Electro-Mineral Accretion Assisted Coral Growth: An Aquarium Environment.

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Abstract

Scleractinian corals play a key role in the development of coral reef substrate. With increasing pressures being placed on these ecosystems, there is more focus being payed to artificial reef applications. One technique known as Electro-mineral accretion could help the development of artificial reefs or the recovery of damaged coral reefs. The technique uses the principles of a galvanic cell where an electric current is passed from an anode to a cathode causing the precipitation of aragonite (limestone). There is some evidence to suggest that corals grown with the assistance of this technique potentially show increasing growth and recovery rates. To investigate the effects of this technique coral nubbins from two *Acropora* species were collected from Magnetic Island, Australia and transplanted onto control and electro-mineral treated platforms in Reef HQ Aquarium. Growth rates were established over a three-month period using wet weight measurements. Electro-mineral treated platforms were found to have a twenty six percent increase in growth rate than the control platforms.

Introduction

Background
Coral reefs and their associated communities are facing many adversities in this day an age. Many of the worlds reef systems have increasing pressures inflicted on them, some of which are anthropogenic. These include, but are not limited to, bleaching (possible related to global warming), sedimentation (linked to deforestation), over fishing and associated destructive methods such as dynamiting, species-specific fishing and pollution (e.g. from sewage or oil spills). Coral reefs endure natural hardships such as cyclonic weather (breakages), natural salinity and temperature fluctuations (bleaching), wave action, crown of thorn outbreaks and plagues (disease) to name a few. Although many organisms face similar problems, emphasis on conserving our ecosystems is increasingly in the spot light. The reasoning behind this strong focus may partly be related to the slow growth rate and associated long recovery time of corals and whole reef systems, in particular scleractinian corals.

Although corals can grow to a very large size and reach old ages, only a few grow at a rate which one would consider substantial. For example, several *Acropora* species that can grow at rates of 10-15 centimetres per year, however; almost no other coral grows that fast and some like the massive *Porites* only grow at a rate of nine millimetres a year (Veron 1986). With this in mind and in conjunction with present pressures on our reefs, it is no wonder many of the world's leading conservation representatives voice concern over the future health of coral reef systems.

With most research aimed at understanding and recording the natural progression of our reef ecosystems and their associated communities, there is a need for studies in human assisted regeneration and restoration of damaged coral reef systems. A coral reef system that has lost much of its structure cannot only affect the diverse array of organisms, which are directly and indirectly connected to it, but it can also negatively influence socio economics within a country or even expose whole islands to destructive oceanic processes. For example, in the Maldives, coral mining over a twenty-year period has eroded the natural barrier of the islands, which protect them from waves and ocean surges, not to mention the damage caused to the ecosystem itself (Edwards and Clark 1995). Recovery is mostly very slow and in some severe cases unrecoverable (Pearson 1981; Treeck and Schuhmacher 1997).

In several countries around the world, the technique of EMA is used with the expectation to increase the growth rate and recovery of stressed scleractinian corals in localised areas. This technique is applied on artificial reefs using electrolysis and coral transplants. A German Architect/Marine Scientist, Professor Wolf H. Hilbertz first developed the technique in 1974 and since 1988 he and coral ecologist, Dr Thomas J. Goreau, have researched and developed the technique with a focus on coral propagation, reef restoration and mariculture (http://www.biorock.net/Technologies/index.html).

EMA technique description

The company developed by these men, called 'Biorock', now sells this technique. The process follows the principles of a galvanic cell. An electrical current (direct current) is passed from an anode to a cathode using seawater as the electrolyte. An oxidation-reduction reaction occurs with electrons flowing between the electrodes, in turn adjusting the microenvironment surrounding each electrode. Seawater is generally at a pH of 8.0, however; the reaction changes the pH of surrounding water (microenvironment) at each electrode (Hilbertz 1992). The water surrounding the Anode becomes more acidic and produces gaseous chlorine (Cl_2) and oxygen (0_2). The cathode on the other hand becomes more alkaline resulting in the precipitation of calcium carbonate ($CaCO_3$) and magnesium hydroxide ($Mg(OH)_2$) (Hilbertz 1992). The accreted material is chemically similar to reef limestone (Meyer and Schuhmacher 1993). As a result, the cathode becomes covered with accretion.

This then hardens after the current is disconnected for several hours. (Schuhmacher and Schillak 1994, Schuhmacher et al 2000, Van Treeck and Schuhmacher 1998).

Various theories regarding increased coral growth and recovery using EMA speculate on how this process is actually achieved (Sabater and Yap 2002). However, little work has been done to prove the physical mechanisms by which corals might utilise the EMA effects. One theory suggests that the increased availability of calcium ions in the water surrounding the cathode may facilitate coral calcification (Sabater and Yap 2002). Sabater and Yap (2004) describe how a concentration gradient of calcium ions drives the influx of calcium ions into the coelenteron of coral polyps before being taken to the calicoblastic epithelium where the process of calcification begins. Therefore an increase in the concentration of mineral ions provided by EMA could increase growth, reducing the time needed for coral reefs to recover and also allowing improved attachment (lower fragment losses) (Sabater and Yap 2002).

As described before, EMA increases the pH of the microenvironment surrounding the cathode. In one study, Millepora dichotoma was subjected to increased pH and experienced enhanced calcification (Marubini and Atkinson 1999). In contrast, Porites *compressa* was subject to lowered pH and experienced a decrease in calcification (Marubini and Atkinson 1999).

From a theoretical perspective, the EMA technique does seem offer some potential influences on coral growth. Whilst some research does indicate this technique increases growth and recovery, there is little documentation of direct comparables in contrast against controls. In fact one project found a slight increase in growth for treated colonies compared to untreated (although no significant difference) but naturally growing colonies grew better than both of them (Sabater and Yap 2002).

Implications of technique

Coral nurseries and aquariums could possibly utilise this technology should the process prove viable. Coral nurseries for example can grow and transfer coral fragments to suitable sites where and when needed. An increase in production would obviously be an attractive investment. Aquariums would equally appreciate the ability to grow coral fragments or whole colonies at an increased rate with less chance of mortality. It is here also that the observation on such a technique could be scrutinised and developed whilst minimising any ailments that may negatively influence or prejudice the outcome.

Scope of study

The aim of this project was to utilise previous studies and attempts to grow coral fragments using EMA, and produce a study that directly compares treatments (EMA) to precise controls with the intention of discovering whether EMA does in fact increase coral growth. The research was

undertaken within Reef HQ's main coral reef aquarium where all replicates were exposed to the same conditions.

Other aims of this project also include:

- Improving the experimental design
- Determining which species can be successfully transplanted
- Establishing accretion rates on the cathode
- Estimating a cost for continued operation of EMA in a tank environment.

Method

Collection site and collection technique

Magnetic Island is located off the coast of Northern Queensland Australia, adjacent to the city of Townsville. The island lies approximately eight kilometres north of Townsville and is a typical in-shore fringing reef island. The collection site at Nelly Bay (S19° 09.894' E146° 51.175') is situated on the windward side of Magnetic Island. Collection of the coral nubbins took place on the 13th September 2005 at 1100am with a low tide of 0.8 meters at 1130am. All nubbins were collected from a depth of approximately 2-3 meters and within a twenty-metre radius of each other. Two species were selected:

- *Acropora microphthalma*
- *Acropora muricata*

Access to the collection site was by small boat (The Stinger), with scuba diving used for actual collection. The two different species of Acropora colonies were identified and nubbins were broken off both species with side cutters. Nubbins were broken off colonies at points that still left several branches for each nubbin and had an average size of 4-5cm. This increases survival rates after their removal compared to small single branch nubbins (Soong and Chen 2003). All nubbins were collected from one large colony for each species to reduce any genetic variation that may be seen when collecting from numerous colonies. Nubbins were stored on collection trays whilst under water which were then transferred to nally bins aboard the boat. Transfer from colonies in the field to refuge tank at the aquarium took approximately three hours.

Experimental set-up

The experiment was carried out in the Coral Reef Exhibit (CRE) situated at Reef HQ Aquarium, Townsville. Research was conducted between September 30th and December 30th 2005. The CRE is one of the largest living coral reef exhibits and holds 2 500 000 litres of water and is four metres deep. This experiment was conducted (four metres) with the site directly beneath the wave machine cavity with several circulators also directed towards the site to maintain water flow. Furthermore, the coral reef aquarium at Reef HQ should provide ideal conditions for this experiment because generally high water

temperatures and salinity (which occur during the summer months) support accretion (Treeck and Schuhmacher 1997).

Fixation of nubbins on platform

Nubbins were acclimated in refuge tanks at the aquarium for one week where, there after they were fixed to growing platforms within the CRE. Four growing platforms were made to maximise light, flow and minimise predation. First, PVC frames were constructed with holes drilled in them to counteract buoyancy. To increase rigidity and stability, plastic eggshell material was used to construct four levels on each platform. This material also allowed sufficient water flow around and under each coral nubbin. One millimetre gauge by five millimetre square galvanised wire covered the entire platform. Any areas of the wire that were not used for growing was then cut out to reduce the surface area of each platform. The galvanised wire acted as cathodes for the treatment platforms. On each platform level, alternating coral species were mounted with five nubbins per level and therefore 10 nubbins of each species per platform. The mounting incorporated a two-part epoxy to adhere the nubbins to the frames ensuring physical contact of each nubbin to the metal galvanised wire. There were therefore two sets of nubbins (two treatment platforms) exposed to current and two other nubbin sets (two control platforms) with no current. The two

Accretion measurement

Each nubbin was taken out of the refuge, shaken to liberate excess water and then weighed with digital scales before being mounted on the growing platforms in the water. Extraction of nubbins after three months included prising nubbins from the epoxy, liberating excess water and taking the final weight. Previous studies such as Sabater and Yap (2004) have used longitudinal measurements for growth but after preliminary testing it was decided that these measurements were not particularly accurate as the nubbins did not grow straight up but in fact twisted and grew in all different directions.

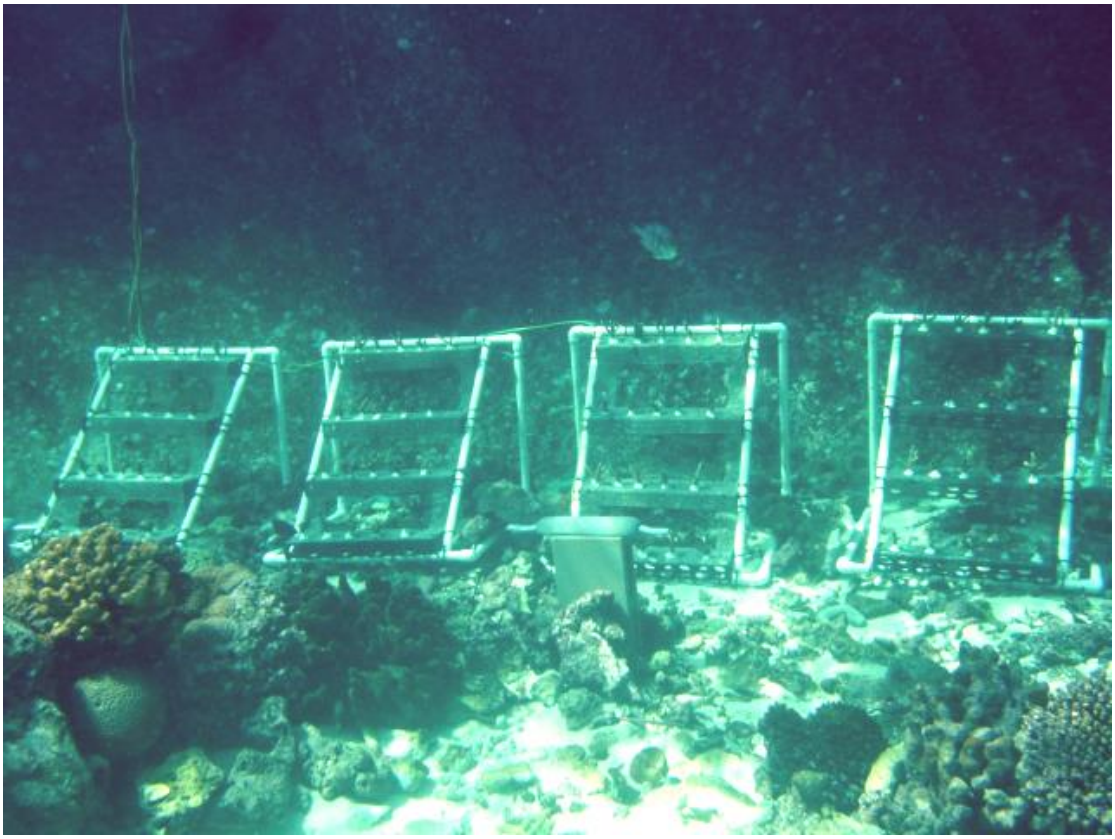

Figure 1. Arrangement of platforms without enclosure. The platforms were arranged treatment 1, control 1, treatment 2 and control 2 (looking from left to right).

A fifty-by-fifty millimetre enclosure was placed over the entire experiment. This was to eliminate predation of the nubbins by the larger fish such as Parrotfish. A PVC frame supported the mesh that was cleaned of algae once a week by scrubbing it *in situ*.

Electrical set-up

Two current regulators were used for each of the treatment platforms, which allowed a constant current of 2Amps to each treatment platforms. The power supplied to these regulators was supplied by selectable power supplies, which stepped mains power (240volts AC) down to 12volts DC. A timer was also incorporated into the circuit (fig. 2) to apply current for only 12 hours a day (during daylight hours). Four millimetres square single insulated building wire cable connected the current regulators to the treatment platforms (cable length of 10 meters) with the positive cable connected to a magnesium anodes and the negative cable to the cathode (galvanised wire) (fig. 1). All connections were compression unions using nuts and bolts to clamp the wire.

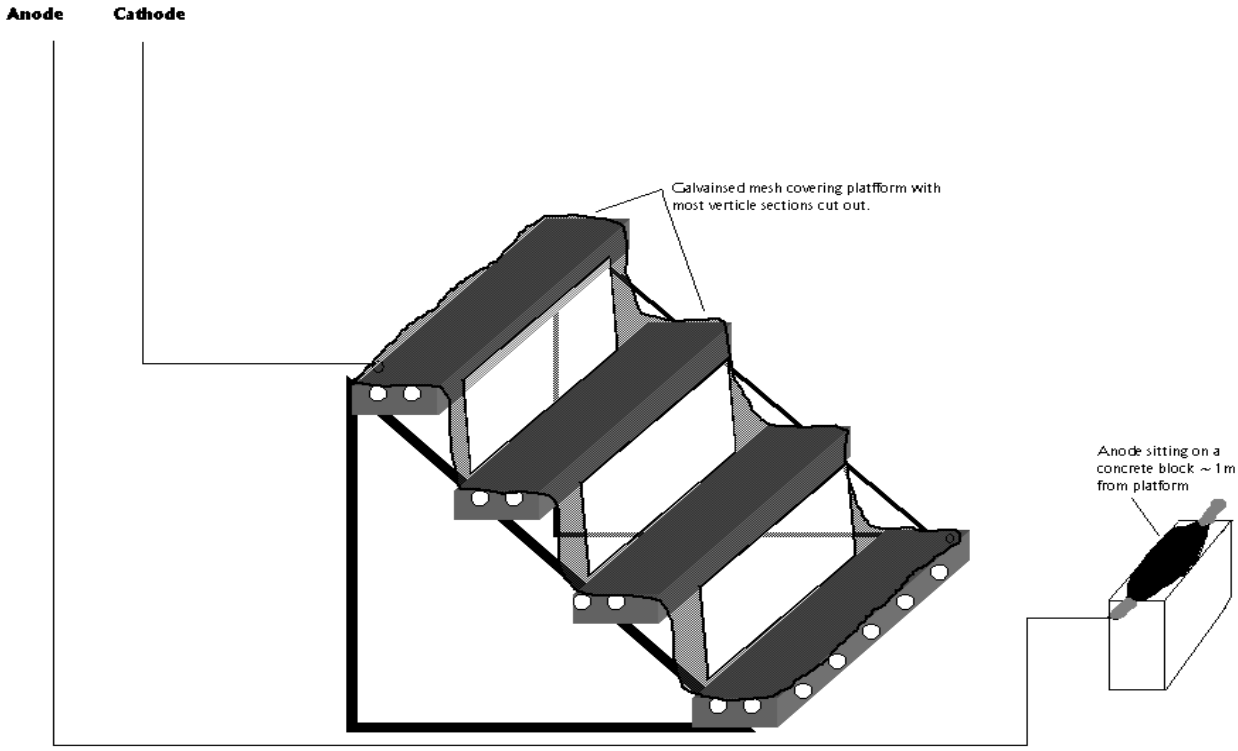

Figure 2. Diagram of platform used to mount and grow coral nubbins with plus electrical set-up of treatment platform

Figure 3. One of the treatment platforms with nubbins mounted and anode in the foreground

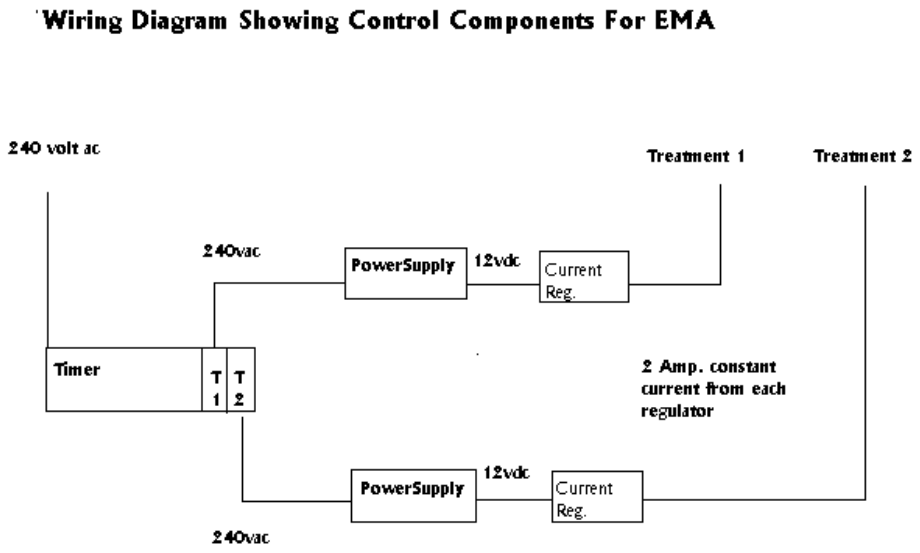

Figure 4. Electrical diagram of circuit in line with treatment platforms

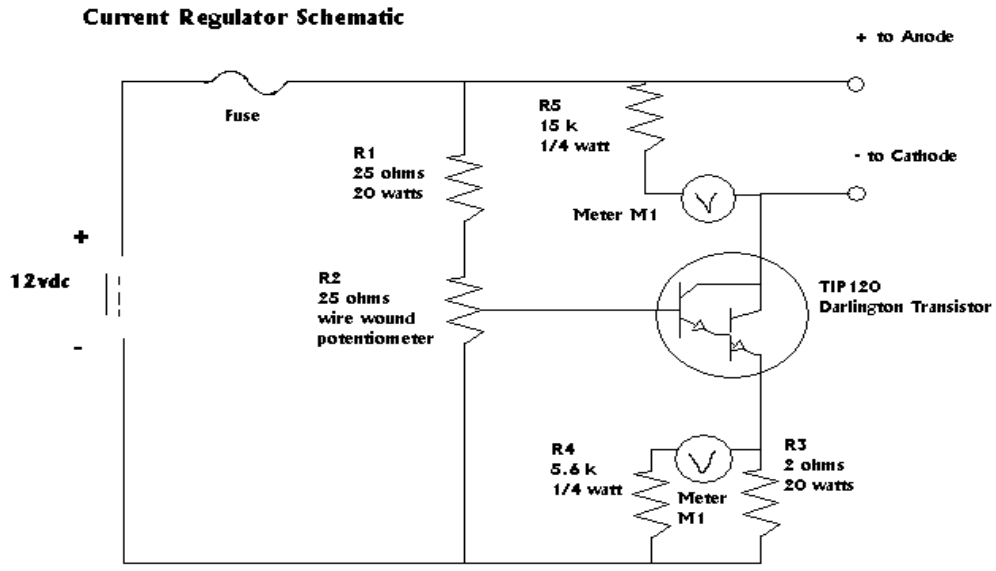

Figure 5. A circuit diagram of a current regulator similar to one used in this project.

Measurement of growth

1. Conversion of weight difference to relative growth rate of corals

The growth rate of each nubbin was calculated by converting the weight difference after 95 days into a relative growth rate according to equation 1.

$$Tf = [(T1-T0)/ T0]*100 \quad \textbf{(Eq. 1)}$$

Where:

- Tf = Growth rate in weight (percentage)
- T0 = Weight (grams) at time zero
- T1 = Weight (grams) after 95 days

Accretion measurement

2. Accretion estimation

The accretion was estimated according to equation 2. The amount of accretion on treatment platforms created by EMA (not including nubbin accretion) was estimated in g/cm^2 for each platform by cutting four equal areas of wire mesh from each platform (away from nubbin locations) before and after the project.

$$\text{Accretion} = \frac{\frac{(wf_1 + wf_2 + \ldots + wf_4) - (wi_1 + wi_2 + \ldots + wi_4)}{4}}{\text{Area}} \quad \textbf{(Eq. 2)}$$

Where:

- wf = final area weight
- wi = initial area weight

Running cost

3. Electrical cost

The cost per day is estimated according to equation (3). The costs of running this project in terms of electricity use are based on the use of mains electricity as a supply. If a solar panel and batteries were used then set up cost, maintenance and repairs would be necessary for evaluating cost.

$C=\{(V*I)/1000\}*El*P$ **(Eq. 3)**

Where:

- C = costing in cents per day
- V= Voltage (12volts)
- I = Amperage (2amps * 2amps)
- El = Cost of Kilowatts per hour (9.5 cents per kilowatt hour)
- P = Period (12 hours)

Analysis

The Nested and One-way ANOVA were produced using SPSS statistic software with significance set at ninety five percent. Assumptions were tested before carrying out Analysis of Variance.

Results

1.1 Visual comparison of growth and species resistance to transplantation.

Figures 6a and 6b are a comparison of a control rack seen over a two-month period. The 1st, 3rd and 5th nubbins from the left are *Acropora muricate*, which became partially bleached by November. There does not appear to have been any growth. *Acropora microphthalma* are the 2nd and 4th nubbins and appear to have grown considerably over this period.

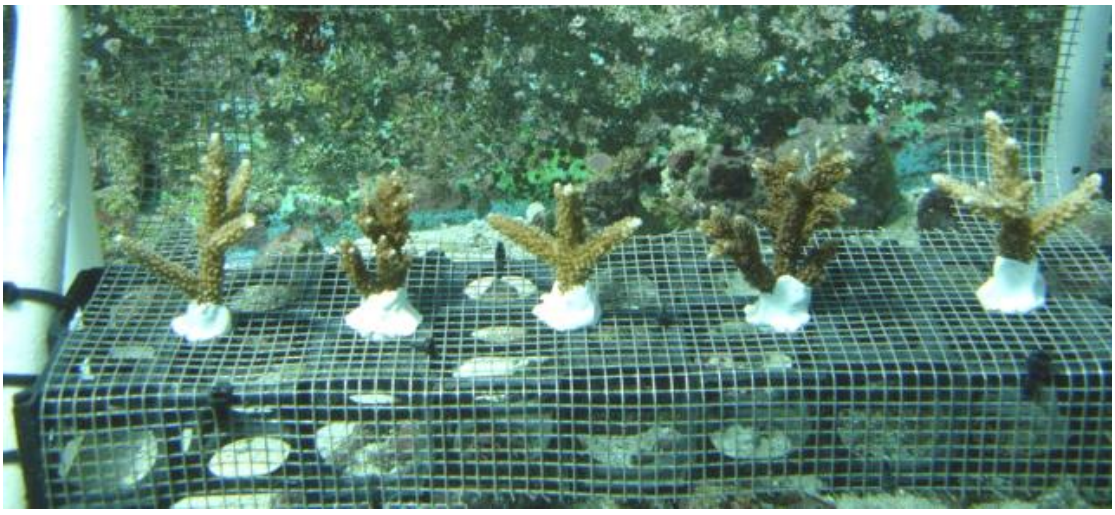

Fig. 6(a) September photo

Fig. 6(b) November photo

Figures 7(a) and 7(b) are a comparison of a treatment rack seen over a two month period. The 1st, 3rd and 5th nubbins from the left are *Acropora muricate*, which became bleached by November 2005. There does not appear to have been any growth. *Acropora microphthalma* are the 2nd and 4th nubbins and appeared to have grown considerably over this period.

Fig. 7(a) September photo

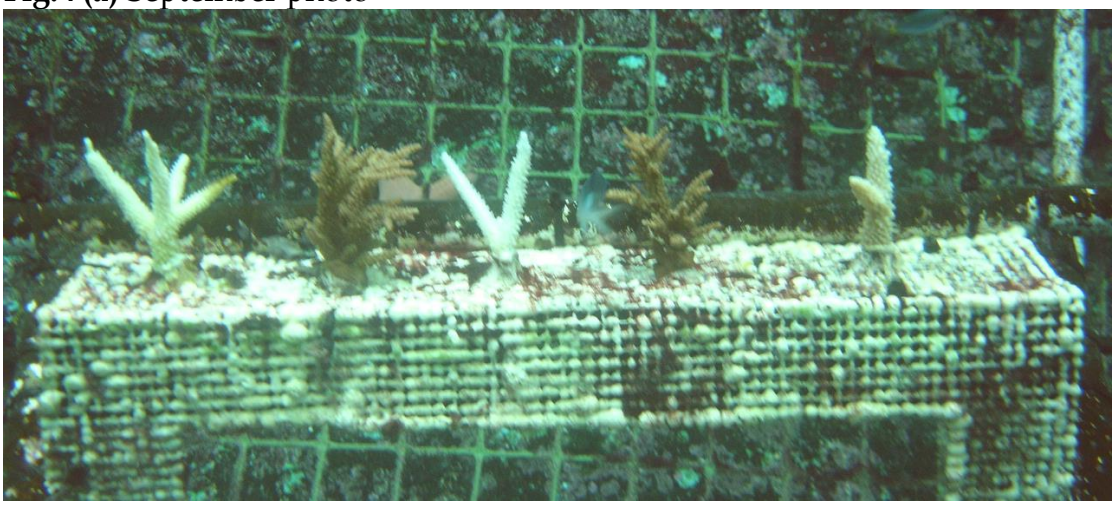

Fig. 7(b) November photo

1.2 Individual platform growth rates

Fig. 8 shows the mean relative growth rates for electro-mineral assisted platforms (treatment 1 and 2) and those platforms without assistance (control 1 and 2). The highest mean relative growth rates were treated platforms (treatment 1: 72.3 +/- 5.6%, n=10 and treatment 2: 73.7 +/- 7.8 %, n=10) followed by the control platforms (control 1: 51.9 +/- 5.0, n=10 and control 2: 42.4 +/- 3.3, n=10). The percentage growth rates for treatment were significantly higher than those of control ($p=0.03$, $df=1$, $F=28.98$) and there was no significant difference between levels on different platforms for treatment or control platforms ($p=0.49$, $df=2$, $F=0.72$)(table 1).

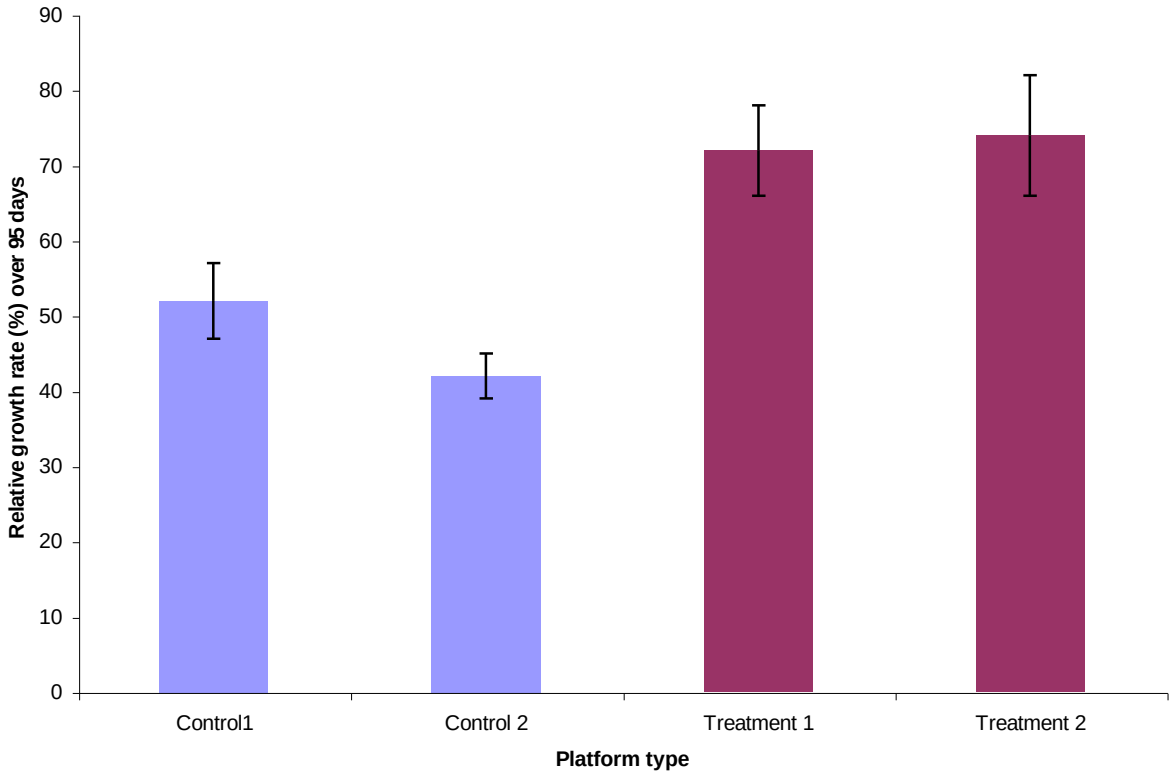

Figure 8. Acropora *microphthalma* mean (+/- S.E.) relative growth rates for both control and treatment replicates.

Table 1. Univariate nested analysis of variance comparing Acropora *microphthalma* percentage growth rates between treatment and control platforms including any difference seen between platform levels of the same or other replicate.

Tests of Between-Subjects

Dependent Variable:

Sourc		Type III of	df	Mean	F	Sig
Intercep	Hypothes	144360.2	1	144360.2	626.22	.00
	Erro	461.05	2	230.52 [a]		
Platform	Hypothes	6682.22	1	6682.22	28.98	.03
	Erro	461.05	2	230.52 [a]		
Level(Platform)	Hypothes	461.05	2	230.52	.72	.49
	Erro	11411.5	36	316.98 [b]		

1.2 Combined treatment and combined control growth rates

Fig. 9 combines both Treatment platforms and Control platforms respectively; the overall projection indicates Treatment percentage growth rate is highest (74.7 +/- 4.28, n=20) with Control percentage growth rate considerably less (47.1 +/- 3.10, n=20). This 27% (+/- S.E) increased growth rate for treatment compared to control is significantly different (Table 2; p=0.0001, df=1, F=21.4).

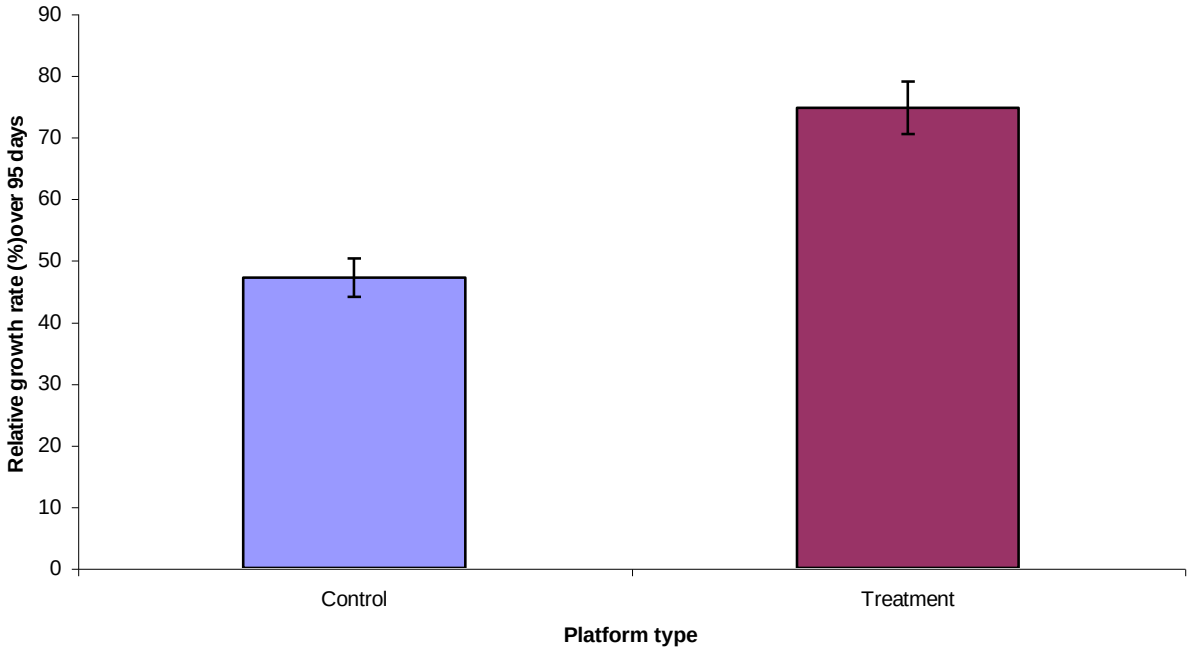

Figure 9. Acropora *microphthalma* mean (+/- S.E.) relative growth rates for combined control and combined treatment replicates.

Table 2. Results of ANOVA comparing Acropora *microphthalma* relative growth rates for combined control and combined treatment replicates.

ANOVA

control

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	6682.225	1	6682.225	21.388	.000
Within Groups	11872.550	38	312.436		
Total	18554.775	39			

2.1 Contrasting accretion data from EMA experiments and natural reef accretion

The greatest accretion recorded for the three projects conducted at Reef HQ, was Damien Eggeling (95 days @ 2 amps.) recording 5.3 g/cm^2 which was approximately double that of Fam Charko (92 days @ 1 amp.) and Fleur Lacharmoise (82 days @ I amp.), recording 3.2 g/cm^2 and 2.6 g/cm^2 respectively. Natural calcification upon Rib Reef has the highest rate overall with a conservative rate of 8.9 g/cm^2 measured over a 95 day period.

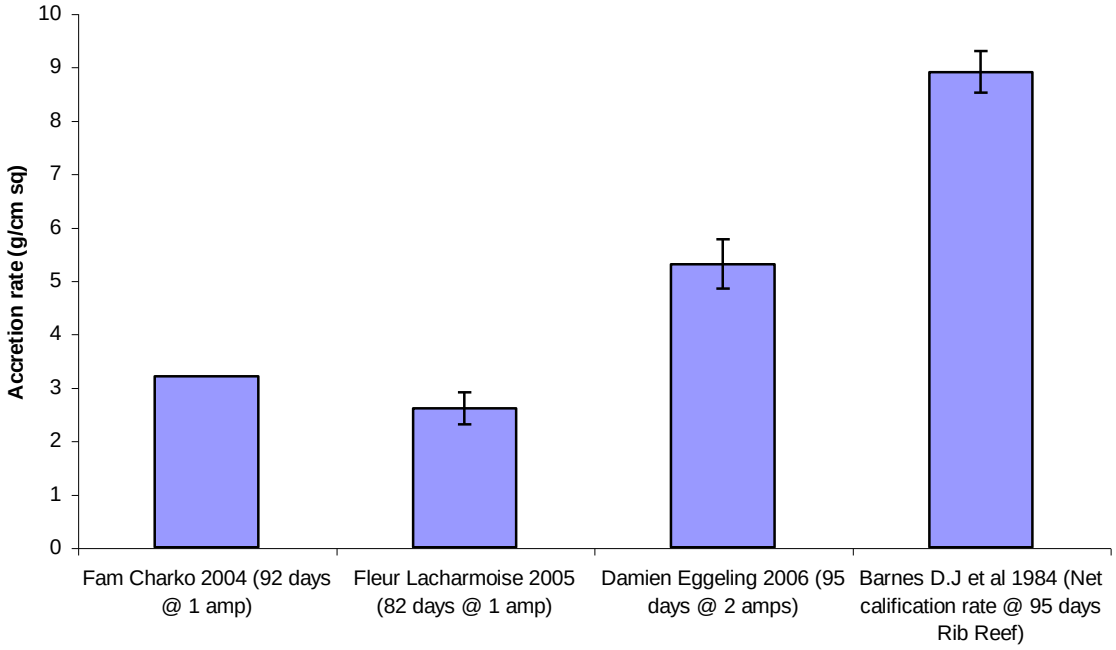

Figure 10. Comparison of mineral accretion from three different experiments at Reef HQ, including net calcification on a reef off Townsville, Australia.

Fig. 11 Accretion is clearly visible on the galvanised wire of one of the treatment platforms after 95 days

3.1 Power consumption in relation to running costs

Running cost of this project is extremely low with electricity costing between 5 and 6 cents a day using mains power. For isolated locations where main power is not available, initially cost is the set up of batteries and solar panels.

C={(V*I)/1000}*El* P
C= {(12*4)/1000}*9.5*12
C= 5.4 cents a day

Discussion

Technique development and improvement

Previous work on EMA at Reef HQ has contributed considerable information regarding issues that previously blemished results. For example establishing a mounting agent that gave sufficient support to the nubbins. Another was determining which coral species are grown successfully in the aquarium. The two Acropora species selected was not entirely a random process. *Acropora muricata* is a very dominant species found in neighbouring waters (virtually the same water as the aquarium intake water) and was therefore expected to have low mortality. Previous experiments with this species in the CRE had proven successful in terms of survival, so it was disconcerting that all the nubbins of this species experienced mortality by the second month into the experiment and had to be eliminated from the results. It was thought at one point that this mortality may be an opportunity to observe treated nubbins of this species under stress and assess if they could recover like Goreau et al (2004) and 'Biorock' claim. All nubbins of Acropora *muricata* however, from treatment and control replicates, experienced the same amount of tissue necrosis with little knowledge or understanding to what caused the mortality. Both species were collected in exactly the same spots and under the same collection procedure, so what induced one hundred percent mortality on one species whilst the other experienced one hundred percent survival is a mystery.

Enclosure

Earlier projects at Reef HQ and literature indicated that predation on coral nubbins by herbaceous fish such as parrotfish can cause extensive damage to nubbins and be responsible for negative growth. The cage developed in this experiment, which surrounded the whole experiment, protected the platforms (nubbins) from predation by fish or any other organism proving a worthwhile protective measure. Some Holothurians did enter the enclosure; however the only risk they presented was related to obstructing light whilst they manoeuvred around the nubbins or dislodging them. Inspections of the set up were assessed twice a week and infiltration by these echinoderms was rare. One problem that was evident during the hotter months was the increase of cyanobacteria covering the enclosure and platforms. If left too long (1-2 weeks) the nubbins would have incurred partial mortality by direct contact and by shading. Therefore, once a week the entire enclosure was scrubbed toremove any algae and cyanobacteria. Putting the enclosure over the entire set up meant all platforms were subjected to the same obstruction of light. Due to the large mesh size of the enclosure this obstruction was estimated to be less than five percent.

Accretion measurement

With differing results presented in various papers on the effectiveness of EMA with respect to increasing coral growth, there were no preconceptions on an outcome for this particular experiment. During the three months of observing the *Acropora microphthalma* nubbins, it was impossible to tell by visual analysis if the treatment nubbins were indeed growing faster than the controls. One study completed by Sabater and Yap (2002) found the girth growth rate of treated nubbins to be significantly greater than the control however both the treatment and control nubbins in the CRE were growing equally well around the girth. Both sets had extending growth at the nubbin base that covered the solid epoxy setting and both sets seemed visually healthy. Polyps were extended both during the day and at night.

Although buoyant weight would be the preferred method of weighing the nubbins (accounting for water saturation), the method of wet weight proved satisfactory in this study. In retrospect though, weighing the coral nubbin and epoxy (as opposed to just the nubbin) would be the preferred method as removing the epoxy for final weights was somewhat tedious. One disadvantage of using the wet weight technique was not being able to distinguish the difference in skeletal weight over time. Weight increase also included any increase of polyp flesh weight. Therefore, there is some conjecture as to what portion of increased weight is accounted for by aragonite.

Accretion rate of EMA

The findings of treatment increasing *Acropora microphthalma* nubbins growth rate by as much as twenty seven percent are considerable, especially in relation to the branching form represented by Acropora *microphthalma*. The boundary layer where calcium ions are increased, decrease away from the cathode. The margins of this layer are not well defined in any of the literature. Sabater and Yap (2002) had significant increase in girth size for treatment compared to control with no significant difference in longitudinal growth. This suggests the upper reaches of nubbins were not exposed to the boundary layer and therefore did not benefit from increased growth. Unfortunately this evidence is not very reliable because the nubbins were exposed to high levels of predation and in most cases the nubbins experienced negative growth. Increased knowledge on this boundary layer is needed and could define the types of coral form best suited for EMA assisted growth.

One other important aspect when using EMA is related to coral density. Sabater and Yap (2002) and Sabater and Yap (2004) illustrate a trend where nubbins had smaller but increased density of corallites at the basal region.

This indicates polyp division is accelerated with the mineral ion enrichment. Untreated nubbins show different patterns of corallite size and density with fewer and larger corallites at the base and smaller, denser ones at the tip. The important aspect that needs to be considered here hinges on whether this difference would make nubbins weaker and therefore more susceptible to breakage.

Accretion rates observed over the three different experiments at Reef HQ showed that accretion approximately doubled when twice as much current was applied. The problem with furthering this action is that the softer brucite begins to deposit rather than the stronger aragonite (Schuhmacher and Schillak 1994). Most of the literature agrees that low direct current voltages of somewhere between 8-12 volt dc is best with somewhere between 2-4 amps being drawn provides a strong limestone substrate accretion (Treeck and Schuhmacher 1999; Hilbertz et al 1977; Schuhmacher and Schiller 1994).

Rib reef, a typical reef system, lays down a reasonably higher quantity of calcium carbonate than EMA does, however that's not to say EMA would not be useful in appropriate situations. For instance the ability to construct near natural substrate, in small-localised areas with low costs associated, is most achievable.

Conclusion

There is evidence to support the increased growth of Acropora microphthalma using Electro-mineral accretion. This study has improved the experimental investigations of EMA in aquaculture tanks by alleviating predation, discovering an appropriate mounting substance suitable for EMA (epoxy), establishing a working electrical design and providing accelerated growth of one Acropora species. There are still some important facets of the technique, which need further study. These include but are not limited to; determining whether coral density and strength is affected, defining the boundary layer where higher calcium ions and alkalinity are present and also determining the chemical make up of accretion for varied power applications. It may be more beneficial to use different coral forms as opposed to branching coral only. For example encrusting and laminar forms may allow more of the colony to be within the margins of this boundary. Coral nurseries and aquariums could possibly gain the most from this technique, however there is definite potential for this technique to assist in the recovery of localised coral reefs in the field.

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