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Effects of substratum on the growth and survivorship of *Montipora capitata* and *Porites lobata* transplants

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ABSTRACT

Artificial transplantation of corals is a common method used to restore damaged or unhealthy coral assemblages. Though a number of studies have successfully transplanted coral fragments, there is no general consensus on the type of substratum to be used. The present study focused on the growth and survivorship of *Montipora capitata* (rice coral) and *Porites lobata* (lobe coral) fragments, which were transplanted onto different natural and synthetic substrata. No significant differences in coenosarc tissue growth or survivorship were observed between the species. Measurements after 184 days of growth, found transplant growth to be significantly higher on rhyolite breccia and amorphous coral skeletons than on black ʻAʻā lava. Nevertheless, no significant differences were observed between any of the other substrata. After 365 days of growth, survivorship was also observed to not be significantly different between substrata; with the only exception of being lower on glass substratum. It is hypothesized that success in a coral reef restoration project is largely determined by the actual coral fragmentation and transplantation process; as no distinct substratum affinity was observed for *M. capitata* and *P. lobata* transplants.

1. Introduction

Coral reef deterioration has been reported worldwide (Birkeland 2004). The observed degradation in coral assemblages is a result of natural causes, anthropogenic effects, or a combination of the two. In terms of natural causes, extreme atmospheric disturbances can dramatically alter the structure of the assemblage by destroying large sections of the reef in a short period of time (Foster et al. 2011; Osborne et al. 2011). Large spikes in ultra violet radiation can also have a negative impact on coral assemblages, by directly damaging the DNA of zooxanthellae and corals (Anderson et al. 2001). Excessive solar radiation also raises the ambient temperature of the water, which frequently leads to the mortality of planulae (Aranda et al. 2011) and the expulsion of zooxanthellae in colonies (i.e. bleaching) (Lough and van Oppen 2009). In addition to damage caused by solar radiation, different forms of infection can also have a dramatic impact. Bacterial, fungal, or protozoan infections can lead to rapid tissue deterioration of colonies, which depending on the virulence of the pathogen, can also lead to significant deterioration of the whole community (Aeby et al. 2011).

In terms of anthropogenic effects, terrestrial runoff is one of the most detrimental effects. Terrestrial runoff, which can be a result of urbanization or changes in land use, often leads to sedimentation (Lee et al. 2006). Sedimentation leads to an increase in turbidity, which inhibits photosynthesis rates of zooxanthellae (Hunte and Wittenberg 1992). Furthermore, high levels of sedimentation can directly abrade and smother coral tissues (Jordan et al. 2010). This often leads to increased energy expenditure of the corals, which is a result of mucous production and using ciliary action to clear the sediment. In addition to causing sedimentation, anthropogenic pollutants and terrestrial runoff can also lead to hypernutrification (Jessen et al. 2014). This often leads to inhibited coral growth that is the result of an imbalance in the exchange of nutrients between the zooxanthellae and the host coral (Dubinsky and Stambler 1996). Hypernutrification also reduces light penetration due to nutrient-stimulated phytoplankton growth, which also reduces photosynthesis rates of corals (Woodward 2013). Most importantly, hypernutrification also brings about a proliferation of seaweeds; which rapidly outgrow, smother, and eventually replace the slower growing corals (Vermeij et al. 2010). The effects of hypernutrification on algal growth are further magnified, when there is a decline in herbivores due to overfishing (Stuhldreier et al. 2015). Due to all of these negative natural and anthropogenic factors, the slow natural-recovery process, and the high socio-economic value of coral reefs, various kinds of restoration efforts have been conducted.

Contemporary restoration efforts can be broadly classified as the artificial recruitment or artificial transplantation of corals (Ferse et al. 2013). Artificial recruitment of corals is promoted by planting an artificial object into a reef environment. This artificial object acts as a suitable substratum for the settlement, metamorphosis, and growth of planulae (Babcock and Mundy 1996; Petersen et al. 2005). Using a wide-range of

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methods, the artificial recruitment rate and survivorship of planulae have been studied on a number of natural (Norström et al. 2007) and synthetic substrata (Creed and De Paula 2007; Segal et al. 2012). Nevertheless, the results of these previous studies have shown a lot of variability in the rates of recruitment, density, and survival of planulae on different substrata (Harriott and Fisk 1987). Due to the large variability in results, there does not appear to be a general consensus on a substratum to be used for the artificial recruitment of corals.

In the process of coral transplantation, a donor colony is first fragmented into smaller pieces. The resulting fragments are then artificially transplanted onto either a natural or synthetic substratum, and then moved into a suitable location in the marine environment for further growth (Edwards and Clark 1999). In previous studies, coral fragments have been transplanted onto substrata that can be commonly found in the reef environment, such as pieces of rubble (Tunnicliffe 1981; Smith and Hughes 1999), consolidated rock (Bowden-Kerby 2001), sand (Bowden-Kerby 2001), and dead coral colonies (Bruckner and Bruckner 2001; Yap 2004). A few studies have transplanted corals onto natural substrata that are less commonly found in the reef environment, such as the valves of dead *Tridacna* spp. (Cabaitan et al. 2008; Guest et al. 2011). Other studies have transplanted corals onto synthetic substrata such as concrete (Okubo et al. 2005; Herlan & Lirman 2008; Ferse 2010), cultured marble (Schlacher et al. 2007), steel (Romatzki 2014), and plastic (Shafir et al. 2006). In addition, a number of studies have even managed to grow fragments by suspending them in the water column, using wires instead of a solid substratum (Lindahl 2003; Soong and Chen 2003). Though a lot of previous studies have successfully managed to transplant juvenile corals, the survivorship of transplants was seen to be variable among the different substratum (Table 1). As with substrata used for artificial recruitment, there does not appear to be a general consensus on a substratum to be used for the artificial transplantation of corals. This is due to the observed variability in the survivorship and growth of juvenile corals, which are important criteria in the evaluation of restoration efforts (Guest et al. 2011).

The purpose of this study is to evaluate the growth of coenosarc tissue and survivorship of *Porites lobata* and *Montipora capitata* fragments transplanted onto a range of natural and synthetic substrata. These two species were chosen because they are morphologically quite distinct; where *M. capitata* has a branched morphology, while *P. lobata* has a massive morphology. The growth of coenosarc tissue was measured, to determine if a substratum is favored for growth by either species; since the coenosarc is the polyp's dermal tissue that connects it to the substratum and other polyps (Fig. 1), which tends to deteriorate if conditions for growth are poor (Mortensen 2001). The survivorship of transplants was also evaluated (Oren and Benayahu 1997), to determine whether any substratum is more favorable for survival than another. If transplants of a particular species exhibit a positive change in coenosarc tissue area (>50%), and have a high proportion of transplants surviving (>50%), then it will be deemed that the coral transplants have an affinity for the substratum type (i.e. substratum affinity); and that substratum will be deemed suitable for use in future coral assemblage restoration efforts.

2. Methods

2.1. Study site

The study was carried out in the coral nursery of Ānuenue Fisheries Research Center, Honolulu, Hawai'i. This facility housed large circular tanks (12,000 L) that were built with a flow-through system, in which untreated seawater was pumped from the adjacent water body (Honolulu Harbor) into the tanks. Though using untreated seawater posed the risk of importing contaminants, the facility continued to operate using a flow-through system; as healthy coral colonies were observed growing just a few meters away from the intake pipe of the tanks. Water

Table 1
Species of scleractinian corals which have previously been transplanted onto unusual substrata. Survivorship was calculated by dividing the total number of transplants still alive at the end of all of the studies (deceased and missing transplants were excluded), by the total number of fragments generated at the start of all of the studies. Values for survivorship, duration, and number of transplants are expressed as the mean and standard deviation of the combined relevant studies.

Substrate	Survivorship	Duration (days)	Number of Transplants	Species	Source
Galvanized steel (charged)	0.80	310	749	*Acropora pulchra, A. yongei*	Romatzki (2014)
Tridacna sp. valves	0.73	234	700	*Acropora digitata, A. hyacinthus, A. muricata, Echinopora lamellosa, Heliopora coerulea, Hydnophora rigida, Montipora digitata, Pavona frondifera, Pocillopora damicornis, Porites cylindrica, P. lutea, P. nigriscens, P. rus*	Guest et al. (2011)
Marble	0.68	85	146	*Acropora solitaryensis*	Schlacher et al. (2007)
Consolidated rock	0.65 ± 0.13	548 ± 258	360 ± 81	*Acropora palmata*	Bruckner and Bruckner (2001); Forrester et al. (2013)
Cement	0.63 ± 0.21	441 ± 319	1467 ± 2634	*Acropora cervicornis, A. divaricata, A. formosa, A. hyacinthus, A. humilis, A. muricata, A. solitaryensis, A. yongei, Favia* sp., *Favites* sp., *Isopora brueggemanni, Pocillopora verrucosa, Porites lobata, P. lutea, P. nigrescens*	Edwards and Clark (1999); Okubo et al. (2005); Schlacher et al. (2007); Herlan & Lirman (2008); Ferse (2010)
Plastic	0.51 ± 0.35	346 ± 285	3152 ± 4287	*Acropora eurystoma, A. pharaonis, A. valida, Pocillopora damicornis, Porites cylindrica, P. rus, Stylophora pistillata*	Yap and Molina (2003); Shafir et al. (2006)
Wire (suspended)	0.40 ± 0.43	283 ± 141	177 ± 162	*Acropora cervicornis, A. prolifera, A. muricata, A. pulchra, A. vaughani*	Bowden-Kerby (2001); Lindahl (2003); Soong and Chen (2003)
Rubble	0.39 ± 0.24	302 ± 169	607 ± 605	*Acropora cervicornis, A. hyacinthus, A. intermedia, A. millepora, A. palmata, A. prolifera, Agaricia agaricites, Dichocoenia stokesii, Meandrina* sp., *Montastrea annularis, M. cavernosa, Pachyseris speciosa, Pectinia paeonia, Porites astreoides, P. porites*	Highsmith et al. (1980); Tunnicliffe (1981); Smith and Hughes (1999); Bowden-Kerby (2001); Ng and Chou (2014)
Galvanized steel (uncharged)	0.39 ± 0.29	298 ± 195	136 ± 122	*Acropora pulchra, A. yongei, Porites cylindrica, P. frondifera, P. rus*	Yap (2004); Dizon and Yap (2006); Romatzki (2014)
Scleractinians (dead)	0.28 ± 0.29	884 ± 874	122 ± 146	*Acropora cervicornis, A. palmata, Porites. cylindrica, P. porites, P. rus*	Bruckner and Bruckner (2001); Yap (2004); Garrison and Ward (2008)
Glass	0.24	459	120	*Porites cylindrica, P. rus*	Yap et al. (1998)
Scleractinians (live)	0.23	98	17	*Porites cylindrica, P. rus*	Yap (2004)
Sand	0.00	365	48	*Acropora cervicornis, A. prolifera*	Bowden-Kerby (2001)