Enhancing Reef Recovery in Komodo National Park, Indonesia:

A Proposal for Coral Reef Rehabilitation

at Ecologically Significant Scales

Helen E. Fox
University of California, Berkeley
The Nature Conservancy Indonesia Coastal and Marine Program

1. Summary

Pressures from rapid population and economic growth in Indonesia have brought many reef ecosystems to the point of collapse. One of the most devastating threats to reefs comes from dynamite or "blast" fishing, in which homemade bombs are detonated over the reefs. Blast fishing not only kills organisms within the blast radius, but also pulverizes the coral skeletons themselves, leaving a shifting, unstable rubble field that rarely returns to a healthy reef community. This project will rehabilitate a total of four hectares (40,000 m^2) of rubble fields within Komodo National Park, using large piles of quarried rock. The network of rock piles will recreate the three-dimensional structure of an intact reef, providing surfaces for coral recruitment and refuges for fish and invertebrates. This inexpensive and effective method for enhancing coral reef recovery could be incorporated in reef management programs in other regions worldwide with damaged reefs but successful enforcement and alternative livelihood programs, restoring economic and ecological value to these remarkable ecosystems.

2. Background

2.A. Blast fishing and Low Recovery

Coral reefs are among the earth's most productive, diverse, and valuable habitats, rivaled only by tropical rain forests. The apex of coral reef biodiversity lies within the vast island archipelagos of Indonesia and the Philippines, as this region contains the highest diversity of coral species and a staggering number of reef-dependent organisms (Veron 1994). However, pressures from rapid population and economic growth in Southeast Asia have brought many reef ecosystems to the brink of collapse. It is estimated that less than 3 % of the reefs in Indonesia remain in excellent condition (>75% live coral cover) and these are being rapidly degraded, as few of the marine protected areas that exist on paper are effectively managed (Wilkinson et al. 1994; Chou 1997). Komodo National Park (KNP) is a rare exception to this, due largely to efforts of The Nature Conservancy, which in 1996 began assisting authorities to protect the marine areas around the Komodo Islands.

Anthropogenic impacts on corals range from chemical pollution to sedimentation to cyanide and bleach fishing. Despite the harm that they cause, however, at least most of these impacts spare the underlying skeletal framework of the reef, permitting potential future settlement and recruitment. Dynamite or "blast" fishing is especially damaging, killing organisms indiscriminately within the blast radius (including the targeted fish), and shattering the coral skeletons. Chronic blasting results in vast rubble fields that inhibit, if not prevent, coral colonization and fish population recovery. Blast fishing is a relatively cheap and easy way to increase fish catches, but at a tremendous cost to the environment.

Extensive blast fishing destroys mature coral colonies, which are both the structural framework of the reef and the source of new coral recruits. As more of a reef is blasted, there is increased pressure on the areas that remain healthy, potentially leading to a cascade of ecosystem collapse (McManus 1997). Despite being illegal, dynamite/blast/bomb fishing is widespread. It is practiced in nearly 30 countries in Southeast Asia and Oceania, has reportedly caused major reef degradation in half of the countries in the South Pacific (Ruddle 1996), and occurs frequently in the Red Sea (Riegl and Luke 1998) and east Africa (Nzali et al. 1998).

One of the most serious impacts of extensive blast fishing is that new scleractinian coral colonies are slow to grow back in the shifting fields of dead coral rubble that result, even when an area is protected from further blasting. Studies in Komodo National Park suggest that recovery in blasted areas is very slow, despite there being adequate source coral and good water quality. The availability of source coral does not explain the variation in recruitment levels, so there must be differential survival of the coral spat once they settle on the rubble. The vast areas of unstable rubble hinder successful coral recruitment, especially in areas with strong currents or wave action. Long-term and chronic blast fishing transforms complex, biodiverse coral reefs into expanses of shifting rubble. In addition to the removal of the killed fish and other organisms, few fish re-colonize the area due to the loss of the coral structure. The result is a relatively biologically depauperate area with little economic value to fishers, the communities, or tourists (Figure 1).

Figure 1. Broken coral rubble field as a result of chronic blasting. Note lack of three-dimensional structure and fish.

2.B. Reef Rehabilitation as a Potential Solution

Halting blast fishing is clearly a crucial first step in coral reef management. However, once destructive fishing is stopped, it may be advisable to rehabilitate damaged reefs in the hopes of restoring the function and value of the ecosystem. This requires stabilizing the rubble fields that remain, since the loose substrate is preventing natural recruitment (Edwards and Clark 1998). Criteria that should be met before rehabilitation is attempted include: effective enforcement of the ban on blast fishing, slow natural recovery, adequate source coral for larval supply, and good water quality. Komodo National Park meets all of these criteria, and the Park management has indicated their desire to rehabilitate damaged areas within KNP. However, most rehabilitation techniques currently employed are not designed for the shifting rubble created by blast fishing, and most "artificial reefs" are in fact fish aggregating devices and do little to increase coral biomass. Transplantation can also be expensive and labor-intensive, and as most reefs in Komodo are not recruitment limited, is unnecessary. A study comparing these coral restoration schemes and several others found that costs could range from US$13,000 to over US$ 100,000,000 per hectare (10,000 m^2) (Spurgeon and Lindahl 2000).

A relatively inexpensive, cost-effective, and locally available technology to enhance coral reef rehabilitation consists of piles of rocks to stabilize the loose rubble and provide a suitable surface for new coral settlement, at an estimated cost of US$10,000 per ha (Fox et al. 2000). In addition to the ultimate goal of increasing coral and fish biomass, coral rehabilitation projects can have several short-term benefits. Involving the community and park rangers can create a necessary sense of responsibility for managing and protecting their coral reef resources, as well as educate them about the importance of healthy reefs. Reef rehabilitation treatments also have tourism potential for divers and/or snorkelers. Given that marine reserves are widely accepted as the most practical and effective method to manage coral reef fisheries and preserve coral reef resources (Birkeland 1997; Roberts 1997), it makes sense to concentrate efforts to rehabilitate damaged areas in existing parks with successful enforcement programs in place such as KNP. Focusing on areas that are truly protected will maximize chances for successful, sustainable rehabilitation.

2.C. Results from Initial Research

Research was conducted in Komodo National Park to study natural recovery in blasted areas and to test methods to stabilize rubble and recreate a structural foundation, beginning in January 1998 (Figure 2). There are many factors that can influence variation in recovery rates, including source of larvae (adult coral colonies), substrate stability and condition, currents and hydrologic processes, and species interactions, such as presence of coral predators and algal grazers. The study focused on the effects of source coral, water movement, and substrate size and condition, and sought to answer the following questions:

1. Is coral recovering naturally in rubble fields in KNP?
2. Is there potential for coral recovery, i.e. source larvae?
3. How does current strength affect natural recovery?
4. Can we enhance coral recovery with reef rehabilitation techniques?

Results indicated that in general, there was low natural recruitment at all sites. Even in rubble fields with extremely low coral cover, source larvae are in the water, so there are potential coral recruits at all sites. Based on the marked rubble studies, pieces of rubble move several cm per day at all sites, with some pieces moving 10-15, or even 50 cm per day. Such movement would be certainly capable of abrading or burying small coral colonies that had settled on the rubble, and indeed, the greater the rubble movement, the lower the natural recruitment. Likewise, sites with stronger current have lower natural recruitment.

For pilot reef rehabilitation studies ~1 x 1 m quadrats in the rubble fields were installed to compare three different low-cost, locally available treatments: rock piles, cement slabs pinned to the rubble, and fishing net pinned to the rubble. Significantly greater recruitment occurred on the rock and cement experimental treatments compared to the bare, untreated rubble (paired two-sample t-tests on log-transformed counts: mean difference (+/-95% CI)=1.01 (+/-0.55), df=47, t=3.7, p=0.001). Rock piles had the greatest increase in recruitment, were the least expensive, and provided the most natural, complex substrate. After several years, coral colonies on the rocks were 20-30 cm in diameter (Figure 3). Larger rock piles 0.5-2 m^3 in size were installed in areas 100 m^2 in size at nine sites and are being monitored. Coralline algae and other encrusting organisms colonized the rock piles quickly, and within 1 year there were many hard coral recruits 2-4 cm in diameter. Thus far, the rock piles have been resistant to shifting and burial by rubble and sand. There are an average of 15.7 scleractinian recruits per square meter, although the range across the sites is wide (Figure 4).

Overall results indicate that there is good potential to rehabilitate destroyed reefs in Komodo National Park. At all nine sites, chosen to broadly represent rubble fields in the diverse park, there was increased coral recruitment to the treatments, as compared to untreated, bare rubble. In some cases, recruitment (number of colonies per square meter) was over 20 times higher in the experimental plots than on untreated rubble.

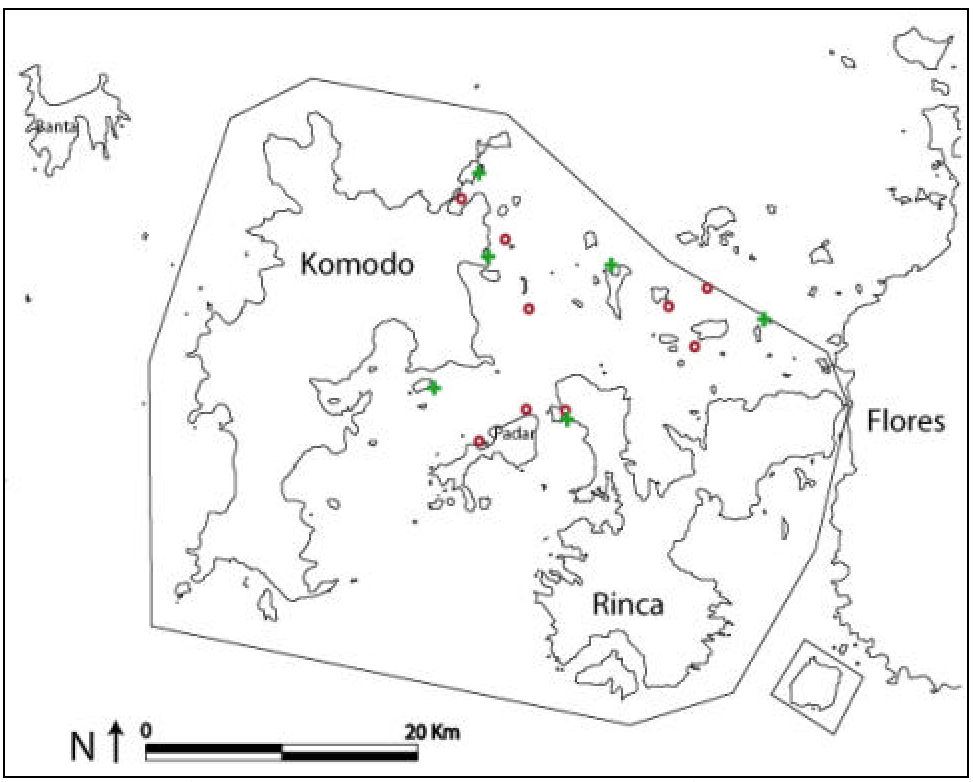

Figure 2. Map of Komodo National Park showing sites for initial research: nine rubble field sites (red circles) and comparison sites with higher live coral cover (green plusses).

Figure 3. Rock piles after 3 years, with colonies of hard corals 20-30 cm in size. Fish populations were higher around the rocks than the surrounding rubble fields (personal observation).

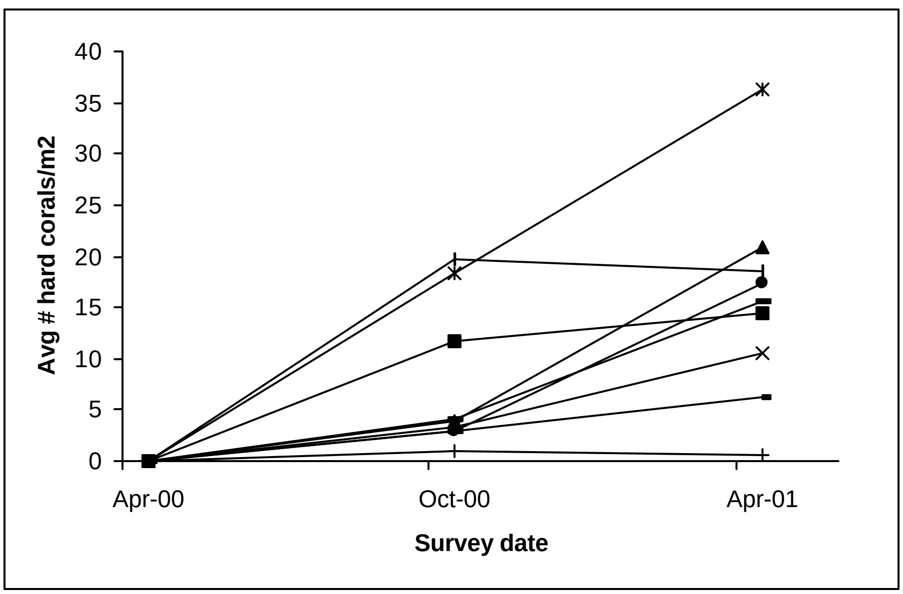

Figure 4. Average numbers of scleractinian recruits per square meter to large (0.5-2 m^3) rock piles within the first year, based on six 1x1 m quadrats at each of nine sites in Komodo National Park.

3. Project Description

3.A. Objective

We propose to undertake ecologically significant reef rehabilitation by installing large rock piles at four sites one hectare in size (40,000 m^2 total) in Komodo National Park. Most other rehabilitation projects cover tens or hundreds of square meters, and as such are primarily pilot studies. Given the tremendous extent of destroyed reefs in Indonesia, a larger-scale approach will ultimately be needed to rehabilitate degraded areas and significantly increase fish and coral populations.

3.B. Study Area

To monitor accurately the recovery of the reef community from anthropogenic impacts, the study requires a well-managed marine reserve that is no longer being heavily blasted. Located in eastern Indonesia between the major islands of Sumbawa and Flores, Komodo National Park (KNP) fulfills this need. The park encompass areas where blast fishing has occurred at varying levels since the early 1950s, declining dramatically since 1996 due to efforts by The Nature Conservancy. In addition, the diverse underwater environments within a relatively small area make studies of coral reef regeneration under a range of conditions possible.

The Nature Conservancy became involved with Komodo National Park as a response to a Rapid Ecological Assessment (REA) of the region. The REA found very high coral and fish diversity, and even higher diversity is estimated. However, blast fishing had destroyed large areas of the coral reef. In 1996 patrols were established to monitor extractive activities in the park and enforce the ban on destructive fishing practices. In addition, a coral monitoring program was established to evaluate the reef environment of KNP and map the extent of damage by destructive fishing methods. The relatively high level of protection makes KNP an ideal site to attempt to rehabilitate large areas of damaged coral reef.

As the reef recovery takes place and fish and invertebrates colonize the rock piles, the sites need to be protected from fishing. As part of the 25-year management plan, several no-take zones were proposed. This management plan has been approved, and the zoning system has now evolved from a plan to a fact. The majority of village leaders have signed a letter supporting the management plan. The enforcement capacity of the Park staff includes two "Floating Ranger Stations," boats with rangers on board who patrol the parks' waters. TNC and Park staff can now truly protect sites in the no-take zones, making coral rehabilitation at ecologically significant scales a sensible approach for the first time.

3.C. Methodology

Basically, this technique consists of installing rock piles 1-2 m^3 in size spaced out every 2-4 meters across the rubble field. The networks of rock piles stabilize the rubble, provide surfaces for coral recruitment, and act as refuges for juvenile fish. The rocks are quarried from nearby sources in western Flores, and loaded onto cargo boats. The boats anchor over pre-selected rubble fields and the rocks are unloaded. Finally, divers pile up the rocks, to minimize burial by the surrounding rubble. For more details on the logistics of installation of the rock piles, see the Appendix. Ongoing evaluation and monitoring of the recovery of coral, fish, and other reef organisms will be incorporated into TNC Komodo Field Office's routine monitoring program (see Appendix).

3.D. Biological And Environmental Factors Considered for Site Selection

The following list, although not exhaustive, covers important biological and environmental criteria that we will use to determine which sites are good potential candidates for successful rehabilitation. Because of the excellent water quality, ample coral larvae supply, and successful management program, there are a number of sites that meet these criteria.

1. Further damage minimized: area is no longer being bombed and is protected from other destructive practices (fishing, trampling, diver damage, etc.)
2. Good water quality: clear water (indicating low nutrients, low sedimentation), no other pollutants or contaminants
3. Good larval supply: area is still receiving inputs of coral larvae from healthy reefs. This can be empirically tested by using settlement tiles (Harriott and Fisk 1988) but can be inferred by searching for small coral colonies (<10 cm diameter), which are likely to be recent recruits.
4. Type of substrate: the rehabilitation method described here is designed to stabilize the substrate to allow natural recruitment to take place. Putting rock piles on cemented rubble, bench, or in areas with standing dead coral does not make sense because there is already a stable substrate for settlement by coral larvae.
5. Depth: If rock piles are placed in areas that are shallow, they are more likely to be scattered in heavy wave action or storms. There is decreased coral growth with decreased light penetration at greater depths, so sites should not be too deep, either. Depths of 5-10 meters are suggested as a starting point.
6. Size of damaged area: It is important that very little live coral be damaged when throwing the rocks onto the rubble field; the risk of this will be minimized if the area to be rehabilitated is a large rubble field. Also, large damaged areas are less likely to cement and recover naturally than small craters.
7. Rubble movement: There will be less chance of the rock piles being buried by rubble if they are placed directly down-current or down-slope from protecting structures, i.e. live reef or intact reef substrate.

4. Anticipated Outcomes

4.A. Benefits of Scaling Up

Results from initial research clearly indicate that coral recruitment can be greatly enhanced by creating stable, spatially complex structures high enough above the rubble to minimize burial and abrasion. In these studies the total area "influenced" by the rock piles is approximately 100 m^2 per site, with increased fish abundance in and around the piles, including juvenile grouper species (based on anecdotal observations). However, to truly provide the benefits of a healthy coral reef, such as fishery production and coastal protection, the area rehabilitated will need to be on the scale of hectares. The vast numbers of rock piles in a hectare stretch of rehabilitated reef will provide tremendous surface area for coral settlement and recruitment, as well as countless small refuges for juvenile fish and invertebrates. Over time, we anticipate that the growing coral, coralline algae, and other encrusting organisms will cement the individual rocks together. Furthermore, the rock piles will stabilize a large portion of the rubble field and provide obstacles for the often-racing current, creating turbulent flow. This will further enhance coral settlement and reduce overall rubble movement, allowing coral to grow more quickly over the rubble in between the rock piles.

4.B. Community Involvement

A large-scale reef rehabilitation project is an excellent opportunity to educate the villagers in and around KNP about the value of their reef resources. For any conservation program to truly succeed in the long term, the local community must develop a sense of responsibility for protection and management of the resources on which they base their livelihoods. In addition to facilitating the enforcement program, TNC is also educating the villagers about the value of healthy reefs and developing alternative livelihood projects.

Implementation of the reef rehabilitation will take place with teams from TNC, staff from the national park office, and community members, building a strong constituency of support for the program. With the large scale of the rehabilitation efforts, the installation of rock piles could be an alternative income for some of the villagers currently involved in unsustainable fishing practices. The reef rehabilitation project will be incorporated into the community awareness campaign. In addition, some rehabilitation sites will be installed in areas specifically intended for education and tourist awareness, in which case support from the dive operators and tourism guides will be crucial. Sites will be monitored with the support of the Park rangers and the TNC KFO monitoring staff, and ideally the dive operators and diving community members as well.

5. Conclusions

Although blast fishing continues to devastate reefs throughout Southeast Asia and beyond, there are other success stories like that in KNP where blasting has been halted and the surviving reefs protected. However, even in these protected areas, large tracts of destroyed reef remain as a legacy of destructive fishing. Ship groundings and severe anchor damage leave similar scars of pulverized coral rubble. If the rubble fields have adequate source coral larval supply from nearby live coral, this method of low-tech, low-cost, large-scale reef rehabilitation is a viable option to restore the structural foundation, thereby facilitating the return of fish, coral, and other reef-associated life. As one of the first attempts at reef rehabilitation on an ecologically significant scale, this project has great potential for leverage in other priority sites for conservation in Indonesia and well beyond.

Workplan and Budget

Below is a schedule for the implementation of this project. Installation of the rock piles could either be a longer-term, continuous project or a short-term, intensive project. We estimate the cost to rehabilitate a stretch of rubble 400m long x 25 m wide (1 ha) to be $10,000. Using one boat that could complete 1 trip per day to rehabilitate a 10 x 10 m area, installing rocks in one hectare would take 100 working days. If, however, four boats (or a boat with four times the cargo capacity) were used, one hectare would be completed in 25 working days (assuming scaling up of rock deliveries, labor, etc.). Whether to use an intensive short-term or longer-term approach will be determined during the logistics preparation phase of this project.

Schedule for Implementation (January 2002 – February 2003)

	Months													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Logistics preparation														
Contracting rock delivery, cargo boats, labor	■	■												
Initial visit reef of rehabilitation consultant		■	■											
Rehabilitation implementation														
Rock pile installation at 4 sites in KNP		■	■	■	■	■	■	■	■	■	■	■	■	
Follow-up visit of reef rehabilitation consultant													■	■
Evaluation and monitoring														
Monitoring coral and fish recruitment (ongoing)						■	■						■	■

Budget Request

		Estimated expenses
A. Materials and Implementation		
Approximate cost per site (one hectare, 10,000 m2)		
Materials (quarried rocks, including delivery)	$ 3,000	
Transportation (cargo boats)	$ 4,500	
Labor (loading and unloading rocks, underwater installation of piles)	$ 2,500	
Total per site	$10,000	
Total for four rehabilitation sites within KNP		**$ 40,000**
B. Reef rehabilitation consultant costs		
Initial visit to survey and map the 4 sites to be rehabilitated, train staff, and supervise start of implementation on first site (October 2001)		
20 days x $250/day	$ 5,000	
Follow-up visit to asses implementation and make adjustments where needed (October 2002)		
20 days x $250/day	$ 5,000	
Total consultant costs		**$ 10,000**
C. Indirect costs		
TNC overhead (salaries, communication, office supplies, related travel in-country, etc.)		
Total Indirect costs		**$ 10,000**
TOTAL BUDGET REQUEST		**$ 60,000**

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Appendix

Logistics for Rock Pile Installation

1. Site selection
    a. Identify precise locations of sites for rehabilitation meeting biological/ecological criteria with dive/snorkel/manta tow surveys, and record the GPS coordinates of the sites chosen.
    b. Determine the size of the area to rehabilitate.
2. Arranging logistics
    a. Delivery of rocks
    b. Cargo boat(s)
    c. Loading and unloading of rocks on the boat(s)
    d. Divers to pile up rocks underwater (Alternative income generation for hookah divers?)
3. Long-term monitoring (conduct monitoring every 6 months).
    a. Measure the length, width, circumference, and height of the rock piles, to see if they are subsiding into/being buried by the rubble. Also note extent of soft coral growth onto piles.
    b. Survey hard coral recruitment to rock piles 6, 1m x 1m quadrats, recording:
        i. LOCATION (Cartesian grid: 0,0 is always lower left corner of quadrat),
        ii. SIZE (Length and width to the nearest mm, using calipers),
        iii. LIFEFORM (based on English et. al. AIMS survey manual),
        iv. TAXON (if can identify family, genus or species) of each hard coral recruit.
        v. Also note approximate percent cover of soft coral (Taxon if known) and coralline algae on the rocks, and any other dominant or prominent taxa (e.g. Crinoids, barnacles, tunicates).
    c. Survey hard coral recruitment to untreated rubble (natural recovery) with 6, 1m x 1m permanently marked quadrats in nearby rubble fields, recording LOCATION, SIZE, LIFEFORM, AND TAXON of each hard coral recruit, as above. Also note approximate percent cover of soft coral.
    d. Take several minutes of video footage at the big rock piles, showing the fish populations associated with the rocks, general appearance of the rock piles, extent of growth of hard corals, soft corals, etc. Also video untreated rubble areas nearby.