Nusa Islands Restoration Site

Blue Corner Marine Research

Andrew C.F. Taylor

Nusa Penida Restoration Project

Project Goals & Description

The Nusa Islands Restoration Project is an attempt to reverse the degradation of reef areas along the northern coastline of Nusa Lembongan & Penida Islands, Bali. Coral reefs are an important source of income for the local community from tourism and fishing activities, but has been subjected to a variety of impacts over the years. Impacts have seen areas which used to be biodiverse coral reefs turn to unstable rubble. The primary goals of this project are to increase ecosystem function and habitat complexity. It is an important reef to the area for tourism, as well as ecologically important being within a marine park.

The restoration project began in the start of 2018 and is directed by Andrew Taylor, professional biologist and certified Ecological Restoration Practitioner from Blue Corner Marine Research (the conservation arm of Blue Corner Dive). A need for reef restoration was highlighted as a priority in the area, so Blue Corner together with support from the Lembongan Marine Association implemented a restoration plan.

Additional information about the coral restoration project can be seen here:

http://bluecornerconservation.org/coral-reef-restoration

Defining the Problem

DEGREDATION DESCRIPTION

Large areas of broken and dead coral rubble have formed on the reef flat and reef crest along the northern coastline of Nusa Penida. As seen in many areas of SE Asia, when reef areas turn to rubble they are rarely able to recover naturally back into a functioning coral reef. The areas in Nusa Penida have not shown signs of recovery in at least 8-10 years which they have been observed. Rubble areas have actually been increasing in size due to erosion in currents and smothering of adjacent and down-slope reef area.

Initial causes of coral rubble was from a host of reasons:

- anchors dragged from various types of boats including fishing boats, dive & snorkel boats, and pontoons
- clearing of coral from the reef flat for seaweed farming, which removed the natural structure of the reef and changed onshore energy
- Clearing coral areas for pontoon tourism - high intensity package tourism in the area has become popular. With over 20 floating tourist rafts each offering sea-walking and other watersports. The rafts shade areas of reef and operators clear adjacent areas of reef for underwater activities.
- Reinforced seawalls along the coastline which causes wave energy to travel back across the reef flat breaking coral
- Historical dragging of fish traps and nets across reef flat

The resulting rubble areas are highly mobile and are showing signs of eroding down the reef slope increasing the size of the impact footprint. Little recruitment survival are seen in rubble areas. There is reduced reef health compared to adjacent reef areas, due to the impact site being 100% rubble.

PRIORITIZING IMPACT AREAS

Due to the high currents in the areas, water quality remains quite good as can be confirmed by healthy coral reef still remaining in adjacent areas.

Several large dead rubble patches exist along the coastline, and while we would like to work towards restoring it all back to a healthy state, we must prioritize which areas will receive the first and greatest restoration efforts. Some areas of reef are being used by intensive pontoon tourism and boat traffic. These areas we classified as "highly impacted harbor sites" or "sacrificial impacted sites" and are a low priority for restoration as the continued pressure on the reef in those areas means that any efforts to restore would be a waste of resources.

Some small areas of rubble may have chance for natural recovery and therefore be low-medium priority for restoration. Identifying characteristics of such sites are:

- Relatively small rubble patches;
- Coralline algae forming upon rubble;
- Recruitment of hard corals and Xenia soft coral within the rubble Areas of reef that were designated as high priority for restoration were high value reefs for the dive tourism industry. The rubble areas in these areas are in need of stabilization as rubble is actively smothering and killing neighboring coral.

ASSESSING NEED FOR RESTORATION

In order to determine if coral restoration should be conducted in an area and subsequently develop a restoration plan, we evaluated the following questions:

DID THE SITE PREVIOUSLY SUPPORT A CORAL REEF?

If the site was not previously a coral reef, then the works cannot be seen as a "restoration" project but rather some other activity.

Based on the rubble present at the site, historical accounts and appearance of adjacent area, we can assume that the restoration site was at one time a healthy and thriving coral reef prior to becoming degraded.

Rubble of dead coral skeleton now makes up close to 100% of the substrate in the area. The predominant types of skeleton seen in the rubble fields appear to be similar species to those growing in healthy adjacent areas, so we can assume that at one time these rubble patches resembled the adjacent "healthy" areas.

Since we can determine that yes, indeed this area was previously a healthy coral reef, then it becomes a suitable candidate for restoration.

HAVE THE CAUSES OF DEGREDATION BEEN STOPPED?

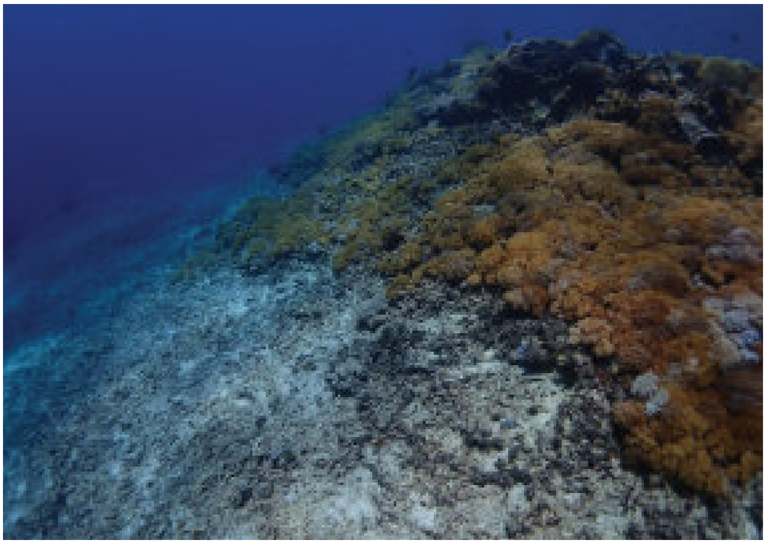
If the activities which caused the initial reef damage continue, then any restoration efforts in the area are futile, as potential gains in ecosystem health will be quickly eliminated by further impacts.

The marine park management has implemented a zoning system within the park as to which activities are permitted within zones. The restoration site has been designated protected area and so the previous boat anchoring and fishing impacts are now reduced. The area has seen a drastic increase in tourism over the last decade, so traditional extractive activities such as fishing and seaweed farming have diminished substantially. This is due to the comparatively higher wages and living standards derived from tourism-based economy.

Additional measures to reduce existing threats to the ecosystem, have included educational programs with watersports operators about providing environmental briefings for guests. Also, waste management initiatives on the island including the recent establishment of a recycling centre in an attempt to reduce waste and pollution from entering the ocean.

Since many of the initial impacts and activities causing degredation have been reduced we are able to proceed cautiously with restoration planning at the site.

IS SELF-RECOVERY POSSIBLE?



In well managed reef areas, if there is suitable stable substrate remaining on the reef and ample larval imput of new young corals settling in the area; then natural unassisted recovery may be possible. If natural recruitment is already high at a site then a restoration program may not be necessary.

This site in Nusa Penida is comprised of unstable rubble and has not shown signs of recovery or successful natural recruitment in the 10 years they have been observed by the Blue Corner Marine Research team. Therefore it appears that self-recovery is not taking place at these reefs and so coral restoration is a suitable option.

CONSIDERATIONS FOR CLIMATE CHANGE

Nusa Penida is in a unique area of the ocean. It is located at the terminus of the "Indonesian Through-flow". As the earth spins equitorial waters of the Pacific Ocean move west into Oceana and Southeast Asia. Much of that water then drains through the various channels of Indonesia into the Indian Ocean. Several of those channels including the primary Makasar Strait funnel into the Lombok Strait - which is a narrow gap between the islands of Bali and Lombok. The Nusa Islands are small obstructions at the bottom of this strait. The passing currents cause strong eddys and upwellings with deep ocean water mixing with surface waters. Water temperature ranges between 15 - 30 degrees in the area with extreme day-to-day variability.

Because of the high variability of temperature in the area, corals growing on the reefs here have a high thermal tolerance compared to other reefs in the region. The mass bleaching events of 2016, 2018 & 2020 showed significantly less bleaching and rapid recovery time of coral in our region compared to neighboring regions.

As many healthy stands of corals exist on the reefs after recovering from 3 recent bleacing events in the last decade, we can incorporate these corals into our restoration planning by using resilient corals such as these as parent stock for nurseries.

Restoration Plan

The restoration plan is being carried out in area of degraded reef flat & reef slope in order to stabilize rubble substrate and stimulate coral recovery. The project involves both structural & biological restoration phases.

SITE ASSESSMENT & PILOT STUDY

The extent of impact area needing restoration was measured and mapped. A pilot project was conducted within an impacted reef area which was deemed high priority for restoration. This initial restoration site is located at Sental Reef on Nusa Penida, Bali (GPS coordinates: 8.676380 S, 115.530045 E). The size of the rubble area within this site is approximately 1325 sq m. Once techniques were established the restoration site was then expanded out to 3 adjacent areas of about 4000 sq m by the end of 2019.

Healthy Reference Site:

Nearby to the restoration site there are areas of healthly reef at the same depth and exposure. SD Reef (pictured here) was chosen for as the reference community to measure recovery trajectory against.

The reference communituy was also used as one of several donor sites for initial coral transplants to the restoration site.

REFERENCE COMMUNITY

After determining the size of project we needed to determine the target reef community which we were aiming to restore towards. To do this we wanted to understand the historic reef community at the site prior to impact, so that we could have a blueprint of what kind of reef we were trying to restore back to.

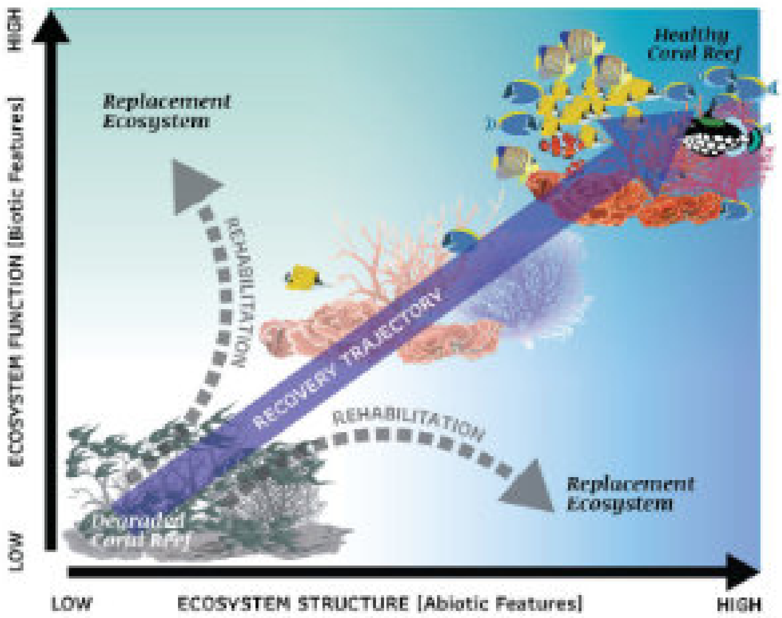
This was done from looking at historical reef health monitoring data and photos of the area, analysising the contents of the rubble in terms of what species dead coral skeletons.

For reference, we looked at the adjacent healthy areas of reef along the same shoreline and depth. Transect surveys were conducted of coral and reef substrates, as well as abundance and diversity of fish species present.

RECOVERY TRAJECTORY

Any attempt to restore a coral reef ecosystem needs specifically defined management goals. In order to determine if a coral reef has been successfully restored, aims must be set for target endpoints measureable by some means of indicator.

The primary aim of restoration is to improve the degraded reef in terms of ecosystem structure and function. Ecosystem structure is the physical or abiotic features of the reef - such as topographical complexity, heterogeneity of habitat, and water quality parameters. Ecosystem function is the biotic geatures of living organisms of the system and their complex relationships.

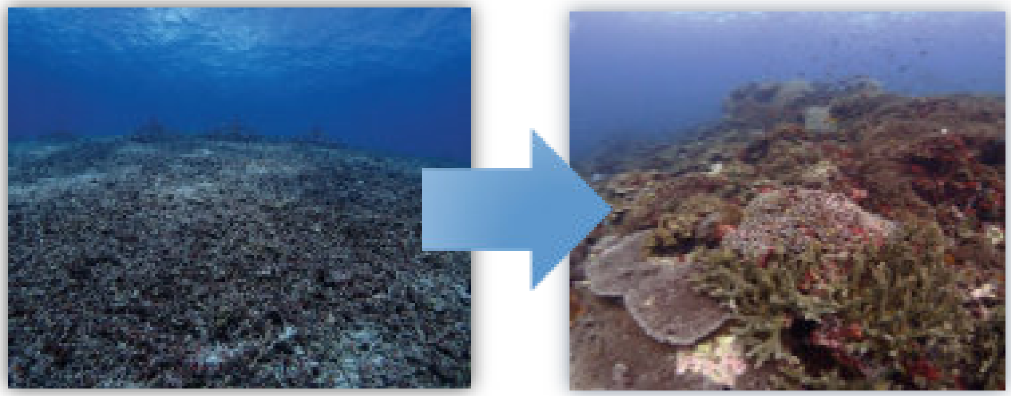


Recovery Trajectory:

The changes in physical and biological aspects of the environment from its degraded state towards a healthy state is referred to as the recovery trajectory.

In a healthy reef system with good resilience, a small impact will recover naturally to its pre-disturbance state along a recovery trajectory (which is the successional populations of organisms settling into the site and their relative abundances). Active restoration aims to mimic this and assist natural processes. We are assisting the reef along a recovery trajectory towards a defined healthy state.

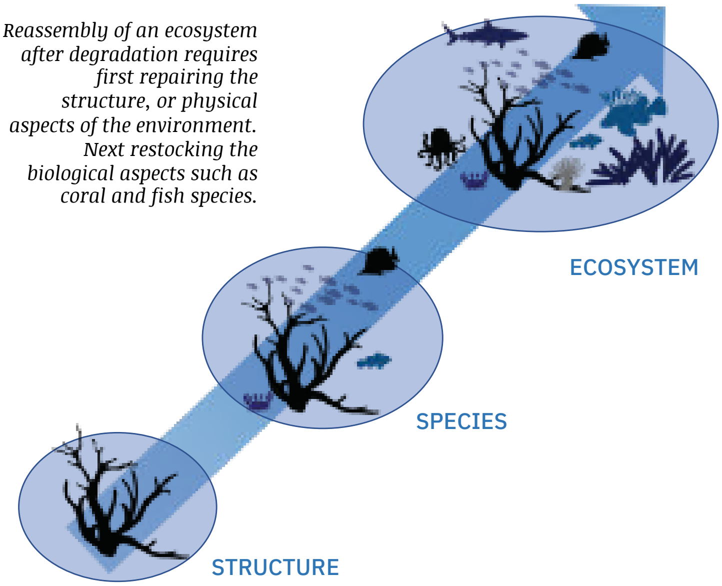
The goal of our restoration site in Nusa Penida is to take the site from its current state almost completely denuded of living coral and structure into a healthy state of high coral cover and diversity with multiple functional aspects of the ecosystem. In order to do this we must recreate the topographical structure of the reef to provide habitat, and stabilize the rubble and erosional aspects of the site. The next step is to re-establish the primary habitat forming organisms in an attempt to attract key marine species and re-instate the fundamental roles of the ecosystem.



ACTIVE RESTORATION MEASURES

Active Restoration:

Reassembly of an ecosystem after degradation requires first repairing the structure, or physical aspects of the environment. Next restocking the biological aspects such as coral and fish species.



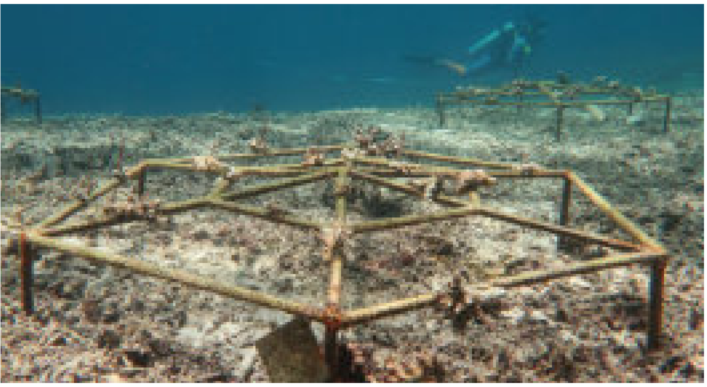
PHYSICAL RESTORATION

Physical restoration refers to repairing the structure of the reef and prepare the substrate for marine life to come and settle. Physical restoration must take place before biological restoration is likely to be successful. For example, transplanting living coral colonies onto unstable rubble substrate will simply result in mortality of the transplants.

As the Nusa Penida restoration site consisted of unconsolidated substrate which is prone to erosion in ocean currents, we determined that structural restoration was needed prior to restocking of biological communities.

Structural restoration of the site involves a variety of measures including installing coated metal frames, and mesh rubble fencing to provide a stable substrate and habitat for marine life to utilize.

We designed modular metal frames and covered them in a non-toxic calcium carbonate coating (epoxy & sand). Rebar frames are coated to prevent premature metal degradation and to promote coraline algae settlement and coral attachment. The frames provide tropographical structure to the reef and are used as building blocks for habitat formation. They also provide a stable substrate for coral transplantation.



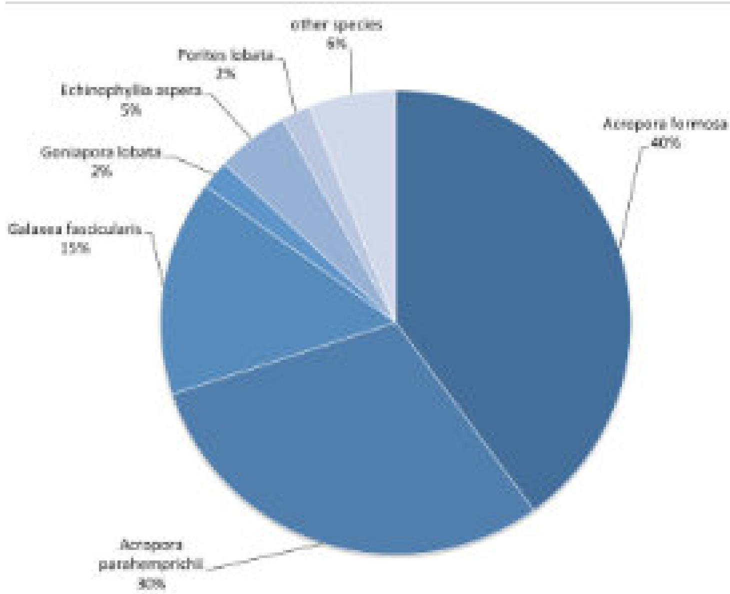
Structures were deployed onto the restoration site in a formation along the natural reef crest and clustered in other high erosion areas within the reef flat and slope. This formation had two physical restoration purposes - firstly to trap rubble from shifting down the reef slope and eroding into healthy reef areas; and secondly to reduce onshore wave energy. Biological rationale to the design was to provide patch-reefs in which herbivorous fish and invertebrates could easily colonize by immigrating from adjacent reef area.

Additional factors influencing structure design was ease of installation and cost effectiveness. Structures were transported to the restoration site and installed by volunteers. The site is in a high current area at the terminus of the Indonesian-Through-Flow ocean current. Therefore the structural restoration techniques required needed to be designed to handle strong forces from high water currents.

In addition to frames we have rolled out metal roofing mesh across areas of rubble in attempt to stabilize rubble movement. This structural restoration step was added after we conducted a test plot of mesh for several months to track rubble movement and erosion. We found that the mesh stabilized rubble for a long enough period of time for sponges and soft corals to settle and begin to naturally stabilize the area

BIOLOGICAL RESTORATION

In an attempt to stimulate recovery of biological aspects of the reef we chose to increase habitat for fish and invertebrates by transplanting corals upon the structures. Biological restoration measures used for this project involve transplanting suitable species of coral & building coral nursery for sourcing future transplants.



Suitable coral species for transplantation were defined by analysis of our target community. Target species composition based on surveys of adjacent healthy areas of reef. A list of target species was compiled in appropriate proportions according to water depth and reef zone. Additionally studies in recovering areas were done to determine successional coral community species so that habitat forming foundation

species were utilized for the initial biological restoration efforts.

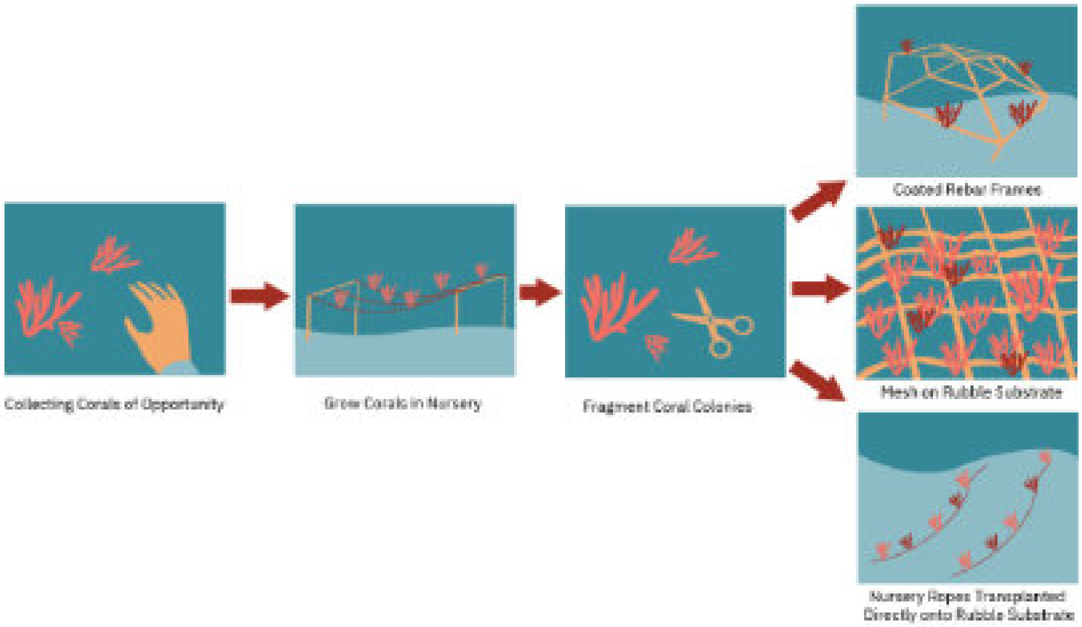
We chose to focus on the dominant species growing in adjacent areas at similar depths and environmental conditions. As well as some of the quick growing habitat forming species such as Acroporas.

After structural restoration was started, we began transplanting coral fragments into the area. Three species of Acropora corals were transplanted as these pioneering species are known to grow quickly to aid in substrate stabilization and provide refuge for natural settlement of coral larvae. Transplants were sourced from an area within the same 1km area and environmental conditions, so as to not introduce new genetic stock or species. In an attempt to kick-start recovery and successional coral communities we transplanted several more species in order to more accu rately reflect the community composition of the nearby reference community. Which included Glaxea corals - a slower growing massive-type formation, foliose shaped Echinophylia corals, and several other branching species such as Montipora.

Frames have had transplants of both single-species per frame and multiple-species per frame to study the effects of competition and promote diversity.

Corals were sourced from both healthy parent colonies of target species and "corals of opportunity" in the adjacent area. Corals of opportunity are recently broken coral fragments found scattered around the reef, which can then be transplanted to grow into full colonies - or fragmented further and grown into several colonies

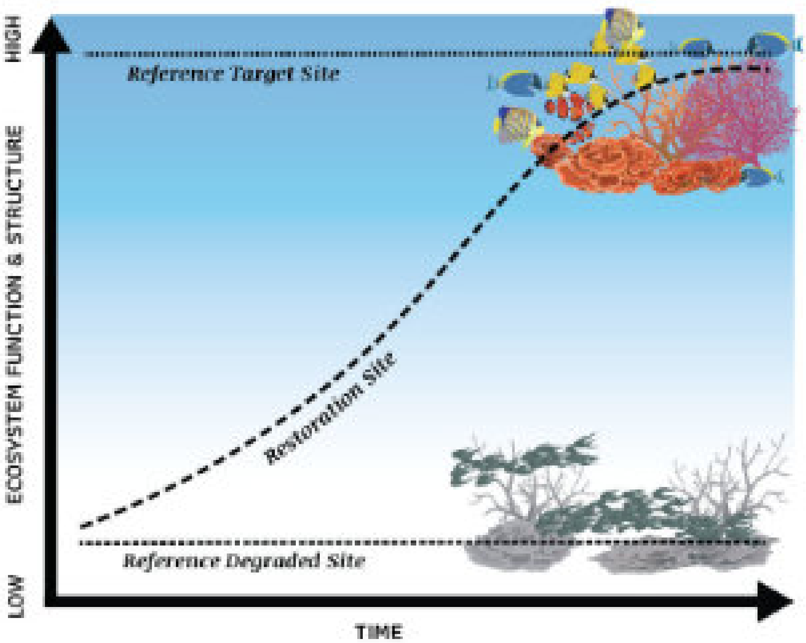
In order to reduce pressure on donor colonies from our healthy reference sites we established a coral nursery. It is a rope nursery design located in the reef flat adjacent to the restoration site. The nursery allows coral fragments to grow under optimal conditions with good water movement and away from benthic predators. Coral fragments are taken to the nursery and grown for several months until they are large enough to be used as parent stock for providing further fragments for transplanting onto the restoration frames.



MONITORING

We must have a clear definition of the healthy state or "reference community" in terms of measurable parameters.

While it may be difficult to monitor every single species and parameter over time at the restoration site, we can track key indicators. By using measurable indicators we can determine if recovery is on tract towards our defined healthy state, or if it is progressing to some state different from the original ecosysytem. In which case, "rehabilitation" may have been achieved through improvement of the ecosystem's function or structure, but not full restoration. Alternatievely the active restoration measures may disappoint and lead to a rather different ecosystem state, in which case the restoration plan will need to be adapted and revised.



We are monitoring the restoration site in comparison to adjacent reference sites of both healthy and un-restored impacted reef. Regular monitoring is conducted on the site to look at:

- transplant growth. Measurements of linear extension on coral transplants are made at regular intervals.
- transplant survivorship;
- Coral coverage. Photographs of each frame show percent cover coral increase.
- coral health.
- if the transplanted corals will begin sexually reproducing in the next spawning season. Transplants were taken from multiple parents so that the restoration plan included genetic diversity of corals.

By transplanting coral it also stimulates natural settlement of secondary substrate-forming species (including soft corals, sponges, hydroids, etc). Mobile grazing organisms (such as parrotfish and butterfly fish) then also begin to use the area and attract both predators and stimulated the settlement of invertebrates. Therefore we are also monitoring the site for:

- secondary settlement;
- fish utilization; Reef Check surveys at regular intervals give measurements of fish and invertebrate abundance.

Results & Progress

The branching Acropora Formosa transplants appear to be growing fastest upon the structures, so this is a useful species to continue to use. During the study we learned that one of the species of Acropora that we are growing is endemic and rare to the area, so although it grows at a slower rate, efforts should be made to preserve this species.

The massive coral Galaxea appears to survive well at the restoration site however is slow to accrete onto metal frames. We adapted the structure design in later phases of the project to create frames covered with a metal mesh for encrusting and massive coral species. This adapted structure design seems to be more effective in allowing those coral growth forms to attach.

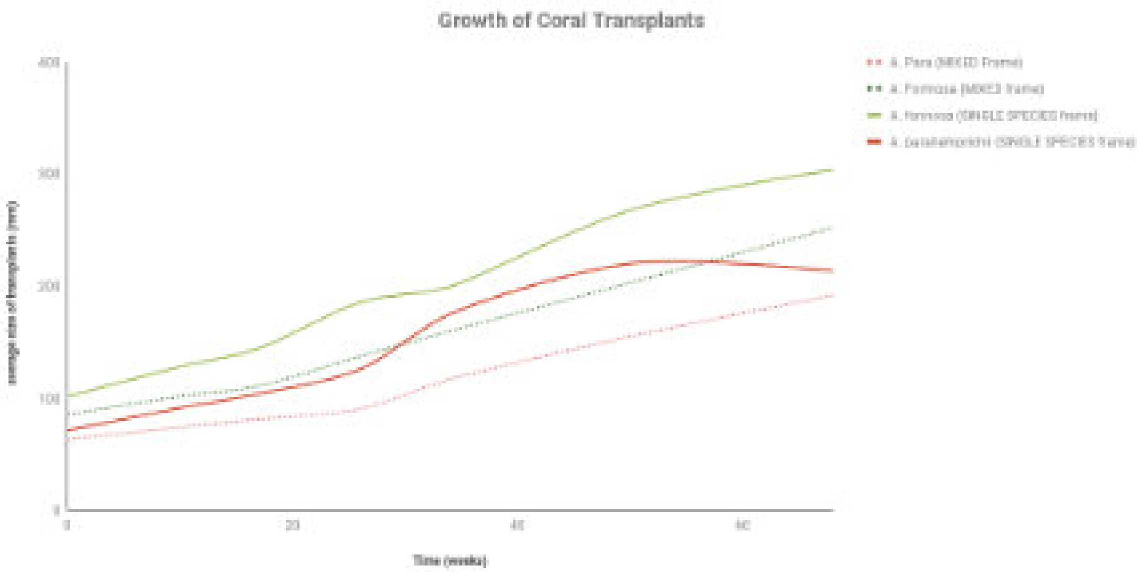
The metal frames held position well in strong currents and waves. The structures also reduced erosion of rubble below them. While other projects have used metal structures continuously placed across entire area, we think it would be more cost-effective to cluster the structures in groups allowing some spacing between them for other restoration techniques or structures.

During the pilot study, the metal structures were placed in the middle of the rubble impact area. Although coral growth was high on these structures, this placement method may have not optimized the natural functions of the reef community. In subsequent phases of the restoration project we placed structures close to the periphery of the impact zone (close to living reef) in an effort to heal the edges of the rubble patch first. This allows symbiotic organisms to aid in restoration efforts - such as herbivorous fish spilling over into the restoration site to keep algae away from coral transplants.

We also experiemented using some frames that were coated with the the epoxy/sand treatment and frames that were not coated. Anecdotally, marine biologists working with coral frames in the Maldives found that coating the frames provided a natural-like substrate and prolonged the life of the frame before rusting away in the ocean. We found that both coated and uncoated frames took similar length of time before they were colonized by a layer of coraline algae. Coraline algae is vital for structures to attract new coral larvae to naturally settle upon them and a superior coating to the artificial epoxy/sand coating. Therefore in areas (such as Nusa Penida) where coraline algae recruitment is high then adding the extra step of coating the restoration frames with epoxy and sand seems to be an unnecessary expense.

We experiemented with frames hosting only a single species of transplants versus frames with multiple species. Restoration projects in other locations have found that planting multiple species of coral together in clusters is more effective for growth and survivalship. However in our project we have found the opposite of that effect - our frames with single species transplants had higher growth and transplant

survival rates than those frames with multiple species! An interesting thing to note was also that frames with multiple species transplants had a greater amount of settlement from other reef organisms such as hydroids, sponges, algae & soft corals.



Growth Rates of Coral Transplants:

We have found that coral transplants growing in single-species clusters are showing higher growth rates rather than when planted in mixed-species clusters, for the initial year

One year into the project we added a novel approach of using metal wire mesh across areas of rubble in an effort to stabilize the shifting substrate and reduce erosion. Our test plot was 6m long and 1m wide and placed along the reef slope. We then monitored the site for rubble movement and natural settlement of corals and other reef organisms.

After one year of monitoring the test plot we found that the mesh was able to reduce rubble movement down the reef slope and prevent erosion below. Additionally the trapped rubble became stabilized and hosted Xenia soft corals, sponges, and Coraline algae - all exciting organisms to colonize the area; representing the initial stages of reef recovery!

As we expand our coral restoration project over a larger area of degraded reef, we have started to use this technique of wire mesh stabilization. We are rolling out mesh across areas of rubble between the coral frames in an effort to promote settlement of soft corals and other living substrates. If we are also able to reduce rubble movement and erosion then this area of degraded reef will be able to regenerate.

The exciting thing about coral restoration is adapting techniques to the specific environmental conditions of a particular reef. Our restoration site at Sental Reef on Nusa Penida is on a steep slope exposed to strong currents so is prone becoming a “rubble desert” unless we can reduce erosion and re-establish reef building coral communities.

Stakeholders

The Nusa Islands Restoration Project is led by Andrew Taylor (Certified Ecological Restoration Practitioner, SER-CERP #235) with operational support through Blue Corner Marine Research.

The Lembongan Marine Association together with Komunitas Penyulam Lembongan are committed to reducing impacts on the reef through community education and adopting codes of conduct for responsible marine tourism operators. We work together with these local community organizations and have been conducting workshops for the local dive and marine tourism professionals in these two organizations to train them in basic marine ecology and coral restoration techniques.

This project is financed through private donations, fundraising events and volunteers. Our aim is to use a technique which is inexpensive and feasible with the personnel and resources already present in the community.

Project Contacts

Marine biologist Andrew Taylor and our Blue Corner Marine Research team has been working on this project since March 2018. Andrew Taylor has a graduate degree in Marine Ecology and is a Certified Ecological Restoration Practitioner with the Society for Ecological Restoration. is the director of Blue Corner Marine Research This project is ongoing and we are working to restore additional sites which have recieved similar impacts in the area. The area is part of the Nusa Penida Marine Protected Area and so efforts are being made with the local community and tourism operators to reduce further impacts. The local dive community has been helpful in assisting with transplantation and installation of many coral frames.

www.bluecornerconservation.org

Correspondence:
andrew@bluecornerdive.com

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Andrew C.F. Taylor