“Designed” Artificial Reef Program for Bahrain

For

Ministry of Works and Housing
Special Projects Department
Kingdom of Bahrain
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Submitted to

Jassim Al Qassir

By The

REEF BALL
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With Team Partners Including

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Kuwait Reef Ball Company

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Background

In 2002, Jassim Al Qassir graciously invited the Reef Ball Foundation (RBF) to visit Bahrain and to offer our suggestions for an improved "designed" artificial reef program. Due to scheduling conflicts, this trip was postponed. In July 2003, Reef Ball staff was in Kuwait to train Kuwait Reef Ball so Jassim Al Qassir re-offered to sponsor a visit. Todd Barber, (CEO of the Reef Ball Development Group, Ltd.), Mike Symns (President of Kuwait Reef Ball), and Dr. Lee Harris of the Florida Institute of Technology accepted his invitation. Reef Ball conducted three brief underwater surveys of some Reef Ball like structures created in 2002 and of a nearby natural reef. Reef Ball interviewed fishery staff and reviewed several other sources of information about marine problems facing Bahrain. We also visited the Ministry's aquaculture facilities and storage area for artificial reef materials of opportunity. As a courtesy to the Bahrain Artificial Reef Program, we wrote this report.

Between the initial invitation and the visit, Delft Hydraulics and A.S.R. completed a (draft) report on Artificial Reefs in Bahrain that was reviewed by Reef Ball before writing this report. The Delft report largely represents a review of published (scientific) information on Artificial Reefs but lacks practical relevance (and experience) and is unnecessarily complex. In particular, the report is weak in its understanding of the "designed" approach to artificial reef development. Therefore, to best supplement the Delft report, this report will focus concisely on the direct and practical enhancement of the Artificial Reef Plan. Because we only had a very limited site visit, this report was written from the perspective "What we would do in Bahrain if given the task of developing the Artificial Reef Plan" rather than from an internal perspective.

Primary Impacts and Issues -Bahrain Marine Resources

Even on our short visit, it was clearly apparent that dredge and filling operations, intensive shrimp trawling, and active local and foreign fisheries have largely reshaped Bahrain's marine ecosystems. The damages/changes were so apparent that it was not surprising that the Directorate of Marine Resources was actively developing an Artificial Reef Plan to guide the offsetting of damages/changes occurring to the marine environment. Practically speaking, the developmental and fishery activities are likely to continue and even if curtailed they will continue to be the most significant factors shaping the marine environment in Bahrain for some time. Whereas other countries may have artificial reefs programs with general goals, the dominating forces for the artificial reef program in Bahrain is to address and reverse these major impacts which affect fisheries, species diversity, recreational opportunities, species of high economic value, and other marine resources. Like other programs that need additional enforcement capabilities, artificial reefs in Bahrain may also be used to help regulate (i.e. anti trawling reefs), mitigate (i.e. required for dredging or filling permits), or compensate (i.e. to offset losses to fishing people in the case of new marine reserves, etc.) as a tool of active fishery/resource management. Regardless of the many possible benefits of artificial reefs, Bahrain is faced with dredge and fill, shrimping /netting and fishery practices that have resulted in a need for more active marine resource management to minimize impacts and maximize the asset value of Bahrain's marine resources through its Artificial Reef Program.

Impact of Dredging and Fill Operations

Years of dredging and filling operations in Bahrain have lead to significant economic gains for Bahrain, but have come at a price in terms of the marine environment. Sedimentation has resulted in the direct covering of many reef resources, stresses on remaining corals and low visibility near shore resulting in lower productivity. Sedimentation has also created areas of soft (rather than hard) bottom that is permanently unable to re-develop into reef systems. Direct changes to the shoreline have resulted in the loss of inshore juvenile fishery habitats such as mangrove and estuary systems. Combining these activities with other marine impacting on-land activities and it is clear that, in particular, the near shore marine ecosystems in Bahrain have lost a great deal of productivity.

Although Bahrain has not had a proactive mitigation program requiring dredge or fill operations (or other resource damaging projects) to offset potential marine resource damages, the Directorate of Fisheries has been working in this area. In 2002, one mitigation project with three deployments of Reef Balls like structures was accomplished. The Directorate of Fisheries is facing a difficult challenge to require mitigations since Bahrain has not required marine mitigation in the past and contractors are typically required to keep a variety of contingency fees aside instead (which have rarely been used for mitigation). Further complicating the process is the fact that it is relatively difficult to measure the impact of a single dredge or fill operation over the background noise of thousands of operations over the years. Even with these difficulties, mitigation programs have proven successful in much of the world to help maintain a balance in marine ecosystems verses the need for economic growth and expansion.

High sedimentation systems limit coral growth and therefore reduce the surface complexity of natural reefs. Fouling community members normally found at the base of reefs also try to migrate higher on reefs to reach the more limited sunlight in turbid waters and to avoid higher sediment loads traveling near the seabed. Artificial reef designs for Bahrain need to address this issue either by site selection or material design that will be addressed in the design section of this report.

Impact of Intensive Shrimp Trawling

Just above the seafloor, complexity in the natural reef systems has been greatly reduced in Bahrain by the dragging of nets across the seabed. We witnessed hundreds of examples of reef scars from nets and trawling in our short survey. Interviews and reports indicated that nearly every marine area in Bahrain has been affected to some degree by netting and trawling damage. One can picture a forest made up only of tree stumps instead of trees and envision exactly the type of damage that has occurred over vast areas of the Bahrain marinescape. Several regulatory attempts have been made including the prohibition of steel hulled trawler and addition of seasonal requirements; however, trawling efforts continue to climb even while facing reduced catches. Shrimp trawling has an extremely high percentage of by-catch and is therefore a very inefficient use of marine resources from a management point of view.

Presuming that these activities will be difficult or impossible to stop, artificial reefs used in Bahrain will need to be resistant to net damage and should mimic the types of above seafloor complexity destroyed by netting damage. This will require a specialized artificial reef design in Bahrain that will be addressed in the design section of this report.

Impact of Fisheries

There are several types of local fisheries that are impacting marine resources. The least damaging are the traditional fish traps and hook and line fishing. Although there are no enforced species or size limits, these methods do not create substantial habitat damage and therefore fisheries could recover when management techniques are used. However, drift nets/ gill nets are still used to some degree and they not only reduce fish stocks but also dama ge marine habitats. Given a review of the published fishery numbers, it is much more likely that fish stocks are declining due to habitat losses than from direct fishery take except for a few highly exploited species (such as shrimp). In contrast to the Delft Hydraulics report, we believe that Hamour (grouper) and bream (perches) in particular are much more likely habitat limited and not over-exploited by direct fisheries which better explains fluctuations in fish stocks over time. Rabbit fish, lobsters and crabs are partially reef dependent and likely fall in between. Pelagic fish such as Spanish mackerel, and other semi-reef dependent species are probably over-fished and suffering from region wide habitat loss rather than habitat loss only in Bahrain. Given that there are substantial harvests of fishery targets, Artificial Reefs in Bahrain should be designed to slightly favor the habitat preferences of the key targeted species. This will require some specialized design points such as reef layouts and materials design.

Artificial Reefs As A Management Tool…"Designed Reefs"

The Delft report detailed a wide range of artificial reef type alternatives and even specific recommendations for Bahrain; however, the reported lacked the more modern artificial reef approach of "designed reefs". The modern concept of designed reefs involves a focused; goal oriented approach to reef building verses the shotgun approach of the 1970-1990s. Modern artificial reef programs first develop a set of goals for their progra ms, and then choose methods; materials, locations, layouts and monitoring to insure these objectives are being met. Being a leader in worldwide designed artificial reef building, Reef Ball Foundation does not recommend specific materials, methods, locations, layouts or monitoring types until goals are formalized and prioritized. Reef plans must be created in such a way as to adapt to changing goals so that a designed reef approach can be maintained. Designed artificial reefs programs, worldwide, are nearly always successful whereas random artificial reef building will nearly always lead to varied results…usually with some successes and some failures.

Because the artificial reef program in Bahrain needs guidance, we have attempted to set up the first "stake in the ground" of an appropriate goal set for the country. (Note that our normal approach for setting these goals is to meet with representatives of all stakeholders such as government, fishing groups, diving groups, tourism councils, construction grou ps, NGO or other environmental groups, etc. and to use process consulting to form a group goal set giving the appropriate weight to each stakeholder group. Since this was not a formal project, this approach has not been undertaken). Using the conclusions of the preceding "Primary Impacts and Issues" section of this report, we have listed the most logically appropriate goals for Bahrain with an additional management option goal. “Other Possible Goals” were listed to demonstrate the range of traditional artificial reef goals as outlined in the Delft report, but most are just too lofty or impractical for Bahrain given the overwhelming impacts of island development and trawling at this time.

Non-prioritized “logical” goals for Bahrain Artificial Reef Program

1) To counter the direct loss of marine habitat due to sedimentation and siltation on the natural reef systems.
2) To counter the direct reduction in above sea floor natural reef complexity due to trawling and netting practices.
3) To increase fish stocks in commercially important fish, including but not limited to groupers, breams, rabbit fish, lobster and crabs.
4) To restore loss of near shore/ estuary habitats.

Additional *optional* management goals

1) To reduce illegal trawling

Other possible artificial reef program goals (Perhaps not considered high priority for Bahrain at this time but which might represent beneficial “side effects” of the Artificial Reef Plan or future goals).

1) To enhance species diversity
2) To restore or enhance coral reef areas
3) To enhance recreational fisheries
2) To enhance tourism/diving opportunities
3) To create/protect beaches
4) To provide fishing locations for local commercial fisheries
5) As an aid for waste disposal programs
6) As an educational tool
7) To provide scientific research opportunities
8) To enhance specific (endangered, threatened or target) species
9) To improve water quality targets
10) Other specific goals (RBF has encountered over 200 known goals for artificial reef construction).

Artificial Reef Plan

The first step in refining and executing Bahrain's Artificial Reef Plan is to confirm or refine the goals of the program and then rank them by priority. Priority ranking is important to help in allocating limited resources likely a constraint to the artificial reef program. These goals can then serve to guide and when necessary refine the Artificial Reef Plan. Four purposes of discussion, we the remainder of this report presumes the first four goals with higher weights to goals #1 & #2, and the lowest priority to goal #4.

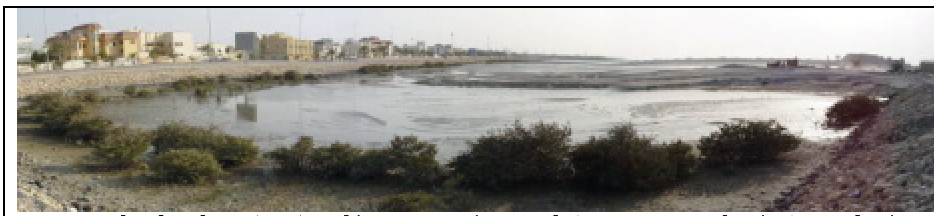
If one presumes that the selected four goals were appropriate, the Artificial Reef Plan becomes relatively straightforward in strategy (and more focused in actual implementation which is where the real work occurs).

1) **Site Selection**

a) *Exclusion Mapping* (Well defined in the Delft report)

b) *Identification of affected (lost) habitats*

Due to the large amount of marine habitat lost in Bahrain, initially this process will be fairly easy by just looking to historical facts to generate a simple list of areas most affected and what their original state was (or could have been) compared to present state. Higher quality habitats (coral reefs, estuary reefs, nearshore hardbottom reefs, and seagrass beds) should be given preference to marginal or lower quality habitats. Major habitat losses in Bahrain mean that this process will not need to be as precise and exact as in other areas were losses are more difficult to define. As more and more habitat is restored, this process will need to become more defined and precise. In all likelihood, a lack of financial resources will constrain this process before sites appropriate for restoration are limited.



Example of Inshore (Lost) Habitat Restoration Work (Mangrove Replanting)In Bahrain

In Bahrain, careful though needs to be given to degraded, rather than lost habitats. For example, areas that have been exposed to netting damage may still have some functioning low profile hard reefs or hard bottom even though the higher relief habitats have been lost. Other areas, where sedimentation is high may have functioning higher relief, but loss to the seafloor habitats that were covered in silt. Silty areas may have lost high light requirement species or delicate species such as corals. Much like the areas totally lost, it will be easy to identify areas for restoration at the start of the program due to the large areas affected.

c) *Selection and Initial Investigation of potential sites*

After eliminating bad sites, and identifying areas of need, the next step is to select areas that are suitable for artificial reef development and unlikely to see future damages. In many programs, it is helpful to prioritize potential sites so that more costly locations/designs can be balanced with expected benefits. Since the modern Artificial Reef Plan in Bahrain is relatively new, again it is expected that areas of high need and without the need for more costly locations/designs would be in abundance so this step might also be eliminated for now in favor of action over further delay.

In Bahrain, the areas damaged by trawling and netting will be easily identifiable as ideal for artificial reefs due to the loss of the complex reef structure without damage to the underlying reef base presuming netting can be controlled in an area or net resistant designs are used. However, in areas close to shore where sedimentation may have created bottom types not suitable for artificial reefs this may prove more challenging. It is likely that special artificial reef techniques such as the use of anti-settlement bases/geosynthetic underlayments or rubble basing may be required for these areas. These adaptations are relatively straightforward with designed artificial reef structures but may be difficult or impossible with some materials of opportunity.

<u>HOW TO COMBINE ARTIFICIAL REEF & BURROW AREAS.</u>

In this case it is possible through a Scientific & Professional Long Term Approach to combine the installation of Artificial Reef & utilization of the Resources of Sand (Soft Materials).

<u>The Methodology to do this combination is as follows:</u>

1: A ‘ Shallow Water Seismic Survey’, (SWSS) has to be carried out for the areas shown on ‘sheet 21’ as ‘MOST SUITABLE AREAS FOR ARTIFICIAL REEFS’, (MSAAR),

2: Then ‘The 3-D maps of the Soft Materials Deposits’ are studied, and core samples have to be taken in areas where the thickness of soft materials is substantial.

3: Based on the result of the core sampling, the expected quality of the soft materials (sand or fines) have to be evaluated and recorded – preferable in the Proposed <u>DATA BASE FOR MARINE RESOURCES</u> (DBMR), (which never has been established).

4: Based on the recording of such core samples, it will be possible to locate areas on the MSAAR, shown on sheet 21, which from a ‘Dredging Point of View’ could be good as ‘Potential Burrow Areas’ (PBA).

5: Investigations with divers have to be carried out of such Potential Burrow Areas, so the Marine Eco - System in each of such areas can be surveyed & recorded.

6: If the Eco -System is “Like a Seabed-desert”, then the area could be ‘The Optimal Solution for a Burrow Area’ as well as ‘The Optimal Solution for Artificial Reefs’.

7: Such areas can then first be used as Burrow areas for filling materials, and when the recoverable amount of sand is removed, then the areas can be used for establishing of artificial reefs.

8: During the dredging operation all biological life will be destroyed, so the seabed will be ‘Totally dead’ (Seabed Desert). Therefore, establishment of an artificial reef will help to mitigate the damage done by t he dredging by restarting a reef ecosystem.

9. Newly dredged areas must be left for a period of time to reach “equilibrium as there will be some readjustments of the sands from the higher areas to the lower areas of the burrow pit.

10. After equilibrium is reach, Artificial Reefs should first be established (when the depths do not interfere with navigation) around the edges of burrow pits in order to increase current flows and mixing within the burrow pits to increase dissolved oxygen levels within the pit. Porous artificial reef materials capable of creating whirlpools and mixing of the water column are suitable. If possible, parameter net deterring reefs could be established so that the structures used within the burrow pit would not have to be as net resistant.

11. Artificial Reefs should not be placed close to the slope or walls of the burrow pit. Also, they should avoid the extreme low spots. Both areas are more prone to sand filling in around the artificial reefs making them less functional.

12. Small rocks can be scattered around the burrow pit before building the interior artificial reefs in help to re-establish the live sand bottom previously on the location.

13. Artificial Reef can then be established with success.

After identifying potential sites, an underwater site inspection is needed. A simplified approach includes the following steps:

1) Obtain/Record Site Coordinates

Obtain accurate GPS coordinates of all the corners of the site. (Typically, two sets of coordinates will be recorded, planned corner coordinates and actual corner coordinates surveyed). Do not take a center coordinate only with the assumption of a circular distance around the point as this makes mapping very difficult. Use an accurate GPS with a good mounted antenna (not a handheld GPS) that is locked onto a maximum number of satellites. Record the estimated position error for each point. Buoy each corner of the site as coordinates are taken directly below the antenna. Recheck each corner if possible for quality control. It is best to do this work on a calm clear day. Record depth on the bottom finder and note the tide. Take multiple depth recordings at recorded GPS readings if the bottom is not relatively flat. If you have a Secci disk on board, recording the visibility can be helpful just as a point estimate…be sure to note if there are unusual conditions affecting visibility. Next, start your survey dive.

2) Assess Bottom Composition

b) Sand, Mud or hard bottom?
c) If Sand or mud, depth to hard bottom (rebar probe works well)
d) If no hard bottom, check firmness of sand (grain size distribution or behavior of known materials in the area) and assess current potential. (A Ziplock™ bag should be carried with the divers to obtain a sand sample, which is necessary only if there is no hard bottom present with 50 cm).

Artificial Reef Design Implications of Bottom Composition

Exposed hardbottom- (**Often Acceptable**)
-Check for potential impact to existing live bottom community
-Increased lateral stability requirements (s ome designs may require lateral stability anchoring/modifications)
-Ideally suited for hard coral transplant projects (Due to natural fragmentation and propagation of corals and generally less sedimentation in the areas).

Sand/Mud over hard bottom-(**Usually Ideal**)
-Ideal depth is 25-50 CM of Sand/Mud over Hard Bottom, calculate expected loss in design height as a tradeoff for increased lateral stability. (If less than 25 cm see exposed hard bottom implications if greater than 50 CM see Sand/Mud bottom consideration).
-Subsidence is limited by hard bottom.
-Typically, this type of sea floor is less productive before artificial reefs are added than hard bottom or pure sand bottoms and therefore can represents a maximum resource gain.
-Acceptable but not ideal for coral transplant projects if sand is firm, not recommended over mud bottoms

Sand Bottom (**Generally not optimal but in some areas is the only available space**)
-Subsidence and/or scour is a real possibility. Sand "firmness" (grain size distributions), currents, and shape of the materials must all be considered. This is considered an "advanced" process and should be avoided when using a wide variety of materials due to the need for individual analysis.
-Anti-Settlement bases and anti-scour methods (aprons, etc.) can be considered as needed.
-Stability requirements are generally less as materials settle into the sands and create a type of suction anchor.
-There is often an interaction between materials placed closely together in terms of scouring patterns that must be considered.
-Acceptable but not ideal for coral transplant projects if sand is firm

Mud Bottom (**Generally undesirable for Artificial Reefs**)
-Subsidence is generally a given.
-Scour may or may not be an issue. Generally less than with sand unless high currents are present due to mud's ability to refill in.
-Very specialized light weight anti-settlement bases are required or geotextile underlayments. Material design generally need to be lighter than more classic materials.
-Deployment over mud bottoms is generally considered "experimental"

Other Bottoms
-Any other bottom type will generally require specialized or experimental designs. Contact RBDG for more information.

3) Assess Fouling Community

a) Try to find natural hard objects in the area and note the types and amount of growth on the objects. Ideally, assess additional placed objects with known deployment dates (even buoy anchors, fish traps, lost anchors, pipelines, trash items, etc. can be useful).
b) Note Fouling community indicator species: hard corals (note reef building or non-reef building species), photosynthetic soft corals, non-photosynthetic soft corals, tunicates (particularly sea squirts), pearl oysters, coraline algaes, hair algaes, turf algaes, cyanobacter species (indicator of poor water quality), sponges (particularly species with nudibranchs on or near them), and sea urchin populations. Also, note any unusual findings.

Use this data for COMPARISON to other sites, not as an exact indicator of the predicted fouling community as artificial reef material, surface texture and shapes will also be determining factors. Indicator species will also give you an idea of average turbidity, average plankton loads, average sunlight penetration, possible pollution loading, and general environmental parameters that define reef species (such as temperature ranges, salinity ranges, etc.).

2) Complete Full Bottom Visual Check

Survey the entire area between the corner coordinates for live rock, sea grasses, reefs or coral reefs or other ecosystems that should not be disturbed by artificial reef construction. If found, note location for adjustment of corner coordinates. Note irregularities in bottom composition, depth, and any unusual currents.

d) Final selection with biological or goal prioritization

Just like sites are excluded, sites that are selected as appropriate and physically suitable need to be prioritized in terms of likelihood of good biological/goal achieving benefits. In addition to the data collected in the surveys, there are two basic advanced approaches to final site selection that are particularly useful for larger deployments:

1) Standardized Reef Comparison

This method involves the construction and monitoring of a large number of small control reefs (usually a group of 3-5 designed reefs made in exactly the same way) placed in all potential artificial reef sites. Monitoring results are used to guide future reef building efforts. **[See attached sample (DRAFT) monitoring forms for Bahrain at the end of this report].**

2) Scientific Modeling or Expert Opinion

This method includes using water quality parameters, local scientific and historical knowledge, input from stakeholders and other experts to form an “expert opinion” to guide site priorities. Usually, once construction has begun, monitoring provides a feedback mechanism to continually correct future prioritizations.

2) **Materials Selection**

For purposes of simplicity this report is laid out with materials selection and layout being sequential tasks, however both need to be considered simultaneously in the case of enhancing specific species such as the Hamour which requires both reef habitat and surrounding sand flat habitat to create an optimal overall living habitat. There are other reasons why integrating the two steps together may be important such as the case of designing materials that are to be protected from netting by barrier net stopping materials.

Once the appropriate sites are selected, and the goals of the artificial reef program are well defined, selection of materials becomes a much simpler, rather than daunting task. At any case, the need for "shotgun" approaches such as suggested in the Delft report is not appropriate for a designed reef program and the Artificial Reef Plan will define more precisely what is required and expected of the materials selected. In fact, we HIGHLY recommend against the use of a wide range of materials for a relatively new Artificial Reef Program, as the number of variables to consider is so large that mistakes are often the result. Do choose the number of materials needed to achieve all the program goals but limit the range to specific design requirements needed.

-*Materials Exclusion*

Just like exclusion mapping details areas where artificial reefs should not be constructed, some artificial reef materials can automatically be excluded from consideration based on the Artificial Reef Plan's goals, specific conditions/requirements in Bahrain and materials already documented to be ineffective

For example, using the previously defined goals and observations in this report we could suggest the following exclusionary rules:

1) Exclusion of materials that are not trawl/net resistant.

- -Low Density/ Low Stability Materials
  - -Pre-cast Pipes less than 1 meter in diameter
  - - Tires
  - -Plastic or Fiberglass materials
  - -Aluminum Materials
  - -Light gauge steel structures
  - - Concrete with exposed rebar which would catch on nets unless heavy enough to stop nets (generally 1 ton or greater)
- -Fragile Materials
  - -EcoReefs (except in offshore coral reef areas protected from netting)
- -Unsuitable for Goals
  - -Demolition materials unless sorted for larger size and washed (to avoid further sedimentation effects)
  - -
- -Lack of Complexity for Goals
  - -Quarry Rock

2) *Recommended Materials*

The Delft report detailed a wide range of available materials (although there were significant errors in material suitability, costs, benefits and reasons for use).

Note: Designed Artificial Reef Materials are nearly always designed for VERY specific end use goals. Reviewing other artificial reef programs and mimicking techniques, materials and methodologies is unlikely to yield desired results given the unique set of conditions faced by each individual artificial reef program. The use of engineering firms to guide artificial reef programs may be similarly unwise as most do not have the wide range of experiences with designed reefs necessary to develop suitable artificial reef programs especially for artificial reef programs that have not already defined specific artificial reef plans. We recommend working with other artificial reef programs or industry specialists for the best possible advice and to avoid generalists until your program goals are clear, supported and articulated.

From our brief survey, any reef design for Bahrain should at a minimum meet the following criteria:

1) High above seabed complexity including "duck and cover" areas for fish avoiding trawling nets. (To offset losses in above seabed complexity).
2) Stability against netting (either with an trawl resistant profile, perimeter anti-trawl devices or individual weight sufficient to arrest nets). [Note: Trawl resistant profiles are recommended when artificial reef modules are used in Bahrain when not intended to deter netting activities as the "captured" nets can act as unattended fish traps].
3) Non-growth dependent complexity (except for the limited offshore and protected high diversity coral reef areas)…i.e. structure alone is sufficient for fish production independent of the fouling community which may be limited by net damages and sedimentation impacts.
4) Barge deployable (there seem to be an abundance of barges available for artificial reef deployments which are often available at little or no cost to the department).
5) Designed for fish production rather than fish attraction (goals align with restoration of fish stocks, not concentration of fish for reducing catch effort).
6) Capable of delivering large area footprints at a relatively low cost (there is an abundance of affected marine habitat, so in this case more, high surface area/complexity is better).
7) Resistant to subsidence if deployed in an area without suitable underlying hard bottom (i.e. for nearshore in high sediment areas).

Due to the inability to control the quality of demolition materials, the recommended materials for Bahrain could include Designed Pre-Cast Materials (Reef Balls, Layer Cakes, Concrete Mounded EcoReefs, or other suitable designs), Modified (designed) Pre-cast or Demolition Scrap Units, Designed Pre-cast Pipe Modules, and Designed Anti-Trawling Units.

The specific chosen design would be selected for each restoration site based on goals and constraints such as bottom type, activities in the area, proximity to natural reefs, depth, deployment style, specific project budgets, planned layout of reef site and availability of materials of opportunity for inclusion into specific designs.

The Reef Ball Development Group and Reef Ball Foundation are recognized world leaders in helping our clients select the appropriate designs once the Artificial Reef Plan defines goals and site selection is completed and the physical parameters are defined. There are far too many factors that must first be defined to recommend an exact materials design for Bahrain yet, but we stand ready to assist as these parameters are defined. However, we do have some initial ideas based on the assumptions in this report.

A specialized "general" design for Bahrain that immediately comes to mind would be a grouping of Reef Balls with void bottoms and "layer cake" tops with an angle concrete perimeter wall to allow trawling nets to pass over the structure without snagging. (Void bottoms for Hamour, layer cake tops for above sea floor fouling community independent complexity and perimeter wall to create a trawl/net resistant profile). Embedding the whole structure in a "Reef Form" slab (with fiberglass rebar and lifting points) would add to easy of handling for barge style deployments.

Left: Inside of Layered Cake Pallet Ball with Void Space Bottom ***Right: Layer Cake Top on Bay Ball***

3) **Layout Of Reef**

There is significant scientific debate about reef density, layout and spacing to optimize fishery yields for a given amount of artificial reef materials. In areas with reef environments somewhat similar to Bahrain (Gulf of Mexico), scientific evidence (from Dr. Bill Lindberg) supports small patch reefs (i.e. small groups of artificial reef units) randomly spaced across the seabed with an average interval of 25-75 meters particularly for gag grouper that is a close relative of Hamour. Due to the nature of some of the goals of the program (Hamour enhancement), this approach is recommended as a starting point for Bahrain. [Note: There is a great deal of pressure to build artificial reefs with a large number of units in many artificial reef programs to service the need of recreational fishing and scuba diving, however, there is not a great deal of pressure for this in Bahrain]. Because there is a great deal of fishing trap pressure, it makes even better sense for Bahrain to build a large number of small artificial reef sites so that exploitation does not occur.

Furthermore, it would be wise not to publish the coordinates of artificial reefs built by the program to best meet the given goals except for reefs built specifically to benefit.

In general, a "default" layout should be to create the density, high variations, and layout of the undisturbed natural reefs. This approach best mimics the natural systems and will most likely yield the good production. Fine tuning over time via monitoring can help maximize productivity, and other program goals.

As far as layout patterns go, close groupings of units takes advantage of the spacing between units to function as additional void space at the expense of access to open foraging spaces. Other than this effect, fancy groupings as detailed in the Delft report have little effect except to satisfy the need of humans to organize things. Average density over an area of artificial reef development (including natural reefs if nearby) on the other hand is a critical factor and very important to species diversity and population densities.

4) Monitoring

The Reef Ball Foundation can help guide a program to achieve its goals based on our 10 years of experience in over 4,000 artificial reef projects worldwide, yet only local monitoring and adjustments will allow a program to achieve its goals consistently over time. This is because their will always be unique local conditions that require adaptations in artificial re efs (hence the name "designed reefs"). Furthermore, your goals may change over time requiring changes to the Artificial Reef Plan. A good monitoring program goes a long way to insure that you adapt your reef-building program to designs that will work bes t for program goals. Monitoring can be as simple as regular diving or even fishing on your reefs or it can be in depth enough to provide true scientific rigor and publishable results. Either way, not including monitoring into your artificial reef plan will guarantee long-term program inconsistencies and even failures. Even successful programs, without monitoring to prove their effectiveness, can suffer from lack of funding and public support.

Next Steps

This report is designed to be a simple, highly effective, and focused way to develop a modern and successful artificial reef program for Bahrain. Obviously, there are many details that need to be added, but they must be added as a result of the exact program goals and priorities. (For example, adding priority to the goal of near shore habitat restoration would express the need to detail an exact approach for mangrove replanting and estuary artificial reef projects). The Reef Ball Foundation, Reef Ball Development Group, and our network of Reef Ball A uthorized Contractors and worldwide staff of over 100 artificial reef professionals are available to guide to process as needed.

How you actually implement your program may dictate the best way to work with us. From complete training to do everything in-house or working directly with one of our authorized contractors for a turnkey solution…we stand ready to support Bahrain's efforts to achieve Artificial Reef Program goals.

As appropriately noted in the Delft report, the Artificial Reef Plan is only on e component of the overall management of marine resources. Be sure to incorporate the overall marine resources strategies with the Artificial Reef Plan for the greatest likelihood of achieve overall marine resource goals.

Appendix: Sample AR Monitoring Forms

RBF, Inc. Artificial Reef Assessment Dive Team
Underwater Observation Data Form

LOCATION NAME:______________________ DIVER:________ DATE:____/____/____

LAT:____°____.____'   LONG:____°____.____'

I. Water Data

1. *Visibility*- Surface___________Bottom________   5. *Depth*____________
2. *Temperature*-Surface___________Bottom________
3. *Current(TO)* Surface___________Bottom________
4. *Strength*- Surface___________Bottom________
(Stong-moderate-nil)-(strong-moderate-nil)

N
W   E
S

II. Bottom Data

1. *Bottom type*
   A. *Particle Type*: (shell) (gravel) (sand)
   B. *Particle size*: (coarse) (fine) (silt)
   C. *Color*: (D.brown) (L. brown) (gray) (black) other__________
   D. *Sand Ripples*: Length__________Direction to:____________
2. *Hard bottom*: (NO) (YES)
   A. *Type*: (outcrop) (ledge)   B. *Relief*_____ft.
   C. *Percent cover*: (25%) (50%) (75%) (100%)

III. Reef Material Data

1. Material Type ________________   Deployed Date ____________________

2. Unit Measurement (Tons, Units, S.A.) Amount ______________________

Estimated Cost per unit amount $________________/ (Tons, Units, S.A.

3. *Orientation*: (upright) (onside) (upsidedown) *layers* (yes) (no)
4. *Complexity*: (1) (2) (3) (4) (5)   5. *Stability*: (1) (2) (3) (4) (5)
6. *Max.Relief*:_____ft.   8. *Settlement*:_____Inches

IV. Dive Data

1. *Seas*:______ 2. *Air Temp.*:______ 3. *Wind*:____MPH from_____

4. *Time in*:________ 5. *Time out*:_______ 6. *Bottom Time*:________

IV. a. Supplemental Water Data   **10. Sun/P. Cloudy/Cloudy**

7. D.O. Surface _______ 8. D.O Bottom _______ 9. Salenity ________

Approx. Tide
High
Low

COMMENTS:

5/7/2002

RBF, Inc.-BAHRAIN FISH CENSUS FORM

NAME______________________________ DATE____________ LOCATION________________________________

A = Abundant >100 , M = Many 11 to 100, F = Few 2 to 10, S = Single individual

TEMPERATE *Arabian Gulf* SPECIES **F:/Commondocuments/Bahrain/report.doc**

Reef Species	**A**	**M**	**F**	**S**		**Pelagic**	**A**	**M**	**F**	**S**
Anglelfish (Other)						Tunas/ Mackerels (other)				
YellowBar Angel						***Spanish Mackerel***				
Butterfly Fish						**Cobia**				
Baracuda						**Jacks (Other)**				
Breams (other)						***Golden Trevally***				
Doublebar Bream						***Amberjacks***				
Yellowfin Bream						Rays				
Cardinalfish						Sharks				
Damselfish						**Other**				
Emperors						**Slipper Lobster**				
Flounders						Blennies				
Fusiliers						Triplefins				
Goatfishes						Jawfishes				
Grunts						Puffers				
Grouper (other)						Gobies				
Hamour						Dartfishes				
Parrotfish						Frogfish				
Pompanos						Dottybacks				
Rabbit Fish-Pearlspot						Surfeonfish/Tangs				
Rabbit Fish-Safy						Remoras				
Scads/Herring						Triggerfish				
Snappers (Other)						Filefish				
Blackspot Snapper						Trunkfish				
Russells Snapper										
Spadefish						Video?				
Wrasses						Photos?				
						7-May-02				

Draw in distinctive features (spots, lines, fins, etc.) for unidentified species on drawings below.