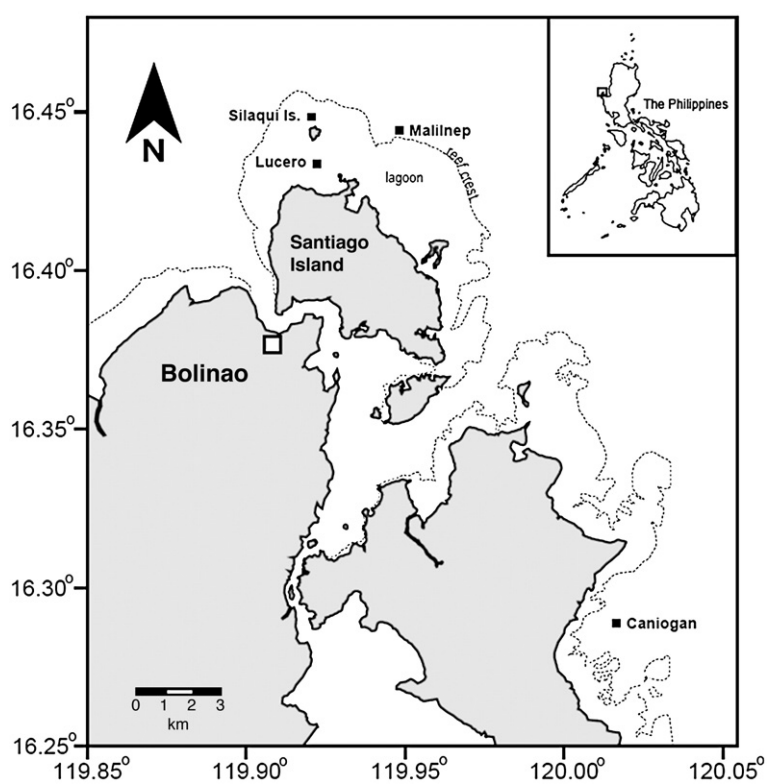

Fig. 1. Study area in the Philippines, showing the nurseries (Silaqui Island) and the coral collecting sites (Lucero, Malilnep and Caniogan).

2. Methods

2.1. Area description

The study was conducted in Bolinao, Pangasinan, a coastal town in northwestern Philippines (16°22′ and 16°27′ N latitude and 119°52′ and 120°00′ E longitude, Fig. 1) along the eastern side of the South China Sea. The fringing reefs of Bolinao with slopes dropping to 120 m in certain areas, experience the northeast monsoon from November to March and the south-west monsoon from June to October. Reef flats are mostly fine sediments, covered with sea grasses and seaweed, whereas some fore-reefs extend up to several kilometers from the shore, with coral cover (average 20%), reaching down to about 30 m (Gomez, 1997). The Bolinao reef complex has been subjected to over-fishing and destructive fishing practices such as blast and cyanide fishing (Gomez et al., 1994; Gomez and McManus, 1996; Gomez, 1997, 2001).

2.2. Nursery construction

The site selected for the coral nurseries was in front of Silaqui island (16°26′43.5 N latitude and 119°55′26.7 E longitude; Fig. 1), in a shallow (2–4 m) sandy lagoon. Two coral nurseries were constructed side-by-side during June–September 2005: (1) a suspended nursery, situated at invariable depth of 2 m, therefore swinging from 1 m above substrate at high tide to less than 50 cm above substrate at low tide (Fig. 2A); and (2) a fixed-to-bottom (leg-fixed) nursery, situated 1 m above substrate (Fig. 2B). Both nurseries were made of modular structures, each made of a 60 × 80 cm plastic mesh tray (Fig. 2D) attached by cables to 0.5″ PVC pipe frame (Fig. 2C). Each of the

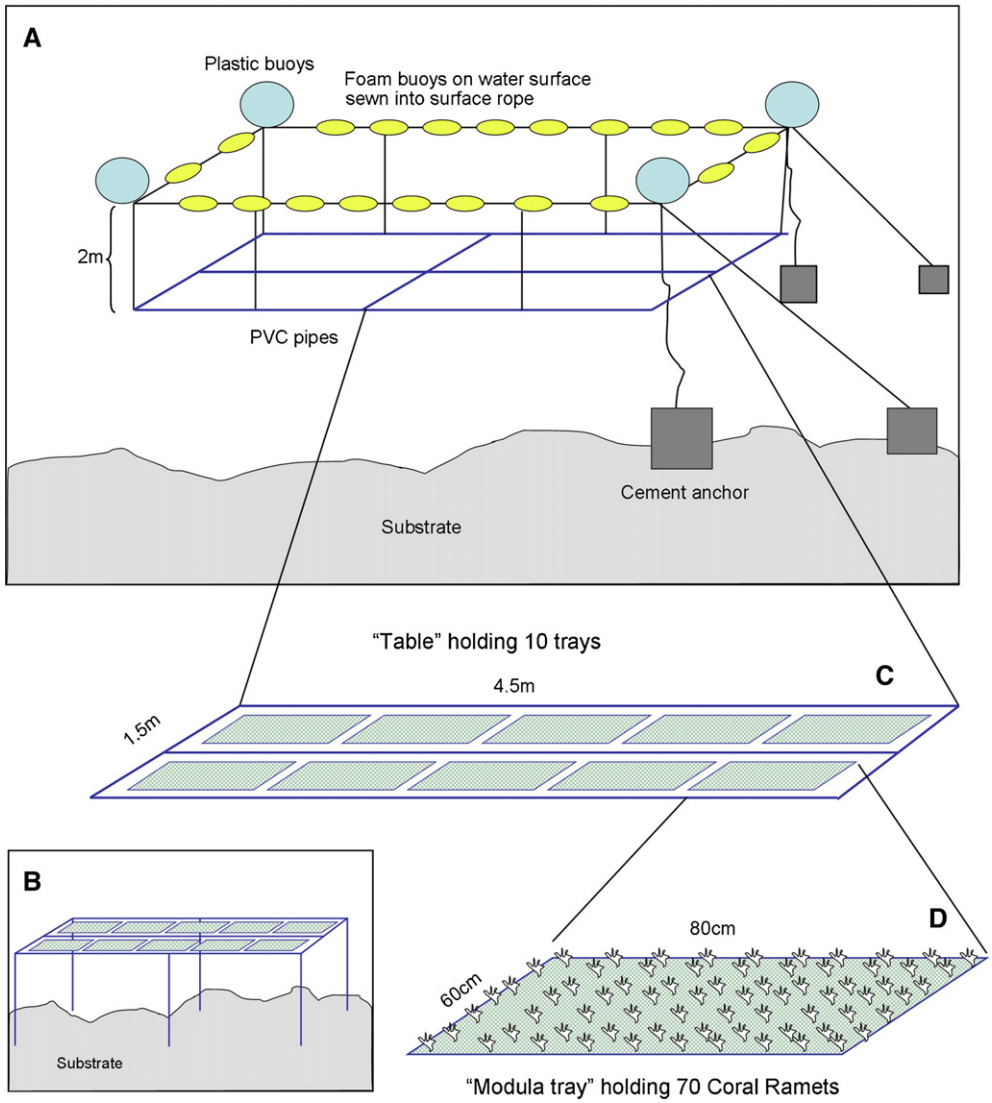

Fig. 2. Schematic illustration of the nurseries. (A) The suspended nursery, plastic buoys and foam buoys are on the water surface, connected by 2 m ropes to the PVC pipes. The nursery is anchored at 4 corners with 50 kg cement blocks connected to the large plastic buoys; (B) The leg-fixed nursery, the PVC construction is secured to the sandy bottom by 1 m length PVC stilts, each tied to an iron bar, inserted 1.5 m into the substrate; (C–D) The nurseries' modular units; (C) The "table", a PVC frame 1.5 × 4.5 m rectangle holding 10 trays; (D) A PVC tray 0.6 × 0.8 m, with a plastic mesh connected by cable ties, on which 70 coral ramets are held.

Table 1
Coral species farmed in the nursery

Species	Morphology	Growth rate	Number of genotypes	Number of ramets	Collection site	Depth of collection (m)
Merulina sabricula (Dana, 1846)	Leaf-like	M	2	1260	Malilnep	3
Echinopora lamellosa (Esper, 1795)	Encrusting	M	3	2030	Malilnep	3–4
Montipora digitata (Dana, 1846)	Branching	F	3	1960	Lucero	0.5–1
Pocillopora damicornis (Linnaeus, 1758)	Branching	F	2	570	Lucero	0.5–1
Porites rus (Forskål, 1775)	Sub-massive	S	1	354	Lucero	0.5–1
Acropora formosa (Dana, 1846)	Branching	F	1	333	Caniogan	2–3
Montipora aequituberculata (Bernard, 1897)	Leaf-like	M	1	317	Caniogan	2–3

F = fast growing, M = medium growth rate, S = slow growing.

ten trays were connected by cables to a 1.5 × 4.5 m rectangle ("table") made of 0.5″ PVC pipes (Fig. 2B). The suspended nursery was made of seven tables, containing 70 trays; the leg-fixed nursery was made of five tables, containing 50 trays.

The suspended nursery was held in place by four cement sinkers, 50 kg each, secured to the sandy substrate with anchors, to prevent it from moving during storms. Each sinker was connected to a large buoy by ropes (the ropes were stretched at high tide and relaxed in low tide), which in turn, were interconnected by other ropes into which small foam buoys were sewn at one-meter intervals (Fig. 2A). The PVC tables were tied to the floating ropes by five ropes (2 m long each, one at each corner and one in the middle), so that the trays stayed at fixed depth of 2 m (Fig. 2A). The tables were interconnected in a row by ropes, creating a platform of 32 × 1.5 m. In the leg-fixed nursery, the PVC "tables" were constructed of 0.75″ PVC pipes and five PVC stilts (one at each corner and one in the middle). The stilts were connected by a monofilament line to 1.5 m long angle-bars, which were wedged deeply into the soft substrate. The tables were interconnected in a row by ropes, creating a platform of 23 × 1.5 m.

In the interest of determining the economics of using nurseries in coral reef restoration, the time required for the construction as well as the cost of the materials used were recorded. The issue of reef restoration costs is addressed in Edwards and Gomez (2007).

3. Material studied

3.1. Coral collection and transplantation in the nurseries

We studied seven coral species, representing different colony morphologies and growth rates (Table 1). Five of the species were abundant in the study area and two (*Acropora formosa, Montipora aequituberculata*) were collected from Caniogan Island, 20–22 km from Silaqui lagoon (45 min by boat). Coral fragments were taken from 1–3 genotypes per coral species, grown at maximum depth of 4 m (Table 1).

The colonies were detached from their natural substrates by chisel and hammer, carried in a basket to the boat, where they were placed in individual buckets filled with seawater. Side cutter pliers were used to cut colonies of branching forms into small fragments (ramets), 1–3 cm long from the branching forms and those of the encrusting, sub-massive and leaf-like forms to 2–3 cm^2. Ramets were paper-toweled from excess water and glued with cyanoacrylate adhesive ("Loctite" Super Glue) to an artificial substrate deemed most suitable for the species' growth pattern. For the fragments of branching-species, we used 10 mm flexible plastic tubing, 4 cm long each. Each fragment was inserted by forceps into the tube and further secured by a drop of super-glue around its edges. All plastic tubes were inserted side-by-side into the PVC tray meshes (Fig. 2D). Fragments of the other species were glued individually, onto 8 × 10 cm dense plastic mesh tied onto the PVC tray by a thin insulated copper wire. Each PVC tray contained 70 fragments from a single donor genotype (Fig. 2D). The numbers of ramets from each species deployed into the nurseries are summarized in Table 1.

3.2. Maintenance and monitoring

A monitoring and maintenance protocol was performed monthly. Dead, missing and bleached ramets were documented fortnightly. The dead ramets were removed from the trays to avoid recounting in successive monitoring sessions. Growth rates were monitored on 10 fragments from each donor colony; the fragments were tagged with names and serial numbers using Dymo tags. These fragments were photographed monthly with a digital Olympus camera using a side ruler for calibration. The maintenance of the nursery structures, including fixing of

Table 2
Person–hours invested in nurseries establishment, producing and deploying farmed fragments

Task	Detailed manpower	Time invested (person–hour)
Nursery construction outside the water	2 persons, 10 h day, 10 days	200
Making net trays (n = 120)	2 persons, 7 h day, 5 days	70
Construction of the threaded ropes with buoys	2 persons, 10 h day, 3 days	60
Deploying of the nurseries	5 persons, 4 h day (diving time), 1 day (per nursery)	40
Fragments' preparation, transplanting fragments on trays (70 ramets per tray) and deployment	4 persons, 7 h day, 80 days	2240
Average preparation time per fragment (glue and transplant)	1.5 min	
Total (nursery construction alone):		370
Grand total (including fragments):		2610

Table 3
Cost of materials used to build the two nurseries

Material	Cost PHP	Cost USD
PVC pipes	28,866	529
PVC connections	1352	25
PVC glue	9554	175
Plastic net	3653	67
Cable ties	7412	136
Ropes	4094	75
Buoys	20,780	381
Metal bars	4074	75
Cement	682	12
Miscellaneous (brushes, borers, screws etc.)	9298	170
Total	89,765 PHP	1645 USD

PHP — Philippines peso.

damaged/worn-out parts and removal of settled algae around the growing corals was done once a month.

3.3. Data analysis

Picture analyses (measurements of growth) were carried out with Photoshop and Image-Tool software. Statistical analyses were performed using a SPSS 13.01 2001 data editor. In these tests, the preliminary assumption was the existence of normal distribution. Transformations were performed (ARSIN — on percentages and Log10 — on counting numbers) in cases were no normal distribution was found. When transformation failed to change the distribution of data, we employed non-parametric tests like Mann–Whitney *U* Test and Kruskal–Wallis Test.

4. Results

We used 13 genotypes from seven coral species. Constructing the two nurseries and stocking them with 6824 coral ramets was completed within four months by a team of up to five people (total of ca. 16 person–months; Table 2). Building the nurseries construction on land was done by two people within one month (June 2005), whereas setting up the constructions, sinkers and ropes and assembling all parts was achieved by five people in two working days. Collecting coral source material, fragmenting donor colonies and installing the fragments took four people three working months (July–September 2005; Table 2). The use of SCUBA gear for donor coral collections took only 20–30 min per colony (searching for the suitable colony was the most time consuming). The time used on fragmenting colonies and attaching ramets onto artificial substrates depended on the species morphological characteristics. For the branching forms it took only 0.5 min per ramet, whereas in the case of *M. sabricula* with its very delicate leaf-like colonies preparing the ramets took 2–3 min per ramet and for *E. lamellosa* and *P. rus* 2 min/ramet. Freshly glued ramets were left to dry for 3–5 min prior to submerging them into containers filled with seawater. Packing a tray with 70 ramets of the encrusting species (connecting the mesh to the tray net with insulated copper wire) took 15–20 min and only 20 s for the branching-species (inserting the plastic tube into the net holes). The total cost for the material used (construction of two nurseries) was estimated at US$1645 (Table 3). The nurseries were assembled as perennial structures, reducing the cost per nursery to about US$150/year for a five-year operational period. The cost of gluing the fragments onto substrates was minimal, estimated at US$7/100 fragments.

When constructed, the suspended nursery held 4184 coral fragments in 70 trays and the leg-fixed nursery 2640 fragments (50 trays). After one year in the suspended and in the leg-fixed nurseries, 91.1%–85.3% of the overall fragments, respectively, survived and only 4.7%–4.9% became detached (Table 4). No significant difference was found between the suspended and the leg-fixed nurseries in fragment survivorship or detachment rates (Mann–Whitney *U* Test, $p > 0.05$). Similar results were obtained for bleached fragments (2.4 ± 1.7% in the suspended nursery, 2.1 ± 1.9% in the leg-fixed nursery; Mann–Whitney *U* Test,

Table 4
The status of 1 y farmed coral ramets in underwater nurseries

Species (genotype)	Suspended nursery			Fixed to substrate nursery		
	Initial fragment number	% Detached	% Survivorship	Initial fragment number	% Detached	% Survivorship
Merulina sabricula (A)	350	4.57	90.57	350	19.43	77.71
Merulina sabricula (B)	350	22.29	68.00	210	3.33	92.38
Montipora digitata (A)	350	0.29	99.43	350	0.57	99.43
Montipora digitata (B)	350	3.43	97.71	280	2.50	96.07
Montipora digitata (C)	350	0.57	94.57	280	0.00	30.36
Echinopora lamellosa (A)	350	4.29	97.43	350	5.43	95.71
Echinopora lamellosa (B)	350	4.00	98.00	140	4.29	97.86
Echinopora lamellosa (C)	420	13.10	93.81	420	4.29	87.86
Pocillopora damicornis (A)	190	0.00	93.16	130	6.15	86.92
Pocillopora damicornis (B)	120	0.00	94.17	130	3.08	88.46
Porites rus (A)	354	4.80	65.54	n.d.	n.d.	n.d.
Acropora formosa (A)	333	0.60	97.60	n.d.	n.d.	n.d.
Montipora aequituberculata (A)	317	2.84	94.01	n.d.	n.d.	n.d.
Total	4184			2640		
Average		4.67	91.08		4.91	85.28
Standard deviation		6.34	11.07		5.46	20.35

n.d. — not done.

$p>0.05$) after one year of mariculture (Table 4). Consequently, further analyses of differences between the studied species were performed on the pooled data from both nurseries.

Comparisons drawn between the farmed coral species pertaining to the numbers of detached ramets, dead ramets and bleached ramets, after one-year of nursery rearing, revealed species-specific differences (Table 4). As the data was not normally distributed, non-parametric tests were performed. Fragment detachment occurred mainly between weeks 10 and 16 after deploying the ramets into the nursery (Fig. 3A). Analyses revealed that the average number of detached ramets in the encrusting, leaf-like and sub-massive forms (*M. sabricula*, *E. lamellosa*, *P. rus* and *M. aequituberculata*), were higher compared to the branching coral forms (*M. digitata*, *P. damicornis* and *A. formosa*; Kruskal–Wallis; $p<0.05$, Mann–Whitney; $p<0.05$; Table 5, Fig. 3A).

Similar conclusion may be drawn for coral mortality (Table 5, Fig. 3B). Mortality rates were species-specific and persistent during the year, except between weeks 36 and 40 when mortality increased due to a strong typhoon that blew over Bolinao area in mid-May 2006 (Typhoon Caloy; winds up to 150 kph, pressure 963 hPa; Typhoon2000.com PAGASA Tracker). *Merulina sabricula* was the most susceptible species to this typhoon (Fig. 3B). However, even then, survivorship was high (>85%) in the six coral species, except for *P. rus* that had the highest average number of dead ramets (Mann–Whitney; $p<0.05$;

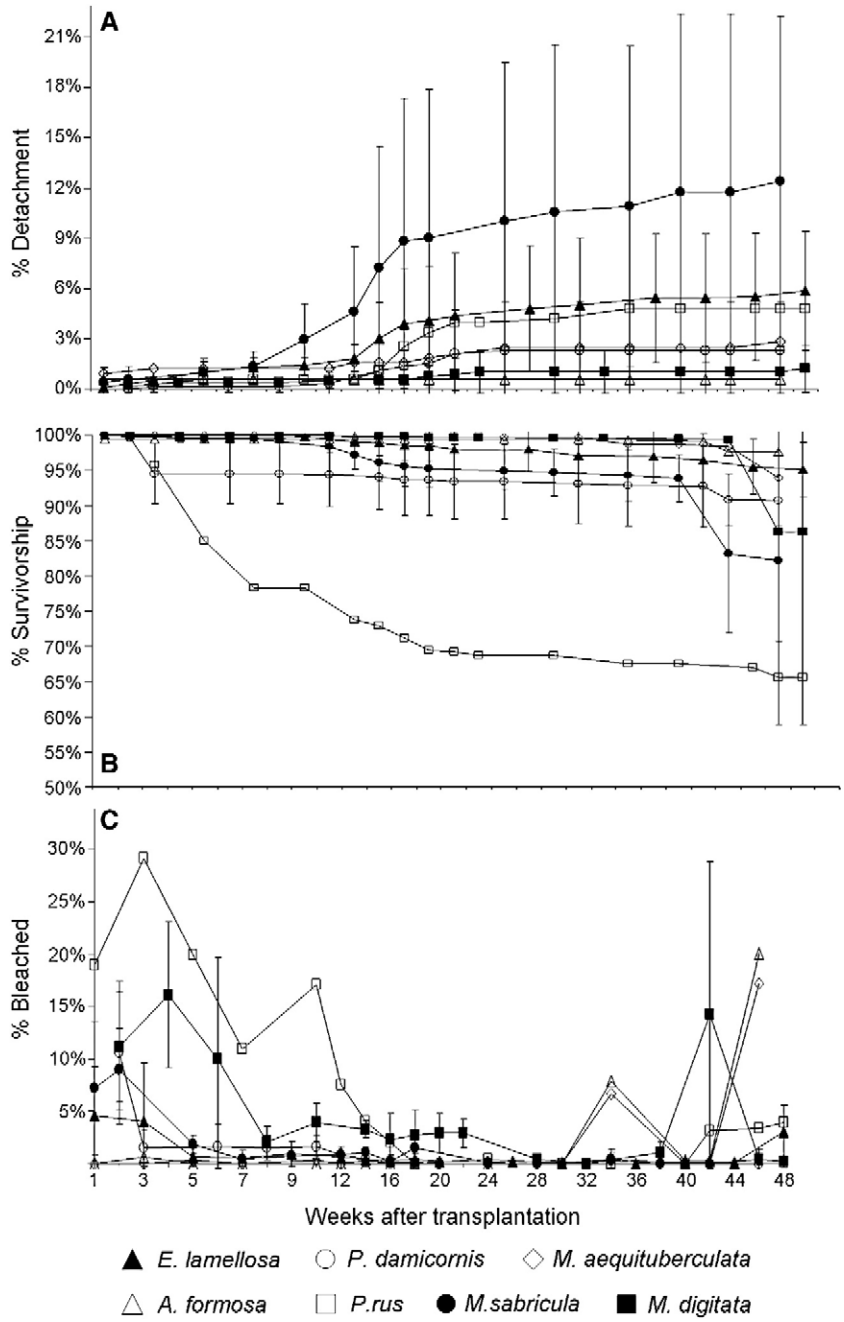

Fig. 3. Pooled values for survivorship (A), detachment (B), and bleaching (C) of maricultured fragments of the different coral species during 1 y of nursery phase.

Table 5
Average parameters' values monitored over 1y of nursery rearing

Species	Detached		Dead		Bleached	
M. digitata	0.77±0.91	A	2.70±12.12	C	4.63±6.89	C
M. sabricula	6.91±7.87	B	5.04±6.69	D	1.59±3.20	B
P. rus	2.86±1.90	B	27.24±8.14	E	7.56±9.02	C
P. damicornis	1.40±2.16	A	6.28±4.54	A	1.25±3.13	A
E. lamellosa	3.53±3.23	B	1.89±2.84	B	1.00±2.29	A/B
M. aequituberculata	1.87±0.64	B	0.80±1.53	A/B/C	1.94±5.40	A/B
A. formosa	0.60±0.00	A	0.26±0.63	A/B/C	1.66±4.64	A/B

Letters represent grouping of insignificant differences between species. Species that are not different from several other species are marked with more than one letter.

Table 5, Fig. 3B). *M. sabricula* revealed higher mortality compared with *E. lamellosa*, *M. aequituberculata*, *M. digitata*, *P. damicornis* and *A. formosa*, but lower than *P. rus* (Mann–Whitney; $p<0.05$; Table 5, Fig. 3B). *M. digitata* had higher mortality than *E. lamellosa* and *P. damicornis* (Mann–Whitney; $p<0.05$) that did not differ from *A. formosa* and *M. aequituberculata* mortality rates (Mann–Whitney; $p>0.05$; Table 5, Fig. 3B). *E. lamellosa* exhibited higher mortality than *P. damicornis* (Mann–Whitney; $p<0.05$), that did not differ from *A. formosa* and *M. aequituberculata* mortality levels (Mann–Whitney; $p>0.05$; Table 5, Fig. 3B). *P. damicornis*, *A. formosa* and *M. aequituberculata* showed no significant difference in average numbers of dead ramets during one year of nursery rearing (Mann–Whitney; $p<0.05$; Table 5, Fig. 3B).

Bleaching of farmed colonies appeared as peak events during the studied period (Fig. 3C). The main bleaching event occurred during the first seven weeks post-fragmentation and ramets' deployment onto nurseries, declined, and then another bleaching event was recorded in week 32 proceeding up to week 44, corresponding with the strong typhoon at this time. The levels of bleaching were similar in ramets of *P. rus* and *M. digitata*, cumulatively and significantly higher in these species than in the other five studied coral species (Mann–Whitney; $p<0.05$; Table 5, Fig. 3C). *M. sabricula* had higher bleached ramets than *P. damicornis* (Mann–Whitney; $p<0.05$), which did not differ from *E. lamellosa*, *A. formosa* and *M. aequituberculata* (Mann–Whitney; $p>0.05$; Table 5, Fig. 3C). *P. damicornis*, *E. lamellosa*, *A. formosa* and *M. aequituberculata* showed no significant difference in numbers of bleached ramets (Mann–Whitney; $p>0.05$; Table 5, Fig. 3C).

Different fragments from the same genotypes of *M. sabricula*, *M. digitata*, *E. lamellosa* and *P. damicornis* were deployed in both nurseries, enabling comparison between nursery impacts on survivorship, detachment, bleaching and growth. Most outcomes revealed insignificant differences among coral genotypes and between ramets of a specific genotype distributed in the two nurseries. The few significant differences were found in the number of detached ramets between genotypes A (10.91±7.87%) and B (0.73±0.88%; Mann–Whitney; $p<0.05$) of *M. sabricula* in the leg-fixed nursery, and between *M. sabricula* genotype B in the suspended nursery (13.35±8.62%) vs. genotype B in the leg-fixed nursery (0.73±0.88%; Mann–Whitney; $p<0.05$). The same applied to the mortality of *E. lamellosa* genotype C in the leg-fixed nursery (6.52±4.11%) compared to genotypes A (1.14±1.26%) and B (0.71±1.05%), and for bleaching rates of genotype C ramets at the leg-fixed nursery (1.40±2.59%) compared to genotype B (0.35±1.00%; Mann–Whitney; $p<0.05$). Further comparisons revealed that *E. lamellosa* genotype C had lower number of dead ramets in the suspended nursery (2.06±1.73%) compared to genotype C in the leg-fixed nursery (6.52±4.11%; Mann–Whitney; $p<0.05$). *M. digitata* and *P. damicornis* genotypes showed no differences at all (Mann–Whitney; $p>0.05$).

Table 6
Growth parameters of nursery reared ramets, originating from the encrusting and sub-massive coral species following a 1-year nursery period

Species	G-type	Number	Days	Sizes (cm^2)	Size augmentation (cm^2)	Growth rates (%/d)
E. lamellose	A	18	0	2.57±0.61		
	A		365	9.30±3.49	6.73±3.09	0.71±0.29
E. lamellosa	B	19	0	2.06±0.63		
	B		365	6.36 ±2.56	4.31±2.38	0.62±0.36
E. lamellosa	C	14	0	3.00±0.94		
	C		365	11.58 ±3.12	8.58±2.81	0.87±0.43
M. sabricula	A	14	0	2.93±0.92		
	A		365	5.26±1.69	2.33±1.13	0.23±0.15
M. sabricula	B	18	0	2.62±0.84		
	B		365	4.67±1.94	2.05±1.43	0.21±0.15
P. rus	A	5	0	1.61±0.53		
	A		365	4.62±1.33	3.01±1.36	0.57±0.30
M. aequituberculata	A	9	0	3.03±0.30		
	A		365	3.86±2.65	0.83±2.72	0.08±0.26

G-type=genotype number.

These results revealed that both nurseries were equally fitted and the differences were probably related to episodic micro-local environmental/biological conditions rather than to nursery type. The same applied to growth rates of the ramets derived from the same coral genotype that were distributed between the two nurseries (One-Way ANOVA, $p>0.05$). We therefore pooled results of genotype growth analyses from both nurseries. Results of the genotype analyses revealed similar tendencies. For example, the two *M. sabricula* genotypes (A, B) did not differ significantly from each other after 1 y nursery growth (surface area growth per day 0.23±0.15% and 0.21±0.15% respectively; Table 6, Fig. 4A). This trend was also consistent with other species, even when initial fragments were of different sizes. Within the three *M. digitata* genotypes (A, B and C), a significant difference was found between the initial height of genotypes A (2.44±0.86 cm) compared to B (3.25±0.87 cm; One-Way ANOVA, $p<0.05$) and initial width of genotype A (0.85±0.36 cm) compared to genotype B (1.87±1.35 cm; One-Way ANOVA, $p<0.05$; Table 7, Fig. 5A,B). After one year of nursery growth, no difference was recorded in the final sizes (height and width) of the three genotypes, or in the growth rate per day (Table 7, Fig. 5A–C). In *E. lamellosa* genotype B initial fragment sizes were significantly smaller than of genotypes A and C (2.06 ± 0.63 cm^2 compared to 2.57±0.61 cm^2 and 3.0±0.94 cm^2, respectively, One-Way ANOVA, $p<0.05$). After one year, sizes of all three genotypes still differed from each other (B: 6.36±2.56 cm^2 < A: 9.30±3.49 cm^2 < C: 11.58± 3.12 cm^2; One-Way ANOVA, $p<0.05$), but the growth rate per day did not differ significantly among the genotypes (Table 6, Fig. 4B). Fragments of *P. damicornis* genotype A were significantly larger in the one-year height and width dimensions compared to genotype B (height: 4.50±1.19 cm compared to 5.52±0.72 cm; width: 5.46±1.54 cm compared to 6.95±0.9 cm, respectively; One-Way ANOVA, $p<0.05$). No significant difference was recorded for initial sizes and growth rates per day, both in height and width of the different genotypes (Table 7; Fig. 5D, E). In *P. rus*, *M. aequituberculata* and *A. formosa* only one genotype was deployed onto the nurseries (Table 6, 7, Fig. 4C, D and Fig. 5F).

The one-year nursery phase resulted in a significant increase of fragment sizes in colonies with sizes applicable for transplantation (Figs. 6, 7). This was noteworthy in the branching forms. *A. formosa* percentage of height added (367±98%) was the most striking outcome, significantly higher than *P. damicornis* (225±100%) and *M. digitata* (220±100%; Mann–Whitney *U* Test, $p<0.05$, Table 7; Fig. 6). Of the branching forms, *P. damicornis* had significantly lower percentage of width added (252±103%) compared to *A. formosa* (758±250%) and *M. digitata* (1032±683%; Mann–Whitney *U* Test, $p<0.05$; Fig. 6). *A. formosa* fragments, while growing fast in all three dimensions (Fig. 5F), did not initiate inward growing branches to fill up empty spaces between branches (Fig. 6A), as did the other branching forms, notably the *P. damicornis*, where spherical compact colonies with a complex branching system developed (Fig. 6B). *M. digitata* fragments grew almost equally in horizontal and vertical dimension (Fig. 5A–C) with initiated side branches that did not fill up the spaces (Fig. 6C) as in *P. damicornis* (Fig. 5D, E; Fig. 6B). After one year in the nursery, *M. digitata* fragments developed colonies that occupied the largest spaces of the branching forms, creating thickets of continuous sheets of branches on the nursery bed, which eliminated clear distinction and separation between individual colonies (Fig. 6D).

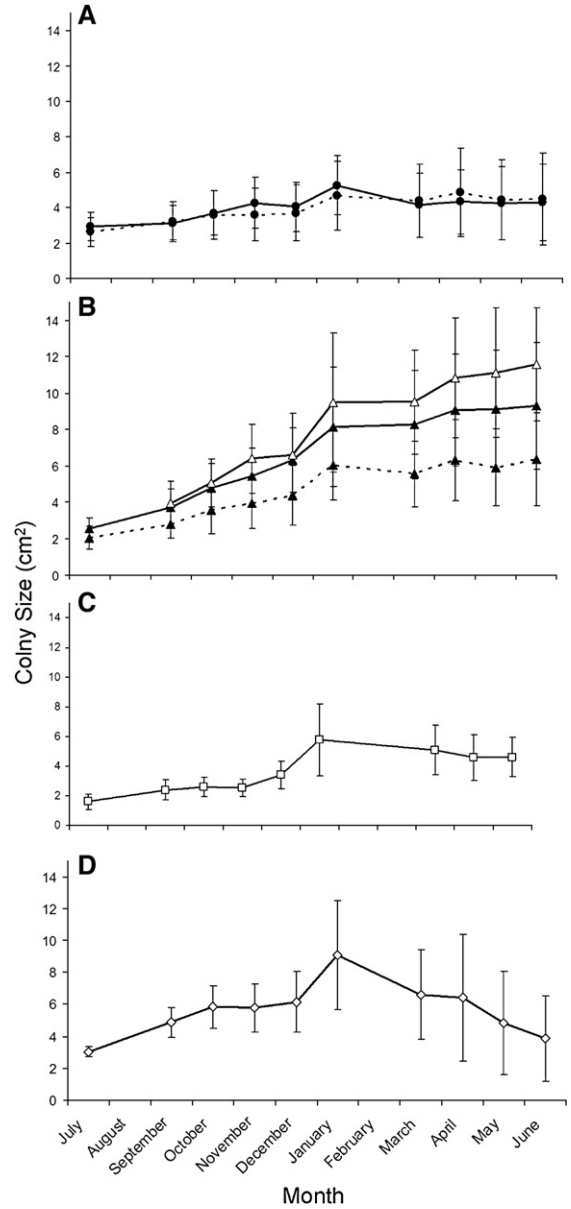

Fig. 4. Growth rates of the encrusting and sub-massive coral species along 1 y nursery period. (A) *M. sabricula*: solid line genotype A; dashed line genotype B; (B) *E. lamellosa*: solid line with genotype A; dashed line genotype B; empty triangle genotype C; (C) *P. rus*; (D) *M. aequituberculata*.

The encrusting and sub-massive species, while growing slower than the branching forms, revealed impressive growth rates and patterns. *E. lamellosa* and *P. rus* added significantly higher percentages of surface area growth (263±133% and 206±111%, respectively) than *M. sabricula* (81±55%) and *M. aequituberculata* (30±95%; One-Way ANOVA, LSD Post Hock, $p<0.05$; Figs. 4 and 7). *E. lamellosa* growth pattern led to the development of small colonies with nearly completely perfect round shapes (Fig. 7A), whereas *P. rus* fragments extended mostly on the surface and only after

Table 7
Growth parameters of nursery reared ramets, originating from the branching coral species following 1-year nursery period

Species	G-type	Number	Days	Sizes (cm)		Size augmentation (cm)		Growth rates (%/d)	
				Height	Width	Height	Width	Height	Width
P. damicornis	A	19	0	1.67±0.79	1.72±0.79				
	A		270	4.50±1.19	5.46±1.54	2.83±0.73	3.73±0.32	0.73±0.32	0.92±0.37
P. damicornis	B	16	0	1.65±0.48	2.11±0.60				
	B		270	5.52±0.72	6.95±0.90	3.87±0.66	4.84±0.40	0.96±0.40	0.94±0.40
M. digitata	A	17	0	2.44±0.86	0.85±0.36				
	A		365	7.91±1.96	9.46±2.07	5.47±1.39	8.61±0.19	0.65±0.19	3.15±1.24
M. digitata	B	18	0	3.25±0.87	1.87±1.35				
	B		365	9.44±2.09	10.21±2.81	6.18±2.28	8.33±0.32	0.58±0.32	2.39±2.36
M. digitata	C	16	0	3.15±1.01	1.04±0.38				
	C		365	8.76±1.56	10.27±2.75	5.61±1.77	9.24±0.31	0.57±0.31	2.97±1.83
A. formosa	A	9	0	2.69±0.43	0.92±0.44				
			365	12.42±2.55	7.36±2.39	9.73±2.45	6.44±0.27	1.00±0.27	2.08±0.69

G-type = genotype number.

one year initiations of vertical growth (Fig. 7B). *M. sabricula* fragments, while representing relatively slow growth rates under nursery conditions (Fig. 4A), added during this period colonial leaf buds to form small colonies with the typical leaf-like shapes (Fig. 7C). *M. aequituberculata* grew the slowest under the nursery conditions (Figs. 4D, 7D). It is possible that fragments of this species were placed incorrectly on the nursery bed, i.e., horizontally, thus allowing competition with algae and other sedentary organisms. Preliminary results on vertically positioned fragments of *M. aequituberculata* revealed faster growth rates and better colonial shapes than in the current experiment (unpublished).

In general, coral fragments in the nursery, started growing almost immediately after being deployed onto the nets. Between

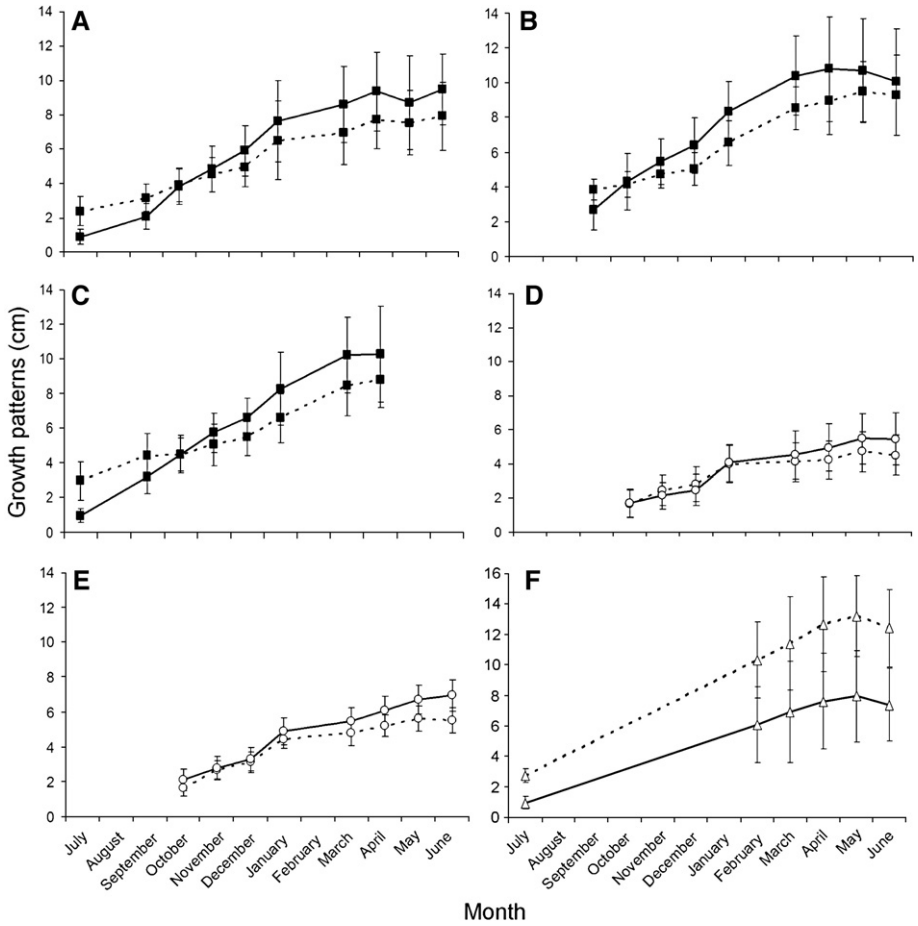

Fig. 5. Growth patterns of the branching coral species during 1 y nursery period. Dashed lines = height measurements, solid lines = width measurements; (A) *M. digitata* genotype A; (B) *M. digitata* genotype B; (C) *M. digitata* genotype C; (D) *P. damicornis* genotype A; (E) *P. damicornis* genotype B; (F) *A. formosa*.

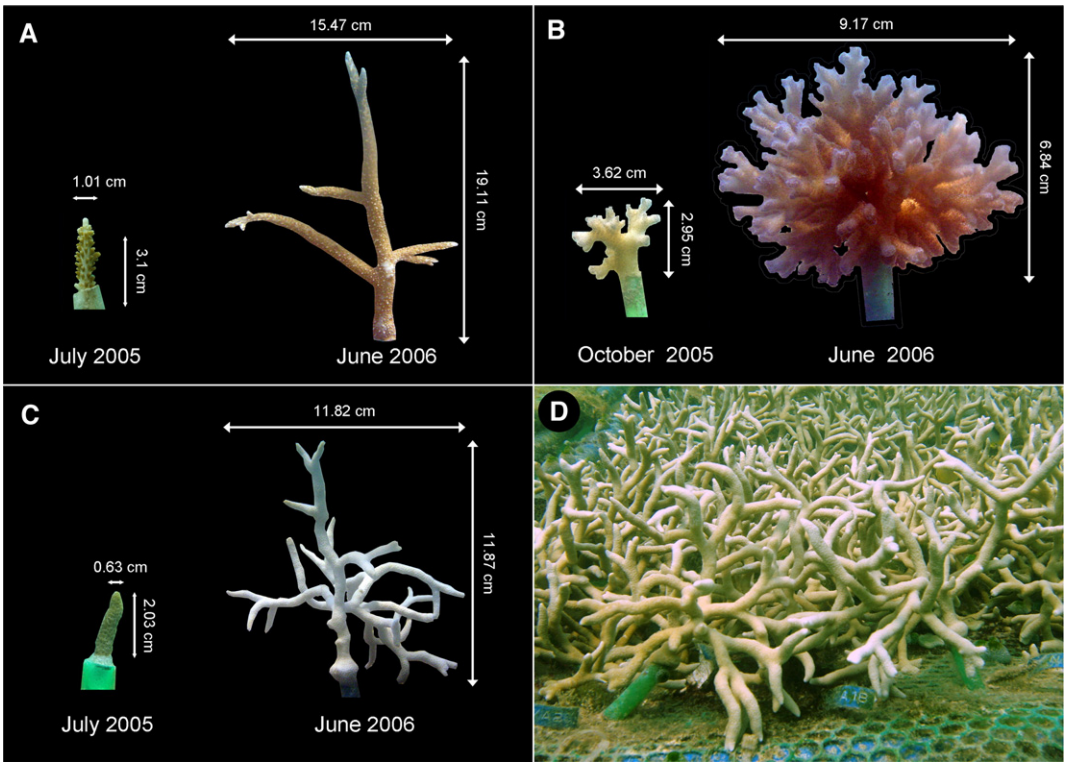

Fig. 6. Example of nursery-grown colonies after 1 y; (A) *Acropora formosa*; (B) *Pocillopora damicornis*; (C) *Montipora digitata;* (D) A thickets of *M. digitata* colonies after one year in the nursery.

December and January, all species showed a substantial increase in growth, while between April and June growth rates were reduced and colonial sizes of *M. digitata* (genotype B), *M. aequituberculata*, *P. rus* and *A. formosa* species even regressed, probably as a result of competition with fouling organisms (Tables 6, 7; Figs. 4C, D and 5C, F).

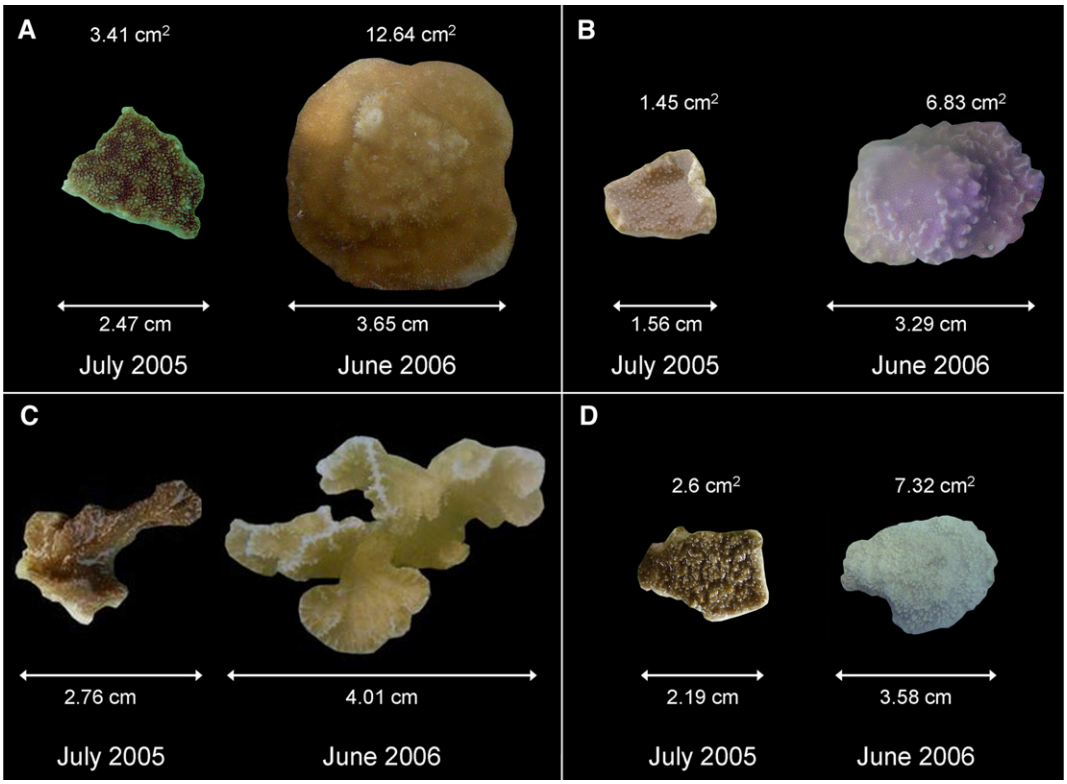

Fig. 7. Example of nursery-grown colonies after one year. (A) *Echinopora lamellosa*; (B) *Porites rus*; (C) *Merulina sabricula*; (D) *Montipora aequituberculata*.

5. Discussion

In this study, a simply constructed nursery, composed of common and cheap material was successfully established in Bolinao, the Philippines. A team of four (two scientists and two technicians) assembled two prototype nurseries (leg-fixed and suspended) within a short period of three months, holding about 7000 coral fragments. While constructing these nurseries, we had considered Shafir et al. (2006a,b) and others' (Yap et al., 1990; Edwards and Clark, 1998; South et al., 2001; Fox et al., 2002; Lindahl, 2003; Edwards and Gomez, 2007) suggestions, adapting them to local conditions: (1) Nursery constructed in a sheltered area (sheltered lagoon at 2 m depth) and fragments planted in rows for easy maintenance; (2) Adjusting substrate types during nursery time to the different growth forms of the farmed species and for imminent transplantation; (3) Adapting the numbers of farmed fragments/colonies to the available manpower; (4) Farming, simultaneously, several coral species under the same *in situ* nursery conditions; (5) Minimal nursery period, adapted for each of the different farmed species, for improved economical considerations; (6) A monthly monitoring scheme for fragments' status, mortality, growth rates and 3D development, aided by photographing, a fast way for data documentation. Following the above criteria, we successfully monitored the two nurseries in the Philippines that accommodated several thousands new colonies, derived from seven different coral species (13 genotypes) of various architectural forms and growth rates.

This study also compares outcomes of floating (Shafir et al., 2006b) vs. fixed-to-substrate nurseries, both under shallow-water conditions, a situation not examined previously. One nursery was held afloat by a series of buoys, swaying with the currents at a fixed 2 m depth, improving water circulation around the farmed corals, whereas the second was fixed on stilts, 1 m above sea bottom. No difference was recorded in survivorship and development of farmed corals. However, the leg-fixed nursery proved to be more durable in strong currents and its construction as well as maintenance were simpler (data not shown).

Both nurseries were successful operations. After one year of monthly maintenance regimen, over 85% survivorship was recorded in both nurseries that developed colonies suitable for transplantation. It is interesting to note that not only regeneration patterns of corals are closely associated with colonial structures (branching > bushy > tubular > massive > sub-massive; Woodley et al., 1981; Heyward and Collins, 1985; Hughes, 1989; Vicki, 1997), but also survivorship of farmed species follows that order of shapes. *P. rus* the sub-massive form showed the lowest survivorship, below the plate like forms (*E. lamellosa* and *M. sabricula*) and the branching forms (*P. damicornis*, *A. formosa* and *M. digitata*), revealing the highest survivorship rates. There are still various technical aspects that may improve total survivorship. One important issue is fragments' detachment (13.1–22.3% in different genotypes of the encrusting species *M. sabricula* and *E. lamellosa*), that started about seven weeks after the ramets were deployed in the nurseries. These ramets were glued horizontally to small pieces of plastic mesh, unlike the branching forms that were firmly inserted into plastic tubes. Apparently, the glue was insufficient to keep the corals of the encrusting species from being detached by strong currents or from being competitively overgrown by algae spreading on substrates.

The same applies to fragment mortality that displayed species-specific curves. *P. rus*, the sub-massive slow growth species, presented the highest number of dead ramets (34.5%) in addition to partially dead fragments that were covered by fast growing turf algae and fleshy algae (like *Padina* sp., *Sargassun* sp. and *Dictyota* sp.). The thin leaf-shaped *M. sabricula*, the species ranked second for high mortality, did not develop (in contrast to other species; data not shown) tissues and skeleton on the artificial substrate. Within a relatively short period of one-month, the glue that held these corals fouled, a process enhanced by recruitment of algae and tunicates and their developing between the coral colonies and the substrates, embedding *M. sabricula* colonies within live biological material. While farmed corals can survive and grow in this state, the death of the biological matrix that attaches coral colonies to the substrate will cause their demise. As in silviculture (i.e., Oliet et al., 2005), nursery regimes may influence stock quality and affect the capacity of 'seedlings' to establish successfully under harsh natural conditions. Producing stock coral colonies with sizes suitable for 'out planting site' is a key element in successful coral transplantation. Understanding biological properties of farmed coral fragments (including protocols for attachment to substrates, fragment sizes, etc.) and the effects of nursery culturing practices on the overall health of the "maricultured" corals is key to improving 'seedling' quality in a nursery. Application above needs often requires site-specific adaptations (South et al., 2001).

6. Conclusion

This study evaluates the first step of the 'gardening of the coral reefs' concept (Rinkevich, 1995, 2005a) by establishing two types of large *in situ* coral nurseries in Bolinao, the Philippines, and testing the applicability of several nursery properties, such as simultaneous cultivation of multi-species under the same nursery conditions. Both nursery types that held several coral species of different morphological architectures were equally adapted to the Bolinao conditions. Restoration acts that combine multi-species transplantation measures should result in increasing habitat complexity for reef dwelling organisms, helping in biodiversity conservation. Much remains to be learned about the proper management and restoration of coral reef ecosystems. Establishing this ecological discipline will generate approved technologies for better use of existing coral reefs worldwide (Risk, 1999; Rinkevich, 2005a, 2000, 2006).

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