Over one-half
of the world's population lives
within **100 kilometres**
of the sea.

Coral Reef Restoration and Remediation Working Group

Long-term efficacy and cost-effectiveness of coral reef restoration interventions

Management Implications

Coral reefs worldwide are suffering degradation from a number of disparate natural and man-induced causes. Tackling the root-causes of degradation through effective coastal management measures is likely the best way both to reduce further damage and to allow reefs to return to viable healthy states. Nevertheless, there can also be opportunities for direct intervention to actively restore degraded coral reefs.

At present we have only a rudimentary understanding of a) the complex processes that contribute to natural recovery of coral reef systems from disturbance, and b) the types and advisability of interventions (i.e. restoration actions). It is therefore difficult to assess both the recovery potential of different sites and the likelihood of any given site benefiting from active restoration interventions. Criteria are needed that can specify the degree to which an injured site might benefit from better management and/or active restoration. To develop these, we need to understand more about the factors and processes that contribute to both the time-course and the success or failure of natural recovery and of active restoration interventions.

Image: G. Levy

The research being carried out by the CRTR Restoration and Remediation Working Group (RRWG) is seeking not only to address many of the knowledge gaps which hinder restoration but also to channel advice (however limited this may be) to the management community so that restoration projects can be undertaken in a more informed way and with better chance of success.

Image: University of the Philippines

TENETS

- Coral reef restoration is in its infancy. We *cannot* create fully functional reefs.
- Ecological restoration is the process of *assisting* the recovery of an ecosystem that has been degraded, damaged, or destroyed.
- Improved management of reef areas is the key to their health. However, within an overall management plan, active restoration offers managers a useful and potentially powerful tool for assisting recovery of degraded reefs.

Society for Ecological Restoration, 2004

The Coral Reef Targeted Research & Capacity Building for Management Program (CRTR) is a leading international coral reef research initiative that provides a coordinated approach to credible, factual and scientifically-proven knowledge for improved coral reef management.

The CRTR Program is a proactive research and capacity building partnership that aims to lay the foundation in filling crucial knowledge gaps in the core research areas of Coral Bleaching, Connectivity, Coral Diseases, Coral Restoration and Remediation, Remote Sensing and Modeling and Decision Support

Each of these research areas are facilitated by Working Groups underpinned by the skills of many of the world's leading coral reef researchers. The CRTR also supports four Centers of Excellence in priority regions, serving as important regional centers for building confidence and skills in research, training and capacity building.

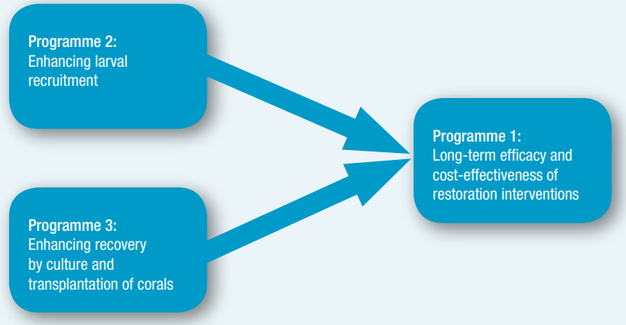
The CRTR Program is a partnership between the Global Environment Facility, the World Bank, The University of Queensland (Australia), the United States National Oceanic and Atmospheric Administration (NOAA) and approximately 40 research institutes & other third parties around the world.

March 2007

WORKING GROUP GOALS

- To improve our understanding of natural recovery processes on reefs so that we can better advise managers on appropriate management options for degraded reef areas.
- To evaluate and compare the long-term cost-effectiveness of a range of the active restoration interventions currently available.
- To investigate ways of improving implementation of existing restoration techniques so as to minimize environmental impacts, maximize survival of transplants, and lower costs.

Achieving these goals will enable us to better advise managers and policy-makers on options for restoration, relative costs of these and likelihood of success in different management contexts.



Montastraea spawning
Image: James Guest

Progress to Date

For the initial five years of the project, the RRWG has set up three research programs.

1. Enhancing recovery by culture and transplantation of corals

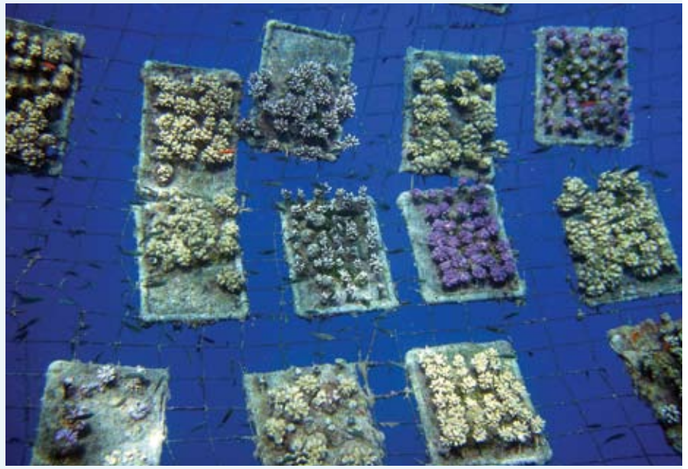
This program focuses on asexual propagation of corals to assist restoration. The key to cost-effectiveness in restoration using transplants, is balancing the costs of nursery rearing and effective use of limited source material against the likelihood of survival of transplants. This program is investigating the effect of the size and structure of coral fragments on subsequent growth and survival for a range of species. Low-cost approaches involving direct transplantation are being compared to more costly approaches involving periods of *in situ* culture prior to transplantation to damaged reefs. Research is focused on a lagoon near the Bolinao Marine Laboratory in the Philippines which has suffered from both blast fishing and mass-bleaching and subsequent mortality of coral during the 1998 El Niño Southern Oscillation warming. Recovery since then has been negligible. Blast fishing has now ceased but there is still heavy fishing pressure in the area.

Key questions being studied:

1. How important is the choice of coral species on both the success of transplants and the sustained growth and reproduction of the donor colony?
2. What is the relative efficacy of restoration using coral nubbins and coral fragments, with and without *in situ* nursery rearing?
3. What is the impact of the initial size and structure of pruned coral fragments or nubbins on subsequent growth and colony development?
4. Are low-profile (≤ 50 cm above substrate) or high-profile *in situ* nurseries better for coral maintenance and ultimately which are more cost-effective?
5. What effects do the density of coral transplants have on survival and overall success of restoration?

Three types of coral nursery have been set up close to the Bolinao Marine Laboratory in the Philippines. These include one floating nursery, one bottom-attached nursery and one low-cost experimental rope nursery. The floating nursery has the advantage that corals are held at a constant depth (the whole nursery moving up and down with the tide). Further, in the event of El Niño warming the corals can be moved to greater depth or the nursery towed to a site with better mixing. The bottom-attached nursery is cheaper to make but water depth varies with the tide. The experimental rope nursery is very cheap as coral fragments are just slipped between the strands of a rope and then allowed to grow. Approximately 10,000 1-4 cm coral nubbins derived from 17 donor colonies belonging to nine species have now been reared for about one year. Results after one year show that overall about 10% mortality and 6% detachment of coral fragments is achievable. Preliminary results show not only significant differences between species in terms of growth and survival, but also between different genotypes of the same species. Faster growing species have already grown into small colonies in the nurseries and many hundreds of these have now been transplanted to degraded bommies (large coral heads) to see how they will survive there.

In parallel, a series of degraded bommies have had coral fragments transplanted to them directly at two different densities to compare survival and growth of directly transplanted common coral species. This is cheaper but uses more source material. Initial results are promising with about 85% survival overall after 5 months.



Trays of coral nubbins being cultured
Image: S. Shafir

2. Enhancing larval recruitment

This research program focuses on the sexual propagation of corals from the larval stage following spawning. This involves a higher level of technology and at present much higher costs, but does offer the potential of rearing 100,000s of sexual recruits for restoration. Research is being carried out in Palau in collaboration with the Palau International Coral Reef Center (PICRC) with additional work on coral reproduction at the Bolinao Marine Laboratory in the Philippines.

Key questions being studied:

1. Does enhancement of coral larval recruitment significantly enhance recovery on a 5-10 year timescale and is it cost effective?
2. Does the use of "larval flypapers" to effect controlled settlement and metamorphosis of larvae of selected coral species in a lab-based hatchery facility contribute to enhanced growth and survival of recruits out-planted to the field for purposes of restoration?
3. Could mass culture of corals in open water using sexual reproduction significantly enhance efficacy of coral reef restoration and is it cost effective?

Spawning of key *Acropora* species in Palau was confirmed to be predictable to the day allowing mass culture of coral larvae using either laboratory based tank culture or simple low-cost floating-pond culture. Indoor and outdoor *ex situ* hatcheries were successfully built and made operational. Colonies of *Acropora digitifera, A. hyacinthus, A. tenuis* and *A. humilis* were spawned and single colony crosses and batch fertilization carried out. Developing larvae were cultured indoors for about 6 days until ready to settle and then settled onto larval "flypapers" before transfer to the outdoor hatchery to grow to a transplantable size. Growth and survival is being monitored.

In a slightly different approach over 600,000 planula larvae, obtained from *Acropora* spp. colony segments spawned in the laboratory, were mass-cultured in tanks and about 170,000 coral spat settled out on tiles. These were then transferred *in situ* in cages where the corals were co-cultured with grazing snails (*Trochus*) to keep down the algae. Within only 4 months some species had grown to mean diameters of almost 1 cm. Survivorship is less than 20% but starting numbers are very high. Clearly there are economies of scale that can be made but at present the cost per transplantable coral appears to be at least 20 times what can be achieved using nubbin culture.

3. Long-term efficacy and cost-effectiveness of restoration interventions

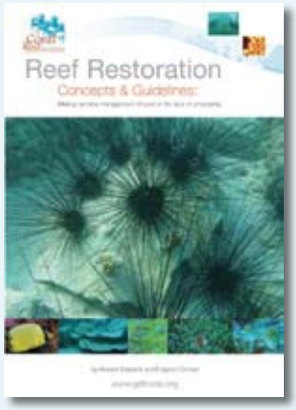
Efficacy of restoration interventions should be judged in terms of what these interventions achieve in comparison to what occurs with natural recovery over at least a 5-10 year timescale. The natural reef is varied and it is difficult to perform adequately controlled comparisons using patches of natural reef as there are too many potentially confounding factors. To address this problem, this program is using standardized artificial structures of sufficient scale and replication to allow long-term statistically rigorous comparisons to be made between the outcomes of natural processes and the outcomes of a range of interventions. The manipulative experiments are being set up in Mexico, Bolinao and Palau so that various active restoration interventions can be compared to natural recovery at sites with very different recovery potentials.

Key question being studied:

1. To what degree do active restoration interventions significantly enhance recovery of coral reef communities in comparison to what would be achieved by natural recovery processes over a 5-10 year time-scale?

Restoration interventions which will be tested include (1) direct

transplantation of naturally detached coral fragments ("corals of opportunity"), (2) enhanced larval recruitment using pond cultured spawning slicks, (3) transplantation of nursery farmed corals, (4) enhanced grazing using *Trochus*, and (5) enhanced invertebrate settlement. All will be compared to the outcomes of natural recovery at each site. Key processes such as coral recruitment, mortality and growth rates, and herbivory rates will be monitored to gain a better understanding of what factors are crucial for recovery.



Expected Outcomes

We intend to produce at least two outputs specifically for managers. These include *Reef Restoration Concepts and Guidelines: making sensible management choices in the face of uncertainty* and towards the end of the project a more substantial *Reef Restoration Manual*. The first is now available for distribution via the CRTR Program website (www.gefcoral.org). It is aimed primarily at the kind of people, usually with some biology background, who act as technical advisers to reef restoration projects. The early sections aim to provide simple advice on coral reef restoration to coastal managers and decision makers, whereas the later provide more detail for those who may be involved in community-based reef restoration efforts. The second is planned as a multiauthor book involving people from several international reef restoration projects currently being undertaken. We hope to make chapters on individual aspects of restoration methodology available over the internet as Fact Sheets. Among a range of questions which we hope to be able to better answer are:

- What minimum local conditions and management need to be in place for active restoration interventions to have a chance of success?
- Under what circumstances is active restoration likely to be of little benefit?
- What is the relative cost-effectiveness of a range of restoration interventions?
- How is asexual coral transplant survival related to size in different species and in different environments?
- Which coral species are not well suited for transplantation?
- What effects do pruning coral colonies for asexual fragments have on the reproduction, growth and survival of donor colonies; how much can be safely excised?
- How does the nursery rearing environment affect survivorship of outplanted corals on the reef?
- At what size is it most cost-effective to outplant sexual recruits reared from coral spawn?

Monitoring and cleaning mid-water cages
Image: The Akajima Marine Science Laboratory

Shallow water coral nursery in the Philippines
Image: G. Levy

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- RESEARCH UPDATE

Further Information

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