Reef Balls ™: How Hotels, Tourism Associations, Cruise Lines and Others Use Designed Artificial Reefs to enhance the environment, create beaches and create tourist assets.

Todd Ryan Barber, President, Reef Ball Development Group, Ltd., Chairman, Reef Ball Foundation, Inc, 6916 22nd Street West, Bradenton, Florida, 34207 (tel 941-752-0169, E-mail reefball@reefball.com Website www.reefball.com, www.reefball.org)

Reef Balls are state of the art designed artificial reefs used primarily to restore ailing reefs or to create new reefs for ecological enhancement, fishing, scuba diving, beach erosion protection, and many other specific end use goals. Reef Balls have been used in over 4,000 projects worldwide with over 500,000 Reef Balls deployed. Reef Balls are the most widely used designed artificial reef system in the world. One of the fastest growing segments of the artificial reef market has been using reefs to enhance ecotourism.

There are a wide variety of projects using Reef Balls that fall within the boundries of enhanced tourism. Some examples include: Royal Caribbean Cruise Lines, Four Seasons Resort, Plantation PortaMari, and St. Marteen Nature Foundation Coral Propogation & Transplant Projects, Marriott Cayman Islands, Iberostar, Gran Domicus Hotel, Porto Progresso, City of Miami, and Hotel Mayan Palace Beach Restoration Projects. Reef Ball Foundation Ecotourist Reef Building Vacations (Dominica, St. Lucia, Turks and Caicos). Green Image projects from hotel associations like the Barbados Marine Trust. Underwater Scuplture parks such as Club Cozumel Carib in Cozumel. And PADI's European Project Aware Reef Ball program which is now in 5 European countries and growing rapidly.

Mr. Barber will give a powerpoint presentation that highlights these and other examples of how one can increase ecotourism and benefit not only the environment but also the tourist assets of a community.

Keywords: Reef Ball, Reef Balls, Artificial Reefs, Designed Reefs, Coral, Reef restoration, mitigation, beach erosion, scuba, diving, fishing, reefball, artificial reef

Related Web Resources: www.artificialreefs.org www.reefball.com , www.reefball.org, www.eternalreefs.org

1.0 Preface

This paper was written for the International Conference On The Role Of Divers In Protection Of The Marine Environment, Kuwait, 22-25 May, 2000. This paper does not reflect a scientific study, rather it is a combination of case studies, internal research and experiences of the Reef Ball Development Group, Ltd (RBDG) and related companies. The purpose of this paper is to provide a roadmap to organize a Reef Ball project. Supplemental reading for clients is found in the Reef Ball training manual(s).

For specific science on Reef Balls, it is important to note that the Reef Ball Development Group, Ltd. encourages outside research on Reef Balls and provides free molds to universities and researchers to build Reef Balls for research. We archive worldwide research on artificial reefs at www.artificialreefs.org where you can find thousands of scientific papers on Reef Balls and artificial reefs in general.

2.0 Introduction

Reef Balls are state of the art designed artificial reefs used primarily to restore ailing reefs or to create new reefs for ecological enhancement, fishing, scuba diving, beach erosion protection, and many other specific end use goals. Reef Balls have been used in over 1,000 projects worldwide with over 100,000 Reef Balls deployed and functioning as reef ecosystems. Projects are already proposed or planned that will bring this total to over 1,000,000 Reef Balls within 3 years. Reef Balls are the most widely used designed artificial reef system in the world. Reef Balls are widely used because they are cost effective and have significant unique features that allow them to be adapted to mimic nearly any natural reef system, are easy to construct, and because they have been proven and well documented.

Because Reef Balls are designed artificial reefs, rather than "materials of opportunity," they can be altered to fit specific design criteria to enhance to achievement of the goals of any individual reef construction project. Defining the precise nature of the goals of individual reef project is an important part of the process of creating Reef Ball reefs.

Once goals are established, reef builders must customize the Reef Balls to match the intended use of the Reef Balls. The experiences of other reef builders using Reef Balls for similar goals is an excellent starting point to begin assessing the alternatives available, but local knowledge (often including the interviewing of local divers and fishermen) and investigation are key to fine tuning the Reef Balls for each individual project.

Major variables which are often considered as part of this process include site selection, number and sizes of Reef Balls to be used, layout of the Reef Balls, and specific design features (hole sizes, weight, surface textures, concrete mixtures, etc.). The site selection process includes pre-selection bottom surveys by divers to assess pre-existing habitats, bottom composition, depth below sand to hard bottom, and other factors that insure the reef will function properly. Site selection is perhaps the most important factor that contributes to a successful reef building project.

The next task is to plan for construction and deployment of the Reef Balls. The construction planning involves considering a wide range of alternatives that are often constrained by either budget or time. The deployment of Reef Balls also presents many alternatives that may have similar constraints, but that also entail other factors such as weather, diver availability, and regulatory matters.

Concurrently, a monitoring plan is created to allow the reef builders long term feedback on how well the goals of the project are being achieved. Good monitoring programs suggest on-going improvements to the project or future projects as gauged by the project goal(s). Most methods include the use of scuba divers for monitoring, often involving video or photographic documentation, species counts, or other scientific data gathering methods.

Scuba diving plays an integral part in all phases of Reef Ball planning, construction, deployment and monitoring. Reef Balls were made to mimic natural reef systems in both species diversity and population density, but a requirement of their design was to be aesthetically pleasing...a feature added specifically for scuba divers who will enjoy diving on the reefs. A team of 27 folks with various multi-disciplinary functions designed Reef Balls sharing one thing in common, they were all scuba divers.

Over 50% of all Reef Ball reefs are built to support scuba diving activities and scuba divers have been involved with virtually all Reef Ball projects. Some tasks, such as monitoring and deployments can be very difficult without scuba divers, yet nearly effortless and often fun with scuba divers involved. All areas of the reef building process should involved local divers when possible. In the construction phase, for example, local divers may have ideas from observation as to hole sizes, surface textures or other design features that will accommodate local species. In planning the location, divers have first hand knowledge of bottom characteristics, currents, visibility, and even negative factors such as the presence of pollution. Divers can almost always be counted on to volunteer time to help build and deploy Reef Balls too. Diving can also be one of the goals of a reef project, when this is the case, diving constraints need to be added to the equation such as maximum depths, depth profiles, optimal sizing to be explored during a single tank dive, etc. The role of the scuba diver in Reef Ball reefs is integral and nearly always required.

3.0 Reef Ball Features

Reef Balls have a variety of features that are customizable by the reef builder to meet project goals. Some of the variables that can be tuned to meet natural conditions include:

3.1 Stability

3.11 Definition of Stability

In order for a reef to function properly, it must last as long as natural reefs do...often hundreds or thousands of years. There are 5 major components of stability:

1) Resistance to destruction of the material by storm (physical processes),
2) Resistance to destruction of the material by time (chemical processes),
3) Resistance to movement by storm,

4) Resistance to loss of orientation by storm (overturning or rotation),
5) Subsidence (settling into a sandy or muddy bottom).

To overcome destruction of the material by storm, a strong material should be used. Any design that involves movement of any parts (such as with popular kite FADs [fish attraction devices]) etc. will not last over time in storms. Reef Balls use high strength, abrasion resistant, concrete to withstand storms, anchor drops, and passing debris without destruction.

To overcome destruction of the material by chemical processes, the material chosen must have a known resistance to seawater. Wood, iron, steel, many plastics, and non-marine grades of concrete all have limited lives in seawater. Reef Balls utilize a concrete mixture that is highly impermeable and resistant to chloride ion attack. Structurally, Reef Balls are designed to last over 500 years in seawater. With the aid of some protection from the natural reef that grows around the concrete, Reef Balls are expected to last indefinitely turning into a natural reef over time.

To overcome movement by storm, physical engineering is required which takes into account the expected storm sizes (in terms of wave heights and periods) verses the material being used. When using "materials of opportunity", this must be calculated for each material and location. Reef Balls have been designed to offer the greatest stability possible with the minimum amount of concrete for the unit's height, and have proven universally stable in ocean depths of greater than 10 meters. For depths less than 10 meters, a complete stability analysis has been conducted by the Florida Institute of Technology and the additional weight required in for any given sized Reef Ball can be computed. To date, Reef Balls have never moved in any storm event including the direct hit of several major hurricanes.

NOTE: There are significant engineering features which address stability built into Reef Balls such as the top opening to resist lifting forces, a wavey bottom to increase drag on the seafloor, and side holes to allow passage of wave energy. For a complete rundown of these features please refer to our web site.

To overcome overturning, weight distribution is important. Reef Balls are designed with 80% of the weight of each unit in the bottom 20% of the unit's height. This makes them impossible to overturn by storm events.

Rotation is caused when forces are exerted unevenly on a unit. Resistance to rotation is seafloor friction, which is essentially a combination of bottom weight (calculated by the weight of the material less displacement) and the co-efficient of friction at the sea floor. Different sea floor beds have different co-efficient of friction. Reef Balls have a wavy bottom to increase the friction. However, rotation can only occur in materials that unevenly present themselves to currents or waves. Reef Balls are rounded and symmetrical so that rotational forces are not exerted to any great extent. Rotation usually occurs in materials that are elongated, or that have flat vertical surfaces, where rotational forces are greatest.

When subsidence occurs, materials are buried in sand or mud and can loose much of their functioning surfaces. **Subsidence is one of the greatest challenges in the Arabian Gulf due to a high percentage of shifting sand bottoms.** The best resistance to subsidence is a good bottom survey to select a location with a firm bottom, or a firm bottom at a known depth below softer bottoms. In cases where a soft bottom must be used, Reef Balls can be made with a solid bottom (rather than the standard method which has a single hole in the bottom) and lighter reef balls can be engineered (a small amount of subsidence actually increases other forms of stability).

Our internal work has shown that clustered Reef Balls have less of a chance of subsidence than individual Reef Balls probably due to the disturbances caused by the whirlpool generating side holes which might keep sands that would otherwise settle in suspension. When deploying on sand or mud, a particle distribution size analysis is one of the best tools to help predict if a reef will subside. Only qualified physical engineers should interpret sand size distributions. Since Reef Balls are inexpensive, another common method often used is to put one or a few units down in an area as a test to check for subsidence after a given period of time.

3.12 Overall Weight Adjustment

If the stability analysis concludes that additional weight is needed for applications less than 10 meters, the center bladder in the mold can be inflated less which can increase the weight of each unit (up to double the standard weight). Note: Reef Balls may require additional flotation in addition to the center bladder for floating deployments if the weight is increase. In the same way, Reef Balls can be made up to 30% lighter than standard weights by over inflating the center bladder for deep deployments, protected areas, etc. where stability is not an issue to save on concrete costs. Extra weight can also be accomplish by the addition of stones or other materials in the center of the Reef Balls after deployment, addition of concrete "footers" or the addition of anchors in extreme environments such as beach protection projects.

3.2 Holes

3.21 Void Spacing

Reef Balls have an internal void to allow for fish to shelter from currents (whereby conserving valuable resources) and to allow for a floating style deployment. When this space is left open, it will provide shelter for fish up to the size of the void. Many projects seek to enhance the survival and growth of smaller fish. In these projects, filling Reef Balls with rocks, cinder blocks, or other suitable materials can divide void spaces. This increases unit complexity and enhances juvenile habit by creating multiple small voids.

3.22 Hole Sizing

Every Reef Ball is unique because the inflatable balls that create holes in the Reef Balls can be moved and they can be inflated to different sizes before each casting. By placing two or more inflatable balls together, the reef builder creates a larger hole. The same occurs by putting more air (or less in the case of a smaller hole) to make a larger hole. Larger holes allow ingress by larger fish whereas smaller holes can act as a poor man's "predator exclusion device." Holes also increase the surface area of the units and many animals in the fouling community prefer to locate themselves next to the holes since the whirlpools they create also bring them food. There is ample literature on hole sizes and placement that can be drawn upon for particular issues.

3.23 Hole Complexity

Reef Balls, particularly the larger sizes, can have interconnected holes (holes that connect from one hole to the other rather than into, or out of, the Reef Ball like Swiss cheese) which create one form of complexity. Other complex hole shapes can be added endlessly to Reef Balls such as lobster holes created with sand on the bottom of Reef Balls or smaller holes created with small inflatable toys. One can add biodegradable items to create holes too. Reef Ball trainers will expand on the range of options.

Normal rounded Reef Ball holes are designed specifically to create vortexes (whirlpools) around the Reef Ball units. These whirlpools are important to bring nutrients to the growth on the Reef Balls. Vortex holes are especially important biologically near the top of the Reef Balls and for subsidence avoidance near the base of the Reef Balls.

3.3 Surface Texture

3.31 Physical Surface

In most applications, Reef Balls are made with a rough surface textures accomplished by putting sugar water on the side of the molds and rinsing the unhardened cement surfaces with water to expose aggregates in the concrete mix. This is suitable for most members of the fouling community. There are notable exceptions that prefer smooth surfaces such as abalone. Increasing the roughness of the surface of a Reef Ball greatly enhances the surface area of a Reef Ball. A smooth full sized Reef Ball has 130 square feet of surface area (12.1 m^2) whereas with a rough texture the number rises to 2080 (185 m^2)! Obviously, physical surface features impact what type of life that may attach and grow on the Reef Balls and should be carefully thought out.

3.32 Physical Surface-Micro

On a microscopic scale, small texturing is also important for larval stages of the fouling community to attach more easily to the reef. Therefore all Reef Balls use concrete which is air entrained. This means that there are tiny air bubbles in the concrete, which at the surface of the concrete make tiny pits for larva to hold on easier. It should be noted that it is sometimes difficult to find the admixtures for air entrained concrete in countries where freezing temperatures are not reached. An acceptable substitute is one teaspoon of non-perfumed, biodegradable dishwashing detergent per cubic meter of concrete.

3.33 Surface chemical composition (i.e. pH, exposed aggregates, etc.)

The chemical composition of the surface can also affect the settlement and growth of marine animals and plants. RBDG prefers that the pH of the surface matches that of seawater so that all marine life can settle rather than just species that are resistant to the higher pH. (See lecture handout) Different aggregates in concrete can affect settlement too. Limestone aggregate seems to be better for hard corals than granite. In cold waters where seaweed is desired, iron supplements are being tried, but this should be avoided in any water where hard corals are present. Some biotech companies are even working on coral attraction chemicals...perhaps in the future we'll know even more about how surface chemical composition works with reefs. For now, the best recom mendation is usually to make the surface as inert as possible, chemically.

3.4 Bottom Features

Reef Balls can have a variety of bottom shapes, typically wavy to allow for spaces for animals that live underneath the reef. Often, "caves" are added from the side of the Reef Ball toward the center for animals such as eels and lobster. Many other shapes on the bottom edges are possible depending upon the desired goals. The area were the reef contacts the seafloor can be an especially biologically active region and careful attention should be paid to this design feature.

3.5 Size of units in both height and width

Reef Balls come in at least 8 different sizes. From smallest to largest the are called, Model Reef Ball, Oyster Ball, Lo-pro Ball, Mini-Bay Ball, Bay Ball, Pallet Ball, Reef Ball, and Ultra Ball. See the following table for specifications.

Style	Width	Height	Weight	Concrete Volume	Surface Area	# Holes
Ultra Ball	6 feet (1.83m)	4.5 feet (1.37m)	4000-6000 lbs (1814-2722 kg)	1 yard 0.76m ^{3}	150 ft ^{2} 13.9 m2	29-34
Reef Ball	6 feet (1.83m)	4 feet (1.22m)	3000-6000 lbs (1360-2722 kg)	0.75 yard 0.57m ^{3}	130 ft ^{2} 12.1 m2	29-34
Pallet Ball	4 feet (1.22m)	3 feet (0.9m)	1500-2200 lbs (680-998 kg)	0.33 yard 0.25m ^{3}	75 ft ^{2} 7.0 m2	17-24
Bay Ball	3 feet (0.9m)	2 feet (0.61m)	375-750 lbs (170-340 kg)	0.10 yard 0.08m ^{3}	30 ft ^{2} 2.8 m2	10-16
Mini-Bay Ball in development	2.5 feet (0.76m)	1.75 feet (0.53m)	150-200 lbs (kg)	less than 4 50 lb bags		8-12
Lo-Pro	2 feet (0.61m)	1.5 feet (0.46m)	70-100 lbs (kg)	less than 2 50 lb bags		6-10
Oyster	1.5 feet (0.46m)	1 foot (0.30m)	30-45 lbs (kg)	less than 1 50 lb bag		6-8

Table 3.5 Reef Ball Sizes, Weights, Volume & # of Holes

There are obviously a lot of considerations in choosing which sizes to use. The most pop ular sizes are the Bay and Pallet Ball for a variety of reasons both biological and physical. It is a mistake to jump to the conclusion that the best size is the biggest one the project can physically handle. The goals of your project should determine the best sizes to choose. One observation from experience, the best reefs (in terms of matching species and population densities to naturally occurring reefs) are usually a combination of several different sizes.

As one might expect, the larger sizes tend to house larger fish and the smaller ones smaller fish...but the larger ones can be used for smaller fish by filling the void as previously mentioned with rock. Stability has only been calculated for Bay Ball and larger sizes, smaller sizes should not be used in areas where stability is a major issue unless inside of a larger Reef Ball.

About some specific sizes: The Pallet Ball is the largest size that can be rolled down a beach without lifting equipment and this requires 4-6 people. The Bay Ball is the largest size that can be moved underwater without lifting bags or lifting equipment. The Pallet Ball is the best size for stacking because it has a flatter top...it also fits well on flatbed trucks for efficient transportation on land. The Ultra Ball is best for beach protection or breakwater applications because it is the tallest and fits together with other Ultras to form less open spaces due to a high vertical slope. The Lo-Pro Ball will fit nicely on top of a Pallet Ball and an Oyster Ball will fit nicely on top of a Bay Ball if you want to reduce the size of the top opening (for predator exclusion). [Use heavy-duty nylon zip ties to secure them in place] There is an even larger experimental size, call the Super Reef Ball...but it uses 2.5 yards of concrete and gets very difficult to move. We do not recommend its use for normal applications. Before you select your size ratios, eliminate the sizes that are not appropriate (i.e. you don't have the equipment to handle or too small for stability).

3.51 Proportioning of Sizing Ratios

This goes right back to the goals of your project. However, if you are in an average or unknown situation and want a generic recommendation to best mimic an average natural reef follow these guidelines.

50% Bay Balls
35% Pallet Balls
15% Reef or Ultra Balls

Species specific observations:
Kelp prefers to attach to the shorter Bay Balls.
Adult Jewfish prefer Pallet, Reef or Ultra Balls, turned on the side or with very large side holes.
Pelagic species prefer Pallet or larger sized Reef Balls.

NOTE: Reef Balls give an "underwater signature" of double the physical height of the units. As documented by Japanese studies, fish use their lateral line nerves to sense low frequency vibrations of currents flowing across reefs. The whirlpool holes in the Reef Balls are designed to create a low frequency "whistle" in the range sensed by the lateral line. Therefore, a 4 foot tall Reef Ball will attract pelagic fish normally attracted to 8 foot tall structures.

Vary these guidelines according to the species you want to favor.

3.6 Density of units

The density or the number of Reef Balls over a given area will have a great affect on how the reef functions, just as we see natural differences between patch reefs and densely packed reef expanses. With the "default goal," the best rule of thumb is to mimic the density of the natural reef system in the area. Based on our experiences, an average of one unit every 3 meters or less will create a high diversity coral reef like environment, whereas spaced an average of 20 meters apart will create a reef system better for foraging fish such as grouper. It is important to note that density is an overall average of units per area, not specific spacing between each individual unit.

3.7 Other Configurable Factors

There are a variety of other options and probably many more for the creative mind not mentioned here. Some examples include:

-Predator exclusion devices (ways of physically blocking larger fishes from entering center void area)
-Concrete "bases" (by placing a reef ball in a pit dug into the sand and pouring concrete around it, additional footprint can be added to the units. Bases are also used to create mooring buoys with Reef Balls)
-Internal "Mounding" (a process where the inside of the Reef Ball is half filled with sand and liquid concrete is poured on top to create an internal mound)
-Reef Balls can be intentionally overturned or placed sideways (to create jewfish habitat)
-Units can contain plaques or signs
-Etc.

4.0 Goals of Individual Reef Projects

One of the most important difference between using "materials of opportunity" and designed reef structures is the ability to change the reef to met specific goals. RBDG has documented at least 300 different reasons to build artificial reefs...and we are quite sure there are many more. It is important not only to identify the goal(s) but to prioritize them if the project is multi-goaled (which in our experience is the vast majority of reefs built today).

However, it is also possible to build a reef with the "default" goal which should underlie all artificial reef projects...to create a reef that is as close to a natural reef as possible. RBDG defines a successful environmental reef as one that, "**closely mimics nearby natural reefs in terms of total species diversity and population densities**." This means no more or less species and no more or less densities of these species than what you would find on a natural reef with similar conditions. This applies to all life forms, not just fish. And an over-abundance of a particular fish* (even if a target species) is not usually desirable. (Over populated fish often over compete for resources and therefore exhibit reduced growth rates and fecundity [ability to produce eggs]).

* Note: These observations are to be based on long term averages, not individual observations as fish populations, in particular, are highly variable by day, time and season.

There are two major difficulties in assessing this...first is monitoring...how do you identify and count all the life forms? The second problem is to find a comparable natural reef. Natural reefs are often quite different even with close proximity and therefore this can be a difficult task since depth, currents, and a host of other factors come into play and affect species diversity and population densities.

Even with measurement problems, the goal is still appropriate. It is our experience that on average with a "standard" mix of Reef Ball sizes a Reef Ball reef will typically achieve 80% species diversity within three years. "Local tuning," the act of monitoring and fine tuning the reef to match local species requirements can bring this number above 90% within five years in many cases. Population densities also follow similar patterns. The number of years required to achieve this is longer in clear, tropical waters and faster in temperate or colder climates with lower species diversity. Currents and depth also impact these figures...currents often speed up the process whereas depth can slow things down. Again, there are local exceptions to all these observations.

Because RBDG, worldwide researchers, and the family of Reef Ball companies have built up a significant expertise in what types of modifications are required to meet specific goals, a well written project plan with goals clearly spelled out will help RBDG recommend the best starting approaches for our clients. There is no point in making the same mistakes that other reef builders have made...it is much more important to concentrate creativity and efforts toward fine tuning the Reef Balls to match local goals and species requirements.

5.0 Customizing or Designing The Reef

5.1 Site Selection

Site selection is perhaps the most important factor that contributes to a successful reef building project. The process for selecting sites can also be one of the most difficult aspects of reef building. This aspect is especially challenging in the Arabian Gulf due to the large expanses of seabed exposed to shifting sands that can bury a poorly sited reef.

First interview all constituents such as local divers, fishing folks, environmental agencies, governmental permitting agencies, etc. **nominate** potential sites. Everyone will have some suggestion, some good and some bad. It is easier to get input first to explain why certain site were not chosen then to explain later why a site was not considered.

The next step is to **eliminate** all areas known to be a poor choice...navigation channels, restricted areas, areas with user conflicts (i.e. shrimp trawlers, military operations, etc.), polluted areas, areas with known shifting sand bottoms, etc. Good maps and good local knowledge will save lots of time physically checking out bad spots.

Once you have narrowed down (on average only 1 in 5 sites is ideal so be sure to pick backups) sites to **validate**, it is time to solicit the help of scuba divers for a site surveys. You will need to find advanced divers, capable of using equipment underwater such as measuring tapes, slates, video cameras and probs.

A very basic, but highly affective survey technique is as follows.

Local the boat in the center of the area to be surveyed and take a GPS reading for the center point. Send divers down with a 25 meter measuring tape, a slate, a video camera, 5 zip lock bags and a 1 meter piece of iron rebar. At the center point, take a sample of sand, label the bag and record the bottom type. If sand, use the rebar to work into the sand until hard bottom is felt, record the depth. Move directly N, S, E and W of the center point and repeat. Now, roll the video camera and swim an inward spiraling circle around the center point with the distance between passes determined by the visibility and width of camera view...the idea is to document any life already existing on the site. Repeat this procedure for all potential sites and for additional zones if the site is larger than 50 meters across.

During the dives, divers should make any notes about each site that might affect the selection or removal of a site from the list. These factors may include, but are not limited to, visibly, currents, other users in the area, depth, tides, anchoring location, pollution, etc. It is also helpful to find objects of known age in the area where the growth can be observed...this can often reveal the type of reef growth to be expected.

If "live" bottom or reef already exists on the site, it cannot be used unless the deployment is such that the Reef Balls can be placed without harming these existing structures.

If the hard bottom is more than 1/2 meter below the sand, then a sand grain distribution analysis is required to determine if subsidence might occur or if measures need to be taken to minimize subsidence.

The final site selection **correlates** all the observations against the project goals to select appropriate sites. There are often additional regulatory matters that must be addressed to obtain specific permits that vary by country and locale.

Pre-deployment bottom surveys can be a relatively simple procedure, but if not performed, all of the reef building efforts can be wasted.

To summarize the site selection process:

-Nominate…your suspicions
-Eliminate…the troublesome
-Validate…by bottom survey
-Correlate…to project goals

5.2 Reef Ball Sizes & Quantities

In 95% of all reef-building projects, the limitation on the number of Reef Balls to be used is budget constraints rather than biological or physical constraints. So in most cases a sound approach to sizing a project is to determine a project budget, apply the ratio of sizes which were selected by biological and physical factors and then with simple math, determine how many Reef Balls can be made.

As a good rule of thumb, the following are the average prices Reef Balls sell for in the US delivered to the staging area. Outside the US the prices can vary...usually based on three major factors, cost of labor, cost of concrete and size of project.

Bay Ball =$80 ($25 Kuwait Dollars)
Pallet Ball=$180 ($55 Kuwait Dollars)
Reef/Ultra Ball=$300 ($92 Kuwait Dollars)

To help with cost estimates, here are some of the factors to consider (movement and cleaning included in labor estimates and concrete wastage including in concrete estimates)

	Labor	Concrete	Low/Medium/ High Project Size <100 / 1000+/ 10,000+
Bay Ball	1.25 hours	.15 (.1 m^3)	+20%/-10%/-35%+
Pallet Ball	2.0 hours	.4 (.3 m^3)	+25%/-15%/-40%+
Reef/Ultra Ball	2.5 hours	.9 (.7 m^3)	+30%/-20%/-45%+

US Estimates are based on an average labor cost of $US 10/hour ($3/hour Kuwait Dollars) and a yard (.76 m^3) of concrete with all admixtures costing $ US 80 ($25 Kuwait Dollars). Costs estimates are for a contractor company making Reef Balls with an allowance for profit, reduce estimates by about 30% if the project is done in-house for larger projects or if the project is conducted on a non-profit basis.

Deployment costs vary widely and depend upon the deployment style. Options range from low equipment cost/high labor floating deployments to high equipment /low labor barge deployments. Deployment costs are typically range from 10% of construction costs to 100% of construction costs. Each site is different and must be evaluated to nail down deployment costs.

The important thing is that with Reef Ball, the reef builder has many choices in how to deploy the Reef Balls. There are advantages and disadvantages to each. Divers are required whenever precise placements are required (i.e. when there is existing reef in the area that must be avoided or when stacking is desired, etc.).

When comparing costs of Reef Balls verses other materials be sure to factor in surface area comparisons (the active part of the reef) and longevity (how long the reef will function). It will become obvious why Reef Balls are the most cost effective reef which can be built.

5.3 Layout Or Spacing On The Sea Floor

There are some interesting studies on this topic (i.e. Bill Lindberg, University of Florida) that indicate for some species (Gag grouper in particular) that there needs to be "foraging space" around reefs. But this area of science is still in its infancy.

In general, one will see a higher population of adult fish around clusters of Reef Balls than on individual units. Diversity appears to be higher in larger clusters too. However, individual units are often seen with more juvenile fish. Fish use the spaces between Reef Balls as additional void space when the Reef Balls are close together. Keeping Reef Balls close to each other also aids in reducing subsidence as mentioned earlier. Reef Balls can also be used to link existing reef areas and can serve as "stepping stones" from juvenile to adult habitats. However, there are local exceptions to all these observations.

For the most part, random deployments seem to function as well as rationally laid out plans as far as biology goes if the density and ratio of Reef Ball sizes are held constant over a given area. (and assuming there is adequate clustering). However, there are reasons to consider a specific layout.

For example, consider access by scuba divers. We have found that figure "8" style deployments are good for divers. [See Figure 2] Also, it is possible to use Reef Balls for navigation underwater...i.e. a trail between two ship wrecks or will a single square hole in each Reef Ball facing the center tie up buoy.

Fishing folks prefer a more spread out reef than divers do so that boats don't get too crowded. [See Figure 1] The point is, there are physical, environmental, end user and other considerations that must be taken into account to determine the best layout. And don't forget to look at the natural reefs...if they are all in lines, consider that pattern as potentially important. There are a large number of factors that help to determine a good reef layout.

5.4 Specific Design Features

There are obviously lots of different ways to customize your Reef Balls. RBDG will have lots of good ideas and suggestions for a project if one has well defined goals. The rest will come from a good monitoring program with feedback to the construction and deployment phases, local research and observations, experimentation, and creativity of the folks involved with the project. An important component is also feedback to RBDG, without this feedback, other reef builders will miss the benefit of your program's successes and failures.

There are some guidelines of what CANNOT be done in Reef Ball projects.

-Do not use any materials which contain known toxins
    -Such as heavy metals, petroleum products, tires, degradable plastics, etc.
-Do not use any materials which are known to be biologically active (unless part of an experimental treatment)
    - Iron or other active minerals, fertilizers, food sources, etc.
-Do not use any materials which can disassociate
    -Wood, objects that breakdown over time, etc.

In general, RBDG considers a good reef material to be :

1) Proven stability, generally dense materials of moderate to low profile.
2) Contains no toxins (heavy metals, petroleum, PCBs, etc)
3) Contains no biologically active compounds (iron, copper, fertilizers, vitamins, etc.)
4) Offers high complexity (multiple entrances, exits and places where fish can swim to shelter in at least 3 different directions)

5) Offers at least one internal cavity which fish can use to shelter from currents
6) Long lasting material that should last at least 50-100 years...longer if in the tropics.
7) The reef creates a similar species and population density of all marine life when compared to natural reefs in the same area.

Bonus) And of course since the Reef Ball group is made up of divers, we like to see things that look natural or are interesting.

Try to make sure your modifications stay within these guidelines for best results.

6.0 Building and Installing Reef Balls

Reef Balls are made by pouring concrete into a fiberglass mold containing a central Polyform buoy surrounded by various sized inflatable balls to make holes. Eight mold sizes are available. Molds can be leased in the US or bought with a copyright license internationally. Any type of concrete can generally be used, including end-of-day waste, but additives are needed to give the Reef Balls high strength and to make the concrete suitable for marine life growth.

RBDG provides clients with custom concrete specifications depending upon your biological goals and material constraints (i.e. availability, budget, etc). Building an artificial reef usually requires artificial reef permits or access to use a permitted area. RBDG can help clients get or secure permission to use a permit, particularly in the US, but the responsibility is left with the client. A training manual on how to use the molds and how to deploy the modules is also included with the mold systems.

Authorized Reef Ball contractors can provide additional on-site training to make sure your project goes smoothly and are highly recommended. Special programs are available to subsidize university research projects and other worthy projects through the Reef Ball Foundation. Reef Ball Foundation also encourages participation in projects by private organizations and has several sponsorship packages available for companies that want to help the environment while gaining excellent press exposure. The Reef Ball Group was formed to help folks build quality artificial reefs.

6.1 Construction

One of the decisions facing Reef Ball reef builders is to decide if it is best to make the Reef Balls themselves or to hire an authorized contractor to make the Reef Balls for them. The question is often more than just economics, because the act of building a reef can in itself be an educational and rewarding activity. It can also be time consuming, problem ridden and expensive...it all depends on the circumstances and resources of the reef builder.

6.11 In House Construction

80% of Reef Ball's international clients choose to purchase their own molds and build Reef Balls in house. 95% of these elect to have an authorized Reef Ball contractors train them for a week or two to get things started. In the United States, 80% of Reef Ball's clients choose to have an authorized contractor build and deploy the Reef Balls for them, whereas only 20% purchase molds. Economics have a lot to do with these statistics...because many of our international clients are in areas not served in a cost effective way by the network of authorized contractors. However, the network is growing and more international clients are being served by authorized contractors.

Most clients that plan to build Reef Balls themselves plan long term, on-going projects with their molds. Molds represent an initial investment and the cost per Reef Ball declines as molds are used more often. Reef Ball has molds still in service after 8 years that have produced thousands of Reef Balls. Reef Ball molds need only minor maintenance to last indefinitely. It may be difficult, however, to justify the cost of a mold system to produce just a few Reef Balls.

One of the first questions to be answered is if the project will utilize concrete from ready mix trucks or if concrete will be mixed by hand. In the case of trucks, most clients elect to have enough Reef Ball molds on hand to accept the minimum amount of concrete required to have concrete delivered (in most cases this is from 2-4 meters of concrete). If mixing by hand, this is not a factor.

After that, computing the number of molds required is a simple matter. Most projects build one Reef Ball per mold per working day. As a rule of thumb 8 of 10 business days are working days with the other two reserved for bad weather, clean up and maintenance tasks. (Two castings per day are possible, but rare because it requires a second shift).

Labor or volunteers is another component that must be computed. With paid labor, two men can operate up to 20 molds in a day. With volunteers, double or triple the number of workers. No single task requires two people so all the work can be done by a single individual, but for volunteer labor the fun is lost by working alone.

Labor varies greatly from site to site depending on variables such as working condition (i.e. heat), availability of tools, and how the concrete is being produced. It is best to talk to RBDG about the specifics of your project when trying to estimate the amount of labor required to operate the molds.

6.12 Hiring an Authorized Contractor

Reef Ball has 17 worldwide authorized contractors, trained to build and deploy quality Reef Balls at the best possible price.

If you are looking into a large project, it is almost always cheaper to contract with an authorized contractor. If you are only considering a small or medium sized project, it is still sometimes worth contracting it out. With an authorized contractor, you know you are getting Reef Balls built as then are intended to be built and with the added quality insurance that at least 95% will be deployed upright and intact. Some projects are large enough to warrant the commissioning of authorized contractor status to a local company capable of building and deploying Reef Balls. Contact RBDG for information on becoming an authorized contractor.

To find a current list of authorized contractors, go to www.reefball.com/contract.htm on the Internet.

6.2 Deployment

Reef Balls are the only reef materials that can be floated to the deployment site with an internal bladder using any sized boat. Therefore, there are some unique options for deploying Reef Balls not available to other types of reef projects. One major advantage of doing small deployments over a long time frame is that species diversity is observed to be larger on reefs that are deployed at different times during the seasons. (This is likely due to different settling organisms being available for colonization at different times of the year).

At any rate, the reef builder must decide which method of deploying is the best. And like construction, more than economics can enter the picture. Floating deployments have been conducted by even personal watercraft so they allow anyone with a boat to help such as when volunteer involvement is desired. Barge deployments are often the most reliable for tough weather, large jobs or jobs far offshore.

6.21 Floating Deployments

When fitted with the included flotation bladder, Reef Balls can be towed out to sea at speeds ranging from 2 -5 knots depending on engine size and towing line capacity. As you approach 5 knots, fuel consumption goes up. Conversely, At 2 knots or less there is very little drag. A swimmer with fins can actually push a floating Reef Ball several hundred yards when there are no currents without undue effort. Reef Balls should not be floated when seas are greater than 2-3 feet (.75-1 meter).

For (lifting) equipment free deployments of even larger sized Reef Balls, it is possible to cast the Reef Balls on a boat trailer and later launch from a boat ramp directly. Pallet Balls and Bay Balls can be built on the beach and rolled dire ctly into the water without equipment too.

Always add an extra buoy tied to the top of the floating Reef Ball for extra buoyancy in case a wave submerge the Reef Ball temporarily (which reduces the lifting force of the bladder due to increased water press ure) and to mark the Reef Ball for passing boats. The Reef Balls are designed to float only a few inches out of the water. With divers, let enough air out where the Reef Ball is nearly neutral and stand on top, the increased pressure on the bladder will cause the Reef Ball to begin sinking. After it lands, the divers can descend and before the air is let out of the bladder it is easy to move around to the desired location (a lift bag may provide additional assistance for the largest sized Reef Ball when deployed in deep water). Once in place, let the air out and remove the center bladder.

If deployment without the assistance of scuba divers is required, put a second floatation bladder attached to the top of the internal bladder. Remove the air valve from the bladder inside the Reef Ball and the Reef Ball will release from the internal bladder and descend to the sea floor. With this method, expect 5-20% of the Reef Balls to land on their sides rather than upright depending upon depth. Care must be take n with this method to insure that Reef Balls do not land on each other because breakage can occur with impact.

Fresh water deployments may need to add additional floatation due to the lower density of fresh water. Reef Balls made heavier than standard weighs may also require additional flotation.

Hybrid deployments are possible such as pushing Reef Balls off of barges with the internal flotation bladder installed. This allows divers to position Reef Ball precisely on the seafloor.

It is not recommended that clients do a floating deployment without training from RBDG or an experienced authorized contractor. Over-inflated center floatation buoys can break Reef Balls and sometimes with enough force to be dangerous. Properly inflated floatation buoys left in the hot sun can also expand enough to cause the same problem...even when floating in the water.

6.22 Barge Deployments

When the projects are large or when the selected site is a considerable distance from the staging area, the use of a barge, landing craft, or other vessel may be the most economical or most expeditious method of deploying Reef Balls. There are several methods used to off load the Reef Balls from the barge depending upon the project goals and equipment available.

The preferred method is to lower the Reef Balls to the sea floor with a crane. A special release mechanism has been designed that allows for an unaided release of the Reef Balls from the crane once the Reef Balls contact the sea floor. With this method, it is possible to use spreader bars in various configurations to deploy multiple Reef Balls at one time. This can provide an exact bottom cluster configuration and is highly desirable.

A second method entails "parachuting" Reef Balls to the sea floor with flotation bladders attached to the top of the Reef Balls designed to release as specific depths. When this method is used, the Reef Balls can be pushed over the side with a front end loader, Bob Cat, hand pulley systems, or rollers.

Another method involves lowering the Reef Balls over the side and using a "Pelican" quick release to just let them drop to the sea floor. As with unaided (without diver method) floating deployments, expect 5-20% of the Reef Balls to land on their sides rather than upright depending upon depth. Care must be taken with this method to insure that Reef Balls do not land on each other because breakage can occur with impact.

The worst case scenario is just pushing Reef Balls over the side. With this method, 50% or more of the Reef Balls may be on their sides or even upside down. With this method, divers should be sent down after the deployment with large lift bags to upright the units and position them as desired.

In any of the "free falling" methods, make sure that the Reef Balls have maximum strength by following good concrete methods and allowing the Reef Balls to cure in a humid environment for at least 30 days. This will help prevent breakage. If Reef Balls are broken, pieces not connected to an intact bottom ring of a Reef Ball should be placed inside intact Reef Balls as added internal complexity. Units broken, but with an intact lower bottom ring, can remain in place and will function as habitat.

7.0 Monitoring & Modifying Reef Design

In order to be a successful reef builder, the process of building reefs must constantly be improved, refined and adjusted to achieve the project goals. An effective and regular monitoring program, with direct feedback to the construction and deployment phases of the reef building program is the best way to insure success.

An entire paper could be written on monitoring Reef Balls, and in fact many have, so it is important to do further reading if you are tasked with designing a monitoring plan. Much like a reef building program, you need specific mon itoring objective to be able to best design the monitoring protocol for an individual project.

GM, a Reef Ball Contractor in Australia, has developed a categorization of monitoring types that helps to define some monitoring standards as follows.

"Monitoring Type Categories

The following is designed to reduce confusion and help make it easier for everyone to understand the various types of monitoring that may be required, planned or actually taking place. These 'Type' categories are also ideal for labe ling monitoring sites on your maps. Please feel free to use them!

TYPE I
NO counting of organisms in the field or from video or photos taken.
Examples:
- Measurements, distances, depths, current speed, visibility, temp etc
- Mapping of prominent features, bottom types.
- Recording species present but not abundance, i.e. 'counting'.
- Identification and area measurement of impacts such as anchor damage or coral bleaching.
- Photo or video documentation encouraged but not with the intention of using if for percent cover or species counts etc.

OBJECTIVES

?? General site characterization (includes mapping) to help determine need for further studies and to provide the basic information needed for planning future work.
?? Description of species present in order to initiate species inventory of the area

TYPE II
Counting of organisms but NO permanent transects or permanent markers.
Examples:
- Species counts along temporary transects or within quadrants etc.
- Percent cover estimates.
- Crown of thorns or other introduced species counts.
- Photo or video documentation encouraged and to be conducted in a way that enables future analysis for percent cover or species numbers etc.

OBJECTIVES

?? Surveys to determine number of different species and/or number of particular individuals per area.
?? First Type to use transects or quadrants.

TYPE III
Permanent transects or markers.
Examples:
- Installation of permanent transects or permanent markers or tags.

- Photo or video documentation to be later used to count percent cover or species numbers etc.

OBJECTIVES

- ?? Highest level of monitoring and can be used to detect changes with time.
- ?? Only Type to use permanent transects or markers. "

There are many goals of monitoring that directly impact what type of monitoring program to undertake. Here are a few examples,

-Compliance Monitoring
    -Regulatory Permits
    -Grant Requirements
-Biological Monitoring
    -Species Diversity
    -Species Densities
    -Fish Censuses
    -Fouling Community Censuses
    -Sand Bio-sampling
    -Other
-Stability Monitoring
    -Any of the five stability types
-Longevity Monitoring
    -Chemical Breakdown
    -Physical Breakdown
    -Subsidence
    -Other
-Comparison Monitoring
    -Features
    -Layout or Groupings
    -Reef Design
    -Natural Reef
    -Other
-Effectiveness Against Goals
    -Quantitative
    -Qualitative
    -Economic
    -Other

There are also many monitoring protocols that have already been developed such as REEF and RECON. For standard monitoring practices and comparison to worldwide data these can be effective systems to implement. However, our experience is that an overall custom program should be designed to best match capabilities to available resources. The best monitoring programs are installed with long term objectives and continue over time. It is very difficult to come to valuable conclusions without the ability to look at data over time.

8.0 Scuba Diving and Reef Balls

Scuba diving, and the role of the scuba community, is integral to every aspect of the reef building process with Reef Balls. Although it is technically possible to create a

Reef Ball reef without scuba divers, the reality is that scuba divers are nearly always involved...heavily.

Scuba divers are the only group of humans on the planet that see, from day to day, the amount of destruction going on in our world's oceans. If man was destroying land at the rate we destroy underwater habitats, everyone would see this and work to correct the problems...but since underwater is out of sight for most people, the world must rely on this group of pioneers, the scuba diver, to sound the alert. Therefore, many Reef Ball projects are started or inspired by scuba diving clubs, organizations and individuals.

After the start, scuba divers are often involved in the planning phases, volunteering in the construction phases and actively involved with scuba diving for the deployment phase. After the Reef Balls are installed, on going monitoring and scuba go hand in hand. Even a pleasure scuba visit to the Reef Balls is an ongoing engagement with the new reef. All scuba divers should be involved in preservation, conservation or restoration of reef systems, or our grandchildren may not have the same pleasures from scuba diving that we enjoy today.

Acknowledgements

The following companies are part of, or directly licensed by, the Reef Ball Development Group, Ltd. and have contributed to the information in this paper. Information about these companies can be accessed from the Reef Ball web site. Within this paper, companies will be refereed to by their abbreviated names .

Reef Ball Development Group, Ltd (RBDG), Reef Ball Foundation, Inc. (RBF), Reef Ball Coalition, Inc. (RBC), Eternal Reefs, Inc. (ER), Reef Innovations, Inc. (RI), Coastal Reef Builders, Inc. (CRB), Geothermal Energy Management (GEM), Green Marine, International (GM), Reef Ball New Zealand (RBNZ), Instituto Ecoplan (ECOPLAN), Ecoturismo Mundial Y Proyectos Ambientales, World Ecotourism & Environmental Projects Co. (EMPACA), CORALations, Inc., MariLim (ML), Roman Stone Construction Company (RSC), Sea Systems Inc. (SS), Cosmo Enterprises (CE), Neptune Resources and Ride Innovations, Inc. (RI).

One can access information about any of these companies at www.reefball.com/contract.htm.