CRC REEF RESEARCH TECHNICAL REPORT

EXPERIMENTAL TEST OF THE EFFECTS OF METHODS OF ATTACHMENT AND HANDLING ON THE RAPID TRANSPLANTATION OF CORALS

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A report funded by the CRC Reef Research Centre.

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National Library of Australia Cataloguing-in-Publication entry

Experimental test of the effects of methods of attachment and handling on the rapid transplantation of corals

Bibliography.
ISBN 0 642 22767 5

1. Coral Rehabilitation - Australia. 2. Methods of attachment and handling. 3. Rapid transplantation. 4. Experimental test of. 5. Cost estimate. 6. Great Barrier Reef - Australia. Series: Technical Report CRC Reef Research Centre Australia; no. 1.

This publication should be cited as:
Kaly, U.L. (1995). *Experimental test of the effects of methods of attachment and handling on the rapid transplantation of corals.*
CRC Reef Research Centre
Technical Report No. 1.
Townsville; CRC Reef Research Centre,
24 pp.

Published by the Cooperative Research Centre for Ecologically Sustainable Development of the Great Barrier Reef.

Further copies may be obtained from CRC Reef Research Centre, c/- James Cook University Post Office, Townsville, QLD 4811.

Printed by James Cook University of North Queensland

Table of Contents

1. Summary

The main objective for this pilot project was to conduct an experiment and carry out surveys designed to provide a preliminary test of some of the techniques most likely to be successful for small to moderate sized coral reef restorations on the Great Barrier Reef. To do this, it was necessary to review the scientific literature on previous attempts in Australia and elsewhere so that techniques known to have little chance of success could be eliminated from the study. The field research was carried out at Lizard Island between March and July 1994.

Two methods of attachment of corals were thus examined: namely, attachment to masonry nails using cable ties and cementation directly on to bare reef substrate. These two methods were combined with an investigation (within the same experiment) of methods of handling corals prior to attachment. In a future rehabilitation, it may be necessary to gather coral fragments from locations quite far away (perhaps tens of kilometres) from the area to be restored and ship them in. Because this may involve many thousands of fragments, two methods of handling were examined. Fragments were either collected and stored for two hours in baskets in the lagoon, or were covered by a wet canvas tarpaulin and stored for the same period of time in air in a boat. Clearly for transportation purposes, the second method if successful would be the simplest and most cost-effective. All coral fragments treated in these ways were compared with controls which were branches of corals left attached to their parent colony but which were marked at the location from which they would have been severed had they been removed to provide a fragment.

All fragments and controls were monitored for growth, mortality, bleaching, numbers of tips and whether they had made an independent attachment with the substrate.

These treatments were applied to five species of corals which were chosen because they display a range of characteristics and may, therefore, provide some insights into the responses of a wider range of species present on the reef. The species examined included branching, finger-like, solid and delicately-walled tube-like forms, as well as a soft-bodied gorgonian coral (sea fan). Some of the species are considered robust and fast-growing, while others are sensitive to disturbance or relatively slow-growing.

The results of this preliminary experiment show that wholesale reintroductions of coral fragments may prove to be a useful, though expensive tool for restoring coral reef areas. Attachment by cement, although more difficult and expensive appears to be superior to the use of nails and cable ties, possibly because the cement holds fragments firmly, allowing greater opportunity for attachment and reducing the risk of abrasion against other surfaces. For most species, exposure to air for transportation was a disadvantage.

The cost of full rehabilitation with a target density of 245,000 fragments per hectare has been estimated at $580,000, plus ship time. However, replacement of 10% of the density might cost around $58,000 plus ship time, which may be a justifiable amount in a medium-scale restoration.

The results of this experiment have identified the focal issues and set the stage for future work on the development of techniques needed for the successful reconstruction of disrupted coral reef habitats. Further experiments are now being carried out on the effects of timing, source colony and other factors on the rates of success of transplantations of corals. Future research should be aimed at carrying out experimental rehabilitations to determine how effective our efforts are at accelerating the process of regeneration of damaged coral reef areas.

This study provides the industry and management with preliminary information about the efficacy of restoring coral reefs which have been damaged. This will be particularly useful in cases where a tourist site has been compromised by natural causes such as cyclone or crown-of-thorns starfish. The increasing level of tourist activity and associated infrastructure such as pontoons will mean that, in the foreseeable future, moving a pontoon to a new site following degradation at a present site will not be as appropriate as it has been in the past. Knowledge of the best methods of rehabilitation and the associated cost is, therefore, particularly relevant to industry and management.

2. Technical Report

2.1 Introduction

Research into the restoration of coral reef habitats is in its early stages despite the historic focus on impacts to these systems. Recent reviews of human impacts on coral reef and other coastal areas (e.g. Hatcher *et al*, 1989) have pointed out the necessity for developing methods of restoring coral reef habitats in areas affected by development if coastal diversity, productivity and aesthetic values are to be maintained. It is these qualities which support Australia's flourishing tourist & fishing industries centred on the Great Barrier Reef.

Although some work on the rehabilitation of coral reef habitats has been undertaken in the past (e.g. Adey, 1987; Hudson & Diaz, 1988; Guzman, 1991), most of the studies have used a "stab-in-the-dark" approach and have met with variable (and unexplained) rates of success.

The aim of this pilot study was to examine some of the methods most likely to be used in small to moderate scale rehabilitation projects on the Great Barrier Reef. Methods of transplantation of corals which were found previously to either require many resources (time, cost) or cause damage to the source communities were discarded *a priori*. Only techniques with the potential for rapid, relatively inexpensive reintroductions of corals into a damaged area were tested.

Species were chosen to represent some of the wide diversity of coral types that would have to be included in any rehabilitation. Few previous studies have tried to determine optimum techniques for transplantation of corals other than branching and massive forms.

Specifically, the study was designed to determine whether:

?? corals of a variety of types, including soft corals, branching, corymbose, encrusting, branching and massive forms can be successfully reintroduced into a damaged area;

?? any particular technique is more successful than others;

?? suitability of a technique varies with species: and

?? the survivorship and growth rate of manipulated corals is similar to that observed in naturally-occurring colonies in the same area

The main emphasis of this work is to methodically derive optimum techniques for relocation of habitat-forming species with an emphasis on cost-effectiveness and ability to place very large numbers of fragments. This work was carried out so that future research on the effects / success of rehabilitation could be undertaken

without problems of poor replacement technique. Most attempts at restoration to date have tended to ignore this step - a factor which could explain some of the mixed and unaccountable rates of success noted above.

2.2 Methods

Sites

This study was carried out at Lizard Island, Northern Great Barrier Reef, between March and July 1994. Two bommies near the mouth of Lizard Island Lagoon were used for the study as both the sources of the fragments used and the sites of attachment for the experiment. Coral fragments were transplanted only within the area in which they were originally found as any effects of translocation were not included in the scope of the design.

Experimental Design

Forty fragments around 5-10 cm in maximum dimension were collected for each of 5 species at each bommie (hereafter termed Bommie A and Bommie B). An additional 10 fragments of each species were marked *in-situ* at each bommie to serve as controls. These were branches of similar size to the fragments used in the experiment, but which were marked with plastic-coated wire at the position at which they would have been cut if they had been detached from the colony. Only colonies from which no fragments had been taken were used to provide controls.

This pilot project consists of a multifactorial experiment designed to examine the effects of:

Handling - corals were subjected to two treatments:

Exposed: corals collected and taken to the surface and stored under a wet tarpaulin for 2 hours to simulate conditions of easy collection and transport of fragments: and

Unexposed: corals collected, handled and stored in baskets underwater, but otherwise reattached without exposure to air.

Method of attachment

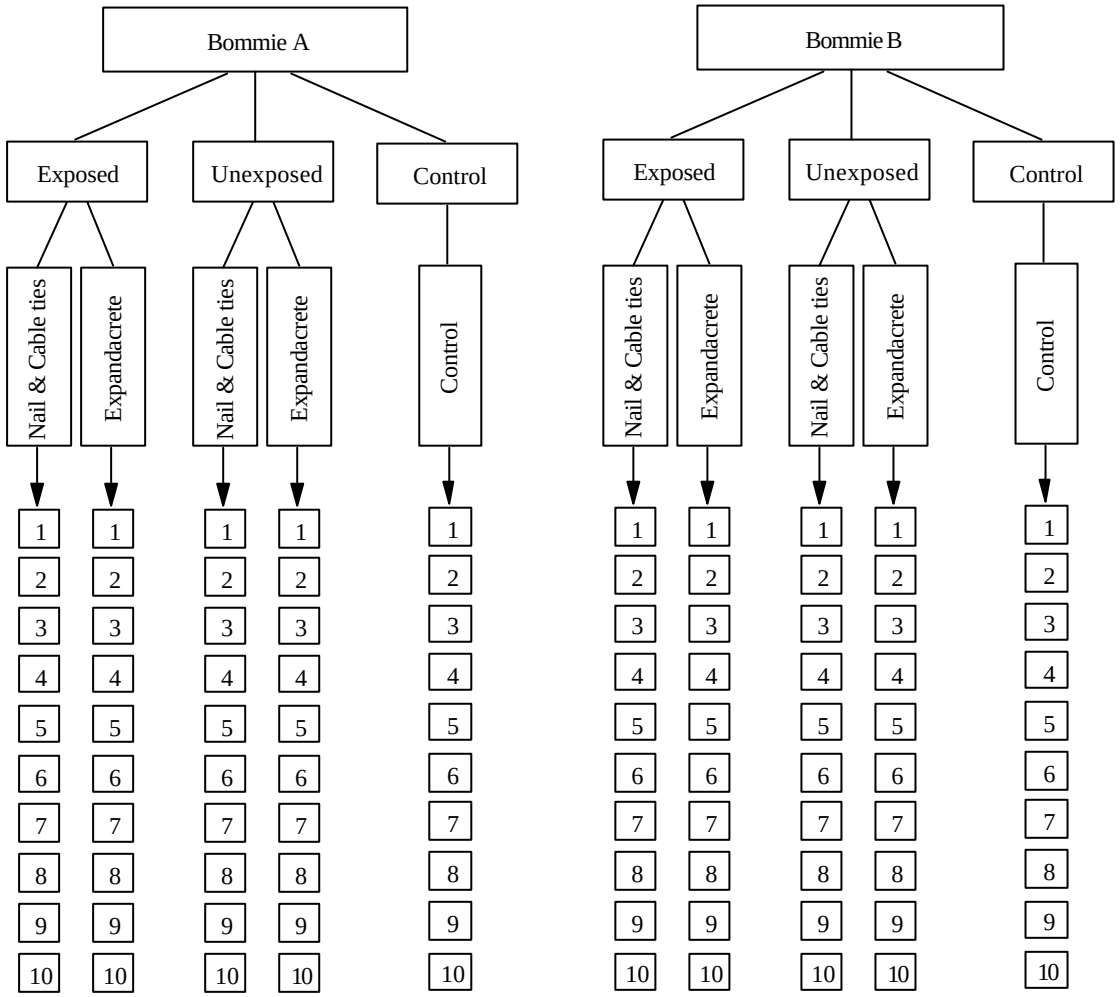
Nails & cable ties: corals attached using cable-ties to masonry nails hammered into the substratum; and

Expandacrete: corals attached to freshly drilled and chiselled holes in the substratum using an underwater epoxy cement.

This experiment was repeated on 5 species of common habitat-forming corals all subjected to each treatment combination. The species tested were:

SPECIES	ORDER/FAMILY	CHARACTERISTICS
Stylophora pistillata	Pocilloporidae	branching, relatively robust
Acropora gemmifera	Acroporidae	digitate, robust
Favia stelligera	Faviidae	massive
Echinopora lamellosa	Faviidae	plating with thin-walled upright 'tubes', delicate
Rumphella sp.	Gorgonacea	soft bodied

The design of the experiment for each species was thus:



The experiment was set up between 31 March and 13 April with initial information recorded about:

1. Time taken to attach each species for an analysis of techniques and cost of materials in order to estimate the costs of a larger scale rehabilitation;
2. Height maximum width of each fragment for 4 of the 5 species, with an additional length measurement for *Favia stelligera* which is of a more massive growth form;

3. Condition of fragments at the time of attachment, expressed as percentage partial mortality and bleaching. The percentage was estimated to the closest 10%, with an additional category at 5%;
4. Number of "ends" (tips of branches) as a measure of "branchiness" of the fragments.

A second field trip was undertaken between 12 and 22 July. On the second field trip, measurements of height, width, length, percentage partial mortality (including 100% total mortality), percentage bleaching and number of ends (tips of branches) were repeated from which the amount of change for each coral fragment/control was estimated. Change was calculated directly for partial mortality, bleaching and number of ends as that found at Time 1 subtracted from that found at Time 2. For the estimate of growth, an index was calculated from the measurements of height (H), width (W), and length (L) to represent overall growth, irrespective of its direction. That is, I was interested in any changes in size, irrespective of whether some corals grew laterally, while others grew in height. The index of change used was thus:

for *Favia stelligera*: Growth = (H2+L2+W2) - (H1+L1+W1);

for all other species: Growth = (H2+W2) - (H1+W1).

Additional information was collected at Time 2 on any losses of fragments or tags and any evidence of fragments making their own independent attachment to the substratum.

Analyses

Data on change in growth (using the above index), partial mortality, bleaching and number of ends were analysed using a 3-factor MANOVA for each species with the main effects tested being; Bommie (random), Exposure (fixed), and Attachment (fixed), followed by univariate tests for each variable. Multivariate tests on the main effects of Exposure and Attachment and the Exposure*Attachment interaction were not available due to a lack of degrees of freedom. These factors were interpreted from the univariate tests. Controls were excluded from the formal analyses, but were examined graphically.

2.3 Results

The number of tagged fragments and controls recovered at Time 2 of this study across all treatments varied between 91% and 98% among the 5 species examined. This included treatments for which corals had gone missing - an indication that the attachment had not be successful. Of the recovered corals, between 71% and 90% were alive (Appendix 6) with only 2-4% found dead in most species. *Stylophora pistillata* showed the highest rate of complete mortality at 18% of all fragments marked at the time of setup.

Stylophora pistillata

No differences in the partial mortality, amount of bleaching, growth or numbers of ends were detected for this species by the multivariate test. There was, however, a tendency, detected by the univariate tests, for greater partial mortality and a reduction in the number of ends found on fragments of this species at Bommie B, particularly in those fragments attached by nails and cable ties (figure 1, appendix 1).

There was little measurable difference in the change in partial mortality, or the number of ends in the bulk of the experimental treatments as compared with controls (figure 1). There was, however, a tendency for greater negative growth in experimental fragments than in controls. An apparent improvement in the percentage of bleaching in fragments as compared with controls was driven by an initial bleaching of *Stylophora* fragments which accompanied their transplantation. This initial bleaching did not occur in controls, and the current negative change in bleaching signals a recovery from that initial mild bleaching event that accompanied handling and attachment (figure 1).

Acropora gemmifera

A significant difference between bommies was detected in the growth of *Acropora gemmifera*, with most treatments at BommieA showing positive growth (similar to controls). The significant Bommie ? Attachment interaction detected by the MANOVA tests (appendix 2) was caused by negative growth at Bommie B, particularly in fragments attached using nails and cable ties (figure 2). There were no other clear patterns in changes in partial mortality, bleaching, growth and number of ends among treatments, and treatments appear to have behaved in a similar fashion to controls (figure 2).

Favia stelligera

No significant differences in partial mortality, bleaching or growth were detected for *Favia stelligera* by the MANOVA tests (Appendix 3). An interaction between Bommie ? Exposure was detected by the ANOVAs which suggested that unexposed fragments at Bommie B reduced in size over the period of the experiment while for those at Bommie A, all of the exposed treatments at both sites, and the controls showed no change (Figure 3, Appendix 3).

Echinopora lamellosa

A significant effect of bommies was detected in the partial mortality and growth of *Echinopora lamellosa* (figure 4, appendix 4). There was a greater increase in partial mortality at Bommie B treatments and controls than occurred at Bommie A. A similar result was obtained for growth, although for this variable, the controls at Bommie B behaved the same as most treatments and controls at Bommie A (figure 4). There is some suggestion from the graphs that the unexposed, cemented fragments at Bommie B survived and grew better

than all other treatments, but this difference did not occur at Bommie A. The univariate tests also suggested

growth varied with method of attachment in this species, with cemented fragments tending to grow approximately as fast as controls, while those attached by nails and cable ties tending to decrease in size (figure 4).

Rumphella sp.

Fragments of *Rumphella* grew significantly more ends, regardless of treatment (including controls) at Bommie A, than at Bommie B (figure 5, appendix 5). Differences in growth were also detected by the univariate tests, suggesting that growth of fragments of this species was better in cemented, unexposed treatments (at both bommies). The cemented and unexposed fragments appeared to have behaved in a similar fashion to controls (figure 5). Fragments not exposed to air and attached using nails and cable ties behaved similarly to, or perhaps worse than, fragments exposed to air regardless of method of attachment.

Attachments formed by the corals

Some individuals of 3 of the species, *Acropora gemmifera*, *Echinopora lamellosa* and *Rumphella* sp. were able to form independent attachments despite the short duration of this experiment (3.5 months) (Figure 6). A greater number of fragments were found with the beginnings of attachment, but because the corals had grown only onto cement or nails, they were considered still dependent on the artificial structures for support and excluded from these results.

The majority of the independent attachments were found in association with the epoxy cement treatment irrespective of exposure to air, especially in *Acropora gemmifera*. No fragments of *Favia stelligera* or *Stylophora pistillata* were found to have even begun any attachments by the second survey.

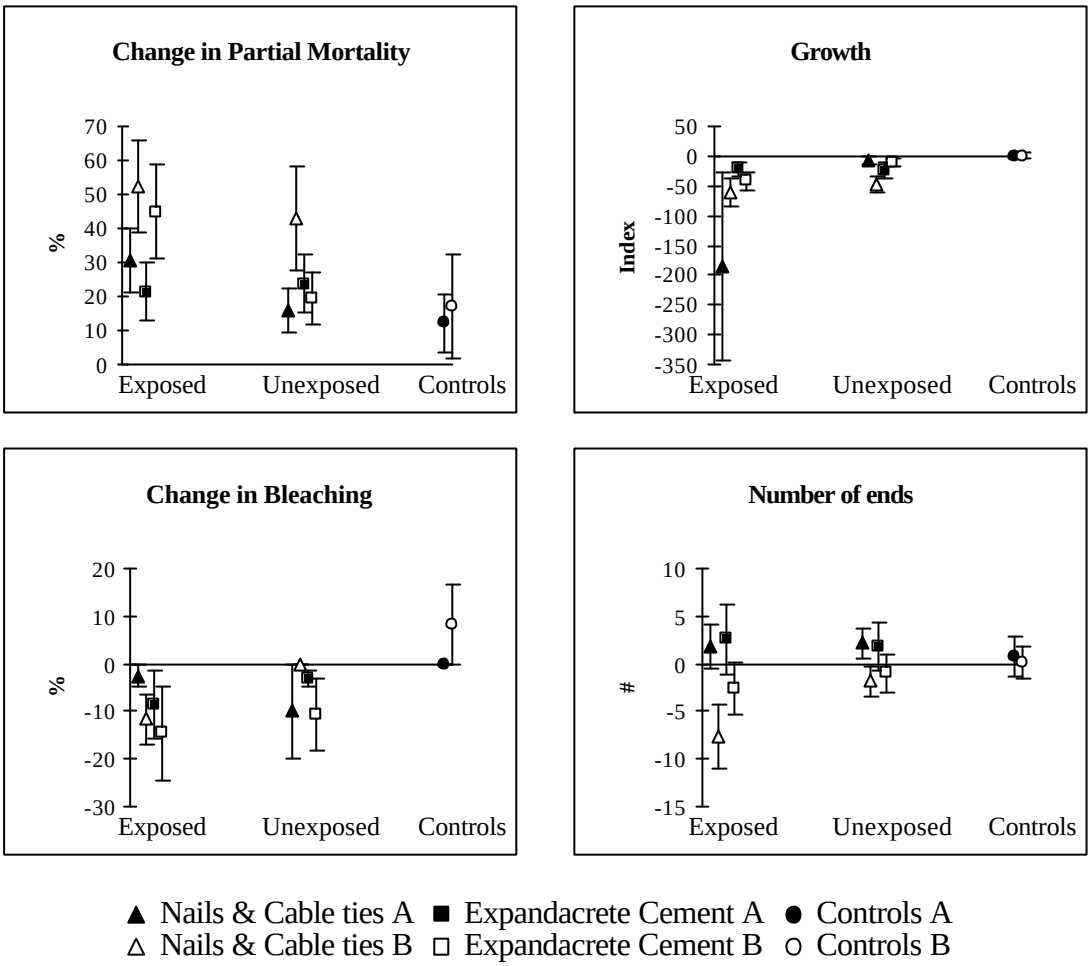


Figure 1: Changes in partial mortality, bleaching, growth and number of ends in *Stylophora pistillata.* A and B in the legend refer to bommie identification; plotted values are means +/- S.E.

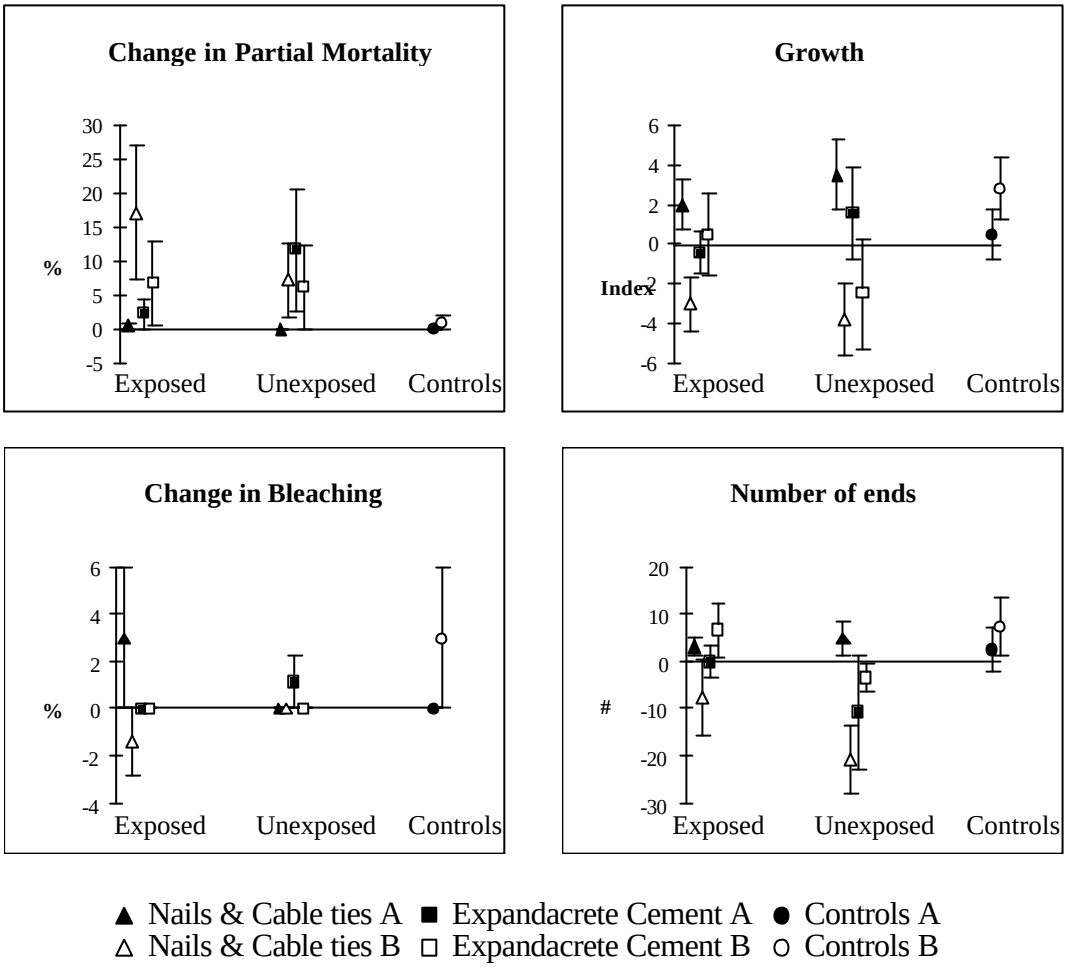


Figure 2: Changes in partial mortality, bleaching, growth and number of ends in *Acropora gemmifera*. A and B in the legend refer to bommie identification; plotted values are means +/- S.E.

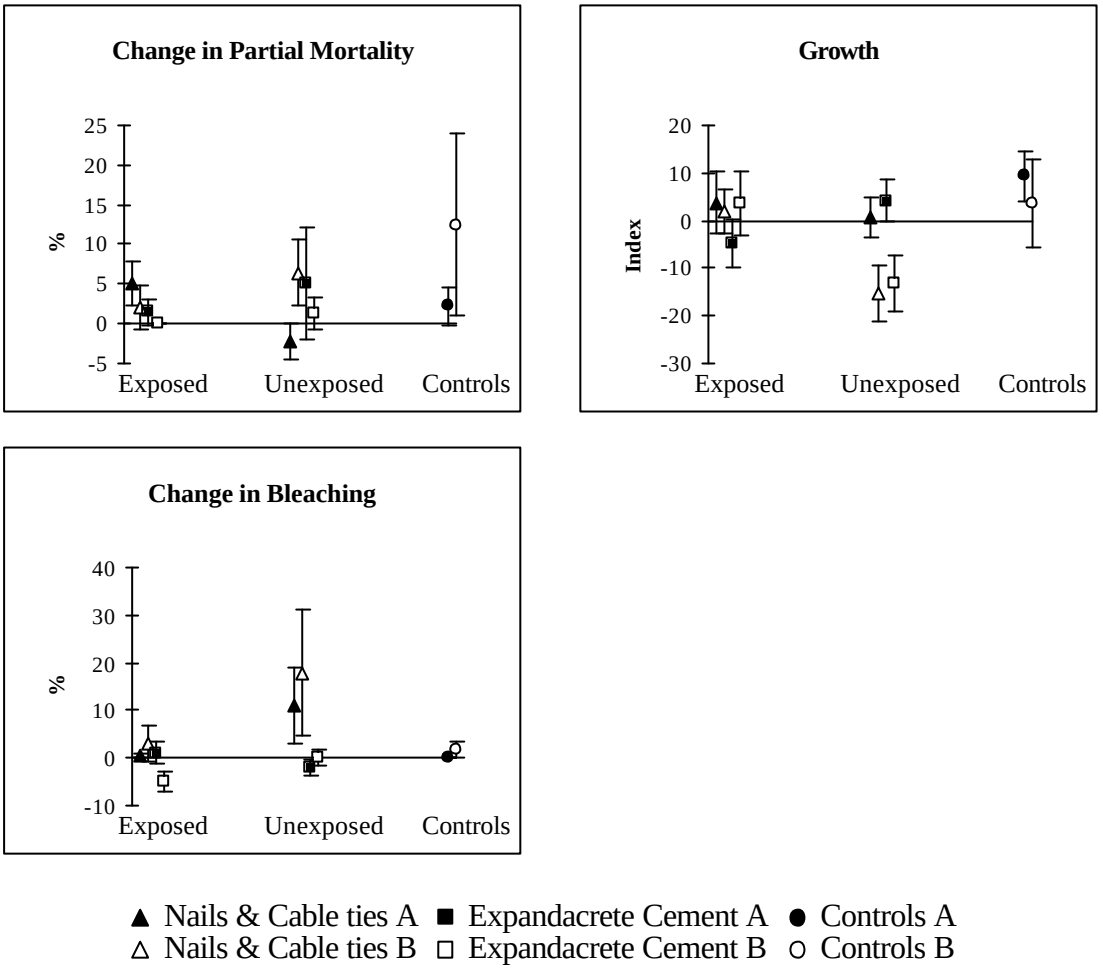


Figure 3: Changes in partial mortality, bleaching and growth in *Favia stelligera*. A and B in the legend refer to bommie identification; plotted values are means +/- S.E.

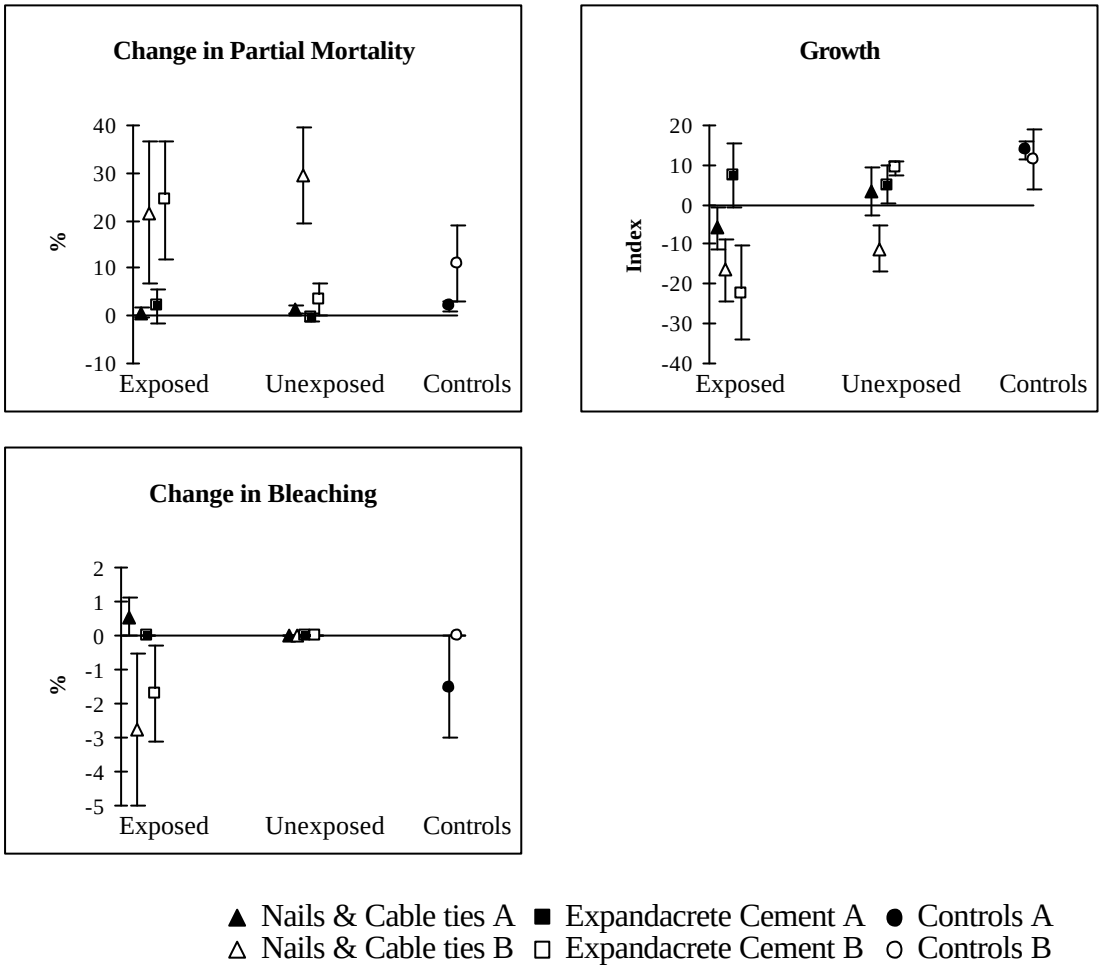


Figure 4: Changes in partial mortality, bleaching and growth in *Echinopora lamellosa*. A and B in the legend refer to bommie identification; plotted values are means +/- S.E.

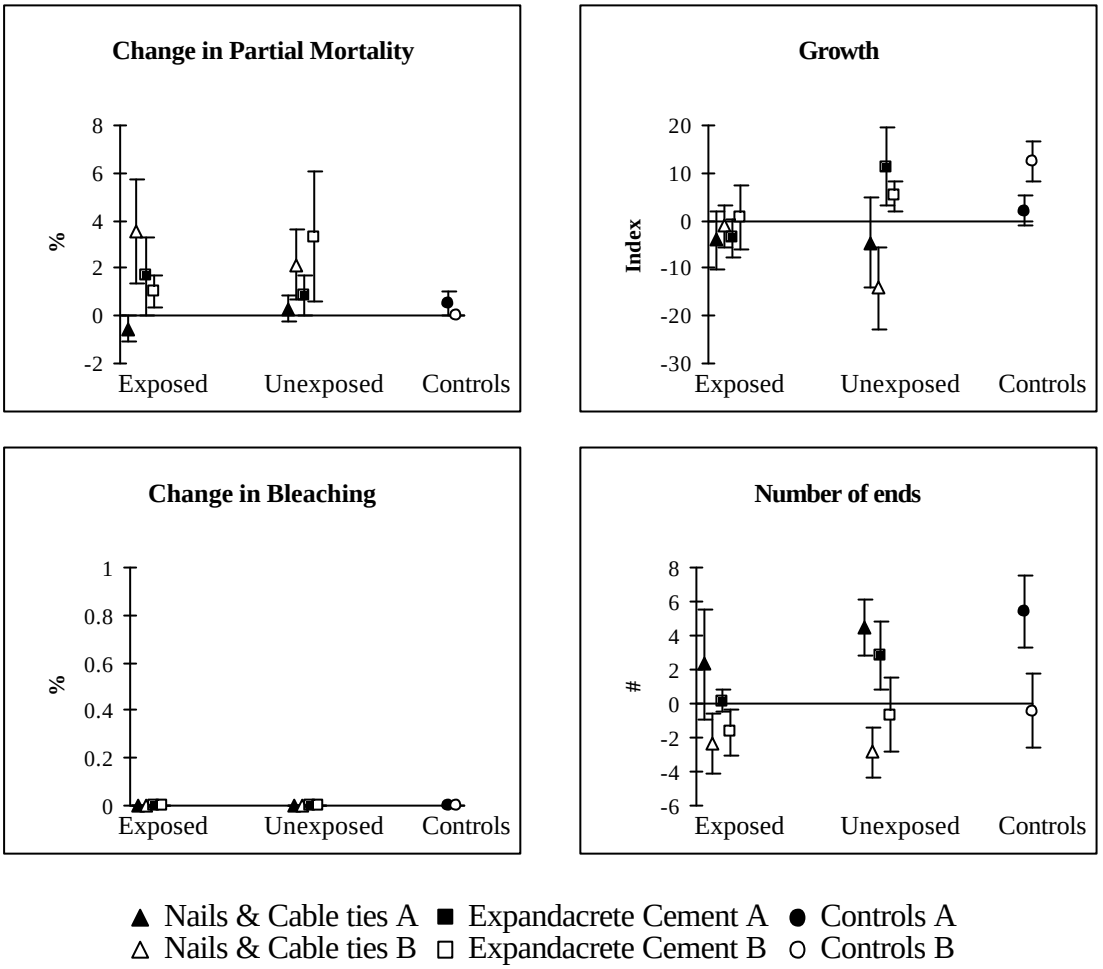


Figure 5: Changes in partial mortality, bleaching, growth and number of ends in *Rumphella* sp. A and B in the legend refer to bommie identification; plotted values are means +/- S.E.

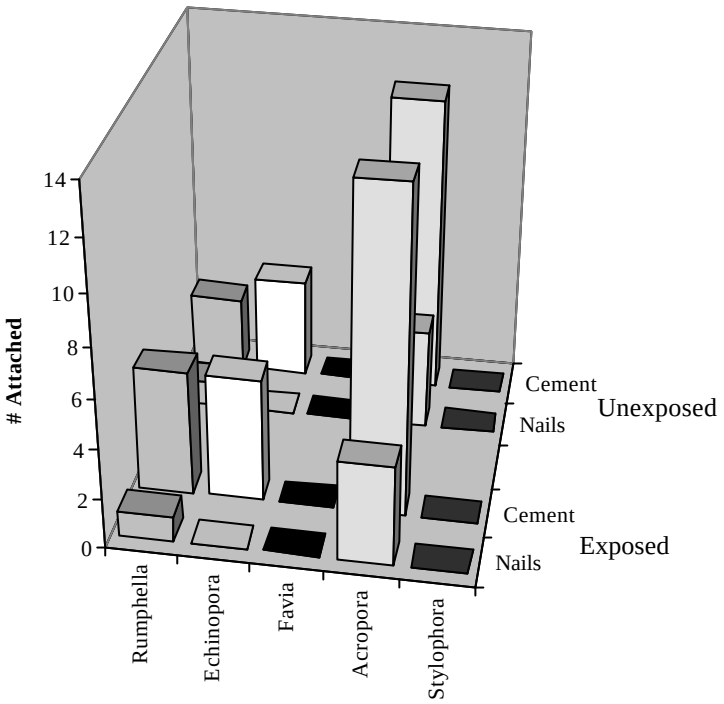


Figure 6: Number of fragments in each treatment which formed an independent attachment with the substratum during the pilot experiment (total n=80 per species).

2.4 Discussion

Although a few large differences in partial mortality, bleaching, growth and number of ends were detected in some fragments during this pilot experiment (table 1), most individual fragments changed by a much smaller amount. The small effect sizes observed to date may increase or disappear through time. Measurements of growth in this experiment were taken using plastic field callipers and are probably subject to several mm of error or each of the measurements taken (height, length, width). So far, this experiment has only been running for 3.5 months and it is likely that further differences among treatments, if they exist, will only become apparent when the total increment of growth exceeds the cumulative error of measurement. The corals will be measured again at the end of this year. Despite possible errors of measurement, consistent differences between the bommies and treatments in the faster growing species did emerge. The differences between bommies might be attributable to different levels of exposure (Bommie B was more exposed), implying that site to site variations might greatly affect the outcomes of rehabilitation.

Table 1: Summary of overall measures of change obtained in the experiment for all species.

	Partial Mortality	**Bleaching**	**Growth**	**# Ends**
Mean change	14.4%	-0.4%	-4.66mm	-1.2
Standard Error	0.15	0.05	0.122	0.07
Maximum	100%	90%	63mm	18
Minimum	-50%	-80%	-165mm	-21

Optimum transplanting methods

Based on the results obtained to date, it appears that most of the species responded the best to being firmly attached to the substratum with epoxy cement rather than using nails and cable ties (table 2). The exception so far has been *Favia stelligera* which did not show any difference among any of the methods of attachment or handling, and showed no evidence of growth during the time of the project. The reason the better response to cement appeared to be two-fold:

i) loose attachment using the nails/cable ties allowed the base of corals to shift constantly with water movement which probably made it difficult for the fragments to grow down onto the substratum; and

ii) because corals could move around they appeared to become abraded on the rock and sometimes came into contact with other corals. In one instance a neighbouring *Platygyra* sp. attacked a fragment of *F. stelligera* which had twisted on its nail and come into contact. Abrasion was a particular problem in *Rumphella* sp. Many of the fragments attached to nails and even some of the controls which had plastic coated wire wrapped around them suffered damage at the point of contact, often exposing the coral's skeleton.

Table 2: Summary of best and worst methods of transplanting fragments in all species examined.

SPECIES	BEST METHOD	VARIABLE OPTIMISED	WORST METHOD
Stylophora pistillata	Unexposed, Cement	Partial mortality	Nails & Cable ties
Acropora gemmifera	Cement	Attachment & Growth	Not clear, site-specific
Favia stelligera	Any	All similar	None
Echinopora lamellosa	Unexposed, Cement? (but site-specific)	Partial mortality & Growth	Exposed treatments? Not clear, site-specific
Rumphella sp.	Unexposed, Cemented	Growth	Cable ties, possibly worse if also unexposed

With regard to exposure, two species (*Stylophora pistillata* and *Rumphella*) showed a measurable negative response to exposure to air during transportation. It is clear that if these corals require transport to a rehabilitation site, they will have to be kept submerged. In contrast, *Acropora gemmifera* and *Favia stelligera* did not respond negatively to exposure and it should be possible to move them from site to site in a boat covered by a wet tarpaulin. Harriott and Fisk (1987) reported that corals survived covered transport out of water for several hours but that for periods longer than 2 hours, the fragments should be submerged. The results of this experiment suggest that for some species any exposure to air will significantly affect their survivorship and growth. *Echinopora lamellosa* was borderline in its response to exposure, and should, therefore, probably be treated in the same way as *Stylophora* and *Rumphella*.

Costs

Costs of rehabilitation, calculated on a per hectare basis, are likely to be high (figure 7). (See also Harriott & Fisk, 1987). The cost in dollars of restoring either Bommie A or Bommie B with a target density of 245,000 fragments per hectare (for present density, see Appendix 7) would be in the order of $580,000/ha plus ship time. Complete replacement at full density is therefore not viable for such high density communities. In the case of the Lizard Island bommies, replacement of 10% of the target density might cost around $58,000 plus ship time, a figure which would be more justifiable in a medium-scale restoration. Further rehabilitation experiments are urgently needed to determine which species are amenable to transplantation and what proportion of target densities are required to achieve enhanced recovery of a damaged area.

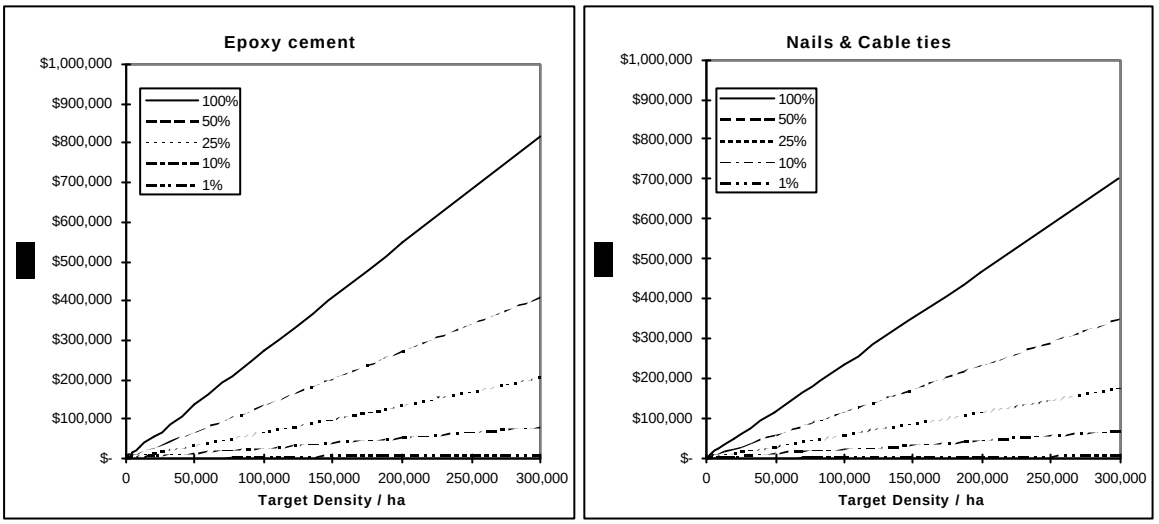


Figure 7: Estimated costs of rehabilitation of one hectare of reef in relation to different target densities of corals, and the percentage of the target to be actively replaced. The costs assume shallow water diving and include all consumables required for each method and a 4 person dive team able to place 500 corals per day. Costs of access to the site (shiptime, regional travel and living costs etc), because they are so variable, were excluded.

2.5 Acknowledgements

Thanks to Jenny McIlwain, Geoff Jones, Mark Hixon, Rohan Pratt, Ellen Twiname and Ian Keay for their assistance with setting up and monitoring this experiment. Thanks also to Bette Willis for reviewing the manuscript. This study was undertaken using the facilities of the Department of Marine Biology, James Cook University, and Lizard Island Research Station.

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3. Appendices

Appendix 1: Results of MANOVA and ANOVAS for *Stylophora pistillata.*

(a) MANOVA

	Wilks' ??	**df 1**	**df 2**	**p-level**	
Bommie	0.83	4	47	0.07	NS
Exposure	-	-	-	-	
Attachment	-	-	-	-	
Bommie*Exposure	0.94	4	47	0.59	NS
Bommie*Attachment	0.96	4	47	0.77	NS
Exposure*Attachment	-	-	-	-	
Bommie*Exposure*Attachment	0.89	4	47	0.26	NS

(b) ANOVAS

	MS Effect	**MS Error**	**F**	**p-level**	
Bommie			(1,50)		
%PM	4178.51	845.00	4.94	0.03	*
%BL	144.59	303.11	0.48	0.49	NS
# ENDS	413.53	48.18	8.58	0.01	*
GROWTH	5344.23	28740.91	0.19	0.67	NS
Exposure			(1,1)		
%PM	2012.18	452.87	4.44	0.28	NS
%BL	165.60	280.60	0.59	0.58	NS
# ENDS	45.74	53.18	0.86	0.52	NS
GROWTH	43612.24	15601.29	2.80	0.34	NS
Attachment			(1,1)		
%PM	946.65	803.62	1.18	0.47	NS
%BL	145.95	184.96	0.79	0.54	NS
# ENDS	36.93	25.76	1.43	0.44	NS
GROWTH	35953.50	7297.78	4.93	0.27	NS
Bommie*Exposure			(1,50)		
%PM	452.87	845.00	0.54	0.47	NS
%BL	280.60	303.11	0.93	0.34	NS
# ENDS	53.18	48.18	1.10	0.30	NS
GROWTH	15601.29	28740.91	0.54	0.46	NS
Bommie*Attachment			(1,50)		
%PM	803.62	845.00	0.95	0.33	NS
%BL	184.96	303.11	0.61	0.44	NS
# ENDS	25.76	48.18	0.53	0.47	NS
GROWTH	7297.78	28740.91	0.25	0.62	NS
Exposure*Attachment			(1,1)		
%PM	0.64	995.75	0.00	0.98	NS
%BL	24.91	379.70	0.07	0.84	NS
# ENDS	25.08	8.43	2.97	0.33	NS
GROWTH	23874.48	34915.50	0.68	0.56	NS
Bommie*Exposure*Attachment			(1,50)		
%PM	995.75	845.00	1.18	0.28	NS
%BL	379.70	303.11	1.25	0.27	NS
# ENDS	8.43	48.18	0.17	0.68	NS
GROWTH	34915.50	28740.91	1.21	0.28	NS

Appendix 2: Results of MANOVA and ANOVAS for *Acropora gemmifera*.

(a) MANOVA

	Wilks' ??	df 1	df 2	p-level	
Bommie	0.83	4	59	0.02	*
Exposure	-	-	-	-	
Attachment	-	-	-	-	
Bommie*Exposure	0.86	4	59	0.06	NS
Bommie*Attachment	0.84	4	59	0.04	*
Exposure*Attachment	-	-	-	-	
Bommie*Exposure*Attachment	0.94	4	59	0.45	NS

(b) ANOVAS

	MS Effect	MS Error	F	p-level	
Bommie			(1,62)		
%PM	576.19	271.14	2.13	0.15	NS
%BL	33.13	15.88	2.09	0.15	NS
# ENDS	255.69	30.04	8.51	0.00	*
GROWTH	564.79	349.86	1.61	0.21	NS
Exposure			(1,1)		
%PM	2.77	410.14	0.01	0.95	NS
%BL	0.23	11.88	0.02	0.91	NS
# ENDS	0.08	57.19	0.00	0.98	NS
GROWTH	1141.26	223.91	5.10	0.27	NS
Attachment			(1,1)		
%PM	4.99	654.93	0.01	0.94	NS
%BL	0.23	11.88	0.02	0.91	NS
# ENDS	0.16	90.72	0.00	0.97	NS
GROWTH	162.59	2745.53	0.06	0.85	NS
Bommie*Exposure			(1,62)		
%PM	410.14	271.14	1.51	0.22	NS
%BL	11.88	15.88	0.75	0.39	NS
# ENDS	57.19	30.04	1.90	0.17	NS
GROWTH	223.91	349.86	0.64	0.43	NS
Bommie*Attachment			(1,62)		
%PM	654.93	271.14	2.42	0.13	NS
%BL	11.88	15.88	0.75	0.39	NS
# ENDS	90.72	30.04	3.02	0.09	NS
GROWTH	2745.53	349.86	7.85	0.01	*
Exposure*Attachment			(1,1)		
%PM	399.68	0.45	879.39	0.02	*
%BL	7.77	33.13	0.23	0.71	NS
# ENDS	3.20	8.00	0.40	0.64	NS
GROWTH	89.39	243.32	0.37	0.65	NS
Bommie*Exposure*Attachment			(1,62)		
%PM	0.45	271.14	0.00	0.97	NS
%BL	33.13	15.88	2.09	0.15	NS
# ENDS	8.00	30.04	0.27	0.61	NS
GROWTH	243.32	349.86	0.70	0.41	NS

Appendix 3: Results of MANOVA and ANOVAS for *Favia stelligera*

PM = Partial Mort
BL = Bleaching

(a) MANOVA

	Wilks' ??	df 1	df 2	p-level	
Bommie	0.94	3	59	0.33	NS
Exposure	-	-	-	-	
Attachment	-	-	-	-	
Bommie*Exposure	0.88	3	59	0.05	NS
Bommie*Attachment	0.97	3	59	0.56	NS
Exposure*Attachment	-	-	-	-	
Bommie*Exposure*Attachment	0.94	3	59	0.33	NS

(b) ANOVAS

	MS Effect	MS Error	F	p-level	
Bommie			(1,61)		
%PM	0.29	100.07	0.00	0.96	NS
%BL	30.14	233.29	0.13	0.72	NS
GROWTH	752.82	259.60	2.90	0.09	NS
Exposure			(1,1)		
%PM	3.58	91.80	0.04	0.88	NS
%BL	794.43	152.47	5.21	0.26	NS
GROWTH	855.28	1691.15	0.51	0.61	NS
Attachment			(1,1)		
%PM	13.68	129.70	0.11	0.80	NS
%BL	1575.38	189.16	8.33	0.21	NS
GROWTH	1.11	89.26	0.01	0.93	NS
Bommie*Exposure			(1,61)		
%PM	91.80	100.07	0.92	0.34	NS
%BL	152.47	233.29	0.65	0.42	NS
GROWTH	1691.15	259.60	6.51	0.01	*
Bommie*Attachment			(1,61)		
%PM	129.70	100.07	1.30	0.26	NS
%BL	189.16	233.29	0.81	0.37	NS
GROWTH	89.26	259.60	0.34	0.56	NS
Exposure*Attachment			(1,1)		
%PM	62.74	202.47	0.31	0.68	NS
%BL	578.59	13.84	41.82	0.10	NS
GROWTH	159.58	146.40	1.09	0.49	NS
Bommie*Exposure*Attachment			(1,61)		
%PM	202.47	100.07	2.02	0.16	NS
%BL	13.84	233.29	0.06	0.81	NS
GROWTH	146.40	259.60	0.56	0.46	NS

Appendix 4: Results of MANOVA and ANOVAS for *Echinopora lamellosa.*

(a) MANOVA

	Wilks' ??	df 1	df 2	p-level	
Bommie	0.77	3	57	0.00	*
Exposure	-	-	-	-	
Attachment	-	-	-	-	
Bommie*Exposure	0.90	3	57	0.11	NS
Bommie*Attachment	0.97	3	57	0.63	NS
Exposure*Attachment	-	-	-	-	
Bommie*Exposure*Attachment	0.94	3	57	0.31	NS

(b) ANOVAS

	MS Effect	MS Error	F	p-level	
Bommie			(1,59)		
%PM	5750.04	498.18	11.54	0.00	*
%BL	26.03	7.82	3.33	0.07	NS
GROWTH	2583.43	399.06	6.47	0.01	*
Exposure			(1,1)		
%PM	221.39	141.42	1.57	0.43	NS
%BL	15.83	26.03	0.61	0.58	NS
GROWTH	1931.53	892.03	2.17	0.38	NS
Attachment			(1,1)		
%PM	564.13	556.69	1.01	0.50	NS
%BL	0.26	2.68	0.10	0.81	NS
GROWTH	889.88	0.31	2867.45	0.01	*
Bommie*Exposure			(1,59)		
%PM	141.42	498.18	0.28	0.60	NS
%BL	26.03	7.82	3.33	0.07	NS
GROWTH	892.03	399.06	2.24	0.14	NS
Bommie*Attachment			(1,59)		
%PM	556.69	498.18	1.12	0.29	NS
%BL	2.68	7.82	0.34	0.56	NS
GROWTH	0.31	399.06	0.00	0.98	NS
Exposure*Attachment			(1,1)		
%PM	1021.78	674.37	1.52	0.43	NS
%BL	0.26	2.68	0.10	0.81	NS
GROWTH	220.43	1437.40	0.15	0.76	NS
Bommie*Exposure*Attachment			(1,59)		
%PM	674.37	498.18	1.35	0.25	NS
%BL	2.68	7.82	0.34	0.56	NS
GROWTH	1437.40	399.06	3.60	0.06	NS

Appendix 5: Results of MANOVA and ANOVAS for *Rumphella sp.*

(a) MANOVA

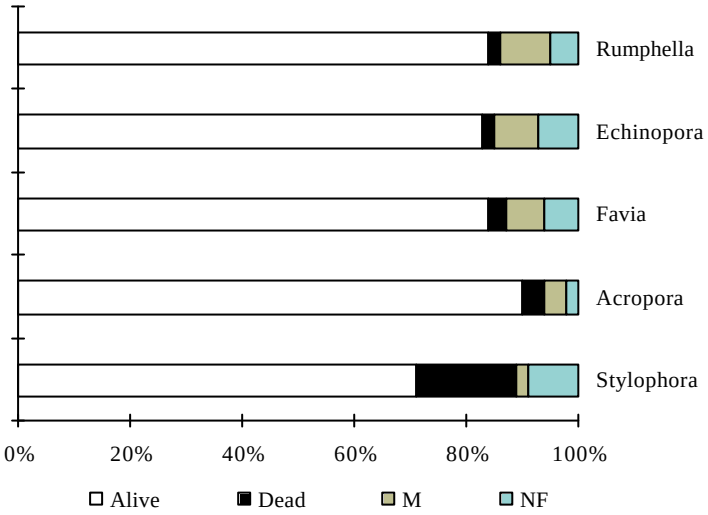
	Wilks' ??	df 1	df 2	p-level	
Bommie	0.86	3	56	0.04	*
Exposure	-	-	-	-	
Attachment	-	-	-	-	
Bommie*Exposure	0.97	3	56	0.67	NS
Bommie*Attachment	0.97	3	56	0.69	NS
Exposure*Attachment	-	-	-	-	
Bommie*Exposure*Attachment	0.96	3	56	0.55	NS

(b) ANOVAS

	MS Effect	MS Error	F	p-level	
Bommie			(1,58)		
%PM	60.07	20.30	2.96	0.09	NS
# ENDS	299.58	33.67	8.90	0.00	*
GROWTH	68.40	386.40	0.18	0.68	NS
Exposure			(1,1)		
%PM	0.88	0.80	1.10	0.48	NS
# ENDS	28.28	18.52	1.53	0.43	NS
GROWTH	30.84	524.95	0.06	0.85	NS
Attachment			(1,1)		
%PM	1.92	16.82	0.11	0.79	NS
# ENDS	1.01	43.90	0.02	0.90	NS
GROWTH	1395.34	22.81	61.18	0.08	NS
Bommie*Exposure			(1,58)		
%PM	0.80	20.30	0.04	0.84	NS
# ENDS	18.52	33.67	0.55	0.46	NS
GROWTH	524.95	386.40	1.36	0.25	NS
Bommie*Attachment			(1,58)		
%PM	16.82	20.30	0.83	0.37	NS
# ENDS	43.90	33.67	1.30	0.26	NS
GROWTH	22.81	386.40	0.06	0.81	NS
Exposure*Attachment			(1,1)		
%PM	4.19	29.26	0.14	0.77	NS
# ENDS	4.19	1.11	3.79	0.30	NS
GROWTH	1081.53	2.67	404.53	0.03	*
Bommie*Exposure*Attachment			(1,58)		
%PM	29.26	20.30	1.44	0.23	NS
# ENDS	1.11	33.67	0.03	0.86	NS
GROWTH	2.67	386.40	0.01	0.93	NS

Appendix 6: Rates of recovery (recapture) of fragments and controls transplanted or marked during the experiment.

Recovery rates are numbers of 100 individuals at setup (Time 1) recovered at Time 2. M=tag recovered, but coral missing; NF=neither tag nor coral was found.



Appendix 7: Densities as percent cover and number of colonies of corals found at Bommies A and B.

Data are means of 3 transects (1 at A, 2 at B) 10m*1m. Percent cover was estimated using 100 points along the transect.

	Mean % cover	SE	Mean # per $10m^2$	SE
Acropora divericata	1	1	7	3
Acropora sp1.	2	1	9	7
Acropora gemmifera			3	2
Acropora humilis			1	0
Acropora hyacinthus			2	1
Acropora millepora	1	1	1	1
Acropora nastuta			1	1
Acropora spp.			4	1
Acropora elseyi	4	4	33	33
Cyphastrea			1	1
Echinopora lamellosa	2	1	3	1
Faviids	3	1	12	3
Fungiids	1	1	3	1
Goniastrea			1	1
Hydnophora spp.			1	1
Lobophyllia			2	0
Lobophyton	1	1	6	3
Millepora			2	2
Montipora spp.	1	0	14	12
Mycedium			1	1
Pectinia			1	1
Platygyra spp.			2	0
Pocillopora damicornis	1	1	4	1
Pocillopora meandrina			1	0
Porites spp.	6	2	59	21
Rumphella			8	5
Sarcophyton	12	3	33	14
Sinularia	7	3	25	8
Stylophora pistillata			4	1
Turbinaria	1	1		
Zooanthids			1	1
TOTAL	**43**		**245**	