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Survival and Growth of Re-attached Storm-generated Coral Fragments Post Super-typhoon Haiyan (a.k.a. Yolanda)

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ABSTRACT

Coral reefs in Eastern Samar, Philippines were badly damaged by super typhoon Haiyan, which left many reefs in a fragmented state – with many branching corals and other coral forms scattered in loose pieces. As part of the efforts to address this problem, we tested the re-attachment of 43 species of coral fragments to sturdy natural substrates in three reef sites in Eastern Samar (Can-usod and Monbon in Lawaan, and Panaloytoyon in Quinapondan). The results revealed that 88% of re-attached coral fragments survived (45% showed positive growth, and 43% survived with partial tissue mortality). Those that showed positive growth exhibited high growth rates. We also found that fragments of some coral species are more fast-growing (e.g., *Cyphastrea decadia*, *Echinopora pacificus*, and *Millepora tenella*) than others (e.g., *Porites lobata* or *Pectinia paeonia*). Overall, our results suggest that if Local Government Units (LGUs) invest in the re-attachment of fragmented corals (e.g., reefs damaged by super typhoons or by various human activities such as fishing), then coral reef degradation in the Philippines would have a better chance of recovering.

Keywords: Coastal management, conservation, Leyte Gulf, reef restoration, super typhoon

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INTRODUCTION

Philippine coral reefs have been experiencing degradation since the 1980s – caused mainly by exploitative activities, such as fishing, including destructive fishing (e.g., dynamite and cyanide fishing) (Gomez et al. 1994; White and Vogt 2000). In addition, human activities, such as deforestation of upland and coastal areas, land conversion and industrialization, urbanization, and over-fertilization of farmlands, have added more sediments, nutrients, and pollutant run-offs onto Philippines coastal areas, where most reefs can be found. Recent accounts of the status of Philippine reef benthos using meta-analysis techniques have demonstrated that Philippine reefs remain in degraded conditions (Magdaong et al. 2014). Moreover, climate-related disturbances, such as ocean warming and acidification (McLeod et al. 2010; Pandolfi et al. 2011), and super typhoons (Knutson et al. 2010; Anticamara and Go 2016), have added more stresses to many degraded Philippine reefs. Thus, there is a need to test options for actively recovering extensive degraded reef areas in the Philippines, in order to meet the increasing demands for reef ecosystem services, such as food fish, tourism areas, and livelihoods, from the rapidly growing Filipino population.

Over the last three decades, there has been a growing global interest in testing active restoration methods for coral reefs (Yap and Molina 2003; Abelson 2006; Rinkevich 2014). The existing coral restoration techniques can be generally categorized into three types: (1) direct transplantation of fragments (Garrison and Ward 2008; Boch and Morse 2012); (2) coral transplantation using nursery and coral gardening techniques (Shaish et al. 2008; Lohr et al. 2015); and (3) growing coral nubbins from coral spawn for later transplantation (Shafir et al. 2003; Guest et al. 2014; Leal et al. 2016). A less popular coral restoration technique involves the use of electrodes to augment coral larval settlement in a chosen area (van Treeck and Schuhmacher 1999; Benedetti et al. 2011). Among the existing coral transplantation methods, the most promising one for the Philippines is direct fragment transplantation, simply because of the cheaper cost and the abundance of coral fragments in many Philippine reef areas, especially those that are subjected to frequent storms or human activities, such as unregulated diving (Anticamara et al. 2015; Go et al. 2015).

In recent years, some of the Philippine coral reefs, especially those facing the Western Pacific Ocean (WPO), have been subjected to super typhoons, resulting to the eradication of some shallow reefs and the extensive damage to many reefs

(Anticamara and Go 2016). To date, there is no published literature on any attempts to recover degraded reefs facing the WPO following the impacts of a super typhoon using available coral restoration techniques. In fact, we have noted that, in most coastal and reef areas that experienced devastation by super typhoons, most of the responses from the international donor agencies or Local Government Units (LGUs), National Government Agencies (NGAs), and other Aid Institutions (AIs) were the provision of more fishing boats, engines, and fishing gears in the affected areas (Anticamara and Go 2016). This is counterintuitive, considering that the devastation of corals due to typhoons have obvious negative effects on the productivity (fisheries) of impacted reefs based on established trophic interactions and the loss of habitats for many fishes (Lassig 1983; Dollar and Tribble 1993, Tan et al. 2017). Thus, there is a great need to test and demonstrate the potential of currently available coral restoration techniques in typhoon-prone areas of the Philippines to help alleviate the negative consequences of storms on the reef productivity of the said areas.

In the Philippines, coral restoration techniques have been tested and have demonstrated promising results, such as relatively high coral growth rates and survival post transplantation (Shaish et al. 2010; Dela Cruz et al. 2014; Cabaitan et al. 2015). However, to date, coral restoration in the Philippines has been mostly conducted in limited reef sites (mainly Bolinao in northwest Luzon) using few sets of coral species (Dizon et al. 2008; Shaish et al. 2010; Gomez et al. 2014; Cabaitan et al. 2015) (Appendix Table 1). Thus, there is still a need to expand current studies and tests on coral restoration in many sites in the Philippines for many coral species.

The main goal of this research is to quantify the growth rates and survival of 43 species of re-attached storm-generated coral fragments in three reef sites of Eastern Samar– an area that was heavily damaged by super-typhoon Haiyan in 2013. Here, we used direct transplantation of coral fragments collected from the same reef site where the fragments were re-attached. We believe that this preliminary study (of similar duration to most published literature on coral restoration, Appendix Table 1) is necessary for providing insights on the possibility of recovering storm-impacted reefs in the Philippines, which have been mostly abandoned and left to further unregulated exploitation and degradation.

MATERIALS AND METHODS

Study sites for re-attaching coral fragments

We re-attached storm-generated coral fragments in three reef sites (i.e., Can-usod, Monbon, and Panaloytoyon) in Eastern Samar (Figure 1). The reef sites of Eastern Samar were generally in a degraded state due to (a) over-exploitation, including destructive fishing, such as the use of dynamite (Anticamara et al. 2015; Go et al. 2015), and (b) frequent impacts of strong storms– among which, the strongest was super-typhoon Haiyan in 2013 (Anticamara and Go 2016). However, the three sites selected for the re-attachment of storm-generated fragments were within the regulated and well-enforced Marine Reserves (MRs) in Eastern Samar (Figure 1), to ensure that blast fishing, which is still practiced in Eastern Samar (personal observation) will not damage the re-attached coral fragments. The selected three study sites are very important in Eastern Samar as these are the last remaining protected reefs in the area, supporting the fisheries demands of the largely fisheries-dependent communities living in nearby coasts (Anticamara and Go 2016).

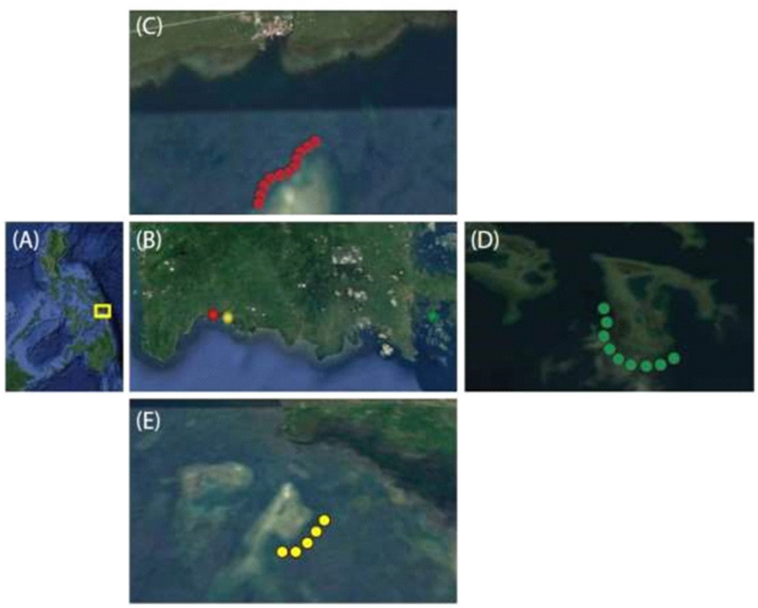

Figure 1. (A) Philippine map; (B) Southern coast of Eastern Visayas showing location of the three coral fragment re-attachment sites: Can-usod (red circle; coordinates: Lat11.133323, Long125.284957), Monbon (yellow circle; coordinates: Lat11.125751, Long125.302617), Panaloytoyon (green circle; Lat11.127674, Long125.543586); (C) Can-usod with 11 attachment sites; (D) Panaloytoyon with nine attachment sites; and (E) Monbon with five attachment sites.

Coral fragment attachment protocol

Within each reef site, we selected 5-11 square attachment areas, each measuring 10x10 m^2, with their borders marked by a rope. Within each attachment square, coral fragments were attached to sturdy substrates, such as dead massive or submassive corals, rocks, or to a PVC pipe, using concrete nails for hard substrate and cable ties. The choice substrate type was mainly based on what was found in the attachment square, and we did not test the effects of substrate types for this particular study. In addition, within each attachment square, up to 30 re-attached coral fragments were haphazardly selected and tagged using numbered security seals. All re-attached coral fragments were collected from coral fragments found within the study reef site, and only coral fragments that were alive and free of algae or bleaching marks were re-attached. Within each attachment square, we re-attached over 30 fragments, but did not count or track those that were not tagged due to limitations in terms of time and monitoring resources (i.e., limited funding).

Monitoring growth rates and survival of attached coral fragments

After re-attachment, the tagged coral fragments were visited every quarter and were monitored from July 2015 to June 2016. At the start of the study and during each visit, all tagged coral fragments were photographed with a ruler in the frame beside the re-attached coral fragment to provide a scale for growth measurements later in the lab.

Data processing and analyses

Photographs of the tagged corals were processed using the software Coral Point Count with Excel Extensions CPCE v4.1 (Kohler and Gill 2006) to compute for the area of each coral colony fragment. There have been reports of many different ways of measuring coral growth, such as linear extension, surface area, and ecological volume (Shaish et al. 2008; Gomez et al. 2011; Guest et al. 2011; Rinkevich 2014; Cabaitan et al. 2015). We deemed it best to monitor the coral growth in terms of area (in cm^2) so as to account for the differences in coral growth forms (i.e., branching, foliose, or submassive). In addition, the mean monthly growth rate per re-attached coral species were also expressed as percentage of original colony area during initial re-attachment (Appendix Table 2). All tagged and re-attached coral fragments across the three reef sites were later identified at the species level and according to the life form using online resources (http://coral.aims.gov.au/) and publications (Veron 1986; Veron and Hodgson 1989; Veron et al. 1996). All analyses presented in this manuscript are descriptive in nature. Our main purpose is to demonstrate the preliminary results of re-attaching storm-generated coral fragments, which were mostly left to die in Eastern Samar, since there has not been much effort in reef assessment or recovery in the area post super-typhoon Haiyan. We hope the preliminary results presented here, albeit descriptive, will provide some insights on the possibility of actively recovering degraded reefs in Eastern Samar. We also presented calculations of the incurred costs of re-attaching coral fragments in Eastern Samar, to help guide LGUs, NGAs (e.g., BFAR, DENR, DSWD), and AIs interested in investing in reef recovery in Eastern Samar.

Literature review and data compilation

We compiled published peer-reviewed literature to extract the following information: (1) types of coral restoration (i.e., direct re-attachment of fragments, coral gardening using nursery, or growing coral nubbins from larva); (2) the re-attached species; (3) the survival per species; (4) the growth rate per species (standardized as mean monthly growth rates (%) for comparison and discussion purposes); and (5) the incurred cost per re-attached fragment. The compiled information were utilized for discussion purposes (Appendix Table 1).

RESULTS

General findings

A total of 651 tagged coral fragments (belonging to 43 species and 15 families) were re-attached across the three study sites (Appendix Table 2). Majority of the storm-generated fragments that were re-attached belong to the Poritiidae family, since they comprise most of the live fragments that were left after super-typhoon Haiyan impacted the reefs of Eastern Samar (Figure 2). Of the 651 tagged coral fragments, 320 were re-attached in Can-usod, 75 in Monbon, and 256 in Panaloytoyon (Figure 3).

After a year of quarterly monitoring, 295 (45%) of the tagged and re-attached coral fragments showed positive growth, 282 (43%) stayed alive but with partial tissue mortality, and 75 (11%) were lost (either dead or detached, and no longer found during the monitoring period).

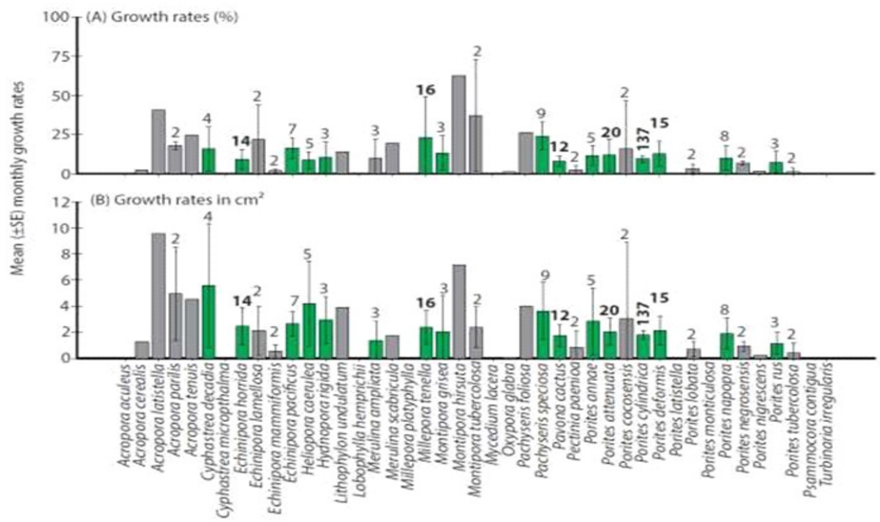

Figure 2. Barplot showing the mean (±SE) monthly growth rates by coral species. The number above the bar shows the number of re-attached fragments for each coral species. Numbers in bold are species with ≥10 re-attached fragments/colonies. Green bars represent species with ≥3 re-attached fragments.

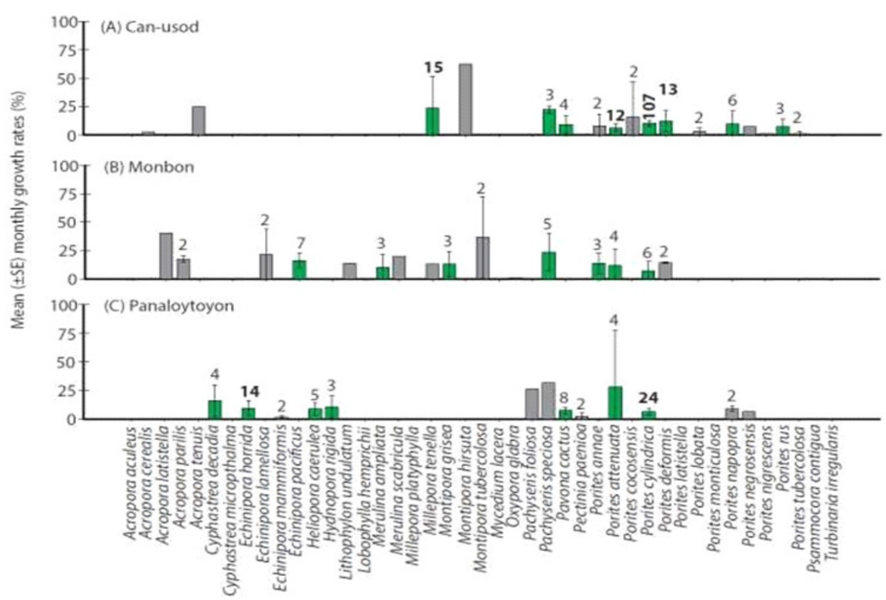

Figure 3. Bar plot showing the mean (±SE) monthly growth rates (%) of coral species in the three study sites. The number above the bar shows the number of re-attached fragments for each coral species. Numbers in bold are species with ≥10 re-attached fragments/colonies. Green bars represent species with ≥3 re-attached fragments.

Growth rates of re-attached coral fragments by species

For those tagged and re-attached fragments that showed positive growth, the calculated mean (± Standard Error SE) monthly growth rates by species (those with ≥3 colonies) ranged from 7-24%, but with high variability within and across species (Figure 2A). The tagged and re-attached coral fragments exhibited mean monthly growth rates by species (those with ≥3 colonies) of about 1-5 cm^2, albeit with high variability within and across species (Figure 2B). Among those corals with ≥10 tagged and re-attached fragments, the following showed mean monthly growth rates ranging from 2-3 cm^2 (or 10-20%): *Echinopora horrida*; *Millepora tenella*; *Pavona cactus*; *Porites attenuata*; *Porites cyclindrica*; and *Porites deformis* (Figure 2A-B; Appendix Figure 1A-C)

Growth rates of re-attached coral fragments by species and site

The tagged and re-attached coral species with ≥3 fragments showed variable growth rates across and within species, but also exhibited mean monthly growth rates ranging from 5-25% in all the three study sites (Figure 3A-C). It was difficult to compare mean monthly growth rates across species and across sites because of the differences in numbers of tagged and re-attached fragments across sites by species (Figure 3A-C). However, those species with ≥10 tagged and re-attached fragments across the three study sites demonstrated that coral fragments can achieve high growth rates within a month of at least 3% and up to 25% (Figure 3A-C).

Growth rates of re-attached coral fragments by coral life form

Five coral life forms were represented by the tagged and re-attached coral fragments across the three sites in Eastern Samar (Figure 4A-E). Most of the tagged and re-attached coral fragments were of branching forms (Figure 4A-E). It was difficult to compare the growth rates of re-attached coral fragments by life form across the study sites due to the unequal and variable number of re-attached fragments per site. However, those tagged and re-attached coral fragments with ≥10 fragments showed mean monthly growth rates of at least 3% and up to 25% (Figure 4A-E).

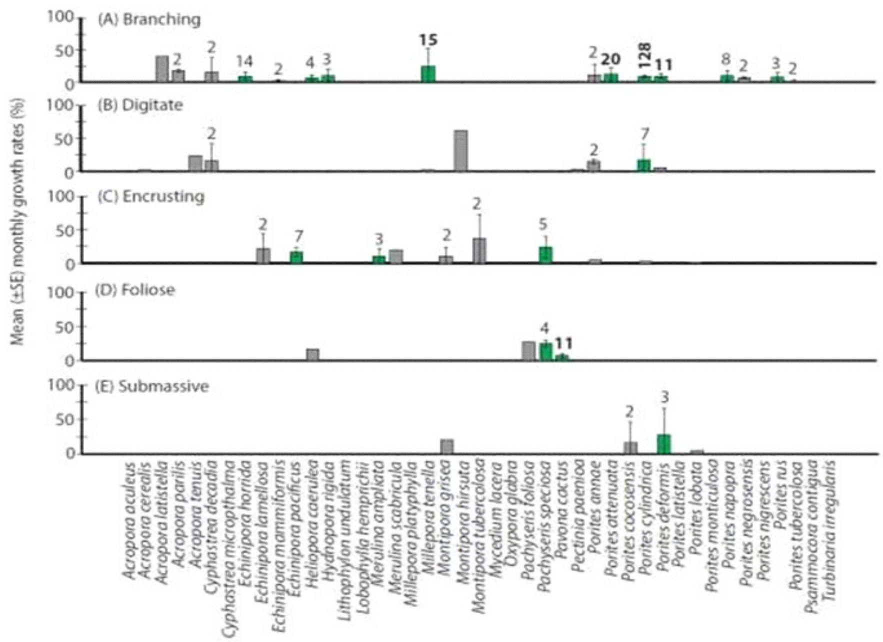

Figure 4. Barplot showing the mean (±SE) monthly growth rates (%) by coral life forms. The number above the bar shows the number of re-attached fragments for each coral species. Numbers in bold are species with ≥10 re-attached fragments/ colonies. Green bars represent species with ≥3 re-attached fragments.

Incurred cost of coral fragment re-attachment in Eastern Samar

The total cost of re-attaching 300 coral fragments was 544 USD (US Dollar), based on 50 PhP (Philippine Peso) per 1 USD conversion rate, which is equivalent to 1.8 USD per fragment (Table 1). Majority of the incurred cost went to logistics (e.g., boat, land transportation, SCUBA rentals, and accommodation), while the cost of materials (e.g., cable ties, concrete nails) were minimal (Table 1).

DISCUSSION

Overall, the preliminary results of this study suggest that re-attaching storm-generated coral fragments may aid in the recovery of degrading reefs in Eastern Samar, as indicated by the high survival and growth rates of re-attached fragments after a year of observation. In addition, estimated growth rates by species indicated that some coral species fragments may grow relatively faster than other species by a factor of 2-3 times, although variability in growth rates was also observed within species. Moreover, the incurred cost of directly re-attaching coral fragments is relatively cheaper compared to other methods that require additional costs of nursery maintenance or growing coral nubbins from coral spawns up to sizeable coral colonies for transplantation. A detailed discussion of the key findings in relation to published literature is presented below.

Table 1. The cost of re-attaching storm-generated coral fragments in Eastern Samar per day based on three SCUBA divers doing three dives in a day. Each diver was able to re-attach 100 coral fragments per day

Item	Unit	Cost (USD)	Remarks
Boat	1	60	
Honorarium-Local Aids	2	20	Local aids help collect fragments
Honorarium-Divers	3	75	Honorarium for 3 divers re-attaching the coral fragments underwater
Accommodation	1	60	
SCUBA tanks	9	45	Rental costs of 3 tanks per diver; 3 divers diving 3 times per day
SCUBA gears set rental per diver	3	150	Rental costs of 3 sets of SCUBA gear per day for 3 divers
Land transportation	1	80	Transportation used to carry gear and personnel from the base to the location of the boat and back
Food	6	24	Food for all the crew involved in coral re-attachment activities
Cable ties	300	20	
Concrete nails/PCV	300	10	
TOTAL COST/DAY		**544**	

On survival of re-attached coral fragments

This study shows that re-attached coral fragments mostly survived (88%) after a year, although some of the colonies showed partial mortality (43%). This survival rate is comparable to those observed in other places based on published literature data (Appendix Table 1), although we noticed that many of the studies did not account or report partial mortalities of surviving re-attached coral fragments. Our results show that, if coral fragments (produced by disturbances such as typhoons, anchoring damage, or diver impacts) were regularly re-attached, then most of the reefs can retain live cover. We noticed that, during the monitoring of reefs impacted by super-typhoon Haiyan, most coral fragments that were left un-attached died after sometime from the abrasive impacts of other rubble (produced by super-typhoon Haiyan) when the tides and currents changed and moved. Leaving unattended coral fragments produced by large-scale (typhoons) or frequent disturbances (fisher or diver impacts) have largely contributed to the decrease in live coral cover of Philippine reefs. Thus, investments on regular re-attachment of coral fragments per LGU (i.e., municipalities and cities with coral reefs) should be promoted to help alleviate the decline of live coral cover in most reefs of the country.

However, our results also show that re-attached coral fragments may experience partial death and some mortalities, suggesting that the re-attachment of coral fragments as conservation or recovery strategy should not be a one-shot activity, but rather a regular part of monitoring and management of both protected and exploited reefs of LGUs. Other studies based on reviews of published literature on coral restoration also highlighted the importance of regular monitoring of re-attached coral fragments and perhaps regular re-attachment of coral fragments within managed reef sites, in order to help reefs cope with the ever expanding and intensifying impacts of human-induced disturbances on reefs (Appendix Table 1).

On growth of re-attached coral fragments

Based on our one-year observation of re-attached coral fragments in Eastern Samar, we found that most of the coral species that we re-attached show considerably high mean monthly growth rates, comparable to those reported in published literature (Figure 2A-B, Appendix Table 1, and Appendix Figure 1A-C). Most of the coral species with ≥3 re-attached colonies showed mean monthly growth rates ranging from 7-24% (1-5 cm^2) (Figure 2A-B). We noticed during our observations of the re-attached coral fragments that if the goal of the coral recovery was to increase the volume of coral habitable areas, then re-attaching branching species from the genera *Acropora*, *Hydnopora*, *Millepora*, and *Porites* can greatly help achieve such goal (Appendix Figure 1A-C). However, if the goal is to stabilize reef areas that are covered with great amount of rubble, as in the case of Eastern Samar reefs after super-typhoon Haiyan's impacts, then re-attaching encrusting corals from the genera *Echinopora*, *Montipora*, and *Pachyseris* is beneficial in achieving such objective (Appendix Figure 1A-C). However, we would like to emphasize that the long-term goal of any coral recovery project and management should be to establish diversity of coral life forms in an area, ideally resembling the natural coral assemblages found in the area. Thus, re-attaching coral fragments from the same vicinity should be encouraged and enforced as a protocol.

Nonetheless, the concerns about changes in coral disturbances related to climate change should also be considered in coral recovery activities. Our observations based on the assessment of super-typhoon Haiyan's impacts in Eastern Samar indicate that branching coral species found in shallow reef flats and exposed to typhoons' path will be wiped-out in the event of a typhoon impact (Anticamara and Go 2016). Therefore, if typhoons become a frequent event impacting what used to be a branching coral reef area, then re-attachment of typhoon-resistant species (e.g., from encrusting genera) should be considered, in order to maintain live coral cover in such a reef and to maintain its habitat and productivity, as opposed to leaving it dead. This is perhaps one climate change adaptation strategy that should be explored in Philippine reef recovery and management.

Cost of re-attaching coral fragments

The costs we incurred in re-attaching corals in Eastern Samar were modest, especially if we consider only the cost of the materials (i.e., if LGUs already have sufficient logistics, SCUBA, and personnel to support such activities). We find it difficult to compare our costs with those coral restoration and recovery projects in published literature because (1) most of them did not report costs, and (2) when the costs were reported, they usually did not present all the categories of coral recovery costs that we considered (i.e., materials, logistics, SCUBA, personnel, and technology costs) (Appendix Table 1). Nonetheless, we think that the costs of re-attaching coral fragments is small, and thus, should be affordable to most LGUs if initial investments in big item costs, such as SCUBA equipment, boat, logistics, and personnel support, are already in place. The cost of materials such as cable ties, concrete nails, or PVC pipes is considerably minimal. Also, the cost of re-attaching fragments should be viewed in light of all the ecosystem services and benefits provided by every km^2 of reefs to the coastal communities of each LGU, from food, livelihood, recreation, and protection (De Groot 2013).

However, to date, in most of the LGUs that we surveyed throughout the Philippines and in Eastern Samar, there was no allocation for reef management cost, especially recovery cost in case of damage. In fact, many of the reefs that we surveyed were not assessed after super-typhoon Haiyan due to lack of assessment funding allocation. This is most ironic since majority of coastal communities living near reefs in the Philippines or Eastern Samar are heavily dependent on reefs and coastal resources for food, livelihood, and income, but there has never been any funding for regular assessment or recovery of damaged reefs. Allocating a budget for reef and resource management should be tackled when improving coastal management of many reef and coastal resource-dependent LGUs. Interestingly, even in reefs that generate a lot of money from tourism (e.g., Batangas, Hundred Islands, etc.), we noticed the lack of allotment for regular reef assessment and recovery, and the huge allocation for enforcement of MPAs, patrols, or further infrastructure development (e.g., building more sheds and accommodations). Thus, funds for reef or coastal assessment, monitoring, and recovery are always lacking in most Philippine LGUs. The revision and implementation of funding allocation should be considered for each LGU for the maintenance of reef productivity, in light of increasing human-induced disturbances and exploitation of reefs and coastal resources.

CONCLUSIONS AND RECOMMENDATIONS

This study demonstrates that many species of coral fragments produced by disturbances (in this case, a super-typhoon) can be successfully re-attached, highlighting its potential for the recovery of degraded and impacted reefs. The results also show that different species perform variably, but in general, the branching species can produce a rapid increase in volume of available reef habitat, while the encrusting species can help stabilize rubble-covered reefs. Moreover, results from this study demonstrate that reef recovery via re-attachment of coral fragments need to be executed as part of the regular program or strategies of LGUs to assess, monitor, and recover degraded and exploited reefs, rather than as a one-time activity, in order to ensure continuous provisions of ecosystem benefits that coastal communities derive from reefs and coastal resources. Re-attachment of coral fragments from various human-induced disturbances or large-scale impacts such as typhoons should be given consideration and funding allocation in every LGU that derive huge benefits from reefs to sustain their communities. Long-term studies on coral re-attachment using multiple local species in representative sites of the Philippines should be implemented to help improve the techniques and scientific understanding of this strategy of recovering degraded reefs of the Philippines or degraded reefs in general.

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Appendix Figure 1

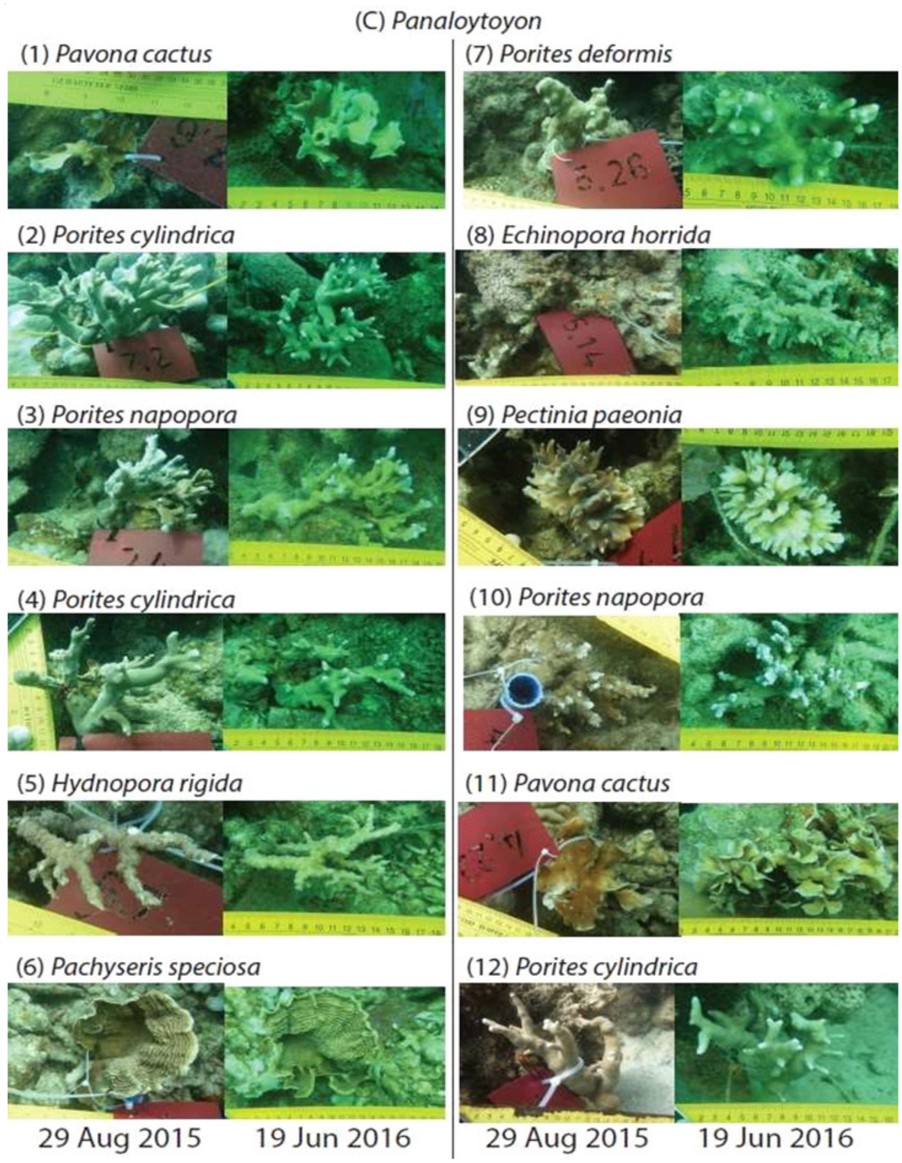
Photos showing the growth selected re-attached coral colonies in (A) Can-usod, (B) Monbon and (C) Panaloytoyon, Eastern Samar within one year.

Appendix Figure 1 (cont'n.)

Photos showing the growth selected re-attached coral colonies in (A) Can-usod, (B) Monbon and (C) Panaloytoyon, Eastern Samar within one year.

Appendix Figure 1 (cont'n.)

Photos showing the growth selected re-attached coral colonies in (A) Can-usod, (B) Monbon and (C) Panaloytoyon, Eastern Samar within one year.



Appendix Table 1

List of coral restoration publications, their location, duration, restoration type, number of species, coral growth, coral survival, and cost per colony restored or re-attached

Ref #	Author and Year	Country	Site	Duration (months)	Restoration type	No. of species	Species Code	Mean Monthly % Growth rate	% Survival	Cost per Coral fragment or colony (USD)
1	(Cabaitan et al. 2015)	Philippines	Bolinao	12	Direct transplant	4	13,32,75,86	15	7-95	
2	(Dela Cruz et al. 2015)	Philippines	Bolinao	12	Gardening	2	9,17	2-6	8-20	
3	(Griffin et al. 2015)	US	Virgin Islands	4	Direct transplant	1	45	35	98	
4	(Griffin et al. 2015)	Puerto Rico	Tallaboa	48	Direct transplant	1	45	2		
5	(Lohr et al. 2015)	Cayman Islands	Cayman Islands	3	Gardening	1	45			
6	(Dela Cruz et al. 2014)	Philippines	Bolinao	19	Direct transplant	2	55,63	47-67	68-69	0.37[a,b]
7	(Gomez et al. 2014)	Philippines	Bolinao	20	Direct transplant	1	32	91	80-98	
8	(Ng and Chou 2014)	Singapore	Singapore	5	Gardening	2	26,28	21-50	64-97	
9	(Romatzki 2014)	Indonesia	North Sulawesi	9	Electric field	2	63,66	1-6	47-100	
10	(Tortolero-Langarica et al. 2014)	Mexico	Bahía de Banderas	12	Direct transplant	3	88,89,90	10-11	75-99	
11	(Ngai et al. 2013)	Vietnam	Co To Archipelago	12	Direct transplant	10	68,70,71, 72, 73,85, 87,93,97, 99	0-1	0-100	11
12	(Boch and Morse 2012)	Palau	Palau	12	Direct transplant	1	47	64	47-81	12
13	(Garrison and Ward 2012)	US	Virgin Islands	60	Direct transplant	1	59	4	9	13
14	(Griffin et al. 2012)	Puerto Rico	Caribbean	12	Gardening	1	45	99	96	14
15	(Bongiorni et al. 2011)	Singapore	Singapore	12	Nubbins from spawn	11	13,54,56, 64,67,74, 81,89,93, 95,96	0-8	34	
16	(Guest et al. 2011)	Philippines	Bolinao	12	Direct transplant	1	81	7	10-70	
17	(Nakamura et al. 2011)	Japan	Okinotori-shima	14	Nubbins from spawn	1	5	37	60	9.46a, b,c,d
18	(Borell et al. 2010)	Indonesia	North Sulawesi	5	Electric field	2	63,66	7-21	65-100	

Appendix Table 1

List of coral restoration publications, their location, duration, restoration type, number of species, coral growth, coral survival, and cost per colony restored or re-attached (Cont'n.)

Ref #	Author and Year	Country	Site	Duration (months)	Restoration type	No. of species	Species Code	Mean Monthly % Growth rate	% Survival	Cost per Coral fragment or colony (USD)
19	(Ferse 2010)	Indonesia	North Sulawesi	24	Gardening	4	57,66,76,90		5-33	0.08[a]
20	(Mbije et al. 2010)	Tanzania	Zanzibar	9	Gardening	5	32,51,52, 58,90	26-59	56-100	0.11
21	(Shafir and Rinkevich 2010)	Israel	Eilat	60	Gardening	3	60,89,98	36-59	50-95	
22	(Shaish et al. 2010)	Philippines	Bolinao	24	Gardening	8	9,17,40,51, 74,80,81,89	5-20	20-100	
23	(Garrison and Ward 2008)	US	Virgin Islands	60	Direct transplant	3	45,59,94		25	21.00[a,b,c]
24	(Shaish et al. 2008)	Philippines	Bolinao	4	Gardening	7	9,17,40,51, 80,81,89	6-22	30-98	0.24[a]
25	(Raymundo et al. 2007)	Philippines	Negros Oriental	10	Recruitment				64	
26	(Forsman et al. 2006)	US	Hawaii	10	Gardening	2	35,91		48-100	
27	(Shafir et al. 2006)	Israel	Eilat	5	Gardening	3	50,60,64	47-56	60-90	
28	(Soong and Chen 2003)	Taiwan	Henchun	4	Gardening	1	63	17		
29	(Bowden-Kerby 2001)	Puerto Rico	La Parguera reef system	12	Direct transplant	2	45,61	14-18		
30	(Bruckner and Bruckner 2001)	Puerto Rico	Mona Island	24	Direct transplant	1	59	14	69	673.13a, b,c,d,e
31	(Ammar et al. 2000)	Egypt	Red Sea	6-12	Direct transplant	6	52,53,65, 69,89,98		8-93	
32	(Nagelkerken et al. 2000)	Curacao	Caribbean	4	Direct transplant	1	78	1	39	
33	(Rinkevich 2000)	Israel	Red Sea	12	Gardening	1	98	0-5	50-89	
34	(Clark 1998)	Maldives	High energy reef flat	28	Direct transplant	9	35,39,46, 48,53,54, 90,92,93		50-80	
35	(Clark and Edwards 1994)	Maldives	Galu Falhu	8	Direct transplant	6	39,46,53, 54,90,93		62-77	
36	(Yap et al. 1992) Island	Philippines	Cangaluyan	18	Direct transplant	3	54,86,89	0-10	0-100	
37	(Harriot and Fisk 1988)[f]	Great Britain		5-7	Direct transplant	2	32,89		75	

Appendix Table 1

List of coral restoration publications, their location, duration, restoration type, number of species, coral growth, coral survival, and cost per colony restored or re-attached (Cont'n.)

Ref #	Author and Year	Country	Site	Duration (months)	Restoration type	No. of species	Species Code	Mean Monthly % Growth rate	% Survival	Cost per Coral fragment or colony (USD)
38	(Plucer-Rosario and Randall 1987)[f]	Guam			Direct transplant	4	27,49,77,83		0-100	
39	(Auberson 1982)[f]	Philippines		12	Direct transplant	6	12,18,44,62, 79,82		44-100	
40	(Birkeland et al. 1979)[f]	Guam		2-10	Nubbins from spawn	1	32		0-47	
41	(Maragos 1974)[f]	Hawaii			Direct transplant	2	84,91		6-71	

Items included in the estimated cost per fragments:
[a] Materials (e.g., cable ties, nails, PVC, etc).
[b] Logistic cost: transportation, accommodation
[c] SCUBA cost: gear rental, oxygen tank
[d] Technology cost (e.g., spawning corals and growing larvae)
[e] Other unspecified costs
[f] Taken from (Harriot and Fisk 1988) review paper, but cannot trace or access the original source of data.

Appendix Table 2

List of coral species re-attached (1) in Eastern Samar (Species code 1-43) and (2) in other areas as reported in literature (Species code 44-99). Also presented are the mean monthly growth rates (%) (1) observed in Samar, (2) reported in literature, and (3) the difference between Samar and literature growth rates whenever available. Highlighted in bold are species with ≥3 re-attached colonies.

Species Code	Species	Family	Mean initial coral size in cm^2 ± SE (n)	E. Samar Mean Monthly % Growth rate ± SE	Literature Mean Monthly % Growth rate ± SE (n)	Differences
1	*Acropora aculeus*	Acroporidae				
2	*Acropora cerealis*	Acroporidae	52.6 (1)	2.4		
3	*Acropora latistella*	Acroporidae	23.6 (1)	40.6		
4	*Acropora parilis*	Acroporidae	28.7 ± 12 (2)	17.8 ± 1.3		
5	*Acropora tenuis*	Acroporidae	18.4 (1)	24.7	37.3 (1)	-12.6
6	***Cyphastrea decadia***	**Faviidae**	**37.2 ± 2 (4)**	**15.8 ± 7.1**		
7	*Cyphastrea microphthalma*	Faviidae				
8	***Echinopora horrida***	**Faviidae**	**36.1 ± 4 (14)**	**9.3 ± 3.2**		
9	*Echinopora lamellosa*	Faviidae	10.2 ± 1 (2)	21.9 ± 11.0	15.1 ± 4.8 (3)	+6.8
10	*Echinopora mammiformis*	Faviidae	27.2 ± 5 (2)	1.9 ± 0.5		
11	***Echinopora pacificus***	**Faviidae**	**17.9 ± 4 (7)**	**16.3 ± 3.3**		
12	***Heliopora coerulea***	**Helioporidae**	**49.0 ± 7 (5)**	**8.7 ± 2.6**		
13	***Hydnophora rigida***	**Merulinidae**	**34.1 ± 7 (3)**	**10.5 ± 4.9**		
14	*Lithophylon undulatum*	Fungiidae	27.9 (1)	13.9		
15	*Lobophyllia hemprichii*	Mussidae				
16	***Merulina ampliata***	**Merulinidae**	**16.4 ± 2 (3)**	**10.1 ± 5.9**		
17	*Merulina scabricula*	Merulinidae	8.9 (1)	19.7	4.7 ± 1.4 (3)	+15.0
18	*Millepora platyphylla*	Milleporidae				
19	***Millepora tenella***	**Milleporidae**	**19.9 ± 6 (16)**	**23.0 ± 13.0**		
20	***Montipora grisea***	**Acroporidae**	**15.9 ± 6 (3)**	**13.4 ± 5.4**		
21	*Montipora hirsuta*	Acroporidae	11.4 (1)	62.6		
22	*Montipora tuberculosa*	Acroporidae	7.0 ± 1 (2)	37.1 ± 17.8		
23	*Mycedium lacera*	Pectiniidae				
24	*Oxypora glabra*	Pectiniidae	6.5 (1)	1.0		
25	*Pachyseris foliosa*	Agariciidae	15.1 (1)	26.5		
26	***Pachyseris speciosa***	**Agariciidae**	**16.7 ± 3 (9)**	**24.1 ± 4.6**	**21.1 (1)**	**+3.0**
27	***Pavona cactus***	**Agariciidae**	**29.3 ± 6 (12)**	**7.9 ± 1.6**	**0.4 (1)**	**+7.5**
28	*Pectinia paenioa*	Pectiniidae	29.2 ± 8 (2)	2.5 ± 1.4	50.3 (1)	-47.8
29	***Porites annae***	**Poritiidae**	**27.9 ± 9 (5)**	**11.6 ± 3.2**		
30	***Porites attenuata***	**Poritiidae**	**31.3 ± 5 (20)**	**11.8 ± 5.1**		
31	*Porites cocosensis*	Poritiidae	**17.8** ± 1 (2)	16.0 ± 15.3		
32	***Porites cylindrica***	**Poritiidae**	**26.1 ± 1 (137)**	**9.4 ± 1.1**	**55.1 ± 22.3 (3)**	**-45.7**
33	***Porites deformis***	**Poritiidae**	**20.2 ± 5 (15)**	**12.8 ± 4.0**		
34	*Porites latistella*	Poritiidae				
35	*Porites lobata*	Poritiidae	22.7 ± 1 (2)	3.1 ± 1.4	0.2 (1)	+2.9
36	*Porites monticulosa*	Poritiidae				
37	***Porites napopora***	**Poritiidae**	**26.6 ± 5 (8)**	**9.8 ± 4.0**		
38	*Porites negrosensis*	Poritiidae	**13.8** ± 4 (2)	6.8 ± 0.5		
39	*Porites nigrescens*	Poritiidae	14.2 (1)	1.6		
40	***Porites rus***	**Poritiidae**	**17.3 ± 4 (3)**	**7.3 ± 3.5**	**15.6 ± 1.5 (2)**	**-8.3**
41	*Porites tuberculosa*	Poritiidae	34.0 ± 0 (2)	1.2 ± 1.1		
42	*Psammocora contigua*	Siderastidae				
43	*Turbinaria irregularis*	Dendrophyliidae				
44	*Acropora brueggemani*	Acroporidae				
45	*Acropora cervicornis*	Acroporidae			30.7 ± 18.3 (5)	
46	*Acropora cyatherea*	Acroporidae				
47	*Acropora digitifera*	Acroporidae			64.2 (1)	
48	*Acropora divaricata*	Acroporidae				
49	*Acropora echinata*	Acroporidae			1.2 (1)	
50	*Acropora eurystoma*	Acroporidae			47.2 (1)	

Appendix Table 2

List of coral species re-attached (1) in Eastern Samar (Species code 1-43) and (2) in other areas as reported in literature (Species code 44-99). Also presented are the mean monthly growth rates (%) (1) observed in Samar, (2) reported in literature, and (3) the difference between Samar and literature growth rates whenever available. Highlighted in bold are species with ≥3 re-attached colonies. (Cont'n.)

Species Code	Species	Family	Mean initial coral size in cm^2 ± SE (n)	E. Samar Mean Monthly % Growth rate ± SE	Literature Mean Monthly % Growth rate ± SE (n)	Differences
51	*Acropora formosa*	Acroporidae			21.2 ± 15.0 (2)	
52	*Acropora hemprichii*	Acroporidae			30.6 (1)	
53	*Acropora humilis*	Acroporidae				
54	*Acropora hyacinthus*	Acroporidae			3.8 ± 1.2 (2)	
55	*Acropora intermedia*	Acroporidae			46.7 (1)	
56	*Acropora millepora*	Acroporidae			2.72 (1)	
57	*Acropora muricata*	Acroporidae				
58	*Acropora nasuta*	Acroporidae			26.0 (1)	
59	*Acropora palmata*	Acroporidae			8.8 ± 4.9 (2)	
60	*Acropora pharaonis*	Acroporidae			45.9 ± 9.9 (2)	
61	*Acropora prolifera*	Acroporidae			14.2 (1)	
62	*Acropora prominens*	Acroporidae				
63	*Acropora pulchra*	Acroporidae			23.1 ± 14.9 (4)	
64	*Acropora valida*	Acroporidae			26.6 ± 23.5 (2)	
65	*Acropora verweyi*	Acroporidae				
66	*Acropora yongei*	Acroporidae			13.6 ± 7.9 (2)	
67	*Diploastrea heliopora*	Faviidae			0.02 (1)	
68	*Echinophyllia aspera*	Pectiniidae			1.2 (1)	
69	*Favia stelligera*	Mussidae				
70	*Galaxea fascicularis*	Oculinidae			1.1 (1)	
71	*Goniastrea favulus*	Faviidae			0.6 (1)	
72	*Goniopora columna*	Poritiidae			1.1 (1)	
73	*Goniopora lobata*	Poritiidae			0.01 (1)	
74	*Heliopora coerulea*	Helioporidae			3.0 (1)	
75	*Hydnophora rigida*	Merulinidae				
76	*Isopora brueggemani*	Acroporidae				
77	*Leptoseris gardineri*	Agariciidae			1.1 (1)	
78	*Madracis mirabilis*	Astrocoeniidae			0.9 (1)	
79	*Millepora dichotoma*	Milleporidae				
80	*Montipora aequituberculata*	Acroporidae			2.3 (1)	
81	*Montipora digitata*	Acroporidae			9.4 ± 1.8 (3)	
82	*Montipora prolifera*	Acroporidae				
83	*Montipora pulcherrina*	Acroporidae			0.7 (1)	
84	*Montipora verrucosa*	Acroporidae				
85	*Pavona decussata*	Agariciidae			0.6 (1)	
86	*Pavona frondifera*	Agariciidae			10.0 (1)	
87	*Plesiatrea versipora*	Faviidae			0.5 (1)	
88	*Pocillopora capitata*	Pocilloporidae			10.2 (1)	
89	*Pocillopora damicornis*	Pocilloporidae			20.0 ± 10.2 (5)	
90	*Pocillopora verrucosa*	Pocilloporidae			20.3 ± 9.6 (2)	
91	*Porites compressa*	Poritiidae			0.2 (1)	
92	*Porites lichen*	Poritiidae				
93	*Porites lutea*	Poritiidae			0.2 ± 0.2 (2)	
94	*Porites porites*	Poritiidae				
95	*Porites sillimaniana*	Poritiidae			4.1 (1)	
96	*Psammocora digitata*	Siderastreidae			0.01 (1)	
97	*Pseudosiderastrea tayami*	Siderastreidae			0.01 (1)	
98	*Stylophora pistillata*	Pocilloporidae			21.5 ± 19.4 (2)	
99	*Turbinaria peltata*	Dendrophyliidae			0.5 (1)	