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SET-BACKS AND SURPRISES

Coral Reef Restoration (Bolinao, Philippines) in the Face of Frequent Natural Catastrophes

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Abstract

Restoration of coral reefs is generally studied under the most favorable of environmental conditions, a stipulation that does not always reflect situations in the field. A 2-year study (2005–2007), employing the "reef gardening" restoration concept (that includes nursery and transplantation phases), was conducted in Bolinao, Philippines, in an area suffering from intense human stressors. This site also experienced severe weather conditions, including a forceful southwesterly monsoon season and three stochastic environmental events: (1) a category 4 typhoon hit the Bolinao's lagoon (May 2006) impacted farmed corals; (2) heavy rains (August 2006) caused seepages of freshwater, followed by reduced salinity that impacted transplanted colonies; and (3) a bleaching event (June 2007) caused by warming of seawater, severely impacted both nursery and transplanted corals. This study analyzes the effects of these natural catastrophes on restoration efforts, and presents the successes and failures of recently used restoration instruments. Our results show that (1) in the nursery phase, consideration should be paid to depth-flexible constructions and tenable species/genotypes prioritization and (2) for transplantation acts, site/species deliberation, timing, and specific site selections should be taken into account. Only the establishment of large-scale nurseries and large transplantation measures and the adapting of restoration management to the frequently changing environment may forestall extensive reef degradation due to the combination of continuous anthropogenic and worsening global changes.

Key words: **coral, climate change, gardening concept, Philippines, restoration.**

Introduction

Global climate predictions foretell more frequent and intense catastrophic environmental events (Easterling et al. 2000) that may eventually lead to the destruction of ecosystems through habitat loss and elimination of key species (Allison et al. 2003). Prevailing management considerations refer to the impacts of extreme climatic events, such as large-scale coral bleaching episodes and associated reef dwelling mortalities, as unpredictable forces, influencing habitats beyond the control of local management plans and undermining the achievement of assigned management aims (Mumby & Steneck 2008). However, a modified outlook could employ methodologies that allow the probability of catastrophic disturbances to be incorporated into site selection without enforcing additional conservation efforts (Game et al. 2008; Baskett et al. 2009). To date, there has been little discussion of the impacts of unpredictable forces on the design and execution of long-term restoration of coral reef ecosystems.

Coral reefs are highly important to the ecosystem health and economy of many tropical and subtropical nations (Gomez 1997; Moberg & Folke 1999; Hughes et al. 2003), and have been badly impacted by a combination of human and natural disturbances. For example, Bruno and Selig (2007) pointed to a decline in the Indo-Pacific coral coverage from 42.5 to 22.1%, in the short period from the early 1980s to 2003. An increasing number of publications state that the risks to coral reefs are associated not only with anthropogenic impacts but also with the mounting frequency and intensity of global changes in climate (Pittock 1999; Jackson et al. 2001; Hughes et al. 2003; Wakeford et al. 2008; Baskett et al. 2009) causing variable damages, such as increasing coral reefs bleaching events (Hoegh-Guldberg 1999). Impacts on other ecosystems may also affect coral reefs indirectly. Elevated global temperature causing the increase in global hydrological cycle due to evaporation, may cause successive events of strong rainfall (Pittock 1999) which, in turn, lead to an influx of freshwater that can harm coral reefs by reducing salinity, and to land erosion which increases turbidity and pollution. Therefore, it is necessary to understand the actual impacts of climate changes on coral reefs and revise the essential management protocols to counter them.

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The rapid degradation of reef ecosystems may override the system's capacity to regenerate adequately (Chadwick-Furman 1996; Hodgson 1999; Wilkinson 2002; Rinkevich 2005, 2006, 2008; Manning et al. 2006) causing dramatic, long-lasting, and perhaps irreversible shifts in species composition (Scheffer et al. 2001; Folke et al. 2004). This foreteller dismal fate for reef degradation has initiated the suggestion that the future of coral reefs should be focused on restoration, an active management instrument (Rinkevich 2008). Coral transplantation is a major tool in active reef rehabilitation strategies (Yap 2003; Rinkevich 2006). In this study the rationale emerges from the "gardening concept," which comprises two working phases (Rinkevich 1995, 2000, 2005, 2006). The first phase is the establishment of in situ nurseries (preferably mid-water floating nurseries [Shafir et al. 2006*a*, *b*]) in which large numbers of coral fragments are reared to sizeable coral colonies under controlled and favorable conditions. The second phase is engaged with the transplantation of these nursery-grown coral colonies onto denuded natural habitats (Rinkevich 1995, 2000, 2005, 2006; Epstein et al. 2001). The nursery phase of the "gardening concept" proved to be highly successful in areas less frequented by catastrophic events (Epstein et al. 2001; Soong & Chen 2003; Shafir et al. 2006*a*; Putchim et al. 2008). However, detailed studies that evaluate the performance of the concept in reefs affected by severe weather conditions, or prolonged environmental stressors, have yet to be carried out.

From July 2005 to July 2007 a restoration study, using both phases of the "gardening concept," was performed in shallow reef areas in Bolinao, Philippines. During this period, the area experienced extreme weather conditions brought about by southwesterly monsoons and three stochastic natural catastrophes, which harmed nursery-farmed corals and transplants. In May 2006, a category "4" typhoon (Typhoon *Caloy*) struck Bolinao. In August 2006, an above average lengthy rainy period caused seepage of freshwater from the ground, in several locations along the transplanted area. In June 2007, elevated seawater temperature, unusually low tide and high radiation, caused mass coral bleaching. Here we outline the effects of these natural stressors on the two-phase restoration protocols with an eye to amending reef-restoration measures and the use of proactive threats-based approach in reef restoration. As suggested by Grigg and Dollar (1990), we referred to the stress forces outcomes with a single major parameter, mortality rate, where the degree of mortality reflects the intensity of stress (Grigg & Dollar 1990).

Methods

Study Sites

The study was conducted at Cape Bolinao, Pangasinan, a coastal town in northwestern Philippines, on the eastern coast of the South China Sea. Bolinao, which lies between 16°22′ and 16°27′N latitude and between 119°52′ and 120°00′E longitude (Fig. 1), experiences the southwesterly monsoon from June to October, the northeasterly monsoon from November to March, and weak easterlies from April to May. The fringing reefs of Bolinao, reaching 30 m depth with average live

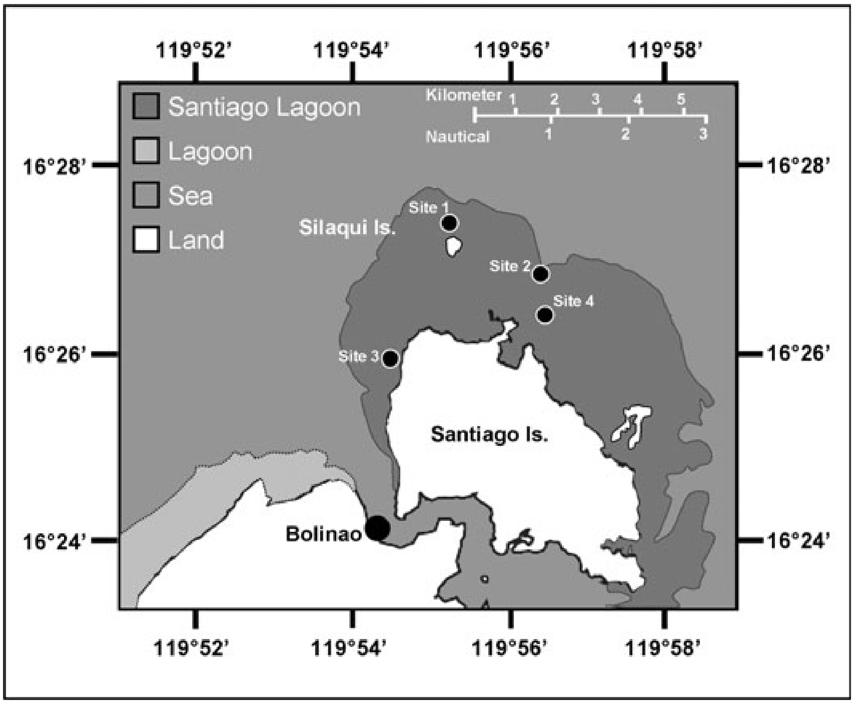

Figure 1. Bolinao, Pangasinan, Philippines, and detailed study sites: site 1, "Silaqui" nurseries location; site 2, "Malilnep channel" transplantation site for *P. damicornis*, *M. digitata*, and *A. formosa*; site 3, "Binabalian Labas" transplantation site for *E. lamellosa*, *M. scabricula*, and *P. rus*; site 4, "Coral Garden" transplantation site for *M. digitata.*

coral cover of 20%, have been subjected to destructive fishing practices (Gomez 1997, 2001; Raymundo et al. 2007), eutrophication (Diego-McGlone et al. 2008), and to natural disturbances such as strong tropical storms (Puotinen 2007).

Our study was conducted at four sites along the Santiago lagoon, site 1 served as the nursery-based area and in sites 2–4, 1-year old nursery-grown corals (NGCs) were transplanted onto bare knolls (Fig. 1). At site 1 the coral nurseries faced the north shore of Silaqui Island, in a shallow, sandy bottom area of the lagoon (2–4 m depth). The site 2 formed part of the barrier reef at the inner mouth of the "Malilnep" Channel connecting the lagoon to the sea, a 3-m deep reef flat, dominated by branching and massive coral species (Acoporids, Pocilloporids, and Poritids). This site is subjected to wave activity and strong currents during SW and NE monsoon seasons. The site 3, "Binabalian Labas" on the west side of Santiago Island, was at a maximal depth of 6 m (the deeper site) and 300 m from the Santiago Island, an area with scattered, bare coral knolls, and little live coral cover. This site is located nearer to the Island shore, in a bay created by the Santiago Island, which protects it from the SW and NE monsoons. The site 4, the "Coral Garden" on the northeast of Santiago Island, was located further inside the lagoon, a shallow water area (3–2 m depth) with sandy bottom and patches of coral rubble exposed to the NE monsoon but more protected from the SW monsoon.

Study Procedures

During July and August 2005, two nurseries were constructed, holding 6,824 coral ramets from seven coral species (*Merulina scabricula*, *Montipora digitata*, *Echinopora lamellosa*, *Pocillopora damicornis*, *Porites rus*, *Acropora formosa*, and *M. aequituberculata*, Table 1; Shaish et al. 2008). For each species, the two to three–donor colonies chosen in the field as a source for ramets were considered as different genotypes (Shaish et al. 2008). The nurseries with farmed corals were maintained and monitored once a month for 1 year by a team of three divers (Shaish et al. 2008). One year later (August 2006), NGC colonies were transplanted onto several bare-of-corals knolls. The knolls were rock structures, comprising dead coral skeletons, mainly those of massive corals. Chosen knolls were selected according to their size, raising about 0.5 m above substrate and with at least 2 m^2 of flat top area. Most large fouling organisms growing on top of the knolls (algae, sponges, tunicates) were removed prior to transplantation. Distances between knolls ranged from 5 to 20 m.

The colonies belonging to two branching forms, *M. digitata* and *P. damicornis*, and one encrusting form, *E. lamellosa*, showed the highest growth and survivorship rates under our nursery conditions and provided the largest number of NGCs ready for transplantation (Shaish et al. 2008). These species were subjected to mono-species transplantation experiments; in each plot, only single species colonies were transplanted. Poly-species transplantations (i.e. in each plot, colonies of more than one species were attached side by side) were divided into two types, one holding fast-growing, branching species (*M. digitata*, *P. damicornis*, and *A. formosa*) and the other, slow-growing, encrusting, submassive and leaf-like species (*E. lamellosa*, *P. rus*, and *M. scabricula*). NGCs ($n = 1188$) were transplanted onto bare knolls ($n = 33$) in three locations inside the lagoon (sites 2, 3, and 4; Table 1; Fig. 1), at a density of 36 colonies per knoll. The fast-growing species combinations were transplanted into the shallower sites (sites 2 and 4) and the slow-growing species combinations into the deeper site (site 3). This selection was based on the abundance

Table 1. Composition and numbers of eight coral species used in the study; additional details for the nursery in Shaish et al. (2008). NGCs—nursery-grown coral colonies.

Species	*M. scabricula*	*M. digitata*	*E. lamellosa*	*P. damicornis*	*P. rus*	*A. formosa*	*M. aequituberculata*	*H. coerulea*
Ramets deployed in nurseries, first year	1,260	1,960	2,030	570	354	333	317	—
Donor genotypes (Nursery 2005)	2	3	3	2	1	1	1	—
NGCs transplanted onto knolls	36	360	360	360	36	36	0	—
Average NGCs size at transplantation[a]	12 ± 5	10 ± 3	17 ± 5	5 ± 1	10 ± 5	16 ± 5	—	—
Distance between corals on the knoll (cm)	10	20	6	10	10	20	—	—
"Mono" species knolls	0	9	9	9	0	0	—	—
Colonies per knoll	—	36	36	36	—	—	—	—
"Poly" species knolls	3	3	3	3	3	3	—	—
Colonies per knoll	12	12	12	12	12	12	—	—
Location of transplanted knolls	site 3	site 2[b] site 4	site 3	site 2	site 3	site 2	—	—
Colonies left in nursery after transplantation	433	1,381	1,066	251	283	251	189	—
New ramets deployed	0	0	0	822	543	0	0	210
New genotypes (Nursery 2006)	0	0	0	3	3	0	0	1

[a] *M. scabricula*, *E. lamellosa*, *P. rus*, and *M. aequituberculata*: aerial surface area (cm^2); *M. digitata*, *P. damicornis*, and *A. formosa*: height (cm).
[b] In site 2, five knolls were transplanted with *M. digitata* colonies and in site 4, four knolls.

of these species on the reef. Knolls' location and corals' distribution are depicted in Table 1.

The transplantation was designed as a grid of 6 × 6 colonies. The branching coral species, grown inside plastic tubes in the nurseries (Shaish et al. 2008), were transplanted by inserting the plastic tubes into holes chiseled in the substrate and secured with small amounts of "Aquamend" glue. The encrusting, submassive, and leaf-like species, which grew in the nursery on small pieces of plastic mesh (Shaish et al. 2008), were attached to the substrate, each by two small umbrella nails on two sides. During October 2006, the nurseries were renovated and refilled. Colonies not used for transplantation were left on the nursery for another year. *Heliopora coerulea* was added to the nursery and new donor colonies of *P. damicornis* and *P. rus* were selected for creating new ramets (Table 1).

Environmental Disturbances

During the course of this study, several stochastic natural catastrophic events affected the area of Bolinao lagoon (Fig. 2): (1) on 12–15 May 2006, 9 months after establishing the coral nurseries, Typhoon *Caloy* hit the Philippines, reaching 150 km/hour in the South China Sea and raising powerful waves inside the Santiago lagoon (Fig 2). (2) During 13–24 August 2006, 2 weeks after transplantation, heavy precipitation occurred over the Pangasinan province (including Bolinao, Fig. 2), with a record rainfall of 274.3 mm (×1.5 times that of rainfall in 2005: Typhoon2000.com). Consequently, we observed foci of freshwater underground seepage within the lagoon, mainly in sites 2 and 3, in the vicinity of the transplantation knolls. At the end of August 2006, seawater around nine knolls were sampled: six knolls at site 2, five carrying *P. damicornis* transplants, and one with poly-species transplants (*M. digitata*, *A. formosa*, and *P. damicornis*); three knolls at site 3, two with *E. lamellosa* transplants and one with poly-species transplants (*E. lamellosa*, *P.rus*, and *M. scabricula*). The knolls were selected in areas where we documented murky waters. Salinity was measured with a portable refractometer (Reichert-Jung; accuracy ±0.05 ppt). (3) From September until November 2006, during the southwest monsoon of 2006, tempestuous weather consisting of three regular typhoons, two tropical depression storms, and two super Typhoons hit the Philippines (Super typhoon *Paeng* on October 27–31, and Super typhoon *Reming* on November 28 to December 8, Typhoon2000.com, Fig. 2). (4) On 16 June 2007, 10 months after transplantation, an extremely low tide combined with clear skies and high irradiation, rapidly raised surface water temperature to approximately 33°C. This combination of high temperature and radiation led to mass coral bleaching in the lagoon and in the fringing reef surrounding it. Bleaching was observed down to 7-m depth.

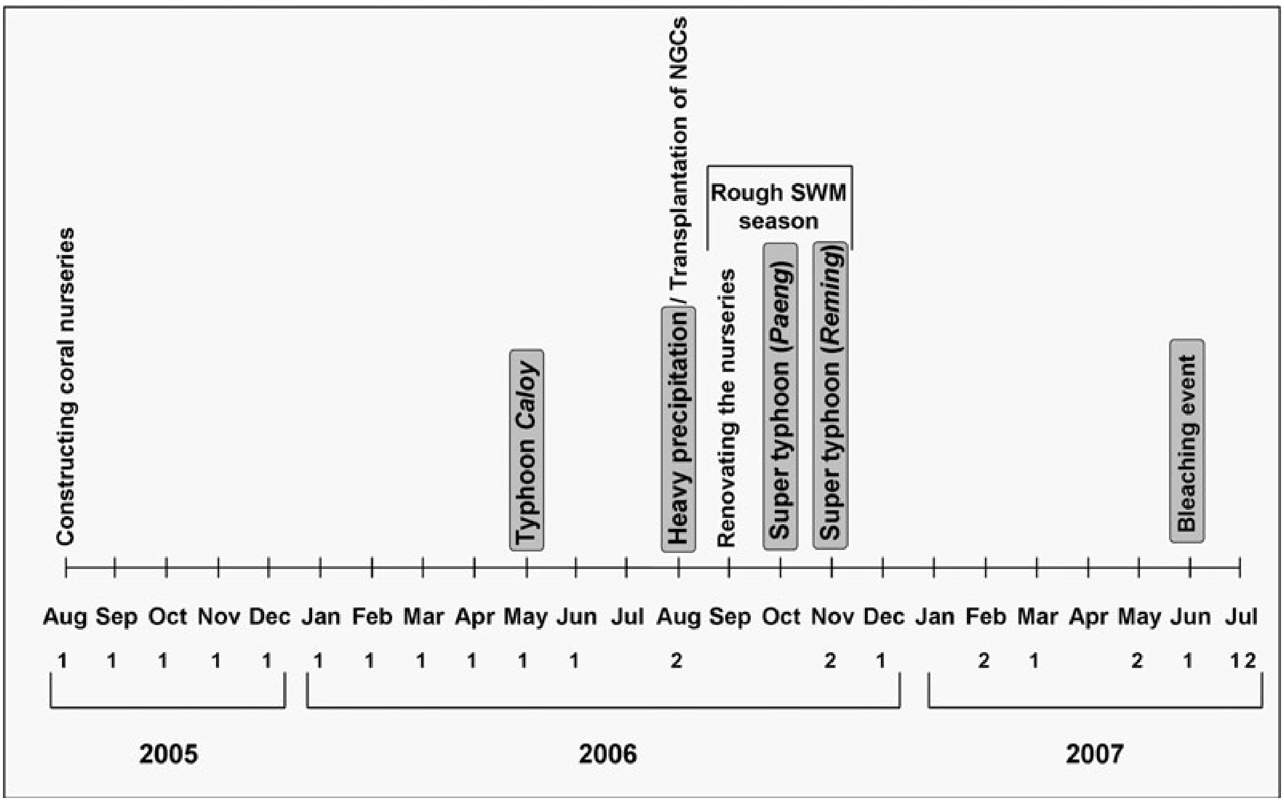

Figure 2. Chronological illustration for restoration operation dates (regular) and major weather events (bold). 1, monitoring dates for nursery; 2, monitoring dates for transplanted colonies.

All weather data on typhoons and rainfall were supplied by the Philippine weather site Typhoon2000.com. Local scientists at the Bolinao Marine Station supplied data on water temperatures.

Maintenance and Monitoring

In the first year, the nurseries were monitored monthly (Fig. 2). Dead, missing, and bleached ramets were counted. The dead ramets were removed from the trays to avoid recounting in successive monitoring sessions. Growth rates of 10 tagged fragments from each donor genotype were photographed monthly with a digital Olympus camera using a side ruler for calibration. Monthly maintenance of the nurseries also included fixing of damaged/worn-out parts and removal of settled macroalgae around growing corals. In the second year, the transplanted colonies and nurseries were monitored every 3 months for 1 year (August 2006–July 2007). A team of two divers recorded the number of dead, detached, partially dead and bleached (of the survived colonies) colonies. Dead colonies in the transplantation experiment were not removed from the plots.

Analyses

Mean percent mortality, detachment, partial mortality, and bleaching were calculated after each monitoring date and referred to the preceding month. Statistical tests were performed using SPSS software. In these tests, one preliminary assumption was tested: the existence of homogeneity of variance (Underwood 1981). Homogeneity of variance was checked using Levene's test. When the data failed to correspond with the assumption, non-parametric tests (e.g. Mann–Whitney U test, Kruskal–Wallis test, and Wilcoxon signed ranks test) were performed.

The effects of disturbances were analyzed in two ways, one by including the results of all the species together exhibiting and overall effects on nursery and transplantation, and the second by calculating the results for each specific species, pointing out species resistance and recovery abilities.

Results

Typhoon Impacts on Farmed Corals

In July 2005, two in situ corals nurseries holding 6,824 coral ramets from seven species were constructed in a shallow lagoon at 2-m depth and monitored over 1 year (results for mortality, detachment, and growth per species are summarized in Table 2). Eight months after the nurseries were established a super typhoon (Typhoon *Caloy*, 9–15 May 2006, Fig. 2) hit the area. Overall average monthly mortality during the pre-typhoon period (August 2005–April 2006) was $0.55 \pm 0.47\%$ ($n = 324$ colonies), significantly lower from the post-typhoon (May and June 2006; $n = 219$ colonies) values of $2.11 \pm 2.05\%$ (Wilcoxon signed ranks test; $p < 0.05$, Tables 2 & 3). Concerning species-specific mortality, an increased post-typhoon mortality was recorded in all species (Table 2), with statistically significant values for *Merulina scabricula* and *Echinopora lamellosa* (Wilcoxon signed ranks test; $p < 0.05$, Table 3).

In addition, overall detachment was significantly higher in the post-typhoon monitoring sessions ($0.58 \pm 0.53\%$) compared with the pre-typhoon period ($1.74 \pm 2.02\%$, Wilcoxon signed ranks test; $p < 0.005$, Tables 2 & 3). This result is the outcome of physical damage to one of the nurseries, where a few trays with *Montipora digitata* colonies tear away by the waves. Analyzing species-specific post-typhoon coral detachments did not reveal any significant differences (Wilcoxon signed ranks test; $p > 0.05$, Tables 2 & 3). This outcome indicates nursery construction robustness.

Overall, bleaching was not significantly different in the post- and pre-typhoon periods (Wilcoxon signed ranks test; $p > 0.05$, Tables 2 & 3). Species-specific analyses revealed significantly higher post-typhoon bleaching values in *M. digitata* and *Pocillopora damicornis* (Wilcoxon signed ranks test; $p < 0.05$, Tables 2 & 3). In general, bleaching is a typical response to stress inflicted during nursery establishment and is evident in higher numbers during the first month after fragments' deployment (Shaish et al. 2008). The only exception is *E. lamellosa* where bleaching was significantly higher in the pre-typhoon period (Wilcoxon signed Ranks test; $p < 0.05$, Tables 2 & 3). Partial mortality showed lower levels (<1%) year round; therefore, data were not included.

Overall pre-typhoon average monthly growth value, $18.7 \pm 24.4\%$, was significantly higher than the post-typhoon values ($0.3 \pm 15.2\%$, Wilcoxon signed ranks test; $p < 0.001$, Tables 2 & 3). The negative effects of the weather on growth rates were further observed in June 2006 values (Table 2). Comparing post-typhoon with pre-typhoon growths, for each species, revealed significantly higher pre-typhoon values for each of the seven species (Wilcoxon signed ranks test; $p < 0.001$, paired samples test; $p < 0.001$, Tables 2 & 3). Growth fluctuations were recorded from 1 month to the following, revealed damages inflicted to coral tissues and branch tip breakage from algal removal during routine maintenance, residing fish activities and predation by coralivorous organisms.

Freshwater Seepage Impact on Nursery-Grown Transplants

At the end of August 2006, a month after transplantation was completed, underground freshwater seepage caused turbidity in the seawater at the bottom of the knolls and a decline in salinity (Fig. 2). On the consecutive days, mass mortality of transplants was evident (Fig. 3a–c). It was first revealed by peeling of coral tissue (Fig. 3b), and then, by rapid settlement of turf algae on the bare skeletons (Fig. 3c). We tested salinity levels in nine knolls in sites 2 and 3 several days following the seepage was first noticed and recorded values of 26–28 ppt compared with 30–34 ppt in ambient water. Average mortality at the examined nine knolls was $48 \pm 23\%$, significantly higher compared with the other 27 knolls ($7 \pm 11\%$, Mann–Whitney test; $p < 0.001$, Fig. 3a).

Table 2. Mortality, detachment and growth for 1 year nursery farmed coral colonies; averages represent coral genotypes within a species; values for *P. rus*, *A. formosa*, and *M. aequituberculata* are for a single genotype in one nursery; average values therefore were not calculated for these species; growth of branching species was calculated as percentages of height added and for massive/encrusting species as percentage of area added (Shaish et al. 2008); in May 2006, monitoring was performed 10 days after the typhoon (in bold).

	Species-Specific Values						
Date	*M. digitata*	*E. lamellosa*	*P. damicornis*	*M. scabricula*	*P. rus*	*A. formosa*	*M. aequituberculata*
Mortality (%)							
August 05	0.1 ± 0.2	0.4 ± 0.6	5.7 ± 4.6	0.2 ± 0.2	18.9	0	0
September 05	0	0.1 ± 0.2	0	0.4 ± 0.5	5.6	0	0
October 05	0.1 ± 0.3	0.6 ± 1.3	0.6 ± 0.8	2.2 ± 2.1	3.3	0	0.3
November 05	0.0 ± 0.1	0.5 ± 0.5	0.4 ± 0.9	1.9 ± 1.5	2.8	0	0
December 05	0	0.5 ± 0.9	0.2 ± 0.4	0.3 ± 0.2	0.8	0	0
January 06	0.1 ± 0.2	0.1 ± 0.2	0	0.4 ± 0.3	0	0	0
February 06	0	0.9 ± 1.0	0.4 ± 0.9	0.4 ± 0.8	1.7	0	0
March 06	0.1 ± 0.2	0.1 ± 0.2	0.2 ± 0.5	0.6 ± 0.5	0	0	1.0
April 06	0	0.6 ± 0.5	0.1 ± 0.3	0.5 ± 0.3	0.9	0.3	0
May 06	**1.6 ± 2.1**	**1.0 ± 1.5**	**2.0 ± 2.6**	**14.2 ± 15.5**	**2.2**	**1.5**	**0.3**
June 06	0	0.5 ± 0.6	0.1 ± 0.3	1.6 ± 2.7	0	0	4.6
Detachment (%)							
August 05	0.4 ± 0.3	1.2 ± 0.6	0.2 ± 0.4	0.6 ± 0.8	0.6	0.6	1.3
September 05	0.2 ± 0.3	0.2 ± 0.3	0	0.8 ± 0.8	0	0	0
October 05	0.1 ± 0.2	1.8 ± 2.0	1.1 ± 1.6	3.3 ± 3.3	2.6	0	0.3
November 05	0.3 ± 0.6	1.0 ± 1.3	0.4 ± 0.9	4.6 ± 5.1	2.0	0	0
December 05	0.1 ± 0.4	0.3 ± 0.7	0.6 ± 1.3	0.3 ± 0.5	0	0	0.3
January 06	0	0.4 ± 0.4	0.2 ± 0.5	1.3 ± 2.1	0.4	0	0.6
February 06	0	0.4 ± 0.4	0	0.7 ± 0.8	0.8	0	0
March 06	0	0.3 ± 0.6	0	0.4 ± 0.5	0	0	0
April 06	0	0.1 ± 0.2	0	1.2 ± 1.5	0	0	0
May 06	**11.6 ± 28.4**	**0**	**0**	**0**	**0**	**0**	**0**
June 06	0.2 ± 0.5	0.4 ± 0.6	0	0.7 ± 1.0	0	0	0.3
Growth Added (%)							
September 05	48 ± 37	52 ± 26	n.d	17 ± 17	53 ± 30	n.d	61 ± 25
October 05	14 ± 18	28 ± 24	n.d	16 ± 17	10 ± 15	n.d	21 ± 21
November 05	16 ± 13	17 ± 13	60 ± 32	8 ± 19	2 ± 21	n.d	−0.3 ± 15
December 05	8 ± 12	10 ± 13	17 ± 15	−1 ± 12	33 ± 12	n.d	6 ± 11
January 06	n.d	n.d	n.d	n.d	n.d	n.d	n.d
February 06	26 ± 26	19 ± 22	32 ± 27	0.2 ± 21	7 ± 21	n.d	3 ± 16
March 06	27 ± 30	15 ± 10	19 ± 17	12 ± 17	n.d	10 ± 12	0.4 ± 14
April 06	10 ± 15	13 ± 13	7 ± 11	−2 ± 14	n.d	12 ± 8	−7 ± 30
May 06	**−2 ± 23**	**−2 ± 10**	**11 ± 12**	**−4 ± 18**	**−9 ± 15**	**6 ± 7**	**−29 ± 14**
June 06	3 ± 14	4 ± 11	−4 ± 10	2 ± 12	3 ± 12	−3 ± 5	−15 ± 30

n.d = no data were calculated.

The coral species were found to differ in their susceptibility to low salinity (Fig. 3a). *Montipora digitata* was the least sensitive, showing no mortality on the knolls with low salinity and an average mortality of 3 ± 4% on the 11 other knolls. *Acropora formosa* showed a moderate 8% mortality on the knolls with low salinity and no mortality on the other two knolls. *Porites rus* and *P. damicornis* exhibited 42% and 40 ± 21% mortalities in the freshwater seepage area compared with 4 ± 6% and 21 ± 12% mortalities on the other two knolls, respectively. The most susceptible species were *M. scabricula* and *E. lamellosa* showing 50 and 75 ± 7% mortality, respectively, in the freshwater seepage area compared with 0 and 2 ± 3% mortality in the two other knolls (Fig. 3a). Due to the low number of repetitions, statistical significance between survivorship at freshwater seepage area versus reference sites was obtained only for *E. lamellosa* (Mann–Whitney test; $p < 0.01$).

Southwest Monsoon Impacts on Nursery-Grown Transplants

The 2006 SW monsoon season was extremely tempestuous. Transplants were exposed to the entire monsoon season at their most vulnerable post-transplantation stage (Fig. 2), before an adequate period of acclimation to local conditions. Transplants were monitored for 1 year, once during the typhoon season (November 2006) and three times later (February, May, and July 2007, Table 4; Fig. 2). Mortality and detachment occurred during the entire period whereas partial mortality and bleaching were observed only in the first month post-transplantation (August 2006, minor events) and 1 year later (major bleaching

Table 3. Summary of statistical analyses for the impacts of environmental catastrophes on nurseries and transplanted corals at Bolinao, Philippines (years 2006, 2007). Bold numbers point to significant differences.

Typhoon Caloy (May 2006) Impact on Nurseries		*Mortality (%)*	*Detachment (%)*	*Bleaching (%)*	*Growth (%)*
Overall	Before	**0.6 ± 1.8**	**0.5 ± 1.3**	1.6 ± 3.6	**19 ± 24**
	After	**2.1 ± 5.7**	**1.7 ± 10.3**	1.5 ± 3.9	**0.3 ± 15**
M. digitata	Before	0.1 ± 0.2	0.1 ± 0.3	**3.5 ± 4.9**	**20 ± 25**
	After	0.8 ± 1.6	5.9 ± 20.1	**0.2 ± 0.7**	**0.1 ± 20**
E. lamellosa	Before	**0.4 ± 0.7**	0.6 ± 1.0	**0.3 ± 0.5**	**21 ± 22**
	After	**0.8 ± 1.1**	0.2 ± 0.4	**1.6 ± 2.0**	**1 ± 11**
P. damicornis	Before	0.9 ± 2.3	0.3 ± 0.8	**0.5 ± 0.9**	**26 ± 28**
	After	1.1 ± 2.0	0	**0**	**4 ± 13**
M. scabricula	Before	**0.8 ± 1.1**	1.5 ± 2.5	1.4 ± 3.1	**7 ± 18**
	After	**7.9 ± 12.3**	0.3 ± 0.7	0.2 ± 0.4	**−1 ± 15**
P.rus	Before	3.8 ± 6.0	0.7 ± 1.0	4.7 ± 7.4	**21 ± 27**
	After	1.1 ± 1.5	0	3.3 ± 0.3	**−3 ± 14**
A. formosa	Before	0.0 ± 0.1	0.1 ± 0.2	1.0 ± 2.6	**11 ± 10**
	After	0.8 ± 1.1	0	10.0 ± 13.7	**2 ± 8**
M. aequituberculata	Before	0.1 ± 0.3	0.3 ± 0.4	0.7 ± 2.2	**12 ± 29**
	After	2.5 ± 3.0	0.2 ± 0.2	8.5 ± 12.0	**−22 ± 23**

SW monsoon (November 2006) Impact on Transplants		*Mortality (%)*	*Detachment (%)*
Overall	November 2006	47 ± 39	10 ± 15
	February/May 2007	38 ± 43	9 ± 23
site 2	November 2006	**56 ± 37**	12 ± 18
	February/May 2007	**39 ± 42**	14 ± 30
site 3	November 2006	46 ± 41	5 ± 7
	February/May 2007	52 ± 45	3 ± 10
site 4	November 2006	1 ± 1	**18 ± 7**
	February/May 2007	1 ± 3	**0**
M. digitata	November 2006	**41 ± 40**	11 ± 13
	February/May 2007	**19 ± 35**	13 ± 27
P. damicornis	November 2006	68 ± 32	14 ± 22
	February/May 2007	58 ± 42	7 ± 27
A. formosa	November 2006	48 ± 47	**11 ± 19**
	February/May 2007	44 ± 39	**53 ± 41**
E. lamellosa	November 2006	59 ± 36	**4 ± 7**
	February/May 2007	86 ± 27	**0**
M. sacbricula	November 2006	42 ± 51	3 ± 5
	February/May 2007	6 ± 7	16 ± 19
P. rus	November 2006	0	9 ± 9
	February/May 2007	25 ± 40	0

Bleaching Event (June 2007) Impact on Transplants		*Mortality (%)*	*Detachment (%)*	*Partial Mortality (%)*	*Bleaching (%)*
Overall	February/May 2007	**39 ± 43**	**9 ± 24**	**0**	**0**
	July 2007	**13 ± 28**	**7 ± 22**	**23 ± 31**	**100 ± 0**
site 2	February/2007	41 ± 42	15 ± 31	**0**	**0**
	July 2007	27 ± 36	2 ± 5	**42 ± 35**	**100 ± 0**
site 3	February/May 2007	**52 ± 45**	3 ± 10	0	**0**
	July 2007	**0**	0	0	**100 ± 0**
site 4	February/May 2007	1 ± 3	0	0	**0**
	July 2007	0	26 ± 43	21 ± 25	**100 ± 0**

Bleaching Event (June 2007) Impact on Nurseries		*Mortality (%)*	*Detachment (%)*	*Partial Mortality (%)*	*Bleaching (%)*
Overall	December 2006/March 2007	6 ± 10	**1 ± 2**	**2 ± 4**	**0.4 ± 1**
	June/July 2007	9 ± 16	**0.6 ± 2**	**15 ± 25**	**79 ± 34**
A. formosa	December 2006/March 2007	5 ± 4	0.3 ± 0.7	2 ± 4	**0.5 ± 0.6**
	June/July 2007	41 ± 46	0	0.5 ± 1	**80 ± 19**
E. lamellosa	December 2006/March 2007	**3 ± 4**	2 ± 2	**3 ± 6**	**1 ± 3**
	June/July 2007	**9 ± 6**	1 ± 2	**22 ± 24**	**79 ± 13**
H. coerulea	December 2006/March 2007	1 ± 3	0.7 ± 0.8	1 ± 3	0
	June/July 2007	4 ± 6	2 ± 4	0	7 ± 13
M. aequituberculata	December 2006/March 2007	14 ± 15	0	6 ± 8	**0.5 ± 1**
	June/July 2007	21 ± 20	0	5 ± 11	**93 ± 9**

Table 3. Continued

Bleaching Event (June 2007) Impact on Nurseries		Mortality (%)	Detachment (%)	Partial Mortality (%)	Bleaching (%)
M. digitata	December 2006/March 2007	0.3 ± 0.5	0.1 ± 0.2	0.7 ± 2	**0.1 ± 0.4**
	June/July 2007	0.4 ± 0.6	0	0	**50 ± 53**
M. scabricula	December 2006/March 2007	5 ± 5	**5 ± 3**	2 ± 3	**0.5 ± 0.9**
	June/July 2007	9 ± 8	**0.4 ± 1**	28 ± 38	**88 ± 17**
P. damicornis	December 2006/March 2007	12 ± 16	0.9 ± 2	2 ± 5	**0.2 ± 0.6**
	June/July 2007	10 ± 16	0.2 ± 0.5	24 ± 31	**91 ± 28**
P.rus	December 2006/March 2007	3 ± 3	1 ± 2	0.3 ± 0.5	**0.5 ± 1**
	June/July 2007	2 ± 2	1 ± 4	12 ± 22	**93 ± 11**

event, July 2007; Table 4; Fig. 4a–c). We compared November 2006 values to the average values of February and May 2007 monitoring sessions in order to define the effects of the SW monsoon season on transplantation, to distinguish from the effects of the fresh-water seepage (August 2006) and the bleaching event (June 2007). Overall percentages of mortality and detachment did not differ significantly between November 2006 and February–May 2007 (paired T test; $p > 0.05$, Tables 3 & 4). However, site-by-site analyses revealed that November 2006 mortality values were significantly higher in site 2 (paired T test; $p < 0.05$, Fig. 4a; Tables 3 & 4), and detachment was significantly higher in site 4 (Wilcoxon signed ranks test; $p < 0.05$, Tables 3 & 4; Fig. 4c). In site 3, no significant difference was recorded between the two periods tested (paired T test; $p > 0.05$, Tables 3 & 4; Fig. 4b). Analyzing species-specific results revealed that in site 2, mortality in *M. digitata* was significantly higher in November 2006 compared to February and May 2007 (paired T test; $p < 0.05$, Tables 3 & 4). In *A. formosa,* detachment was found to be significantly lower in November 2006 (paired T test; $p < 0.05$, Tables 3 & 4). In site 3 detachment in *E. lamellosa* was significantly higher in November 2006 compared to February and May 2007 (paired T Test; $p < 0.05$, Tables 3 & 4).

No partial mortality or bleaching was observed in any of the knoll during November 2006 (Fig. 4a–c); therefore, no comparison was made with the other monitoring months. Comparing coral mortality in mono- and poly-species knolls (site 2, November 2006) did not reveal any significant difference (one-way analysis of variance [ANOVA]; $p > 0.05$, Table 4).

Southwest Monsoon Impacts on Nursery

Following the first set of transplantations during October 2006, the nurseries were refurbished with 1,876 new ramets, in addition to the 3,772 colonies remaining from the first year (Fig. 2). The nurseries were monitored four times between October 2006 and July 2007 (Table 5; Fig. 2). The first monitoring was performed during December 2006, and the results were compared with those of March 2007, in order to define the effects of the harsh weather of September until November 2006. Comparing percentages of mortality, detachment, and partial mortality, between December 2006 and March 2007, revealed no significant differences for both the compiled results of all species and for each species individually (Wilcoxon signed ranks test; $p > 0.05$, paired T test; $p > 0.05$, Table 5). The effects of the SW monsoon season did not differ between the nursery-grown corals, new transplants (transplanted in October 2006), and the 1-year-old NGCs transplanted in August 2005 (Mann–Whitney; $p > 0.05$).

Impacts of Massive Bleaching on Transplantation

High irradiation and elevated seawater temperature during the second half of June 2007 were correlated with a massive bleaching event (Fig. 2), severely affecting transplants in all sites (Table 4; Fig. 4a–c). We compared the July 2007 values with the average values of February and May 2007. Bleaching was not recorded during February and May, whereas in July bleaching peaked to 100% in all sites. Overall percentages of mortality and detachment were significantly higher before the bleaching event (Wilcoxon signed ranks test; $p < 0.05$, paired sample T-test; $p < 0.05$, Tables 3 & 4). Analysis per site revealed significant higher mortality before the bleaching event in site 3 only (paired T-test; $p < 0.05$, Tables 3 & 4). In contrast with these results, percentages of overall partial mortality were significantly higher in July (Wilcoxon signed ranks test; $p < 0.05$, Tables 3 & 4). Analysis per site revealed significantly higher percentages of colonies with partial mortality in site 2 only (Wilcoxon signed ranks test; $p < 0.05$, Tables 3 & 4).

Following the bleaching in September 2007, live transplanted colonies were documented in *P. rus* ($n = 9$) and *M. digitata* only ($n = 100$ colonies, data were not compiled into file).

Impacts of Massive Bleaching on Nursery

The massive bleaching event did not spare the nursery-reared colonies (Table 5, Fig. 3d & 3e). The bleaching effects continued during July 2007 (Table 5). Comparisons were preformed between averages of June and July 2007 to the averages of December 2006 and March 2007 monitoring sessions. Total bleaching and partial mortality were significantly higher during the bleaching months (Wilcoxon signed ranks test; $p < 0.001$, Tables 3 & 5). Average detachment was significantly lower during the bleaching months (Wilcoxon signed ranks test; $p < 0.005$, Tables 3 & 5), whereas average mortality did not differ significantly between June and July 2007 to < December

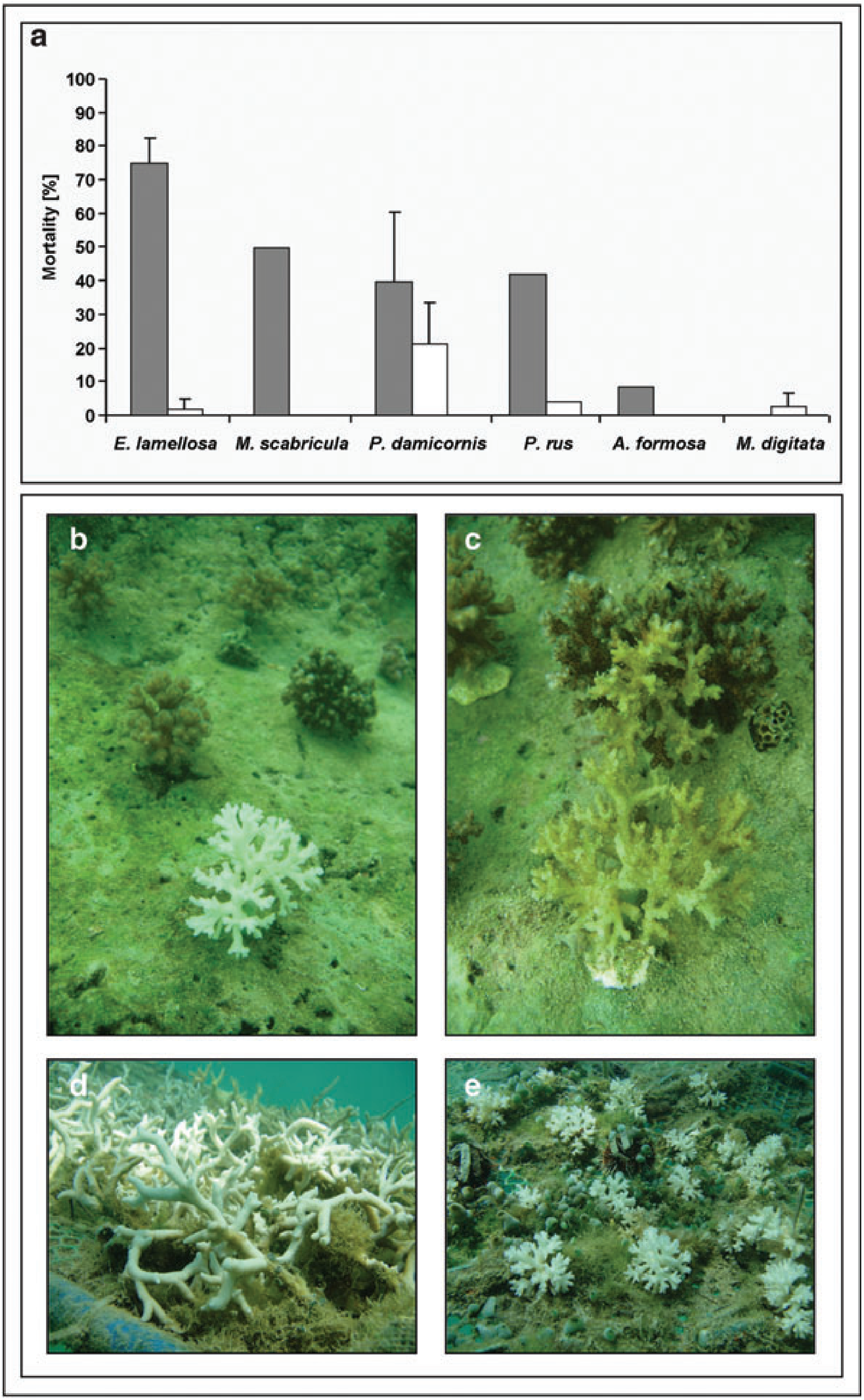

Figure 3. Effects of freshwater seepage at the transplantation site monitored 31 August 2006, 1 month after transplantation, and 2 weeks following the unusual heavy rain (a–c) and bleaching effects on nursery, July 2007 event (d,e). (a) Average mortalities (%) of six different coral species on knolls where low salinity was recorded (solid) and on other knolls in the area (white). (b) A colony of *P. damicornis* with peeled tissue (17 August 2006). (c) *Pocillopora damicornis* colony, showing turf algal settlement on bare skeleton (18 August 2006). (d) Bleaching of reared *M. digitata* corals. (e) Bleaching of reared *P. damicornis* corals. This figure appears in color in the online version of the article [doi: 10.1111/j.1526-100X.2009.00647.x].

Table 4. Status of transplanted colonies and knolls, 1 year after transplantation; the monitoring of 31 August showed the fresh-water seepage impacts in sites 2 and 3; November monitoring revealed the heavy SW monsoon season and July 2007 monitoring was preformed after a mass bleaching event. “mono” and “poly” refer to combinations of single or several coral species transplanted on a specific knoll.

Species	*Site No.*	*Date*	*Knolls with Live Corals*	*Alive Colonies*	*Detached Colonies*	*Colonies with Partial Mortality*	*Bleached Colonies*
M. digitata (mono)	2	1 August 06	5	180	0	0	0
		31 August 06	5	167	11	39	6
		November 06	4	77	21	0	0
		February 07	4	69	6	0	0
		May 07	3	42	17	0	0
		July 07	3	23	0	11	23
P. damicornis (mono)	2	1 August 06	9	324	0	0	0
		31 August 06	9	202	0	19	7
		November 06	7	37	32	0	0
		February 07	3	14	0	0	0
		May 07	2	5	0	0	0
		July 07	1	1	0	0	1
M. digitata (poly)	2	1 August 06	3	36	0	0	0
		31 August 06	3	33	1	4	0
		November 06	3	17	3	0	0
		February 07	3	12	3	0	0
		May 07	2	11	0	0	0
		July 07	2	8	1	5	8
P. damicornis (poly)	2	1 August 06	3	36	0	0	0
		31 August 06	3	32	0	1	1
		November 06	3	8	2	0	0
		February 07	1	4	1	0	0
		May 07	1	3	0	0	0
		July 07	1	3	0	2	3
A. formosa (poly)	2	1 August 06	3	36	0	0	0
		31 August 06	3	29	6	3	0
		November 06	2	13	4	0	0
		February 07	1	1	4	0	0
		May 07	0	0	1	0	0
		July 07	0	0	0	0	0
Total for site 2		**1 August 06**	**17**	**612**	**0**	**0**	**0**
		31 August 06	**17**	**463**	**18**	**66**	**14**
		November 06	**14**	**152**	**62**	**0**	**0**
		February 07	**10**	**100**	**14**	**0**	**0**
		May 07	**7**	**61**	**18**	**0**	**0**
		July 07	**6**	**35**	**1**	**18**	**35**
E. lamellosa (mono)	3	1 August 06	9	324	0	0	0
		31 August 06	9	261	6	18	6
		November 06	7	124	5	0	0
		February 07	1	17	0	0	0
		May 07	0	0	0	0	0
		July 07	0	0	0	0	0
E. lamellosa (poly)	3	1 August 06	3	36	0	0	0
		31 August 06	3	26	0	1	0
		November 06	1	10	4	0	0
		February 07	1	7	0	0	0
		May 07	1	1	0	0	0
		July 07	1	1	0	0	1
P. rus (poly)	3	1 August 06	3	36	0	0	0
		31 August 06	3	30	0	5	0
		November 06	3	27	3	0	0
		February 07	3	23	0	0	0
		May 07	2	19	0	0	0
		July 07	2	19	0	0	19

Table 4. Continued

Species	Site No.	Date	Knolls with Live Corals	Alive Colonies	Detached Colonies	Colonies with Partial Mortality	Bleached Colonies
M. scabricula (poly)	3	1 August 06	3	36	0	0	0
		31 August 06	3	30	0	0	0
		November 06	2	20	1	0	0
		February 07	2	16	3	0	0
		May 07	2	12	3	0	0
		July 07	2	12	0	0	12
Total for site 3		**1 August 06**	**12**	**432**	**0**	**0**	**0**
		31 August 06	**12**	**347**	**6**	**24**	**6**
		November 06	**10**	**181**	**13**	**0**	**0**
		February 07	**4**	**63**	**3**	**0**	**0**
		May 07	**2**	**32**	**3**	**0**	**0**
		July 07	**2**	**32**	**0**	**0**	**32**
M. digitata (mono)	4	1 August 06	4	144	0	0	0
		31 August 06	4	141	0	30	7
		November 06	4	115	25	0	0
		February 07	4	114	0	0	0
		May 07	4	112	0	0	0
		July 07	4	81	31	23	81

2006 and March 2007 (Wilcoxon signed ranks test; $p = 0.05$, Tables 3 & 5).

Species-specific values revealed significant differences. Average bleaching was significantly higher during June and July 2007 in seven of the eight species reared in the nursery (Wilcoxon signed ranks test; $p < 0.05$, Tables 3 & 5), and only in *Heliopora coerulea* no difference was recorded (Wilcoxon signed ranks test; $p > 0.05$, Tables 3 & 5). Although, in most species, mortality and partial mortality values were higher in June and July 2007, only in *E. lamellosa* was the difference significant (Wilcoxon signed ranks test; $p < 0.05$, Tables 3 & 5). We assume that the non-significant results are due to the high differences recorded between June and July. In *M. aequituberculta* and *M. scabricula*, mortality was recorded in June while in *A. formosa* and *P. damicornis* mortality increased in July (Table 5). Partial mortality was observed and recorded mainly during July, after the peak of the event. Detachment did not differ significantly in seven of the eight species, except for *M. scabricula* detachment, where it was significantly higher in December 2006 and March 2007 as compared to June and July 2007. The effect of the bleaching event did not differ between the new transplants (transplanted in October 2006) and the 1-year-old NGCs transplanted in August 2005 (Mann–Whitney; $p > 0.05$, one-way ANOVA; $p > 0.05$).

Discussion

The reef restoration experiments reported here for both nursery farmed and transplants in Bolinao (Philippines) were severely influenced during the 2 years of study, by a forceful southwesterly monsoon season and by stochastic massive environmental events.

The two coral nursery phases in the sheltered area of the Bolinao's large lagoon suffered from two major environmental catastrophes: the 2006 typhoon and the 2007 bleaching events, the latter being the most devastating. In contrast to the other stochastic events, the combined effects of higher water temperatures and irradiation were predictive early warning signals for coral bleaching (Brown 1997; Hoegh-Guldberg 1999; Hughes et al. 2003). Improved nursery management, such as lowering of the nursery bed to deeper water during critical periods to reduce the effects of irradiation and water temperature could have prevented bleaching in nursery-farmed corals, relative to naturally growing shallow water colonies. Susceptibility to bleaching was found to be species-specific. In the nurseries placed at 2-m depth, one (*Heliopora coerulea*) of the eight species showed resistance to bleaching while partial recovery was observed mainly in *Montipora digitata* and *Porites rus.*

Transplantation in this study took place at the beginning of the SW monsoon season, after the summer season. The summer in the Philippines is an unfavorable period for transplantation because of elevated seawater temperatures (Yap 1992; Yap et al. 1998). The transplanted colonies withstood two more stochastic natural disturbance events and a tempestuous southwesterly monsoon season, all potentially affecting survival. The catastrophic event of low salinity resulting from unusually torrential precipitation occurred 1 month after transplantation (August 2006). Similar events had been previously reported on shallow water reefs, with increased sedimentation, nutrients, and reduced light, synergistically affecting mortality (Goreau 1964; Egana & Dislavo 1982; Paerl et al. 1990; Yap et al. 1994; Yap et al. 1994; Larcombe et al. 1996; Porter et al. 1999). Mortality showed species-specific patterns: *Echinopora lamellosa*, *Merulina scabricula*, *Pocillopora damicornis*, and *P. rus* were considerably affected by the lower salinity whereas *M. digitata* and *Acropora formosa* were marginally influenced. The June 2007 mass bleaching was more devastating to transplants. The entire northwest part of the Philippines had been badly affected by bleaching in the 1998 mass-bleaching event (Arceo et al. 2001). During this massive event, Bolinao reefs showed the greatest decrease in live coral cover and were exposed to elevated sea temperature longer than other areas in the Philippines. As in the nurseries, bleaching of transplants showed species-specific patterns (cf. Marshal & Baird 2000; Hughes et al. 2003; McClanahan et al. 2008). *Porites rus* was more resistant than other species to bleaching. These results are similar to those reported by Yap (2004). The above occurrences emphasize the importance of identifying the most

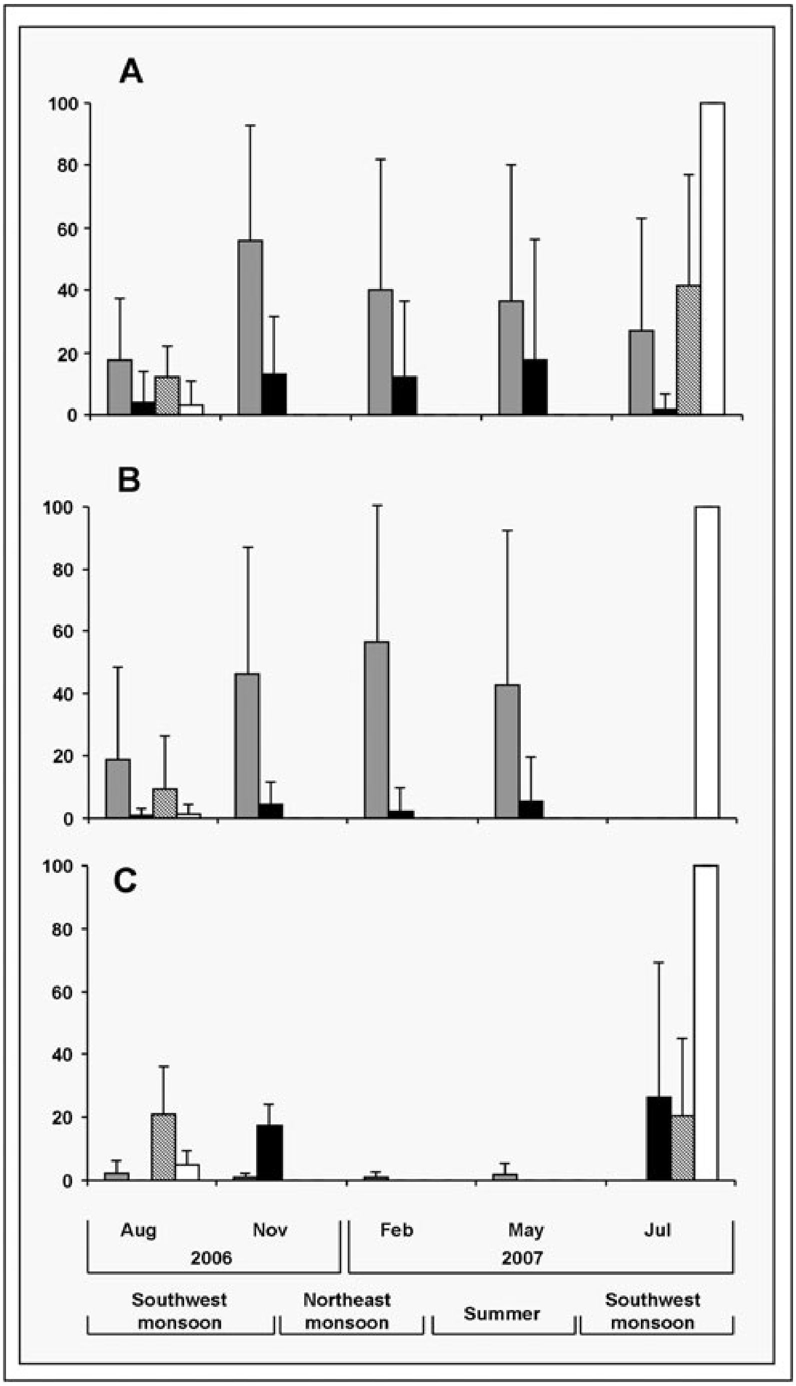

Figure 4. Cumulative status of transplanted colonies, between August 2006 and July 2007 at different sites: (a) site 2, (b) site 3, and (c) site 4 (only *M. digitata)*. Mortality, gray; detachment, black; partial mortality, hatched; bleaching, white.

Table 5. Second year nursery; average changes for mortality, detachment, bleaching, and partial mortality of colonies belonging to eight farmed species; the monitoring of July 2007 was preformed after a mass bleaching event.

Species	*Date*	*Mortality (%)*	*Detachment (%)*	*Bleaching (%)*	*Partial Mortality (%)*
A. formosa	December 06	6.8 ± 3.7	0	0.8 ± 0.8	0.6 ± 0.2
	March 07	3.4 ± 4.1	0.7 ± 0.9	0.2 ± 0.3	3.7 ± 5.2
	June 07	1.4 ± 0.6	0	79.5 ± 18.0	1.0 ± 1.4
	July 07	79.8 ± 17.6	0	80.5 ± 27.6	0
E. lamellosa	December 06	2.2 ± 1.7	2.5 ± 3.2	2.4 ± 4.6	0.9 ± 1.4
	March 07	3.4 ± 5.2	1.7 ± 1.6	0.2 ± 0.5	4.8 ± 9.0
	June 07	9.4 ± 6.1	2.2 ± 2.2	82.6 ± 11.9	0.7 ± 1.6
	July 07	9.5 ± 6.7	0.5 ± 1.1	74.9 ± 14.3	43.1 ± 14.7
H.coerulea	December 06	0	0.7 ± 1.0	0	2.9 ± 4.1
	March 07	2.6 ± 3.7	0.7 ± 1.0	0	0
	June 07	7.8 ± 6.9	4.0 ± 5.6	0	0
	July 07	0	0	13.0 ± 18.4	0
M. aequituberculata	December 06	11.9 ± 12.7	0	1.1 ± 1.5	2.6 ± 3.7
	March 07	15.8 ± 22.3	0	0	9.0 ± 12.7
	June 07	31.6 ± 22.9	0	85.7 ± 8.1	10.9 ± 15.4
	July 07	10.9 ± 15.4	0	100 ± 0	0
M. digitata	December 06	0.2 ± 0.4	0.1 ± 0.3	0.2 ± 0.5	1.4 ± 3.1
	March 07	0.4 ± 0.7	0.1 ± 0.1	0	0
	June 07	0.4 ± 0.7	0	0	0
	July 07	0.4 ± 0.7	0	98.5 ± 4.1	0
M. scabricula	December 06	3.7 ± 2.6	4.1 ± 2.5	1.0 ± 1.2	2.7 ± 3.2
	March 07	6.6 ± 7.2	5.5 ± 4.2	0	1.6 ± 2.1
	June 07	10.4 ± 10.7	0.7 ± 1.4	87.1 ± 17.5	8.4 ± 15.8
	July 07	8.4 ± 6.1	0	88.8 ± 19.0	48.0 ± 45.9
P. damicornis	December 06	19.1 ± 19.2	1.5 ± 2.6	0.4 ± 0.8	0.7 ± 1.3
	March 07	4.1 ± 5.6	0.4 ± 1.1	0	2.7 ± 6.3
	June 07	7.8 ± 10.1	0.4 ± 0.7	87.5 ± 33.0	1.2 ± 3.5
	July 07	13.0 ± 21.1	0	89.4 ± 11.7	46.7 ± 28.7
P. rus	December 06	3.0 ± 3.1	0	0.6 ± 1.2	0.3 ± 0.5
	March 07	2.7 ± 2.1	2.0 ± 3.3	0.3 ± 0.9	0.3 ± 0.6
	June 07	2.5 ± 2.8	2.5 ± 5.9	89.9 ± 14.3	0.1 ± 0.2
	July 07	2.4 ± 1.8	0	96.7 ± 3.1	24.3 ± 26.5
Total nursery values	**December 06**	**4.7**	**0.9**	**0.8**	**1.3**
	March 07	**3.3**	**1.2**	**0.1**	**2.4**
	June 07	**4.8**	**0.8**	**56.8**	**0.8**
	July 07	**16.0**	**0.1**	**82.3**	**22.1**

suitable species for restoration in the target site, species with a capability of resisting extreme environmental changes, such as temperature and radiation. Of further importance is the seasonality of transplantation—providing the new transplants an optimal duration for establishment. The most favorable season for transplantation in Bolinao would be January–February, at the end of the NE monsoon season and before the beginning of the summer.

The present bleak situation of coral reefs does not leave much room for an optimistic future, a view supported by the Wakeford et al.'s (2008) conclusion that disturbance intervals shorter than 8 years could reduce the present of dominance of hard coral groups. Furthermore, even commonly occurring natural events such as rainfall and storms may develop to natural catastrophes when their frequency and intensity enhanced (Thibault & Brown 2008).

Many conservation programs and policies focus on a threat-based approach to management of ecosystems (http://pdf.usaid.gov/pdf_docs/PNADE258.pdf; http://conservationmeasures.org/CMP/IUCN/SitePage.cfm) with an eye to mitigating the most pressing threats to biodiversity. Such conservation planning and action strategy is ineffective and inadequate in areas where unpredictable large-scale natural catastrophes, enhanced by global changes, are occurring frequently. While the persistence of coral reefs depends on the potential for coral communities to respond to climate change, ecological sustainability of impacted reefs cannot seek abatement of most pressing threats to biodiversity anymore. Employing active restoration is becoming an important and inevitable path to reef rehabilitation. Therefore, the assumption that some proportions of habitat goods and services are recoverable through active manipulations, may serve as the best rationale and the best applied tool for mitigating devastating impacts (Rinkevich 2008). Our 2-year follow-up experiments in Bolinao further revealed the significant challenges imposed by natural forces/global changes on planned restoration efforts. They also support suggestions that the current conservation and restoration practices might not be sufficient for forestalling loss of species due to the combination of continuous anthropogenic and worsening climate changes (Hughes et al. 2003; Hoegh-Guldberg et al. 2007). Taking this message further, recent discussions on conservation responses to climate change have offered the option of using dramatic measures, such as the "assisted colonization" approach, suggesting to rescue target species by moving them to sites where they do not currently exist or have not been known to exist in recent history (Hoegh-Guldberg et al. 2008). Whereas the above suggestions may suit a limited number of situations such as conservation of endangered species, they may not be equally suitable to reef restoration as a whole. It is also evident that the current best management tools employed in coral reefs worldwide has failed to achieve conservation objectives, and coral reefs in increasingly documented cases, continue to degrade (Hughes et al. 2003, 2005; Bruno & Selig 2007; Rinkevich 2008).

Responding to the conflicting needs above, we suggest that the establishing of large-scale nurseries and transplantations, together with traditional management tools, are needed to cope with extensive reef degradation on a global scale (Rinkevich 2005, 2006, 2008). With regard to the nursery phase, this study points to the need for depth-flexible structures and for testing species prioritization as pre-site decision. Our results further support the assumption that while it is imperative to considerably revise management protocols and include active reef restoration as an integral part of routine management (Rinkevich 2008), restoring of badly damaged whole reefs is yet an unrealistic aim, given current coral restoration methods and anticipated climate change impacts. Therefore, to generate timely information for management, there is a need for prioritization of the most appropriate and beneficial restoration instruments, developing alternative protocols adapted to specific conditions and circumstances. Parameters such as depth, wave action impacts, substrate composition, and species tolerance, should be carefully evaluated in detailed studies.

Implication for Practice

- The underwater coral nursery is an approved practical instrument to farm large numbers of coral colonies from a variety of species, preceding their transplantation into denuded reefs. The nurseries constructed for this study withstood rough weather conditions, attesting to their long-term use. Improving the nursery construction to fit environmental changes will enhance survivorship rates of farmed colonies.
- Corals revealed species-specific tolerance and growth capabilities under different environmental stressors. Of the seven species used in this study, two exhibited high tolerance to low salinity and bleaching. Restoration acts should consider negative impacts of unpredictable harsh weather. Taking into account the use of species combination is an advisable management instrument for the successes of restoration.
- Global climatic changes are expected to impose ever-increasing challenges on future restoration measures. However, it is our view that extensive reef degradation on a global scale can only be counteracted by establishing large-scale nurseries and transplantation acts, together with traditional management tools.

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