BUOYING AND MARKING OF ARTIFICIAL REEF - A CLUB EXPERIENCE

Nicholas J. Delmedico

This paper presents a cheap easy to build visible marker buoy which can be constructed from materials commonly found around the home, that is, if one happens to live in a hardware store. The price per buoy breaks down to about $17.00 in material costs, and with proper incentive when initiating the assembly, this could feasibly be the final net cost of each buoy. The Jacksonville Offshore Sports Fishing Club has been in the buoy business for twenty years and it is our pleasure to share the club's experience with interested parties.

Introduction

The first artificial reef built by the Jacksonville Offshore Sports Fishing Club was constructed in the fall of 1959 with over 200 auto bodies, 1200 junked appliances, and 7,000 auto tires (added one year later). Since then JOSFC has constructed new reefs and augmented existing natural reefs with over 100,000 passenger car tires, 5,000 large truck tires, 500 tons of culverts, 3,000 junk appliances, 1 ferryboat, 15 tugboats, 2 large drydocks, 1 LST (landing craft), 2 medium drydocks, and over 20 accessory boats (lifeboats, small yachts, etc.).

A scant year and a half after the club's inception, an ambitious project to buoys 17 natural and artificial reef areas offshore from the St. John's River jetties was put into operation. Two buoys were placed, one half mile apart and lying north and south over each reef or fish haven, and proved to be excellent aids to navigation in these waters.

An art work overlay was drawn to fit Coast and Geodetic Survey Chart No. 1242 giving distance in miles, compass course and reciprocal to each of the 17 numbered buoys. These charts were printed and made available to the membership and general public through sporting goods outlets, fish camps, and area marinas.

One year after this, the club chart was expanded to include reef areas off both Fernandina and St. Augustine to the north and south of the St. John's River inlet. The clubs of these communities were responsible for the construction and maintenance of their own buoys with the new chart available to both groups.

Basic Materials and Procedure

Buoys design and construction has varied little in the past twenty years, the current design undergoing slight modifications as experience...
showed. A list of needed materials may be found in Table 1. The following procedures are used by JOSFC in the construction of their buoys: A conical mold is filled with wet styrofoam and a piece of galvanized pipe (used in tops of chain link fence) passed through the center. When dry, this is removed from the mold and painted dayglow red. A 2' - 3' piece of rebar is inserted in the pipe and allowed to rest on the very bottom as a counterweight. A 20' calcutta pole is inserted in the top of the pipe and secured with a galvanized bolt. A quarter of an inch chain is secured to the bottom of the buoy and an appropriate length of 1\(\frac{1}{4}\)" polypropylene line fastened to a bottom weight of about 170 pounds. The line is eyespliced to a 46" length of 1" chain which in turn is secured to the bottom weight. It has been found that black line is best to use since lighter line seems to facilitate fouling by its increased ability to support growth. Weights have varied over the years, the best choice having settled upon scrap catapillar tread. I-beams were found to move too much and additionally corrode at a faster rate. A scope of 10 - 15' is well suited for the purpose, as no scope was found to facilitate "walking" along the bottom, even with shackles and 1\(\frac{1}{4}\)" chain.

The weakest point in the whole buoy system is where the polypropylene line connects to the chain. Even with a strong metal eye, the constant movement and stress caused by marine forces will eventually wear away this section. Divers who use the reefs and respect these navigational markers will usually report worn buoy parts to club members or to the club's home base at Monty's Marine, Mayport, Florida. (Fig. 1).

**Buoy Assembly**

Once materials are accumulated, the assembly process can be initiated. JOSFC employs an effective method of putting the materials together. A club event, carefully headlined as a "Buoy Building Party" is used to attract club members to a large staging area where assembly is done. A large turnout is almost assured if the following conditions are met: 1) plan the event during a time of rough seas, foul weather, or similar conditions when the probability of successful offshore fishing is minimal; 2) copious amounts of mixed beverages have always been known to attract fishermen, and it would be wise to have this on hand in addition to buoy materials (cost not included in overall figure of $17.00 per buoy); 3) a club membership of over 1,000 (as JOSFC spouts) helps innumerably; 4) the use of food, prepared by wives, lovers, and acquaintances of club members, as an additional attractant may be employed.

At such an event, there is never a lack of duties to perform. Flags must be sewn, buoys painted, lines rigged, all in addition to the basic required assembly. A detailed breakdown of the buoy may be followed in figure 1 as a guideline for assembly. Minor changes may be required, but basically, buoy design has not varied over the twenty years in which the club has provided this community service. By following these guidelines, JOSFC has continued to effectively build and maintain buoys in the area offshore Jacksonville.
Figure 1.
Reef buoy used by Jacksonville Offshore Sport Fishing Club

- Naugahyde strip (doubled over)
- Nylon camper cloth
- Calcutta Pole 10' - 20' length
- Aluminum fencepost
- Reef designation sign secured with U bolt
- Styrofoam cast
- Rebar counterweight is inside lower shaft
- Galvanized bolt
- To bottom
Placement of Buoys

Once assembled, the buoy placement is sub-contracted to a local headboat operator for a reasonable sum of money. Alternative methods were explored, and this seemed the best possible mode of operations. Buoys placed in this manner are always exactly on the charted locations; headboat captains are usually quite familiar with the offshore bottom and can be depended upon for this aspect of a buoy program.

For years JOSFC club members were prevailed upon for placement of buoys, but this system has since been proven unreliable. With the advent of high fuel costs, it is almost impossible to get volunteer buoy placement. The services currently received for the set, fixed fee include an as-goes monitoring of buoys by the headboat captain in addition to an as needed replacement of buoys lost during adverse weather.

A buoy board is also maintained by the club at Monty's Marina which tells whether a reef's buoy is properly placed, missing, or off charted location. JOSFC now limits each reef to one buoy, rather than two as once was the original plan.

Conclusions

An effective, low cost buoying program can be successfully implemented provided one has the manpower, materials, and the means to oversee such an ambitious project. Proceeds from sales of charts marking these locations can be used to augment existing funds. As in all undertakings, time and energy are a premium, but JOSFC has shown that the task is far from impossible. Following this model, fishing clubs in Fernandina and St. Augustine have had similarly successful programs.
<table>
<thead>
<tr>
<th>Material</th>
<th>Dimensions</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naugahyde</td>
<td>36&quot; x 8&quot;</td>
<td>secure flag to pole</td>
</tr>
<tr>
<td>Nylon camper cloth</td>
<td>21&quot; x 36&quot;</td>
<td>flag material</td>
</tr>
<tr>
<td>2 galvanized bolts</td>
<td>¼&quot; x 2½&quot;</td>
<td>secure chain and flagstaff to buoy</td>
</tr>
<tr>
<td>Plywood</td>
<td>16&quot; x 8&quot;</td>
<td>small sign to designate reef</td>
</tr>
<tr>
<td>Calcutta pole</td>
<td>10' to 14' length</td>
<td>flag pole</td>
</tr>
<tr>
<td>U-bolt</td>
<td>1½&quot; center to center</td>
<td>secure sign to body shaft</td>
</tr>
<tr>
<td>Conical steel mold</td>
<td>12&quot; diameter tapering to 1½&quot; over 46&quot;</td>
<td>casting</td>
</tr>
<tr>
<td>Styrofoam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminum fence top rail</td>
<td>1&quot; x 48&quot;</td>
<td></td>
</tr>
<tr>
<td>Polypropylene line</td>
<td>3/4&quot; x length as needed</td>
<td></td>
</tr>
<tr>
<td>Bottom chain</td>
<td>1½&quot; x 42&quot;</td>
<td></td>
</tr>
<tr>
<td>Rebar</td>
<td>2' x 3'</td>
<td>counterweight</td>
</tr>
<tr>
<td>Paint</td>
<td>vinyl daglo</td>
<td></td>
</tr>
<tr>
<td>Bottom weight</td>
<td>150 pounds minimum</td>
<td></td>
</tr>
</tbody>
</table>
BUOYING AND MARKING OF ARTIFICIAL REEFS -- A STATE EXPERIENCE

Howard T. Lee

My personal experience in the marking of artificial reefs area is somewhat limited in that it only goes back to 1958. Rather than shatter your illusion that everything is done on a large scale in Texas, I'll tell you that in just under four years at five sites we've laid out over $103,000. Now let me attempt to explain why.

The sites I will describe are those where Liberty Ships were sunk in the Gulf off Texas. The funds I refer to were derived from the salvage contract we negotiated for reef construction and in no way can they be considered as taxes or license fees.

Texas asked for and was granted 12 of 18 surplus Liberty Ships from the Defense Reserve Fleet at Beaumont. Our application to MARAD indicated an intent to construct four reefs of three ships each. The application specified the locations and contained copies of Corps of Engineers permits as well as Coast Guard authorizations specifying the type of buoy to be used.

Several factors were considered in determining the buoy type. Water depths of 90 to 110 feet of course meant 130 to 150 feet of chain or cable. Daymark visibility -- radar reflector height of at least six or eight feet -- meant additional buoyant capacity. Nighttime shrimping operations dictated a lighted buoy, so extended time battery capacity was needed. Fishermen would much rather tie up to a buoy using a small deck rope than drop 150 feet of anchor line and maybe not be able to retrieve it, so a batter-resistant (metal) body seemed best.

Metal buoys present a hazard to small boats in fog, so a 1/2 mile fog signal -- and more batteries -- were added.

We're now really in the buoy business and Coast Guard experience indicated a buoy similar to their BLS-620 designation was called for. BLS means "buoy with light and sound" (Fig. 1). The 620 refers to diameter of body (6 ft.) and overall height (20 ft.). Now that is a Texas sized buoy. A corresponding anchor would be needed and transportation and placement could cost a good bit. But, the ships were going to the site and also going to the bottom, so we put the buoy on the deck and attached the chain to a special pad-eye welded in place for that purpose. We even provided a spare pad-eye, so that when the lower portion of the chain needed to be replaced due to chafing we could install a new short section sort of like a bridle to the extra eye. That should have provided a system better than the Coast Guards -- they lift a 5,000 pound block of concrete to the deck of a buoy tender to replace the bottom section of chain. They also have the resources of the Federal government behind them.

Texas Coastal and Marine Council, Austin, Texas

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One thing the Coast Guard doesn't have with their concrete anchor is a 900 ton ground plate to speed up the galvanic action. After the third buoy got loose, we recovered enough chain to be able to pin that down as our biggest problem. So, we went back to the drawing boards of a diverse group of engineers and came up with an alternative that appeared to work pretty well.

In this, we replaced the single length of 1 1/8 inch stud-link chain with two lengths of 1 1/8 inch diameter polyethylene clad steel cable interrupted by two sunberged spherical buoys to keep the lower section taut and erect. In all shackle joints, double-nutted safety shackles were used and stainless steel cotter pins held the second nut in place ... until somebody decided they didn't want the buoy on location at the offshore Freeport site. It's been on the beach of Matagorda Peninsula for over a year now. We replaced the buoy, but when the crew got back to the ship to attach it, they found that an enterprising crab, octopus, or maybe even a scuba diver had taken the entire mooring assembly for a souvenir.

That one finally went back with all new moorings with the shackle nuts welded in place. This time, a supertanker must have used it for a mooring because in just a couple of months, the buoy was found adrift with the cable pulled in two. A good bit of damage to the bottom of the buoy body was evident when removed from the water. As of the last week in July, it is still in intensive care.

I mentioned earlier our plans to sink 12 ships at four locations. We were 91.6 percent successful in that effort. The twelfth ship -- the grand finale with all the media fan-fare we could muster -- had to be the exception. Something called a low pressure system popped up and took that hulk for quite a ride before swamping it nearly 30 miles from the intended site. It's just about seven miles offshore in 60 feet of water -- right in the center of one of the better white-shrimp grounds near Freeport.

Since marking is required and our experience with the buoys was not the best, we decided to put the light on a tripod tower mounted to the deck of the ship. About 30 feet of water above the deck wasn't all that much. A 45 ft. tower was installed with a light, fog signal, battery box and solar charging panel at a cost of $46,000. That included a rental of temporary buoy while the tower was being fabricated, and six spherical mooring buoys to reduce the temptation to tie up to the tower.

The mooring buoys lasted but a few months. Even an inexperienced diver could free one of them at a depth of only 30 to 35 feet. The tower lasted over a year; but in time, was laid over on the deck by unidentified forces. It has been extended to compensate for settling of the ship, with wider foot spacing to distribute forces better, and has been in operation for about eight months now.
Some of our buoy costs may be exceptional. Due to the currents in the western Gulf, the buoy from the Port O'Connor reef was carried into Mexican waters when it was detached. It was located in a Mexican Navy Yard at Vera Cruz. The telephone bill for calls to the Embassy in Mexico City was almost as much as the costs to have it tracked back across the river. Recovery of one buried in the sands of Padre Island was more expensive for us.

Let me then summarize the costs for the five locations in Texas. I'll not break down each item, but lump various costs by sites to get a comparison and some averages.

The attached table is accurate as of the end of July, but not as of 1 September. As shown, the original cost of a complete buoy was $11,500 in a lot of four. This included the five mile light with flasher and bulb changer, daylight switch, 1/2 mile sound signal, two packs of batteries calculated to power the light and horn for one year, identifying markers on the daymark, bridle, and full shot of 1 1/8 inch stud-link chain.

For reference purposes, a replacement lantern costs about $400. The battery packs run around $1,200. The sound signals are about $2,550 each. Bridle and chain (one "shot" or 15 fathoms) costs about $1,800. The largest item in buoy maintenance has been the service required to transport buoys and divers to reattach them on location.

Using professional hard hat divers necessitates tenders, decompression chambers, pumps, etc., and therefore, a larger vessel. In a couple of instances, we've had to rent a boat and a cherry picker to put aboard it in order to be able to pick up the fully equipped buoy. Weight of the buoy runs about three tons.

The question then arises as to why we did not enter into a service contract and turn all these problems over to someone else. We did, of course, consider this. In 1975, about the time the first buoy was put in service, we accepted proposals.

The best offer at that time was for a $1,600 per site per month charge to provide quarterly inspection and routine maintenance. Annual replacement of batteries and any repairs occasioned by damage or vandalism would have been additional. A $75 per hour plus travel expense for personnel and all replacement parts added to that just didn't seem appropriate. It now appears we made the right choice, since our problems have largely been in that last category anyway.

I guess I can best summarize by saying that, in deep ocean water, buoys are not cheap. After a period of time, they may not be necessary. Careful consideration of all factors should precede a commitment to install and maintain such buoys.
Table 1.
Marker Costs Per Month at Five Texas Sites

<table>
<thead>
<tr>
<th>Site</th>
<th>Original Buoy</th>
<th>Repairs, etc.</th>
<th>Replacement Buoy</th>
<th>Total Cost</th>
<th>Months</th>
<th>Cost per Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Padre Island</td>
<td>$11,500</td>
<td>7,951</td>
<td>16,975</td>
<td>$36,426</td>
<td>46</td>
<td>$791.87</td>
</tr>
<tr>
<td>Port Aransas Site</td>
<td>$11,500</td>
<td>12,016</td>
<td></td>
<td>$23,516</td>
<td>40</td>
<td>$587.90</td>
</tr>
<tr>
<td>Port O'Connor Site</td>
<td>$11,500</td>
<td>21,219</td>
<td></td>
<td>$32,719</td>
<td>39</td>
<td>$838.95</td>
</tr>
<tr>
<td>Freeport Site - offshore</td>
<td>$11,500</td>
<td>44,519</td>
<td>8,487</td>
<td>$64,506</td>
<td>37</td>
<td>$1,743.40</td>
</tr>
<tr>
<td>Freeport Site - onshore</td>
<td>$26,210</td>
<td>46,431</td>
<td>31,300</td>
<td>$103,941</td>
<td>31</td>
<td>$3,352.94</td>
</tr>
<tr>
<td>Buoys only - 4 sites</td>
<td>$157,167</td>
<td></td>
<td></td>
<td>$157,167</td>
<td>162</td>
<td>$970.17</td>
</tr>
<tr>
<td>Buoys &amp; Tower</td>
<td>$261,108</td>
<td></td>
<td></td>
<td>$261,108</td>
<td>193</td>
<td>$1,352.89</td>
</tr>
</tbody>
</table>

Note: Costs through July 1979. Freeport replacement includes recovery, reconditioning, resetting original buoy from South Padre Island site.
The BL-820, BL-620 and BL-717 buoys are excellent rugged markers for underwater obstructions and navigation channels. They can easily be equipped with sound signal apparatus.

The buoy bodies are made of ¾ inch steel plate. Eyes for the bridle moorings are welded to the buoy bodies. When properly moored, the buoys will withstand hurricane force winds and seas.

**Note:** Standard buoy does not include lantern, batteries or mooring. (Bridle is included)

Steel buoys standard finish: sandblast outside after fabrication, Dimetacote type D-6 Coating; one coat primer, one coat vinyl color.

<table>
<thead>
<tr>
<th>Specifications</th>
<th>BL-820</th>
<th>BL-620</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dimensions:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>19'7&quot;</td>
<td>26'0&quot;</td>
</tr>
<tr>
<td>B</td>
<td>9'0&quot;</td>
<td>10'9&quot;</td>
</tr>
<tr>
<td>C</td>
<td>10'7&quot;</td>
<td>15'3&quot;</td>
</tr>
<tr>
<td>D</td>
<td>1'11&quot;</td>
<td>2'5&quot;</td>
</tr>
<tr>
<td>E</td>
<td>7'7&quot;</td>
<td>11'11&quot;</td>
</tr>
<tr>
<td>F</td>
<td>6'0&quot;</td>
<td>8'0&quot;</td>
</tr>
<tr>
<td>G</td>
<td>2'4&quot;</td>
<td>3'7&quot;</td>
</tr>
<tr>
<td>H</td>
<td>1'10&quot;</td>
<td>2'0&quot;</td>
</tr>
<tr>
<td><strong>Bridle (size):</strong></td>
<td>1/4&quot;</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td><strong>Recommended Moorings:</strong></td>
<td>5,000 lbs.</td>
<td>6,500 lbs.</td>
</tr>
<tr>
<td>Anchor, concrete</td>
<td>1/4&quot;</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>Chain size</td>
<td>2 - 4 times water depth</td>
<td>2 - 4 times water depth</td>
</tr>
<tr>
<td>Chain length</td>
<td>1/4&quot; steel</td>
<td>1/4&quot; steel</td>
</tr>
<tr>
<td>Body Material</td>
<td>345 lbs.</td>
<td>7,600 lbs.</td>
</tr>
<tr>
<td>Pounds/Inch Immersion</td>
<td>5,700 lbs.</td>
<td>12,000 lbs.</td>
</tr>
<tr>
<td>Reserve Buoyancy</td>
<td>8'0&quot;</td>
<td>11'10&quot;</td>
</tr>
<tr>
<td>(without moorings, light or batteries)</td>
<td>7' ft.</td>
<td>17.5 ft.</td>
</tr>
<tr>
<td>Day Mark height</td>
<td>7 ft.7</td>
<td>14 ft.</td>
</tr>
<tr>
<td>Day Mark area</td>
<td>10 ft.</td>
<td>16 ft.</td>
</tr>
<tr>
<td>Recommended optional equipment</td>
<td>FA-249</td>
<td>FA-249</td>
</tr>
<tr>
<td><strong>Lantern:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Batteries</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry primary</td>
<td>12v, 2,000 ah</td>
<td>12v, 4,000 ah</td>
</tr>
<tr>
<td>Wet primary</td>
<td>12v, 4,000 ah</td>
<td>12v, 6,000 ah</td>
</tr>
<tr>
<td>Rechargeable</td>
<td>12v, 1,000 ah</td>
<td>12v, 2,000 ah</td>
</tr>
<tr>
<td>Sound Signal</td>
<td>SA-850/1A</td>
<td>SA-850/1A</td>
</tr>
</tbody>
</table>

Figure 1. Buoy used in Texas project.
THE ELECTRODEPOSITION OF MINERALS IN SEA WATER FOR THE
CONSTRUCTION AND MAINTENANCE OF ARTIFICIAL REEFS

Dr. Wolf H. Hilbertz

Introduction

Sea water contains nine major elements: sodium, magnesium, calcium, potassium, strontium, chlorine, sulfur, bromine, and carbon. These elements comprise more than 99.9 percent of the total dissolved salts in the ocean [1]-[4]. The constancy of the ratios of the major elements throughout the oceans has long been well known [5]. In 1837, following the work of Davy on the protection of iron by zinc anodes, Mallet demonstrated that zinc so used became covered with a thick layer of zinc oxide and calciferous crystals which blocked the zinc surface [6], [7]. In 1940 and 1947, G. C. Cox was issued U.S. Patents No. 2 200 469 and No. 2 417 064, outlining methods of cathodic cleaning and protection of metallic surfaces submerged in sea water by means of a direct electrical current. During the cleaning process, a coating is also formed cathodically, consisting of magnesium and calcium salts [8]. If this coating is hard and continuous, it affords a considerable degree of corrosion protection to the enclosed metal [9], [10]. Lower marine organisms utilize the minerals in solution surrounding them to build structural formations. Mollusk shells, for instance are generally composed of calcium carbonate crystals enclosed in an organic matrix. A significant proportion of the soluble protein of the matrix is composed of a repeating sequence of aspartic acid, separated by either glycine or serine [11].

This sequence, comprising regular repeating negative charges, could bind Ca\(^2+\) ions and thus perform an important function in mineralization of the template [11].

Although impressed current produced CaCO\(_3\)/Mg(OH)\(_2\) formations were precipitated since the 1940's, these were never thought of as possible reef building components until recently. Consequently, only few publications outline structural testing of these materials, describe experiments and techniques using the electrodeposited material for a wide variety of structural purposes, and report on the possible suitability of the material as a substrate for biological growth in mariculture facilities and as a primary construction material for same [12]-[22].

Large-scale studies with galvanized iron mesh cathodes and iron/lead anodes immersed in sea water have provided evidence for the role of electrochemical processes in the accretion of minerals [18]. A preliminary qualitative model for these processes has been proposed (Figs. 1, 2).

The Marine Resources Company, Austin, Texas and the University of Texas at Austin, Austin, Texas.
Artificial Reefs

It has long been evident that substrates to which marine organisms can attach themselves and/or find shelter within, attract fish populations.

The oldest recorded establishment of artificial reefs dates back to the early 1800's [23]. Since the early 1950's American marine fishery interests have been investigating the possibility of using artificial reefs as management tools for manipulation of fish populations [24], [25]. Calculations of fish populations or artificial reefs as compared with control areas or before reef placement showed increases of between 3 to 16 times [26]-[28]. Since the choice of material determines to a large extent transportation, construction, and maintenance cost of artificial reefs and their design, this factor becomes very important.

Preliminary investigations indicate that the mineral accretion process produces a very suitable substrate for marine growth and, at the same time, a strong primary building material [18], [19]. Accreted wire mesh components also present a reduced profile, compared to solid components which reduces resistance to water currents, thus increasing stability while offering open volumes and entrances for shelter to marine organisms.

Placement of steel mats or wire mesh as an artificial substrate in areas dominated by soft, fine-grained sediments has been suggested [29]. Accordingly, the use of accreted wire mesh may be particularly well suited for these areas.

Two artificial reefs were constructed and placed in Tague Bay, St. Croix, in August 1976. These constructions were built to determine the parameters of the electrodeposition process onto large surfaces as substrate for marine growth, and to support the hypothesis that wire mesh formations covered by electrodeposited minerals can support marine communities that are usually found inhabiting natural reef formations [18]. Both of these reef components were placed in shallow waters approximately 8' deep, on relatively barren and sandy substrate with small amounts of seagrass (Thalassia) present. Direct electric current was supplied intermittently to the reef components by an unregulated power supply in the range of 3-16V/10-40A.

Reef I consists of an assembly of regular and irregular shapes constructed with wire mesh of different gauges a total surface area of 253 ft.² (Fig. 3). Overall dimensions of the reef are 4' by 12.67' by 3'. Average accretion thickness on the wire mesh is 3/8" with thickness in some areas up to 3 in. Fish censuses preformed 4½ months and 15 months after placement indicated 127 individuals (5 species), and 483 individuals (19 species), respectively. The most dominant fishes were medium-sized grunts, parrot fish, and damsel fish.

Twenty hours after submersion white accreted material was visible on all surfaces of the structure. Seventy-two hours after submersion diatomaceous and blue-green algae growth was observed on the outer
+ ANODE

\[ \text{CL} \rightarrow 2e^- \rightarrow \text{Cl}_2 \uparrow \]

\[ \frac{1}{2} \text{O}_2 + \frac{1}{2} \text{O}_2 \rightarrow \text{O}_2 \uparrow \]

\[ \text{H}_2\text{O} + \text{CO}_2 \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ \text{HCO}_3^- \rightarrow \text{CO}_3^{2-} + \text{H}^+ \]

\[ \text{Ca}^{++} \rightarrow \text{CaCO}_3 \]

\[ \text{Mg}^{++} \rightarrow 2\text{OH}^- + \text{H}_2 \uparrow \]

\[ \text{OH}^- \rightarrow \text{Mg(OH)}_2 \]

\[ \text{H}^+ \rightarrow 2\text{H}^+ \rightarrow \text{H}_2 \uparrow \]

CATHODE

\[ \text{Na}^+ \rightarrow \text{NaCl} \]

\[ \text{O}_2 \uparrow \]

Seawater average oxidation (acidic)

\[ \text{pH PROFILE} \]

\[ \text{pH} = 8.2 \]

reduction (alkaline)

Figure 1
ELEVATION
1/2'-1'-0'

PLAN
1/2'-1'-0'

SURFACE AREA
1'' x 2'' MESH  141/4 SQ. F.
1/2'' MESH  583/4 SQ. F.
1/4'' MESH  331/3 SQ. F.
1/8'' MESH  183/4 SQ. F.

Figure 3
surface of the structure, gradually covered all surfaces, and had reached a length of 8 cm, 280 h after inhabiting the structure. The first sample of the electrodeposited material was taken 437 h after the start of electrodeposition (Table I, Sample 33); the second sample was taken 1991 h after the start of electrodeposition and 1508 h after the power supply was disconnected (Table I, Sample 95). Mineral deposition thickness on 1" by 2" mesh measured 5.4 mm (diameter of metal wire = 1.75 mm) after 480 h of electrodeposition, consumption of electricity is shown in Fig. 4. The temperature of the electrolyte ranged between 82° and 88° F. The anode consisted of a cast iron 7' OD metal pipe with a length of 9' 2", and was placed parallel to the cathode at a distance of 4' 0" on sandy ground.

A moderate input of electrical power provided a mineral substrate that allowed rapid diatomaceous and blue-green algae growth which, possibly in connection with the availability of protected spaces, attracted various fish populations. The electric field between anode and cathode did not negatively affect algae growth, as was clearly established by the observation of an electrodeposited control sample without electric field under identical conditions.

Inhabiting fish populations visibly were not affected negatively by the electric field; individual animals moved freely in and around the structure.

Preliminary conclusions from X-ray diffraction analysis show, that, after a phasing sequence, the crystalline structure of the accretion matrix becomes more apparent. Peak intensities and breadths indicate more well-ordered crystals and less non-crystalline material.

Reef 2 consists of identically folded wire mesh formations of two different gauges with a total surface area of 144 ft². Overall dimensions are 7.5' by 7.5' by 6'.

The anode consisted of a cast iron 6 3/4" OD pipe with a length of 7' 3" and was placed under the reef (Fig. 5).

Fifteen hours after submersion white accreted material was visible on all surfaces of the structure. Seventy-two hours after submersion the same growth as on Reef I was observed covering the entire structure and reaching a length of 8 cm, 190 h after submersion. Schools of small fish were observed grazing off the growth and inhabiting the structure.

Consumption of electricity is shown in Fig. 6. One material sample was taken 413 h after submersion (Table II, Sample 32). Mineral deposition thickness on the 1" by 2" wire mesh measured 6.2 mm (diameter of metal wire 1.75 mm) after 485.5 h of electrodeposition.

Fish censuses performed 4½ months and 16½ months after placement indicated 92 individuals (6 species) and 142 individuals (14 species), respectively. Again, the fish population was dominated by grunts, parrot fish, and damsel fish.
<table>
<thead>
<tr>
<th>#</th>
<th>Description</th>
<th>Brucite</th>
<th>Aragonite</th>
<th>Calcite</th>
<th>Halite</th>
<th>Quartz</th>
<th>Other</th>
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<td>33</td>
<td>taken 437 hrs after</td>
<td>50%</td>
<td>10%</td>
<td>4%</td>
<td>-</td>
<td>1%</td>
<td>35%</td>
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<td></td>
<td>power initialized</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>95</td>
<td>1508 hrs after</td>
<td>98%</td>
<td>2%</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>0%</td>
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<td>disconnect</td>
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</tr>
</tbody>
</table>

Table I

Figure 4
ELEVATION

$\frac{1}{2}^{\prime} - 1^{\prime}-0^{\prime}$

CATHODE CONNECTION

$\frac{1}{2}^{\prime\prime}$ MESH

$1^{\prime\prime} \times 2^{\prime\prime}$ MESH

ANODE CONNECTION

$3^{\prime}-0^{\prime}$

$3^{\prime}-6^{\prime}$

$7^{\prime}-6^{\prime}$

PLAN

$\frac{1}{2}^{\prime} = 1^{\prime}-0^{\prime}$

$6^{\frac{3}{4}}^{\prime\prime}$ O.D.

METAL ANODE

$3^{\prime}-9^{\prime}$

$3^{\prime}-9^{\prime}$

$7^{\prime}-3^{\prime}$

$7^{\prime}-3^{\prime}$

ARTIFICIAL REEF 2

Figure 5
Artificial Reefs 3A and 3B were built to determine to what degree the electrodeposited minerals on wire mesh formations enhance the development of marine communities, and to what degree the wire mesh formation simply acts as an attractant. Two reef components were constructed and submerged in August 1977, in Tague Bay. Both components are identical in size and construction, each consisting of folded plate ½" galvanized wire mesh formations on a wood frame, having a total mesh surface area of 192 ft² and overall dimension of approximately 19.5' by 4.5' in height (Fig. 7).

Both components are situated in a water depth of about 15' on relatively barren, sandy bottom with small amount of seagrass (Thalassia) present. One component (Reef 3A) is supplied with dc from an unregulated power supply in the range of 6-12 V/10-20A; the other component (Reef 3B) is not under power, thus acting as a control since no electrodeposition occurs, and is situated 265' from Reef 3A. Floral and faunal censuses were taken every 6 weeks at both the accreting reef and the control reef. Fish counts taken 6½ months and 8 months after placement of Reef 3A indicated 17 individuals (8 species) and 33 individuals (8 species), respectively. Fish counts taken at the same time of Reef 3B indicated 33 individuals (10 species) and 16 individuals (7 species). More than 39 spiny lobsters (Panulirus argus) were seen in Reef 3A, while none were seen in Reef 3B, 8 months after placement.

Reefs 4 and 5, two larger artificial reefs, that utilize the mineral accretion process, were built and submerged in Corpus Christi Bay in water depth of about 12' on sandy bottom and 6 mi offshore Port Aransas in a water depth of about 60'. The two reef assemblies are supplied with dc each by a 600-W wind-driven alternator, facilitating the utilization of locally available energy (coastal winds). The wind-driven units are located on platforms near the reefs.

Each reef assembly consists of 10 folded plate ¼" galvanized hardware cloth components having overall dimensions of 3' 0" by 4' 0" by 10' 0". (Figs. 8, 9).

Total surface area of the hardware cloth used in each assembly is 2000 ft². The components were arranged uniformly over an area measuring 46' by 18' on the sea floor (Fig. 10).

The reef sites with widely varying characteristics were selected on the Texas Gulf Coast. One criterion was the availability of platforms in close proximity to mount wind-driven DC generators. The other, that one reef site was representative of shallow bay waters and one reef site representative of deeper offshore waters.

Sites for Reef 4 and Reef 5

Site Reef 4: This site is located at latitude 27° 48' and longitude 97° 10' in Corpus Christi Bay, State tract 397, next to a platform owned and operated by Atlantic Richfield Co. The average depth of the mudline is 8 ft. (Fig. 11).
ARTIFICIAL REEF COMPONENT NO. 3

FOLDED HARDWARE CLOTH CONSTRUCTION

NOTE: CONTROL REEF 3D IS IDENTICAL EXCEPT FOR ANODES AND ANODE / CATHODE CABLES

WOODFRAME: 2" x 4" FIR NAILED, MESH FASTENED WITH NAILS

---

ELEVATION

1/4" = 1'-0"

1/16" x 6" x 9" LEAD ANODE
2" x 2" WOOD STRUT
2" x 4" WOOD FRAME
ANODE CABLE AWG 14 COPPER
CATHODE CABLE AWG 14
1/2" HARDWARE CLOTH (GALV.)
192 sq. feet
19'-6"

---

PLAN

1/4" = 1'-0"

1/16" x 6" x 9" LEAD ANODE
2" x 2" WOOD STRUT
ANODE CABLE AWG 14 COPPER
CATHODE CABLE AWG 14 COPPER
1/2" HARDWARE CLOTH (GALV.)
192 sq. feet
2" x 4" WOOD FRAME

---

Figure 7
133
ARTIFICIAL REEF 4 AND 5
TYPICAL COMPONENT 200 sq. ft.
1/2" GALV. HARDWARE CLOTH

FOLDING PLAN
ELEVATION
3/4" = 1' - 0"

ACCESS HOLE • NO SCALE

Figure 9
ARTIFICIAL REEF 4 AND 5
10 COMPONENTS 200 sq. ft. EA.
1/2" GALV. HARDWARE CLOTH

PLAN
1/8" = 1' - 0"

STAKE

ELEVATION 'A'

ELEVATION 'B'

Figure 10
Existing Platform on Submerged Barge

North Elevation
Scale: 1/4" = 1'-0"

Purpose: Research Study on Artificial Reef Material
Owner of Existing Platform: Atlantic Richfield Company

Proposed Artificial Reef

In Corpus Christi Bay
In State Tract 3317
Nueces County, State Texas
Application by WLF Hilbertz
Plan 1 of 1 Date: 6/9/76

Figure 11
Site Reef 5: This site is located at latitude 27° 45' 15" and longitude 96° 59' 28" off Mustang Island, State tract 747-L next to a platform owned and operated by Energy Reserves Group, Inc. The average depth of the mudline is 62 ft. (Fig. 12).

Arrangements with Atlantic Richfield Co. and Energy Reserves Group were made to use the platforms as a base for the wind-driven dc generator units.

Design of Artificial Reefs 4 and 5

The substrate material for mineral accretion reefs has to be conductive and fairly structural. For these reasons ¼" galvanized hardware cloth was chosen.

Design criteria included:

a. maximize surface area of substrate material used
b. use modular construction
c. use simple and effective joining techniques
d. provide sufficient structural strength of the components
e. develop a design that allows assembly of reef components on land, boat, or barge and submersion as an entity.
f. provide for the use of locally available power to facilitate the mineral accretion process
g. provide constant electrical power through the use of a specifically designed circuit and wind-driven generator
h. marinize all hardware

A relatively light artificial reef component resembling a folded plate beam was designed. This component, through modular coordination, can be handled by two workers. The total surface area of each component measures 200 sq. ft. All connections were designed to be made with tie wire or hog nose rings. The electric circuit was designed and tested (Fig. 13).

Placement of Artificial Reefs 4 and 5

Reef 4: The preassembled reef consisting of ten components described earlier was lowered into the water in scissor-like fashion from a barge and positioned on the sea floor on October 10, 1978. It was connected to a wind-driven generator plant located at the top of the neighboring platform at a height of about 50 ft. by two AWG 6 insulated multistrand copper cables with a length of 120 ft. each. The peak output of the wind-driven generator is 600W direct current, average output 120-360W at 12 V in winds ranging from 15-25 knots per hour.

Reef 5: The reef was preassembled on the boat and flotation devices were fitted. It was lowered into the water and positioned floating above the selected site. Two nylon ropes extending from the neighboring platform were fastened to the reef assembly. The flotation devices were deflated and the reef was positioned on the sea floor.
Figure 12
It was connected to a wind-driven generator plant identical in output to the one used for Artificial Reef 4 and erected on the middle deck of the neighboring platform with 150 ft. of AWG 6 insulated multistrand copper cable.

Two 8-lb. lead anodes were positioned approximately 30' from the reef in Corpus Christi Bay, and approximately 90' from the reef offshore.

These reef formations, once accreted, will represent a considerable reduction in transportation and material costs when compared to concrete block or tire reefs, as the bulk of the material (substrate for marine growth and shelter) is assimilated on the site. In addition, the initial layer of electrodepoted material presents corrosion of the wire mesh template.

**Underwater Sculpture**

An underwater sculpture, doubling as an artificial reef, was built and submerged during April, 1979, outside of Tague Reef, St. Croix, U.S.V.I. (Figs. 14, 15, 16).

The central shaft is of double-layer construction, consisting of 1" by 1" galvanized hardware cloth with 2 inch spacing. Twelve ballast tanks consisting of a single layer of 1 inch galvanized hardware cloth are fastened to the central shaft.

Direct electrical current is supplied by 20 photovoltaic panels with a peak output of 3.8V/2.5A each. These panels are mounted on a metal rack in the vicinity of the structure. No accretion data are available at the present time.

**Testing of Mechanical Properties**

Twenty samples of electrodeposited minerals obtained on ¾" galvanized hardware cloth in Port Aransas and St. Croix, were prepared and tested at The University of Texas Structural Testing Laboratory. Following standard procedures for concrete testing, compression forces were recorded at the point of breakage [25]. For comparison, concrete that is typically used for stairs and steps, sidewalks, driveways, slabs on grade and basement wall construction (probably 28th day strength, normal Portland cement Type 1, 15 percent less than recommended by ACI Joint Committee) breaks at about 3500 psi [30].

**Summary and Conclusions**

Electrochemical accretion of minerals in sea water and other media appears to be as old as life itself and seems to have proven its worth during evolutionary time. Construction, maintenance, and destruction technologies as used at the present, are mainly brain children of the first industrial revolution with built-in limits [12]. Example given: A concrete or steel element in sea water, once broken or decayed, is
UNDERWATER SCULPTURE OFF TAGE REEF
ST. CROIX, U.S.V.I.
SITE PLAN 1
SHEET 1 OF 3
WOLF H. HILBERTZ

Figure 14
Tague Reef

Anodes

Anode Wires

Cathode Wire

Depth of Water 10m m.l.t.

20 Photovoltaic Panels 1 ft. by 2 ft.
On Steel Profile Rack
11 ft. by 5 ft. by 10 ft.

Underwater Sculpture
Off Tague Reef
St. Croix, U.S.V.I.

Site Plan 2
Sheet 2 of 3
Wolf H. Hilbertz

Figure 15
MATERIALS
CYLINDER A CONSISTS OF A DOUBLE LAYER OF 1" HARDWARE CLOTH WITH 1" SPACING
ALL OTHER CYLINDERS CONSIST OF A SINGLE LAYER OF 1"
HARDWARE CLOTH

UNDERWATER SCULPTURE OFF TAGUE REEF
ST. CROIX, U.S.V.I.
SHEET 3 OF 3
WOLFGANG H. HILBERTZ

ELEVATION
useless because it cannot meet its design specifications unless it is repaired. In most cases repair necessitates removal from the site and repositioning, thus incurring unreasonably high cost.

An element produced by electrodeposition, however, can be repaired or reconditioned in situ after failure. With renewed electrical power input the same conditions and resources which formed the element initially can be utilized again. This characteristic is not found in any commonly used construction method or material. Conversely, when, for instance, a reinforced concrete volume is cured and has left the form, its structural and formal characteristics can be altered only by major operations. Thus strict limits concerning the element’s adaptability to changing conditions in situ are enforced.

Other applications for the electrochemical accretion process can be seen readily: floating habitats and industrial islands, settlements on banks, shoals, and the continental shelves, mariculture facilities, breakwaters, storage tanks, dams and jetties, pipelines, bridges, tunnels, airports, beach solidifications and accretions, current diverters, building components for use on land, sea walls, marinas, atoll closures, and power as well as sedimentation generating facilities.

Structures, while accreting, can double as artificial reefs. Thus a combination of aquaculture facilities and building component plants is envisioned.

Building components can be accreted at greater depths and be designed and calibrated in such a way, that, when surfaces are closed by the electrodeposited materials, accumulated hydrogen, oxygen, or chlorine gas provides uplift and "mature" components can be harvested at the water surface. In a similar way building processes can be designed that allow structures to "grow" out of the electrolyte.

Moveable articulated form generators can be designed to produce a variety of configurations continuously by unspooling or weaving of cathodic material formations. These devices can "ride" on the generated profiles of pipes, anodes can be integrated in the generator or positioned independently in the vicinity of the form to be accreted. Energy requirements for the electrodeposition of minerals in sea water generally vary between 0.4 and 2 kW for 1 kg of accreted mass, depending on various parameters. Solar energy in its various forms can be harnessed everywhere to meet these requirements. The medium for construction, maintenance, repair, and reclamation of structures produced by the mineral accretion process covers 70.8 percent of the earth and thus represents a major resource for building in the oceans.

Furthermore, plasticity, a major principle in organic evolution, has to be maintained and augmented in order to ensure valid developments within the context of a continuously evolving world [13]. To this the process described above can contribute.
Summary and Conclusions

Electrochemical accretion of minerals in sea water and other media appears to be as old as life itself and seems to have proven its worth during evolutionary time. Construction, maintenance, and destruction technologies as used at the present, are mainly brain
REFERENCES


RAPPORTEUR'S REPORT

Dr. Fred A. Kalber

I had something running through my mind yesterday morning to the
effect that I was going to stop agreeing to summarize. This assembly,
however, changed my mind about that and a number of other things. I
never felt I couldn't be further educated, and that conviction stood
me in good stead during this meeting. More than anything else, it's
given me some new perspectives about artificial reefs, as I'm sure it
has you.

We at the Bayboro, Florida, Laboratory thought that an early
engagement with artificial reefs was one of the first. But I found
to the contrary in 1977, when we had a reef conference in St. Petersburg,
that Corps of Engineers records show that artificial reefs have been
constructed since 1896.

It's exceptionally difficult to easily put together an integrated
summary of the extremely sophisticated and well-tuned technology that we
heard about this morning. I usually try to avoid going 1, 2, 3, 4,
however, I think it's going to be a better treatment for you of what
we've heard this morning if I do a little bit of that.

We started with the air full of feathers and we ended with the
water full of fish in some very meaningful ways. I think that what we
heard from Jim Brown and several others today is an extremely important
thing to keep in mind -- an echo from yesterday in effect -- and that is
you are in a people business in a hurry if you get into artificial reefs.
Environmentalists say it's done for the benefit of fish, but way down
deep, we all know that it's folks you've got in mind. Jim Brown's
program for example, has done an excellent job of bringing attention to
that. Mr. Talley reminded us that Goodyear does more than photograph
the Superbowl game from a blimp. They and other industries have, in
fact, been heavily engaged in the artificial reef business for a long
time. They see a great many multifold and integrated advantages in this.
I think everyone should be happy to see that their interest is being
carried with the kinds of research and technical development that they're
putting into artificial reef engineering.

Sinking ships was made to seem deceptively easy by a number of
people today. This procedure for creating productive reefs has reached
a level of elegance, as you heard, in projects off Mississippi and Texas,
and many other places. As I was making some mental comparisons between
the incredible number of things that you can put under water to serve as
reefs, sinking ships seems to be a very efficient way considering the
enormous amount of surface area that you get with relatively high levels
of cost effectiveness, and efficiencies of motion and engineering.
Lonnie Ryder brought up the issue again of public profile in reef building. I want to emphasize his remarks for you in a very careful way. I don't intend to repeat what Lonnie said, for I couldn't do it so well, but to tell you that there is a very delicate connection between selecting substance for your reef and good public relations. You have heard this several times today, I would like to emphasize it.

Innovation is important in a great many directions. For instance, big oil has gotten into the reef business. Dr. Ditton told us about how and why they're there by excellent examples of the use of industrial operational hardware and its offal, when pumping is through, toward human and ecological welfare. This is a thing that I think has been ignored by many people interested in ecological restitution. Not just in tire technology, but in many ways, the private sector is extremely interested in working with you. They need direction in many cases, and they are clearly getting it from people such as Ditton and others.

I think Dr. Hilbertz excited us all by showing that not only can you put another new thing in place for reefs that will be attractive to fish and people, but you can also gold-plate it if you like. The addition of Hilbertz's electrolysis technology, and I hasten to think of another word for it because it's as much art as it is engineering, I feel is a high point in the history of artificial reefs or environmental treatment. A procedure that uses all that energy blowing in the wind, and that coming from our nearest star, to help the underwater picture I think deserves a great deal of credit and attention. I'm going to get back to that a little bit later.

Mr. Delmonico gave you, I think, the first Mother Earth News approach to making artificial reefs that I've heard — a do-it-yourself kit — amaze your neighbors by doing it in your back yard! In fact, this brings a new dimension, in a very important sense, to artificial reefs by showing that it's not necessary to lose as much money as Howard Lee has. Reefs can be made on a shoestring, with those important ingredients of human involvement and interest.

Guidelines to be used in reef construction have become highly sophisticated and show what I'm calling elements of elegance. These now pay attention not only to matters of complex engineering and cost effectiveness, but also to human attitudes, involvements and needs. There is a very pervasive drive to do the best job possible to fulfill the aims of the guidelines, and so achieve goals that will satisfy a broad range of requirements that extend from effective operation to aesthetics. As a mark of this development, it seems that the time has come to write manuals that will tap the results of your experiences and hard work to aid others. I think that if the noted anthropologist Margaret Mead could have heard what I have today, she might say, as she did of some Pacific cultures, that artificial reefs have come of age. Thank you.