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Should coral fragments collected for restoration be subdivided to create more, smaller pieces for transplanting?

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Should coral fragments collected for restoration be subdivided to create more, smaller pieces for transplanting?

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Widespread coral declines have created a need for their restoration (Gardner et al. 2003, Schutte et al. 2010). Various approaches to coral restoration have been tested, including the propagation of coral fragments in nurseries, raising larvae in the laboratory, and encouraging coral growth with electric currents (Rinkevich 2005, Precht 2006, Williams and Miller 2010). We focused on the simplest approach, the direct transplanting of coral fragments broken from parent colonies by storms, boat groundings, or diver contact.

We studied *Acropora palmata* (the elkhorn coral) because it was formerly the dominant reef-building coral on shallow wave-exposed Caribbean reefs, but has declined dramatically since the 1980s (Precht et al. 2004). Direct transplanting of fragments has been used by researchers and practitioners to restore *A. palmata* to reefs where it has disappeared or become rare (Bowden-Kerby 2001, Bruckner and Bruckner 2001, Garrison and Ward 2008, Krumholz et al. 2010, Williams and Miller 2010, Forrester 2011).

We addressed a simple practical question: when fragments are collected for transplanting, should they be left intact or further divided to produce a greater number of smaller fragments? Fewer, larger fragments might be better if larger colonies grow and survive better than smaller ones, perhaps because they have more combined resources and so are more capable of recovering from damage (Hughes 1984). Alternatively, dividing a coral fragment into several smaller pieces might increase the chance fragments will survive (Cook 1979) by spreading the risk of mortality from disease, predation, or localized disturbances. The act of cutting or splitting fragments might, however, have a negative effect by either damaging tissue or by exposing the coral's underlying calcium carbonate skeleton. Exposed areas might become infected, or colonized by predators that bore into the skeleton (Rogers et al. 1982, Soong and Chen 2003). The net effect on colony growth and survival will thus depend on the relative effects of subdivision per se, and of reducing fragment size.

The restoration site was a shallow reef (0.4-1.6m deep) near Guana Island (18°29'N, 64°35'W) in the British Virgin Islands. *A. palmata* was formerly abundant at this site, based on personal observations by locals and the presence of skeletal remains, but has been absent for over 20 years.

We collected 110 fragments for restoration in August 2011 from two nearby source sites, Harris Ghut and Great Camanoe. Snorkelers collected all fragments encountered, so the size distribution of fragments reflects that available. Fragments ranged from 6 – 1041 cm^2 in surface area (mean ± SD = 233 ± 240 cm^2). Corals were placed in plastic bins filled with seawater in a small boat and transported immediately to White Bay.

The 110 fragments were paired by size. One fragment in each pair was split into 2-5 pieces underwater using a hammer and chisel (experimental) whereas the other was left intact (control). Most experimental fragments were divided into 2 (n = 35) or 3 (n = 14) pieces, but a few were split into 4 or 5 (n = 6) pieces unintentionally. The 55 control fragments and 138 experimental pieces of coral were attached individually to projections on the reef using nylon cable ties. Each paired control:experimental group was placed close together (spaced 0.3 - 4.5 m apart), and a numbered tag was fixed near each coral so they could be tracked individually.

We tested the effect of subdivision by comparing the probability of survival and the colony growth of the controls to the overall probability of survival and the combined growth of their sub-divided counterparts. The size of each coral colony was measured as the surface area of live tissue, which is a good measure of body size for corals that grow over a surface as a single layer of clonal modules (polyps). Colony surface area was estimated using image analysis software (ImageJ) from digital photographs taken with a ruler in the frame for scale (Figure 1) (Bythell et al. 2001, Abramoff et al. 2004).

The site was revisited after 3 months and 12 months to check for survivors. Surface area of each survivor was also measured at 3 and 12 months. Because corals are modular organisms and a colony is a collection of genetically identical polyps, change in colony size reflects the net gain (via asexual reproduction) or loss (via mortality) of polyps. We thus used the percent change in surface area as a composite measure that captures colony growth (positive change), partial mortality (negative change), or complete mortality (change of -100%). We report only the results after 12 months, because treatment effects were qualitatively identical after 3 and 12 months.

The potential benefits of subdivision are illustrated by a simple model for survival, if a coral's probability of death (d) is constant and independent, when we break a fragment into n pieces the chance of at least one piece will survive is $1-d^n$ (Smith and Hughes 1999). For our control fragments, $d = 1-0.82 = 0.18$ (Table 1), and we broke the experimental fragments into $n = 2.5$ pieces on average. Under this model, the expected probability of survival for subdivided fragments = $1-0.18^{2.5} = 0.99$, which is significantly higher than the observed survival (0.78) (Yates corrected $\text{Chi}^2 = 220.2$, $df = 1$, $p = 0.0001$). In fact, the survival of the experimental fragments (they were considered to have survived if one or more piece remained alive) and control fragments was not distinguishable (Table 1; Fisher's exact test, $p = 0.812$).

When the 138 pieces of the experimental fragments were tabulated separately, they showed significantly poorer survival than the 55 intact control fragments (Table 1; Fisher's exact test, $p = 0.024$). To better isolate why subdivided pieces survived poorly, we performed a logistic regression to separate the effects of coral size (measured after the experimental fragments were split) and experimental treatment on survival (a binary variable: casualty or survivor). For this analysis, experimental pieces were analyzed independently (i.e. n=138 experimental pieces and n = 55 controls). The regression revealed that smaller pieces were more likely to die than larger ones (Wald z-test, z = -3.45, $p = 0.001$) but subdivided pieces were no more likely to die than controls, after controlling for the effect of size (Wald z-test, z = -0.64, $p = 0.522$).

When we calculated the percent change in surface area of the original fragments (for experimental fragments we summed the surface area of surviving pieces), control fragments increased in area after 12 months by roughly twice as much as subdivided fragments (Figure 2). A 2-way analysis of variance confirmed that the effect of subdividing corals was statistically significant ($F_{1,55} = 4.59$, $p = 0.037$), after accounting for differences among size-matched pairs of control and experimental corals ($F_{54,55} = 2.02$, $p = 0.005$).

Overall, the net effect of subdividing transplanted corals hinges on the extent to which the potential costs of reduced colony size and harmful effects of being divided are offset by potential benefits arising from spreading the risk of damage and mortality. Relative to controls, subdivided fragments experienced reduced colony growth and no increase in survival, showing that the net costs of subdividing *A. palmata* fragments outweighed any benefits. Previous studies of *A. palmata* reported lower survival of small colonies than larger ones (Garrison and Ward 2008, Forrester 2011), and size-dependent survival appears to have contributed to the net cost of subdivision we observed. Independent of the influence of colony size, there was also a direct cost of subdividing the fragments that was manifest as reduced colony growth. Although transplanted corals can exhibit measureable transplant shock (Yap et al. 1992), *A. palmata* appears reasonably robust to careful handling and transport (Garrison and Ward 2008, Forrester 2011, Forrester G.E. et al. in press). Branching corals, including acroporids, have been pruned and split in several restoration studies (Yap et al. 1992, Epstein et al. 2001, Soong and Chen 2003, Shafir et al. 2004, Forsman et al. 2006) but, in our study, splitting the *A. palmata* fragments caused a measureable reduction in growth.

Directly transplanting storm-generated *A. palmata* fragments is a simple, cheap restoration method that can be incorporated into educational programs as a way to combine conservation with increased awareness of environmental issues (Forrester 2011). For the size-range of fragments available at our sites, when transplants are spaced a few metres apart, we suggest that volunteers collecting fragments to transplant should leave them intact, rather than splitting them into smaller pieces. Further work is, however, needed to establish how well our findings extrapolate to different situations. Three factors particularly likely to alter the net effects of subdivision are: (1) spacing - subdividing to spread mortality risk might be more effective if fragments were spread more widely (e.g. 10s or 100s of meters apart) across sites with different biological and physical regimes, (2) morphology – the act of splitting colonies may be less harmful for finely branched species that can be easily pruned with cutters than for more robust species like *A. palmata*, (3) environment – we observed poor survival of small fragments on the reef but small size might not be a disadvantage in sheltered in-situ nurseries with few predators and limited environmental stress (Soong and Chen 2003).

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Table 1. Survival of transplanted *A. palmata* fragments after 12 months. Experimental fragments were subdivided into 2-5 pieces before transplanting, whereas controls were left intact. Survival is tabulated in two ways: (a) for the original fragments, in which case the experimental fragments were considered to have survived if one or more piece remained alive, and (b) after subdividing the experimental fragments, where each piece of an experimental fragment is tabulated separately.

	Experimental	Control
a) Original fragments (before subdivision)		
Initial number	55	55
Number surviving	43	45
Proportion surviving	0.78	0.82
b) Final fragments (after subdivision)		
Initial number	138	55
Number surviving	90	45
Proportion surviving	0.65	0.82

Figure captions

Figure 1. A control *A. palmata* fragment shown in photographs taken when it was initially attached and then 12 months later (Scale bars are both 10 cm).

Figure 2. Colony growth (measured as average percent change in surface area) of coral fragments 12 months after transplanting (mean ± SE).

Figure 1.

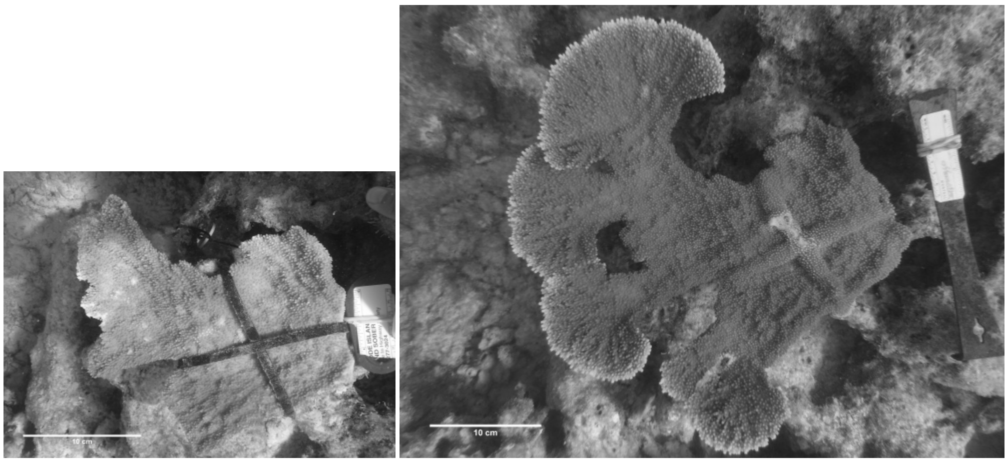
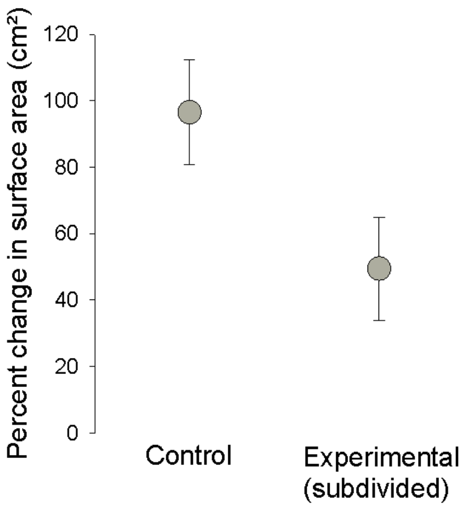


Figure 2.


Percent change in surface area (cm²)
120
100
80
60
40
20
0
Control
Experimental
(subdivided)