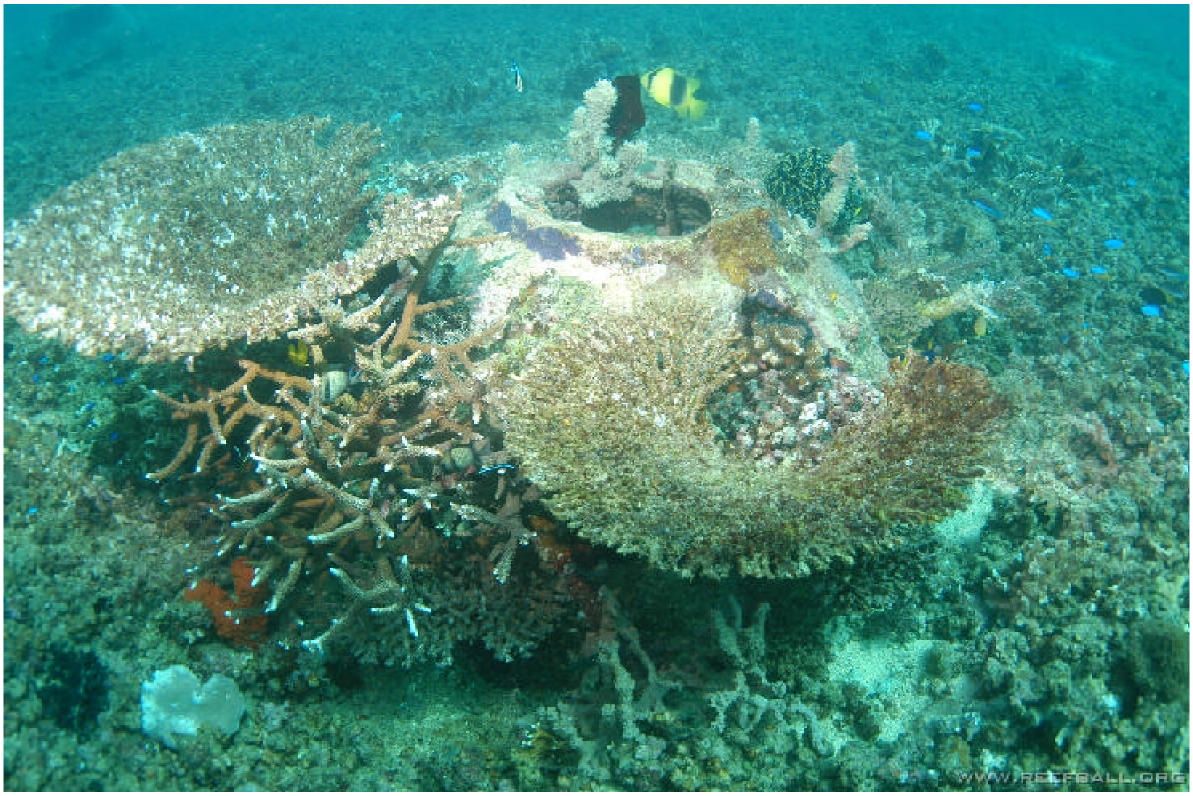
REEF BALL FOUNDATION

Restoring our world's ocean ecosystems

A step-by-step guide for grassroots efforts to

Reef Rehabilitation



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890 Hill Street • Athens, Georgia 30606

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Dedication

We dedicate this manual to all of you who have worked, in some way, to improve the state of our world's oceanic ecosystems. It is your experiences, researches, trials, errors, and feedbacks that have been combined to create knowledge that emboldens us, in some way, to attempt rehabilitating some of the scars humans have left on our oceans.

This manual is also dedicated to all of those who have attempted reef rehabilitation work, and faltered; for it is only through trial and error that we learn to do things better. There are common pitfalls such as lack of resources, knowledge, or learned skills and sometimes politics or pride that can get in our way. Whatever the reason, this manual aims to help avoid common mistakes and to improve collective worldwide efforts that aid what all of us in this endeavor cherish, the ocean and its marvelous life.

An environmental magazine once headlined, "We know what is killing the corals…They are allergic to humans." It is certain that areas of higher human population density are closely correlated to areas of reef degradation, almost without exception. But even remote pristine reefs are not safe as additional global impacts are looming, such as atmospheric CO2 rise. This compels all of us to strive to preserve, protect, study and maybe even rehabilitate oceanic resources and habitats.

This manual was compiled over 10 years by the cumulative efforts hundreds of dedicated Reef Ball Coral Team members and stems from experiences conducting projects in over 55 countries worldwide.

Right: Reef Ball Coral Team working at a coral propagation table in Antigua.

Credits / Key Manual Contributors:
Todd Barber, Chairman, Reef Ball Foundation, Editor & Author of manual
Jason Krumholz, Reef Ball Intern, Editor in Chief & Author of sections on science method
Tom Maher, President, Marine Habitats Inc., Technical Editor
John Walch, President, Reef Ball Coral Team, Author of sections on corals
Dr. Catherine Jadot, President, Mangrove Solutions, Author & Editor of sections on mangroves
Dr. Lee Harris, Consulting Engineer & Professor at Florida Institue of Technology, Editor, Author on sections of stability and coastal engineering
Larry Beggs, President, Reef Innovations, Inc. Author on sections of construction techniques
Marjo Van Der Buick, Reef Ball Coral Team Leader, Author on sections on monitoring
Wayne Young, Author on Oyster Appendix
Kathy Kirbo, Executive Director, Reef Ball Foundation, Contributing Editor

Preface

This guide is specifically written for grassroots organizations, government agencies, scientists, non-government organizations (NGOs), and reef user groups that are interested in "hands on" and practical reef rehabilitation. It is evident that the best predictor of success for a rehabilitation effort is ones level of knowledge, skill and abilities combined with the strength of the partnerships in the effort. Local/national government, universities, scientists, NGOs or grassroots organizations, reef rehabilitation professionals, and community stakeholders are ALL required to join hands to maximize the potential success of a rehabilitation effort. Projects that don't involve all these stakeholder groups are prone to failure.

If you are reading this guide for the first time, we suggest you read the glossary (appendix b), to familiarize yourself with the terminology in this guide. We have had to create some new terms to describe specific steps or methods in the rehabilitation process to it would be expected that you would not understand some of the referenced words unless you have participated in Reef Ball Coral Team projects. When a word or phrase is presented *italicized* in the text, there is a corresponding entry in the glossary.

On the advice of the Executive Director of the Reef Check Foundation, we have chosen to use the phrase "reef rehabilitation" rather than "reef restoration" to emphasize the point that even with rehabilitation efforts, it is impossible to fully restore a damaged reef because reefs are unique, dynamic and complex living systems. Rehabilitation is <u>not</u> a cure all. In order to ensure the health of our ecosystems, conservation efforts must be increased both on a system wide level and local level. **As you read this guide, keep in mind that rehabilitation is only a single tool available to aid reefs among many conservation tools and approaches.**

This guide certainly devotes many chapters specifically to **coral** reefs, but it was written to offers a step-by-step framework suitable for rehabilitation efforts on any type of *reef* including oyster reefs, temperate reefs, kelp reefs, and others. It is possible that non-reef marine ecosystems such as submerged Red mangrove root ecosystems or seagrass beds could also be guided by many of the guide's basic principles and techniques.   We include guidance for common design goals such as projects designed for fish enhancement . If you are looking <u>only at coral</u> rehabilitation, you might also find useful the book, "*The Coral Reef Restoration Handbook: The Rehabilitation of an Ecosystem Under Siege*". It was released in May 2006. You can find information on this at: http://www.pbsj.com/Press/Releases/NewBook/index.asp.

Additionally, if you have a specific interest in **coral** reefs, you may wish to join the CORAL-LIST maintained by NOAA, primarily for scientific exchange of thought on issues affecting coral reefs. We monitor this discussion group and frequently add comments. For more information see
http://coral.aoml.noaa.gov/mailman/listinfo/coral-list

Techniques presented, particularly those associated with corals, were developed for projects with participation by non-professionals and have been designed as cautious approaches to rehabilitation. Scientists or professionals may have originally developed these methods but they have been refined and/or simplified for practicality and consistent results with volunteers.. Because the writing of this manual was guided by this, and constrained to being field tested and practical, some of the "rules" presented (in red) can be relaxed at the discretion of the professional. For example, we recommend that volunteers limit themselves to working with coral fragments no larger than a 35 mm film canister, whereas under the right circumstances, a professional (or an expertly guided volunteer) might choose to work with larger fragments. However, these "rules" aid in avoiding failures, so even professionals should carefully consider all consequences before bending them.

We do not take credit for developing coral *propagation* technologies (although we have improved many specific handling techniques). Asexual coral reproduction can be credited to many scientists, practitioners and marine aquarists. Our contribution was to develop hands on approaches to apply propagation techniques and to allow production scale *propagation* with efficient, reliable *planting* for **long term** success. As we develop new techniques, and if demonstrated successfully by monitoring, they will be added to our reef rehabilitation guide. When monitoring bears out processes that are unwise, adjustments are also made. This feedback allows the Coral Team to continually improve the processes and to expand the range of species that can be propagated with success. Please check the date of this document with the version available on line and start your project with the most current version. Note that we have attempted to footnote other's contributions but we have not followed rigorous standards as seen in scientific papers and we may have unconsciously omitted some credits.

It is helpful to understand the way the Reef Ball Foundation organizes *Coral Teams* as a model for your own projects. The Reef Ball *Coral Team* is a worldwide group of individuals, mostly volunteers, that have participated in at least one Reef Ball coral rehabilitation project and earned a certification level (there are 5 specialties and 5 levels within each specialty based on the individual's knowledge, skill, and ability). These people include coral professionals, scuba divers, aquarists, consultants, scientists (marine biologists, engineers, oceanographers, etc.) and others. They all enjoy sharing their skills and learning new techniques in an effort to aid our ocean ecosystems.

Whenever a local group needs assistance for a project, a Coral *Team Activation* alerts the entire team soliciting volunteers and experts with the skills needed for that project. Team members apply to participate in the project based on their skills and interests. *Coral Team Leaders* then select a team based on the compensation (or costs) involved in the project and the skill sets needed. The teams join the local project and the processes and procedures in this guide are practiced. When team members return to their local countries they help to spread the techniques they learned and encourage best practices in rehabilitation efforts.

Following the steps in this guide will help you determine which type(s) of rehabilitation efforts are suited for your particular project. This is a working guide and presumes that you have a project in mind when you work through the steps. However, it can be used as an educational guide for gaining a better understanding of reef rehabilitation options.

Reef Ball rehabilitation effort in Minahasa, North Sulawesi, Indonesia, PT Newmont Minahasa Marine Habitat Enhancement Program

Any brand names or products mentioned in this guide are simply from our experiences and to help users to easily find suitable items for projects and do not reflect our endorsement of any specific product. We were not compensated for listing them. Because our monitoring and testing was performed using particular products, we can't make assurances that brand substitutions will not have unintended consequences but unless specifically noted in the manual generic or other brands may be suitable. The same disclaimer applies to any external websites referenced in this document.

Suggested edits, corrections, or other comments on this document are always welcome. New versions of this manual will be made available on our websites as editing time allows.

The Reef Ball Foundation was not compensated to create this guide. If you find it useful, please consider a small, tax free, donation. Simply go to www.reefball.org and click the ***Donate Now*** button.

Step 1: Determine Project Goals, Budget, Resources and Timeline

Setting Primary Project Goals

The best reef rehabilitation projects start with a pre-defined set of well-articulated project goals. Goals will be used to determine everything from project scope to monitoring plans. If you have a written set of project goals, it will be much easier for you to complete the steps in this guide.

If you have not formulated the project goals, this becomes the first and **most important step**. To start you thinking, here are some real life goals from our clients:

? To mitigate damage caused by a ship grounding.
? To create a SCUBA dive site that is also educational.
? To build a barrier reef to protect our beach from erosion.
? To have a program for our hotel guests to participate in reef rehabilitation efforts as an 'eco-experience'.
? To provide better and safer fishing grounds close to a village which reduce risk to fishermen from long and dangerous trips to distant sites.
? To make a sustainable farming area for aquarium fish collection.
? To make a recreational fishing site.
? To help rehabilitate reefs that were destroyed by a hurricane.
? To demonstrate our company's environmental commitment.
? To mitigate prior or impending damage to a reef from development.
? To have an exciting environmental project for our group.
? To create an educational snorkeling trail.
? To rescue coral that is going to be damaged when we build a dock.
? To rescue coral that is in the path of an impending dredge operation.
? We want our artificial reef to develop into a natural reef faster.
? We want to plant coral as part of an environmental educational awareness program for our school.
? To conduct experimental research.
? We need a way to re-establish mangrove communities damaged by storms or human development

The list of potential goals is enormous, we have documented hundreds of reasons to make, rebuild or rehabilitate reefs. Most projects will have multiple goals, which is better as long as they are **clearly placed in order of priority**.

For most projects, goal setting should be a team effort. If you are spearheading a project, it is critical to immediately start building contacts with government agencies, universities, schools, non-profit organizations, the community and local reef user groups (especially groups that may have conflicting interests). Incorporating all stakeholders into the goal setting process early on will help you avoid unexpected conflicts, delays, setbacks and failures. It is not unusual that groups that would normally be in opposition to your project actually end up helping if they are involved in the entire process.

Trawlers, for example, often volunteer to help with deployments so they can record the geographical coordinates of the site and therefore are able to avoid it in the future.

In most cases, the team will be able to set their own primary goals, however, occasionally it may be necessary to intervene in order to keep the project on task, or to keep one group's interests from dominating the discussion. Remember, at this stage, the team doesn't necessary have to know how to accomplish the primary goals just yet, they only need to be able to articulate them. Occasionally, you may require outside assistance to help guide your team to an appropriate set of goals. This often occurs with complicated projects, when consensus amongst multiple user groups (often with different goals) is required, or when you just need an expert opinion. In cases where an expert opinion is required, we are available to provide consultation assistance, but in situations where there is conflict between stakeholders, we recommend that a trained third party mediator be used. These professionals may come at a steep cost, but this cost is almost always justified based on the value of having consensus as the project moves forward.

Setting Secondary "Reef Function" Goals

After your initial goal setting document is complete, you can now add secondary goals which add secondary biological or physical function to the project such as serving as a *juvenile fish nursery*, *biological bottleneck* elimination, protection of natural reefs (for example by diverting diving or fishing pressures), erosion control, fish spawning site, or enhancement of a specific desirable marine life (such as lobsters, sea urchins, threatened coral species, octopus, or specific fisheries). As secondary goals, they may not have as much importance as the primary goals but they can sometimes be accomplish with little or no extra effort.

For example, hotels frequently approach our Foundation with a focused interest in protecting their beach from erosion using artificial reef modules, without any other goals. But when water quality is appropriate, a little extra effort can yield a breakwater project that protects the beach but also provides snorkeling and diving opportunities for guests, is compatible for turtles passing to nesting sites, and perhaps even serves as the base for a coral rehabilitation project. These secondary goals may, or may not, come into play as you determine your final approach but they are certain worth considering.

*Figure 1: Some example customizations to standard Reef Balls modules that can offer tailoring to create added complexity or **protective void space** for juvenile fish, a common secondary goal of rehabilitation projects.*

? *Check Point #1: Goals Worksheet*

? Before proceeding you should have a written document with primary and secondary goals clearly prioritized.

Primary Goals

Rank	Goal Summary (Try to be as specific as possible)	% Importance (100% total)
1		
2		
3		
4		
5		

Secondary "Reef Function Goals

Rank	Goal Summary (Try to be as specific as possible)	% Importance (100% total)
1		
2		
3		
4		
5		

User note: Make a copy of this worksheet or use your own format to start a project notebook

Determining Budget and Resources

Nearly all rebuilding or rehabilitation efforts are constrained by money, time or other resources. The amount of resources you have available may depend on a grant, a court settlement, a corporate budget or on donations and volunteers. Whatever your resources may be, carefully document any constraints or opportunities that might change the budget or availability resources.

As with any project, having more resources will allow you to do a better job, but is it almost always possible to make some positive impacts even with a minimal budget and resources. Usually your resource budget will limit your rehabilitation options or project scope, but other times you may be able to increase the impact of your project by doing more of the work yourself or with volunteers, while retaining your original project scope. Sometimes, there are timeline constraints combined with budgetary limitations. For example, you may have an annual rehabilitation budget or an on-going revenue stream that can be directed to the project. In this case, you may have to look at solutions providing on-going efforts, instead of a specific project. We see many projects where a grant funds the initial set-up and training as one project, but the on-going rehabilitation work is funded locally.

In almost all damaged coral projects, limited resources are cited as the number one reason for the lack of rehabilitation efforts or ineffective actions. This is one of the main reasons the Reef Ball Foundation has focused on developing rehabilitation options that are cost-efficient, and methods that can be employed by grassroots organizations.

Working alone, governmental agencies and scientific groups usually consume too many resources to do cost-effective rehabilitations. These organizations need the linkages to community resources and volunteers provided by grassroots organizations to be able to bring together teams that can be more cost-effective. On the other hand, grassroots organizations that work alone often lack specific required technologies and scientific methods, the ability to obtain permits, and an ability to think outside of the box in their area of specialty. Once again, teamwork will help to increase your budget and resources to accomplish the project goals.

After reading this manual, it is our hope that the next time someone or something destroys your favorite reef that you will feel empowered to take action regardless of your budget or resources; and will build a team that can affect successful rehabilitation.

<< INSERT SECTION FROM KATHY KIRBO ON SOME FUNDING SOURCES FOR REEF REHABILITATION WORK>>

? *Check Point #2: Budget & Resources Worksheet:*

? You should have a written document describing your budget and resources (including limitations and constraints) available for your project before proceeding.

Funding Sources

Funding Source	Funding Amount	When Funds Are Available

Resources Available

Resource	Resource Details / Contribution to Project / Benefit	When Resource is Available

User note: Make a copy of this worksheet or use your own format to add to a project notebook

Timeline

To complete this step, a working timeline is required. Is the situation an emergency that requires immediate attention to rescue coral that have been damaged? Or, is it a case of a long-term reef loss where you hope to make long-term rehabilitation efforts? Perhaps there are specific weather constraints, or seasonal limitations such as monsoon or hurricane seasons that the project must work around. All of these things need to be considered when building a timeline

When coral are imperiled or injured, immediate action is required in order to temporarily stabilize the situation while work plans are being designed. To accomplish this, it may be necessary to create a temporary *disaster nursery*. If that is the case, proceed through this manual far enough to determine if you will be stabilizing mature or large coral colonies, or if you will be using *genetic coral rescue* (*propagation* and *planting*) methods. In most projects of an emergency nature, a combination of both is the best approach, given sufficient resources. Once these decisions have been made, a nursery protocol can be designed and implemented. Once the situation has been stabilized, more time is available to re-evaluate the situation and complete a more detailed work plan (see the next heading, creating a temporary *disaster nursery* for a quick introduction).

Assuming your project is not an emergency response, the season of the year can be an important variable. Artificial reefs can be built year round, but are best deployed during calmer seas. Coral *propagation* and *planting* cannot typically be done when water temperatures exceed 30°C (86°F). In fact, the best time to plant a coral fragment is when you are entering a cooler season because the fragments don't have to deal with as much algae growth, bleaching events or lower oxygen levels; that are associated with higher water temperatures. In climates with distinct wet and dry seasons, it can be best to plant when you are entering a dry season because rain and run-off can impact coral health and reduce the efficiency of divers and propagation efforts. However, mature or large coral colonies can generally be re-stabilized year round because to wait might mean colony loss. In tropical areas, seasons for algae growth and temperature changes may not follow a seasonal pattern, so it is important to understand local conditions in order to make the right rehabilitation choices. Often, just knowing when the coral *mass spawns* in your area will give you the information about when it is optimal to plant fragments. Ideal planting times are typically within a few months following coral spawning events. If you are planning on deploying base substrate without any coral planting, then it is best to place your modules immediately after the spawn in order to maximize natural coral recruitment. If you deploy at other times, you need to insure good herbivore coverage (e.g. long spiny sea urchins, *Diadema antilarum*, or Turbo Snails (also known as turban snails), *Turbo fluctuosa*, or other similar species in order to reduce competition to young coral recruits.

Crisis Timelines: Creating Temporary '*Disaster Nurseries*'

In an emergency situation where a large number of imperiled corals have been damaged and need to be rescued in order to preserve the genetics of corals impacted by the disaster or to temporarily stabilize some of the most important adult coral heads for later re-stabilization, divers can create a temporary *disaster nursery.* These nurseries are designed to keep the coral healthy long enough to build and deploy appropriate artificial substrate (or to prepare the natural bottom); and to form a *coral team* with the necessary supplies to complete the rehabilitation.

If you have had *Rapid Response Training* and already have your *Coral Disaster Response Kit* on site then may be able to skip this step (see Appendix A). Even so, a *disaster nursery* may be a wise option to protect the most important coral colonies.

Most disaster nurseries are designed to keep corals coral healthy for a few weeks or months, although occasionally, it may be necessary to hold corals in a temporary nursery for up to a year. The objective of a *disaster nursery* is to get the coral safely into conditions that minimize the risk of damage from waves, shifting sediments and the possibility of being buried by sand. The *disaster nursery* must provide stability so that currents or waves cannot further damage the coral. This type of nursery can be very simple welded steel frames made from rebar or angle iron with wire mesh attached to the frame to serve as attachment points as shown in Figure 2. There are a variety of other possibilities for construction of temporary *disaster nurseries* and the exact choice will most likely depend on the specific local conditions.

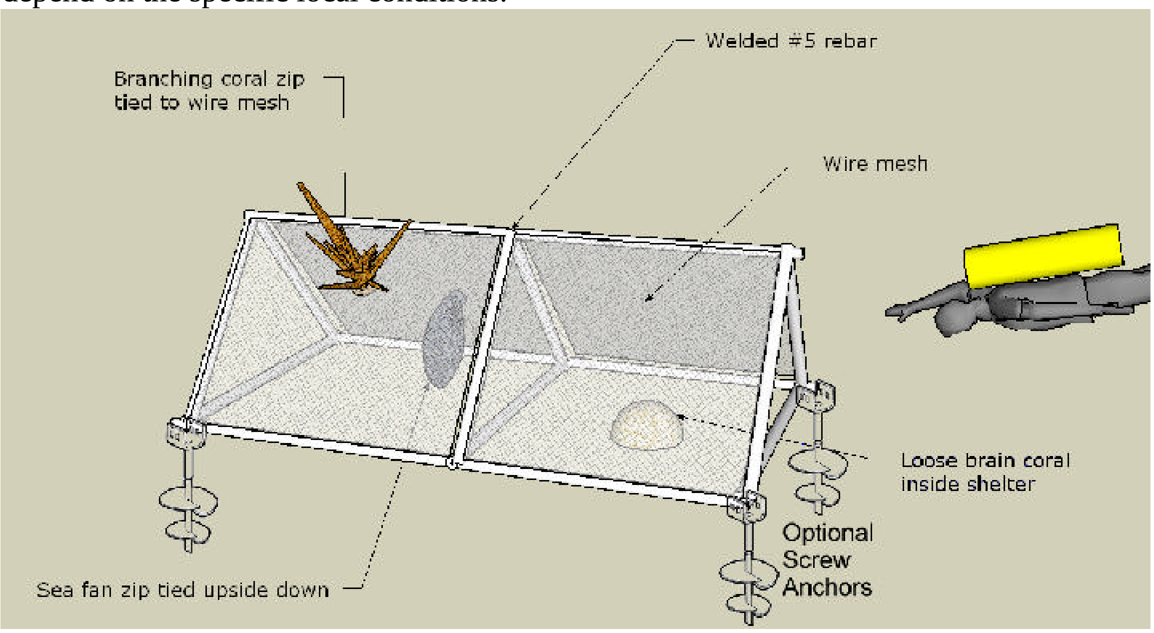


Figure 2: A temporary disaster nursery constructed from wire mesh attached to a tetrahedral frame made from welded steel. Imperiled corals would be attached to the wire mesh with plastic cable ties or thin wire to protect them from damage by waves or sedimentation until a permanent solution can be implemented. If necessary, "disaster nurseries" can be anchored with screw anchors

The shape is often triangular or tetrahedral, so that it can be deployed from a boat into a protected area, and will always land upright without additional effort. Deployment is best over a sandy bottom because it minimizes damage to natural fauna and facilitates anchoring, which is recommended if the nursery will be needed for more than a few weeks or if storms are expected before the corals will be relocated to a permanent emplacement. The nursery site should be as close to the original location as possible. If the original location is impractical, a site with similar water conditions (depth, light, salinity, temperature) should be found for the nursery. Screw anchors (Figure 2) are often used as temporary anchors because they are inexpensive, readily available, and screw into the seafloor easily. There are many other anchoring options for temporary nurseries. The anchoring system to be used depends on the bottom type and the strength of waves and currents in the area. When in doubt, it is best to use the strongest anchors available within the resources allowed by the project.

For genetic coral rescue projects, it is optimal to make at least 3 fragment *plugs* from each adult coral colony that is impacted. If possible, create multiple separate temporary nurseries, which allows preservation of coral genetic lines in case a storm or some other unforeseen situation destroys one of the nurseries.

It is important to carefully document the entire process, to facilitate scientific record keeping and documentation. The easiest way to accomplish this is to use digital still photography and a *monitoring frame* to record the donor colony and the fragmented coral saved. A monitoring frame allows you to calculate the size of the coral colony by referencing to a known grid, and also makes photographing easier, because it fixes the focal length. In this regard, be sure to use the same camera for each monitoring and to make sure the zoom feature is turned off or all the way zoomed out. It is best to work methodically over the site, consistently documenting your progress. Most disaster nursery rescue teams will develop some protocols including which coral are the highest priority for rescue, documentation procedures (often critical when there are liability issues) and handling techniques. Later sections in this guide will provide guidance on developing these protocols.

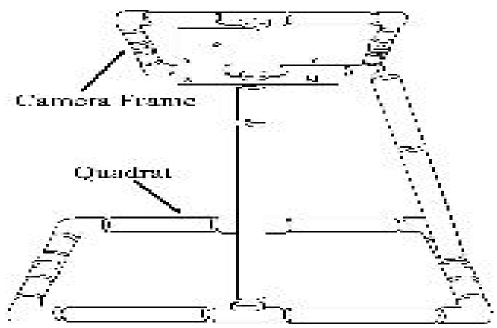


Figure 3: A quadrat framer built to standardize pictures taken from a digital camera in an underwater housing. The camera attaches onto the plate at the top of the monitoring frame, and the focal length of the camera is set to capture the entire area inside the quadrat of known volume at the bottom. This allows estimation of abundance and concentration of organisms. By marking the edges of the quadrat, this device can also be used to approximate length. Figure from Preskitt et al. 2004.

Following your protocols, attach the coral to the wire mesh using the *zip tie method* with plastic electrical ties or low-grade steel wire. Ensure that no colonies are touching and allow for growth or shifting of colonies, depending upon the length of expected nursery stay. Look for the healthiest coral possible and do not place any diseased coral in the nursery. The sheltered area under and around the nursery is a suitable place to store smaller adult colonies (such as softball or smaller brain coral) that need to be re-attached by hydrostatic cement methods. Coral that comes from deeper locations than the nursery depth are at risk of being *sunburned* during their nursery period, but these corals can be put inside the wire frames to reduce the risk of *sunburn.* Adult colonies that will ultimately be re-stabilized can usually be left where they are located, but they may need to be repositioned so that the *polyps* and their associated zooxanthellae can photosynthesize. If the adult colonies must be moved, it may be better to try to organize the emergency movement and re-stabilization as one process. This may require professional assistance, as this type of work is likely beyond the scope of grassroots organizations unless they have been trained in advance and have experience dealing with mature or large coral colonies.

Non-Crisis Timelines: Project Management

If your project is not in crisis, you will need to produce a written timeline with at least the most important milestones that must occur to keep your project on track. A simple calendar may do for small projects whereas more complicated projects will benefit from using commercially available project management software. Ideally, choose one that, at a minimum, produces simple Gantt charts.

The complexity of your projects will probably determine what level of technology is appropriate. Professional project management programs, such as Microsoft Project have heavy learning curves but offer more features. Some simple program such as, PlanBee http://www.guysoftware.com/planbee.htm, are available at little or no cost and minimize learning requirements but don't have features for very complex projects).

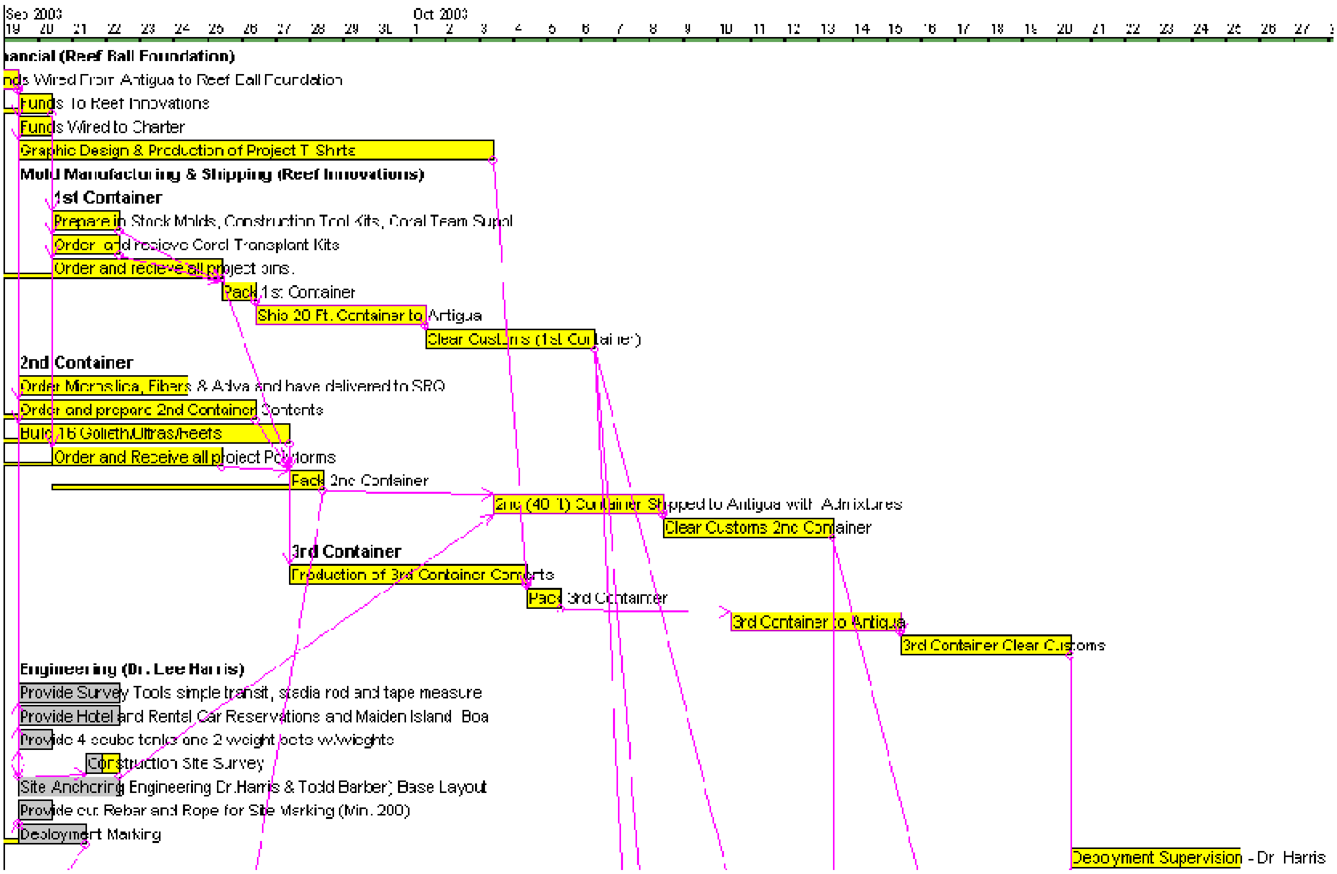


Figure 3b: Portion of a complex Gantt chart generated by PlanBee software to aid in the project management of the deployment of over 3,500 reef modules and planting of 10,000 coral fragments and 14 tons of adult coral transplants in Antigua, 2003-2004.

Check Point #3: Timeline

- You should have a written or electronic timeline to help determine when milestones must be achieved to keep your project on track with your planning.

  User note: Create custom timeline and add to your project notebook.

Step 2: Damage Assessment

If your project is attempting to rehabilitate a specific damaged or degraded reef, read this section, if not, skip to **Step 4: Site Selection**. If you have a keen interest in monitoring, you might want to read this section for a review of several monitoring techniques.

An assessment can be done in a variety of ways and the method used depends on the reason for the assessment and project goals. Below is a list of quantitative and qualitative methods most often used for damage assessment by the Reef Ball Foundation.

Quantitative Measures:

Area of Bottom Impacted

The area of impacted bottom is the simplest quantitative assessment method, and simply reflects the footprint of the damaged area. It is useful for rapid assessment and determining the logistics of the project, but it is an extremely poor estimator of the degree and severity of ecological impact in any but the most homogeneous of systems (e.g. sea grass systems, or sandy/rocky bottom habitats).

Cubic Volume of Reef Habitat Lost

This method is also fairly easy to compute and is a better method than the simple calculation of area when describing damage to reef ecosystems. An accurate survey of the bathymetry (often by side scan or multi-beam sonar) of the impacted area must be conducted to generate a three dimensional map of the damaged area. Alternatively, a simplified version of this method can be accomplished by multiplying the original average height of the reef by the square footage/meters of the area of bottom impacted. This can be a bit complicated if the original height was highly variable or unknown. The approximation of maximum pre-incident relief can be important because impacts to taller, typically more mature coral reefs are much more severe than impacts to lower, typically younger reef systems, even when the footprint of the damage is the same. This measure, however, fails to consider the complexity of the reef lost and therefore cannot be used to estimate the amount of *protective void space* loss. This method can be enhanced by increasing the precision of data collected on the habitat types within the entire impacted area.

Reef Head Size and Density

Surveying adjacent, non-impacted areas can be useful to estimate the reef head size and density lost. This can be helpful in planning the proper levels of *protective void space* rehabilitation. Once you have calculated the approximate density and relief of nearby habitats, planned base modules can be built to approximate the complexity, density and size of the adjacent reef heads. In the case of coral reefs, this method can be enhanced with an independent analysis of certain high value coral species, particularly the large *protective void space* creating coral species.

Diversity of Coral, Fish, Invertebrates, and Other Impacted Species

If the project team has good monitoring capabilities, the most complete assessment method is an inventory of species diversity and population densities. For most reefs (especially coral reefs), this can be an extremely complex and time-consuming task, and it is probably only feasible to focus on the specific species that are judged most important in **Step 1: Determine Goals**. A number of scientific papers have been published which detail different methods of underwater visual census (UVC) which may be more or less appropriate for your specific project. However, a thorough discussion of these methodologies is beyond the scope of this manual.

Number of Coral Colonies Impacted

Some projects may only be concerned with coral. These might include, projects that are initiated because of coral damage, or projects addressing specific threatened coral species such as elkhorn (*Acropora palmata*) and staghorn (*Acropora cervicornis*). In these projects it is appropriate to focus solely on the coral of interest. By refining the focus of your monitoring efforts, resources can be devoted to categorization of coral heads by size or age estimates in order to more accurately focus rehabilitation efforts.

Semi-Quantitative Measures

These methods are based on quantitative techniques, but can include factors that vary for different reef species, or are more difficult to quantitatively estimate. Factors such as protective void space and biologically active surface area must be assessed differently if you are concerned with the protection of tiny creatures versus large ones. Nonetheless, these factors are critical to understanding meaningful rehabilitation. To be most useful, these analyses need to be tailored to your project goals. For example, if your interest is in juvenile fish production, protective void loss should be examined from a small fish perspective; whereas if you are looking at adult fish populations the analysis should be from an adult fish size perspective. Similarly, the biological surface area from the perspective of a lobster is different from the biological surface area for a tiny copepod. Tiny surface holes and wrinkles make a big difference for copepods but do not provide additional habitat for an adult lobster.

Protective Void Space Loss

Protective void space is the habitat that reefs create for fish. Just like trees create habitat for birds, providing them shade, hiding places, nesting sites and wind protection.

The most critical function that coral (or any *reef* structure) provides to reef associated fish is *protective void space*. Protective void space is the area that protects fish (or other mobile marine life) from larger predators and provides shelter from energy-draining currents. All reef dwelling demersal fish species (as opposed to pelagic fish species) exhibit a certain degree of habitat fidelity, and need *protective void space*. The amount of *protective void space* provided by a reef helps to determine the carrying capacity for fish and other marine life of the reef. Reefs with higher carrying capacities for small fish will also support a larger number of pelagic predators which feed on reef associated fish species. *Protective void space* is created by reefs. A reef is defined as “a submerged ridge of rock or coral near the surface of the water” by the dictionary [Source: WordNet (r) 1.7] but for purposes of this manual it can be defined more loosely as rocks or outcroppings in the sea. Outcroppings can develop from coral branches and in the interior of the coral structures. The interior often contains holes and cavities of the eroded limestone. Outcroppings can also come from other biological organisms such as oysters and rocks can form from exposed hard bottom or other geological processes on the seabed.

When considering rehabilitation options, it is often useful to try to quantify that amount of *protective void space* that has been lost or is being created by the lost or degraded reef.

To compute an EPVS, calculate the maximum foray distance in all directions, which can be further defined as resting, foraging, mating, high current, predator attack, or other foray category as needed for the specific analysis goals, and subtract the volume of the reef space (natural or artificial) that cannot be occupied by the species. It may be easier to understand the concept by thinking of a single artificial reef module place on an open bottom as in the illustration below.

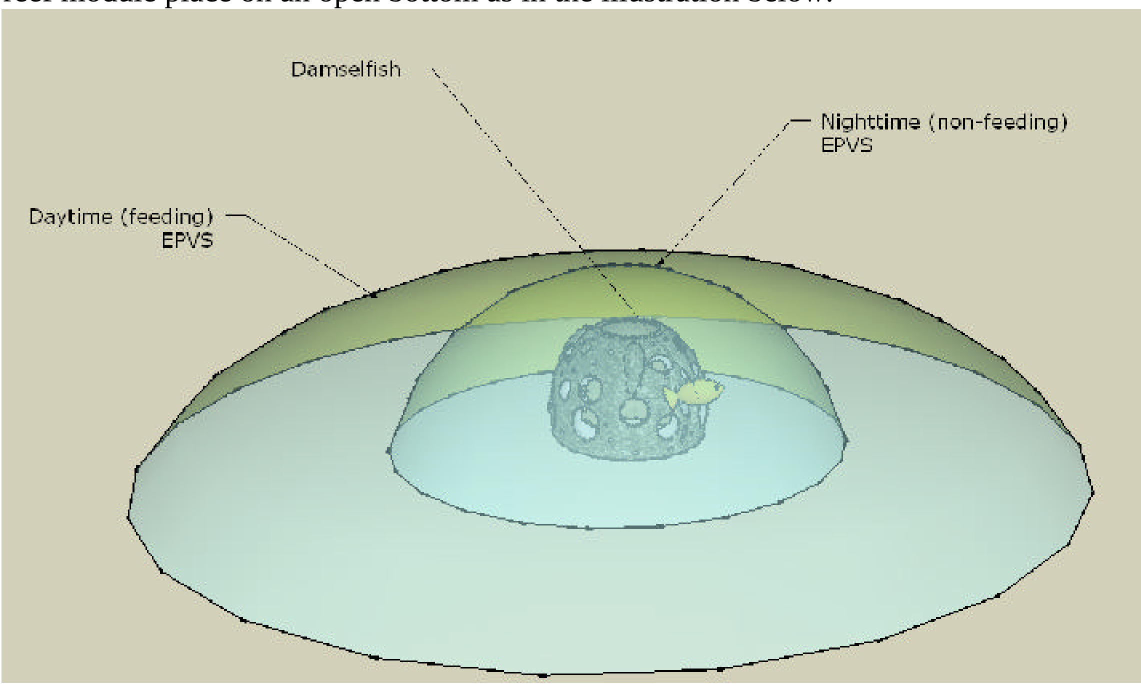


Figure 4: Illustration of effective protective void space (EPVS) for Damselfish on a Pallet Ball sized Reef Ball categorized by daytime and nighttime foray. For example, nighttime EPVS for the above-pictured Damselfish in a Pallet Ball would be approximately 16.5 cubic meters (592 cubic feet) if one based the radius of the foray (sphere shaped) around the reef module at 2 meters (6 feet 7 inches).

Calculation example: Use ½ of volume of sphere formula 4/3(**¶*** $r^{3)}$ *minus the volume of the artificial reef module since a Damsel fish would occupy the interior void of the above reef module.*

*Nighttime Volume of Foray = ½ * (4/3 (*$\P*2^3$*))=16.75* m^3
Volume of Pallet Ball = .25 m^3 [Source: http://www.artificialreefs.org/Technical/reef.htm]
16.75 m^3*-.25* m^3*=16.5* m^3
So,
Nighttime EPVS is ***16.5*** $\mathbf{m^3}$

Areas around the reef where eddies and back currents form also provide a type of *protective void space* that is especially important in areas where there are currents.

During times of low current velocity, the void space **expands** to the greatest distance a particular fish is able to venture from safe cover and still return to cover safely if chased presuming the fish is in a foraging mode. Functional void space shrinks during storm events and times of high velocity currents. At these times, the void space is limited to interior cavities of the reef and areas close to the edges of larger reef structures where there is sufficient shelter from the force of the ocean to conserve energy. Rehabilitation of void space is particularly important to rehabilitating sustainable fisheries on coral reefs, and is often overlooked. It is rare to find demersal reef associated fish far from a protective void space, except when they are displaced, migrating, spawning or foraging in nearby sandy areas. Furthermore, mortality of fish at the time of transition from pelagic larvae to demersal juveniles is extremely high, and survival has frequently been shown in studies to be proportional to available habitat.

Larvae that settle onto unsuitable habitat have virtually 100% mortality, while larvae that are able to find some measure of protection have a higher probability of survival. Since many of these demersal site associated fish species exhibit density dependent mortality rates, and appear to be habitat limited in their production, any rehabilitation effort that fails to create protective void space may have little, if any effect on populations of these fish species.

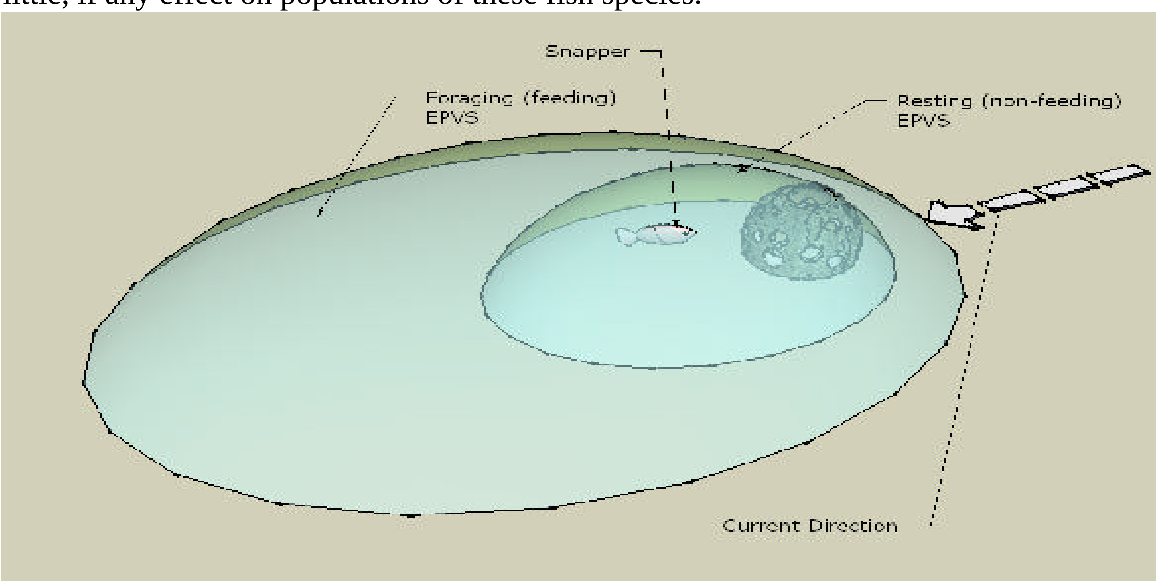


Figure 4a: Illustration of how currents typically alter foray. In currents, fish prefer staying inside, near the leading edge or behind reefs because they offer back eddies or lower current conditions so that less swimming effort is required. When currents bring feeding opportunities, the range can expand keeping a similar shape or surprisingly complex shapes can arise for fish using the cover of the reef to "pick off" food items passing by in the current. The complexity of those shapes are often correlated with the size and nutritional value of the food offered. (For example, fish eating plankton passing in a current stay very close to the lowest current area their biological ranking will allow, whereas fish eating larger prey may wander further from the zone. In some larger fish eating prey..especially those more loosely associated with reefs such as flounder higher currents offer a time of concentrated food sources as they move into the areas just around the reefs where smaller fish are congregating to avoid the currents.

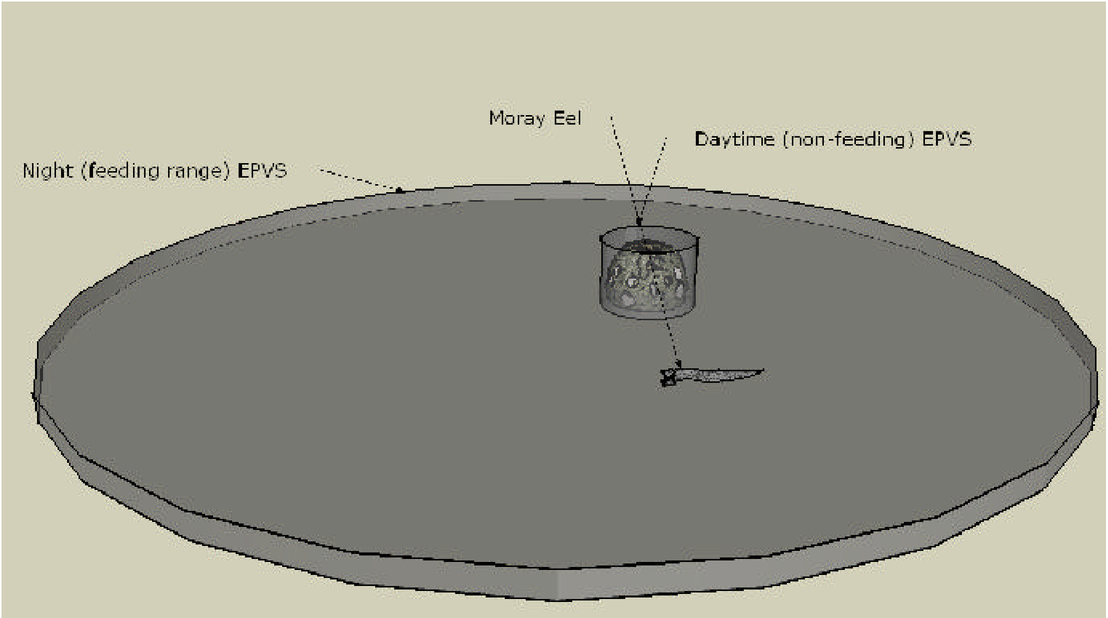


*Figure 4b: Illustration of how some marine life can alter their EPVS for specific behaviors such as feeding, mating, migration, or displacement. It is useful to understand that although under normal conditions fish might be closely associated with a low volume EPVS under some conditions might nee to expand their ranges for important behaviors. When considering the footprint of the rehabilitation effort, it is important to consider which behaviors **NEED** EPVS, which **BENEFIT** from EPVS which **DON'T NEED** EPVS and which are **INHIBITED** by EPVS.*

Examples include:

- *large foray areas for food collection,*
  *(If sand forager, **INHIBITED**, if reef forager, **BENEFIT**)*
- *migration to other habitats for different life cycle stages,*
  *If migrition requires cover, **BENEFIT**, if migration presents threat of reef associated predation on species, **INHIBITED**...etc.*
- *travel to and from mating grounds,*
- *displacement from a pollution event,*
- *a lost territorial battle,*
- *temporary relocation during major storms,*
- *other factors.*

In looking at reef ecosystems, one often needs a system wide EPVS understanding including distances between larger EPVS zones. This is where non-reef ecosystems such as sea grass beds and submerged mangrove roots can heavily interact with reef rehabilitation plans as they both offer specific types of EPVS even though they are not technically defined as reefs. There are many other non-reef features that create EPVS that should be considered in system wide views.

EPVS can also be used to predict species inbalances. For example, let's assume your project includes the decommisioning and sinking of a large vessel or oil platform. Such projects are going to provide a lot of non-feeding and current protected foray. However, if a species is a sand forager or must travel to reef habitat for feeding it might be limited by specific EPVS types. Any project that deploys base materials higher than the average relief of the natural reefs in the area risks an imbalanced EPVS that can attract too many fish without providing all the needed EPVS sub-types and therefore should be undertaken only when there is sufficient low height structures nearby providing the needed foray(s).

User Note: Because of the powerful attraction features of very large EPVS (tall base structures), when *EPVS balancing* is not possible by either site selection or augmentation with additional low profile materials then we recommend classifying the structures as “Marine Protected Zones” and not allowing human harvesting of the marine life. Without this step, very large EPVS creation will likely contribute to a depletion rather than a supplement to marine resources in the area (harvestable resources such as fish).

For example, providing one artificial reef module in the middle of the sand far away from any reef might provide EPVS for a species that never leaves the reef (such as an attached coral), but without nearby additional natural or artificial reefs the EPVS could be unsuitable for a species that obtains food from the fouling community (let's say a Parrot fish that eats coral) because the surface area of the individual module is too small to support the Parrot fish.

To determine a simplified *effective protective void space* (*EPVS value*) for any species of a particular object (coral head, artificial reef module, etc.) simply monitor the maximum distance the species will venture away from the structure during normal reef-dwelling behavior during low current times. Monitor both the horizontal and vertical distances and then compute the volume of the area the species occupies. Then subtract the solid volume of the structure (if significant). If openings in the structure are too small for the species in question to penetrate, the structure should be considered to be solid for the purposes of this calculation.

If there are very frequent high current velocity events, such as a reef at the entrance to an inlet where tidal or wind-driven currents may be strong, you may want to repeat the calculations during a high current event and use a weighted average of the two measurements based on how frequently the site in question experiences high versus low current conditions (for example, if current is high for 4 hours out of a 12 hour tidal cycle, multiply the EPVS calculated at low current level by .66 and the EPVS at high current by .33 and sum them to calculate the weighted average). The result of the computation will be the amount of *protective void space* created for that species, by the object studied, in the particular current climate studied.

Such measurements *of protective void space* can be used to compare rehabilitation methods and estimate the relative potential success of the method for a particular reef species. For projects concerned with diversity or community health, and if you are using a diversity index [such as Simpsons, or Shannon-Weiner, Reef Check or other methods the concept of EPVS can help you fine tune your rehabilitation to get better results. For example, if you find your rehabilition is not providing enough habitat for Moray eels compared to the natural habitat you can add new EPVS or re-arrange your existing EPVS to better suit that species.

Once the concept of EPVS is understood, a well-trained expert eye can approximate the amount and complexity of base material that must be used to rehabilitate a lost reef’s function fairly accurately, without performing these complex analyses. In many cases, your project may not have the resources to recover all the lost void space. In these cases, it is important to do whatever you can, and remember that some rehabilitation effort is usually better than none. Conversely, if your project has extra resources, or you’re not sure how much was lost, and need to allow a margin of safety, we are not aware of any cases where constructing more complexity than was lost has been detrimental to a system. In the worst case, adding more habitat than needed would lead to an inefficient use of that habitat by the resources provided you did everything correctly following the steps to avoid negative project consequences.

Biological Surface Area Loss

This is a theoretically quantifiable measure of the biologically active surface area lost during an event. While functional, and easy to understand, there are many complications associated with the calculation. The most important assumption regards the scale of detail with which area is measured. Rugosity and fine scale complexity at different size ranges are important to different organisms, so making an assumption about what is functional surface area depends on what the target species. If you are working with larger organisms, it may be adequate to make the assumption for calculation purposes that the surface is perfectly smooth. In this case, a standard CAD program can calculate the surface area, or one of many photo imaging analysis software packages can calculate surface area.

On a real reef, however, surfaces are anything but smooth, so depending upon what scale you define the surface, the result changes greatly. For example, if you consider a piece of corrugated tin, if you were standing a mile away, you would probably measure area by simply multiplying length by width. Once you got closer, and could see the grooves, you might change your calculation to account for the additional area from each of the grooves. If you looked at the tin under a microscope, you would see many small pits and cracks, which would increase the surface area further! The same holds true for a coral colony or a patch reef. Once again, this also depends upon which marine creatures you are judging for habitat purposes. It might be appropriate to judge a surface on a millimeter scale if looking at copepods. It is probably better to look at a centimeter scale for coral settlement or to assume a totally smooth surface for adult coral base space.

For this reason, it is impossible to compare calculations of area lost between different sites or events, but this tool can be quite useful for estimating the amount of impact when comparing areas within the same project as long as the resolution is kept the same for all computations.

Qualitative Measures:

Loss of Reef Functions

There are a number qualitative indices used to define loss. Some commonly cited losses include;

? Fishery Resource
? Recreational Value
? Erosion Control
? Ecological Function
? Biodiversity

Sometimes, the most important things to consider cannot be measured quantitatively. This may be because of lack of resources or expertise to carry out appropriate quantitative analysis, or it may be because the factor being considered is difficult to put into numbers. That does not make these measures any less important. While qualitative measure often cannot be defended precisely, they are still useful for discussion and debate of rehabilitation options. However imprecise the measures may be, they do represent real issues that are often very important, and sometimes qualitative concerns can over-ride recommendations which arise from quantitative analysis. Not surprisingly, many rehabilitation efforts are decided upon using qualitative rather than quantitative analysis methods. Hopefully, as rehabilitation science continues to increase, more and better quantitative analysis tools will become widely available which will facilitate better analytical decision-making. Until that time, however, we must often work with what we have, and make decisions based on the best information available at the time.

Expert Opinion

Many grassroots organizations are best served by expert opinion. As mentioned earlier, there are a great many factors that go into rehabilitation projects, and it is impossible to go into depth on all of them in a manual of this scope. For this reason, it is best to consult experts when a situation stretches beyond the knowledge of your team. There may be excellent local scientists or consultants available to share their opinion, or formal governmental assessment teams designed for this purpose. You may call upon the Reef Ball Foundation to help you find or to provide experts. If resources are very low, sometimes an expert can provide an opinion without a site visit, especially if necessary local information such as underwater video or digital photographs can be gathered in advance and shared via the Internet.

A true expert opinion can be quite valuable, but the opinion is only as good as the expert! If you decide to use expert opinion, be sure to select experts that you can trust. If you need a second opinion, please feel free to contact us. When choosing an expert, make sure they have local experience or pair experts with knowledgeable locals to facilitate better recommendations.

Whatever method(s) you choose for damage assessment, it is helpful for you to document the entire process as thoroughly as possible, including taking measurements before any rehabilitation has started so that when you make rehabilitation efforts you will be able to measure your success (or lack thereof).

Check Point #4: Damage Assessment Worksheet

- You have assessed and documented the damage to your reef
- You have a reasonable idea of the amount of rehabilitation effort that would be required to approximate the losses.

Measurement	Calculated Loss	% Weight	Rehabilitation Effort*
Area of Bottom Impacted			
Cubic Volume of Reef Habitat Lost			
Reef Head Size and Density			
Diversity of Coral, Fish, Invertebrates, and Other Impacted Species			
Number of Coral Colonies Impacted			
Protective Void Space Loss			
Biological Surface Area Loss			
Loss of Reef Functions			
Expert Opinion			

Motivation Level	Amount to Recover Target (circle target level)	Targeted Effort(s)
Lowest necessary		
Highest possible		
Weighted Average or Specified Target		

* Rehabilitation effort could include definitions of how much you expect to rehabilitate and which measurement you will use to judge your success. It may include specific techniques that have know measurements such as numbers of corals to plant or artificial reef module characteristics.

User note: You may need to make multiple copies of this page for your project notebook to account for multiple rehabilitation approaches. If you are using multiple measurements, circle the amount to recover level you are targeting (i.e. lowest amount necessary, highest amount possible or targeted average (with relative weights) as your final "Amount To Recover Target". in the final row.

Step 3: Rehabilitate an Existing Reef or Build a New Reef?

It is necessary to carefully review the findings from **Step 1: Determine Goals** during this step to decide if it is best to rehabilitate an existing reef or to build a new reef.

Rehabilitating an Existing Reef

In an ideal world, existing reefs that have been physically damaged would always be rehabilitated as soon as the conditions that caused the damage are no longer a threat and in the same location as the damage occurred. However, timelines are rarely immediate and working within a damaged or degraded reef provides challenges that don't always allow ideal rehabilitations.

Why isn't it always best to rehabilitate exactly where the damage occurred? Consider a common problem, if you are going to be deploying artificial reefs as your base substrate for planting coral fragments, careless deployment techniques could damage the remaining natural reef. There are many cases of artificial reefs, carelessly deployed, that damaged the very reefs they aimed to rehabilitate. **Any type of deployment of materials when live coral reefs are present should only be conducted with divers in the water to confirm the deployment location is clear of natural coral and should be performed by experienced people/contractors.**

Figure 5: Example of a poorly deployed (and poorly designed for purpose) artificial reef in Thailand when after the 2004 tsunami local groups attempted unguided rehabilitation in a desperate attempt to recover lost coral resources . Thinking artificial reefs would perform best where the natural reefs were located, they dropped simple concrete cubes weighting several tons each, indiscriminately ***ON TOP*** *of natural corals. This caused extensive damage to the natural coral reef habitat and provided no benefits toward rehabilitation goals..*

An important first consideration is the logistics of the reef being rehabilitated. Are there a lot of open areas or large scars that will make it easy to do the rehabilitation tasks without threatening the natural reef left? Note that your decision on the suitability of working within an existing reef can be impacted by the types of material or methods you choose for rehabilitation. For example, some modular units, such as Reef Balls, are designed to be floated into place, and can be deployed reasonably close to natural reef without risk. Larger or non-floatable artificial reef modules may have to be deployed off a barge, which is less accurate and will require more distance to minimize risk. Even coral planting activities need to have some (minimal) space for divers to work and that can depend on the skill level of selected divers. Take into account the deployment accuracy and working space requirements as you consider the options.

Another consideration is how the damaged site will recover on its own. For example, we have seen numerous ship and submarine groundings that dug channels through limestone rock. If the timeline does not allow for quick rehabilitation corals may begin to recolonize the newly exposed rock and it would not be wise to work in that area. While there may definitely be a loss of ecological function associated with the grounding, in this case adding reef nearby at a selected suitable site might be more prudent than disturbing hard substrate recovery processes. If the same scar went through sand, one might not expect any coral recovery but doing rehabilitation work in the “sub grade” depression might increase the chances of your work being covered by sand as the depression caused by the grounding fills back in to normal sea floor levels.

One must also consider why the original reef was damaged. Perhaps its location made it vulnerable to human activities? Obviously, it may not be best to rehabilitate a reef in the middle of a boat channel or in an area near a popular tourist beach that is constantly being re-nourished year after year. In situations where the factors which stressed or damaged the coral are still occurring, or are likely to occur again, it may be best to invest resources in mitigation, and build a ‘replacement’ reef in an area that is under less stress.

Working within, or at least close to, existing reef systems has significant rehabilitation advantages, including easy access to imperiled coral for *brood stock* purposes. The less distance coral must be transported for processing in the *fragmentation nursery,* and *coral propagation table* the less stress they will undergo during the processes required to *propagate* and *plant* them. Additionally, the closer your rehabilitation efforts are to the original damage (especially if you make a speedy rehabilitation) the more likely you will be providing habitat for the originally displaced marine life that depended upon the reef before it was degraded. When working close to a natural reef, one can nearly always assume water quality and environmental conditions are right for coral fragmenting and planting, and the risk of transplanting corals into an area with different conditions is minimized. (Note, this presumes that the damage to the corals was temporary in nature and not caused by long term water quality changes). Sandy patches adjacent to natural reef are often ideal locations for base substrate deployment.

However, building close to a natural reef is not without disadvantages. This increases the possibility of *coral predators* attacking your newly planted coral fragments. If you are concerned about this, the *coral predators* glossary entry in appendix B contains suggestions on minimizing the impact of coral predators. Furthermore, building close to a reef may not meet the goals of your project if you are trying to reduce diving or fishing pressure on the natural reef.

Building a New Reef

If you can't rehabilitate the exact location of the damage, or the goals of your project are best served by working away from existing habitat, building a new reef is a viable option. The new reef may be quite close or quite far away from the natural reef.

However, there are disadvantages of building a new reef. The project may require substantially more base substrate to create enough *protective void space* to provide an equivalent amount of *essential fish habitat.* Typically, constructing and deploying base artificial reef substrate is the most expensive portion of a coral rehabilitation project. Also, moving a project to an area without natural coral, a great deal of attention must be paid to water quality to ensure that conditions are suitable for coral growth, and that transplanted or propagated corals are brought in from an area with similar physical and chemical conditions.

On the other hand, starting on a fresh site can reduce coral predators and possible disease contact. New sites can be configured to maximize project goals or targets such as specific EPVS goals for select species. Choosing a site allows one to consider a variety of human interactions such as travel distances to the reef from ports, usability features such as diving, locations protected from future damaging activities, and a host of other intriguing possibilities such as erosion control. Sites can be selected to reduce budget or resource burdens and this alone can make the choice of building a new site economically attractive.

At this point, you should be able to determine the proper course of action for your project by reviewing your work in previous steps of the process, and taking into account the timeframe before work will actually occur. If you are having trouble determining this, wait until the next step (site selection) is completed as it may provide clues to guide you.

Check Point:#5: To Build or Renovate?

Unless there are complicated issues or mixed goals;

- ? If you prefer to rehabilitate the damaged reef in it's existing location check first that none of these conditions apply:

- ? There are *coral predators* or *coral diseases* present at the damaged location that will thwart rehabilitation efforts
- ? The damaged location is unacceptably vulnerable to future damage
- ? We don't have the skill or resources to work within the area without the possibility of doing further damage to the reef.
- ? We don't have the skill or resources to work with the depth range of the damaged reef

And then you may proceed to step **Step 4B: Bottom Survey** to see if the physical conditions are acceptable for rehabilitation.

User note: You may still have to return to step 4 if the conditions at the site are not acceptable for rehabilitation efforts.

- ? Or you have chosen to work in a new location and must proceed to Step 4: Site Selection

Step 4: Site Selection

Step 4a: Determining Sites for Surveying

By this point, most project organizers will have an idea of the general area where they want the rehabilitation to occur, but many not know **exactly** where to do it. In this case, you must identify sites to conduct detailed bottom surveys that help narrow down a final choice. If you already know the exact location, skip to **Step 4B: Bottom Survey**.

Determining which sites to survey is a process of elimination. The best place to start is a mariner's chart with depths (A free US chart source is http://www.navquest.com). It's very useful to supplement chart information with additional information sources like Google Earth™ , a free web based application that provides satellite images of various detail anywhere on earth. There are often government or privately available Geographical Information Systems (GIS) databases that can be helpful in getting system detail. Libraries, web searches and local contacts can aid in revealing data or studies that have been done in the proposed area. It is useful to know currents, wave heights, tide ranges, etc. These can be sometimes be found in formal scientific literature, but it is often a good idea to get the input of local people that spend time on or in the water, such as fishermen, boat captains, and SCUBA divers because these types of conditions can be quite variable, seasonal, or site specific. Find out about water clarity, local pollution, traditional fishing areas, and discuss other aspects of your project to maximize your information gathering.

Once you have gathered as much information as possible from these, and any other sources of data you may know, begin eliminating areas that are not suitable for your project. It may be helpful to photocopy your map, or use a computer program and physically block out areas that are not suitable. In order to focus your thinking, below, you will find a list from the US EPA of some additional areas to exclude:

? Shipping lanes
? Restricted military areas
? Areas of poor water quality (e.g., low dissolved oxygen, dredged material disposal sites, Sewer outfalls, river drainage, and other point sources of pollution)
? Traditional trawling grounds
? Unstable bottoms
? Areas with extreme currents, or high wave energy
? Existing right-of-ways (e.g., oil and gas pipelines and telecommunication cables)
? Sites for purposes that are incompatible with reef development

Most marginal areas should also be eliminated from consideration. Do not overlook local restrictions as well. For example, building inside locally designated marine reserves usually requires special permits, which may be difficult or impossible to obtain. Do the necessary research to ensure that you know the permitting regulations for your chosen sites to avoid unpleasant surprises later on. Often, marking out areas too shallow or too deep for your project can eliminate a large portion of the otherwise suitable areas. Consider any constraints that may be imposed by your project goals. Talk with your team and add constraints they suggest. It is also best to avoid areas with healthy reefs, sea grass beds, or other live bottom types unless you have very specific goals in mind.

Now that all of the unsuitable places have been eliminated, reverse the procedure. From the areas left over, where is it best to build? Do your goals or does your team suggest an ideal depth? From a substrate point of view, keep in mind that the easiest place to add artificial reef substrate is an empty sandy bottom that has hard rock or firm bottom 10-20 cm below. Firm sand is okay. Hard bottom is fine if it does not contain a *fouling community.* Your team and goals may provide ideas for ideal sites, for example where currents will carry the larval coral and fish generated by your rehabilitation efforts to places where they are needed. Go back to those goals one more time…what do they suggest to you about where to build? If you are doing an erosion control project, you may have very tight tolerances for potential sites in this case you will need the assistance of a coastal engineer.

By the end of this process, you should have identified at least one and often several areas that fit your project criteria. It will be easiest if you identify these locations using GPS coordinates (specify *map datum*).

Check Point #6: Potential Site(s) Map Worksheet(s)

- You need to prepare a map, ideally with GPS coordinates, area(s) that you plan to survey for possible selection for your project. Depending upon available technology and your skill level, this may be a simple marked marine chart or very sophisticated electronic charts / CADS / side scan sonar reading / etc. Most permitting agencies will require 4 corner coordinates but some allow non-square shapes.

Potential Site #:_____ Site Name ___________________________________

Datum ___________ Format ___________(	**Center Coordinate**	North West Corner Coordinate	North East Corner Coordinate	South West Corner Coordinate	South West Corner Coordinate
Latitude (Specify N or S)					
Longitude *(Specify E or W)*					
Charted Depth *(Specify feet, meters or fathoms)*					
Notes/Map					

User note: Copy this page for EACH potential site. Don't forget to write in Datum and Format of your GPS coordinates. Make sure coordinates are compatible with your (boat's) equipment (GPS). Add a map and notes as required for navigation. Add to project notebook. Program coordinates into GPS.

Step 4b: Bottom Survey

At this point, you have one or more sites selected and you need to determine if the site is suitable for deploying a base substrate and supporting coral. This survey is best conducted by SCUBA…but it is possible to snorkel for shallow areas. In addition to your SCUBA/snorkeling gear, you will need the following equipment:

Depth Gauge & Compass (even if snorkeling, but wrist mounted is preferred for snorkelers)

Small hand-held sledge hammer

(2 or more)1 meter lengths of #5 rebar (5/8' or 1.59 cm) diameter iron rebar (If possible, mark the rebar stakes so you can use it as a measuring tape)

Fiberglass tape measuring reel
(50 Meters +)
(Don't use metal tapes, they will rust)

GPS (Hand-held or Boat Mounted)

Digital Camera and Underwater Case (Always clean and lubricate o-ring before use. Pack & seal in a low humidity environment, such as an air conditioned room, before diving. If you must transport the camera for any duration in hot conditions after packing keeping it in a small bucket or plastic bag full of water will help avoid sudden temperature changes and damage. When possible use a larger memory stick and fully charged battery so you do not have to open the camera in the field.)

User Note: RBF Coral Team uses Cannon Powershot (400-700 series) with manufacturer's underwater case which is economical and allows white balance function while working underwater which is essential for true color photographs). Most any underwater setup is suitable for this step but compactness is helpful due to other tools being carried.

Underwater slate, strap, graphite pencil & eraser.

User Note: Solid graphite pencils (available at art stores) are more reliable in marine use. AquaSketch [http://www.aquasketch.com] makes advanced specialty slates especially well suited for survey and scientific work.

Site Marking Buoys

4 or more marking buoys (many different types will work, even a milk jug tied to a dive weight). Whatever style you select, make SURE it is stable enough for the wave conditions and has enough line for the depth so that it does not move. Marking buoys made especially for divers with enclosed weight such as the SCUBApro buoy signal (shown below) are easiest to use.

Figure 6: Various styles of site marking buoys (SCUBApro left, generic middle, and Cressi-sub right)

Once you have your equipment ready, and when diving/boating conditions are **good** follow this procedure. Go to the site and anchor up so your **boat** is in the center location of the area you want to survey. When the anchor is **well** set, throw in a marker buoy and take a GPS reading. Dive to the bottom below the boat and start at the marker buoy (which should be the same place as your GPS reading). Record the depth and look to see if the site contains enough open space to place your base structures. If it is obvious right away that the site is not suitable, for whatever reason, proceed immediately to the next site. Don't waste the day surveying sites that you probably won't use. If it looks good, ideally open sandy areas with hard bottom below and otherwise clear, then continue. If it is hard bottom, use the camera to record that there is no growth or *fouling community* on the hard bottom. If sand, take your rebar and carefully drive it into the bottom making even strokes counting them as you drive the stake. Your stroke should allow the hammer to fall under it's own weight, guided by a little added pressure for guidance from a distance of about .3 m (1 foot). Record the depth to firm bottom and the number of strokes it takes to get there. If you do not hit firm bottom, record the number of strokes to go .6m deep (2 feet). It is important to be consistent with this process between sites so you can compare the relative softness of the different sites. This will help you determine when there is no hard bottom below the sand and if it is firm enough to support your chosen base substrate or artificial reef.

Note: Contact the supplier of your base substrate or artificial reef designer to determine how firm the bottom sand must be to avoid *subsidence* for your selected material if firm bottom is not found within 0-20 cm of the bottom surface. Do not plant coral closer to the seafloor than the distance to hard bottom determined by this survey on any material that is not supported by anti-*subsidence* anchoring or the coral may eventually be covered by sand, you may need an even larger safety distance to account for possible *accretion.* There are advanced anchoring options for difficult situations but this will require further investigation not covered by this manual.

Use your slate to start drawing a map with your current location being the center point. Leave this first rebar stake in the sea floor and lay your tape measure over the rebar. Decide roughly how big of an area you want to survey. Then extend your tape out to that length heading in a compass direction of due east (or whichever point on the compass (N, S, E, or W) is most perpendicular to the current, to preserve your visibility). Then, take your next sample by repeating the rebar procedure or taking a photo of the hard bottom and then place one of your marking buoys at this place. Mark your slate with the information and then do the remaining points (either rebar or photographic method depending on bottom type). As you sweep around directions, use the tape measure to determine distance from the center and map any areas that are not suitable for deployment (such as on an existing reef head, or were the bottom appears too soft.). Take notes on anything you find unusual that could affect your project such as changes in depth. Take digital photos of the general area and any specific features as you go. Finally, return to the center reeling in your tape as you go and retrieve your first rebar. When you surface, remove the anchor and travel to each buoy location and take GPS readings and retrieve your buoys. Record which *map datum* your GPS is using, especially if you may use a different GPS for deployment day.

If you have a *secchi disk*, it is nice, but not required to record the water visibility. This helps when interpreting the accuracy of the findings. Secchi disk readings must be repeated over time if you want to have an ideal of the average visibility. Time permitting, a secchi disk can be made by attaching a marked line to any roughly circular flat white object (such as a plastic bucket lid) and blacking out 2 of the 4 quadrants with black permanent marker or electrical tape. A quick Internet search will yield several guides to building a homemade version, for example, http://www.angfa.org.au/secchi.html.

Hopefully, this process will help you to identify the ideal site or sites. When you have finished surveying, transfer all of your data from the slate and digital camera into a computer and organize it while it is fresh in your mind. Everyone has their own methods for organization of the data. We have found Google™'s free program Sketch-up to be very useful for making 3-D drawings of the actual and planned site. These can be geo-referenced to Google Earth™ but if you do this you can't see negative elevations. We have already created a large library of 3-D models that can be imported into Sketchup for your use including scale models of all sizes of Reef Balls.

Helpful Tip: Many of the 3-D renderings of objects you will see in this manual were made with Sketchup™ and are available on-line. Go to the glossary under Coral Propagation Table for instructions to get Sketch-up and the models. Use other keywords like 'Reef Ball' to find even more models.

Sometimes it takes a while to find a suitable site; sometimes you get lucky and find it on the first dive. Occasionally, there is no suitable place and if that is the case you need to consider an alternate location, or another rehabilitation option. If possible, it is always best to find a few backup sites in case the situation changes, and water quality or another variable makes your chosen site less desirable.

Check Point #7: Updated Potential Site Map Worksheets

- You need to REPLACE your potential site map worksheets from Check Point #6, with the NEW **actual** GPS coordinates you took during your bottom survey step. Update the *datum* and *datum format* for the GPS unit you used.

Potential Site #:_____ Site Name ___________________________________

Datum ___________ Format ___________(	**Center Coordinate**	North West Corner Coordinate	North East Corner Coordinate	South West Corner Coordinate	South West Corner Coordinate
Latitude (Specify N or S)					
Longitude *(Specify E or W)*					
Charted Depth *(Specify feet, meters or fathoms)*					
Notes/Map					

User note: Copy this page for EACH potential site. Don't forget to write in Datum and Format of your GPS coordinates. Use the same GPS for relocation of the site(s) if at all possible.. Add copy of your slate showing the mapped area and field notes on bottom conditions. Remove all surveyed original potential site survey worksheets and replace with updated potential site surveys in the project notebook. Remove old coordinates in GPS and rename new coordinate way points appropriately.

If your selected site has similar depth and water conditions as the nearby reef and if you plan to use coral *broodstock* from that reef, then you may skip to **Step 5: Permitting**, if in doubt about water quality then proceed to **Step 4c: Check Water Quality**.

Step 4c: Validate Site Water Quality Supports Goals

Now you have a selected a site that is physically suitable, and that is desirable from a goal stand point of view. The next thing is to do is to make sure the water quality is suitable for your rehabilitation goals. If the water quality is not suitable you must either fix the problems affecting the water or go back to the beginning of **Step 4: Site Selection** and try again.

Fixing water quality is not usually within the scope of smaller grassroots projects, however, it is always desirable to improve water quality whenever practical. Perhaps there are point sources of pollution that can be identified and controlled. Perhaps a reef clean-up after a damaging storm is in order. Use common sense to implement these changes if you can. For now, let's assume you have done what you can for your selected site and need to determine if the water quality is now suitable enough for your project.

Water Quality to Support Human and Use Goals

Before you begin your validation for desired species support, check your non-species goals. For example, if you are trying to create a site for SCUBA or snorkeling activities be sure the site is safe from currents or other human perils and the visibility is sufficient for underwater recreational activities. If you are creating a site for artisanal fisheries, make sure the sites are convenient and productive enough for their needs. Site selection, in this case, can literally be a matter of life and death. Thousands of fisher people die each year going too far out to fishing grounds in boats ill equipped for the task.

If your team identifies conflicts go back and re-do **Step 4: Site Selection** otherwise proceed.

Water Quality To Support Desired Species

Next, look at your goals and determine the most environmentally sensitive specie(s) that you are trying to protect or rehabilitate. Generally, most projects fall into one or more of these broad classes that share similar water quality requirements:

- Fish
- Soft coral and hardy hard coral, or non-coral reef builders (such as oysters, mussels, etc.
- Fish with tropical hard coral
- Tropical hard coral only
- Any of Above plus specific target species (such as lobster, or particular fish species, etc).
  Once you have identified which category your project falls within, read all of the categories below which pertain to your project.

Fish

If your project is aimed at fish enhancement only, then water quality parameters will be more relaxed than a project for planting corals.

User note: Some fish species NEED coral or other benthic life for feeding purposes. If the fish you are targeting are dependent on those habitats, you may still need to find better water quality associated with those particular habitats.

For fish, make sure *dissolved oxygen (DO) levels* can support fish and rarely, if ever, become hypoxic (low oxygen levels). Use *Dissolved Oxygen (DO) Test Kit* if you are in water you believe might be marginal. (See the glossary for information on DO test kit use). While there is no universally accepted threshold for dissolved oxygen, in most cases, water with less than about 3ppm (parts per million) of dissolved oxygen is considered hypoxic, and is too low for most fish species. Water with between 3-5ppm is marginal, and greater than 5ppm is normoxic, or normal.

Salinity is also important for many fish species especially estuarine fish. Salinity can be measured with a *hydrometer* (specific gravity meter) or *refractometer.* Specific minimum and maximum salinity reference levels very widely from species to species. Some species can tolerate water all the way from fresh (0ppm) to fully saline (?35ppm). Some can only tolerate a very narrow band of salinity. Be sure to study the requirements of the specific species you are trying to protect.

Temperature ranges and depth are also important to fish. Your local experts can assist in determining the particular conditions that your target species prefers. In many cases you will find ample scientific research on the subject. Consider investigating online databases such as Fishbase (www.fishbase.org) as a starting point for your research. In some cases, you may have to rely on the instincts of local experts. Fishing and diving groups are usually knowledgeable sources. You will probably learn that their may be other local conditions that play an important role in site suitability.

Toxicity is an important factor, and not only toxicity to fish but toxins that can accumulate and build up in fish tissues making them dangerous for human consumption. If you are working in an area (either water column or sediments) that might contain heavy metals, red tides, PCBs, or suspected carcinogens you will need to test for their presence and consult local authorities about acceptable levels. Do not use base materials that contain toxic elements. It is beyond the scope of this manual to identify all the tests and potential toxins to be concerned about in your project so we suggest obtaining local experts.

If you have sufficient resources and expertise, Geographic Information Systems (GIS) analysis and remote sensing techniques to determine spatial and temporal distribution patterns may be useful.

If the conditions are suitable for your target species, then the most important factor for rehabilitation of reef dwelling fish (and reef associated pelagic populations) is *protective voice space* and for fish that obtain significant dietary contributions from the *fouling community*, the surface area of hard substrate. This is a combination of the size and complexity of the artificial reef or base rock chosen and its layout on the sea floor. Contact the artificial reef manufacturer or local fishery scientists for information on how to choose the right sizes, layout and styles of artificial reefs or base rock for fishery enhancement purposes.

In general, if there are reef-associated fish on or near your site, more fish will be there once you add protective void space (via your base materials). ‘Fish only’ projects do not need to plant corals. In environments where corals can grow, they will recruit to the artificial substrate naturally over time, so it is best to focus project funding on protective void space creation. These projects are better classified as artificial reef or fisheries rehabilitation projects, as they usually don't focus on reef rehabilitation.

Soft Coral, and Non-Coral Reef Builders (Oysters, Kelp, Mussels, etc.)

If your goals include rehabilitation of both fish and soft corals, be sure to read the section above regarding fish projects. This section deals with reef rehabilitation projects that do not intend to target hard corals, either due to budget, climate, or site conditions. This is a common goal in non-tropical or subtropical areas or in tropical areas with high sedimentation, variable salinities, low visibility, deep water or other conditions that prevent reef building hard coral growth on firm substrates. In these cases, it is still important to take into account water quality requirements of soft and hardy coral and/or other desirable reef building marine creatures (such as oysters, kelp, blue mussels etc.) that will inhabit the chosen substrate to create a reef ecosystem.

This type of project can be used when a more natural reef is desired than a ‘fish-only’ project can provide. Perhaps divers will visit the reef or perhaps the reef is being built for habitat rehabilitation purposes. Possibly, the project orientation is ‘fish only’, but there might not be any extra cost to make the project more suitable for other *benthic* marine life.

To develop a good fouling community, it is best to make sure *dissolved oxygen (DO) levels* are not below species-specific requirements. Use a *Dissolved Oxygen (DO) Test Kit* if you are in a location where you suspect low oxygen levels. Test at times you believe the levels will be the lowest such as during calm, hot weather events, neap tides, or if the project is coastal, after heavy rains. Minimum DO levels vary widely by species. In general, *benthic* communities can tolerate lower oxygen levels than fish, so if your project targets both, be sure to use the threshold of the most sensitive species. As mentioned above, most organisms can survive as long as oxygen does not dip below 5mg/l (milligrams per liter), and only the hardiest can survive DO levels below 2mg/l. If your conditions are intermediate, or you are unsure, consult a local expert.

Salinity will also play a role, at different ranges for different fouling communities. Salinity is typically measured with a *hydrometer* (specific gravity meter) or *refractometer.* In general, as you move toward more sensitive soft corals and hardy hard corals; salinity levels must remain fairly constant over time.

When working with fouling communities, the effect of currents, light and plankton levels play an important role. In general, the more current, light and plankton present, the faster the fouling community will grow. Oysters and other filter feeding communities do not directly require light, as long as current conditions are sufficient to provide enough plankton to feed them. Corals are divided into two classes, some are *phototropic* (requiring light), and in addition to filter feeding, these species photosynthesize to produce energy, with the help of symbiotic *zooxanthellae* (a brown algae which lives inside the coral tissue). Others are non-phototropic, and do not need light to grow. These corals are strictly filter feeders. Depending on the requirements of your target species, you may need to alter your site selection (see **Step 4: Site Selection**) to accommodate the needs of the species in question. If you are unsure of what conditions are required for your project, consult an expert.

Data for these parameters may be available in local scientific literature, or you may be able to ask a local expert for assistance. In a pinch, light penetration can be approximated using a *secchi disk* or calculated using a standard photographic light meter at the surface, a *secchi disk*, and *Beer's Law* (see glossary for help with this calculation). Plankton levels can be approximated by measuring the level of *chlorophyll* in the water, which can be done by most basic science labs. Current is a bit more difficult, and here, it is best to seek out local knowledge from the fishing or diving community, or local scientists. In a pinch, surface current can be measured by dropping a floating object into the water, and timing how long it takes to move a known distance (make sure your boat is well anchored and is not moving). However, if you are doing this, it is important to measure currents at various periods of the tidal cycle, and during different types of weather.

If the project is species specific, its goals will be best served by selecting substrate materials that will encourage the growth of the specific target organism(s). This is because soft coral, oysters, mussels, kelp and most other non-coral reef producing creatures are fairly rapid growers. For this type of rehabilitation, check with your module manufacturer or local scientists to determine what module features complement the water quality in the area to achieve these goals. Items to consider when selecting modules are: material longevity, complexity, available surface area, stability, cost, surface textures, ability to create protective void space, and suitability to your project goals.

You may need to look at some very species-specific requirements. Oysters and kelp have tight site specific requirements. Many soft and hardy hard coral species need good water quality, but can tolerate temperature changes and higher levels of turbidity better than their tropical reef cousins. Again, talk with your module manufacturers or scientific specialists for your area specific requirements.

Narrow down target *fouling community* types or non-coral reef building species to types that can be supported by the water quality at your selected site. If the communities supported by your site are not in line with your goals, go back to **Step 4: Site Selection**.

Tropical Coral (Tropical Coral Reefs)

If your goals include tropical coral re-stabilization or coral propagation and planting to speed up the development of a coral reef ecosystem, water quality will indeed be a very important variable. Before you invest a great deal of time and effort, however, remember from **Step 2: Damage Assessment** that if you are rehabilitating a reef in its original location and only using *brood stock* from that location you may skip this process if there have been no changes to water quality, and move on to **Step 6: Permitting**, because water quality has not changed from what you know to support the life on your site.

User Note: If you are building a new reef, you should ensure that the project goals included selecting a site with the best possible water quality available.

Once the best site has been determined, the next step is to determine which coral you will be able to successfully work with and plant. Coral cannot be planted in every desired location. Common sense will dictate that water quality, lighting conditions, and any other requirements of a coral species must be present before one can re-stabilize or propagate and plant that coral species with success. Often (but not always), if you can't find a coral species growing naturally on hard substrates in an area, you will not be able to plant that species with success. However, there are soft bottom areas where coral species may not be present but could be if hard bottom was supplied.

Start by assuming that any coral that you can find within a reasonable distance (say 30 miles or an hour's boating range) and of similar water quality as of your site has the possibility of being planted or stabilized on the selected site. Local coral identification books, often found at local dive shops can often provide an initial list. Next, narrow down the list of usable corals by eliminating corals not found growing naturally in areas which match your site in the following criteria:

? Water Depth/ Lighting Level Range
? Water Temperature Range
? Saliently Range
? Current/ Wave Climate Preferences
? Biological Tide Line
? Sedimentation Tolerance
? Species not Amenable to Propagation, Transplant or Stabilize
? Species not Cost Effective to Propagate, Transplant or Stabilize

Water Depth and Lighting Level Range

The first variable, water depth range, should already have been recorded in your survey. By looking at the natural reefs in these depth ranges, you will get an idea of which coral species you might be able to propagate and plant. A first point of reference might be *coral reference guides* as they contain species reported depth ranges.

User note: Scientific *coral reference guides* tend to be broader in scope and contain more details than the local coral reference guide mentioned in above for obtaining an initial species list..

In coral reference guides, reported ranges are the **maximum reported** ranges for the species so it is always better to try to get corals into the mid range of their depth tolerance. Depth ranges are usually based on light availability, which is critical for most tropical coral species. In optimal light ranges coral can thrive, in sub-optimal light they can survive, but may not grow as fast, or at all. Below or above the acceptable range they will slowly die. Conversely, if too much light (or a rapid change from darker to lighter conditions happen) they will *sunburn* or overheat which is usually fatal. Treat coral just like you would a plant…learn what lighting levels are correct for the individual coral or 'plant'. If you must change those conditions do so slowly, just as you would acclimate a plant to changes in light levels. You would not put a houseplant in the full sun nor try to grow tomatoes in dim lighting. Use the same techniques with coral. If your team has a good coral expert, this person will give you advice about what lighting levels are appropriate for individual species. Knowing the local depth range of a species can give your team good clues as well. If you really want to be sure, you can buy a light meter that measures *lux, lumen or candlepower* and have an underwater case built for it, or use the light meter in conjunction with a *secchi disk* to calculate light penetration using *Beer's Law* (see Appendix B). There are several underwater light meters for underwater photographers that can be adapted for this purpose. Simply take a reading from where you are sourcing your *broodstock*, and be sure that you are moving the corals to areas with similar conditions. Take all readings at the same time of day under clear skies and make sure to adjust for changes in surface lighting by calculating the fraction of surface light which reaches a coral. Simply divide surface reading by reading at the bottom at the same time, and multiply the result by 100 to get percent surface light penetration:

$$\frac{Bottom}{Surface} ? 100 ? \%available$$

Narrow down the species by eliminating those for which you cannot provide appropriate water depths or lighting ranges.

Water Temperature Range

Water temperature range is critical. If you have an open water site the temperature range is probably similar to other open water sites at the same depth but this is not always true. Upwelling, oceanic currents and other factors can affect a particular site's temperature range. There are many websites that can help you determine the *Sea Surface Temperature* (SST) range but it is much harder to find ranges at depth were your coral would be planted. Sometimes the easiest way is to simply use a direct temperature measurement, but be aware that many factors including tidal cycle, time of day, and prevailing weather conditions can affect the temperature at a site, so be sure that your measurements are comparable.

If you are close to shore or in a lagoon or bay with restricted or tidal flushing, your site may be subject to higher temperatures that might limit the coral species to those that can survive in those conditions. Some c*oral reference guides* give temperature ranges for specific species. Typically, tropical corals flourish in temperature ranges of 19-30^{o}C (66^{o}F-86^{o}F). The highest normal range we have seen for a coral is 33.9^{o}C or 93^{o}F., (in the case of corals in Kuwait). Corals that can tolerate temperatures ranges below 10^{o}C or 50^{o}F are generally termed *Hardy Corals* for purposes of this manual. But tropical corals can often tolerate slightly lower or higher temperatures for very brief periods. There has been research in American Samoa that indicates that corals can tolerate temperatures above their normal ranges when water movement is high [Mike King, American Samoa, corl.org 2005-2007] but this is not to surprising because the real danger of high water temperature is low oxygen content which can exacerbate bleaching.

Narrow down the species that you do not have appropriate temperature ranges for.

Salinity Range

If your project is in the open ocean, salinity is most likely not a serious concern, but projects near large sources of freshwater may have a limited number of coral species available. Occasionally salinity can play a localized role in open water sites. For example, off the coast of the Riviera Maya in Mexico, there are numerous cenotes (or underground springs) and many coral species cannot be placed within the influence range of these springs. These situations demand extra caution because the influenced area may grow exponentially in size during the wet season… the same is true for large rivers. Projects on islands that have mountains or high relief must be especially cautious in this regard.

It is also important to consider that fresh water can impact the availability of oxygen (by intensifying stratification), and increase turbidity, both factors which can be detrimental to corals.

Eliminate species that you cannot provide appropriate salinity ranges for.

Current/ Wave Climate Preferences

Many coral species prefer certain currents or wave climates. Elkhorn coral (*Acropora palmata*) prefers the highly oxygenated waters near breaking waves, whereas delicate *Distichopora spp.* and other solitary corals prefer the confines of a calm cave. Most coral can adapt to a range of wave climates if they are started as small fragments and allowed to grow into a form (*morphology*) adapted for the conditions (within the limits of the species). But adult coral colonies cannot adapt as easily to changes and can respond negatively to changes in any and/or all parameters. This may be one reason why planted fragments have higher success rates than transplanted adult colonies.

Eliminate the species for which you cannot provide appropriate Current/Wave Climate. (Note: this may restrict transplant of adult colonies but not fragments for some species.)

Biological Tide Line

If you are planting in shallow water, especially in areas with very high tide ranges, then you must be mindful of the biological tide line, the highest point where hard corals can grow without being overly exposed to air during low tide. The biological tide line can be different for different species, depending upon their tolerance to light and dessication; but for most shallow water species it is a fairly well defined depth. It is not advisable to calculate this from tide charts, rather, it is much more effective to look for obvious signs of the maximum natural reef crest and use that as your benchmark to adjust minimum depths for planting. Keep in mind that corals will grow upward….so you may need to plant well below the biological tide line to allow for upward growth. Note that the biological tide line can vary due to tidal cycles that are longer than a month; so when in doubt, plant a little bit deeper if resources permit.

User note: In addition to monthly and annual tides, their can be tidal variations over multiple years. For example, there is month or two of extreme tides in the Caribbean about every 17 years. [Source: Dr. Lee Harris]

Eliminate the species that you cannot plant below their biological tide line while still allowing for normal growth.

Sedimentation Tolerance

Suspended sediment in the water poses a number of health hazards to corals, and must be carefully monitored. Different coral species often have a strict range of acceptable prey size. Sediment particles of the same size that a coral normally preys upon can therefore interfere with feeding. Additionally, sedimentation can cause a coral to produce excessive mucus to clear its polyps that requires energy expenditure. Finally, sediment can block sunlight from getting to a coral's zooxanthellae, reducing its ability to photosynthesize energy. Extreme sediment can completely cover a coral colony and this will kill most colonies within a few days or weeks.

If you are concerned about higher sedimentation rates, you may want to start by analyzing the grain size distribution, sand composition, or amount of sediments transporting through your site. For example, sediment or *sand sieve analysis* can be performed to see what size particles are present. This is not a serious concern if you are moving corals from an area of more sedimentation to an area of less sedimentation presuming particle sizes are similar in distribution, but be extremely wary of moving a coral species into an area with increased sedimentation rates.

Figure 8: Results of a sediment grain size analysis. A sample of sand is passed through stacked sieves with decreasing sized mesh. The proportion of the sample retained in each sieve can be used to approximate the distribution of grain sizes in the sediment at the site.

It is also very important to know how much sediment is traveling at a particular height off the bottom at your site. This is critical, because it is an essential component in determining how high a particular coral species must be planted above the sea floor to avoid sedimentation stress. A simple sediment trap (Figure 9, also available in sketch-up) can be made to determine what level of sediment a particular coral can tolerate in its natural habitat, and then these data can be applied to your planting strategy. The length of time the trap must be in place depends on the volume of sediment in the area, but the duration should be the same in all your samples so sediment volume or weight is comparable. If it is impossible to use identical duration, be sure to calculate sedimentation rate relative to time (e.g. milligrams per day) in order to correct for variations in deployment time. Note the design allows for adjustable heights and easy retrieval of the sediment trap collection tubes.

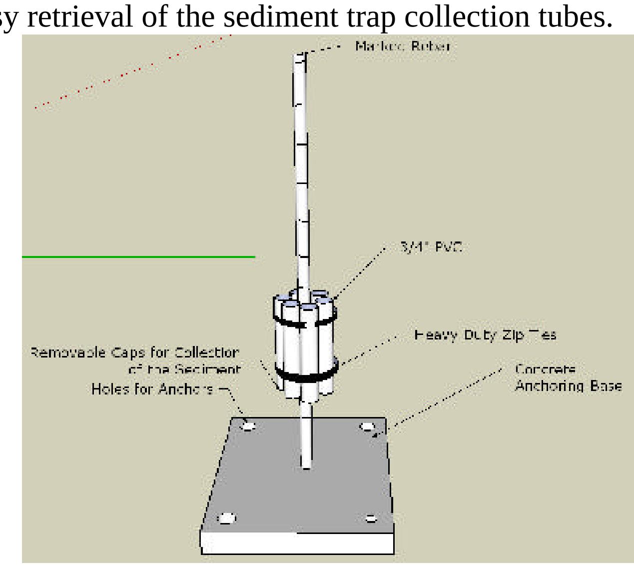


Figure 9: Construction of a basic sediment trap to estimate sedimentation rates at a project site. Sediment accumulates in the PVC tubes, and can be retrieved and measured (by weight or volume) by removing the caps at the bottom of the PVC tubes and collecting the sediment within. <u>Note:</u> This method only provides a relative estimate of the amount of sediment at a specific depth, and not an exact value because it measures the vertical settling of sediment, and not horizontal transport.

Eliminate species for which you cannot provide a location with low enough sedimentation rate.

"Non-Worthy" Corals

Many coral species simply are not worth the effort involved in propagating and planting them. This depends greatly on the goals of your project. Non-reef building corals that don't add complexity or contribute to usable *protective void space* might not be worth the effort for projects that have goals emphasizing fish production, but if the goal of your project is to maximize coral diversity, or to replicate natural coral assemblages as much as possible, the extra effort may be justified. In addition, some coral species may already be prevalent at the site, or may naturally re-establish themselves so rapidly that it is inefficient to devote resources to their propagation or transplant. The latter is often the case for many common soft coral species. Propagation is typically the most time consuming and expensive portion of a project, so it is very important to make sure that propagation efforts directly support the project goals. Remember, most properly selected, sited and designed base materials will eventually turn into a natural reef without any assistance at all, propagation and transplant just speeds the process along.

Eliminate species that are not worth the effort.

"Impractical" Corals

In almost all cases, insufficient resources are available to transplant every coral species desirable for your project. Economics is a common reason to do a genetic coral rescue instead of a re-stabilization. When resources are limited, is your project better served by rescuing one adult colony or by preserve the genetics of a hundred colonies? On one hand, you have one large beautiful colony and on the other hand planting fragments saves more but may take decades or even centuries to reach the size of that one re-stabilized colony. This is a tough question, and it depends on your answers from **Step 1: Determine Goals.** Similarly, there are many coral species that are just not economically suitable for propagation, either because survival rates are low, or costs are too high.

Eliminate species that consume more project resources than the benefits they provide.

"Impossible" Corals

Sometimes, you will have to accept the fact that a coral species (or at least some individual colonies) cannot be saved. Some corals cannot be propagated, transplanted or re-stabilized by professionals, much less grassroots organizations. Perhaps there is no stock left after a disaster, or the remaining stock is so diseased or injured that rescue efforts would not be effective. Perhaps the damage is in a place that is too remote or deep to facilitate safe access. In these cases, it is best to devote resources to re-stabilizing, propagating, and rehabilitating colonies that have a higher success rate without posing safety hazards to your team.

Eliminate species that are impractical or impossible to save and note whether this applies to individual coral colonies or all colonies of a certain species.

Hard Coral Species Only

Occasionally, your project may be concerned only with tropical hard coral. This is a common goal for research projects, coral farming, or coral breeding. Most of these projects have a temporary rather than long term focus because the corals are ultimately used in another location. This manual is focused around long term rehabilitation projects, but can be adapted for projects with both short and long term goals by simply adding any short term objectives in **Step 1: Determine Goals**. If your project goals are short term only, you probably won't need to take as much care in substrate selection or in long term coral *basing* needs. Often, steel and wire frames, such as those used to create temporary disaster nurseries (Figure 2) are sufficient. There are several emerging technologies aimed to accelerate coral growth. These include captive breeding techniques,ocean based feeding, calcium supplementation, "accretion" or electricity based calcium supplementation. Temporary projects such as these are outside the scope of this manual, but there are resources out there to assist your team. A good place to start your search might be the Geothermal Aquaculture Research Foundation (GARF) website at www.garf.org , or www.reefs.org, popular sustainable reef-keeping forums. For electricity based calcium supplementation, which has an added benefit of creating substrate, check into the Global Coral Reef Alliance (GCRA) http://www.globalcoral.org/.

Specific Target Species (such as lobster, grouper, etc.)

In addition to the fish and coral species addressed earlier in this step, your project may have some very specific target species. These may include the rehabilitation of commercially or recreationally important species such as lobster, abalone, octopus, grouper, snapper, or any of the hundreds of species heavily exploited by humans. Most species that have high human value also have a great deal of information regarding their needs available in the scientific literature. If your project has targeted interest in the rehabilitation of a specific species, it is advisable to seek out experts in that particular species. There are often very specific things you can do to better accommodate a particular species. This may be a combination of multiple factors including base design, layout, height, or specific habitat requirements. Your target species may also have specific water quality needs that must be considered in **Step 4: Site Selection**. Make notes to investigate specific species requirements if these species are an important part of your goals.

Check Point #8: Coral Species Targeted For Cultivation

? You should now have a list of corals that you plan to re-stabilize, transplant or propagate and plant.

Handling Style Group: ____________________*			Check All That Apply**			
Published Common Name	Genus (capitalized)	Species	Re-stabilize	Propagate	Plant	Trans-plant

- *Handling Style Groups* are: Fire Corals, Soft Corals with Woody Stems (excludes sea fans), Sea Fans, Soft Corals W/O Woody Stems, Finger Sized Branching Corals, Large diameter Branching /Pillar Corals, Encrusting Corals, Mound/Boulder/Brain Corals, Leaf/Plate/Sheet Corals, Flower/Cup/Single Polyp Corals, Black Corals, Other. Generally, each group has similar characteristics for propagation or restabilization although there are exceptions. Use “Other” category for exceptions.

** Definitions for categories: Re-stabilize means attaching adult coral colony to the sea floor. Propagate means asexually reproducing the coral by division into fragments. Planting mean attaching a propagated fragment to hard substrate. Transplant means an adult colony has been moved more than one meter either horizontally or vertically.

User note: Make a copy of this page for EACH *handling style group* your team plans on working with during the project. Check each technique you will be employing.

Step 5: Permitting

In most cases, you will need to use the results from your underwater survey as part of your application for an environmental permit. You may only need an artificial reef permit, or you may need both an artificial reef permit and a permit to work with corals or other protected species. Permit procedures vary widely by country and location, and may be quite difficult or costly to obtain, especially if you have not been through the process before. Check with your local authorities well in advance to learn the procedures that are required to obtain the appropriate permits for your project. In some countries, it is nearly impossible for grassroots organizations to get their own permits; the United States is a prime example. In these cases, it is best for your organization to partner with governmental organizations or entities that can obtain the permits.

Taking this one step further, we feel that it is important to re-iterate that in any country, for any project it is best to partner with local government and scientific organizations, even if you are going to be issued your own permits. Incorporating as many as possible of important stakeholders and user groups into a project is critical to the success of the project in every stage from planning, to surveying, permitting, implementation, and monitoring. It does not matter which group you represent, or what your goals are, attempting a project alone is much more likely to lead to failure. If you have not done so already, often, the permitting process will help you make linkages to these groups. Instead of thinking about the permitting process as a bureaucratic necessity; use the opportunity to strengthen your rehabilitation project by making important connections.

Note: you will probably have had to work through all 10 steps before applying for your permit. Most permits will require a large amount of detail about the materials, methods, and expertise associated with the project.

Permitting can easier if you select base materials that have a proven track record of success in similar environments, and can be more difficult if you use novel materials, or novel applications. In our experience, we have found that having scientists, experts or certified volunteers on your team will aid in obtaining permits to work with live corals or other animals. In some cases, you will need a doctorate level Principal Investigator (PI) to oversee the project if you plan on applying for research permits.

A tightly defined goal set, along with a clearly defined project ethic will also aid in portraying your intent to regulatory agencies. In many cases, the permitting process has developed from the need to control practices that are damaging to the environment. For example, many of the rules for permitting of artificial reefs have been generated to protect against projects which are simply a clever spin on disposal of unwanted materials. When these factors are considered, it is not surprising that the permitting process can be more burdensome than one might first expect for a rehabilitation project.

Similarly, there have been many attempts to rescue or relocate coral that have resulted in failure and unintended consequences. When you have finished reading this manual, we think you will appreciate the complexity in working with corals; and why a conservative step by step approach is needed to minimize risk in this sensitive field. By gaining the knowledge, skills and ability to safely handle corals through reading and applying the skills demonstrated in this manual, and monitoring your results; in the future you will be able to more easily convince regulatory agencies that you can successfully accomplish your project without negative consequences. As we have stressed, a carefully designed transparent process which incorporates as many local stakeholders as possible will strengthen your team, and strong teams impress regulatory agencies more than any other factor.

Note: In emergency rescue situations, nearly all governments have processes for immediate issue of permits; or to allow work to begin before permits are secured. By working with the environmental departments of the local government, you may also be able to circumvent this process, as these agencies also have the power to work without permits in emergencies.

- ? Check Point: You should have contacted the regulatory agencies, and developed a plan to obtain the necessary permits. As you develop this plan, you may need to adjust your timeline to reflect delays that are imposed by the permitting process. You may need to adapt your plan to account for constraints required in the permitting process.

Step 6: Base Substrate Creation (Artificial Reef or Natural Bottom)

Step 6a: Determine which artificial reef type or substrate type is required

Substrate Requirements

Coral propagation and planting of coral fragments with the methods described in this manual is best accomplished using a fresh clean base substrate designed to accept *coral adapter plug receptacles*. Typically, this means recently deployed artificial reef modules, limestone boulders, or *sterilized hard bottom (*without a *fouling community)* with either pre-cast *coral adapter plug receptors* or drilled plug receptors. If necessary, clean hard bottom with a minor fouling community can also be used for re-stabilization techniques that don't require coral *basing*.

These requirements are necessary to be efficient, to provide a clean (non-competitive) substrate for long term coral *basing,* and to avoid mature *fouling communities* with abundant *coral predators*.

Figure 10: Different styles of Reef ball artificial reef modules equipped with coral plug adapters indicated with red arrows.

As a rule of thumb, all coral planting activity must be completed between 30-90 days after the substrate is deployed, depending upon season. The same is true for recently exposed *sterilized hard bottom*. Experiments with planting coral after that time indicate that the *fouling community* competes too heavily for the *basing* space and that there are increases in *coral predation* from members of the *fouling community*. Less competition for newly transplanted corals results in higher survival rates, and more rapid growth.

Naturally, we have the most experience with projects using Reef Balls as the base substrate, but it is possible to use other designs provided they are stable (will not move during storms), can be fitted with coral adapter plugs (if your project involves coral transplant), designed without iron rebar, and made from materials that will last long enough to accomplish your project goals. pH neutralized concrete and a roughened surface texture, (patented features of Reef Balls) are NOT necessary to support propagated or transplanted coral colonies, but without them, there will be less natural coral settlement on the base substrate in areas not planted with coral.

Substrate Types Usable With The Methods In This Manual

The following modules/artificial types are methods we are familiar with, and are confident will meet the requirements for using the methods present in this manual, provided coral adapter plug receptors are present. There may be other designs we have not reviewed and we will be happy to review any design you might be interested in using to determine if, in our opinion, it is suitable for your particular project.

1) Reef Balls (all sizes, all styles when deployed as recommended)

Figure 11: Photos of different styles of Reef Ball artificial reef modules. Reef Balls are available in a wide range of sizes (from less than 20kg to over 2000kg (40-4400 lbs.)) and styles, and can be adapted for almost any artificial reef project.   The 3-D model of a Bay Ball at left can be downloaded and viewed using Google Sketch-up™

2) DERM Modules (not for sand only substrates)

Figure 12: Divers assist in the deployment of a DERM artificial reef module

3)Natural Limestone Boulders

Figure 13: Piles of natural limestone boulders can be used to create an artificial reef. Natural boulders can be drilled to accept coral adapter plugs for coral rehabilitation projects. From our experience we recommend that boulders be at least 3 tons, and be deployed in a stable configuration, in order to prevent shifting in storms.

4)Poured Concrete Seawalls or Pilings

Note: Coral adapter plug holes can be drilled into the substrate, or added during construction. When using this method, ensure that all corals are planted below the coral biological tide line.

5) Solid Concrete Tetrahedrons or Geometrical Pre-cast Modules

Figure 12: Solid concrete tetrahedral blocks used as an artificial reef. Solid blocks do not create as much void space as hollow designs, but if deployed properly, can be extremely stable.

Geometrical modules come in a wide variety of shapes and sizes (hollow squares, boxes, pyramids, etc.). In general, these designs can be used as long as they are stable and the design does not require iron rebar for integrity. Modules such as these can be pre-cast with coral adapter plugs, or they can be drilled in after deployment.

6) Reef Forms.

Figure 13: Reef Forms are large blobs of concrete cast into a mold made of sand and affixed with coral adapter plugs. Reef Forms are inexpensive to make and deploy, but do not provide as much EPVS as hollow modules.

The Reef Ball Foundation began using Reef Forms as a way of putting concrete leftover from casting Reef Balls to good use. In order to be safe for deployment in areas with natural or planted corals, these structures must be heavy enough to be stable, and must be deployed in areas where they will not subside.

7) Sterilized Hard Bottom

It is possible to transplant or propagate corals directly onto sterilized hard bottom environments (for example, in response to a ship grounding which exposes large amounts of sterilized bottom). While this method does not require the use of artificial reef modules, and can be accomplished by drilling holes for coral adapter plugs, the development of *EPVS* from a project of this nature is extremely slow, as it depends exclusively on the growth of transplanted and propagated coral colonies.

Substrate Types Requiring Alternate Methods

The following modules/artificial reef types are not fully compatible with the techniques presented in this manual for coral propagation and planting. These techniques may be suitable for 'fish only' projects, or may be used with corals using other coral rehabilitation methods. If, in working through the manual to this point, you feel that the goals of your project are best accomplished using one of these methods, we recommend that you contact the manufacturer regarding their specific procedures for siting, stabilizing, and planting corals.

1)Biorock Reefs™

Biorocks™ are constructed using accretion technology, and are not directly compatible with the coral adapter plug method described in this manual. However, Biorocks can be used very effectively to create coral nurseries and as a coral fragment generator for second generation brood stock. This method is best suited toward short term coral-only focused projects, such as research, coral farming and coral breeding. While it has been suggested that a metal cage could be placed inside a Reef Ball or other similar concrete module at the time of casting to combine the benefits of both systems, this procedure has not yet been formally tested.

Figure 14: Divers conducting video monitoring of coral colonies growing on Biorock type artificial reef modules. .

2)Eco-reefs ™

Eco-Reef ™ modules are built from ceramic molds and designed to break down over time. Therefore, these modules would be compatible with some *basing* corals, but not with *non basing species*. At this time, Eco-Reef ™Modules are not compatible with the coral adapter plug method used in this manual, but these modules are compatible with *the Zip tie method*

Figure 15: Diver positioning an Eco-Reefs ™ artificial reef module

3) Concrete artificial reef modules designed for 'fish only' projects

Many hollow concrete structures (Figure 16) are designed primarily for 'fish only' rehabilitation projects. These modules typically use less concrete, and depend upon a metal support structure for integrity. This allows for a lighter module which may be less expensive, or easier to deploy. While structures of this type have been shown to be effective for projects focused around the generation of EPVS for fish, modules with a metal support structure are not recommended for use with the coral propagation methods discussed in this manual. For more information regarding the usage and functionality of these modules, we recommend that you contact the manufacturer.

Figure 16: Concrete modules designed primarily for 'fish only' projects. Left: Artificial Reefs 1 Fish Haven ™ Modules. Right: Hand made 'Fish Houses'. Modules of these types are not recommended for coral rehabilitation techniques discussed in this manual because they utilize support frames made from metal, which can reduce the long term durability and stability of the module.

4) Pyramid Modules made from steel and tires or other materials

'Pyramid Reefs', 'Grouper Ghettos™' and other similar reefs types (Figure 17) are designed for fish attraction, and intended specifically for fish only projects. They are not suitable for projects intended on the rehabilitation of corals or fouling communities, as neither steel nor rubber is an effective substrate for coral *basing*. These structures do have the advantage of utilizing materials of opportunity in a constructive fashion, but this comes at the cost of some versatility.

Figure 17: Pyramid type artificial reef modules made with steel frames and using tires or other materials of opportunity to provide additional habitat complexity. These modules are designed to be used exclusively with 'fish only' projects.

5)Reefs made from tires

Throughout this manual, we have tried extremely hard to maintain objectivity with respect to methods and techniques other than our own. Almost all artificial reef creation methods have meritorious application and, if deployed and monitored properly, generally bring about more benefit than harm. However, we feel the need to strongly caution the use of artificial reefs made from tires. While at first, it may seem a very attractive and inexpensive option for generating additional habitat complexity and *EPVS* while also making constructive use of a waste product which is very difficult to dispose of otherwise, there are many potential risks associated with reefs made from tires.

Tires have a low negative buoyancy, which makes their stability uncertain. Tire reefs are typically held together with chains, which weaken rapidly when exposed to salt water. These factors combine to allowtires to break free from the reef over time, and these loose tires can travel large distances during storms or other high turbulence events, doing a great deal of damage to natural ecosystems in the process. Furthermore, rubber is too flexible to be a suitable basing material for corals, and used tires often contain hazardous chemicals and oil, which can leach into the water and sediment around the reef, and can be toxic to fish and other marine life. Especially in light of recent catastrophic failures of tire based reefs in Florida and around the world , we feel that in this case, the potential risks outweigh the benefits.

Figure 18: Some artificial reef projects utilize tires as a base substrate material. We strongly caution this technique as it can have potentially serious ecological consequences. Left: A sunbather reads on a beach littered with tires which broke free from an artificial reef project and washed ashore. Right; Divers inspect a tire based artificial reef held together with chains. If these chains fail, the tires could break free and damage natural habitat.

6)Natural Live Bottom

This is not a recommended option because planting on natural live bottom can displace or damage existing marine life. Furthermore, planting on live bottom exposes recently transplanted corals to an increased risk of predation, competition, and disease, all of which lower initial transplant success rate by stressing the corals. Re-stabilizing colonies on *Sterilized Hard Bottom* is a safer alternative in all respects.

Whatever base substrate you choose, conduct thorough research into the available materials and choose wisely. A good place to start your research is by reviewing material on the websites of various artificial reef manufacturers. Make sure that you also review the goals and resources of your project to help guide your decision. Remember that a healthy unmolested coral colony can live for hundreds, even thousands of years, so if you are planting corals, be sure that your chosen substrate is sufficiently durable. Whether you choose to use Reef Balls or another type of substrate, we hope you will find many of the methods and suggestions in this manual to be useful. There is also an appendix with our concrete mix design for coral friendly concrete that you may find useful for any base substrate creation project.Once you choose your substrate/artificial reef(s) proceed to **Step 6B: Number and Size**

Step 6b: Base Modules: Number, Sizes and Layout

Note: From now on in the guide we will refer to the base material/artificial reef as 'modules' for ease of reference. If you have chosen to use a non-modular base substrate, that does not mean that these techniques are not applicable, simply that you may need to slightly adjust the process to fit your chosen substrate.

The next step in the process is to determine the number and size distribution of modules required. There are many ways to estimate this, and the easiest way to do so is to use the data collected during **Step 2: Damage Assessment** and **Step 4: Site Selection**.

The basic goal of this step is to determine the amount of substrate necessary mimic the nearby natural reefs that are providing the functions you are trying to rehabilitate. So, if the damaged site a widely scattered patch reef with small coral heads, you may want to scatter small clusters of modules throughout the selected area, while if the damaged site is a contiguous fringing reef, perhaps the best rehabilitation method is to use a long thin line of modules. Remember, if you are planting coral, that your project may take many years to reach its final form. When designing the pattern of modules, envision the final results of your project, and account for growth rates and expected sizes of the adult colonies.

It is best to concentrate your efforts on the appropriate module density and size to achieve your goals…not on the total number of modules. In most projects, the total number of modules is more likely to be determined by the available resources or permitting restrictions, rather than by rehabilitation goals. Unfortunately, in many cases, your conservation goals are likely to call for more modules than you can afford or have space for.

Several measures can be used to quantitatively estimate the appropriate density and sizes for artificial reef modules. Some if these methods include a survey to determine average number and size of coral heads per unit area, or more sophisticated *EPVS* measurement analysis. Look back on the data collected in **Step 2: Damage Assesment.** Much of this data can be used here to estimate your project's needs. Expert opinion is also appropriate. Local reef users often have an impressive understanding of the requirements needed to rehabilitate specific reef functions.

EPVS analysis can give you an idea for an optimal layout of reef substrate. This analysis tends to be rather species specific since usable void space varies greatly by size and *functional group* of a species. Therefore, this method is only appropriate when your goals are focused on specific species or *functional group*.

Step 6c: Construction of Modules

Construction methods vary according to module type and project goals. However, a few things are universally required to make the coral planting process efficient. All modules will require *coral plug adapters.* These are depressions in the material of a uniform size and shape (see Figure 10). Coral fragments or colonies can be attached into *coral plugs* made of cement which fit into the coral plug adapters, and can be fastened in place underwater.CREATE FIG 19 here: Coral Plugs before and after attachment

In order to make the underwater work most efficient, it is necessary to know in advance which coral species your project will be working with. In many cases, it is best to determine your *planting strategy* before construction of modules begins. Most coral species can be planted using a standard coral plug that is the size of a medicine cup. Some coral species, particularly gorgonians, can be directly planted without a plug in holes the size of a pencil. Some coral species, particularly larger re-stabilized brain or star corals, may require customized plugs and adapters. For example, Figure 19 shows re-stabilization of a *Montastrea cavernosa* (Cavernous star coral) colony made with a 4-inch core drill. If you are unsure of how to re-stabilize or propagate a specific species with your chosen module type, consult your module manufacturer or a coral propagation expert. For specific construction guidelines pertaining to Reef Balls, see Appendix #

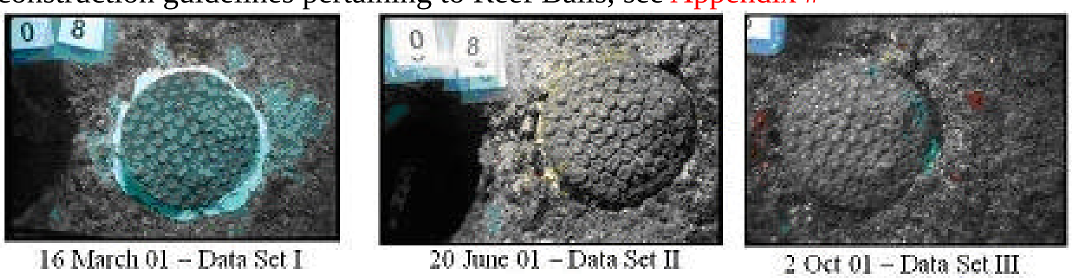


Figure 20: Re-stabilization of Montastrea cavernosa onto a Reef Ball using a 4” drilled hole and epoxy. Photos from left to right show the colony; immediately after stabilization, 3 months, and 6 months post-stabilization.

Step 6d: Deployment and Anchoring

Deployment

Deployment of your modules is similar to other artificial reef projects and should follow normal deployment best practices. Refer to your module manufacturer's construction and training guide to understand best practices for particular base structures. However, there are two important factors that may be different which are deployment timing and choice of proximity to natural reef.

Timing

As mentioned in **Step 6A: Choosing Substrate**, there is a short window of opportunity after you deploy your modules before they become too overgrown by marine life to safely plant coral fragments. If you are working with adult colonies, these guidelines can be relaxed slightly, but is it always easiest and best to plant on freshly deployed modules. If you have the luxury of choosing when the rehabilitation program will occur, try to schedule your rehabilitation project so that modules will be deployed in the season best suited to coral planting.

Proximity to Natural Reef

If you have chosen a site either adjacent to or within a natural reef, you will have to conduct deployments with the utmost care. Barge anchors or spuds can easily destroy the coral you are trying to save. Modules that are dumped indiscriminately can do the same. Never work around natural reefs without a dive team in the water to ensure the protection of the existing reef. If you are building within the footprint of a reef, the best option is to float modules into position guided by divers. For Reef Balls, this can be accomplished using an internal bladder, a unique feature which allows precision deployment in close proximity to natural coral. With other materials, lift bags will provide you with a similar degree of control. Regardless of your material choice, deploying in close proximity to natural reefs is an extremely difficult and potentially hazardous task. If not deployed and stabilized with the utmost precision, unintended adverse consequences can occur (Figure 4), and therefore this type of deployment should be avoided unless absolutely necessary to accomplish the goals of the project. If deemed necessary, deployment in close proximity to natural corals should be implemented or at least supervised by trained experts.

Anchoring

Because you will be planting coral that over time will grow substantially, any movement of a base module can be detrimental to its coral colonies; projects that include coral planting require more stability than standard artificial reef projects. Increasing stability can be accomplished by utilizing heavy modules, modules with a high percentage of the weight in the bottom third of the unit, proper site selection (a site with 10-20 cm of sand over hard bottom provides more stability than a hard bottom alone for example), or anchoring techniques.

There are several methods of anchoring, and complex factors which enter into the decision of whether to anchor your modules. If you are deploying modules in less than 30 feet of water, or in a high energy environment, contact your module manufacturer for a recommendation to anchor or not to anchor and they will help you to make an intelligent choice.

If you choose to anchor your materials, there are a variety of methods. Double helix screw anchors are good choice for sand bottoms if *subsidence* is not an issue. They can be embedded in concrete modules before casting by covering the anchor head with a paper bag full of sand and coating the shaft with sugar water letting the anchor eye stick out of your mold. They work best at 45 degree or higher angles.

Fiberglass rebar anchors are relatively inexpensive and are often used on hard bottoms (short lengths) or firm bottoms (longer lengths). Fiberglass rebar anchors are particularly good at resisting shear forces but are not so resistant to uplifting forces. To use fiberglass rebar as an anchor, PVC pipes are embedded into your mold design and then the rebar is placed in the hole left by the PVC and hammered in (soft bottoms), or a pneumatic drill is used to drill into the bottom, then the fiberglass rebar is then dropped into the hole (hard bottom).

In many projects you may need to use a variety or combinations of anchoring methods due to varying bottom types. Before any new method is used it should be tested in the field for practicality. In most cases, the manufacturer of your artificial reef modules will know what types of anchoring systems are most effective for your particular situation. Be sure to carefully heed their recommendations.

Here are some examples of different anchoring methods used with Reef Ball Modules:

Anchoring Cones

Figure 21: Anchoring cones(circled in red) can be used to prevent horizontal movement in soft to semi-firm bottoms. Cones are cast monolithically when the Reef Ball is made, and designed to settle slowly into the ocean bottom. Once settled, the cones will prevent lateral movement during storms

Anchoring Spikes

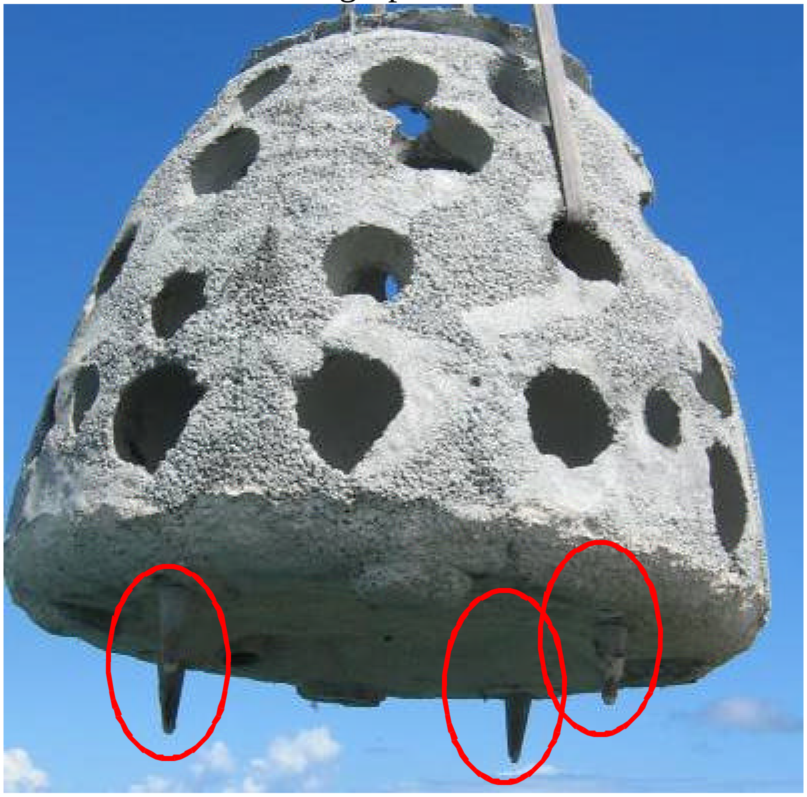


Figure 21: In areas with hard packed bottom, pre-cast concrete spiked with #5 fiberglass rebar reinforcement can be used in place of anchoring cones. They serve the same purpose as anchoring cones, but can penetrate firmer bottom.

Note: Engineering pressure tests should be conducted to indicate the size of the spike necessary self penetrating under the weight of the module.

Specialized Cone Anchors

Figure 22: An advanced anchoring technique adapted for use in a sea grass bed. This technique produces cone anchors (Figure 20), but is adapted to allow the sea grass under the Reef Ball to stay alive.

Battered Pile Anchors

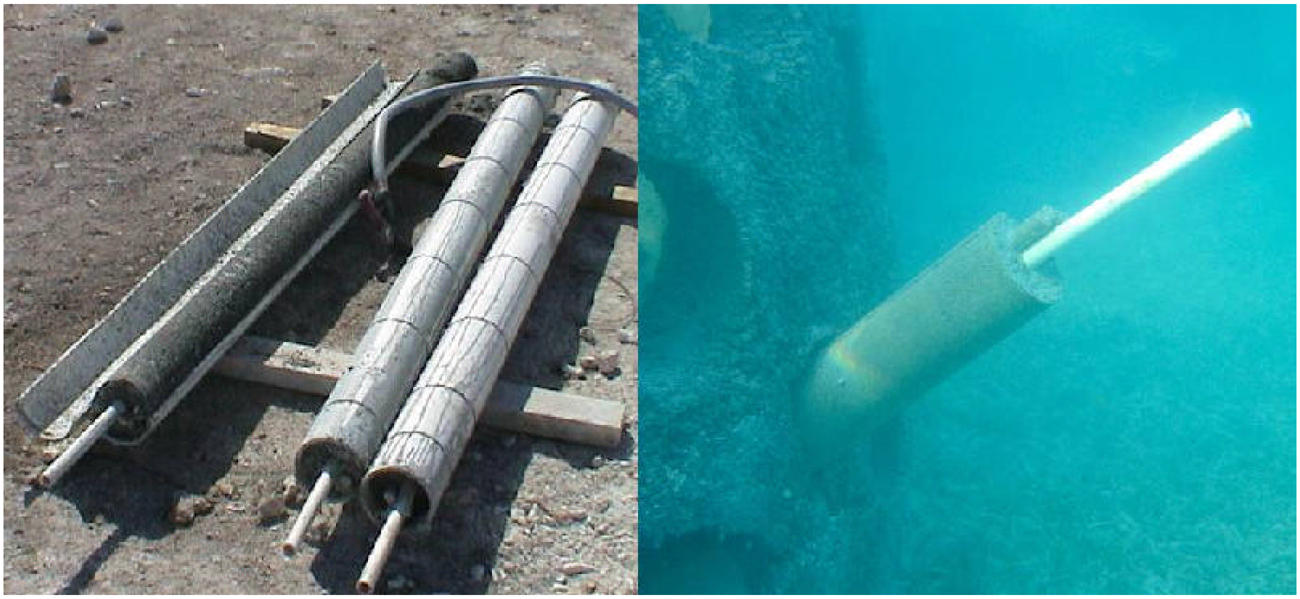


Figure 23: Battered pile anchors before (left) and after (right) installation. Battered piles are used in groups of three or four, to resist both horizontal and vertical movement in areas with soft sediment.

Three or four *battered piles* in a 'tripod' or square pattern can be are hydraulically jetted into the ground through precast holes in the module until they reach the hard bottom below the soft sand. When installing, the crew first determines the exact depth to hard bottom. Next, they would insert a concrete piling of the appropriate length with 1cm (0.5 inch) PVC pipe precast into the pile. The PVC pipe allows the pile to be to 'jetted' to the bottom with compressed air. Three pieces of #3 fiberglass rebar can be added to each precast piling for additional strength. Pilings can be made in lengths ranging from 3 feet to 8 feet. When hard bottom is too deep to be reached using this technique, it can be modified by adjusting the diameter of the pilings to match the friction characteristics of the sediment. In this case the piles are typically called *friction piles.* This anchoring technique requires professional engineering tests of the sea floor.

Anchoring With *Battered* Fiberglass Rebar

Figure 24: A diver drives a length of #5 fiberglass rebar through an anchoring tube cast into the Reef Ball. Battered rebar is driven into pre-drilled holes in the seafloor when the bottom is too hard for other techniques but vertical stability is important..

Note: With Reef Balls, holes for both the fiberglass rebar and the concrete pile anchoring system are cast into every Reef Ball made in order to provide flexibility for crew to adapt to varying conditions at the deployment site. If you are unsure of your anchoring needs, be sure to discuss this with your manufacturer early in the process. Remember than an unstable artificial reef can do more damage than good.

Base Anchoring

Units can be anchored with additional concrete bases, and this can also be helpful to prevent settlement into soft bottoms..

Step 7: Coral Rescue

When corals have been damaged or are about to be imperiled or destroyed it is often possible to organize and implement a coral rescue project which can re-stabilize damaged colonies, either at the original site of the damage, or, if danger persists, at a safer site elsewhere. Unfortunately, there are many reasons why a coral rescue project might be necessary. Here are some of the most prevalent ones that we have seen in our work:

- Coral colonies damaged or broken off in a severe storm
- Corals damaged or broken by a ship grounding or anchor drag
- Corals at risk due to point sources of pollution (sewage outfalls, etc.)
- Corals in an area scheduled to be destroyed or damaged by for construction or development (docks, seawalls, mining operations)

There are 2 basic rescue types, *re-stabilization*, and *propagation*. The use of each depends on the resources available to the project. In *re-stabiliation* adult coral colonies that have broken off or been damaged can be stabilized and reattached in their present location, or moved to a safer location and secured into an alternate substrate, such as an artificial reef module. The alternative to *re-stabilization* is *propagation*. When it is not feasible to move entire adult coral colonies, or when there is too much damaged coral to rescue, small fragments of each colony can be removed and replanted, and will eventually grow into a genetically identical adult colony. This technique is also referred to as genetic coral rescue. INSERT FIG 26: Left Frame: Coral Re-stabilization, Right Frame: Coral Propagation

The type and volume of coral impacted may be the best guide as to which method is most appropriate for your situation. If the impacted corals are high value, difficult species to fragment, or very slow growing, then re-stabilizing may be the best option. If the impacted corals are medium to fast growing, easily *fragmentable*, or there are very large volumes, then propagation and replanting is likely best. In many cases, you will have both coral types and may need to use a combination of both rescue methods to achieve the best result.

Re-stabilization of a large number of coral colonies is often a difficult, costly and labor intensive activity. The resources required for a large scale *re-stabilization* are rarely justified because the survival rates are not typically very high, especially if the colonies must be relocated. However, there are instances were very simple *re-stabilization* techniques can be highly effective. For example, after a hurricane, setting brain corals upright can save thousands of colonies with very little effort. Free living (not attached) coral (such as rose coral or many species of pencil coral) can be easily removed from areas where damage is expected (for example before channels are dredged). From our experience, there is no 'magic bullet' among *re-stabilization* methods. There is a great deal of published information on various methods including the most commonly used method, *hydrostatic cement reattachment. (* video link demonstrating method). *[A pioneer in this method was Dr. Harold Hudson of NOAA]* This is not our area of expertise, and so we have chosen not to discuss it in depth. Our *Coral Teams* are trained in this method, but we only use it occasionally, because in many cases, it is impractical. One of the main disadvantages to *re-stabilization* is that it ignores much of the biodiversity that makes up a reef, corals are only one small part of a truly healthy reef community. When that community is severely damaged, it can take decades to fully recover, even if the largest coral colonies are effectively *re-stabilized*.

For these reasons, and because most of our expertise and novel methodology is in the field of *propagation* and planting techniques on prefabricated artificial reefs as a grassroots method for coral reef rehabilitation, we have chosen to focus our efforts in this manual on this topic. We feel that this technique presents a well balanced short and long term rehabilitation strategy by providing immediate habitat to compensate for loss of *EPVS*, while preserving a wide range of coral colony genetics to facilitate long-term recovery. Using these methods, reefs will recover natural function even if replanting efforts have minimal success, something which cannot be guaranteed with *re-stabilization* alone. With time, *natural recruitment* on artificial substrate will produce an environment closely resembling, if not indistinguishable from natural reef. However, there are many cases where *re-stabilization* is the most effective rehabilitation option. If you feel that your project is best served by a *re-stabilization*, we recommend that you discuss this possibility with an expert in that field in order to determine the best methodology. FIG 27: Progression of a deployed Reef Ball of 1,5,and 10 years, if possible

Another advantage of coral propagation, is that it can also be used to create new reefs. It only takes a very small volume of *imperiled coral* to propagate into enough fragments create a new reef. Even on relatively healthy reefs, it is almost always possible to find enough imperiled coral damaged by small anchor drops, storms, and other natural processes to build a new reef. If your project involves building an entirely new reef, you may have to work a bit harder to find enough species diversity of *imperiled corals*.

It is always better to propagate using imperiled corals, but sometimes it may not be possible to gather enough diversity of imperiled corals to adequately replicate the diversity of the surrounding natural reef. To overcome this, there are safe methods, used by reef rehabilitation professionals, to take a cutting from a healthy adult colony to be propagated in order to establish that species in a new location. Reef Ball Coral Team ethics do <u>not</u> permit this procedure to be performed on our projects unless all four of the following conditions have been met:

1. There are no alternatives to obtain the desired species from imperiled stock.
2. The team has a coral propagation expert or scientist trained in this procedure.
3. There is a monitoring plan to check that no damage was made to the original coral colony.
4. Local governmental approval for this procedure has been obtained.

OUTLINE OF WHAT MORE NEEDS TO BE ADDED?

Step 8: Gathering Imperiled Coral, Fragmenting, Propagation and Planting

Coral Propagation Ethics

Before discussing the steps necessary for coral fragmentation and propagation, it is necessary to discuss the ethics involved in this work. Just as medical doctors take an oath to 'First, do no harm', and boy scouts leave any location 'as clean or cleaner' than it was when they arrived, we feel that the first rule of grassroots rehabilitation efforts is to ensure that no harm comes to an ecosystems by the methods being used to protect it. The Reef Ball Foundation has therefore developed its ethics and standards with the goal of protect enthusiastic well intentioned efforts from doing any harm to the ecosystems they are working so hard to protect. At first, these ethics may seem too stringent, particularly for people who have worked in coral propagation as part of scientific research, where due the small size and exploratory nature of the research, many of these ethical concerns become more flexible because the benefits of the research are great, and the impacts are minimal. In contrast, coral rehabilitation projects can be quite large, involving the planting tens of thousands of coral fragments and therefore any mistakes can have potentially large consequences. Whatever your perspective, please understand that the ethics presented here are meant to serves as guidelines only, and are designed to guide success and not to limit efforts.

Reef Ball Foundation Ethics

These ethics apply to all Reef Ball Foundation *propagation* projects and are principles that we suggest should only be circumvented by scientific researchers or trained professionals:

1) The only source for coral fragments that should be used is an *imperiled coral* which would otherwise die within one year.

Note: If propagation of specific *functional groups* of coral are required to maintain coral diversity and imperiled colonies cannot be located, cuttings can be taken from wild coral colonies reared on artificial substrates which were previously rescued or raised for the purpose of propagation (in order to maintain genetic integrity and avoid disease, use of aquarium reared coral fragments is expressly forbidden). If this procedure is not an option, see step **Step 7: Coral Rescue** for Reef Ball Foundation protocols for making an exception and taking cuttings from healthy corals.

2) Never fragment an overly stressed, bleached, or diseased coral.

3) Never fragment coral when the *NOAA Coral Reef Watch Satellite Coral Bleaching Hotspot index* is 3.5 or higher.See http://coralreefwatch.noaa.gov/satellite/ge/ to get a current map linked to Google Earth.

4) Work should be suspended on days when dissolved oxygen levels are less than 4.5 mg/l; or water temperatures exceed 30°C (86°F). Note: If equipment is available, Oxidation Reduction Potential (ORP) levels can also be measured to insure the coral are not stressed before or during propagation and planting procedures. An ORP reading with a minimum of 375 is required.

5) Never plant coral more than 30 miles (50 km) from their original source. This is a 'rule of thumb' guided by the principle that a coral should not be planted at a distance further than it could have covered in its larval free-swimming stage. In the case where scientific research indicates a broader or narrower range for a particular species, the scientific dispersal range for that species should be used instead.

6) Do not allow different hard coral species to touch each other when planting, and avoid placing them in the same water while in captivity (such as a transportation cooler). This reduces stress on the colonies, and also reduces the risk of injury from *interspecific competition.*

7) All staff directly handling corals must wash their hands *with antibacterial soap* between handling of different coral colonies except when different colonies are derived from the same *broodstock* colony. If gloves are used, they must be latex or other material types that can be sterilized by washing or they must be disposable. Gloves with very rough surface textures should be avoided as they are more difficult to sterilize.

8) *Coral plugs* must be planted to the chosen substrate before a significant fouling community develops. In some environments this can occur as quickly as 30 days…in cooler temperatures or in deeper water this may be as long as 90 days. In order to permit *planting*, several conditions must be met:

a) *Coral Plug Hole* must be clean enough so that epoxy putty makes a good bond. If planting is delayed this can be accomplished by abrasive cleaning with a *Battery Cleaning Brush* or *Plug Hole Wire Brush.*

b) Area adjacent to *coral plug hole* must be clean enough that the coral can freely *base* over the module without competition. If planting is delayed, this may be accomplishable by abrasive cleaning with a wire *Hand Brush*.

c) The *fouling community* cannot support a significant number *coral predators* (this varies by location). Cleaning alone will not likely be enough to ensure fragment survival in this case.

Note: Only a *Coral Team Leader* or *Co-Leader* is qualified to make the decision to proceed with any cleaning activities, and they can make this decision only after verifying by underwater *black light* that corals have not already settled where the cleaning will take place. Therefore, it is best to plant coral on substrate within a maximum of 30 days after deployment. Under ideal conditions, coral should be planted within 7 days of deployment.

Skill Based Ethics

With the *Coral Team* approach, our volunteers and non-professionals are asked to only perform tasks within their skill limits. These limits come in the form of formal certification levels issued by the Foundation based on work completed on previous projects, but can also be guided during a project by decisions made by the *Coral Team Leaders* and *Co-Leaders* who are recognized as professional reef rehabilitation specialists.

The Reef Ball Foundation certifies *Coral Team* members in five different specialty tracks, and uses a 5 tiered certification program for each specialty representing different levels of mastery. For a full explanation of the Reef Ball Foundation certification levels, see Appendix A.

Common Mistakes/Bad Practices

The following list of common mistakes or bad practices is not provided in any order of importance.

- ✍ Finger coral should be planted sideways, not upright to create a better base.
- ✍ Coral *fragments* and *coral plugs* should not be subjected to rapid changes in temperature, salinity or light level.
- ✍ Exposing coral to un-shaded sunlight when out of the water can cause *sunburn* very rapidly and therefore umbrellas or shade producing devices should be provided over *coral propagation tables* and any *temporary disaster nurseries* in less than 4 feet of water.
- ✍ Do not touch coral without first fanning water over them to make sure the *polyps* are fully retracted.
- ✍ Do not use tap water or drinking water to mix *Antiseptic dip* or any iodine based antiseptics. *Antiseptic dip* must be diluted in fresh clean seawater, additionally it must be kept at the same temperature, pH, and salinity as ambient seawater. For this reason it is best to change the *antiseptic dip* frequently, and mix it no stronger than the suggested concentration of 5ml per 250ml of water (1 teaspoon per eight ounces).
- ✍ Do not use too much water when mixing plug cement (or the plugs will be too weak to function). Use additional *Adva Flow* if needed to make the concrete looser.
- ✍ If a batch of *plug cement* comes out too loose or stiff, do not set coral fragments in it. Simply discard it and start again.
- ✍ Do not make *coral plugs* unless concrete is sufficiently loose to form a level surface. Otherwise, the coral fragment will not seal properly and infection or dislodging from the plug can occur.
- ✍ Once a *fragment* has been placed into a *coral plug* do not remove and replace the fragment for any reason. It has a better chance of surviving if placed improperly and left than if removed and replaced.

- ✍ Do not gather more coral fragments than you can propagate and plant the same day.
- ✍ Avoid plug nurseries except for the 24-48 hour *Acropora species RTN* elimination *nursery.* If possible, direct planting after plugging is preferred.

Selecting and Transporting Imperiled Coral

When planting coral, the identification of which species to plant and which colonies to rescue are important and difficult decisions. To aid in this decision, look back at your work in **Step 1: Determine Goals**; to determine whether your project is primarily attempting to rescue coral that have been damaged or whether you just trying to find a good source of imperiled coral for creating a new reef. Of course, just because it is not your primary goal does not mean that you cannot attempt to re-stabilize or transplant a large or difficult damaged colony if your resources and expertise permit, just that you should attempt this only after your primary goals have been accomplished.

Coral Re-stabilization

In **Step 7: Coral Rescue** you decided whether to attempt *re-stabilization, genetic coral rescue,* or a mixture of the two methods. If you are *re-stabilizing* mature or large coral colonies, you may be re-stabilizing in the original location, or moving the colonies to a new site. The former is preferred but not always an option. If the colonies must be moved, whenever possible choose a site close enough to handle by hand or with lift bags. Moving mature or large coral colonies any distance can be very difficult. Massive corals like brain coral are amazingly dense and can be deceptively heavy. Heavy duty lift bags or assistance from a barge and crane are likely to be required.

Only select adult colonies that are within your handling capabilities. Rough handling will only create more problems. It is better to successfully rescue smaller colonies that are within your abilities than to expend a great deal of time and energy trying to save a particularly large colony, only to have it die from stress after all of your work. If you can't rescue all of the imperiled corals in your project area (which is very likely with restabilization methods), select colonies that have features that might make them easier to handle,such as like natural lifting points without *polyps.*

For the most part, corals must be handled as gently as possible to avoid stress. There are a few 'tricks' that can be useful. Most coral species can survive exposure to the air for several hours provided they are kept moist (covered in wet blankets or newspaper). In doing this, however, care must be taken to avoid any process that would wash off the slime the coral use to protect themselves when exposed to air. For this reason, do not hose corals down with salt water to keep them wet (although a light misting is fine). Also, coral out of water can *sunburn* very quickly, even on a cloudy day, so be sure to keep them covered at all times. Smaller colonies can be transported in thermally insulated coolers filled with ambient seawater. If using this technique, however, it is important not to mix species within the same cooler, and to circulate and exchange the water in the cooler as much as possible. If the water stagnates, an oil film can form across the surface, and oxygen levels will plummet, endangering the corals.

When *re-stabilizing*, it can tempting to *re-stabilize* a huge overturned staghorn coral or other fast growing species. It is best to resist the temptation and focus resources on the slower growing colonies. Your chances of success will be greatly improved with the slower growing coral and they cannot be fragmented and grown quickly like branching corals.

Figure 28: The above re-stabilized Elkhorn coral (Acropora palmata) was handled with great care only to die within three weeks of planting from RTN. Compare with Figure 29 below.

Figure 29: This Elkhorn coral (Acropora palmata) began as a 2cm (1 inch) propagated fragment planted into the artificial substrate shown. Within a year, it had grown by 600%.

Figure 30: Two large brain coral colonies rescued from the path of a dredger and re-stabilized. These colonies were detatched, lifted by lift bags, transported a mile by boat covered with wet blankets, and reattached to a prefabricated base using hydrostatic cement. The larger one, which weighed over 150kg (320lbs) suffered some handling scars (visible as thin lines of discoloration in the photo), but both colonies fully recovered. This is an excellent example of when a re-stabilization is required, but also demonstrates the effort required in this endeavor.

When using the traditional *hydrostatic cement method*, practice mixing very carefully before hand. A slight misformulation can create a very weak bond that will break during the first storm. Pick your attachment spots wisely and make sure to get a *mechanical bond* on both surfaces; don't rely on the adhesion of the cement alone.

Coral Propagation (Reef Ball Methodology)

Coral Propagation Table Operations

Fragmentation (Asexual Reproduction or Propagation)

Tools

Different Techniques for Different Species

Choice of Species Size of Fragments Direct Methods

Fragmenting the Coral

Step 9: Coral Planting

With the Reef Ball Coral Adapter Plug system, planting effort can be as easy as mixing a special two part underwater epoxy and attaching a pre-plugged coral fragment to the Reef Ball. A bit of hands on training is required to master this step but a good diver can learn to plant up to about 100 coral plugs per hour.

Unfortunately, planting is not nearly so simple from a long term outcome perspective. Just a a gardener has to carefully plan rows, crop types, sun exposure, soil conditions ect. Similar planning is required for corals.

There is always some risk involved whenever corals are moved. To help increase your success rate when coral planting, one should have a basic understanding of coal biology not simply imitate what you may have seen or read.

Proper Care and Handling during all stages is also critical!

Corals can be arranged into many different categories by many different factors. The simplest is to first divide them into two basic groups HARD (or stony corals are ones that precipitate an external calcium skeleton) and SOFT (coals that do not precipitate an external calcium skeleton).

Since shapes can generally provide a quick identification we can then group them by growth forms. It is however, important to remember that there can be variance from a colonies "normal" distinctive shape that the majority of the corals of a given type tend to form so do not be to quick to judge. In any case the shape or growth form can be an excellent indicator of the conditions a coral prefers to live under. Coral growth formations are effected by water movement, flow rate, depth, light and other unique site conditions. High flow rate normally results in shorter thicker more dense branches.

Growth Forms
Hard or Stony corals

In an effort to always error on the side of safety, it is best when working with stony corals to work with only one species at a time and even better to complete working with one colony before going on to the next colony keeping the fragments separate from each colony.

It is also important to wave your hand passed any coral causing the polyps to retract before touching it. And never remove any coral from the water while it is expanded!!

Branching corals: As the name denotes these corals have a growth form that resembles a tree with branches. They are usually anchored by a common base (basing coral) or tree like trunk if you will. They have adopted this growth form because they are usually found in water conditions of high wave action and surges and their "stage horn" shape allows the water to pass through and around them without much resistance. Branching corals are one of the largest contributor to reef formations and include both the thin and thick branched verities.

Placement on the Reef Ball: When relocating corals from this category be sure to place them high up on the Reef ball where they can be exposed to the strongest current high light and surge conditions.

Fragmentation methodology: Branching corals normally have a fast linear growth rate and their branches lend themselves well to fragmentation. Small thin branches are easily broken off the main branch by hand or with the use of a tool. Fragments of 1 inch (2.5 cm) usually work the best. These corals can be fragmented underwater and it is best not to mix species or even fragments from the same species but different colonies whenever possible. The less pressure points during fragmenting the better so try to hold the main colony at the base or by a dead section of the coral with one gloved hand and once you commit to the placement of the tool within the other hand to the coral is made do not move it until the fragment is broken off. Thick branched coals may require more heavy duty type fragmenting tools like bolt cutters, hedge or tree limb loping shears, and hawk saw.

Handling characteristics: Most branching corals fall into the **Sensitive Coral category** generally the fastest growing hard coral such as many of the *Acropora* species can be more susceptible to coral diseases/damage caused during handling such as rapid tissue necrosis (RTN). Temperature acclimation is also highly recommended when moving corals in the sensitive category. If fragmentation took place underwater of any depth the temperature change to surface or shallow water conditions experienced during the "plug" making process can be detrimental. There are always exceptions in a non-perfect world

Porites porites and *Madracis mirabilis* also called finger or pencil coral and a few others that are considered Branching corals are **Change Tolerant/Hardy Corals** since they are a slower growing coral that handle changes in temperature or turbid conditions well. These coral can often be handled with less care and generally have high survivability. They make good "beginner or team training" corals.
Tools required: Needle nose pliers, bone cutter, scissors,

Example: The genus *Acropora* (pronounced akro-por-a or in the USA ah-crop'-or-ah or ak'-roh-pohr'-ah are also expectable pronunciations) is they most recognizable and most abundant coral in this growth form. Some *Porties* spp. *Madracis* spp. and *Montipora* spp. as well as *Pocillipora*, S*eriatopora*, *Palauastrea*, and *Stylophora* are also branching corals

Encrusting corals: Again, as the name indicates these corals encrusts the surface of the substrate with a veneer or plate like growth. Because of their low profile growth form they are not as usually effected by water movement and can be found throughout most reef conditions. Some of the encrusting corals send up short nodes or projections but not to the extent of a branching coral.

Placement on the Reef Ball: Almost any were on the ball as long as they get some flow past them and are not in total shade.

Fragmentation methodology: By first "popping" off the veneer live coral colonies from the base will make fragmenting easier.

Handling characteristics: Most are **Change Tolerant/Hardy Corals**

Tools required: Hammer and screw driver, crow bar, for removing the colony from its base then needle nose pliers, bone cutter, hack saw to fragment.

Examples: The genus *Montipora* (pronounced mon-tee-por-a) and *Porties* (pronounced por-eye-tees) both contain branching and encrusting species. *Porties astreoides* (mustard hill coral) found through out the Caribbean is a perfect example of an encrusting coral that can be "popped" off and then fragmented into coral plugs or the complete colony can be moved and re-attached on a layer-cake style Reef Ball. *Siderastrea radinas* (lesser starlet coral) and one of the few stony corals found in both the Atlantic and the Pacific Oceans. It is a very hardy slow growing coral that can tolerate extreme temperature fluctuations, most any water movement conditions, all variations in light intensities and can even survive being buried in mud or sand for days. It is however difficult to "chip" off as the colonies are almost permanently affixed to hard substrate and it may be best to move the rock they are attached to at the same time.

Massive Corals: solid body corals that resemble boulders or brains. Slow growing corals (normally 0.4 to 1.2 inches 1-3 cm per year) but normally live a long time. Usually this shape coral is found in shallow and mid-depth waters were high flow rates can occur yet the coral is not dependent on flow.

Placement on the Reef Ball:

Fragmentation methodology:

Handling characteristics:

Tools required: Hack saw, crow bar, hydrolic chain saw,
Example: *Diploria labyrinthiformis* (Caribbean grooved brain)

Solitary corals: Mature corals in this category are normally unattached to substrate or other coral colonies and most often found on sandy or rocky bottoms. They are **not good** candidates for planting but should be moved out of harms way whenever necessary but in most cases do not require anchoring after moving.

Placement on the Reef Ball: They are not good candidates for planting. Be sure when relocating these corals that they are placed upright and on sand or rubble bottom and not in contact with otehr corals.

Fragmentation methodology: Usually single-polyped, single mouthed and they should not be fragmented

Handling characteristics: Care should be taken not to place these relocated corals to close to other corals as they can emit a think mucus and it this comes in contact with most any other coral it will kill them or at a minimum case serious damage.
Tools required: Gloves for moving.

Example: *Fungia* (pronounced fun-dgee-a) *Halomitra* (pronounced hal'-oh-my'-trah) Neptune's cap coral, *Herpolitha* (pronounced her'-poh-lee'-thah) and *Polyphyllia* (pronounced paw'-lee-fill'-ee-ah) both with the same common names of tongue or slipper coral, *Sandalolitha* (pronounced san'-da-loh-lee'-thah) dome coral, and *Cynarina* (pronounced sigh'-nah-ree'-nah) and *Scolymia* (pronounced skahl'-ee-my'- ah) both referred to as button coral, and *Manicina areolata* (Caribbean Rose coral) are all prime example of a Solitary coral.

Tabulate (or Table) corals: Fragments or young colonies of these corals start out encrusting then grow with a a more vertical orientation and eventually develop into flattened, radiating platforms of tightly spaced branches.
Placement on the Reef Ball: Room must be provided for these corals to spread out horizontally as they mature. They should also be place in the upper to mid range quadrants of the Reef ball.
Fragmentation methodology: The skeletal structure is very porous and lightweight especially near the ends of the branches and are easily fragmented.

Handling characteristics: Most tabulate corals fall into the **Sensitive Coral category** generally the fastest growing hard coral such as many of the *Acropora* (table top) species can be more susceptible to coral diseases/damage caused during handling such as rapid tissue necrosis (RTN) and seem to be one of the least tolerant to temperature flux. Temperature acclimation is highly recommended when moving this coral. If fragmentation took place underwater of any depth the temperature change to surface or shallow water conditions experienced during the "plug" making process can be detrimental.
Tools required: Needle nose pliers, bone cutter, scissors, hawk saw.
Example: Formations of this type can be found among species of *Acropora, Montipora,* and *Merulina* (pronounced merry-you-line-a) as well as other less common genus.

Foliaceous corals: form thin upright sheets or plates that resemble curled leaf like formations. Normally found in turbulent fast moving currents helpful in keeping the craves clean of waste and debris while also bringing food to the polyps located within the folds.
Placement on the Reef Ball: These corals require high water movement but not surge, strong light, and high nutrients.
Fragmentation methodology: The thin plates lend themselves well to fragmentation.
Handling characteristics: Susceptible to white-band disease and are not real tolerant of chemicals like coral dips. While slow growing most foliaceous corals still fall into the **Sensitive Coral category.** Always the exception Pavona is considered to be in the **Change Tolerant/Hardy Coral** group.
Tools required: Needle nose pliers, bone cutter, scissors.
Example: *Leptoseris cucullata* (Caribbean lettuce coral) *Turbinaria, Pachseris* (pronounced pak'-ee-seh'-ris) elephant skin coral and *Pavona* (pronounced pa-voh'-nah) cactus coral are examples of foliaceous corals.

Laminar corals: form broad thin, terraced, horizontal plates.
Placement on the Reef Ball: Care must be taken when planting the plug to be sure the polyps are facing up.
Fragmentation methodology:
Handling characteristics:
Tools required: Needle nose pliers, bone cutter, scissors,
Example:

Columnar corals: form non-branching vertical pillars raising from a common usually massive base.
Placement on the Reef Ball:
Fragmentation methodology:
Handling characteristics:
Tools required:
Example: *Dendrogyra cylindrus* (Caribbean pillar coral) *Psammocora*

Turbinate corals: resembling an ice cream cone or vase.
Placement on the Reef Ball:
Fragmentation methodology:
Handling characteristics:
Tools required: Needle nose pliers, bone cutter,
Example: Mintipora capricornis

Planting: Affixing the *coral plug* into the *coral plug hole* with *underwater epoxy putty*.

Mucus is secreted by some corals when under stress. While this is a method of protection for the coral doing the secreting it can be very harmful (toxic) to other corals.

A mucus web can also be secreted to capture food, but the one we are most concerned about is the one used for protection.

Chemical warfare: Because space on the reefs can be limited corals compete in order to expand by producing a toxic compound. The toxic compounds also discourage predation. Only about 50% of the corals produce these compounds and they range in potency from very toxic to harmful.

Soft corals

Before attaching a coral in its new location is is necessary to consider proper placement:
By Compatibility of neighboring species
By water conditions
By lighting conditions
Room to grow
Room to expand
Room for sweeper tentacles

First look at the conditions the coral originated from, this will give you an indication of where it should be place on the Reef ball. Specifically note the the zone, water depth, water conditions i.e. high or low water flow, turbidity, distance from the bottom, compatible or non-compatible species nearby ....
Because the conditions under which a coral grows is a key factor in determining their growth form category a coral falls into

Coral zones:

Planting Team: A dive team that mixes underwater epoxy putty and plants coral plugs onto substrate modules. Sometimes divers work in teams of two, with a mixer and a planter and sometimes each member does both tasks. In many cases, planting teams do not wear fins when planting to avoid accidentally knocking off adjacent, freshly planted coral plugs. Even in shallow water, dive tanks should be used to ensure careful slow movements needed to plant coral without disturbing other freshly planted plugs.

Figure G33: Diver attaches a coral plug to an artificial reef module using epoxy putty.
Figure G34: Schematic of diver planting coral plugs from a Coral Planting Tray onto a Reef Ball. The diver can use the tray to store supplies such as a wire brush, or extra epoxy putty.
Planting teams need to be trained on the project's *planting strategy* to know where to plant coral plugs with specific coral species. Planting errors can take years to show up and avoiding them can be important for long-term success. A veteran planter in good sea conditions can plant 100 or more coral plugs per hour, but variable conditions such as current, surge, or reduced visibility can reduce this number drastically. An experienced and skilled planter uses much less epoxy putty per coral plug than a newly trained beginning planter. A beginning planter may get 5-7 plugs per epoxy stick, whereas a skilled planter can get 20 or more. When computing the amount of epoxy putty needed for a project, take this variable into account.

Planting Strategy: A planting strategy must be developed to allow the base materials to develop as closely as possible to the species diversity and population densities of nearby natural reef. Mastering the development of *planting strategy* takes a level of skill that is beyond most volunteer teams. Typically, the Foundation develops a planting strategy using RBF experts, who are assisted by as much local expertise as can be accessed. Todd Barber, John Walch, Lorna Slade, Marsha Pardee and Mario van der Bulck are currently (2006) the RBF experts that have the level of understanding needed to develop good planting strategies. There are probably some coral rehabilitation specialists/scientists that have similar skills, particularly ones that know specific local environments well. We also hope to develop more experts, but this type of training takes years, not months. Some of the complex factors that go into planting strategy are:

1. Environmental tolerances of the particular species (lighting, currents, sedimentation resistance, salinity, temperature changes, feeding requirements, depth limitation, etc.)
2. Warfare or fusing of coral colonies
3. Expected growth rates of various species
4. Expected natural settlement on the artificial reefs
5. Water quality, present and expected
6. Wave and climate expectations

7. Goals of the individual project (for example aesthetics, specific use, etc.)
8. Capabilities of the project (how many coral can be planted, etc.)
9 Preferences for threatened or endangered species

Plating /Encrusting Coral: Coral that bases but does so in an unlimited fashion typically growing over hard surfaces that are not already colonized by other coral.

Reef Building Coral: substantial calcium carbonate depositing (hard) coral. The environmental assessment found, for example, mustard hill variety, *Porites astreoides,* Lesser Starlet Coral, *Siderastrea radians,* Massive Starlet Coral, *Siderastrea siderea*, and Boulder Star Coral otherwise referred to as *Montastrea annularis* that are reef-building corals.

Non-Reef Building Coral such as soft coral. Most notably *Pterogorgia guadalupensis* (Purple grooved-blade sea whip) and a few common sea fans on the site.

Mobile Inhabitants: animals, reptiles, fish, invertebrates and other marine life capable of moving when threatened.

BY HANDLING CHARACTERISTICS

-**Change Tolerant/Hardy Coral**: generally slow growing hard coral such as brains or coral that handle cold, changing or turbid conditions well such as *Porites porites* (finger coral) or pencil coral. These coral can often be handled with less care and will generally survive well.

-**Sensitive Coral**: generally the fastest growing hard coral such as *Acropora* species that is very susceptible to coral diseases/damage caused by handling such as rapid tissue necrosis. Also includes (attached) coral heads or other complex communities where damage and loss are common with improper handling.

BY ABILTY TO ATTACH TO SUBSTRATE

-**Basing Coral**: coral that will re-attach to base substrate creating a limited base size when replanted. (And can be attached temporarily by a re-planter as long as the attachment will hold until the coral is rebased).
-**Plating / Encrusting Coral:** coral that bases but does so in an unlimited fashion typically growing over hard surfaces that are not already colonized by other coral.

-**Non-Basing Coral**: coral that cannot re-attach to substrate when re-planted. (And therefore must be attached permanently by the re-planter).

BY REPRODUCTION METHOD

-**Asexually Reproducible Coral**: coral that can be (easily) reproduced asexually (Typically coral that are easy to divide).

-**Not Asexually Reproducible Coral**: coral that cannot be reproduced asexually (easily). (Such as individual polyp coral or coral that require advanced techniques such as coring to be propagated).

BY SIZE

-**Coral Heads:** coral colonies that are typically well attached to the seabed and are typically a mixed community of coral species and a benthic fouling community. A coral head it typically defined by a perimeter of sand/seagrass/mud and/or live bottom.

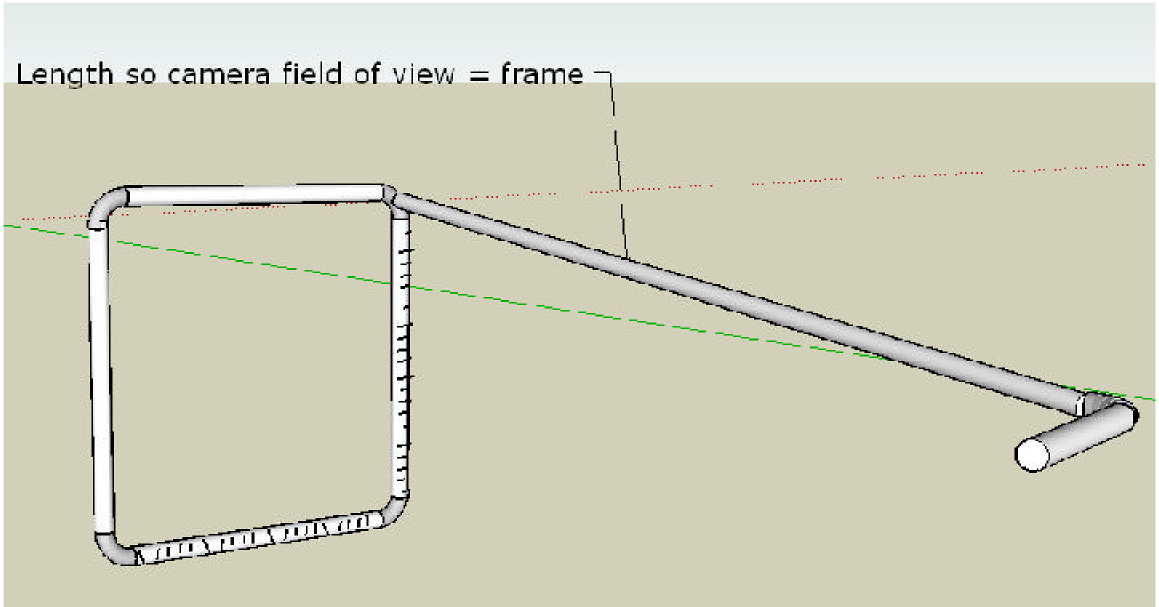
-**Individual Coral Colonies & Live Rocks:** Individual coral colonies or loose rocky substrate with a fouling community that are not well attached, often small, and if coral are usually of a single coral species type. If coral, they are generally too small to have a substantial associated fouling community.

-(Coral) **Fragments:** broken or intentionally segmented pieces of a coral colony normally used for asexual reproduction of a coral colony.

Step 10: Monitoring

[to be written by Marjo van der Bulck]

A PVC camera guide marked with metric and/or English SAE scales. This monitoring frame is used to position the camera over coral plugs to take standardized monitoring photos. Advanced monitoring teams will add movable ‘luggage tags’ with numbers or letters to encode variables such as module identifier, date, or coral colony identifier. Length of the rod varies by the camera and lens being used. Length should be adjusted with camera in wide-angle (un-zoomed) position. When taking monitoring photos make sure camera is in the same position. Most monitors prefer a frame that is neutral or slightly negatively buoyant. Gravel can be put inside the frame for this purpose. Frame should have small holes drilled into it for water to flow in and out.


Length so camera field of view = frame

Appendix A: Red Mangrove Rehabilitation

MANGROVE RESTORATION IN A HIGH ENERGY ENVIRONMENT

Appendix written By Catherine Jadot, Ph.D.

<<Currently Being Written Using This Outline by Dr. Jadot>>

Background

Step 1: Determine Project Goals, Budget, Resources and Timeline
- Setting Primary Project Goals.
- Setting Secondary “Mangrove Function” Goals.
- Determining Budget and Resources
- Timelime

Step 2: Damage Assessment

Step 3: Site Selection
- Tidal inundations survey

Step 4: Permitting

Step 5: Number, Density, Layout, Clusters, Size
- Number

Step 6: Construction of Modules
- Armored Cultivator Pot
- Wrack protector
- Reef Safe Fert Disc™.
- Anchor

Step 7: Rehabilitation Monitoring.

- Biological characteristics.
- Physical characteristics.
- Chemical characteristics.

Appendix B: Oyster Rehabilitation

OYSTER RESTORATION USING DESIGNED REEF STRUCTURES

Appendix written by Wayne Young

Oyster rehabilitation is very complex. Designed reef structures fill a niche in a much larger oyster rehabilitation need, and tend to have a supporting or secondary rather than leading role. Consultation and coordination with knowledgeable practitioners is essential. This section surveys major planning considerations and issues associated with the use of designed reef structures in support of oyster rehabilitation; it is an introduction to the topic. Practical information from previous use of Reef Balls with oyster rehabilitation objectives is also discussed. These projects were correlated or integrated with local area oyster rehabilitation programs as a best practice.

Oysters

Oysters, a keystone species of benthic filter feeders in temperate estuaries and coastal bays, are a type of primitive bivalve with global distribution. An oyster's filtering capabilities enables it to remove large quantities of plankton, nutrients, bacteria, and sediment from the water. A healthy adult oyster can filter 25-60 plus gallons of water per day. A large, healthy oyster population can improve water quality. Oyster beds and reefs also provide valuable habitat for other benthic organisms and fish species.

Predation, harvesting pressure, water quality degradation (e.g., high nutrient loads), and diseases, especially parasites in recent years, have combined to drastically reduce many oyster populations. Combined stresses can cause natural oyster populations to decease below the quantity to rebuild the stock at a rate that offsets or is greater than cumulative losses. Rehabilitation may be an option if environmental and institutional conditions are otherwise favorable.

Oysters have a complex life history that makes rehabilitation extremely challenging. A basic understanding of the oyster and its environment is fundamental to rehabilitation project design. Effective use of designed reef structures must consider the life histories of the oyster species that will be used, the complexities of oyster propagation, growth and mortality factors, the potential for performance to vary significantly according to prevailing conditions, and rehabilitation issues within the ecosystem.

Designed Reef Oyster Rehabilitation Concept

Constructed beds and structures are routinely used to provide hard substrate for direct attachment by oyster larvae or to serve as a

Figure 0 Reef Ball encrusted with oysters. Photo:

foundation for seeding oysters for rehabilitation and commercial oyster cultivation. As a matter of practical necessity or to facilitate harvesting, such structures may not be configured in the vertical or horizontal dimensions so as to approximate the layout and irregular elevations of natural oyster reefs. Use of designed reef structures in rehabilitation projects is an adaptation of these longstanding oyster cultivation practices.

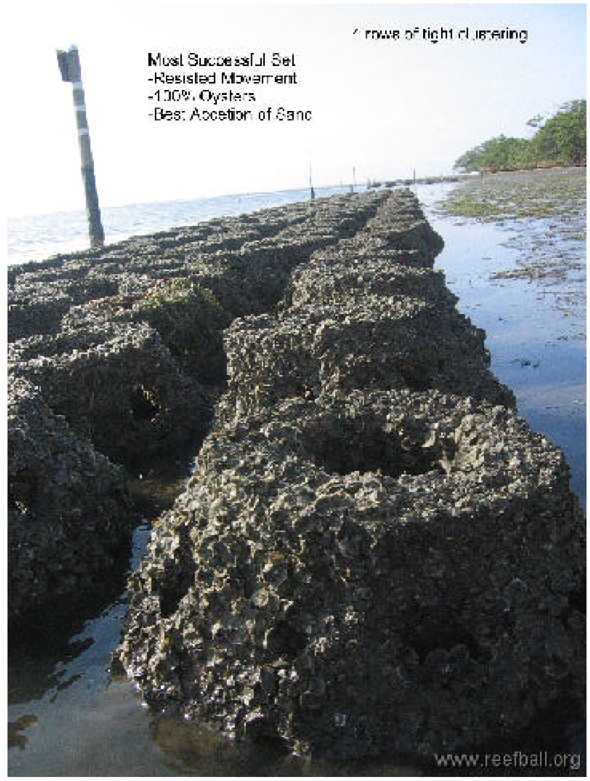


Figure 0 Shoreline stabilization project with oyster recruitment, MacDill Air Force Base, Florida. Photo: *Reef Ball Foundation*.

Rehabilitation of oyster and coral reefs apply the same basic concept. Designed reef structures provide hard substrate for attachment by larval oysters, simulating natural structure (e.g., relic oyster shell formations). The structure provides a core for the reef. Oysters that colonize the core structure form a living veneer of marine organisms. The core and veneer, when fully developed, replicate the functional performance of a natural reef many years in age. Applying this concept, Reef Balls were used successfully as substrate for natural and hatchery-assisted "spat sets" by the American Oyster (*Crassostrea virginica*) in the Tampa and Chesapeake Bay areas, respectively.

Actual and potential applications of designed reef modules include:

? Reestablishment of vertical structure for oyster colonization.
? Use of the inner cavity as a grow-out area for spat on shell for protection from predation by fish (e.g. cow-nosed ray).
? Deployment on oyster bars or suitable rehabilitation project sites for natural colonization.
? Deployment on oyster bars or suitable rehabilitation project sites with spat set directly on or manually attached (e.g. spat on shell) to the modules.
? Deployment of modules (with or without spat attached) in patterns that approximate the configuration of a natural reef system.
? Deployment on oyster sanctuaries or oyster aquaculture sites to deter unauthorized mechanical harvesting or protect grow-out cages.
? Deployment at corners or along sides of oyster sanctuaries or oyster aquaculture sites to provide underwater boundaries detectable by fathometers and sonar.
? As secondary benefit for other designed reef applications (e.g., establishment of reef habitat for fish, shoreline stabilization structures).

Rehabilitation Project Planning

Oyster rehabilitation is usually an ecosystem-wide issue that requires multi-faceted activity on a large-scale. A combination of physical alterations to the substrate of natural oyster bars, overharvesting, or disease (e.g., parasites) are likely to be present. Individual and cumulative stresses from harvesting, disease, water quality degradation, sedimentation, and other factors may have reduced the oyster population below levels that are sufficient to sustain the species or support a commercial fishery. Oyster rehabilitation project sites may also susceptible to unauthorized harvesting, although it is possible to design projects to help mitigate this threat.

Rehabilitation on an ecosystem scale involves environmental, fisheries management, and regulatory issues, large costs and substantial effort. Sponsor and institutional support are essential. Smaller-scale oyster reef rehabilitation projects may be within available resources, and could be used to help development of oyster seed stock, to provide localized reef habitat, and to support secondary objectives such as reef structure beneficial to other marine species.

<u>Scoping Projects</u>

Planning meetings should be conducted to scope a prospective project. Understanding the biological and ecological issues, local environmental conditions, institutional concerns (including fisheries management issues), and regulatory requirements are fundamental to implementing successful projects. Identifying actual and potential stresses to oyster populations is a fundamental consideration.

To assist with identifying issues and concerns and obtaining advice and support, project proponents and planners should reach out to stakeholders and engage their participation. Scientists, natural resource agencies, and regulatory authorities are core stakeholders. Because underwater structures are involved, the process should include those who could be directly or indirectly affected by a project, such as recreational boaters, sailing groups, commercial and recreational fishermen, divers, swimmers, and environmental interest groups that include marine issues in their agendas. Potential co-sponsors also merit consideration in project planning. A large body of relevant literature is accessible through Internet searches and should be consulted.

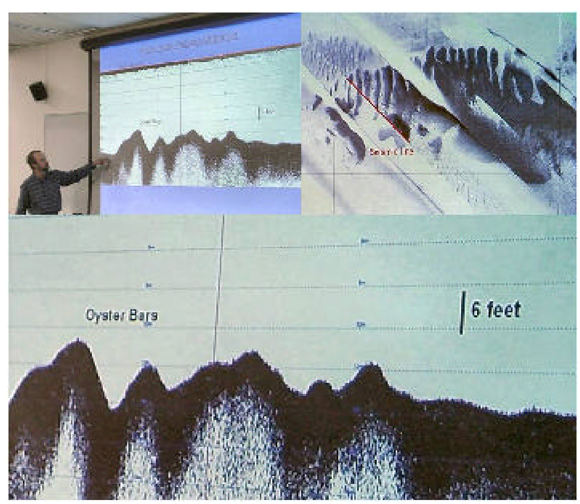


Figure 0 Jeff Halka, Maryland Geological Service, presenting results of sidescan sonar and sub-bottom profiling of historic oyster reefs, upper Chesapeake Bay. Photos: Wayne Young, *Maryland Environmental Service.*

The differing and often competing habitat requirements between species of interest to natural resources, fisheries management, and environmental stakeholders may be a constraining factor as needs of "client species" are represented. Construction of an oyster reef usually involves conversion bottom habitat from one form to another, unless a structure is placed on an existing active oyster bar. The conversion occurs even when a selected site is a former oyster bed or reef that has become buried by sediment. The conversion of benthic habitat may be a fisheries management issue, for example in the United States, where the existing bottom has been classified as "essential fish habitat" by the National Marine Fisheries Service.

The planning factors that are identified should be assessed, project objectives developed, and a consensus reached among stakeholders insofar as practicable regarding project specifics, facilitating such regulatory approvals as may be necessary. However, a consensus may be difficult to achieve inasmuch as oyster rehabilitation is often a hotly debated; there are competing interests and concerns, and in some cases, vested interest in particular rehabilitation activities. Therefore, considerable care must be exercised in scoping and developing projects. Integrating designed reef projects with established oyster rehabilitation activities or as elements of rehabilitation projects sponsored by others may help offset the potential for disagreements. However, it may be necessary to adjudicate the various concerns that associated with any rehabilitation project through the applicable regulatory process.

Setting Project Objectives

Use of designed reef structures to provide high relief substrate for oyster recruitment is typically expensive, resource intensive, and small scale relative to overall population needs. Projects should be designed to provide benefits to the environment in the event that oyster recruitment or performance is substantially below anticipated results or does not occur, for example, if reefs relying on natural propagation do not receive a spat set. In order to accomplish this, projects should include both primary and secondary objectives where practicable. Secondary objectives could include fisheries habitat to improve carrying capacity for reef fishes, recreational diving opportunity, shore stabilization, research, and deterrence of unauthorized mechanical harvesting. These could also be primary objectives for some projects, with oyster rehabilitation serving as a secondary objective.

Large underwater structures can help deter unauthorized mechanical harvesting. But inclusion of deterrence as a project objective may be controversial, if not offensive to some. Implications that poaching could potentially occur should be well validated before being included as a specific project objective. Underwater structures can also snag nets and other fishing gear that may be authorized fishing practices in or in proximity to project areas. Therefore, recreational and commercial fishing interests need to be effectively addressed through the scoping process.

Regulatory Requirements

Project planning must effectively determine the applicable regulatory requirements.

Project implementation must conform to regulatory criteria that are prescribed. Among the issues that have been considered include, but are not limited to, oyster species selection (including hybrids and non-indigenous species), conversion of habitat from one species to another, risk, location, water depth (biological and navigation), pollution, physical conditions and effects, benefits, costs, and effects relative to other rehabilitation projects. The cost and effort to complete studies that may be required to satisfy regulatory issues can be substantial. Therefore, linking or correlating projects with existing oyster rehabilitation work can reduce and make practical applications that might otherwise be difficult to obtain regulatory approvals.

Biological Planning Considerations

Species Selection

A best practice is to select a species that has a proven record of performance under prevailing location conditions. However, only species that are approved for use in the project area must be used. There may be one or several indigenous species, a hybrid of an indigenous species especially bred to be disease resistant, or an introduced (non-indigenous) species. Among the oysters that are cultured are the Eastern, or American oyster, European oyster (*Ostrea edulis*), Pacific oyster (*Crassostrea gigas*), and the Suminoe, or Asian oyster (*Crassostrea ariakensis*). Sterile oysters of a suitable species may be beneficial to commercial aquaculture (no energy lost to reproduction) but would not normally be candidates for a rehabilitation project because they can't reproduce. However, if a project site were located within the hydrodynamic circulation pattern of a reliable source of naturally reproducing oysters, then use of sterile oysters to "jump-start" an oyster reef development with reliance on natural propagation for future recruitment of native stock might be an option.

The oyster species that is selected must be amenable and cost-effective to propagation, transplantation, or stabilization. Oyster species often display characteristics that are evolutionary adaptations to conditions that prevail in their primary ranges. Although one species might have a characteristic that seems potentially favorable to introduction in another part of the globe, the full characteristics of the species need to be assessed to determine actual suitability.

Rigorous international protocols – the International Council for the Exploration of the Sea's *ICES 1994 Code of Practices on the Introductions and Transfers of Marine Organisms* - were developed to guide the intentional introduction of non-indigenous species. These standards are based on past introductions, intentional and non-intentional, that have had adverse or disastrous consequences. There are also national laws, such as the Non-Indigenous Aquatic Nuisance Prevention and Control Act of 1990 (P.L. 101-646) in the U.S., as well as laws in several states, to prevent the introduction of non-indigenous and invasive species that could be harmful. A non-indigenous oyster species should not be used unless it has been certified and approved by proper authority. The research and risk assessments that are associated with the applicable protocols and institutional requirements are expensive, resource intensive, and time consuming.

Brood stock or seed oysters, whether indigenous or non-indigenous, that are imported from another location, may need to be subjected to a quarantine to insure that the stock is not infected, and the packing material is also not infected. Once all requirements and safety precautions have been satisfied, a non-indigenous species may be an option, provided that it is a suitable species relative to project objectives.

If natural reef building is a project objective, then the oyster species that is selected must be an effective reef builder. The American and Pacific oysters are strong space competitors. When conditions are favorable, each species can establish dense populations and can potentially displace other oyster species. The Suminoe oyster tends to build relatively flatter profiles and does not appear to be as good a space competitor as either the American or Pacific oyster. The American oyster tends to become dormant in unfavorable conditions, such as low dissolved oxygen. In contrast, the Suminoe oyster continues to filter under similar conditions. Thus, the Suminoe oyster may be more susceptible to mortality from low dissolved oxygen conditions than the American oyster. Shell thickness is also a consideration, particularly where a species may encounter significant predation pressures, for example, from crabs. Faster growth may result in thinner shells. These factors need to be fully considered in selecting an appropriate species.

Oyster Reproduction and Growth

Oyster growth to maturity and reproduction are highly variable and are influenced by a number of factors. Reproduction is strongly associated with temperature and is also related to salinity. Predation (e.g. crabs, cow-nosed rays) is a constant threat throughout the water column, especially to larvae and young oysters. Field research and practical experience indicate that growth and mortality have strong linkages to hydrodynamics, that is, the flow of water. Other fundamental growth issues that are cross-linked with hydrodynamics include temperature, salinity, and availability of food. When structure is not available, the oysters are forced to live on the bottom where the stresses from low dissolved oxygen, sedimentation, turbidity, and salinity variations are the greatest. Under unfavorable conditions, the animals must expend more energy to survive, affecting growth rates and mortality.

Most species, such as the American and Pacific oyster, have both male and females, although oysters change sex one or more times during their life cycle. Fertilization of eggs takes place when eggs and sperm are ejected into the surrounding water. The fertilized eggs develop into a free swimming embryo that circulates primarily with the currents. This period lasts for several weeks to a month, depending upon the species. Other species such as the European oyster possess both male and female cells. Eggs are fertilized and

Figure 0 Oyster spat on shell. Photo: Wayne Young, *Maryland Environmental Service.*

larvae develop inside the oyster before being ejected. Once in the water, larval oysters are vulnerable to predation, changes in temperature, salinity, etc. A spat set then occurs - surviving oyster larvae settle on and attach themselves to almost any solid object below the surface. (The life stage at which oyster larva extend a foot, settle on and cement themselves to hard substrate, is referred to as “spat set”.)

Oysters in better growing conditions grow faster than oysters in less favorable conditions. There is a greater prospect for more rapid growth off the bottom rather than on the bottom or in the sediment. In general, oysters grow faster closer in moderate to higher flows where the water around the oyster changes multiple times each hour, sedimentation is the lowest, the quality of suspended food is highest, and dissolved oxygen is the greatest. These conditions are more prevalent off the bottom, and vary in different segments of the water column. Vertical structure as substrate helps mitigate the effects of sedimentation and is more likely to put oysters where water flows are greater off the bottom. However, higher locations also increase the potential for fouling of the substrate by other encrusting marine organisms that dwell near the surface.

Off-the-bottom growth rates for oysters set on Mini Bay Balls by the Chesapeake Bay Foundation and placed in Eastern Bay, a tributary to the upper Chesapeake Bay, were 2 to 3 inches in one year while oysters on the bottom in the region grow about 1 inch per year. The State Reef site that was used was in open water at the mouth of the bay with good water flow. Growth rates of 2 to 3 inches in 12 to 18 months has also been observed for off-the-bottom commercial oyster aquaculture in various locations including Maryland, Virginia, and Louisiana.

<u>Disease</u>

Disease is a significant threat to oysters worldwide. In order to prevent spread of infections, only disease-free seed oysters or disease free spat should be used in rehabilitation projects.

Parasitic diseases such as Dermo and MSX that plague the Chesapeake Bay and the American oyster, while not toxic to humans, can kill an oyster in higher salinity waters at about the time it grows to a harvestable size (approx. 2 - 4 years depending upon growth conditions). Other parasites, such as Bonamia (which has occurred as a few locations in Europe and one in North Carolina), can very quickly devastate oyster populations in high salinity conditions.

Oysters are susceptible to other diseases. They may also ingest other pathogens and toxics that are in the water. Although production of oysters for human consumption may not be a project objective, as may be the case with a rehabilitation project, selecting a site that has the least exposure to pathogens and toxics is important. This approach gives the oysters a better chance for survival, and also reduces the potential for illness to humans if oysters are taken and eaten.

There are indications that some form of relationship may exist to an undetermined extent between infection by parasitic diseases and water depth. For example, a few private and commercial interests in the upper Chesapeake Bay have successfully grown virtually disease free oysters in floating cages at the surface. Although the life history of the parasites is uncertain, successful cage farming at the surface while oysters located at the bottom in nearby locations become infected suggests that elevating oysters higher up in the water column while keeping them sub-tidal elevation may help mitigate against this threat. However, oysters growing near the surface reach harvestable size in one to two years, while dermo and MSX parasitic infections take on the order of three years before mortality begins to occur. However, faster growth at higher elevations might increase the potential for natural oyster recruitment and growth to equal or exceed losses from parasitic diseases, absent major losses from other factors, such as harvesting.

Predation

Predation occurs throughout the water column. For example, crabs love to eat spat. Project site selection should consider the potential for localized predation, and minimize this potential insofar as practicable. Projects should minimize proximity to high value crab habitat such as seagrass beds.

Oyster Propagation

Oyster propagation basics are fundamental to rehabilitation design. Oyster propagation is normally accomplished using one or a combination of natural reproduction or hatchery assisted propagation of oyster spat (i.e., oyster larva attached to shell or a shell fragment). Our experience to date indicates that setting spat directly onto Reef Balls in a hatchery followed by interim deployment to an in-water nursery area or attaching grown-out spat on shell to Reef Balls immediately prior to deployment increases the potential for growth and survival, and thus reef development. These practices also defend against the variability of natural propagation, especially in northern climates where reproduction occurs at a lower frequency, and oysters being outcompeted by other marine organisms.

Natural Propagation

Of the two basic approaches in using designed reef structures for oyster propagation, natural propagation is the less costly but the most susceptible to highly variable natural conditions at the most critical stages. However, up to full coverage of the structure is possible, depending upon the spat set. Because there is considerable uncertainty of success when relying on natural propagation, it is desirable for the project to include multiple objectives in order to provide a return on the rehabilitation investment. The oyster rehabilitation component can be either primary or secondary objective, appropriate to the project objectives and other circumstances. Projects in which oyster rehabilitation could be a secondary benefit include shoreline stabilization projects, fishing reefs, and use of reef structures as obstructions to unauthorized harvesting activity, for example, in an oyster sanctuary.

Reef substrate or structures are placed at suitable permitted locations to await a natural spat set. If a project reef is not within the larva circulation pattern of an existing healthy oyster population of sufficient size, then the probability of success for oyster rehabilitation purposes is greatly diminished. Natural propagation is further complicated by seasonal and annual variations in the most critical environmental conditions - water temperature and salinity, and by predation, substrate fouling by other marine organisms, sedimentation, and water quality. The result is that designed reef structures may not receive a spat set or may receive a light spat set, or the spat set may occur after the structure has been fouled by other marine organisms. Although a light spat set could be beneficial to the biological and reef structure value of the immediate reef structure, the contribution to oyster population rehabilitation objectives would be minimal at best, and potentially not self-sustaining.

Figure 0 Horn Point Oyster Hatchery shell bags containing oyster spat on shell and oyster spat on Reef Ball plugs. Photo: Wayne Young, *Maryland Environmental Service.*

Hatchery-Assisted Propagation

Hatchery techniques used with design reef structures include:

? Setting oyster spat directly onto small designed reef structures.

? Setting oyster spat directly onto small designed reef structures with shell fragments or shell embedded into outer layers.

? Setting oyster spat onto plugs for later attachment to a designed reef structure.

? Setting oyster spat onto shell in spat bags for later attachment to a designed reef structure.

Hatchery propagation involves simulation of natural conditions that induce oyster broodstock to spawn. Only disease-free broodstock should be used. Oyster larvae are released into large tanks where they settle on the substrate, typically spat bags full of oyster shell. The spat on shell is then taken from the tanks and placed temporarily into grow-out areas to gain size before deployment to an oyster bed or reef. Somewhat larger sizes makes the juvenile oysters less vulnerable to predation. The timing and duration of hatchery services including grow-out need to be factored into reef project development schedule.

Figure 0 Oyster spat on Reef Ball plugs and oyster shell. Photo: Wayne Young, *Maryland*

Under identical conditions with multiple tanks, spat set will vary by tank, who knows why. The substrate is removed and the spat set is manually counted as a baseline for future performance monitoring.   The substrate is removed from the hatchery tanks to an in-water nursery area or immediately transported for deployment. Although data are limited, grow out in a low wave energy protected location until the juvenile oysters are well established has yielded more favorable results than immediate deployment to reef site. The substrate with oysters attached is then deployed at the reef site.

If plugs or spat on shell are used, the material is attached to the designed reef structure using a non-toxic compound, typically an epoxy that cures underwater. This may be used as the primary method or to supplement spat set directly onto a reef structure. If the former, then only partial coverage of the structure is probable because the spaced not used is likely to be fouled by other marine species unless the structure receives a natural spat set shortly after deployment.   One project to date that used plugs indicated that coral plug adapters made from the concrete mix was marginal for oysters. Setting spat directly to the structures or to oyster shell (for later attachment to the structures) yielded a better result during the same field experiment. A difficulty with plugs was that some spat set on the sides, complication attachment. A plug composed largely of shell fragments might potentially achieve better spat sets, but this concept was not tested.

Shell can be added to Reef Balls in several ways to improve the surface for spat set at the hatchery (as well as for natural propagation). One technique is to use aggregate that already includes shell fragments, as is often the case in Florida. Another technique is to fold oyster shell fragments into the concrete mix along the sides of the mold as the concrete is being poured into the Reef Ball mold. Natural oyster shell is more durable than clam shell and is a better choice. However, only a portion of the shell fragments will occur at the exposed surface. A more time consuming but more reliable approach is to mold oyster shell onto the Reef Ball surface during construction. This can be accomplished by manually oyster shells against the side of the mold, with the interior of the shell facing outward against the interior of the mold. This technique relies on the rugged shape of the exterior side of the oyster shell to provide sufficient protrusions so as to anchor the shell in the concrete.

Figure 0 Bay Balls with embedded shell at oyster hatchery. Photo*: Sea Search of Virginia*.

An alternative method that reduces the potential for shell to dislodge is to manually attach an anchor point that protrudes from the backside of the shell into the concrete to insure a permanent attachment. This can be accomplished by attaching a Reef Ball coral plug adaptor to the natural exterior side of the oyster shell. The smaller diameter end of the coral plug adaptor can be attached to the shell using non-toxic marine epoxy. The shells are then manually placed in successive layers along the interior of the mold with the coral plug adaptor closest to the center of the mold. As the concrete is slowly poured in, it forms around the adaptor, making the attachment permanent. If a shell with spat were to fall off during transit, it can be reattached with non-toxic marine epoxy just prior to deployment at the reef site. Should a shell with spat fall off once deployed, the spat may still survive in its natural benthic habitat.

Physical Conditions

A fundamental question is whether or not a prospective rehabilitation site can actually support oyster growth. Site hydrodynamics linkages to the distribution of food and larvae, water quality oxygen, salinity, temperature, and sedimentation are important. For a site where harvesting may be allowed once oysters reach maturity, whether or not the site would produce oysters suitable for eating would also be an issue. For example, oysters may be able to survive in higher concentrations of pathogens and toxics than might be allowed for shellfish harvesting.

<u>Water Circulation - Distribution of Food and Larvae</u>

The circulation of water is a fundamental issue because oysters are in a fixed location, and completely dependent upon the currents to bring them food and circulate larvae. Assuming that continuing natural recruitment to a reef site is a project objective, the reef site must be in the distribution pattern for naturally produced larvae. Hydrodynamic and biological assessments are fundamental to determining whether or not this condition will exist. If not, then the investment in the reef might still produce nice fish habitat, but not a return on investment relative to restoring oyster populations. Considering the resources and time required for the necessary studies, designed reef structures with oyster rehabilitation as a primary objective should be correlated with existing studies and oyster rehabilitation activities to the maximum extent that is practicable.

<u>Water Depth</u>

In addition to water depth issues discussed earlier, oysters (and reef structures use for oyster rehabilitation) must be within the biological tide line for the selected species. Maintaining subtidal but off-the-bottom growing conditions appears to improve growth potential as discussed earlier, the fact that intertidal oyster species such as the American oyster can remain out of the water for one tidal cycle. However, when out of the water, the oysters clam up, so to speak. They obviously cannot filter feed under such conditions. Although subtidal oysters can survive being frozen while in the water, oysters freeze when exposed to subfreezing air temperatures, often resulting in mortality.

<u>Water Quality</u>

Oysters in large quantities in relation to the size of the water body can improve water quality. However, water quality must be good enough for oysters to survive and grow to maturity. The better the water quality, the lesser the stress on the oyster. If water quality at a proposed project site is toxic to oysters or could become so seasonally, then the project site, or lower portions of the water column in the case of low dissolved oxygen levels, may not be suitable for some or all species.

Salinity Range

The salinity in an estuary varies seasonally and annually, depending upon the inflow of fresh water from rivers, streams, and surrounding land masses. The multi-year salinity range at the project site must be within the salinity tolerances of the selected oyster species.

Oyster growth and reproduction are related to salinity and each other, as well as to temperature. Spat sets will vary from none to heavy, depending upon the correlation of these conditions with oyster biology. This is critically important when relying on a natural spat set to colonize a structure. If a spat set does not occur while the structure is fresh, it will become fouled by other marine organisms and most likely preclude future oyster recruitment.

Oysters reproduce when certain salinity thresholds are crossed, either up or down, depending upon the species. For example, the American and Suminoe oyster require approximately the same conditions for spawning. However, on a relative scale, the American oyster requires an increase above a salinity threshold whereas the Suminoe oyster requires a decrease below a similar threshold. When the Suminoe oyster is in higher salinity water, it does not reproduce. All energy is directed to growth, resulting in accelerated growth. In contrast, the American oyster grows slower in less saline waters but requires more salty conditions for reproduction where it is more susceptible to parasitic diseases which also need more salty conditions.

Water Temperature

Oyster growth and reproduction are related to temperature. The temperature range at the project site must be within the temperature tolerances of the oyster species that is selected. The temperatures are which oyster reproduce varies by species. In general, northern species spawn at somewhat lower temperatures than southern oyster species.

Although feeding habitats vary by species, oysters are more active in warmer water. Thus, oysters would be expected to grow at faster rates in warmer waters, all other factors being equal. This affects the time required for reef development, and needs to be considering in establishing project monitoring and evaluation criteria.

Vertical Structure

When structure is not available, oysters live at the bottom where the stresses from low dissolved oxygen, sedimentation, turbidity, and salinity variations are the greatest. In some areas such as the Chesapeake Bay, natural structure may not be present or greatly diminished relative to historical conditions. Structural characteristics of historic oyster reefs, sometimes referred to as “oyster rock,” may have been reduced or removed through harvesting methods. For example, much of the oyster reefs in the Chesapeake Bay were virtually leveled by mechanical harvesting over a hundred years ago. Or, effects of storm waves or tsunamis may have displaced or covered natural structure.

Reef structures should be not only get oysters off the bottom and into the water flow, but also provide sufficient vertical elevation to provide many years of use relative to sedimentation rates. Reef elevation also needs to specifically address overhead clearances to avoid becoming an obstruction to navigation, unless lesser overhead depths are capable of being permitted. In the latter case, obstruction markers will be normally be required as a permit condition.

Sedimentation

Site selection must minimize the potential for reef structures to be buried through the accretion of sediment. Locations selected for oyster reefs should have low sedimentation rates or alternately, sedimentation rates that do not exceed the rate of natural increase in elevation through oyster growth and recruitment of spat to the reef structure. An exception is beach stabilization structures where accretion of areas shoreward of the reef is usually a project objective. In this case, rehabilitation of oyster habitat would necessarily be a secondary objective with shoreline or beach stabilization taking precedence. Survival of oysters on such reefs depends on whether or not the oysters get buried. Setting spat directly to reef modules in a hatchery for use at a shoreline stabilization project is not recommended if sediment accretion is expected. If spat are to be attached to the reef structures, then the shell or other substrate to which the spat is attached should, in general, be placed on the upper portions of the reef structure and on those that are farthest away from the shoreline where the water would normally be the deepest.

Substrate

Oyster larvae have a strong preference for oyster shell as substrate, although they will attach to almost any hard substrate. Oyster shell generally provides consistent results in hatcheries. Where oyster shell has not been available or not available in sufficient quantity or is too expensive, alternative materials have been used as a foundation for reefs for either natural spat set or deployment of spat on shell, and as substrate for hatchery operations. Options include natural material (e.g., clam shell, conch shell, granite, limestone marl), demolition materials (e.g. weathered concrete rubble free of other debris), and industrial byproducts (e.g., slag with limestone content), and manufactured materials (e.g. tiles).

When using designed reef structures as substrate, bottom conditions must be capable of supporting the structure. If bottom conditions are not favorable, it may be possible to establish a foundation using shell, weathered concrete rubble, or other suitable materials. In view of the costs involved, the suggested approach for small-scale projects is to only use sites that are suitable without modification, or to piggyback the reef structure with another project that establishes a suitable foundation.

Designed reef structure should be cured to their applicable technical specifications prior to deployment. Weathering ashore exposed to the elements for a few months prior to deployment can help "season" the surface and allows further curing to build additional strength. Additional in-water seasoning for a short period, on the order of a few weeks, allows interaction between the surface and ambient conditions, making it appear more natural to oyster larvae. In any case, the modules need to be deployed just prior to the projected start of annual oyster spawning in order to have the best chance of catching a natural spat set while lessening the potential for biofouling by other marine species.

Surface Texture

A very rough surface is highly desirable. Nooks, crannies, and crevices provide both attachment points and cover for oyster larvae. Oysters have also been observed on smooth sided artificial reef structures. In one location in Maryland's Eastern Bay, unusually formed American oysters were observed on smooth-sided reef structures. Uniquely, the oysters were relative flat and one sided; they used the smooth side of the structure as part of their enclosure. Thus, the animal would be killed if it were removed. It is not known whether or not this was a one-time phenomenon. However, it is known that the American oyster performs well in the presence of highly variable surface conditions.

Figure 0 Baseline counting of spat set onto Bay Ball at Horn Point Oyster Hatchery prior to placement in grow-out nursery. Photo: Wayne Young, *Maryland Environmental Service*.

Reef Horizontal Configuration

The importance of reef horizontal configuration relative to the oyster life cycle is uncertain. Reef configuration is related to hydrodynamic conditions. When project objectives include rehabilitation of reef structure, attempting to place structures so as to resemble natural formations and associated hydrodynamic effects and circulation patterns is a logical approach – if the number of modules and foundation conditions are sufficient. Local area data may be available to assist with determining historical reef configurations. If not, then configuring the structures somewhat across the predominant line of flow could increase mixing of the water around the structures, improving distribution of food and potentially increasing dissolved oxygen.

Deployment

Deployment of spat and reef structures with set or attached spat must be carefully planned and must be within the oyster species biological

Figure 0 Maryland Environmental Service volunteers attaching plugs with oyster spat to Bay Balls just prior to placement on Memorial Reef. Photo: Wayne

tolerances. The capability of oysters to remain out of the water for one tidal cycle is critically important to transporting and deploying oyster spat and oyster stock to beds and reefs. This is a time consuming process, the duration of which depends upon distance to the oyster bed or reef, vessel transit speeds and deployment capabilities, and other transportation factors. However, it may be possible to "push" the time oysters can remain out of the water by keeping them wet using water drawn from the estuary. It is also important to keep the oysters from being "cooked" while they or structures with oysters attached are on deck. For example, a tarp could be placed above, but not on, the reef structures or oyster spat, thereby shading the animals but allowing air circulation.

If oyster spat on shell or other suitable substrate is going to be manually attached to reef structures, this should be done just prior to structure placement in the water in order to minimize the potential for mortality on the structures surface, for example, from heating by the Sun. Spat on shell can be attached using non-toxic marine epoxy that cures underwater. For Reef Balls, the shells with spat can be attached to tops of the modules around the center holes as well as the bottom half of the side holes. Smaller shells with spat can be attached to the upper third to half of the Reef Ball surface. Attachment below the middle of the Reef Ball is more susceptible to falling off before the epoxy cures sufficiently to hold the shell permanently in plan.

Figure 0 Tom Humbles and Brandon Ghrist, Maryland Environmental Service, checking bottom profile of Bay Balls on Memorial Oyster Reef. Wayne Young, *Maryland Environmental Service*.

The designed reef structures should be moved gently and placed on the bottom so as to minimize the risk of damage to the modules and attached spat. When using marine heavy lifts, recognize that this approach is dangerous. Qualified personnel and all appropriate safety precautions should be used to protect individuals, equipment, designed reef structures, and attached animals. Fabric lifting straps with adequate rated lifting capacity, preferably with integrated chafing protection, work very well for lifting and deploying Reef Balls and minimize the potential for damage. Marine hooks of sufficient rated capacity with manually controlled or automatic bottom release capability have also worked very well for Reef Ball deployment. Other equipment, lifting slings, and hooks have been used successfully by qualified marine personnel.

Floating deployment may also be an option in some locations. The technique is the same that as applied for deploying Reef Balls for coral reef rehabilitation.

Monitoring

All projects should include environmental monitoring to ascertain performance relative to project specifications and objectives. This is appropriate not only to assess performance, but also to gain lessons learned and to develop data to support planning of subsequent projects. Monitoring should establish a baseline condition of deployed structures as well as initial reef profiles. Subsequent monitoring should determine and assess reef biological performance. Underwater photography using divers or photographic equipment deployed from the surface have been used effectively. Bay Balls and Mini Bay Balls at several locations in the upper Chesapeake Bay were lifted from the bottom for inspection on deck where close inspection.

Figure 0 Maryland Environmental Service - Chesapeake Bay Foundation Hollicutts Noose oyster restoration field experiment. Photos: top and middle, Wayne Young. Bottom – Rich Takacs, *National Oceanic and Atmospheric Administration*.

References

A substantial body of literature exists for oyster cultivation and rehabilitation. Oyster information can be readily accessed through the worldwide web. U.S. Government sources include NOAA's Aquaculture Information Center. Suggested keywords include: oyster; oyster aquaculture, beds, farming, parasites, predation, propagation, reefs, rehabilitation; American oyster, Asian oyster, European oyster, Pacific oyster, Suminoe oyster; *Crassostrea virginica*, *Crassostrea ariakensis*, *Crassostrea gigas*, *Ostrea edulis*; dermo, MSX.

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Appendix C: Glossary of Reef Ball Coral Team Terms

Acropora: A genus of fast growing hard corals that require the highest level of quality standards to be successfully planted. Includes threatened Elkhorn and Staghorn coral in the Caribbean. The Pacific contains a wide variety of Acropora species including the spectacular tabletop corals. They are one of the most desirable corals for propagation and planting due to rapid growth characteristics and classic "reef look" but usually are one of the most sensitive to poor water quality. There are notable exceptions such as *Acropora arabensis*, in the Arabian Gulf, that can handle variable sedimentation and turbidity and a wide range of temperatures.

Adva Flow: Brand name of a high range water reducer and plasticizer. Manufactured by W. R. Grace and Company [http://www.grace.com] and added to cement to make it more liquid without adding water because too much water makes concrete weak. This admixture is required in the plug cement so that the concrete forms a perfect seal around the coral fragment to prevent bottom to top infections and dislodging of the fragment. It is also used in artificial reef module construction to help improve the pH and other concrete characteristics.

Antibacterial Soap: RBF Coral Team participants must wash their hands between each unique coral colony they touch with an antibacterial soap. However, not all sites have fresh water facilities to get a clean rinse so team members often use surgery rated products that offer a clean rinse. An example is LAGASSE, INC.'s "Antibacterial Lotion Soap" which contains 0.3% Chloroxylenol (PCMX), a broad-spectrum degerming agent and offers gentle cleansing with a clean rinse.

Alcohol-based or waterless hand cleaners can also be used, but they don't work well to remove some coral slimes, particularly oily type slimes. Generally they can be used between handling different colonies of the same species but it is best to use a soap based product when changing species types.

Antiseptic Dip (aka RBF Coral Antiseptic Dip): To reduce *rapid tissue necrosis* and other bacterial infections that can occur due to the *fragging* wound, hard coral specimens or fragments are dipped in an iodine based antiseptic solution immediately before being placed into *coral plugs.* RBF uses veterinary strength iodine commonly referred to as "Lugol's solution" and we repack this into user quantities and provide it to clients as "RBF Antiseptic Dip"in our coral kits. It is possible to use over the counter strengths but the amount of iodine needed may change the salinity of the dip, which must then be adjusted with artificial sea salt (available at any marine aquarium store) to match ambient seawater. Doing so will require a *hydrometer* or *refractometer.* Do not use fresh water to mix RBF Antiseptic Dip or any other iodine solution for coral. RBF Antiseptic Dip must be diluted using fresh seawater (or if possible, freshly made artificial sea water adjusted to the exact salinity of the sea where you are working, which has a longer working life). The standard dilution rate is 25ml iodine per liter of water (1 teaspoon per 8 ounces), although the solution can be made slightly weaker for slow growing corals such as brain or star corals, and slightly stronger for fast growing corals such as branching or finger corals. Additionally the dip solution must be kept at the same temperature as the sea, and it may need to be buffered to the same pH as the natural seawater, especially if maintained longer than an hour or two. For this reason, if resources permit, it is best to discard and replace the antiseptic dip frequently.

If the fragment has been handled properly and the only injury is the fragmentation cut, then only that part of the coral fragment needs to be exposed to the dip, however if other injury is suspected, dip the whole fragment. Dipping time should be about 1 second to allow the iodine to penetrate into the coral skeleton. Proper treatment will stain the white skeleton to a slightly yellow color. If a yellow color does not show up after dipping, it is possible the coral have been over handled and the protective slime coating from handling has migrated over the exposed skeleton. If this is observed, advise all coral handlers to reduce the coral stress levels before proceeding. Ideally, coral should be exposed to air only one time during the entire process (when they are *set* into the rapid setting *coral plug cement*). Often, over-slimed coral can be traced to careless fragmenting, a procedure that must be carried out delicately to reduce coral stress.

User notes:

Note 1: Fire coral (*Millepora* spp.) and soft coral species should not be dipped in iodine solutions. To test compatibility with iodine solutions, create one set of test plugs dipped and a second set without dipping and monitor the results. Ill effects from iodine usually appear within 72 hours. Many coral propagation tables have been run successfully without antiseptic dips. If your procedures are very consistent and *rapid tissue necrosis* (RTN) is not showing up in your plugs, it is perfectly acceptable to skip this treatment. (Except for *Acropora* spp. where a dip should always be performed).

Note 2: There are a variety of commercial antiseptic dips available to the marine aquarium trade. Presumably these are safe, and possibly effective but some of these products that are so diluted as to require long dipping times which are not practical for coral propagation table activities, and will overly stress fragmented coral. If used, follow the instructions from the manufacturer exactly. Do not use iodine solutions that also contain soap or detergents.

Note 3: The Coral Team has experimented with some antibiotics (amoxcillin, ceprofloxin and erythromycin), and in our tests they seemed to cause more harm than good. While this technique may, in the future, be refined to the point where it is safe and effective, at this point we don't recommend antibiotic treatments for coral.

Note 4: There is recent science on microbial-coral interactions and new insights may help researchers to understand why the iodine solution is beneficial during coral fragmentation [*"Microbial landscapes on the outer tissue surfaces of the reef-building coral"*, Johnston and Rohwer 2007]

Aquascaping: The act of adding various members of the fouling community to a new base substrate with the objective of making it look more natural. *Aquascaping* can include coral, algae, sponges, attachment of live rock, anemones, etc. At the most sophisticated levels, it may include addition of particular species to benefit the development of the coral reef community such as adding sea urchins (*Diadema antillarum* or *Echinoidea spp.*). The term *aquascaping* was originally used in reference to aquarists arranging rocks and corals in marine reef aquariums and is applied here to base substrate enhancement. Many Coral Teams will send in specific aquascaping teams after all coral have been planted to provide the finishing touch to the rehabilitation process when aesthetics are an important project goal.

Base or Basing: Certain coral species (referred to as "basing coral") have a special 'survival mode' when injured or dislodged from the substrate. This mode directs all the energy of the colony to downward growth and re-attachment to the reef substrate. This means the coral will abandon upward growth and will actually remove calcium from its skeleton to redeposit it at the base to re-attach itself to the substrate. In time lapse photography, a fragment will appear to melt into the substrate losing height but gaining a foothold. The process can take place very quickly…usually within 6 weeks and the process can be seen in some species in as little as 24 hours. After basing, many corals will go into a brief rest mode before resuming upward growth. It is extremely important to encourage this process when planting fragments. If a good foothold is not developed immediately after propagation, the entire colony can break off in a storm, or even under the force of its own weight. Proper basing allows a colony to develop its own attachment to the artificial reef substrate. This means the colony does not have to rely on the coral epoxy putty to hold it.

User note: When working with non-basing coral, the attachment method must be strong enough to hold the adult coral colony permanently because the coral will not be able to further attach itself to the reef as it grows.

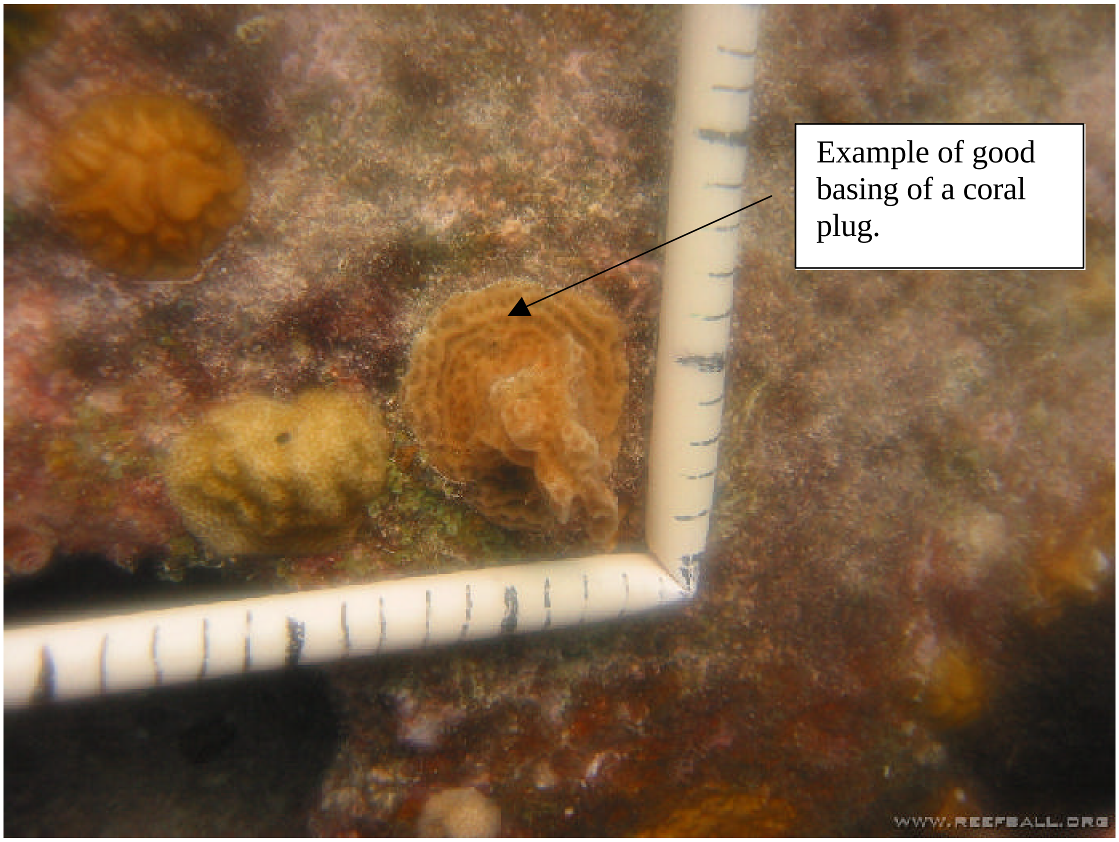


Figure G1: When properly planted, a propagated coral colony will invest much of its energy for the first few weeks to months in the process of basing- establishing a strong reattachment point by redistributing calcium carbonate to its base

Encouragement of basing is accomplished in several ways. When planting into the fast setting plug cement, the cement will injure the colony at the base, which will stimulate basing formation (see Figure G 1).

Additionally, providing fresh artificial substrate without a competing *fouling community* further promotes basing. When placing a basing type coral into the plug mold, it is important that the fragment is placed sideways, not upright as one would intuitively think. This helps to provide a larger contact area for basing and helps to signal the colony that it has been dislodged and needs to go into basing mode. This is one of the biggest errors we have seen in coral planting projects because: 1) Basing is not an issue in marine aquariums because colonies do not grow large enough or exposed to storm wave conditions, 2) Field work is often not monitored long enough to reveal this issue. (It took over 4 years of monitoring in Curacao before we could see the results of improper basing).

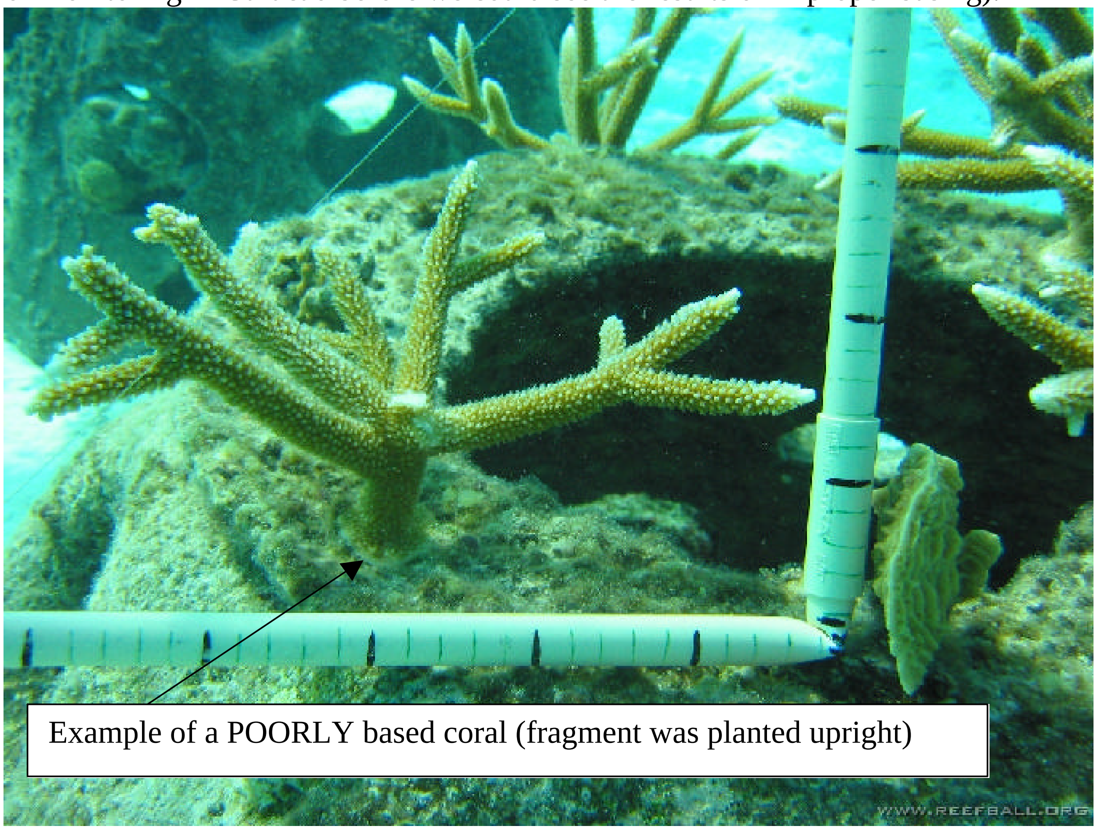


Figure G2: Basing coral species such as Acropora cervicornis (shown) should be planted horizontally, not vertically, in order to provide the largest surface area for basing.

Battery Cleaning Brush or Plug Hole Wire Brush: A small wire brush used to clean the inside of a coral adapter plug hole if the artificial reef module has been deployed more than a few days before planting a plug.

Figure G3: Plug Hole Wire Brush

Beer's Law: A mathematical formula relating the amount of light at depth to the light at the surface by means of an exponential decay. This formula, combined with a *secchi disk* reading, can generate an approximation of the amount of light reaching a given depth, if a surface light meter is available, or the fraction of surface light reaching a given depth if no light meter is available.

"In essence...Beer's Law...states that there is a logarithmic dependence between the transmission of light through a substance and the concentration of the substance, and also between the transmission and the length of material that the light travels through." [Source Wikipedia. Calculation formula can be found at http://en.wikipedia.org/wiki/Beer-Lambert_law]

Biological Bottleneck: Many ecosystems cannot reach their full biological carrying capacity because survival of one or more important species is reduced at a critical point in the organism's life cycle. Compare the population of a species of fish to water flowing through a pipe with several valves representing survival through each stage of the life cycle. In order for the water to flow at full speed, all of the valves must be open. If one valve closes halfway, the flow at subsequent stages will be reduced, even if those valves are open. Similarly, a shortage of juvenile fish habitat may limit the number of adult reef fish even if there is enough food and habitat to support a larger number of adults. For this reason, damage to shallow water reefs, seagrass beds, and mangrove estuaries, areas critical to the development of many reef fish species, can prevent even 'healthy' coral reefs from reaching their full potential. This is a complex subject, and the focus of much scientific research, but it is important to understand that rehabilitation efforts should be focused to aid in bottleneck elimination if possible, to greatly magnify the positive effects of project resources.

Black Light: Black light, a combination of blue and UV frequencies, can be used to detect coral phosphorescence, which can help to identify a coral species or detect newly settled coral that are not obvious to the naked eye. This is the same black light used to make posters glow or to show urine or blood stains on carpets/crime scenes.

Bolt Cutters: Bolt cutters are used to fragment thick coral such as elkhorn or pillar coral, and for extracting propagation 'tears' from brain coral.

Figure G4: Bolt Cutters

Bone Breaker: A tool used by surgeons to cut bone during surgery that is used in the *fragging* process. It is particularly well adapted to the thicker trunks of finger coral.

Figure G5: 'Bone Breaker' shears are a common fragmentation tool for medium to thin corals such as branching or finger corals.

Broodstock: In aquaculture, a *broodstock* is a group of sexually mature individuals of a species kept separately and used for breeding purposes. For the Coral Team, we define it more loosely to refer both to the *imperiled* coral that we intend on rescuing and the cache of *imperiled* coral in the *fragmentation nursery* waiting to be processed and replanted.

Copepods: Tiny marine crustaceans, found in high abundance throughout all of the world's seas and oceans. Copepods are a type of *Zooplankton* and represent a critical stage in the marine food web.

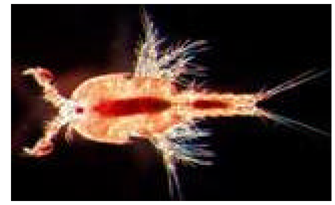


Figure G6: Adult copepod

Coral Core Plugs*:* Coral fragments made by removing a core from a colony with a hollow drill bit. *Coral Core Plugs* are designed for direct planting into a *coral plug hole.* This method is typically used for massive corals including star and boulder corals. This is an advanced technique and not normally used in grassroots projects. Results have been mixed depending on coral species [*Spieler / Quinn, 2003, Memphis Project]*

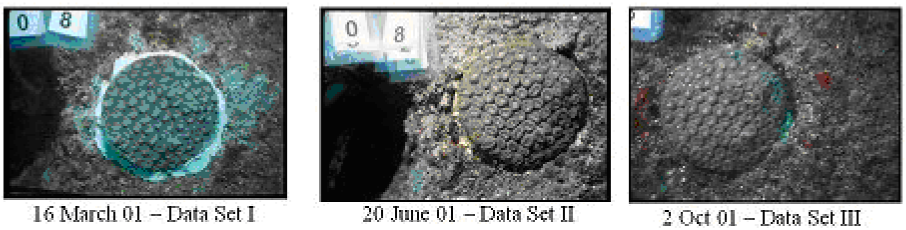


Figure G7: A Coral Core Plug of Montastrea cavernosa transplanted into artificial base substrate. From left to right, immediately, three, and six months post transplant.

Coral Disaster Response Kit: A set of all the molds, tools, equipment and non-perishable supplies required to rapidly mobilize a trained *Coral Team* on a rescue project in response to coral damage.

Coral Diseases: There are a number of specialized websites that provide information on coral diseases and bleaching such as
http://www.coral.noaa.gov/coral_disease/cdhc.shtml
http://www.unep-wcmc.org/marine/coraldis/cd/types.htm

Coral Team participants should familiarize themselves with all common diseases and bleaching from a visual identification perspective. Simply stated, grassroots efforts should not attempt to touch or work with diseased coral in any way. Treatment for coral disease requires exact identification of the pathogen and specialized treatment knowledge. However, it is usually easy to visually distinguish between a healthy and a diseased colony. Any sign of stress, such as bleaching, means that fragmentation success is less likely and any sign of disease could mean fragmentation procedures could contaminate additional coral. Although many divers are tempted to "help" a diseased coral…they will likely do more harm than good in trying.

Coral Epoxy Putty: See epoxy putty

Coral Genetics: *Propagation* is a form of asexual reproduction or "genetic cloning." Because propagation creates genetically identical colonies, it presents unique opportunities for coral reef rehabilitation efforts. For example, when a disaster leaves thousands of adult colonies in peril, taking and replanting just a few fragments from each adult colony can preserve the coral genetics of the entire imperiled coral reef.

Other unique opportunities include cloning of coral colonies that appear to have a better resistance to heat stress, sedimentation, disease, predators or other threats. The cloning of these resistant colonies might be an important future tool to improve coral adaptability

Additionally, it is now possible to use propagation technology to create genetic coral banks; reserves of propagated coral maintained in an area apart from the original reef so that if disaster strikes, a replanting could take place using coral genetically identical to the lost coral, in a similar fashion to human blood banks.

It is becoming increasingly clear that coral reefs will have to face changes in their environments. It is unclear if they can adapt genetically fast enough to cope. However, we believe that science might find a way to identify coral colonies with traits that will allow them to survive. Propagation offers technology to multiply such individual coral quickly.

Propagation and planting has another significant advantage for reef rehabilitation in that specific corals can be positioned where they will be more likely to have reproductive success. Success can be increased both by increasing the number of viable coral spawn, and by rehabilitating corals in locations most likely to transport larval coral to areas suitable for settlement and growth.

The Reef Ball Foundation is constantly adapting its methods and procedures as coral scientists formulate new research results to help achieve these goals.

Corallivorous: Referring to a functional group of predators who feed primarily or exclusively on corals. While a certain amount of coral predation is natural, *coral predators* pose particular risk to freshly transplanted corals, and as such, steps should be taken to minimize their impact on a coral planting project.

Coral Mass Spawn: See Mass Spawn

Coral Plug Adapter: A standardized size device placed into the artificial base substrate mold which can be removed after casting, and leaves behind a depression referred to as a *Coral Plug Hole* which is the size and shape to receive standardized *Coral Plugs*- small discs of cement with a coral colony attached. The standardized size is created with #8 sized rubber stoppers both set into the side of the artificial reef module molds and/or placed on the top of poured base substrates while the concrete is still wet. #8 rubber stoppers create a hole size that fits into coral plugs molded from widely available 30 ml plastic medicine cups.

User note: Do not use marine aquarium fragment plugs (available from aquarium industry aquaculturalists) if they have ever been placed in captivity (an aquarium) for wild plantings (planting in the ocean). This is due to the possible introduction of invasive species or disease. Captive breed corals are equally unsuitable for wild planting.

FIG G8: Coral Plug Adapter

Coral Plug Hole: Any hole drilled or created into the base substrate for the purpose of attaching of a coral fragment or colony by means of a *Coral Plug* or direct *fragment* planting . These range from pencil or smaller sized holes for soft corals attached with *coral epoxy putty*, to medicine cup sized indentions for standardized coral fragment plugs or even larger holes for direct *coral core plugs*. Custom sized plug receptacles are used for specific situations and coral types.

Figure G9: Coral Plug Holes made from coral plug adapters on the sides and tops of Reef Balls awaiting deployment.

Coral Plug Mold: A mold or form from which *coral plugs* can be cast with 30 second quick setting cement. RBF uses standard 30 ml sized medicine cups with a small hole punched or drilled in the bottom (to prevent a vacuum when demolding the plug from the mold), 1/3rd full of sand to make the *coral plug* fit exactly into the *coral plug adapter* hole. .

FIG G10: Coral Plug Mold picture!!

Coral Polyp: The soft fleshy part of a coral that extends out of the limestone cup or coral skeleton. Viewed closely, they may appear as "hair" or tiny flowers on the coral. Divers and snorkelers should never touch or handle a coral unless absolutely necessary. If it is necessary to handle a coral it is very important to make sure all of the polyps have retracted into their skeleton before touching the coral. This can be accomplished by gently fan above the surface of the coral with your hand without actually touching the coral.

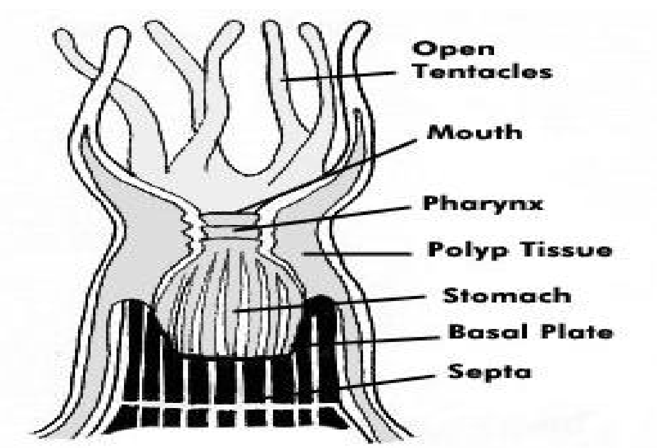


Figure G11: Anatomy of a coral polyp. Coral polyps are extremely fragile, and can easily be killed if touched. When threatened, they retreat into their limestone skeleton for safety. [Source: Marine Reef International, www.marinereef.org*]*

Coral Predators: A major threat to the health of propagated or transplanted corals during the first 90 days after planting is death or stress from coral predators. After transplanting, corals are stressed and weak. This makes them more susceptible to predation, and furthermore, the presence of predators can cause corals to stress further, and even die without necessarily being directly consumed. For this reason, it is particularly important to plant corals on fresh substrate to reduce the impact of *coral predators* and give the newly transplanted corals time to stabilize before having to compete. New substrate does not offer a mature *fouling community* offering them a place to shelter so coral preditors cannot easily move across the smooth new surfaces of fresh base substrate without encountering predators of their own. Some examples of coral predators include parrot fish, crown-of-thorn starfish, corallivorous nudibranchs, corallivorous snails, corallivorous crustaceans (like Acropora red bugs) and corallivorous worms such as fireworms.

There are several defensive strategies to reduce threats:
1) Plant coral on newly laid artificial reef substrate, or freshly exposed hard bottom. This will help to eliminate nudibranchs, snails, crustaceans and worms present in the *fouling community* and will deter movements of crown-of-thorns looking for dense coral cover.

Figure G12: Infestation of coral colony by corallivorous nudibranch. [Source: Walch/Barber, 2000, Malaysia Coral Aquaculture Project]

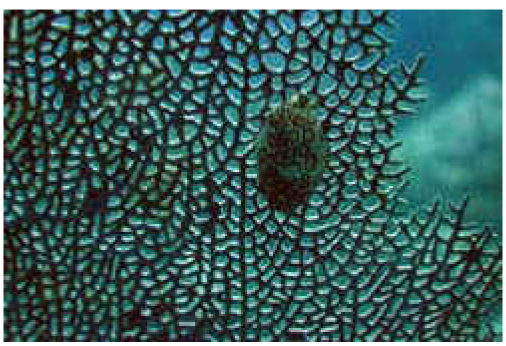


Figure G13:Flamingo Tongue (Cyphoma gibbosum) on sea fan

2) Process fragments as rapidly as possible to reduce stress. Reef Ball Foundation no longer uses propagation methods in holding tanks and now uses open water based processing techniques to allow coral to be rescued and replanted within a few hours and to eliminate the stress of captivity. Our monitoring indicated this was a major factor in decreasing coral fragment mortality in sensitive species.

3) While we do not recommend manipulation of an ecosystem for the sole purpose of increasing the survival rate of propagated corals, we do recommend that if crown-of-thorns starfish (*Acanthaster planci*) which are present near your planting site, they be destroyed by injection with sodium bisulphate (also called Dry Acid).

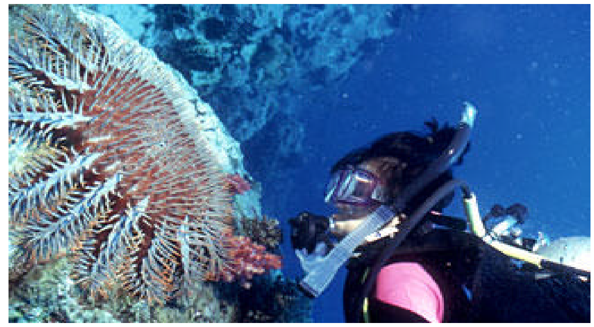


Figure G14: Crown of Thorns starfish (Acanthaster planci). This sea star is a voracious coral predator, and is one of few organisms that RBF condones destroying if present on a rehabilitation site.

We recommend this method because it is biodegradable and does not affect other plants and animals on the reef and there is evidence that Crown of Thorn populations have increased in the wild because of human activities. The chemical is applied by direct injection into the central tissues of the crown-of-thorns starfish. Try to eliminate all starfish within 100 meters of your project area. Use a long hypodermic needle because the spines of crown-of-thorn starfish are extremely painful if you bump into them.

Note: The RBF board of directors debated extensively on this topic after carefully reviewing literature and recommendations from Australian scientists and managers. We arrived at the policy we have chosen based on the likelihood that human impact on marine systems has dramatically increased the abundance of *A. planci*, and if left unchecked, *A. planci* poses a significant threat to coral reefs. If you feel strongly against the destruction of these animals, relocation is an option, but use extreme caution because their spines can cause a painful injury.

Some cushion stars and sea stars may also prey on coral fragments. These just need to be relocated to other areas (spread them out) and not killed since they rarely get to high population levels, unlike crown-of-thorns starfish.

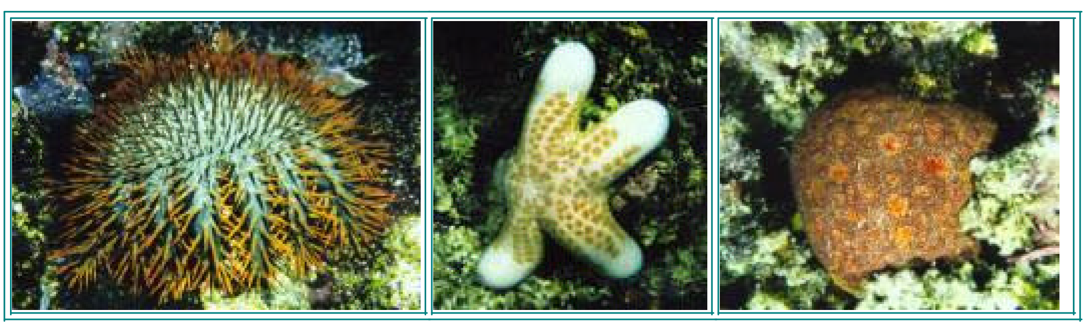


Figure G15: Some species of sea stars such as cushion stars and other sea stars can prey on coral. If present, we recommend moving these species away from the project rehabilitation site, but do not generally condone their destruction.

Parrot fish may nip, but usually do not wipe out fragments that have been handled stress free. If parrot fish populations are very high it is possible to build a temporary protective cage out of chicken wire. We rarely use this technique except for certain very delicate *Acropora* species, particularly high color varieties in the Pacific. In this case make sure to remove the protective cage once the coral's base has completely formed and upward growth has resumed.

Coral Propagation Table:

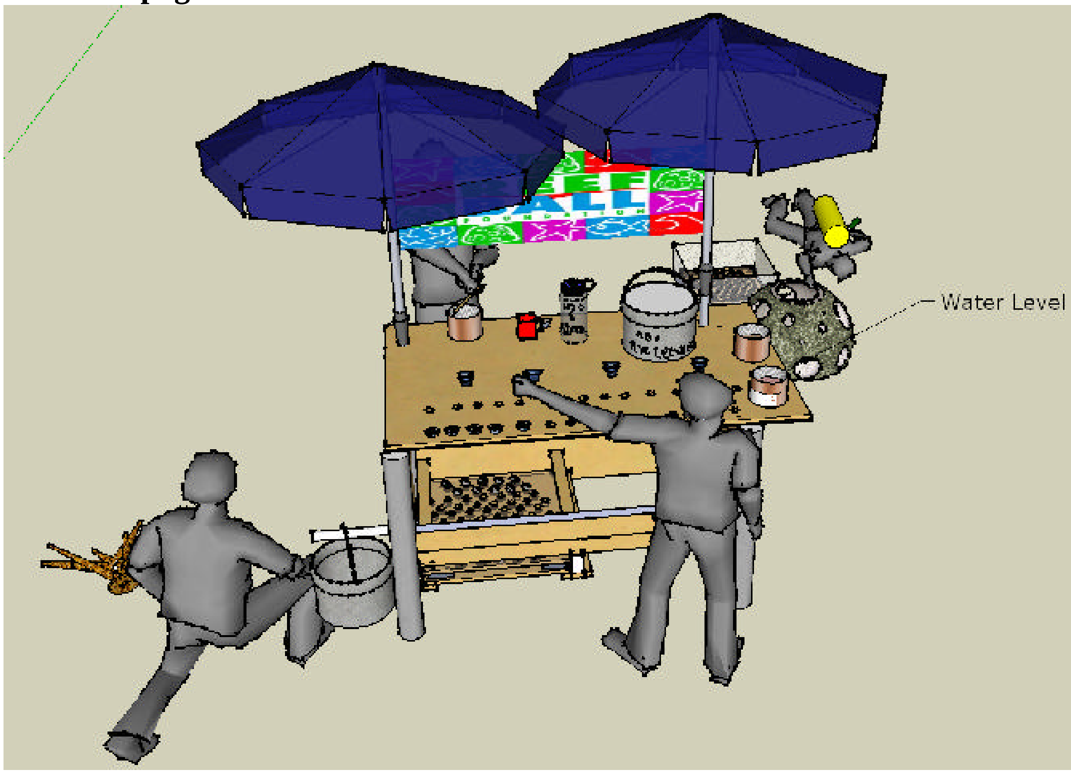
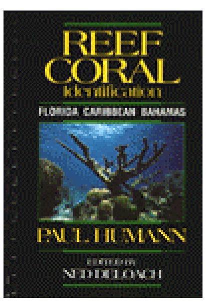
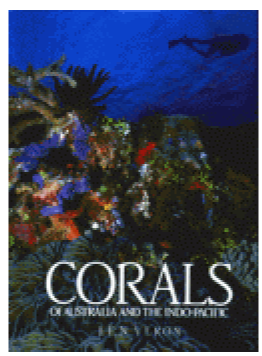


Figure G16: Beach based coral table (available in Sketch-Up™). Table must be underwater to the point where the coral planting tray is under water at all times, and protected from heavy surge. Umbrellas shade the entire table from sunlight. Coral table workers from left to right, 'wet hands' (kneeling), table boss (behind table), dry hands.

RBF uses two types of coral propagation tables depending on the situation; a beach-based table (Figure G16) or floating platform (Figure G17) is used for *fragging*, *plugging* and *plug curing.* A complete 3-D engineering plan can be obtained without cost by downloading Google's free Sketch-Up™utility. For both designs, an umbrella or tarp is necessary to shield coral fragments (and Coral Team members!!) from *sunburn*. Careful attention should be made to ensure that the table is stable in waves. We have made a wide variety of variations of the coral propagation table to accommodate individual project needs. It is important to consider the number of coral propagations you plan to accomplish, the conditions at the work site, and the number of people that will be working before designing your table. A good table increases the comfort level for team members and makes higher volume production easier, but it can take longer to build and is usually more expensive. A small table workspace can be made just about anywhere, but may be uncomfortable and slow for production. If you are just demonstrating the technology for a school, that might be sufficient. If you plan to do tens of thousand of plugs, make the table as comfortable and convenient as possible. If you can spend a few extra hours building the table and reduce the time it takes you to make each plug by even a few seconds, you'll gain two entire work days!

Figure G17: Floating coral table. Floating tables are ideal for use in most low energy locations, are more comfortable for the table workers, and automatically adjust for factors such as tides. If resources and conditions permit, consider the construction of a floating table.





Coral Reference Books: The Coral Team uses Reef Coral Identification by Paul Humann and Ned Deloach as a standard reference for the Caribbean and Corals of Australia and the Indo-Pacific by J.E.N. Veron for the Pacific. Other guides can be used, we have simply found these to be readily available, easy to use, and at the appropriate level of detail. It is always best to supplement a general guide like these with more specific local guides.

Coral Team: A group of volunteers and experts from around the world who agree to adhere to RBF coral propagation and planting ethics. Teams are organized on project-by-project basis from over 200 active Coral Team members, and the team adds new members on almost every project. Members of the *Coral Team* travel to project sites to complete each coral propagation and planting project. Every project team contains at least one Level 5 certified RBF Team Member who functions as a team leader. Other members of the team include local people who have initiated the project, and international experts or trained volunteers. Anyone may participate on a Coral Team project and become eligible for certification. Nearly all team members should be SCUBA certified, although it is not a requirement for participation. There are 5 specialty fields and 5 levels of certification within each field (for a detailed breakdown of the RBF certification levels, see Appendix A).

Coral Team Activation: Whenever a project is required (often on short notice after disasters), all RBF Coral Team members are notified by a posting to the Reef Ball Foundation myspace.com group bulletin posting. Additionally, Coral Team leaders often contact members with specific skill sets relevant to the project. Coral Team members maintain a Coral Team Member resume on file with the Foundation to help team leaders identify the best members for a project. The project sponsor has the option of offering incentives in the form of compensation, daily stipends, accommodations, meals, etc. to attract top experts to apply for positions on the project. Usually, the most economical choice is a mixture of a few paid experts and some less skilled volunteers. Coral Team Leaders are always paid for their work, but for certain eligible projects the Reef Ball Foundation will cover this cost. If quality or speed is at a premium, and resources permit, a project sponsor can specify a minimum certification level before participation is allowed.

Coral Tool Kit: An orange colored tool kit that contains items such as fragmentation tools (bone cutter, wire cutter, wire stripper, bolt cutter, hack saw, etc.) , latex gloves, RBF Coral Antiseptic Dip, RBF Coral Epoxy Putty, RBF Plug Cement w/ADVA Flow, mixing sticks, container for mixing plug cement, medicine cups, container for water/ADVA Flow mixture, submersible thermometer, container for antiseptic dip, oil free sun block, antibacterial soap, battery brush, hand brush, plug twine, dissolved oxygen (DO) test kit and other miscellaneous items that may be required for the coral propagation table operation.

Coral Tray (Coral Cutting and Planting Tray): A wooden tray designed to hold *coral plugs* while curing under the coral propagation table. This tray can be inserted into a larger crate and serve as a carrying tray for divers to transport and plant *coral plugs*. Embedded dive weights make the tray negatively buoyant. (see Figure G11 below)

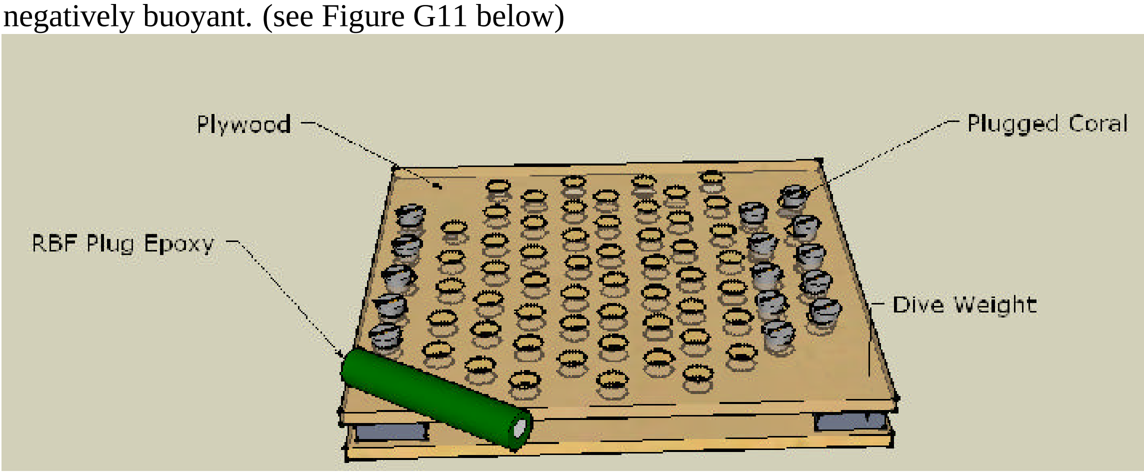


Figure G18: Diagram of Coral Curing and Planting Tray (available in Sketch Up ™). Coral Plugs fit into the holes drilled in the top board, which can be made from plywood or, if available, more water resistant materials such as resin or plastic.

Deployment: A word used to describe the act of placing an artificial reef into the sea. Reef Balls can be deployed from a barge or they can be floated out with their internal bladders called a "Floating Deployment."

Direct Putty Method: A method of attaching a coral, live rock, or other marine life directly to the chosen base substrate or artificial reef using *RBF epoxy putty* or another similar product. Because no plug is used with this method, a mechanical bond on both the substrate and the object being planted is required. This method is often used for *aquascaping*.

Figure G19: Diver using the direct putty method to attach a rock to a base substrate unit using epoxy putty. This method is used primarily for aquascaping- the process of putting the finishing aesthetic touches on a project

Disaster Nursery: After storms, ship groundings, anchor drops and other disasters, there is often a significant amount of damaged coral and no practical way to re-attach them. In these cases, concerned divers can create a short-term disaster nursery to preserve the coral genetics impacted by the disaster. These nurseries must be able to keep the coral alive long enough to build and deploy the chosen artificial substrate and to activate a Coral Team. A Disaster Nursery is designed hold coral up to a maximum of about one year.

User Note: See Crisis Timeline: Creating A Disaster Nursery heading in manual for specific design suggestions.

Dissolved Oxygen (DO) Test Kit: There are many inexpensive and effective DO test kits on the market. We have found that the Lamotte kit is easy to use, accurate enough, and priced under US$50. Be sure to follow the instructions carefully to get an accurate measurement. Testing DO at the site of the coral table is critical when first setting the table up and on particularly hot or stagnant days, or days

following a heavy rainfall. If testing indicates that DO levels are over 4.5 mg/l, it is safe to conduct coral fragmenting and coral table operations.
Figure G21: Dissolved Oxygen (DO) test kit is used to measure oxygen levels in the water at a work site to ensure that coral frags will not be overly stressed.

Dry hand dipper and placer: The person at the *coral propagation table* who handles dry fragmented coral; receiving the *frags* from the wet hands helper, dipping them into RBF antiseptic, shaking off any water on the fragments (water or antiseptic will prevent the frags from setting into the cement properly), and then placing them in the correct orientation in the wet cement in medicine cup molds. Some high-speed tables operate with 2 dry hand dippers and placers.

Figure G22: 'Dry hands' coral table worker positions a fragment of coral into the coral plug mold that is filled with sand and quick setting cement.

Epoxy Putty (aka RBF Coral Underwater Epoxy): A two part epoxy stick with a specific viscosity that allows for easy underwater mixing, yet stiff enough to hold coral plug in place until it hardens. RBF branded coral epoxy putty comes in a 9-minute (green and white) and a 5-minute working formulation.(brown and white) The 5-minute version is better for larger fragments that are prone to dislodging during wave surges, but requires more frequent mixing and is therefore less efficient and prone to waste. The 9-minute formulation is normally used for most situations. If you choose a non-RBF brand, be sure to test that they are not toxic to coral. **(Do not use Devcon branded epoxy for that reason, and generally any strong smelling brands are not suitable.)**. If the brand you choose is too thick, it will be very time consuming and difficult to mix underwater. If it is too thin, it will not hold the plugs in place. If it is too sticky, it will be difficult to remove from your hands. If it is not sticky enough, it will not bond well. Expect some staining of your dive suit and dive gear whatever brand you choose… we consider it the mark of a veteran coral planter!

EPVS value (Effective Protective Void Space Value): EPVS is hypothetical measurement used to estimate how much foray space a particular reef object is providing for a particular species or functional group of organisms. It is sometimes further defined by the type of foray activities so that a single species may have multiple EPVS values. For example food foraging foray may be different than resting or mating foray.

EPVS calculations can be used to compare rehabilitation methods to help predict success for particular species. A group of indicator species weighted by relative populations can be used to compare rehabilitation methods protective void space creation directly.

User note: See Effective Protective Void Space Loss heading in manual body for calculation methods and examples.

Essential Fish Habitat (EFH): Congress defined essential fish habitat as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity." (Federal Register 2002). Basically, this refers to critical geographical areas used by a species for any of the above purposes, an example would be areas of the Florida Keys used for spawning each year by Nassau grouper (*Epinephelus striatus).*

Fouling Community: A general term used to describe the assemblage of marine invertebrates, algae, and other marine life that is attached or lives directly on hard substrates. When a new artificial substrate is deployed, this community will develop over time in somewhat predictable patterns until it reaches its mature state. Typically, diatoms are the first colonizers followed by turf algae. After this, the succession of fouling community depends on the climate but usually includes tunicates and hydroids and some molluscs such as barnacles or scallops. In 3-6 months, with good water quality, coralline algae will form red, pink or purple patches that lay the groundwork for good natural coral settlement. These will be especially prominent when long spiny sea urchins (*Diadema* spp.) or other herbivores are present in good numbers. Without any coral plantings, properly built Reef Balls in the appropriate water quality will naturally develop into a coral reef in 8-25 years. Planting coral can speed this process up significantly. For example, the picture on the cover of this report is of a 5 year old Reef Ball with planted corals.

Fire Coral: Fire coral (*Millepora* spp.) are sometimes desirable to propagate due to the types of fish that use them for protection. Typically, Reef Balls are planted with a monoculture of fire coral, since it will outcompete most other species, and only a few plugs are required because most fire coral species grow and spread very fast. In a calm area, just laying a few fire coral fragments on a Reef Ball may be enough to get them started even without plugging.

Fire Coral Mitt: Fire coral can cause a painful rash when handled with bare hands. Latex gloves can easily tear when handling coral, so when working with fire corals, especially when hand fragmenting, RBF team members will use a silicon oven mitt for protection.

Figure G24: Silicon Fire Coral Handling Mitt can be used to avoid skin irritation when handling these species

Flashing: Flashing, or flash, is used to refer to the moment the *Plug Cement* "skins over", usually between 20-60 seconds after pouring the cement. At this moment, no new coral fragments can be added and it is time to initiate *plug curing*. Anyone at the coral propagation table can call the word "Flashing" when it is observed, in order to signal the dry hand dipper and planter to pass the flashed plugs to the *wet hand coral handler* for placement in the *coral curing and planting tray* in the water below the *coral propagation table. After placement, the wet hand coral handler records* the time so that the plugs can be moved to the *popping station* after 20 minutes.

Fragging Nursery: An temporary underwater area used to hold imperiled corals until they can be further processed into fragments. Water temperature and water quality in the nursery must be the same as the original source of the coral. A sandy bottom away from the reef is preferred because work will be done underwater that could disturb the bottom. The fragging nursery is often located between the source of coral and coral propagation table.

Figure 25: Diver collecting fragments of coral from a fragging nursery. The diver typically fragments the colony into pieces the appropriate size for planting, places the frags in a basket, and then transports them immediately to the coral table for planting.

Fragging: The art of separating individual coral colonies into small fragments suitable for plugging and planting onto substrate. This skill takes a great deal of practice, because each coral species has different tools and techniques required to achieve a viable fragment.

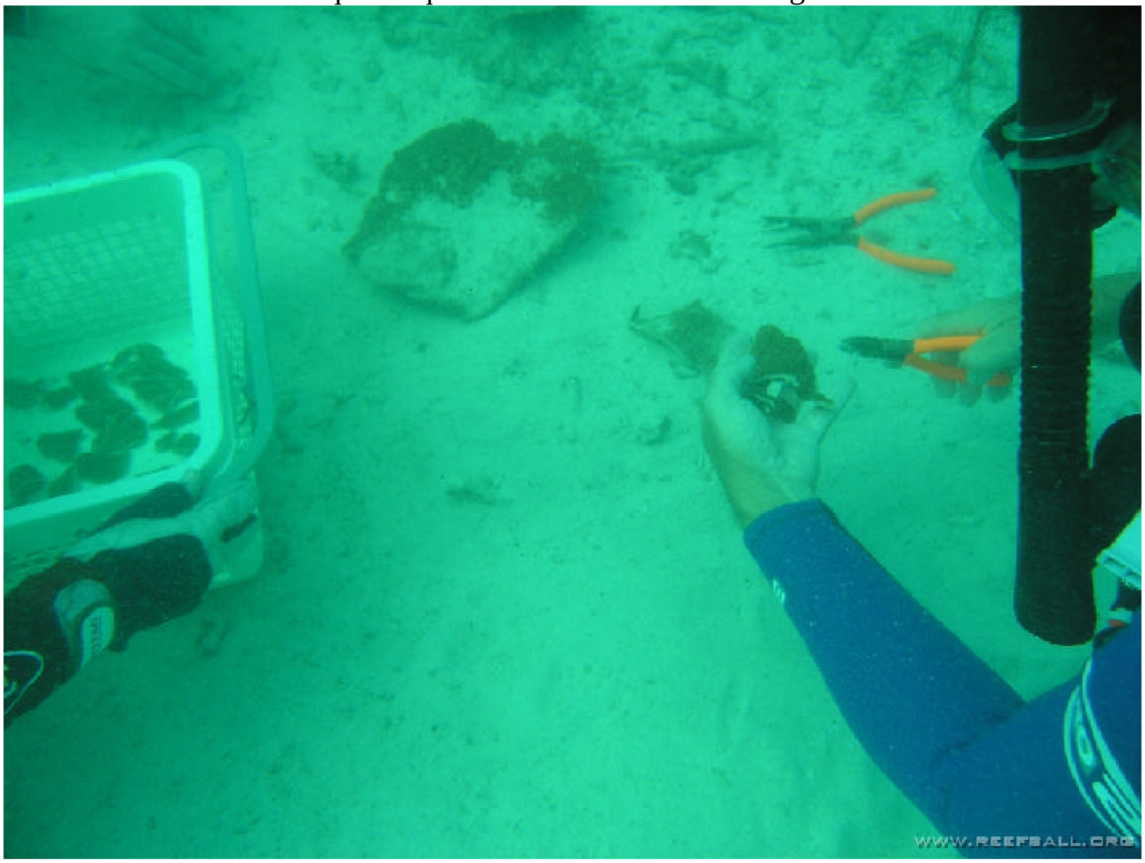


Figure G26: Diver fragging a coral colony using wire cutters. A wide range of tools from small tools for corals like these, all the way up to bolt cutters or even a sledge hammer and crow bar or iron spike are needed for fragmenting the largest densest corals.

Fragment: A subset (small piece) of a larger coral colony that has been separated from the larger colony by mechanical means. A fragment contains the same genetics as the parent colony. If two fragments from the same colony are planted close together, they will re-fuse into a single colony. If two fragments from different parental colonies are planted close together, they will not fuse and instead will compete for space. This is true even within the same species. The only exception is when two different parental colonies that share the same genetics (i.e. they were originally part of the same colony or both were originally fragmented from the same parental colony) in which case they will still fuse together.

Fragmentor: The person who works below the surface, using SCUBA gear, to fragment imperiled coral to prepare them for the *wet hand coral handler.*

Genetic Coral Rescue: A rescue method where a few small fragments are taken from each coral head that was damaged and are replanted to create new genetically identical colonies. See: **Coral Genetics**

GIS: Acronym for Geographical Information Systems. GIS software can be used in conjunction with *GPS* data to generate detailed maps, and access accurate spatial databases of information for an area.

GPS Receiver: A hand-held or boat mounted unit designed to receive data from Global Positioning System satellites and calculate the unit's exact position on Earth's surface. These units can be accurate to within a few meters, and can be used to generate extremely accurate maps of project sites.

Hacksaw: Sometimes compression tools like *bone cutters* are unable to fragment a larger coral. In these cases and a hacksaw can be used. A hacksaw can also be used to make a scar line to aid compression cutting of a coral fragment.

Figure G27: Hacksaw used for fragmenting large or difficult corals

Hand Brush: A wire hand brush is used to clean the area adjacent to the *coral plug hole* before planting on an artificial reef module that has been deployed for more than a few days. This provides space for the coral to *base* and attach itself to the artificial substrate.

Figure G28: Wire hand brush used to clear away fouling to provide more area for coral basing.

Handling Style Groups: Reef Ball Coral Teams group corals into general groups when they share common propagation techniques or are restabilized in similar ways. For example, finger size branching corals are usually divided by a wire cutters and they usually exhibit good *basing* qualities. Following are a stand set of Handling Style Groups:

- Fire/Lace corals,
- Soft corals with woody stems (excludes sea fans)
- Sea fans
- Soft corals without woody stems
- Finger sized branching corals
- Large diameter branching /pillar corals
- Encrusting corals
- Mound/boulder/brain corals
- Leaf/plate/sheet corals
- Flower/cup/single polyp corals
- Black corals,
- Other.

User Note: Specific *Coral Teams* may need to add additional groups based on local coral handling needs. As a training goal, volunteers on a coral team should at least be able to identify most corals as belonging to one of these handling style groups.

Hydrometer or Specific Gravity Meter: A hydrometer is an inexpensive way to approximate salinity that can be found at most aquarium or pet stores. It can be used to check the salinity of the Antiseptic dip if you are not using veterinary strength solutions. It can also be useful if you are working where freshwater runoff can affect the conditions at your nurseries or coral propagation table. *Figure G29: A hydrometer measures the specific gravity of water, which can be used to approximate salinity. It is an inexpensive tool accurate enough for most coral rehabilitation projects.*

Hydrostatic Method: A traditional technique using hydrostatic cement to attach adult coral, live rock, or other marine life directly to the chosen base substrate or artificial reef without *plugging*. To be effective, the team member must be able to make a mechanical bond on both the substrate and the object being planted.

This method involves mixing hydrostatic cement in a plastic bag on the ocean surface and sending it down for a diver to work it into a putty like consistency, which is then used to re-stabilize mature or large coral colonies. This method takes special training and practice to be able to perform reliably. Too much water in the mix can greatly weaken the bond. RBF has seen better results when adding 10% by volume of *microsilica* to the hydrostatic cement mixture, but care must be taken that the dry *microsilica* and dry cement are mixed together well as they tend to separate. The Degussa company makes an admixture called "RHEOMAC UW 450” that can be added to the hydrostatic cement to keep it from causing an underwater cement plume when it is removed from the mixing bag. With Rheomac UW450, the water also remains clear where you place the cement, making it easier to work at the coral’s base without damaging the coral. This method is time consuming, and the materials are expensive, therefore it should be used with discretion.

Imperiled Coral: A coral colony that without assistance will most likely die within one year. Examples include:

a) Loose or broken coral fragments or colonies disturbed by storms, ship groundings, anchor drops, etc. that have landed on non-hard bottom types, where it is expected that they cannot stabilize themselves to prevent sinking into the soft substrate or constant overturning and dying.

b) Coral that will be directly killed in the near future by dredging, marine construction, or other human activities.

Juvenile Fish Nursery: Most marine fish are pelagic spawners and in the larval stages the fish are widely dispersed. Studies have indicated that survival rate in the late larval to early juvenile size range as these larval fish attempt to find shelter and food on the reef, is a key factor in the rate of fish production. Small, low-height, complex or widely scattered structures are ideal for protecting fish at this stage. Red mangrove roots, sea grass beds, and scattered patch reefs are good examples of juvenile fish nursery areas. Artificial reefs can be designed to mimic this function too.

Light Intensity: There are many different units to express the amount of light over an area, some common ones include **Lux, Micro Einsteins, Foot Candles, and Lumens**. Sometimes, light metering devices are used to make sure coral are not exposed to rapid changes in lighting levels that are beyond their ability to adapt. Knowing what levels of light are acceptable requires species-specific knowledge, but in general, and especially when transplanting, it is best to keep a species as close to the ambient light conditions where it was originally found.

Map Datum: *Geographical Positioning Systems* (GPS) use a specific "map datum" to locally reference the GPS receiver to the satellites. If you do not specify the same map datum for the coordinates you are given you may not end up at the same location. So be sure to set your equipment to the proper map datum specification. Unless otherwise specified, the map datum should be defined using "WGS 84", a default datum that is most frequently used to define coordinates in GPS units.

Mass Spawn: Many species of coral synchronize their spawning times so that all colonies of the same species spawn at the same time. When this event occurs it is called a mass spawn. Within a few months is the best time to deploy artificial substrate, in order to maximize natural recruitment, because corals have a better chance of successfully colonizing fresh substrate than substrate already colonized by *fouling organisms* and *coral predators*.

Mechanical Bond: When using the *direct putty method* or *hydrostatic cement method*, a mechanical bond is formed when both surfaces have an undercut, which creates an overhanging portion at the interface between the two surfaces. Mechanical bonds are much stronger than adhesion-only bonds. <u>Note</u>: The rough surface texture created on concrete by using sugar water as a surface texture enhancer and then rinsing with water after de-molding creates an excellent undercut surface for mechanical bonds.

Microsilica: A concrete admixture added to reduce the permeability of concrete, neutralize the pH, and double the concrete strength. It is dosed at about 5%-10% of the total amount of Type II Portland cement used or 15% of the hydrostatic cement volume. Higher dosage rates provide an exponentially diminishing return with no increases in performance beyond a 30% Microsilica/Portland ratio.

Mixer: The person at the coral table who mixes and pours the cement. Typically the *Table Boss*. See: **Table Boss**

Mixing: In RBF terminology, this refers to the phrase shouted at the coral table by the *table boss* at the moment the plug concrete mixing is initiated. At this point, the *wet hand fragment handler* readies the coral fragments for passing to the *dry hand dipper and placer.*

Monitoring Frame: A PVC camera guide with a fixed optical length and a rectangular measuring quadrat marked with metric and English scales. Used to position the camera over coral plugs to take standardized monitoring photos. Advanced users will add movable "luggage tags" with numbers or letters to encode variables such as artificial reef module identifier, date or coral colony identifier. Length of the rod which attaches the monitoring frame to the camera will vary with the focal length of the camera used. Focal length should be adjusted in advance with the camera in wide-angle (non-zoomed) format. When taking monitoring photos, make sure camera is in the same position relative to the subject being photographed for each image. Most divers prefer a frame that is neutral or slightly negatively buoyant. Gravel or lead shot can be put inside the frame for this purpose. Frame should have small holes drilled into it to allow water to flow in and out.

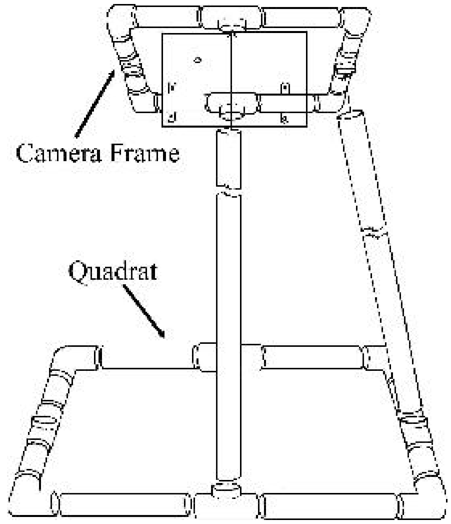


Figure G30: Camera monitoring frame or quadrat framer. This device is built so that most standard underwater digital cameras can screw into the plate in the center of the camera frame, and will take a picture downwards towards the quadrat. The quadrat allows the photo to be standardized for length.

Morphology (Coral Morphology): The ability of many coral species to build a colony in various shapes to adapt to local growing conditions. Factors can include lighting, currents, food availability, etc. A coral planted as a fragment can develop its morphology to suit the new location. An adult colony transplanted to a new location does not have this ability. This difference is one of the major reasons survival rates are higher in fragments than for transplants in coral that have this ability. Morphological differences are one reason why identifying coral species can be so tricky, because the same species can look markedly different in various environmental conditions.

NEW FIGURE

Figure G31: The same coral species can have vastly different physical appearance because coral colonies can adapt their morphology to reflect their conditions. Left: in shallow depths, star corals frequently assume a boulder like form. Right: The same species of star coral assumes a plate like form at deeper depths to have a greater surface area to aid in light absorption.

Natural Recruitment: Base substrate or a properly designed artificial reef will recruit and develop a *fouling community* over time through the process of natural recruitment. That community will include coral and other desirable marine life, presuming the water quality and site location is suitable. In most cases, even without any effort for coral propagation and planting this will occur over time.

Oculina: A group of hardy coral species, some of which can survive at great ocean depths with very low light levels and some of which tolerate very cold temperatures.

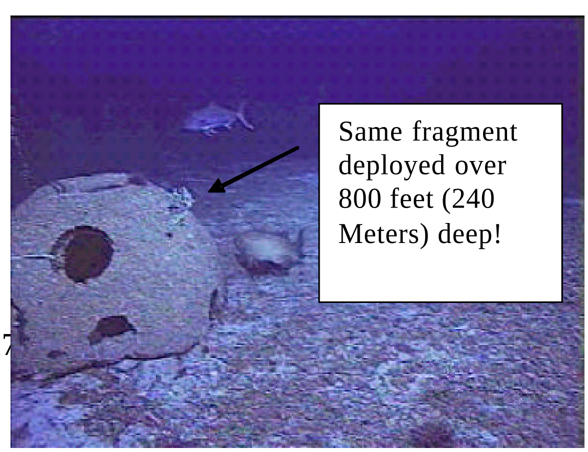


Figure G32: A colony of oculina coral can be seen growing on the Reef Ball in this photo (identified by the arrow). This Reef Ball is deployed in over 240 meters (800 feet) of water, where the water temperature is often below 10°C (50°F).

Oil Free Sun Block: Coral Team members are required to protect themselves from sunburn. Loss of a team member's function due to sunburn can disrupt typically tight project timelines. However, most sun care products contain oil that can contaminate the coral propagation table. Oil is particularly dangerous because it can form a film on corals, or on water containers used for corals, which can disrupt the flow of oxygen across the surface, and stress the coral. Therefore, Coral Team members are required to use oil free sun blockers (typically in spray formats that make frequent applications easier).

Pancake Syrup: This term is used by RBF *Coral Teams* to refer to the appropriate consistency for plug cement, approximately that of unbaked batter or maple syrup. Mixing cement to this consistency takes practice and is one of the most important aspects of quality control on the coral propagation table.

Planting: Affixing the *coral plug* into the *coral plug hole* with *underwater epoxy putty.*

Planting Team: A dive team that mixes underwater epoxy putty and plants coral plugs onto substrate modules. Sometimes divers work in teams of two, with a mixer and a planter and sometimes each member does both tasks. In many cases, planting teams do not wear fins when planting to avoid accidentally knocking off adjacent, freshly planted coral plugs. Even in shallow water, dive tanks should be used to ensure careful slow movements needed to plant coral without disturbing other freshly planted plugs.

Figure G33: Diver attaches a coral plug to an artificial reef module using epoxy putty.

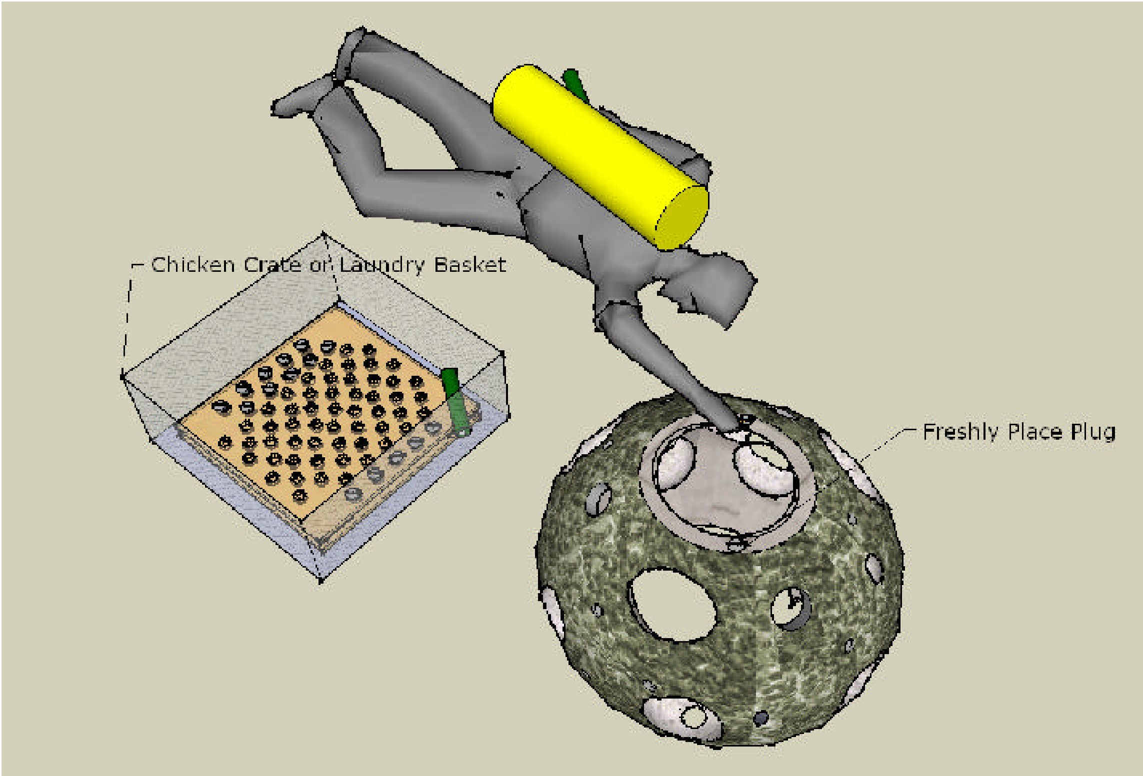


Figure G34: Schematic of diver planting coral plugs from a Coral Planting Tray onto a Reef Ball. The diver can use the tray to store supplies such as a wire brush, or extra epoxy putty.

Planting teams need to be trained on the project's *planting strategy* to know where to plant coral plugs with specific coral species. Planting errors can take years to show up and avoiding them can be important for long-term success. A veteran planter in good sea conditions can plant 100 or more coral plugs per hour, but variable conditions such as current, surge, or reduced visibility can reduce this number drastically. An experienced and skilled planter uses much less epoxy putty per coral plug than a newly trained beginning planter. A beginning planter may get 5-7 plugs per epoxy stick, whereas a skilled planter can get 20 or more. When computing the amount of epoxy putty needed for a project, take this variable into account.

Planting Strategy: A planting strategy must be developed to allow the base materials to develop as closely as possible to the species diversity and population densities of nearby natural reef. Mastering the development of *planting strategy* takes a level of skill that is beyond most volunteer teams. Typically, the Foundation develops a planting strategy using RBF experts, who are assisted by as much local expertise as can be accessed. Todd Barber, John Walch, Lorna Slade, Marsha Pardee and Mario van der Bulck are currently (2006) the RBF experts that have the level of understanding needed to develop good planting strategies. There are probably some coral rehabilitation specialists/scientists that have similar skills, particularly ones that know specific local environments well. We also hope to develop more experts, but this type of training takes years, not months. Some of the complex factors that go into planting strategy are:

1. Environmental tolerances of the particular species (lighting, currents, sedimentation resistance, salinity, temperature changes, feeding requirements, depth limitation, etc.)
2. Warfare or fusing of coral colonies
3. Expected growth rates of various species

4. Expected natural settlement on the artificial reefs
5. Water quality, present and expected
6. Wave and climate expectations
7. Goals of the individual project (for example aesthetics, specific use, etc.)
8. Capabilities of the project (how many coral can be planted, etc.)
9 Preferences for threatened or endangered species

Plug Cement (aka RBF Disk & Plug Mix): A mixture of hydrostatic cement, microsilica and optional proprietary ingredients used by RBF coral teams for making *coral plugs.*

Plug Curing: Placing a freshly plugged coral, still in the medicine cup after *flashing*, into the sea for 20 minutes or more until the *plug* is hard enough to separate the coral & plug from the medicine cup and sand.

Plugging: The process of imbedding small coral fragments into a standard medicine cup; which is filled first with 1/2 inch of sand and then filled to the top with 30 second setting *plug cement*.

Plug Nursery: Sometimes, it is not practical or possible to plant plugs immediately after plug curing. In these cases, a temporary plug nursery can be established, which is a protected area where the coral plugs can be safely stored until it is time to plant them. PICTURE (FIG G35)

Plug: A coral fragment embedded in a small concrete cup so that it can be easily attached to the artificial reef substrate and to promote a good *base* formation.

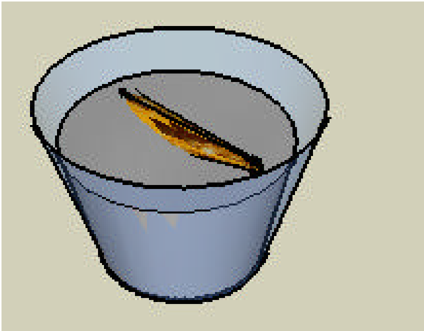


Figure G36: A Coral fragment placed into 30 second RBF plug cement to create a Coral Plug.

Plug Twine: Some coral species, most notably sea fans, are difficult to epoxy into a coral adapter plug hole because the slightest sea surge causes them to pop out of the hole before the epoxy has a chance to harden. Therefore, a temporary brace is created using cotton string (twine) to hold the plug into the surface of the artificial reef module until the coral epoxy putty hardens. The twine is then removed.

Popping Station: After a *coral plug* hardens for 20-30 minutes underwater, the *coral curing and planting tray* is removed from under the table and the *Popper* will remove the plastic medicine cups from the coral plug by pressing their fingers on the sand filled portion of the medicine cup until the plug "pops" up. This is done using a technique to catch the plug from the side so that there is no need to touch the coral. The "popped" plugs are then re-placed in the tray and turned over to the *planting teams*. The medicine cups are recovered and returned to the *coral propagation table* for re-use.

Popper: A *Coral Team* member trained to remove coral plugs from medicine cup molds without touching the attached coral fragment.

Pouring: A term called out by the *Table Boss* when the coral plug molds are about to be poured. This signals the

dry hand dipper and planter to begin treating the coral with an antiseptic dip and then to ready them for placement into the fast setting plug cement. From the time the *Table Boss* starts "Pouring" it is typically 30 seconds until the concrete *flashes.*
Figure G37: Table Boss pouring cement into coral plug moulds.

Propagation: The act of creating multiple coral colonies from a single colony. This is functionally equivalent to cloning plants. **See: coral Genetics**

Propagation and Planting induced Coral Fragment Death:
In the first 48 hours transplanting *plugs*, the major causes of fragment death are *Rapid Tissue Necrosis* RTN or a failed epoxy bond. From 48 hours to 90 days the major cause of plugged fragment death are *coral predators*. Beyond 90 days, losses are usually related to improper *basing* or incorrect placement location for the species such as too much or too little light, incorrect depth, too close to sediments or improper orientation to currents. Survival rates of propagated fragments are variable, based on how well the techniques in this manual are practiced. Properly handled propagated fragments can have mortality rates close to those of natural coral in the area, and this is the goal every project should strive to achieve. A *monitoring* program should be established to determine if this goal is being achieved. When a monitoring program establishes that fragment death rates exceeds the expected rate by more than 10%-20%, procedures need to be reviewed and corrected before additional propagation and planting. If specific techniques can be documented to eliminate part of this mortality, they should be reported to the Reef Ball Foundation for addition to this manual. This is one of the most critical roles of grassroots-based monitoring. Globally, our projects average about 80-90% survival compared to background natural mortality, which is quite good, but there is still room for improvement.
<u>Note</u>: Even though there is an expected mortality rate in fragments above that of natural coral, the net number of new colonies is always higher than without propagation efforts. This is because coral are propagated, not transplanted.

Propagation Tears: Many brain coral, lettuce coral and encrusting soft coral species develop tear-shaped lobes as they naturally try to propagate themselves. These "natural" fragmenting lines can be used to create fragments on coral that typically cannot be fragmented easily.

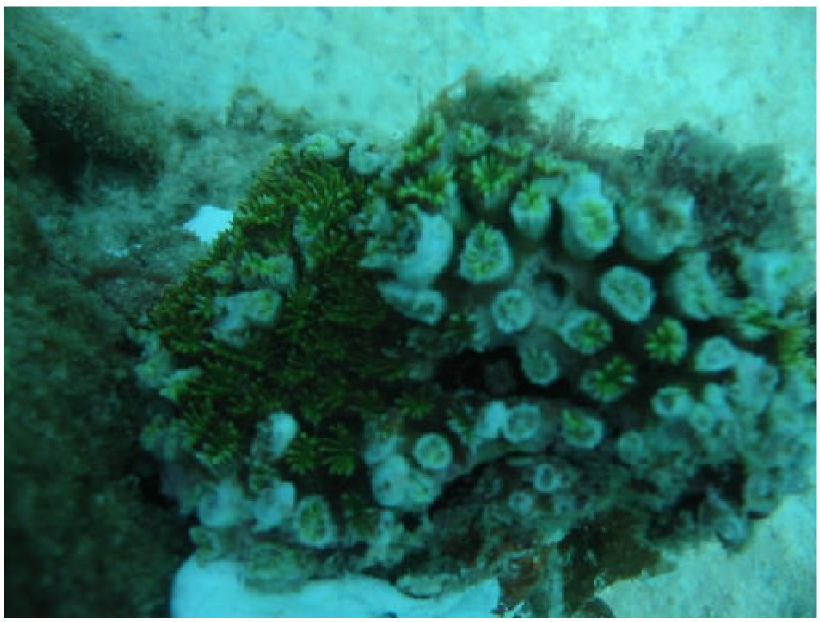
Protective Void Space: The most critical function that coral colonies provide to fish is void space. A void space is an area that protects fish from larger predators and provides shelter from energy draining water currents. Void space is created by coral colonies both in the interior of the structures, in holes and cavities of the eroded limestone, and areas around the reef where eddies and back currents form. During low current conditions, the void space expands to the largest distance a particular fish can be away from the reef and return for safe haven when its particular predators abound. Therefore, note that void space is different for different fish types and sizes. Void space shrinks during storm events and high currents. At these times the space is limited to interior cavities and close to the edges of more solid reef structures capable of creating an eddy. Rehabilitation of void space IS CRITICAL to restoring fishery resources to coral reefs and is often overlooked.

Note: All *reefs* provides protective void space. Several living non-reef communities do so too, such as sea grass beds, kelp forests, submerged mangrove roots, floating sargassum "rafts or mats" or other floating biological masses; and even such surprising things such as whales, manta rays and sharks. Also See: **EPVS**

Rapid Response Training*:* Local training for dealing with coral damage events BEFORE an emergency occurs. Rapid response training is usually given along with the stocking of a *Coral Disaster Response Kit.* Having rapid response training means there is local talent available to deal with coral damage events, without having to rely on international assistance from a *Coral Team* activation. Since all non-perishable rehabilitation tools and supplies are pre-stocked before a disaster, this means there are no delays in dealing with coral damage and typically the *disaster nursery* step can be eliminated, thereby improving the odds of a successful rehabilitation. See Appendix A for detailed information on this program.

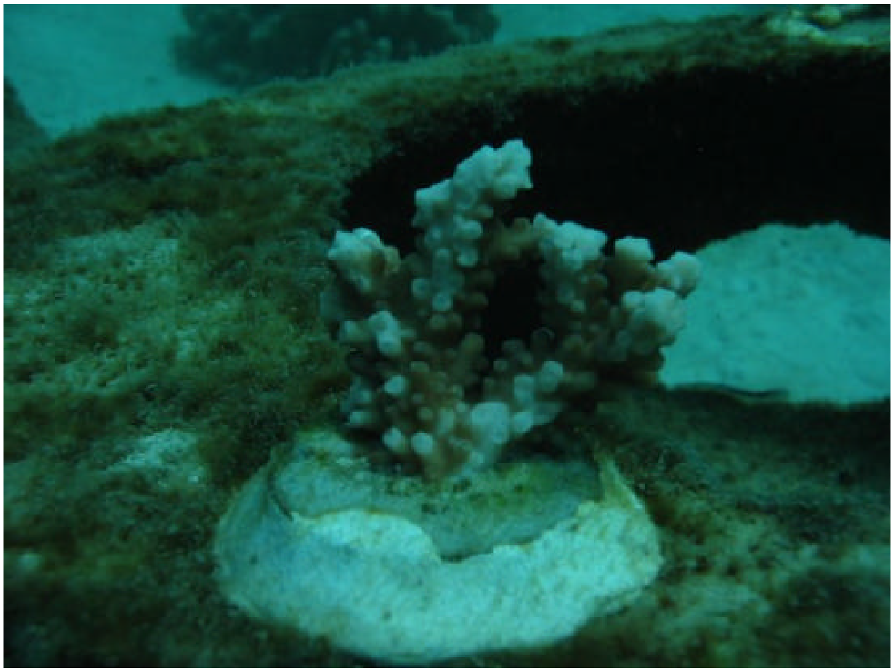
RESUME EDITS HERE

Rapid Tissue Necrosis (RTN): A rapidly spreading bacterial infection distinguishable by a very distinctive smell, fast movement of white tissue across the colony and rapid colony death, usually hours. RTN can occur at any site of injury to the coral. It starts as an area of white coral tissue, usually at the site of fragmentation or when the coral has been injured by handling RTN typically kills the entire fragment within 24 hours. RTN is one of the main reasons that transplanting whole colonies of coral is so difficult, because once started it will almost always kill the entire colony. The cause of RTN is a simple formula: STRESS+INJURY+BACTERIA=RTN.



Prevention is the only treatment for RTN. There is no cure for RTN and once identified in a fragment, the fragment should be destroyed and anyone handling the fragment must thoroughly wash their hands and disinfect any tools with alcohol or other sterilization measures, because RTN is extremely infectious, especially to stressed or injured coral. RTN is common in *Acropora* and other rapidly growing coral species, occasional in medium growth rate coral species and rare in slow growing skeleton coral species. It is fortunate that RTN rarely infects the very slow growing brain coral, so restabilizing adult brain colonies of brain coral can be quite successful even if the colonies are injured slightly in the effort. RTN has not been documented in soft coral species. However, soft coral species can succumb to bacterial diseases that result in death, just slower (usually taking 1-3 weeks to completely kill a plug).

It is presumed that RTN can be caused by a number of different bacteria that are common in the marine environment. It can best be understood by considering RTN as an infected wound, just as an untreated cut can infect a human. Remember that coral are animals and are susceptible to the same kinds of infections that affect all animals.



(This plug has developed RTN in Thailand and needed to be removed. When an *RTN nursery* is not used, a 48-hour monitoring after planting is required and using a screwdriver and hammer all plugs with RTN must be removed and destroyed)

RTN Prevention Strategies: We know the formula for RTN is STRESS+INJURY+BACTERIA=RTN Therefore, effectively dealing with RTN involves utilizing techniques to reduce injury and stress to the corals, antiseptic treatment of injury sites and good hygiene by those handling the coral. In terms of stress levels, this manual is full of tips such as gradual changes in temperature, light and water quality conditions. Handling practices such as ensuring polyps are contracted before contact is important. All transport procedures should insure that different coral species don't come in contact with each other and are not exposed to additional injury. Corals are ideally exposed to air only one time during the entire propagation and transplantation procedures. Every exposure to air reducs the amount of protective slime that protects the coral from infection. People in direct contact with coral (or water that coral is kept in) should only use *oil free suntan lotion*. Dissolved oxygen levels should be maintained at the highest possible levels and never allowed to drop below 4.5 mg/l. These strategies not only reduce the occurrence of RTN but also will create stronger coral fragments that are more resistant to *coral predation*.

Reef: Hard substrate with its associated fouling community that provides essential *protective void space* for fish and other mobile marine life.FIX

Refractometer: A refractometer is a more sophisticated way than *specific gravity meters* (*hydrometers*) to measure the exact salinity or the amount of salt dissolved in seawater. They don't produce variable readings in different water temperature ranges either. Refractometers are available from professional environmental monitoring suppliers. They can be used to check the salinity of the Antiseptic dip if you

are not using veterinary strength iodine solutions. They can also be useful if you are working where freshwater runoff can affect the conditions at your nurseries or coral propagation table. A refractometer is very useful for Red Mangrove projects because salinity must be closely monitored. Simply put a drop on the lens of the water you want to sample and look into the scope for the reading. **Note: Must be calibrated with distilled water before use.**

Release of Liability & Consent to Share Photos and Image Form: All Coral Team members must sign a release of all liability noting they are accepting full risk for participation in projects. This is critical because many government-based projects do not allow diving activities without special certifications due to liability. Additionally, members must agree that we can use their likeness or image in our publications, website, etc. Also, the team members must agree that they will share all project-related photos (not personal photos) with the Reef Ball Foundation and allow their unrestricted use.

Re-stabilization: Reattaching an adult coral colony back to the sea floor or an artificial reef module after it has been dislodged. Typically, this is accomplished using the *Hydrostatic Method* or some other anchoring method. Restabilization be as simple as uprighting a coral head that has been overturned.

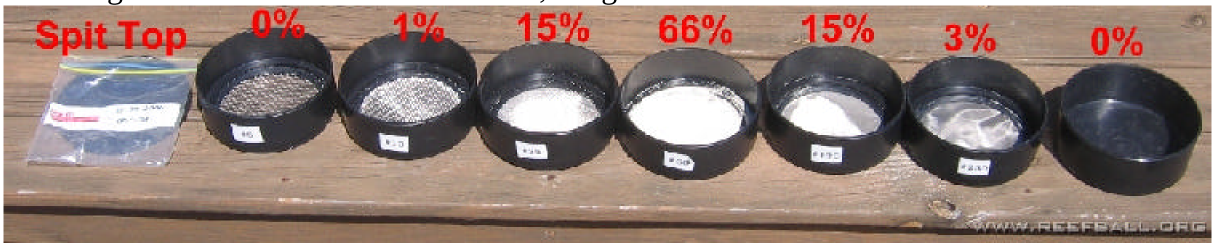
RTN: See Rapid Tissue Necrosis

RTN Nursery: A temporary holding area for *Acropora* plugs (the coral most prone to RTN development), for a 24-48 hour quarantine period before planting on Reef Balls, in order to identify fragments that have succumbed to *Rapid Tissue Necrosis (RTN)* from *fragmentation* and *plugging* stress. This helps to eliminate planting plugs that will not survive, and avoids a 48 hour monitoring period with screwdriver and hammer in hand to remove bad plugs following transplanting. A 5-10% loss of *Acropora* plugs is typical, unless conditions are perfectly managed and therefore slightly more plugs should be made than are desired.

Runner: In some situations, a "runner" is a diver or snorkeler that transports full coral plug trays from the *coral propagation table* to planting teams and returns with empty trays to *the coral propagation table*. In other situations, planting teams do their own running). Divers with aerobic sport training are ideal candidates for this task.

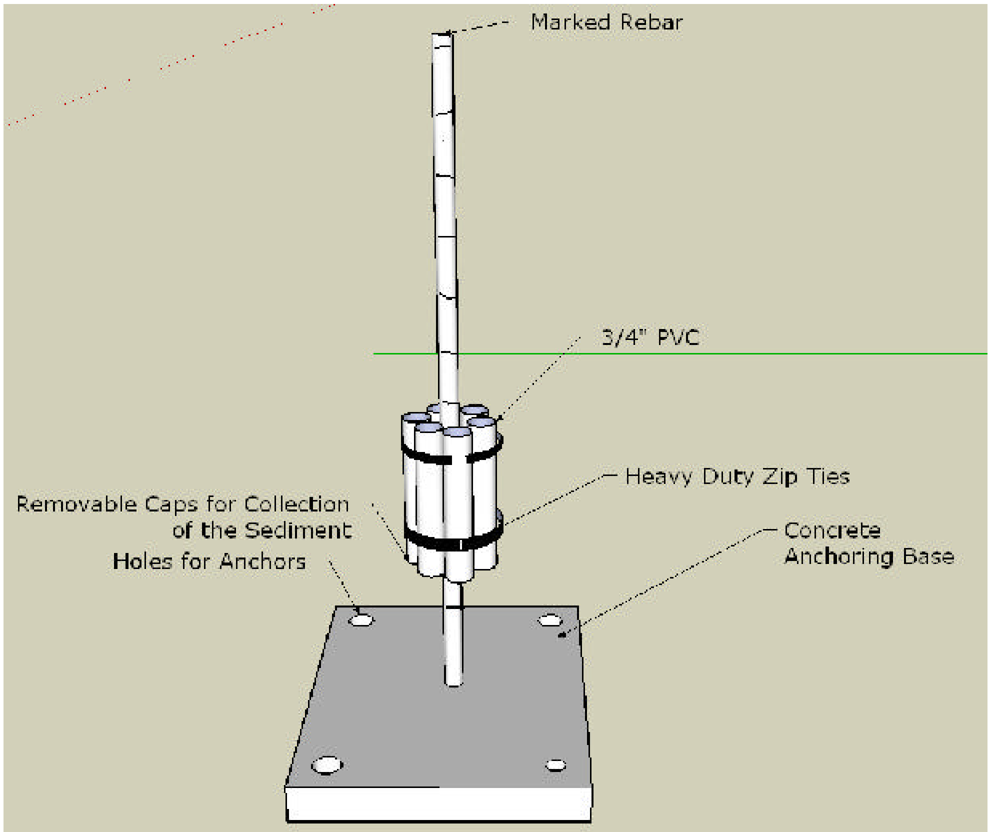
Runner's Socks: Due to the high incidence of blisters on the feet when working in sandy areas, RBF Coral Team members are sometimes required to wear double-layered socks (when dive booties are not used) to prevent blisters. These are commonly available to runners with a common brand named "Wright Sock." You can also obtain lycra socks from a company called "Scuba Doo" but two pairs will need to be worn for the best protection. http://www.cococheznaynay.com/ is the Scuba Doo website. They also produce a Reef Ball "Doo Rag", a popular item among team members to shield their heads from sunburn. When dive booties are worn, only one layer of socks are required to reduce blistering.

Sand Analysis: In some projects, you may need to learn about the grain size distribution, sand composition, or amount of sand transporting through your site as part of your rehabilitation efforts. For example, sand sieve analysis can be performed to see what size grains are present. This is useful for erosion control issues and coral sediment stresses (corals are more stressed by smaller grain sizes). One can obtain standard screens for this analysis at forestry suppliers or similar vendors. Take your sand samples from multiple locations (if an erosion control project as instructed by your coastal engineer) and place in marked zip lock bags. When you return to your lab, dry the sand (a microwave works nicely) and put on a paper plate. Split the sand into four even quadrants and use sand from two opposing quadrants for passing through the sieve screens. You can then compute percentages of various grain sizes on the basis of volume, weight or both.



Sometimes you will want to know more about the composition of the sand. Take a small sample and view with a magnifying lens. Sorry, this is slow work. It can be useful to understand the type of sediment stressing the corals. Generally terrestrial-based (round sand grains) are more stressful to corals than irregular shaped coral or shell sands.

Finally, and usually most importantly, you need to know how much sediment is traveling at a particular water depth in your site. It is VERY important to know what height particular coral species must be planted above the sea floor to avoid sedimentation stress. A simple sediment trap can be made following the diagram below (available in Sketch-up). This trap can be used in the natural reef to determine what level of sediment a particular coral can handle and then be applied to your planting strategy. The length of time the trap must be in place depends on the volume of sediment in the area. What is important that the time frame is the same in all your locations so that sediment volumes or weights are comparable. Note the design allows for adjustable heights and easy retrieval of the sediment trap collection tubes.



SCUBA Certification Card : Nearly all Coral Team members are SCUBA certified. Coral Team members must send an electronic scan of their certification cards to the Reef Ball Foundation before they can participate on Reef Ball Coral Teams. Team Leaders make assignments based on your highest level of certification plus your demonstration of scuba skills in the field. Note: we also recommend that you keep an electronic copy of your passports on file with us in case you lose your passport on a trip.

Sea Surface Temperature (SST): SSTs are used to help predict bleaching events and to help determine temperature ranges on a reef. Remember, SST is a surrogate for reef water temperature, but they are not always the same due to *thermoclines*.

Secchi Disk: An 8 inch disk with alternating black and white quadrants used to determine the degree of underwater visibility.

Markings or knots on the rope identify the distance of the disk from the water surface. The disk is lowered into the water until it disappears and the depth recorded, then the disk is raised until it re-appears and the depth recorded. The two depths are averaged and this becomes the Secchi visibility. Usually, the color of the water is also noted.

Sediment Grain Size Analysis: See Sand Analysis

Setting: The art of laying a coral fragment in the medicine cup mold after it is filled with fast setting plug cement. It is an art because there are several factors that must be considered including a “top” and “bottom” side to many coral species such as Elkhorn and Lettuce coral. Sideways orientation is required for finger corals to stimulate better basing. Knowing just how deep the coral needs to be placed into the plug cement for proper adhesion is an important skill. Some coral species, such as soft coral with woody stems (gorgonians) require exact depth placement with the flesh only touching, but not below the concrete surface. During “setting” the dry hand dipper and setter must judge the concrete setting time exactly and not place a coral during or after *flashing*. Some species require special “setting” techniques such as having some part of the coral braced against the side of the medicine cup mold. Medicine cup mold modification may be required for larger fragments, ask your coral team leader about this if required.

Sterilized Hard Bottom: Areas of freshly exposed limestone rock typically from a ship grounding, tsunami, hurricane or other physical event. This type of bottom can be drilled to create coral adapter receptacle holes and subsequently used for coral planting. Freshly exposed sterile bottom from sand movement is not recommended because the sand can return and smother the planted corals. Note: Without the addition of artificial reefs, it will take much longer for these planted reefs to develop the complexity of a mature reef. However, this approach is often suited for organizations that prefer not to use artificial reefs.

Submersible Thermometer: A thermometer is used to check the temperature of the antiseptic dip and to check the nurseries and coral table plug curing areas. The thermometer is also used to take ambient water temperatures to make sure temperatures don't exceed 30 degrees Centigrade (86 degrees Fahrenheit); which is the temperature when fragmentation and plugging activities need to be stopped. These activities can be continued if a *Dissolved Oxygen* test can be conducted to confirm that DO levels are over 4.5 mg/l (in which case it is possible to continue *fragging* and *plugging)*. If a DO test kit is not available, a rule of thumb is that if it is windy and there is good circulation it will probably be okay, if it is calm or poor circulation it is likely dangerous to proceed. In fact, on calm days or in low circulation environments DO testing should begin at 28 degrees Centigrade or 81 degrees Fahrenheit.

Subsidence: A term used to describe an artificial reef or base substrate sinking into a soft sea bottom type (typically sand or mud).

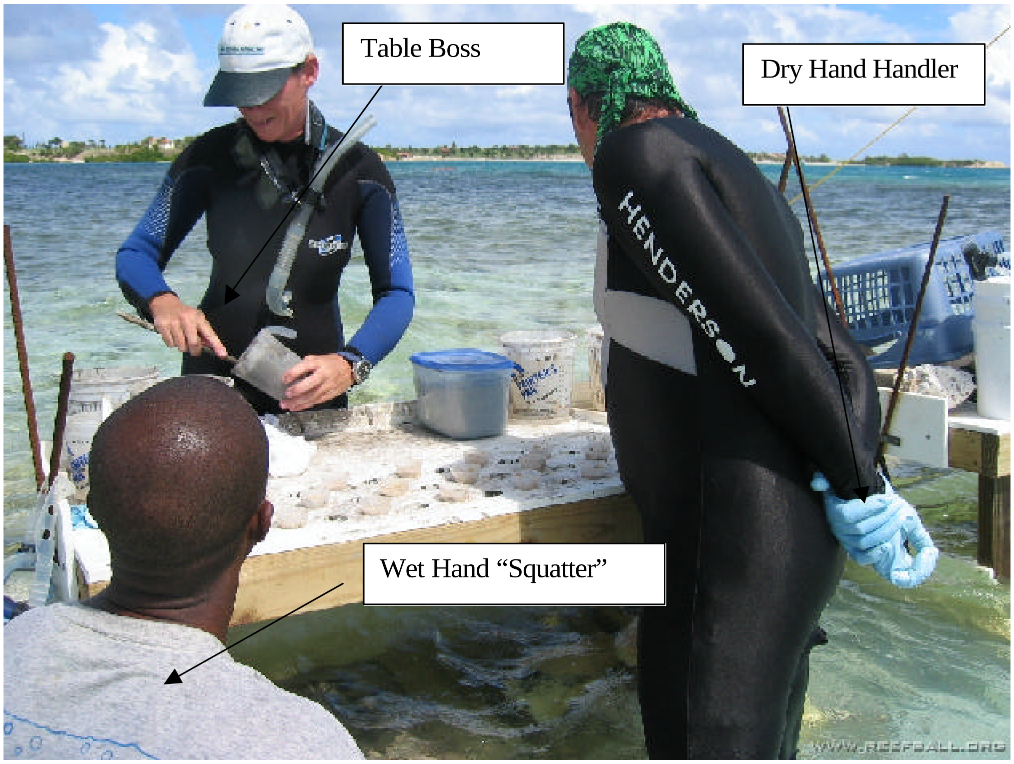
Sugar: Sugar acts to slow down (retard) the setting speed of cement and it can be used in when the fast setting plug cement *flashes* too quickly. Sugar water is used on concrete artificial reef molds to create a rough surface texture with exposed aggregates that encourages natural settlement of larval coral (the module surface must be rinsed with water immediately after de-molding to achieve this effect).

Sunburning: Coral can suffer ill effects of the both the sun's UV rays and changes to higher intensity lighting conditions similar to moving a house plant directly into full sun. Moving corals into shallower water, clearer water, changing compass orientation to a more south (north in southern hemisphere) facing orientation and moving to less shaded areas can all cause sunburn.

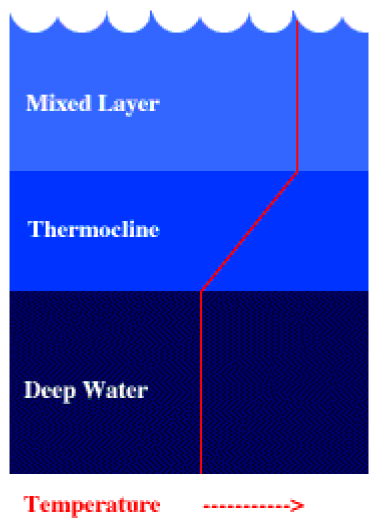
Supply Stocker: The person on the Coral Team designated to bring fresh supplies to the coral table including fresh water, moist sand, plug cement, etc. Often, the supply stocker will help ready planting teams, inventory material stocks, serve as a safety guard, arrange for snacks, meals or hydration, and make store runs for special needs. This position can be filled by a non-diving member of a Coral Team and is critical to overall efficiency. If the team has vehicles, the Supply Stocker is normally in charge of their use and allocation.

Underwater Epoxy Putty: See Epoxy Putty

Table Boss (or Boss or Mixer): The person at the *coral propagation table* who handles mixing and pouring of the 3 minute setting concrete, cleaning of the mixing vessels and who gives directional commands to the other table workers. The Table Boss controls the pace of production and is responsible for quality control and safety.



Thermoclines: Thermoclines or "temperature layers" are distinct horizontal layers in the sea with temperature differences usually getting cooler with each layer passed (if there are multiple thermoclines) on the way to the bottom… sometimes these temperature changes are very substantial. For coral teams, care should be taken not to bring coral through thermoclines if possible…the temperature shock creates a lot of stress on coral. Additionally, if *SST* is used to determine reef water temperature, it should be adjusted if a thermocline is present. A reverse themocline is when the temperature on the bottom is warmer than the temperature on the surface. As seen in the graphic to the right, they can manifest in several complicated forms.



Transplanting: The act of moving a whole coral colony from one location to another location. This is much more difficult than propagation and planting fragment plugs. It requires a special level of certification on the Coral Team and should be considered a useful technique only for high value corals that cannot be easily propagated.

Waterproof Papers and Field Books: Coral Team participants often need waterproof paper for underwater monitoring forms and field books for recording data. You will find these and other specialty field items like sand grain distribution sorters, refractometers, and survey equipment at http://www.forestry-suppliers.com/

Warfare (AKA Coral Warfare, Chemical Warfare): Some species of hard coral (most famously *Galaxia* species) have the ability to sting nearby coral to defend or create new territory for themselves. Being closely related to jellyfish, this is not surprising. *Galaxia* and other species have specialized stinging tentacles that can sometimes reach long distances (a foot or more). Other species have toxins in their slime coats which can affect their enemies. This is one of the reasons why hands must be washed between handling of different species to avoid (the other reason being sanitation) spreading loose tentacles or slime from one coral species to another. The other implication is that hard corals must also be separated when handled in captivity. With expertise, one can learn that not all coral have this ability and it is "okay" to mix certain species, but it is better to err on the side of caution and avoid this practice. Soft corals are not known to have this ability.

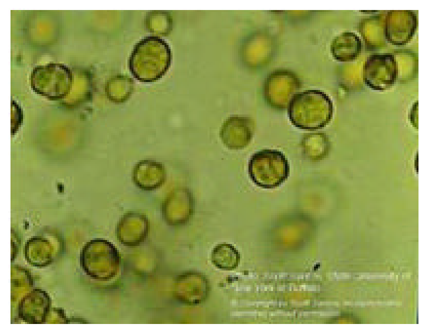
'Wet Hands' Table Worker: The person at the *coral propagation table* who handles wet fragmented coral and the *plug curing process*

Wire (Diagonal) Cutters: A tool used for *fragging*, typically for small finger coral species.

Wire Strippers: (pictured right) A tool used during the *fragging* process for woody-stemmed soft coral (gorgonians). This tool is used to strip back the flesh at the base of a propagated stem, exposing enough of the woody stem to be embedded in the plug for a firm attachment. Care must be taken to hold the gorgonians softly so that there is no crush injury from your grip on the coral. Automatic wire strippers (pictured left) can be used on some soft coral types to avoid crush injury.

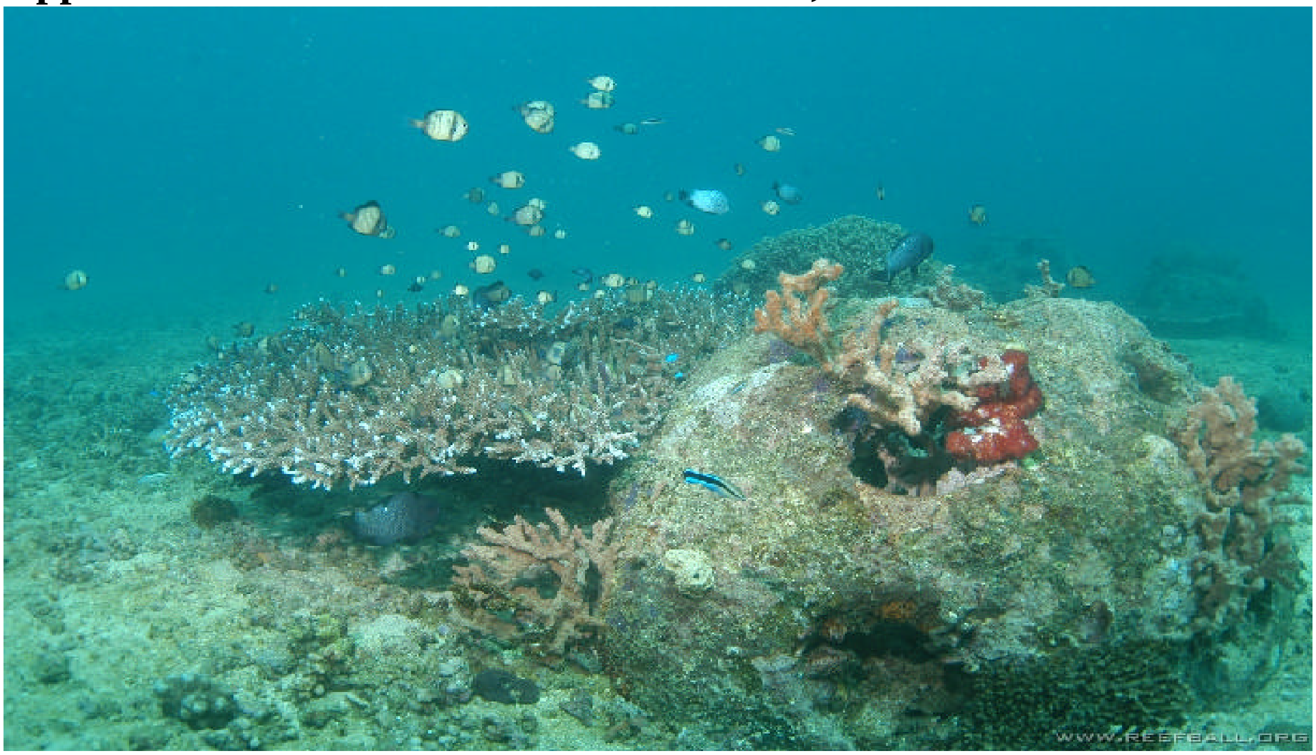
Zip Tie Method: A method of attaching small to medium diameter coral fragments directly to a base substrate or temporary nursery with plastic zip ties. Zip tie methods are generally suitable for larger fragments of basing coral species on stable substrates with small diameter attachment points. The technique is most useful when there is an over-abundance of imperiled finger type corals after storms. This method is often used in coral farming and temporary attachment situations. Variations of this technique include attachment with fishing line, rope, metal wire, etc.. For temporary nursery uses, with gorgonians, the woody stem must be exposed using a *wire stripper* and the zip tie should be attached to the woody part only. Zip ties should be fully tightened for either soft or hard corals, even in nursery situations.

Zooxanthellae: According to NOAA, "Most reef-building coral contain photosynthetic algae, called zooxanthellae that live in their tissues. The coral and algae have a mutualistic relationship. The coral provides the algae with a protected environment and compounds they need for photosynthesis. In return, the algae produce oxygen and help the coral to remove wastes. Most importantly, zooxanthellae supply the coral with glucose, glycerol, and amino acids, which are the products of photosynthesis."



In regard to planting coral, the light requirements of the zooxanthellae must be satisfied and rapid changes in light intensity levels can shock or kill zooxanthellae. Additionally, if a coral is stressed by high temperatures and low dissolved oxygen levels, they can expel zooxanthellae from their body which is called "bleaching" and if the bleached condition lasts long enough the coral will die.

Appendix D: Manual Summaries for Covers, Promotion



This document summarizes the field techniques of The Reef Ball Foundation, an international environmental NGO with over 12 years of experience and over 3,500 projects worldwide. Techniques presented focus on efficient and rapid *propagation* of coral while minimizing underwater effort. Using a properly trained *Coral Team* of experts and volunteers with only 5 divers, it is possible to rescue, propagate and plant 500 coral colonies a day, with supplies costing less than a dollar per coral colony.

This manual presents methods of coral reef rehabilitation that aim to recover lost *protective void space* using prefabricated artificial reef modules and/or natural substrates combined with planting of propagated or rescued corals. A novel approach is presented of preparing the base substrate with indentations to accept standardized coral *propagation plugs.* The combination of providing base reef structure with planted coral speeds up the re-establishment of a natural reef.

By sharing these techniques with managers, stakeholders, and grassroots coral reef rehabilitation groups around the world, The Reef Ball Foundation can better accomplish the goal of transferring global technologies and techniques to the local level and facilitating continued rehabilitation efforts.


REEF BALL FOUNDATION
Step by Step Guide
to Reef Rehabilitation
for grassroots organizations
Todd Barber[1], Dr. Lee Harris[2] Dr. Catherine Jadot[3], Jason Krumholz[4], et al.
[1] The Reef Ball Foundation, Athens GA, 30606
[2] Florida Institute of Technology, Melbourne FL, 32901
[3] Center for Marine Resource Studies, South Caicos, Turks and Caicos Islands, B.W.I.
[4] University of Rhode Island Graduate School of Oceanography, Narragansett, RI 02882
PROJECT GOAL: To produce a step by step guide to reef restoration usable by grassroots organizations and stakeholders around the world.
Simple Coral Nursery
Chapters
1. Setting Goals, Budget Resources & Timeline
2. Damage Assessment
3. Rehabilitate Existing or Build New Reef?
4. Site Selection
5. Permitting
6. Base Substrate
7. Coral Rescue
8. Coral Propagation
9. Coral Planting
10 Monitoring
Appendixes
A. Red Mangroves
B. Oysters
C. Coral Team Glossary
Manual Objectives
1. Should guide the user through reef rehabilitation options in a step by step format with worksheets detailing completeness of each step.
2. Should focus on the proper use of artificial reef technologies, not excluding other options.
3. Should discuss options for coral propagation and planting, including direct transplant and genetic rescue techniques
4. Should be free on website, avoid jargon, emphasizes pictures and sketches, and have specific and illustrated glossary of ever tool, concept, supply or team role so results can be replicated easily even for non-English speakers.
VS
Hands on example: "Proper versus improper coral basing technique based on 10 years of project experiences and multiple studies."
PRESENT STATUS: Version 0.8 is available for download at www.reefball.org. Revision 1.0 is due after ICRS submission deadline in August, 2008. The manual will be continually updated over time as new research and procedures are developed so downloading the most current version is recommended for users.
About The Reef Ball Foundation
Mission Statement: To restore and protect marine ecosystems using Reef Ball artificial reef technology, innovative coral propagation and transplant techniques, public education, and community training to help communities build, restore and protect reefs.
Visit us at www.reefball.org
or ICRS Booth # 605
New concepts, such as EPVS, are introduced and guide complex choices
Exact tools & supplies needed are pictured and defined for coral propagation in glossary
Coral Propagation Table in Google Sketch Up as 3 d drawing to scale

<<This Section Cannot Be Completed Until Manual Version is Finalized>>

Alphabetical Index