Progress report 1.

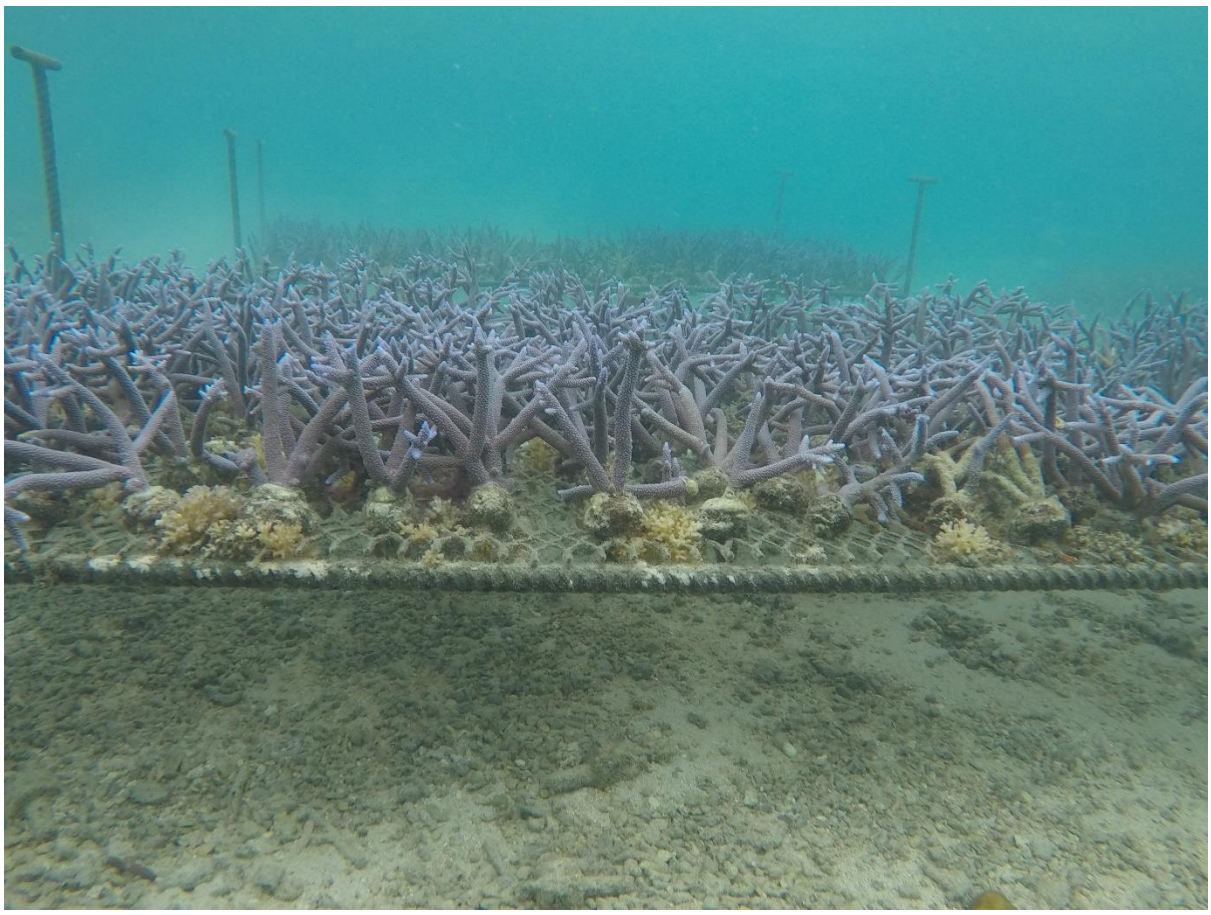
Evaluating the ecological benefits of transplanted coral fragments.

The Aquaculture Development for the Environment Project.

March 2019

Prepared for:

The Aquaculture Development for the Environment Project (A.D.E. Project)



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Progress report 1.

Summarizing Outcome of field surveys including the establishment of experimental plots and preliminary results: Evaluating the ecological benefits of transplanted coral fragments.

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Rev	Date	Description	Author(s)	Reviewer
A	16/01/2019	Issued for Client Review	B. Fitzpatrick, A. Davenport	Zaidy Oceans
B	07/03/2019	Issued for Client Review	B. Fitzpatrick, A. Davenport	Walt Smith / Deb Smith
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Oceanwise Australia Pty Ltd

Contents

Introduction

Document Purpose

The purpose of this document is to summarize work undertaken to date by WSI on coral fragmentation and to outline preliminary baseline results while establishing experimental field trials evaluating the A.D.E. Project coral fragment transplanting approach to coral reef ecosystem restoration.

This will include an initial background review; outside the scope of this document is a complete literature review, which will come in the final stages of project implementation. A discussion of preliminary results gained during baseline measurements conducted on the first field trip will also be included to clarify project status and indicate future directions of the study.

Aim of this study/ report

To determine the effect that transplanting coral fragments into degraded coral reef areas has on biodiversity.

Objectives

To achieve this aim we will measure change in coral reef ecosystems at plots receiving coral transplants at known densities; and nearby reference plots that receive no transplants. We will establish changes in various measures including:

- Rates of natural coral reef recruitment and recovery.
- Coral propagule survival and growth rates.
- Coral cover and habitat complexity.
- Macro invertebrate abundance and diversity.
- Fish assemblage abundance and diversity.

Background

Coral reefs worldwide are under threat from a variety of human and natural impacts. A changing climate is foremost of the threats, heightened temperatures and acidity causing coral bleaching and increasing intensity and frequency of cyclones causing mechanical destruction (Rinkevich 2014, Knutson et al. 2010, Barner et al. 2015). The loss of coral reefs will not only have devastating impacts to biodiversity but will also have significant detrimental effects to people. Foremost of these impacts is to the threat to the primary food supply of an estimated 2 billion people who derive significant amounts of their subsistence protein from coral reefs fisheries globally. Another is to the enormous tourism industry worth $375 billion globally as of 2017 (Opel et al. 2017), representing one of the main incomes for many small tropical islander countries. Another would be the coastal protection that barrier reefs offer, reducing wave energy and erosion of shorelines (Fabian et al. 2013), imperative services for the future of small islander countries, especially with a rising sea level. It is estimated that more than 100 million people receive protection from coastal reefs (Ferrario et al. 2014).

There are numerous efforts to restore coral reefs globally as it has been identified as a priority for the survival of many coastal human populations (Wilson and Forsyth 2018). There are many direct and more general methods to restore these ecosystems (Rinkevich 2014), with a variety of success rates often dependant on factors other than environmental ones (Fabian et al. 2013). Nevertheless, coral reef restoration projects have been found to increase the diversity and abundance of fish assemblages (Opel et al. 2017), demonstrating proven ecological benefits of coral reef rehabilitation.

Fiji's coral reefs have been impacted by coastal development, cyclones, bleaching, and dynamite fishing among other impacts. The ADE project has been working on solutions to reverse this trend.

They utilize coral fragments grown on special bases designed by WSI and transplant these back into the reef in order to rehabilitate degraded areas. In some cases, they provide direct employment and income to local villages and this anecdotally results in greater stewardship and care for the health of traditional coral reef areas (Table1.). This project is designed to demonstrate the underlying assumption that the transplantation of corals onto degraded reefs will result in improved ecosystem health through the increased coral reef fish and invertebrate diversity.

Table 1. Conceptual illustration of the benefits of coral reef restoration.

ADE Project Coral Restoration	**Corals**	**Biodiversity**	**Fish**	**Livelihoods**	**Coastal Protection**
Before ADE Project Assistance • climate change - bleaching, acidification cyclones. • declining water quality and reef habitats. • destructive fishing. • pollution and more.	↓	↓	↓	↓	↓
Intervention • Coral transplants: Improved Governance and management: Education, Protection, Compliance, Enforcement: Alternative sustainable livelihoods					
After ADE Project Assistance • Increased coral cover • Improved fish and invertebrate habitat • New sustainable livelihoods	↑	↑	↑	↑	↑

Methods

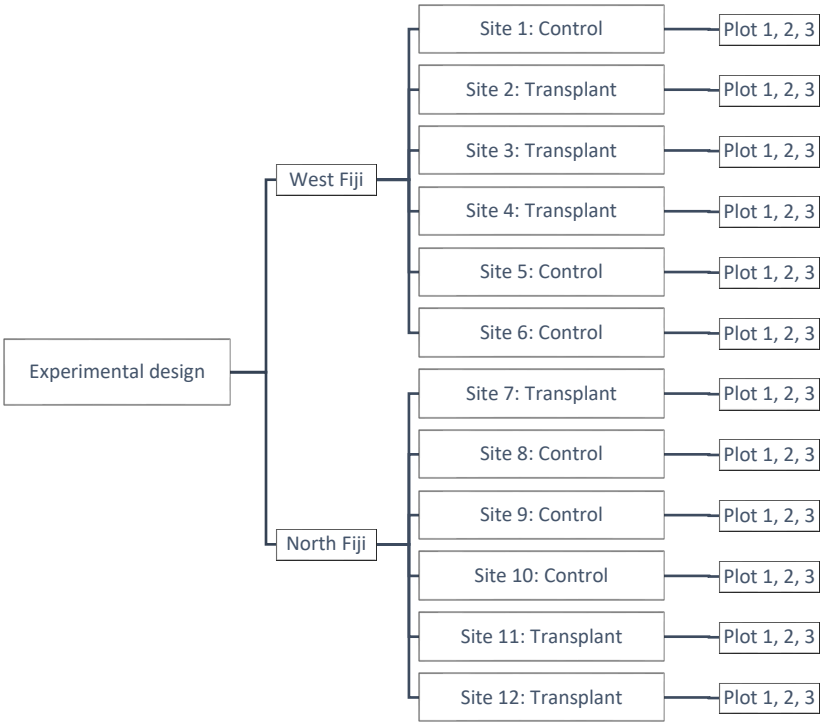
Experimental design

A Multiple Before-After Control Impact experimental design (MBACI) was established to measure the effect transplanting corals has on coral reef habitat and associated biodiversity over time; compared to coral reef habitat that is left to recover naturally and where no coral transplanting is undertaken. This design involves measuring the biological variables before any impact is undertaken, in this instance it will be the planting of coral propagules in degraded areas of coral reef. The same biological variables will be measured twice after the impact, to determine the amount of change that occurs in the biophysical habitat. The biological variables to be measured are the abundance and diversity of fish and invertebrates, as well as the composition and complexity of the benthos.

The experiment has been set-up at two locations including in Western Fiji adjacent Lautoka, and the Northern District Adjacent Drua Drua (**Figure 1**). Specified below are the technical aspects of the experimental design including location, sites, number of plots (**Figure 2)**. Ideally plots would be sampled twice before the impact and at least twice after the impact, but in this case only 1 baseline dataset will be gathered. Six months and twelve months after transplantation subsequent sampling will occur, in order to measure the change due to transplantation.

Figure 1. Map showing two locations experimental coral transplant and control plots were established.

Figure 2. The locations, sites, transplant and reference plots established.



Field trip 1 was completed in Oct 2018 including establishing study site infrastructure and gaining baseline measurements of the coral reef ecosystem prior to transplanting corals (**Figure 2, Appendix 1 and 6**). Six study sites were established at each of the two locations. In the Northern district of Vanua Levu, WSI originally established its current coral propagule farms adjacent Druadrua Island and in the Vunivutu channel, where 2 and 4 sites were set up respectively. Study sites were established in the Western district of Fiji, proximal to the ADE facilities, in proximity of pre-existing farm sites including Kadavu, Star and Walt **(Figure 3**). At each site, three 5 x 5 m plots were set up for a total of 36 plots (**Appendix 1**).

Site selection

Two geographically separate locations were selected to help define the generality of findings and provide insurance against loss of sites due to catastrophic bleaching, cyclone damage or similar occurring at either location. Selection of the sites were based on two criteria: 1) suitable rocky coral reef habitat compatible with hard coral establishment in shallow water (<7m depth), and 2) the proximity to pre-existing coral farms for access to propagules for transplanting. Sites to be transplanted with corals were located within 50m of coral racks, while reference sites were separated by at least 200m (**Figure 4, 5 and 6**). The three 5x5m plots to be installed at each site were chosen based on live coral cover. Those with less cover (10%) were preferable to sites with high coral cover, since we are interested in comparing how rates of recovery are at sites with and without transplanted corals.

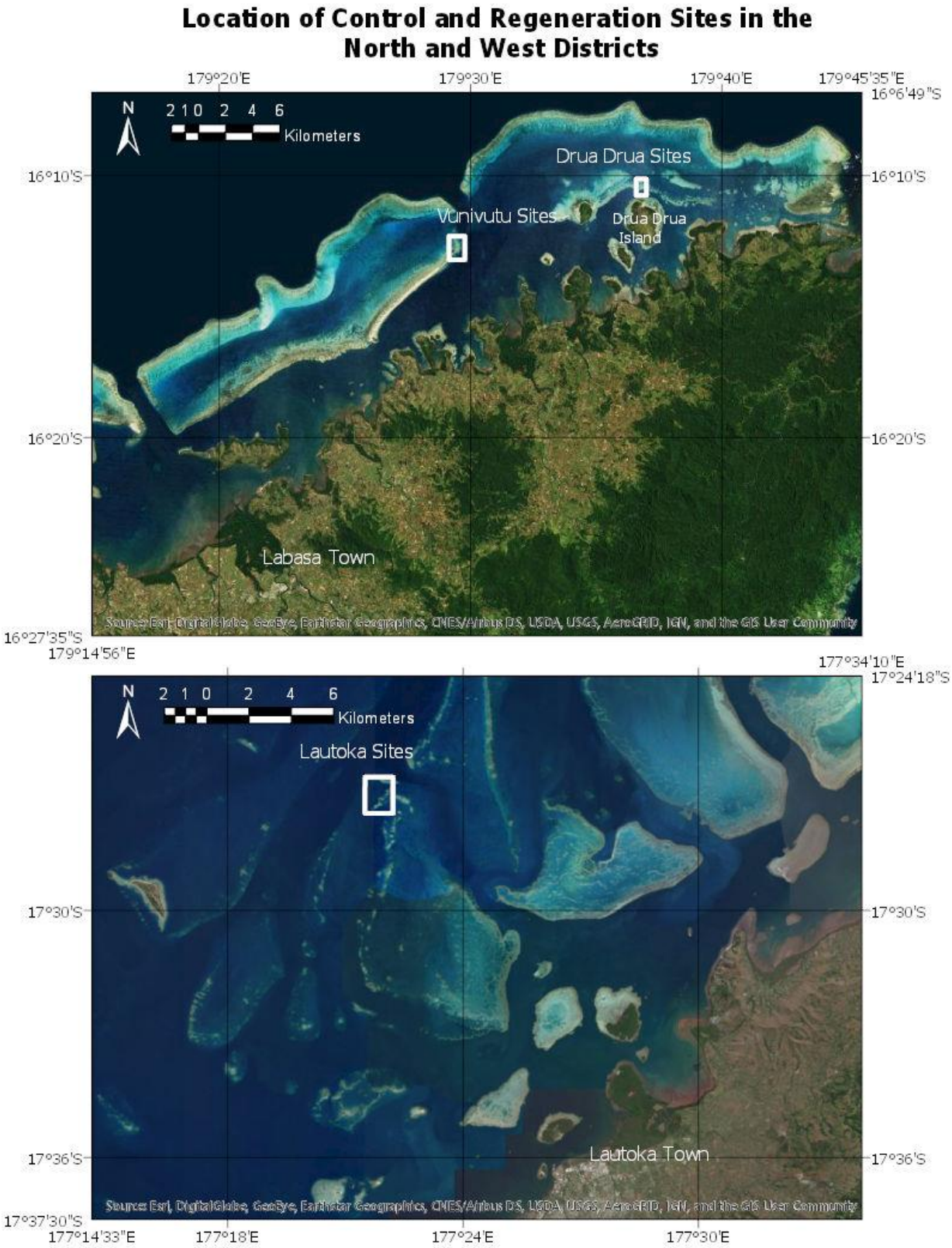


Figure 3. Lautoka and Druadrua in the West and North districts of Fiji respectively. Experimental plots have been established at sites in these two locations as part of this study.

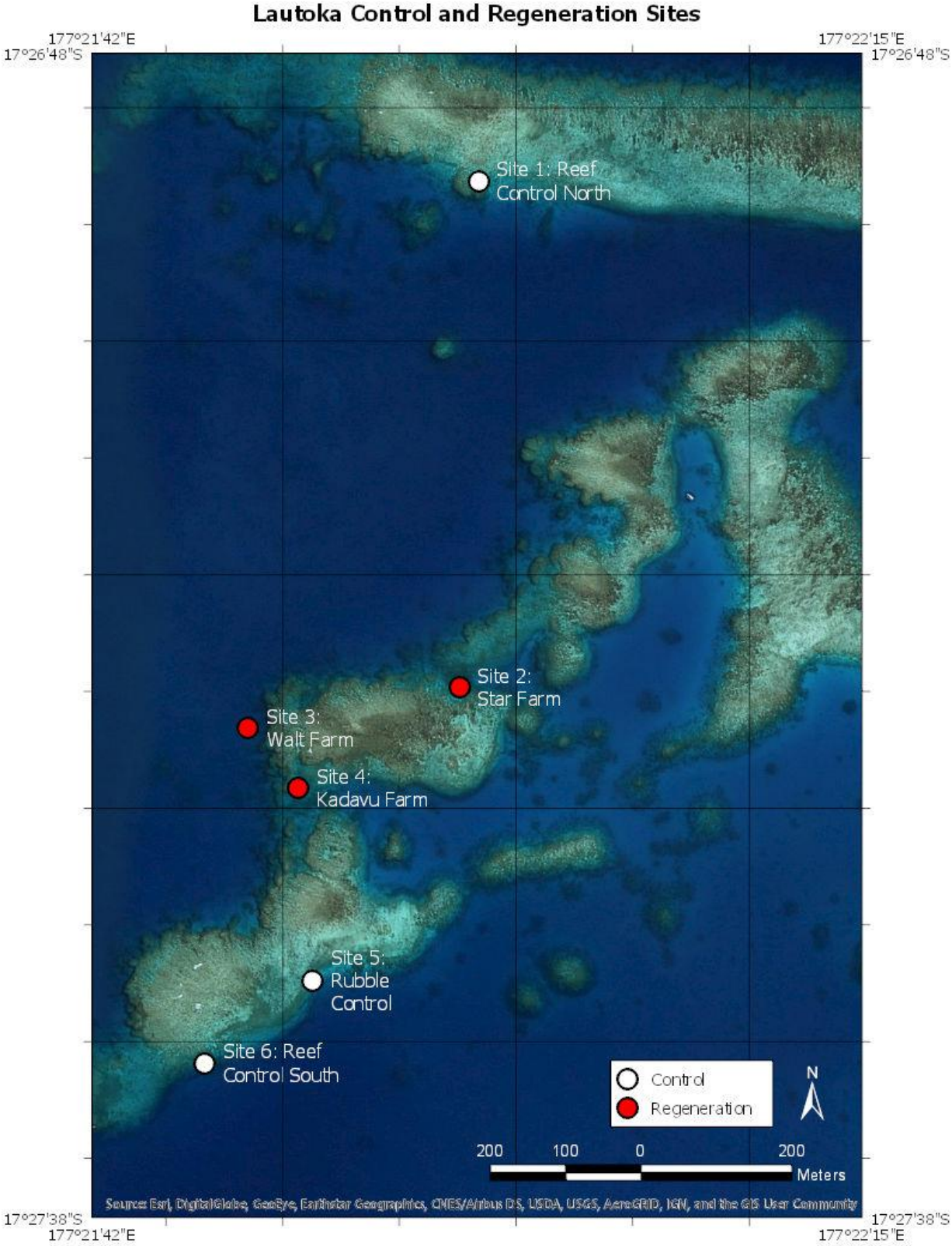


Figure 4. Reference (white) and transplant (red) sites in Lautoka.

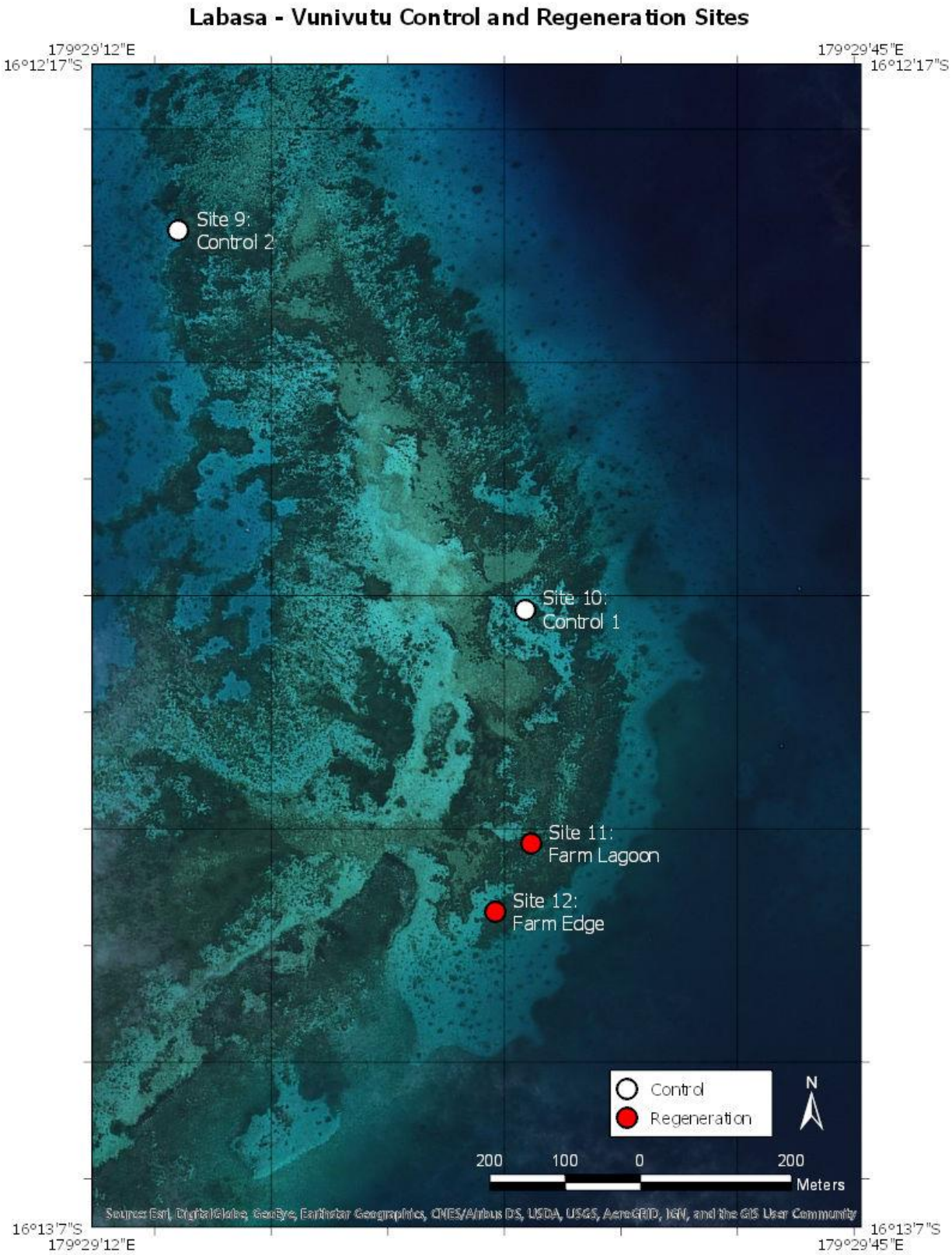


Figure 5. Reference (white) and transplant (red) sites in the Vunivutu channel.

Figure 6. Reference (white) and transplant (red) sites adjacent Druadrua.

Plot Establishment

Scuba divers identified suitable areas of rocky reef habitat and used a fiberglass tape to measure a 5 x 5m square (**Figure 7**). A 1.5m length of reinforcement bar was hammered into the reef at each corner and a small float embossed with the site number installed to assist relocating and identifying sites. Plots were separated by suitable distances to reduce the likelihood of nearby plots influencing one another.

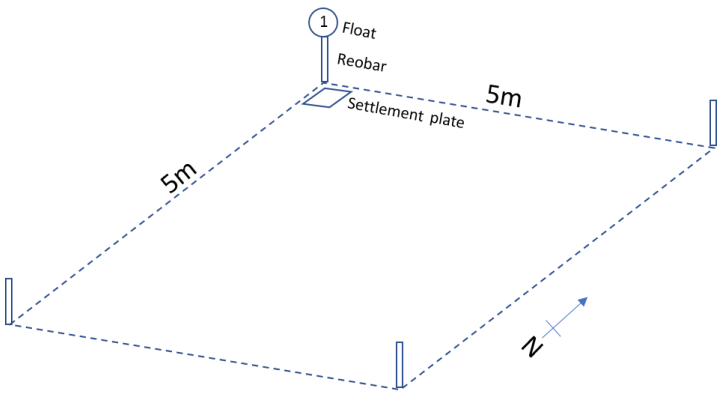


Figure 7. Illustrating an established plot.

Fish Diversity

Once plots were established, fish assemblages were censured using Diver Operated Video (DOV). The DOV rig utilized for this project consisted of three Gopro Hero 5 Black cameras mounted at both ends and in the middle of a rigid 2-metre-long aluminium base-bar. This camera was utilized by swimming along the centre of each 5m plot, 0.5m above the seafloor. The wide field of view of these cameras of 122.9° meant that the resulting footage achieved significant overlap between each camera of 73% at 1m in front of the camera and a FOV of 5.72m to achieve full coverage across the 5 m plot width with one pass. The resulting footage was reviewed in the lab and all animals identified to the species level and total abundance summed within each plot. A full list of fish species sighted can be found in **Appendix 3**.

Macro invertebrate abundance

Invertebrates within each plot were systematically photographed for later identification to the highest taxonomic level. The resulting images were reviewed in the lab and most animals were identified to the species level and total abundance summed within each plot. Where animals could not be identified to a species level they were left as representatives of a higher taxa. A full list of invertebrate species sighted can be found in **Appendix 4**.

Coral and benthic cover, Habitat Complexity

Coral and benthic cover were estimated using well established photo-quadrat methods. A comprehensive set of photos were systematically collected across each plot using the same video camera rig described above. Each camera was set to take images at a rate of one every 0.5 seconds and the camera was swam facing downwards at an angle slightly forward from the perpendicular by 10%, and at a height of approximately 1.5m above the substrate. The camera was used in three parallel passes over the plot parallel to one side, and a further three passes were made over the plot in the adjacent direction. Subsequently a subset of these images was extracted and analysed for percent cover using the established Benthic Classification scheme Attached (**Appendix 5**). Methods for this are well established and were based on Coral Point Count software routines to derive percent of cover and abundance of benthic organisms: https://cnso.nova.edu/cpce/index.html. Subsequently 3D

models of each plot are being constructed from photogrammetry whereby the overlapping images collected across the entire plot are imported into Agisoft Photoscan software: http://www.agisoft.com/. These will be used later for improved measures of biophysical habitat.

Coral recruitment

To establish natural rates of coral recruitment into plots, settlement tiles were installed. A total of 36 settlement tiles were installed, one at each reference and transplant plot. These were installed just prior to the October 2018 spawning period and will be removed at the end of a twelve-month period to capture annual coral settlement events across all sites. This will enable a comparison between locations and sites of the baseline rate of new recruits into reference and transplant plots to establish if there are differences in the natural rate of recruit supply at these sites.

Model coral species, Transplant density and Fragment Survival

Once plots were established and the baseline measures of the coral reef ecosystem present within each plot were conducted, the plots adjacent existing coral farms need to be populated with mature coral fragments. These 6 plots labelled as the transplant plots, will be rehabilitated by planting the corals that are currently sitting in WSI coral racks (now managed by ADE) that are too large and asymmetrical for aquaculture export. This method enables the corals that would otherwise be discarded, to be utilized by ADE in coral reef rehabilitation. The coral fragments that will be used are mainly rapidly growing species of branching Acropora coral, since these are readily available in large numbers. This family holds the greatest potential for rapidly increasing coral cover and reef habitat complexity in the timeframes of this study. These corals are also known to naturally recolonize habitat after mechanical damage from storms or similar disturbances and so are most likely to result in high levels of survivorship. A total of ~2280 coral propagules will be required to populate the 12 transplant plots at these densities.

Transplant density

An appropriate coral transplant density is informed by consideration of target coral cover, transplant growth rate and mortality scenarios. For this trial, relatively fast-growing branching/tabulate acroporid species will be used. At each transplant plot, 190 coral propagules will be planted 35cm apart, as soon as possible to get 12 months of growth before final biodiversity measurements are taken. These transplanted corals will be placed by ADE Project divers, who will work independently of Oceanwise Australia. The completion of coral transplantation at prescribed densities will be required prior to subsequent survey visits. It is anticipated that the 18 plots receiving transplants will be populated over three months following site establishment, with biodiversity surveys subsequently occurring approximately 6 months after initial establishment. This will give the plots and transplanted corals time to properly establish. Assuming these propagules grow at moderate to high rates of 15cm diameter per annum; and experience a high mortality of 30%; plot wide coral cover should increase by 30% a year after transplanting is complete (based on consideration of a range of scenarios in **Table 2**).

Data Processing and Analysis

Biophysical habitat, fish and invertebrate data were compiled into data matrices and imported into PRIMER 7 statistical software package. Data matrices were square root transformed to reduce the influence of highly abundant variables and subsequently transformed using a Bray Curtis Correlation index to produce corresponding similarity matrices. We tested for differences in the habitat, fish and invertebrates at reference and transplant plots prior to planting corals using a PERMANOVA multivariate test of significance. We are only interested in establishing the baseline status of plots prior to transplanting with corals. To visualize these we subsequently compiled distance based RDA plots for fish and invertebrate assemblages.

Table 2. The density of coral transplants required to achieve a certain level of coral cover after accounting for variation in growth rate and mortality. Green highlighted rows indicate scenarios covered under a transplant density of 750 fragments per plot.

Target coral cover (%)	Growth rate (diameter year)	Mortality (%)	Density (per 5m^2 plot)
60	15 (706 cm2)	30	325
30	15 (706 cm2)	30	162
15	15 (706 cm2)	30	80
60	10 (314 cm2)	30	750
30	10 (314 cm2)	30	375
15	10 (314 cm2)	30	190
60	5 (78 cm2)	30	2900
30	5 (78 cm2)	30	1450
15	5 (78 cm2)	30	725

Preliminary Results

Status of biodiversity at plots near WSI farms, compared with reference sites.

A comparison of the effects of ADE farms on biodiversity was visualised to show the ecosystem level impacts. There was no impact of these farms on species richness, animal abundance or species diversity when compared to nearby areas without farms (**Figure 8**).

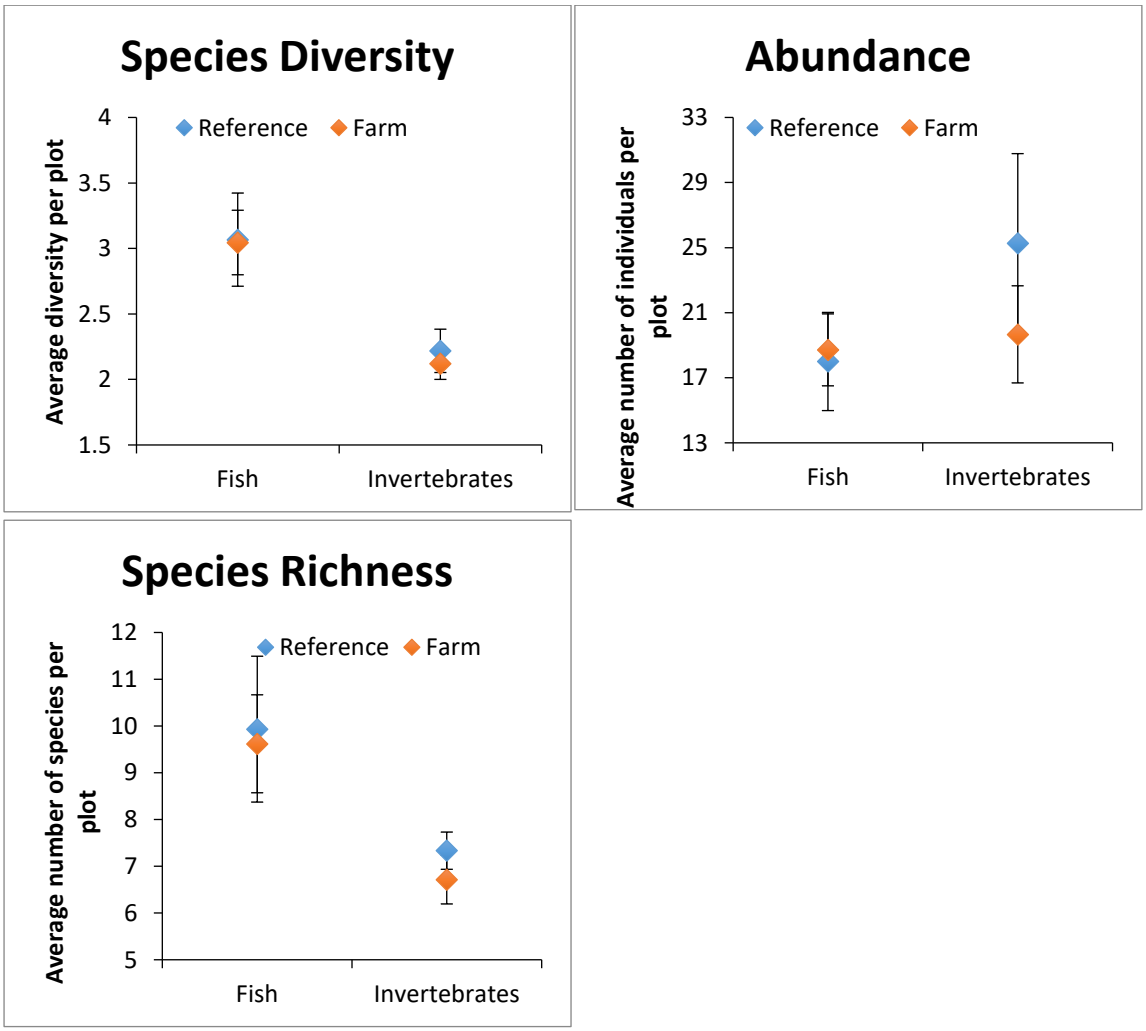


Figure 8. Baseline fish and invertebrate total species, number of individuals and species richness at 21 farm and 15 reference sites.

Habitat, fish assemblages and invertebrates at reference and transplant sites.

Overall there is no difference in the coral reef habitat and associated fish and invertebrate assemblages found in reference and transplant sites established for this study (**Table 3**). Reference and transplant sites have a similar composition of hard coral growth forms and other biophysical habitat forming biodiversity. An example of one of these sites represented by a 3D photogrammetry plot can be seen in **Figure 9**.

The fish and invertebrate species are found in similar diversity and abundance between reference and transplant sites as well (**Figure 10 and 11**). Baselines measures of the total number of species, total number of individuals and species diversity of fish and invertebrates can be seen in **Figure 12**. These will be compared with after measures. We might expect to see the biophysical habitat, fish and invertebrate assemblages at Reference and transplant sites to diverge after transplanted corals have been installed. Raw data is provided in **Attachment 1**.

Table 3. Showing results of Permanova test of the difference in the coral reef ecosystem at reference and transplant sites prior to fragment transplantation. No statistical difference was observed in the biophysical habitat (P value 0.802), fish assemblage (P value 0.273) and invertebrate assemblage (P value (0.426). The treatment in this case is sites that will be transplanted with coral fragments, in areas surrounding the current farms.

Component	Source	df	SS	MS	Pseudo-F	P(perm)	perms
Habitat	Treatment	1	348.06	348.06	0.47869	**0.802**	998
	Res	34	24721	727.1			
	Total	35	25069				
Fish	Treatment	1	3340.9	3340.9	1.1811	**0.273**	998
	Res	34	96175	2828.7			
	Total	35	99515				
Invertebrates	Treatment	1	2349.2	2349.2	0.95375	**0.426**	999
	Res	34	83747	2463.1			
	Total	35	86096				

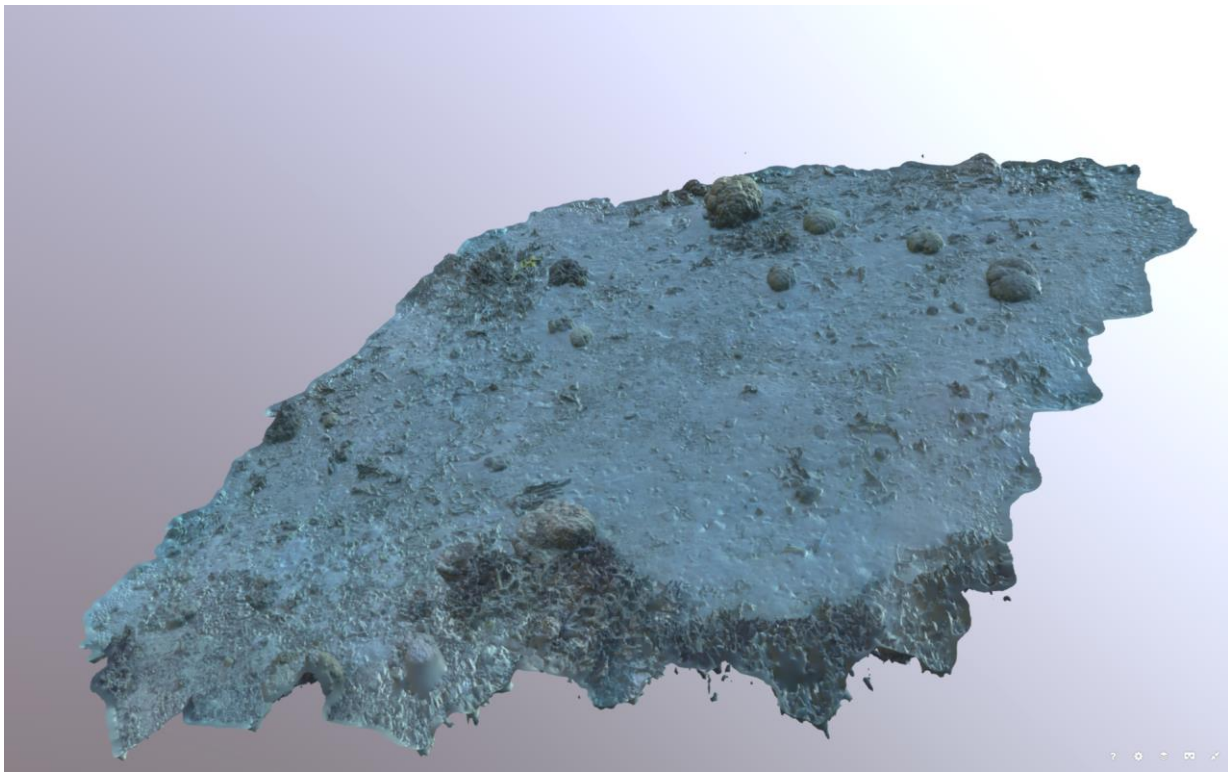


Figure 9. Illustrating the baseline 3D rugosity of Site 9, Plot 1, located at Drua Drua Farm site.

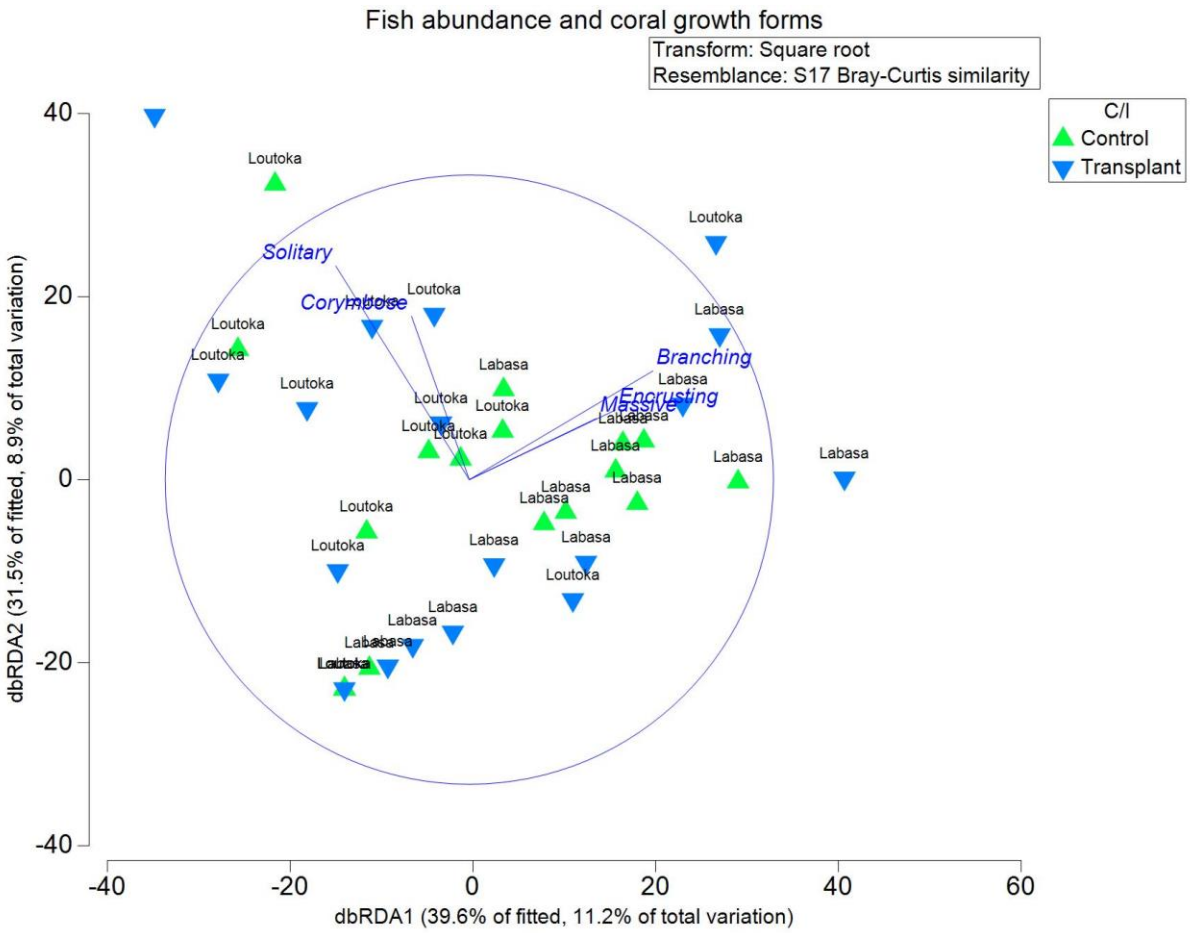


Figure 10. Distance based RDA plot showing the correlation between Fish assemblage structure (species abundance) and coral growth form at reference and transplant plots prior to the placement of corals fragments. A combination of Solitary, Encrusting, Branching, Corymbose, and Massive corals explain a cumulative total of 28.26% variation in the fish abundance.

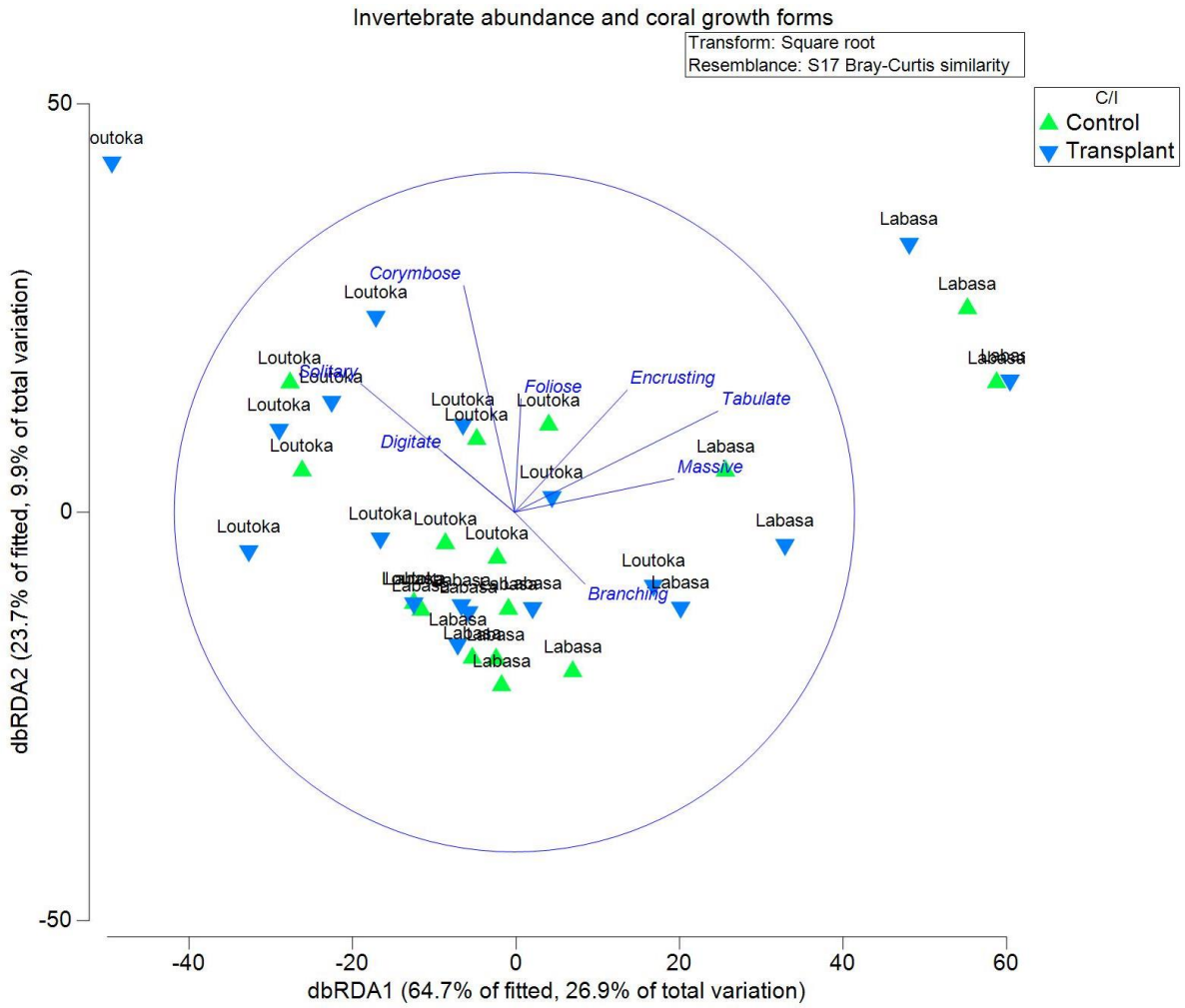


Figure 11. Distance based RDA plot showing the correlation between invertebrate assemblage structure (species abundance) and coral growth form at reference and transplant plots prior to the placement of corals fragments. A combination of Branching, Corymbose, Digitate, Encrusting, Foliose, Solitary, Massive and Tabulate coral explain a cumulative total of 42% variation in invertebrate abundance.

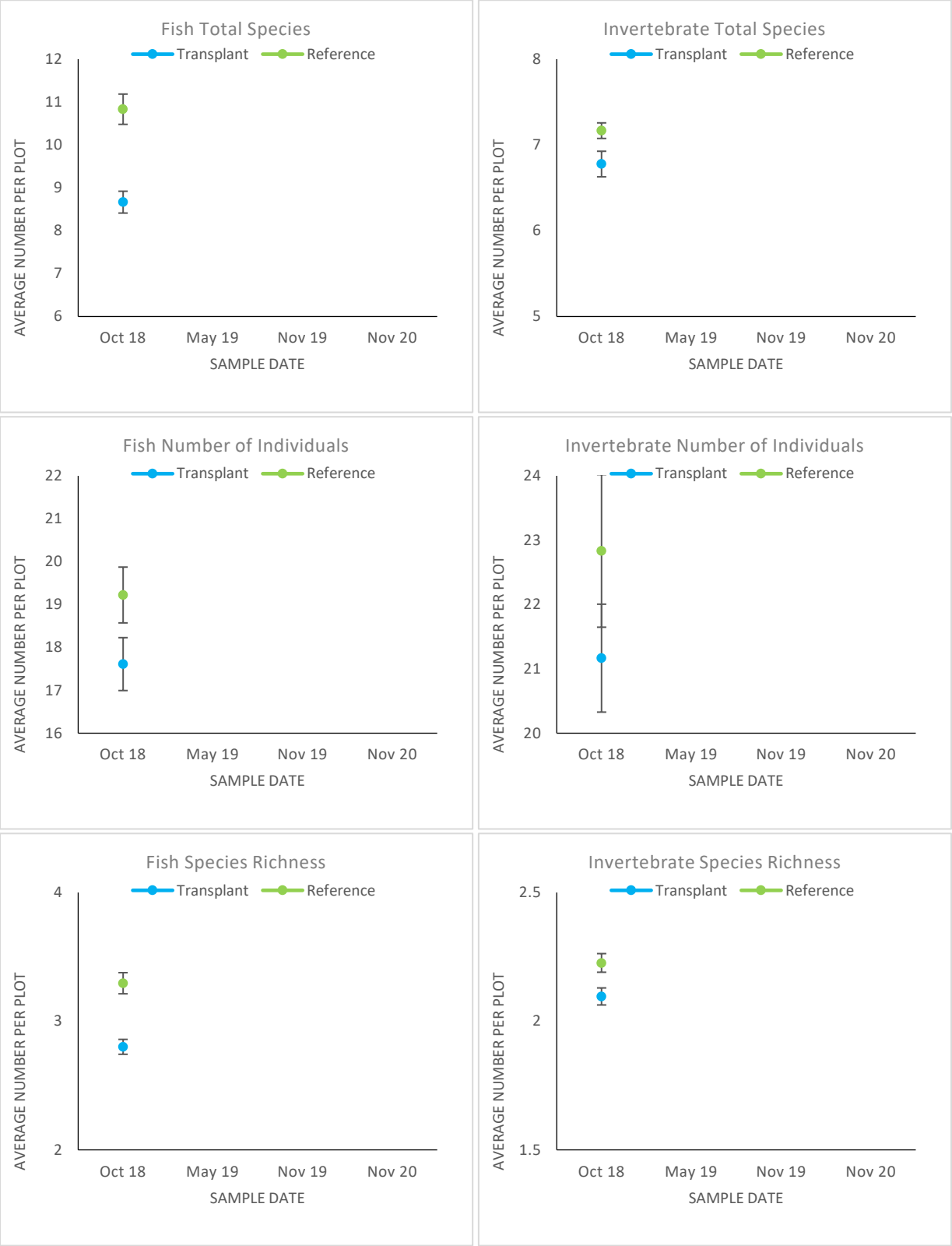


Figure 12. Baseline fish and invertebrate total species, number of individuals and species richness at transplant and reference sites. Coral transplants will be installed at transplant sites and parameters quantified at subsequnt times over two years.

Discussion

The baseline data collected showed that there was no difference between any sites, whether they were transplant or reference sites. This demonstrates that the farm sites have no adverse impact on the surrounding ecosystem. Regardless of this similarity, the purpose of this trial is to quantify if there is a significant impact of transplanting corals into degraded reef areas. Based on results elsewhere (Opel et al. 2017), we would expect that the increase of coral cover and habitat complexity would increase biodiversity, especially fish assemblages. Furthermore, if mature corals are fragmented and immediately transplanted into degraded reef, there are greater growth rates and higher survival rates, when compared with those that have already healed over (Nava et al. 2017). It is suggested to fragment larger corals from the racks before transplanting them onto the substrate.

By comparing the sites that we installed nearby the pre-existing WSI farms to reference sites, no differences were found in any of the biological measures. Even if there were differences, they might not have been caused by the presence of the farms, as we do not have any data from before the farms were installed, and as such no conclusions can be drawn. Benefits from the farms may potentially be measured in the future if ADE actively plant corals grown on the racks into the rocky reef surrounding it. If there is an increase in the biological measures of diversity and abundance of fish and invertebrates inside of our experimental plots only, and not in the reference plots, that would mean that there is a positive impact of these coral farms and coral transplanting. But this remains to be measured from future field surveys.

Summary and Future Survey Timing and Frequency

Baseline measures of coral cover, benthic habitat complexity, invertebrate diversity and demersal fish diversity have now been quantified. Additionally, coral recruitment tiles have also been installed. Preliminary results demonstrate that the coral reef ecosystems are roughly equivalent between transplant and reference sites. One conclusion that could be drawn from this is that it is unlikely that the farm sites have had an impact on these coral reef ecosystems. However, it must be stressed that this project is not designed to test this hypothesis. In fact, sites were chosen based on their overall degraded status. This is to test the hypothesis that transplanting corals will result in improved coral reef ecosystems at transplant sites relative to degraded sites that are left to recover naturally.

Now that all plots have been installed and baseline measures gained, ADE Project staff will commence manual population of the transplant plots, adjacent to the coral farms with coral fragments. As mentioned in the methods, the undesirable corals for aquaculture export will be installed into transplant experimental plots, to measure the potential benefits to biodiversity. These transplant and reference plots will be resurveyed 6 months after coral propagules have been transplanted into the plots, anticipated for May 2019, again 6 months later in November 2019 and ideally again in November 2020 (Table 4). It is strongly encouraged that coral transplanting be completed and all focus placed on fundraising to achieve these field surveys.

Once all surveys have been completed, multivariate datasets describing the changes in coral and benthic communities and how these correlates with changes to invertebrate and fish assemblages; and how these compare to reference sites will be determined. The results at the conclusion of the 12 month project will be written up as a draft manuscript and submitted to the Journal Marine Ecology Progress Series (MEPS) or similar for consideration.

Table 4. Outlining the details and current status of field surveys, including estimates of the number of coral fragments for transplanting and the number of days required to complete the science field work and data reporting.

Sampling scenarios	Number required	Number achieved
Locations	2	2
Sites	2	3
5 x 5m transplant plots at each of two locations	6	18
Number of transplanted coral fragments @ 190 @ 12 plots	~2300	TBA
Reference Plots at each of two locations	6	9
Total number of 5 x 5 plots	24	36
Number of star pickets or 1.5m reinforcement bar lengths required	100	144
Number of buoys needed	24	36
Number of terracotta settlement tiles 10cm x 10cm installed	32	36
Field and Lab time per trip		
Field trip 1 July 2018 – Plot setup and baseline measurements prior to transplanting corals		**Status**
Days Mobilization/ Demobilization	2	Completed
Days in the field	8	Completed
Days for data analysis	15	Completed
Field trip 1: Total time and data processing	**25**	Completed
Cost @ $750 AUD per day	**$18750**	Completed
Field trip 2 ~ May 2019 – first measurement 6 months after plots populated with transplants		
Days Mobilization/ Demobilization	2	TBA
Days in the field	6	TBA
Days for data analysis	15	TBA
Field trip 2: Total time and data processing	**23**	TBA
Costs @ $750 AUD per day	**$17250**	TBA
Field trip 3 July 2019 - second measurement 12 months after plots populated with transplants		
Days Mobilization/ Demobilization	2	TBA
Days in the field	6	TBA
Days for data analysis	15	TBA
Field trip 3: Total time and data processing	**23**	TBA
Costs @ $750 AUD per day	**$17250**	TBA
Analysis and Reporting		
Main deliverable: Final report after Jul 19 (written as draft publication)	15	TBA
Costs @ $750 AUD per day	$11250	TBA
Total 2 x Trip time, Data processing, data analysis, Reporting (AUD)	**$47250**	
Total 3 x Trip time, Data processing, data analysis, Reporting (AUD)	**$64500**	

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Appendices

Appendix 1. Plot mud maps for sites established to evaluate the ecological benefits of transplanted coral fragments.

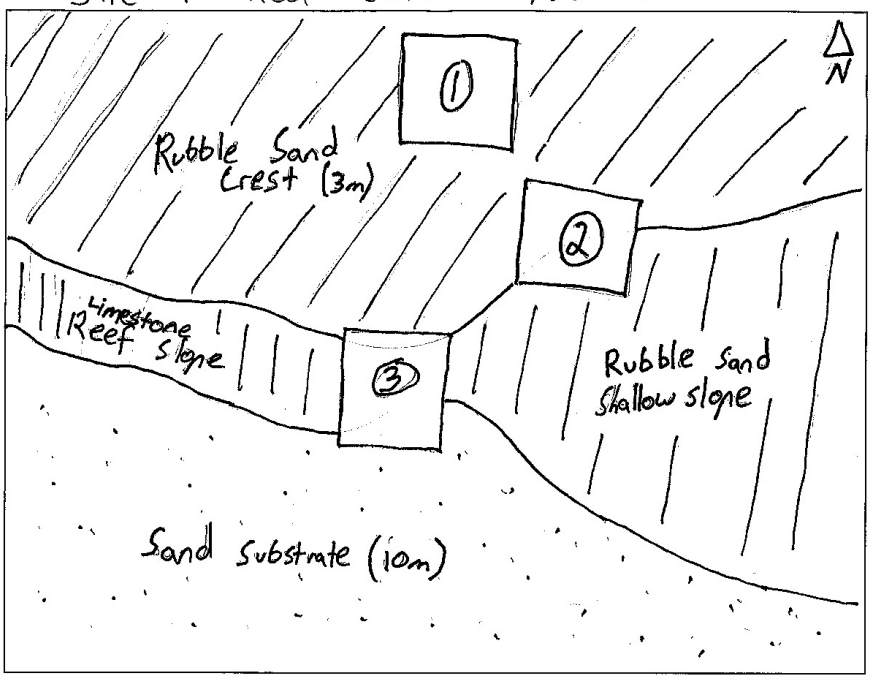
Appendix 2. List of fish species censured across reference and transplant plots.

Appendix 3. List of invertebrate species censured across reference and transplant plots.

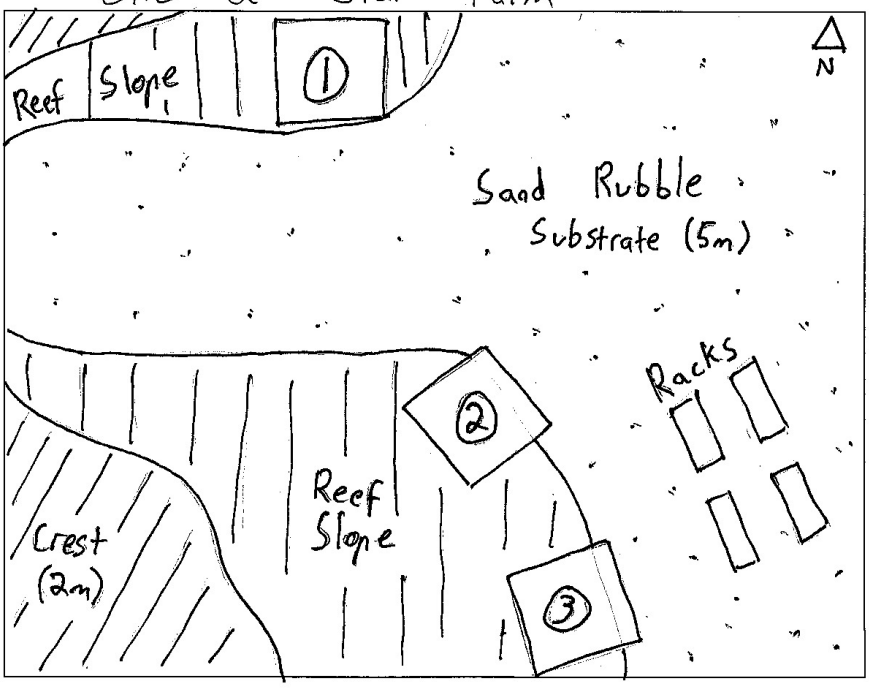
Appendix 4. Benthic classification scheme applied to reference and transplant plot photo quadrats.

Appendix 5. Summary of work undertaken during the setting up of sites and baseline measurements of biophysical habitat, fish and invertebrates.

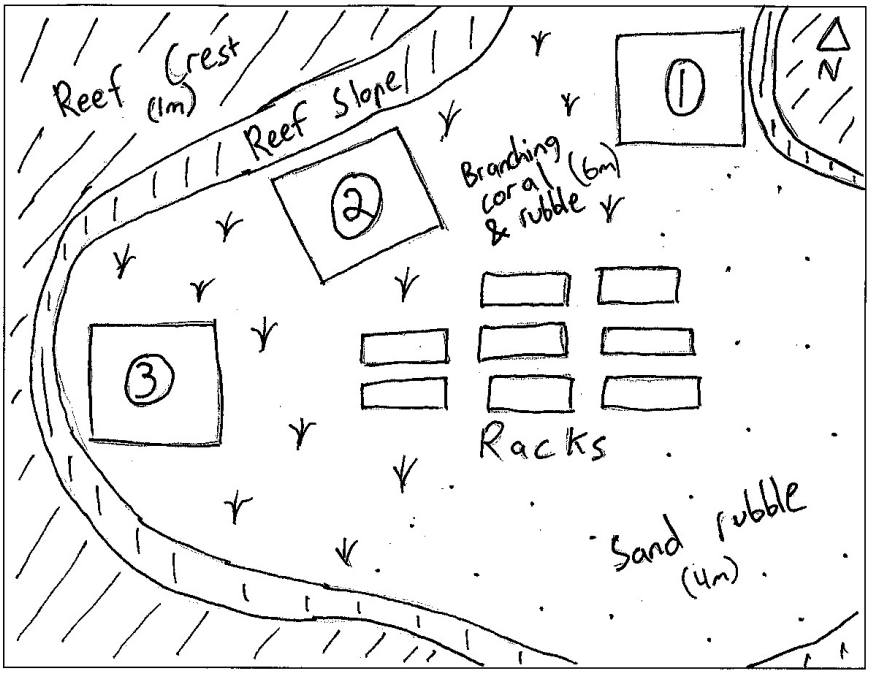
Site 1: Reef control North



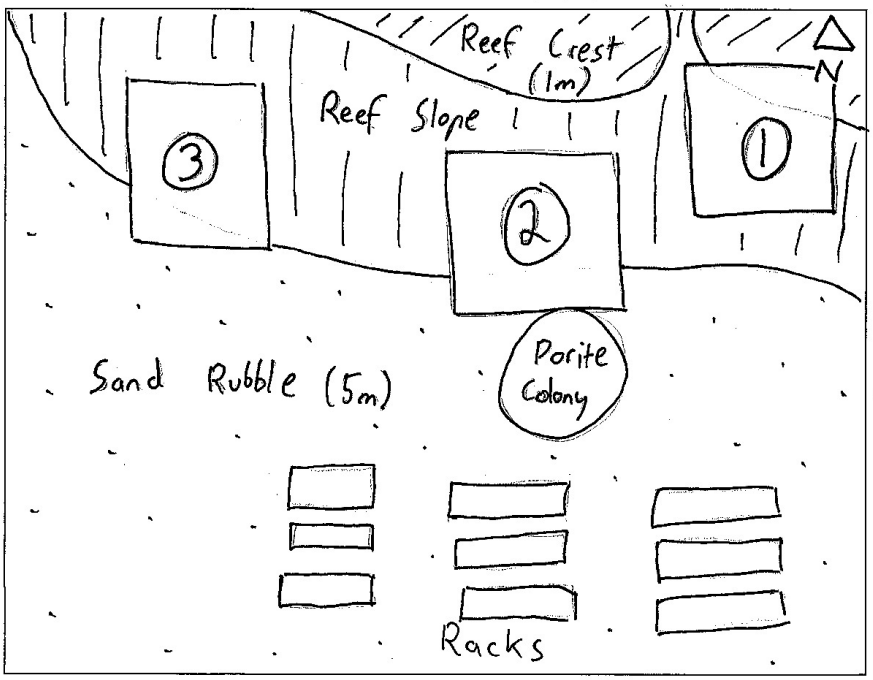
Site 2: Star Farm



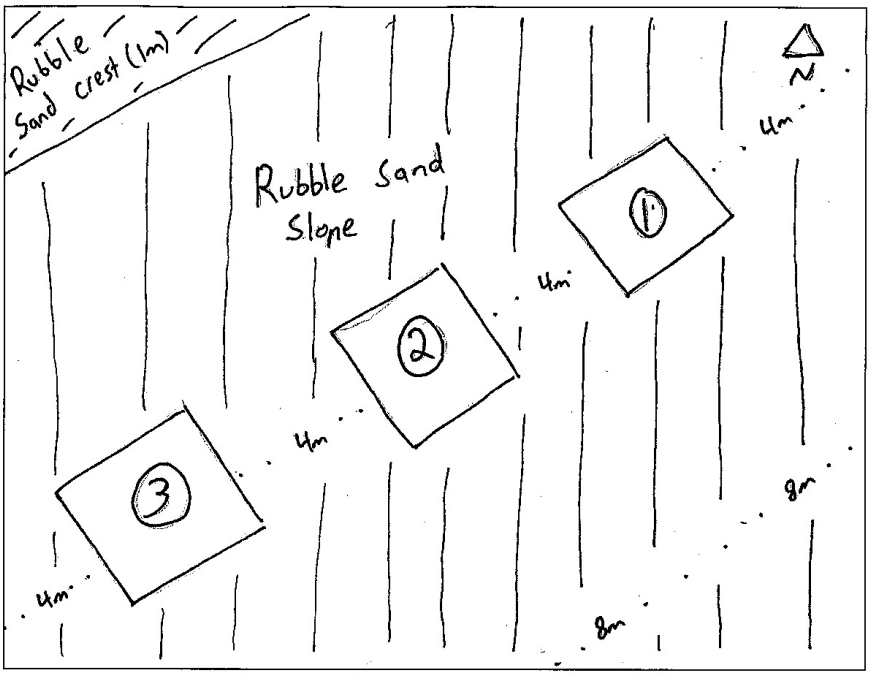
Site 3: WALT FARM



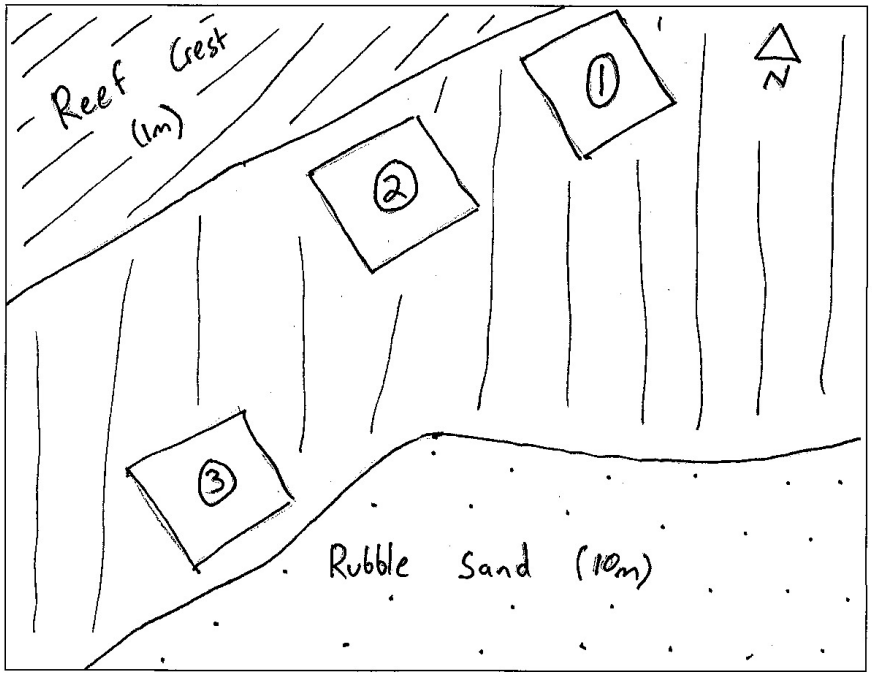
Site 4: KADAVU FARM



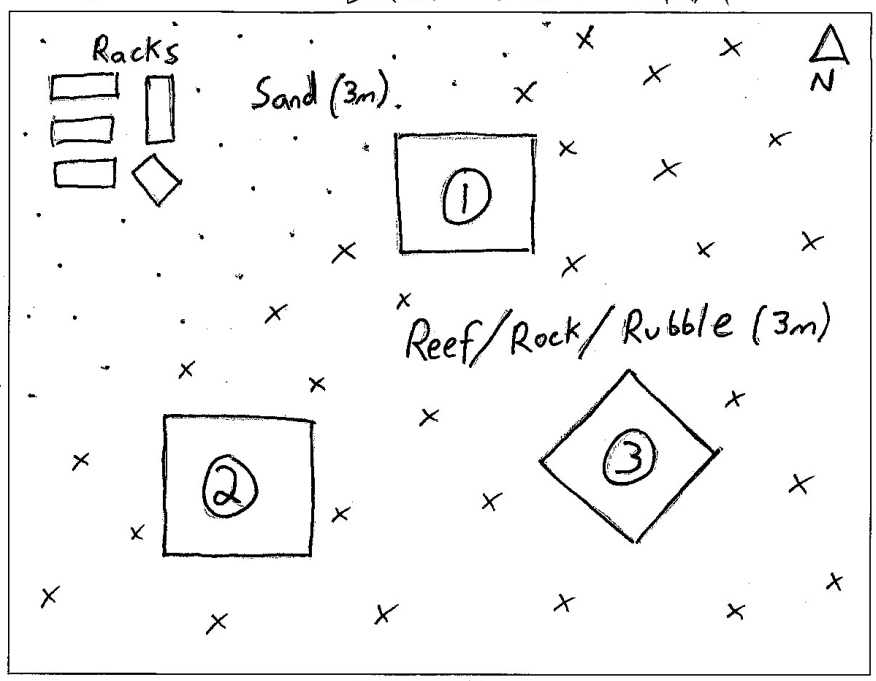
Site 5: Rubble Control



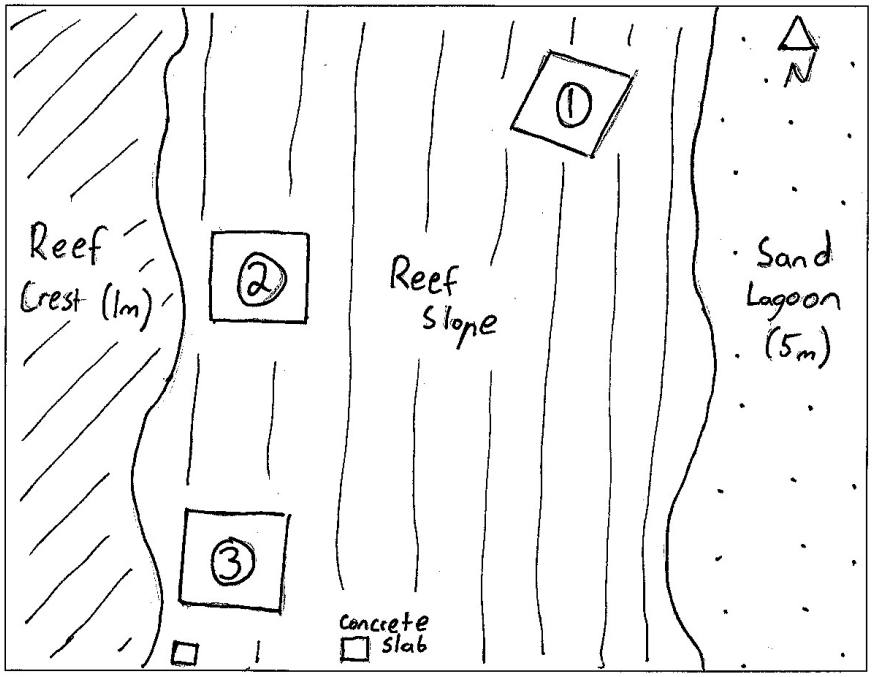
Site 6: Reef Control South



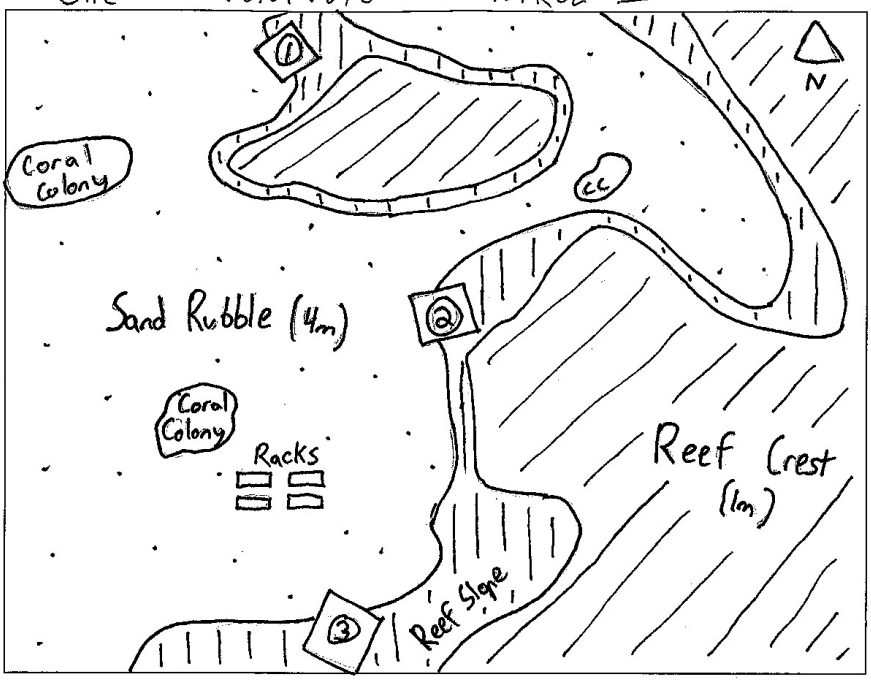
Site 7: DRUA DRUA FARM



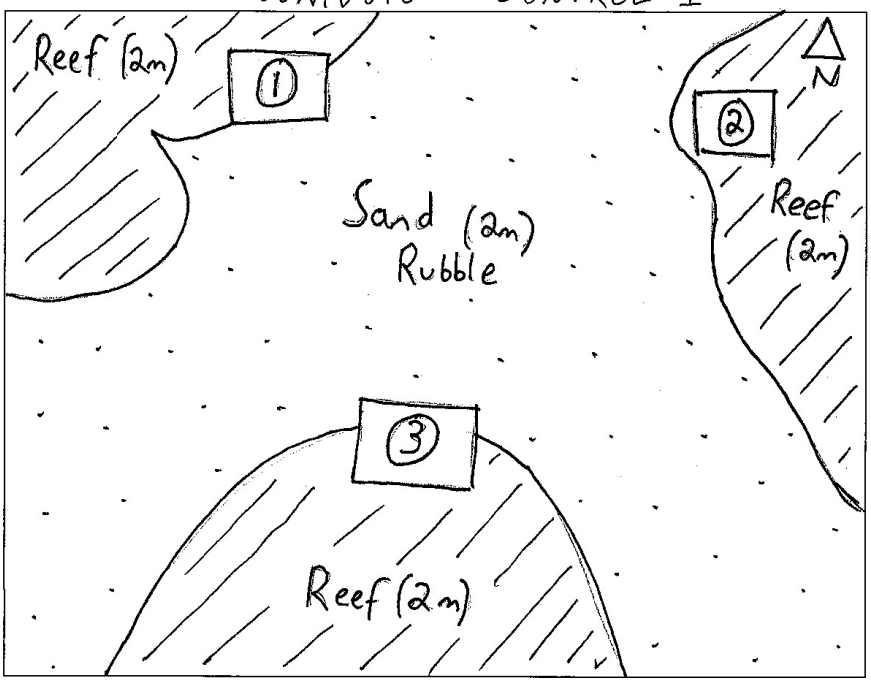
Site 8: DRUA DRUA CONTROL



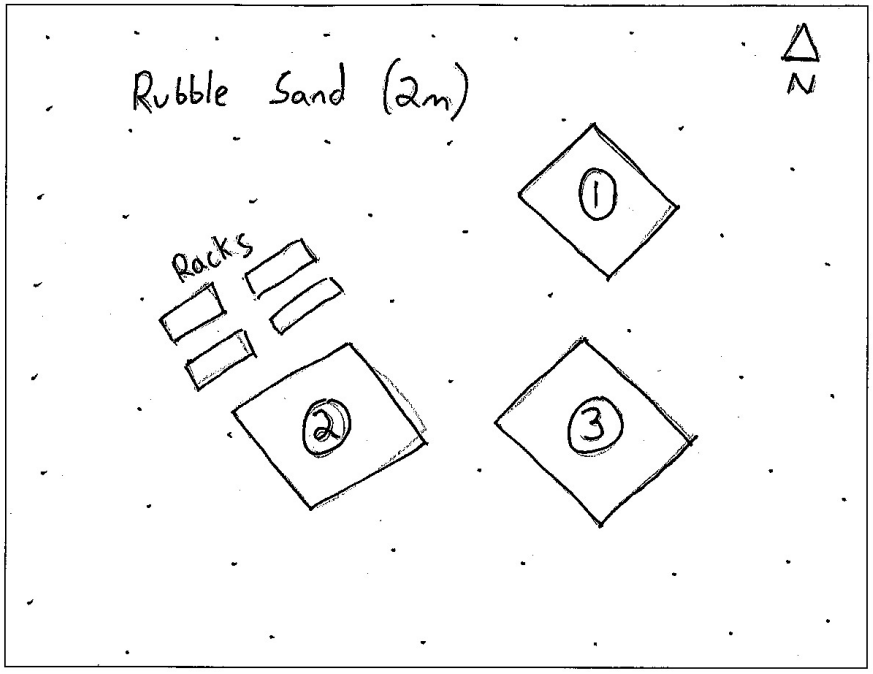
Site 9: Vunivutu Control II



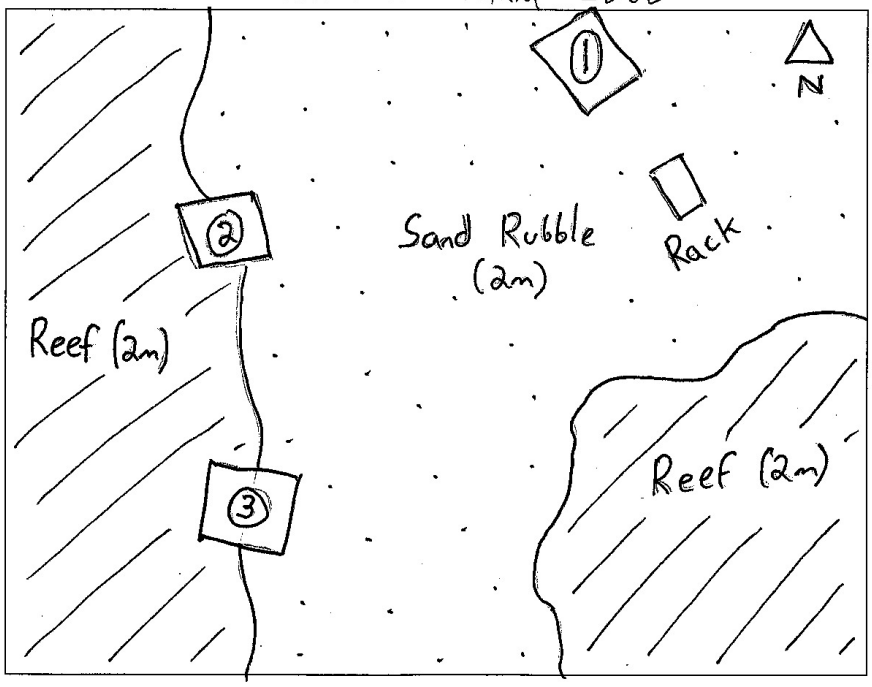
Site 10: Vunivutu Control I



Site 11: Vunivutu Farm Lagoon



Site 12: Vunivutu Farm Edge



Appendix 2. List of fish species censured across reference and transplant plots.

Family	Scientific Name	Family	Scientific Name
Acanthuridae	*A. auranticavus*	Nemipteridae	*S. bilineata*
Acanthuridae	*A. nigros*	Nemipteridae	*S. trilineata*
Acanthuridae	*C. striatus*	Pinguipedidae	*P. hexophthalma*
Acanthuridae	*Z. scopas*	Pomacanthidae	*C. bicolor*
Blennidae	*M. oualanensis*	Pomacanthidae	*C. bispinosa*
Blennidae	Blennidae *sp.*	Pomacanthidae	*C. flavissima*
Caesionidae	*C. caerulaurea*	Pomacentridae	*A. barberi*
Chaetodontidae	*C. auriga*	Pomacentridae	*A. clarkii*
Chaetodontidae	*C. baronessa*	Pomacentridae	*A. curacao*
Chaetodontidae	*C. citrinellus*	Pomacentridae	*A. orbicularis*
Chaetodontidae	*C. lunulatus*	Pomacentridae	*A. sexfasciatus*
Chaetodontidae	*C. vagabundus*	Pomacentridae	*C. glauca*
Cirrihitidae	*C. falco*	Pomacentridae	*C. margaritifer*
Cirrihitidae	*P. arcatus*	Pomacentridae	*C. talboti*
Gobiidae	*V. strigata*	Pomacentridae	*C. taupou*
Holocentridae	*M. violacea*	Pomacentridae	*D. aruanus*
Holocentridae	*N. sammara*	Pomacentridae	*D. reticulatus*
Labridae	*C. chlorourus*	Pomacentridae	*N. carlsoni*
Labridae	*C. fasciatus*	Pomacentridae	*P. atripectoralis*
Labridae	*E. brevis*	Pomacentridae	*P. bankanensis*
Labridae	*E. insidiator*	Pomacentridae	*P. coelestis*
Labridae	*G. varius*	Pomacentridae	*P. flavioculus*
Labridae	*H. melapterus*	Pomacentridae	*P. lacrymatus*
Labridae	*H. prosopeion*	Pomacentridae	*P. maafu*
Labridae	*Halichoeres sp.*	Pomacentridae	*P. pavo*
Labridae	*L. dimidiatus*	Pomacentridae	*P. spilotoceps*
Labridae	*L. unilineatus*	Pomacentridae	*S. punctatus*
Labridae	*P. moluccanus*	Pomacentridae	Pomacentridae *sp.*
Labridae	*S. strigiventer*	Scaridae	*C. bleekeri*
Labridae	*S. trilineata*	Scaridae	*C. sordidus*
Labridae	Labridae *sp.*	Scaridae	*S. dimidiatus*
Labridae	*T. Hardwicke*	Scaridae	*S. frenatus*
Labridae	*T. lunare*	Scaridae	*S. rivulatus*
Lethrinidae	*M. grandoculis*	Scaridae	Scaridae *sp.*
Monacanthidae	*O. longirostris*	Serranidae	*C. urodeta*
Mullidae	*P. barberinus*	Serranidae	*E. merra*
Mullidae	*P. cyclostomus*	Siganidae	*S. doliatus*
Mullidae	*P. multifasciatus*	Tetraodontidae	*A. nigropunctatus*

Appendix 3. List of invertebrate species censured across reference and transplant plots.

Common name	Species name	Common name	Species name
Anemone	Anemone sp. 1	Starfish	Linckia laevigata
Anemone	Anemone sp. 2	Starfish	Fromia indica
Ascidian	Acideacea sp. 1	Starfish	Linckia multifora
Ascidian	Acideacea sp. 3	Starfish	Echinaster callosus
Ascidian	Acideacea sp. 5	Starfish	Fromia milleporella
Ascidian	Acideacea sp. 2	Tubeworm	Spirobranchus sp.
Ascidian	Acideacea sp. 4	Unknown/ NA	Unknown/ NA
Ascidian	Acideacea sp. 6	Urchin	Urchin sp. 1
Bivalve	Bivalvia sp.	Urchin	Urchin sp. 2
Bivalve	Tridacna sp.	Urchin	Urchin sp. 3
Bivalve	Bivalvia sp. 2		
Bivalve	Pinnidae sp.		
Bivalve	Pedum spondyloideum	Soft Coral	Stolonifera
Brittle Star	Ophiocomidae sp.	Soft Coral	Alcyonacea
Crown of Thorns	Acanthaster planci	Submassive Porifera	Porifera sp. 1
Crustacean	Dardanus lagopodes	Tubulate Porifera	Porifera sp. 5
Crustacean	Paguritta corallicola	Encrusting Porifera	Porifera sp. 2
Crustacean	Crustacean sp.	Encrusting Porifera	Porifera sp. 4
Cryptic Fish	Blennidae sp.	Massive Porifera	Porifera sp. 3
Feather Star	Crinoidea		
Flatworm	Acanthozoon sp.		
Gastropod	Cypraeidae sp.		
Gastropod	Gastropod sp. 1		
Gastropod	Muricidae sp.		
Gastropod	Phyllidiella pustulosa		
Gastropod	Phyllidia carlsonhoffi		
Gastropod	Phyllidia ocellata		
Gastropod	Glossodoris hikuerensis		
Gastropod	Phyllidiella annulata		
Macroalgae	Phaeophyta sp. 1		
Sea Cucumber	Bohadschia graeffei		
Sea Cucumber	Bohadschia argus		
Sea Cucumber	Holothuria edulis		
Sea Cucumber	Holothuria atra		

Appendix 4. Benthic classification scheme applied to reference and transplant plot photo quadrats.

Group	Description	Code	Group	Description	Code
Bedforms	"Pavement"	P	Macroalgae	Mixed Rhodophyta (red	Rh
Bedforms	"Rubble"	R	Macroalgae	Mixed Chlorophyta (green	Ch
Bedforms	"Sand"	S	Macroalgae	Mixed Phaeophyceae	Ph
Bedforms	"Mud/Silt"	MS	Macroalgae	Unidentfied Turf Algae	TA
Bedforms	"Coarse Sands (Shell)"	SS	Macroalgae	Unidentified Macroalgae	U
Bedforms	"Gravel"	GRAV	Macroalgae	Macroalgae	MACA
Bedforms	"Pebble"	PEB	Macroalgae	Turf	TURF
Bedforms	"Limestone Pavement"	LIPA	Macroalgae	Halimeda	HALI
Bedforms	"Rock - Low Profile"	RLP	Macroalgae	Sargassum	SARG
Bedforms	"Rock - High Profile"	RHP	Macroalgae	Asparagopsis	ASPA
Bedforms	"Oyster Bed"	OYB	Macroalgae	Caulerpa	CAUL
Bedforms	"Other Bedform"	BOT	Macroalgae	Brown algae	MBL
Bedforms	"Ripple Bedform (<10cm	RBE	Macroalgae	Green algae	MGL
Bedforms	"Waves Bedform (>10cm	WBE	Macroalgae	Red algae	MRL
Bedforms	"Bioturbated Bedform"	BB	Macroalgae	Padina	PAD
Coral - Hard & Soft	Coral	C	Motile benthic	"Worms"	WO
Coral - Hard & Soft	"Recently dead coral"	RDC	Motile benthic	"Zoanthid"	ZO
Coral - Hard & Soft	"Heliopora"	HE	Motile benthic	"Crustacea"	CRUS
Coral - Hard & Soft	"Tubipora"	SOP	Motile benthic	"Fish"	FISH
Coral - Hard & Soft	"Branching hard coral"	HBR	Motile benthic	"Feather star"	EFS
Coral - Hard & Soft	"Columnar hard coral"	HCC	Motile benthic	"Stalked crinoid"	ESC
Coral - Hard & Soft	"Corymbose hard coral"	CHC	Motile benthic	"Unstalked crinoid"	EUC
Coral - Hard & Soft	"Digitate hard coral"	HDC	Motile benthic	"Ophiuroid"	EO
Coral - Hard & Soft	"Encrusting hard coral"	HEC	Motile benthic	"Basket star"	EBS
Coral - Hard & Soft	"Foliose / plate hard coral"	HPC	Motile benthic	"Brittle / snake star"	EBB
Coral - Hard & Soft	"Massive hard coral"	MHC	Motile benthic	"Sea cucumber"	SECU
Coral - Hard & Soft	"Sub-massive hard coral"	HMHC	Motile benthic	"Sea star"	ESS
Coral - Hard & Soft	"Tabulate hard coral"	HTC	Motile benthic	"Sea urchin"	ESU
Coral - Hard & Soft	"Hydrozoa other"	HY	Non-coral sessile	"Unknown"	UNK
Coral - Hard & Soft	"Branching Millepora"	HYB	Non-coral sessile	"Other"	O
Coral - Hard & Soft	"Encrusting Millepora"	HYS	Non-coral sessile	"Ascidian"	ASC
Coral - Hard & Soft	Massive Acroporidae	ACMA	Non-coral sessile	"Bryozoa"	BR
Coral - Hard & Soft	Corymbose Acroporidae	ACCO	Non-coral sessile	"Soft Bryozoa"	SB
Coral - Hard & Soft	Staghorn Acroporidae	ACST	Non-coral sessile	"Hard Bryozoa"	HB
Coral - Hard & Soft	Digitate Acroporidae	ACDI	Non-coral sessile	Anemones, Hydrocorals,	O
Coral - Hard & Soft	Branching Acroporidae	ACBR	Non-coral sessile	Tunicata	T
Coral - Hard & Soft	Encrusting Acroporidae	ACEN	Relief	Flat	F
Coral - Hard & Soft	Plate Acroporidae	ACLA	Relief	Low (<1m)	L
Coral - Hard & Soft	Massive Poritidae	PRMA	Relief	Moderate (1-3m)	M
Coral - Hard & Soft	Columnar Poritidae	PRCO	Relief	High (>3m)	H
Coral - Hard & Soft	Encrusting Poritidae	PREN	Relief	Wall	W
Coral - Hard & Soft	Plate Poritidae	PRPL	Seagrass	"Unidentified Seagrass"	USG
Coral - Hard & Soft	Composite Poritidae	PRCM	Seagrass	"Halophila ovalis"	HAOV
Coral - Hard & Soft	Branching Poritidae	PRBR	Seagrass	"Halophila decipiens"	HADE
Coral - Hard & Soft	"Hard coral Fungiidae)"	HCM	Seagrass	"Halophila spinulosa"	HASP
Coral - Hard & Soft	"Hard Coral Faviidae"	HCFA	Seagrass	"Halodule"	HALO
Coral - Hard & Soft	"Hard Coral Pocilloporidae"	HCPC	Seagrass	"Syringodium"	SYRI
Coral - Hard & Soft	"Hard Coral	HCDE	Seagrass	"Cymodocea"	CYMO
Coral - Hard & Soft	"Hard Coral Mussidae"	HCMU	Sponges	Other sponge	SPO
Coral - Hard & Soft	"Hard Coral Other"	HCOT	Sponges	Encrusting sponge	SES
Coral - Hard & Soft	"Black and Octocorals"	OCTO	Sponges	"Branching sponge"	BRAS
Coral - Hard & Soft	"Stolonifera"	STOL	Sponges	"Cup sponge"	CS
Coral - Hard & Soft	"Alcyoniina"	ALCY	Sponges	"Massive sponge"	SMS
Coral - Hard & Soft	"Scleraxonia"	SCLE	Substrate	Fine Sand	FS
Coral - Hard & Soft	"Holaxonia"	HOLA	Substrate	Boulders	B
Coral - Hard & Soft	"Calcaxonia"	CALC	Substrate	Limestone Pavement w	LPS
Coral - Hard & Soft	"Anemone"	ANE	Total Cover	Bare (<1%)	B
Coral - Hard & Soft	Gorgonian	GORG	Total Cover	Sparse (1-3%)	S

Mollusc	"Mollusc"	MO	Total Cover	Low (3-10%)	L
Mollusc	"Bivalve"	MOB	Total Cover	Medium (10%-25%)	M
Mollusc	"Cephalopod"	MOC	Total Cover	High (25%-75%)	H
Mollusc	"Cuttlefish"	MOCU	Total Cover	Dense (>75%)	D
Mollusc	"Octopod"	MOO	Coralline Algae	Coralline Algae	CA
Mollusc	"Squid"	MOS	Coralline Algae	Encrusting coralline	En
Mollusc	"Chiton"	MCH	Coralline Algae	Coralline algae	CALG
Mollusc	"Gastropod"	MG	TWS	"Tape"	TAPE
Mollusc	"Oyster"	OY	TWS	"Shadow"	SHAD

Appendix 5. Summary of work undertaken during the setting up of sites and baseline measurements of biophysical habitat, fish and invertebrates.

Site	Site 1: Walt Smith Farm			Site 2: Kadavu Farm			Site 3: Reef North			Site 4: Reef South			Site 5: Rubble South			Site 6: Star Farm		
Island	Lautoka			Lautoka			Lautoka			Lautoka			Lautoka			Lautoka		
Transplant or Reference Site?	Transplant			Transplant			Reference			Reference			Reference			Transplant		
Plot Name	North	Middle	South	East	Middle	West	North	Middle	South	North	Middle	South	North	Middle	South	North	Middle	South
5m x 5m plot Installed?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Marker bouys Installed?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Photogrammetry?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Invertebrate counts?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fish counts?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Site map created?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Settlement tiles?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Transplant Installation?	ASAP	ASAP	ASAP	ASAP	ASAP	ASAP	NA	NA	NA	NA	NA	NA	NA	NA	NA	ASAP	ASAP	ASAP

Site	Site 7: Drua Drua Farm			Site 8: Drua Drua Reference			Site 9: Vunivutu Farm Lagoon			Site 10: Vunivutu Farm Edge			Site 11: Vunivutu Reference 1			Site 12: Vunivutu Reference 2		
Island	Labasa			Labasa			Labasa			Labasa			Labasa			Labasa		
Transplant or Reference Site?	Transplant			Reference			Transplant			Transplant			Reference			Reference		
Plot Name	North	East	West	North	Middle	South	North	East	West	North	Middle	South	West	East	South	North	Middle	South
5m x 5m plot Installed?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Marker bouys Installed?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Photogrammetry?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Invertebrate counts?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fish counts?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Site map created?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Settlement tiles?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Transplant Installation?	ASAP	ASAP	ASAP	NA	NA	NA	ASAP	ASAP	ASAP	ASAP	ASAP	ASAP	NA	NA	NA	NA	NA	NA