A REVIEW OF ARTIFICIAL SURFING REEFS AND THEIR EFFECTIVENESS AS RECREATION AREAS, MARINE HABITATS, AND EROSION CONTROL DEVICES

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Introduction

Coastal development is putting ever increasing pressure on our coastal environment. It is estimated that more than 80% of Americans live within an hour's drive of the beach- and that number is expected to continue to rise. As more people seek to use coastal resources to live as well as for recreation, coastal communities will require solutions to the myriad issues their use creates.

One of the most pressing issues facing coastal environments is that of erosion. It is estimated that worldwide 70% of sandy beaches are eroding, and in the United States that number is even higher (Dean, 1999). Yet, the greatest boom of development since the 1970's has been along the coast (Dean, 1999). When development meets eroding shorelines, the answer in many cases is to stabilize and/or renourish the beach. However, once a shoreline is stabilized, it will frequently accelerate the rate of erosion of the beach, or increase erosion down current. Therefore, as development continues in coastal environments, alternate means of preventing erosion besides shoreline hardening should be sought.

Another issue facing coastal environments is that of increasing numbers of people using a fixed amount of resources. One area in which this problem is clearly demonstrated is surfing. It is estimated that there are over 1.8 million surfers in just the United States, with that number growing everyday (Robinson, 1998). There are only a limited number of reef bottomed surf spots available for use. Also, increasing numbers of beachgoers have forced many beach communities to limit surfing to small portions of the beach during summers, further increasing the crowded conditions surfers must face. The result is greater pressure on surfing resources by increasing numbers of surfers.

Fishing and diving also place great demand on our coastal resources. Many states have created artificial reefs to increase habitats for fish, shellfish and invertebrate populations for divers and fishermen. A study from June 2000-May 2001 estimated income in excess of $2 billion was generated by natural and artificial reefs for several south Florida communities. Besides the natural benefits of providing increased marine habitats, there are significant economic reasons for artificial reefs.

In the last two decades, the idea of artificial surfing reefs has become more popular. The artificial surfing reef has the ability to provide a solution to a number of coastal problems. First, the reef can act as an additional surfing resource to relieve crowding at other breaks. Second, the reef can act as a break wall to prevent or decrease coastal erosion. As an added benefit, the reef is submerged, greatly increasing the beach aesthetics while serving as an erosion control device. The reef can also provide an economic benefit to coastal communities by attracting surfers, fishermen, divers, and beach goers to the area. Finally, the reef can enhance the natural environment by increasing marine habitat.

This research paper explores how artificial surf reefs can provide solutions to many coastal issues. To illustrate this, two case studies are provided. Each study begins with the history of why the reef was built. Then, we explore how the reefs were constructed. Both case studies are concluded with the results of how the reef has performed as a surfing reef as well as an artificial marine environment.

We then explore why artificial surfing reefs are beneficial to marine habitats. To explain the science of artificial reef construction, we will examine a bit of the history of the research into how surfing waves are quantified. The paper concludes with the issues and ethics of artificial surfing reefs and final thoughts regarding their use.

What is an artificial reef?

Artificial reefs are man-made underwater structures that are constructed for a number of reasons. As early as the 1700's, Japanese fishermen would sink bamboo structures to serve as habitat for fish. Since that time, humans have devised many ways to build underwater reefs to serve a variety of purposes.

What are uses for an artificial reef?

Artificial reefs are serve many useful functions. One use for artificial reefs is to serve as habitat for marine life. For example, the Sarasota Bay National Estuary Program has placed over 2000 artificial reef structures in Sarasota Bay to restore reef habitat lost to dredging and other activities (www.artificialreefs.org). In 1999, New Jersey placed over 700 artificial marine habitats at sites along the New Jersey coast (www.artificialreefs.org, 2000).

Another use for artificial reefs is for erosion control. Reefs such as the Narrowneck Reef in Gold Coast, Australia or the artificial reef constructed in Avalon, New Jersey were built for just such a reason. Artificial reefs prevent erosion in two ways. One way an artificial reef prevents erosion is by trapping sand. As water moves, it picks up sediments. The faster the water is moving, the larger the amount of sediment it can hold, which is known as its carrying capacity. Artificial reefs trap sand by slowing the water. As a wave moves over the reef, it slows down, which lowers its carrying capacity. The sediments fall out of the water, and hopefully onto the reef. In such a manner, an artificial reef can accrete sand and add to an existing beach (Dean, 1999).

The other method artificial reefs prevent erosion is by attenuating wave energy prior to the beach. As ocean swells approach the beach, they are slowed by the friction of the bottom. This causes the top of the swell to move faster than the bottom and forms a wave. When the wave height reaches 1.3 times the water depth, the wave breaks. In many cases, this wave energy is expelled onto the beach. The swash of the wave after it breaks and the subsequent backwash can mechanically remove sand from the beach. As the backwash loses speed, the carrying capacity of the water is lowered and the sand is lost from the beach to form an offshore sandbar. An artificial reef can prevent this erosion if it is of sufficient size and shallow enough to slow the wave prior to the beach, causing the wave to expend its energy and lessening the impact on the shoreline.

Recreation is yet another use for artificial reefs. Diving, fishing, and surfing are all regularly practiced over and on artificial reefs. For example, the state of Florida has an extensive artificial reef program designed to provide habitat for fishes for the purposes of the fishing industry (Farren, 2003). Many states have sunk ships or other vehicles or objects to provide diving sites for SCUBA divers as well as for fishing use. Australia and the United States have both constructed artificial reefs for the purpose of creating surfable waves.

How is an artificial reef made?

Artificial reefs are made from a number of materials. Indeed, for the purposes of definition, any man-made object sunk in the ocean for the purpose of creating an artificial marine environment can be considered an artificial reef. However, there are several methods that are regularly used and can be practically considered as a means to construct an artificial reef.

One of the most widely used methods for artificial reef construction is the use of "Reef Balls". A Reef Ball is a semi-spherical concrete, hollow ball, with numerous holes to provide entry and exit points for marine life. They come in sizes ranging from 0.3 x 0.45m to 3 x 2.5m. The balls are made by pouring marine friendly concrete (created with micro silica to regulate concrete to a pH of 8.2) into a mold and using floats to tow the final product to the artificial reef site. A study by Nova Southeastern University recently investigated the use of reef balls to determine their feasibility for use as a coral attachment site (Glynn, et al., 2001).

A second method of artificial reef construction is the "Beachsaver Reef" by

Breakwaters International. The reef is an oval, triangular shaped, ridged concrete module 10 feet long along the edge parallel to the shoreline, 6 feet high, and 16 feet wide perpendicular to the beach. Each module weighs 21 tons and interlocks with the other modules to increase stability (www.beachsaver.com).

To date, the most widely used method of artificial reef construction for the purposes of enhancing surfing conditions is the use of geotextile sand bags. In the case of both Pratte's Reef and Narrowneck Reef, geotextile sand bags ranging from 10 by 7 feet to 60 by 15 feet were used. The bags are prefabricated by the manufacturer prior to being transported to the reef construction site. Once on site, local sand from the vicinity of the construction area is pumped along with seawater- forming a "slurry" mixture- into the bags. The bags are then transported by barge or dredge onto the reef site and lowered into place.

The use of geotextile reef bags offers several advantages to other types of reef construction materials for artificial surfing reefs. First, sand bags are softer than other types of artificial reef materials, making them safer for surfers who may come into contact with them. Second, the bags are much easier to remove. This is an important factor in the event the reef has an undesired effect on the environment. The use of locally available sand greatly reduces the logistics of transporting materials to the reef site. If the bags are damaged or leak, the use of local sand has a minimal effect on the environment. Finally, reef bags can be color matched to the surrounding environment, greatly improving their aesthetics (Hiliau and Phillips, 2003).

Finally, artificial reefs can be created by sinking ships, creating mounds of tires or other debris (bridge material, rubble), or submerging other vehicles such as trains. All of these reefs will provide habitat for marine life and provide sites for both diving and fishing. An artificial surfing reef at Cable Station, Australia was constructed using concrete debris. Reefs built to enhance commercial and recreational fishing have been created in many coastal areas of the United States and elsewhere.

Artificial Reefs: Case Studies

Pratte's Reef, Los Angeles County, California

Pratte's Reef, named in honor of environmental activist Tom Pratte, is the first artificial reef constructed in the United States specifically for the purpose of enhancing surfing, as well as mitigation for the loss of a surfing site (Borrero and Nelsen). The background of how this reef came into existence can be traced back to the winter of 1982-83, an El Nino winter that resulted in an unusual period of strong winter storms and intense wave activity. This period of large surf, and the ensuing erosion it caused, brought to light the coastal issues of the area, and provided the impetus for this historic decision regarding public versus property coastal rights.

The large waves and storm activity in California during the 1982-83 winter lead to extensive erosion in the heavily armored Santa Monica Bay. At the conclusion of the winter, Chevron's El Segundo marine terminal and pipelines had lost much of their protective beach. In response to the erosion, Chevron proposed the construction of a 900 foot groin in conjunction with a beach renourishment project to replace the missing sand. As the project included submerged lands, the decision for a permit resided with the California Coastal Commission. A permit was filed by Chevron in 1983 and approved by the Coastal Commission with four conditions: (1) a monitoring program to evaluate the project's impact on sand supply, (2) evaluation of beach profile changes, (3) evaluation of the effects on surfing conditions, (4) mitigation, through renourishment, of any adverse impacts on sand supply on down coast beaches, and (5) rebuilding of the County bike path across the project site (Surfrider Foundation, 1998). The reason conditional approval was granted for this project is due to a provision in the California Coastal Commission regulations (California Coastal Act sections 30233 and 30235) that permits construction of groins and breakwaters, as well as dredging and filling, if it is required to serve coastal dependent uses (California Coastal Commission, 1983). The El Segundo refinery had been present since the 1930's, and therefore was considered a coastal dependent use. In addition, the Coastal Commission acknowledged that the coastal areas of Los Angeles County are one of the most heavily urbanized in the state, and that the shoreline stability has been heavily altered by man and therefore could only be preserved through man-made controls (California Coastal Commission, 1983). Of particular note, however, is the finding that Chevron would be held accountable for changes to surfing conditions. Provisions 03220 and 30221 state the following: "Coastal areas suited for water-oriented recreational activities that cannot readily be provided at inland water areas shall be protected for such use." (California Coastal Commission, 1983) The following excerpt from the permit approval addresses this condition:

> "Effects on Surf Conditions. The overall monitoring shall include a program judging the project's impacts on the availability of surfing in the project area…The program shall evaluate impacts on surfing conditions for at least three years…At the conclusion of the surfing monitoring program, the applicants [Chevron] and the Executive Director shall examine the accumulated information to determine whether or not further mitigation should be required of the applicants to alleviate adverse impacts on the surfing conditions that are directly and objectively attributable to the completed groin project" (California Coastal Commission, 1993).

Despite the concerns that construction of the groin would have a negative impact on the coast, Chevron continued with their plans to build the groin, and in 1983 completed its construction. Chevron investigated several alternative erosion control projects, and consulted with coastal process experts as well. The conclusion reached was that construction of the groin would have no adverse effects on the surf conditions, and indeed, may actually improve them. Several locations were cited where construction of such groins had had such an effect, but in most cases surfing conditions had not been evaluated prior to construction of those groins (California Coastal Commission, 1983). Additionally, the wording of the surfing protection clause of the permit, as well as the lack of criteria regarding the surf conditions evaluation and judgment, may have caused Chevron to minimize their consideration of this part of the permit (Surfrider Foundation, 1998).

An independent contractor, Dr. Andrew Lissner, was hired by Chevron to monitor the surfing conditions for three years as stipulated in the construction permit. Dr. Lissner conducted the monitoring at his own discretion for methodology as no specific guidelines were established. He used visual observation from shore and by aircraft, and took census numbers of surfers using the breaks near the project and contrasted them with the number of surfers using the surf breaks in the local vicinity. In the winter of 1986, another El Nino cycle of storms damaged the groin built by Chevron nearly 3 years earlier. In response, Chevron was granted approval to repair the groin. Another special condition to the permit required Chevron to monitor the surf conditions for an additional 3 years. In 1989, Dr. Lissner published the "Lissner Reports" which concluded the following:

> "The results from the previous (1983-1987) quarterly surf monitoring surveys indicated that the surf quality in the project region was reduced significantly from the old El Segundo groin south to the new Chevron groin as a result of the original groin project. In contrast, surf associated with the Chevron groin was generally very good until it was decreased significantly by the result of storm damage in winter 1986. This reduction in quality was associated with smaller size and poorer [sic] shape, and a corresponding reduction in the number of surfers using the project region…The reduced quality between the old and the new groins is due to a steeper beach slope which resulted in poor surf shape associated with near shore breakers; this condition has persisted from 1983 to this date and has not shown any indication of improvement during this period (Lissner, 1989)."

Chevron opposed this report, and there was significant debate as to whether the surf conditions had indeed deteriorated. A significant portion of the debate was fueled by the fact that no quantifiable method of describing wave shape existed at the time (Surfrider Foundation, 1998). Additionally, scientists lack an adequate way of relating wave conditions in the surf zone to the wave characteristics that qualify as good surf. Yet, based upon the Lissner Reports, the California Coastal Commission ruled that Chevron would be required to mitigate the degradation of the surf area. Using a local water park as an economic baseline, Surfrider was able to claim $244,000 in mitigation costs for the loss of the spot (Surfrider Foundation, 1998). Negotiations resulted in the decision that an artificial surfing reef would be constructed to enhance the surf. Chevron agreed to pay $100,000 for studies of an artificial surf reef, and an additional $200,000 for its construction. Surfrider Foundation agreed to raise money for over budget expenses in the reef's construction.

This mitigation represents an historic decision for several reasons, most notably because it represents the first artificial reef built to enhance surfing conditions. Also, it is the first project to mitigate lost surf conditions and set a precedent of a surf spot as a natural resource. Because such a reef had never been constructed for the specific reason of surf improvement, it was necessary to research how a reef could be constructed to best meet the needs of surfers.

Although many studies have been done on the effects of submerged breakwaters and their effects on waves and shoreline response, none had been conducted specifically on creating "ridable" waves. To determine how to engineer the new artificial reef, Surfrider Foundation conducted studies using Kirby and Dalrymple's REF/DIF1 wave model, and reef shape and location in relation to the shoreline experimentation. Additionally, a study of the wave climate was conducted (Surfrider Foundation, 1998).

The result of the studies, as well as wave tank modeling, lead to an obtuse 'V' shaped reef, with the apex pointing offshore. The reef was constructed of 110 sand bags measuring 4' x 7' x 10' containing 280 cubic feet of sand, and weighing approximately 14 tons. The bags were carried to the site on a barge and lowered onto the site by a crane. The depth of shallowest portion of the reef was approximately 6 feet below mean low water (Borrero and Nelsen). The final bags were laid on September 28, 2000, however a second installation of reef bags was performed on April 23-24, 2001. Termed Phase 2, this phase placed 90 bags on top of the Phase 1 bags, raising the depth to 3 feet below mean low water, widening the crest of the reef, and increasing its volume by 80%.

The beach fronting Pratte's Reef is 180 to 360 feet wide depending on the tide. It is located in a heavily armored portion of Santa Monica Bay with two well know surf spots, "Shitpipe" (the Hyperion Sewage Treatment Plant's one mile outfall) to the north, and the Grand Street Jetty to the south. Monitoring and surf observations were conducted over a two year period for Pratte's Reef. Observations consisted of volunteer "Surf Environment Observations" in which surfers would record wave conditions (height, period, long shore current, etc.), as well as dives conducted by Surfrider Foundation environmental scientists. (Borrero and Nelsen). The results were less than expected. The waves at Pratte's Reef over the monitoring period were considered poor in relation to waves located nearby. Wave heights were generally smaller than other local spots, and few surfers were seen surfing in relation to other spots. However, as there were even fewer surfers surfing at other spots between Shitpipe and Grand Street Jetty, it can be concluded that the reef did improve surfing conditions along that particular stretch of beach (Borrero and Nelsen).

Ultimately, Pratte's Reef is deemed a failure as an artificial reef constructed to improve surf conditions. Given the fact that two very popular surf spots are located near Pratte's Reef, both attributable to man-made structures, the conclusion is that the poor performance of Pratte's Reef as a surfing artificial reef is more due to deficiencies in its design than to poor location. It should be noted, though, that Pratte's Reef had no impact on the shoreline morphology or offshore bathymetry. Additionally, a considerable amount of marine life was observed among the reef, including fish, lobsters, crabs and other crustaceans, mollusks, and other forms of marine life (Borrero, Nelsen, et.al.).

In conclusion, while deemed a failure as a surfing reef, several valuable lessons can be drawn from the Pratte's Reef project. First, this project set a precedent for establishing surfing locations as coastal resources that merit protection. Second, an artificial reef constructed for the purposes of surfing can also be a useful habitat for marine life. Finally, more research is necessary into the use of artificial reefs to affect wave processes to create surfable waves.

<u>Case Study: Narrowneck Reef, Gold Coast, Western Australia</u>

Narrowneck, an artificial reef built 500 feet offshore of the town Gold Coast in Queensland, Australia, represents another surfable reef. "Nazz", as it's known to the local surfers, is different, however, because it was not built to mitigate loss of a surfing resource. Narrowneck Reef represents a solution to the common problem of erosion, while enhancing the surf for the purpose of wave riding.

Gold Coast has had difficulties with beach erosion for years. In a cycle typical of coastal beaches, winter storms would erode the shoreline to create sandbars offshore, while summer calm would gently return the sand back to the beaches. However, development both removed the vegetation that stabilized the sand dunes as well as flattened the dunes to provide better beach views for residential structures in the town (Shaw, 2000). Predictably, the loss of sand to protect the dunes and beach from winter waves threatened the structures built along the coastal areas. Beach nourishment provided a measure of protection. Narrowneck, a stretch of beach between an intercoastal river and the ocean, had been breached three times within the last century, leading city council members to seek alternatives to save their vanishing shoreline.

Coastal scientists evaluated several options to mitigate the erosion problems. Structures such as groins and breakwalls were rejected. Kerry Black, a coastal scientist and reef specialist from New Zealand, estimates 400-500,000 cubic meters of sand erode from Gold Coast beaches every year (Black, 2000). Determining how to protect Gold Coast's remaining beach while minimizing natural sand transport mechanisms which would cause erosion problems down current was a major goal for Black and his team. Also, the city Gold Coast city council didn't want a rock groin or break wall detracting from the aesthetics of the pleasant beach already present. The council wanted a structure that would protect their beach and improve surfing conditions. Therefore, Black began investigating the artificial surfing reef concept.

Construction of artificial reefs offshore to prevent shoreline erosion isn't a revolutionary idea. Numerous examples exist of reefs built to alleviate erosion problems- either caused by man-made or natural processes. What is revolutionary is the proposal to construct the reef to enhance surf conditions- the way in which the wave breaks, as well as provide coastal protection. Why Australia is the first country to propose this is an interesting question. Surfer Magazine, a popular publication in the United States dubbed "The Bible of the Sport" suggests that Australia legitimizes surfing more than the United States.

Another interesting difference between Narrowneck Reef and Pratte's Reef is the amount of funding for each project. In the case of Pratte's Reef, $300,000 was budgeted by Chevron to build the reef as mitigation for destruction of a surf spot. $1.5 million has been spent on Narrowneck Reef, but it is estimated that just one surfing competition on the reef would bring $2.2 million into the local Gold Coast economy (Australian Broadcasting Corporation). This, of course, has lead to a much larger reef at Narrowneck, 1,150 feet by 2000 feet, in contrast to Pratte's Reef at 150 feet by 150 feet. It is speculated that one of the major reasons Pratte's Reef has failed to produce quality surf is due to its small size due to limited funding (Borrero and Nelson). The Gold Coast city council believed that the beach had enormous economic value, and that a recreational reef would attract more tourists; an economic assessment indicated that the project would generate more than 60 times its cost in revenue (Raybould and Mules, 1998- ASR report, 2000). The issue of cost/benefit for artificial surfing reefs is covered later in this paper.

In 1998, Artificial Surfing Reefs Limited (ASR, Ltd.) began investigating the Gold Coast City Council's request to build a submerged structure that would: 1)provide a control point for the widened beach and dunes at Narrowneck Beach, and 2)improve the surfing conditions. At the outset, it was clear to Black and project engineer in charge of construction Agnus Jackson of International Coastal Management Ltd. that a great deal of research was needed for such a project. With no precedent with which to guide him, Black set out to investigate how such a multi-functional structure could be built. Numerous studies were conducted, including on-site field measurements, numerical wave modeling, and sediment transport modeling. Interestingly, a novel study was also conducted by Black to develop a database of the reef bathymetry of world-class surfing reefs to gather knowledge of how these reefs created quality surfing waves. Black recorded characteristics of waves and reef structure from 33 sites in Indonesia, Hawaii, California, Brazil, Australia, and New Zealand (Mead et al., 1998). Additionally, the sediment transport mechanisms of two world class beach breaks on the Gold Coast were poorly understood, so this was also investigated to develop data on how such a reef constructed at Narrowneck may be littorally influenced. The ultimate choice for reef design was a compromise of longshore drift impact, and wave quality throughout a range of swell size and periods, as well as tidal ranges.

The reef is constructed of "Reef Bags" which are geotextile bags filled with natural sand. The bags are pre-sown by the manufacturer and filled on site in the unique split hull hopper dredge used to place the bags. Using GPS measurements from bow and stern the ship is positioned to properly drop the bag onto the planned location. Each bag is between 160-300 tons and 20 meters long by 5 meters wide The 110,000 cubic meter reef is made of approximately 300 such bags (ASR Ltd., 2000).

Orientation of the reef differs significantly from normal submerged breakwalls. The reef is constructed to form a "double-sided underwater headland" with two "arms" (Black et al., 1998). The long northern arm is designed as a beginner's break at the inshore end, while the shorter southern arm has no beginner section. The arms are designed to use refraction to set up the wave orientation and provide the characteristics of the wave. Rides can be as long as 200 meters for wave heights of 1 meter. The reef will continue to break up to its design maximum wave height of 4 meters, albeit with shorter rides of 120 meters in length. The arms are separated for three reasons: 1) to eliminate wave interference on the take-off zones, 2) to provide the space needed to create the peak at take-off, and 3) to provide a paddling channel for surfers during large swells when beaches in the vicinity are closing out. Additionally, the reef was designed to be a shallow as possible without emerging. The reef crest is at 0.25 meters at spring low tide but descends to 10.4 meters at its deepest portion. A benefit of the reef has been the formation of a protected "lagoon" at low tide, the only sheltered swimming beach on this stretch of beach.

The ecology of the reef is similar to that recorded at Pratte's Reef in California. Prior to the construction of the reef, the bottom consisted of a sand seabed supporting a low diversity of benthic flora and fauna. Within hours of the bags' placement, however, numerous small fish were seen around the new reef. After 2 weeks the bags were overgrown with marine algae and organisms. Months later, fish, plant life, and even sharks have been sighted among the Narrowneck Reef (ASR Ltd., 2000). The reef has clearly had beneficial impact on the marine ecosystem in the area and presents new habitat to local marine life.

In addition to providing new marine habitat, the two main goals of the Narrowneck Reef- prevent erosion and improve surfing conditions appear to have been met. This surf report from May 13, 2000 sums up the quality of surf at "Nazz":

> "You want the bomb waves, you go to Nazz. That's the story today. It's going sick up there. Light westerly winds and a 1.5 meter SE swell is making Narrowneck and the northern beaches find some wicked form. Heaps of crew knew it too, they were all too keen for the early offshore sesh. The bulk of the pack is hanging around the artificial reef, but the banks north, south, or anywhere in the nearby vicinity are just as good. The barrel show will hold till those westerlies swing later through the day. Tomorrow should see the offshore last longer. Check the pics and work out why the hell you're not there." (http://www.burleighcam.com.au, 2000)

Indications are that the reef at Narrowneck has also contributed to preventing beach erosion. The beach in the vicinity has been significantly widened (www.bournemouthcivicsociety.com). Research indicates that sand has built up on the shoreward side of the reef and the surf reports clearly show that the reef is a useful breakwall for swells.

Discussion

Artificial Surfing Reefs as Habitats for Marine Life

The construction of an artificial surfing reef can have many benefits for local marine life. Shallow water subtidal sedimentary substrate provides few habitats for benthic life to populate, therefore species diversity is generally much lower than within hard substrate communities such as reefs. Most abundant in such a sandy community are deposit feeding invertebrates, suspension feeders, and bottom dwelling fishes. Additionally, physical and biological interactions lead to a patchy distribution of organisms. Although meiofaunal organisms may be populace, macrofaunal organisms are much fewer (Nybakken, 2001).

Reef communities, by contrast, typically have much greater biological diversity as well as much higher productivity. Tropical reefs in particular have the highest taxonomical diversity of any marine ecosystem . Temperate reefs generally lack the diversity of their tropical counterparts, but have a greater abundance of resident species (Nybakken, 2001). Reefs in both locations have greater diversity, biomass, and production than sandy benthic communities residing at similar latitudes. What this indicates is that an artificial surfing reef built on a sandy substrate bottom should provide additional habitat leading to greater biological diversity and productivity.

It is difficult to estimate exactly how such a reef will evolve however. It is unknown to what degree recruitment versus biological factors such as predation is responsible for the ecological development of a reef. It is feasible, though, to expect that creation of an underwater habitat where none existed prior (ignoring for the time being that a non-vegetated sand substrate supports a diverse meiofaunal population of invertebrates and bacteria) will lead to greater biological diversity and biomass. Therefore, it is reasonable to suggest that artificial reef habitats enhance the marine ecology of the area.

The material and structure used to construct the reef will also have an effect on what organisms will settle there. Geotextile reef bags make a poor substrate for the recruitment of scleractinian corals (Burgess, et al., 2003). Scleractinian corals build upon themselves by a succession of new coral polyps growing on the calcareous skeletons of older ones. As reef bags lack the hard substrate that would provide such a skeleton, it is expected that corals would not be a dominant organisms in artificial reef habitats constructed of them. Although it may be possible for such structures to host hard corals, it is likely that they would be out competed by algae and other soft coral species. Wave action may also limit types of organisms inhabiting the reef. In this case, the community would differ between areas exposed to high wave action and protected areas within the reef (Burgess, et al., 2003).

The structural complexity of the artificial reef has an effect on the abundance and diversity of resident fishes (Burgess, et al., 2003). The use of concrete blocks or reef balls adds a variety of niches and additional habitats with differing amounts of light, wave, and current exposure. Such devices can provide protection from predators for smaller fishes, an increased number of refuges for both large and small fish and invertebrates, and significantly more recruitment sites by increasing surface area of the reef. A study conducted by Sherman et al. in 2002 recorded a twofold increase in the mean number of fishes by including concrete blocks in a hollow artificial reef. While it remains to be determined if geotextile bags are the best material for artificial reef construction, it is clear that consideration should be given to including some amount of hard, complex structure to low profile reef bag reefs to increase diversity and abundance of marine life.

A study conducted by scientists working at Nova Southeastern University demonstrates the use of artificial reefs as recruitment sites for scleractinian corals. In 2001, 160 concrete Reef Balls were distributed in groups of 4 on the bottom off of Dania, Florida. Meandrina meandrites and Montastrea cavernosa were transplanted onto 40 Reef Balls distributed among the 40 reef sites. Monitoring of the corals from March to June, 2001 showed a 100% survival rate of the corals (Glynn, et al., 2001). While no definitive conclusion has been drawn from the study, it is a useful study in that it demonstrates the feasibility of coral attachment to hard substrate artificial reefs.

Narrowneck Reef in Australia provides a useful example of how an artificial surfing reef has provided a marine life habitat. As previously discussed, the reef is located 500 feet offshore in 2 to 11 meters of water. The nearest rocky reefs on that stretch of coast are located more than 25 km distant. The International Coastal

Management filmed the marine life on the reef to provide evidence of the current inhabitants of the reef. The film indicates that most of the bags are covered by brown algae to heights of 30 cm. It is noteworthy that the bags have been impacted by hurricane force waves and still show the algal growth, indicating that the algae species are capable of attaching and growing in a high wave environment (Burgess, et al., 2003).

Additionally, many small fishes have been recorded at the reef. Lobsters inhabit the crevices between the reef bags as well as octopi. Pelagic schools of fish numbering in the hundreds to thousands have been filmed on the reef, as well as a shark, turtle and 2 species of rays. It is suggested that the presence of octopi and other invertebrate species indicates that increasing the use of smaller reef bags, or the addition of more complex structures could increase the diversity of the reef (Burgess, et al., 2003). This is supported by the research previously mentioned.

As previously mentioned, dive surveys were conducted at Pratte's Reef in 2001 and 2002 to document the condition of the reef bags and assess the marine life inhabiting the reef. Schools of small fish, lobsters, sea stars, halibut, mussels, and other invertebrates were observed at the reef. Additionally, the bags were quickly covered by marine algae. Within weeks of the bags' placement, marine life had colonized the reef (Borrero and Nelsen).

The conclusion to be reached from the Narrowneck Reef and Pratte's Reef is that an artificial reef constructed of geotextile reef bags can be expected to increase biological diversity in a marine area. While it must be remembered that the marine ecosystem is a complex environment with many contributing and conflicting factors, it is also clear that the construction of artificial habitats can have a beneficial effect on marine life. These reefs must be taken as site specific examples of what can occur on an artificial reef, but it is reasonable to draw some broad conclusions based on scientific studies that suggest that reefs support greater diversity and abundance than soft substrate environments.

Enhancement of wave quality analysis

Surfers have many ways by which to describe wave conditions. A surfer may say the waves are "tubing" or "closing out." The surf may be "long board" waves or "short board" waves. Conditions may be described as breaking "just like Pipe" or "just like Malibu." While the quality of a surfing wave is a relatively subjective opinion, surfers in general know the difference between good waves and bad ones, or beginner waves and advanced waves.

A quality surfing wave is the combination of several factors. Waves must be open faced enough to allow the surfer to perform maneuvers, but not so steep that the wave breaks prematurely. The wave must peel as it breaks so that a surfer can utilize the wave's energy as it breaks laterally to generate the ride. The seabed shape has the greatest influence on these qualities of a wave, so it is logical that these factors are what research has sought to quantify. Seabed shape is the measure artificial surfing reef creators use to best transform incoming waves into surfable ones (Mead, 2003).

The peel angle of a wave is how waves are classified to determine the speed they will enable a surfer to attain. Quality surfing waves are ones which peel as they break. The peel angle is the angle between the trail of the broken white water and the crest of the unbroken part of the wave as it breaks shoreward. The peel angle can range from 0 to 90 degrees, with 0 degrees representing “close out” conditions where the wave collapses in an unbroken mass to 90 degrees representing a wave breaking too slowly to be used for surfing. Generally speaking, waves with peel angles of 30-40 degrees would be considered advanced, fast breaking waves, while peel angles of 60 degrees or more would be considered beginner range, slow breaking waves.

Determining the optimal angle for a particular wave is a difficult prospect. Although peel angle is a useful means of describing the surfability of a wave, it is only one of the factors. Other factors such as the intensity of the breaking wave, the steepness of the wave, and the height and period of the swell all contribute to a wave’s surfing quality. Also, factors such as wind direction and speed will have a great effect on wave quality. It is the underwater bathymetry that has the greatest effect on the wave, however. Besides affecting the peel angle of the wave, the gradient of the bottom as the wave approaches the shore effects whether the wave will break in a spilling manner or a plunging manner. Spilling waves tend to be more suited to beginners, while plunging waves present a greater challenge to the surfer and are better suited to the intermediate to advanced surfer. As with peel angle, extremes on either end are undesirable (Mead, 2003).

The ability to qualitatively measure wave conditions in terms of their surfability has eluded scientists until recently. The first studies attempting to describe waves in terms of their quality for surfing were undertaken by James “Kimo” Walker of the University of Hawaii in the early 1970’s. Walker conducted tests on Oahu’s south shore to determine the criteria that determined a wave’s difficulty of surfability. He determined that a wave could be defined by a function of its height and peel angle and devised a method of using these factors to rank a wave based on the rider’s skill level. However, difficulties arose when attempting to apply Walker’s measurements to other waves. First, Walker conducted his experiments in Hawaii, which has reefs that lead to more powerful, plunging type waves. Also, Walker’s experiments considered waves up to 25 feet. While waves of this type are frequently ridden in Hawaii, they are more unusual in other parts of the world. In addition, for artificial reef building purposes, construction of a reef to suit waves of this height would be uneconomical due to the large size of reef required to create ridable surf.

To better quantify good quality surfing waves, Black, Mead, Sayce and others set about devising a means of classifying waves based upon their breaking intensity. The results of their studies determined several things. Wave breaking intensity can be used to quantify wave surfability. Additionally, a means of quantifying the shape of the breaking wave was identified by Sayce using mathematical equations to describe the vortex or "eye" of the breaking wave. A final, important discovery made by Mead and Black was that the gradient the wave follows approaching the reef, and not the actual reef gradient, is the most useful means of determining the intensity a wave will break. The final product was a means of delineating wave breaking intensity based on mathematical models, describing the type of vortex generated by the breaking wave (Mead, 2003).

Most of the preceding research into artificial surfing reef design took place after the construction and subsequent failure of Pratte's Reef to create quality surf. This is very likely due to a flaw in the reef's design. As previously discussed, the shape and depth of the reef determine the wave's peel angle and breaking intensity. Pratte's Reef was built using a simple 45 degree wedge facing into the predominant swell direction. On the surface this would seem to be an ample angle to create sufficient peel angle. Yet, a peel angle of greater than 45 degrees is what is actually experienced due to refraction. When a wave approaches the reef, refraction causes the wave to change direction to align more parallel with the contours of the seabed. Depending on the depth of the reef, the wave's resultant direction can lead to a lower peel angle, and subsequently a slower, lower quality surfing wave (Mead, 2003).

Additionally, the small size of Pratte's Reef degrades its ability to adequately transform incoming swells. As previously discussed, underwater bathymetry and gradient is the factor most responsible for the quality of the incoming waves. Pratte's Reef extends only 30 meters offshore, which is insufficient to successfully manipulate swells. Given our knowledge of how offshore processes affect the quality of waves prior to reaching the reef, it is clear that a much larger reef oriented to compensate for refraction and extending far enough offshore to manipulate the gradient is necessary for Pratte's Reef to break properly.

Narrowneck Reef, by contrast, is deemed a success on every level. Quality surf has been observed breaking there consistently since its construction. This can be contributed to several factors. Compared to Pratte's Reef, Narrowneck Reef is a monster project at more than 70 times the volume of Pratte's. Additionally, the reef extends 150 meters offshore to a depth of 12 meters; sufficient to manipulate the underwater gradient. Finally, the reef is built at a far greater than 45 degree angle to the beach to compensate for refraction and ensure that the peel angle is sufficient for the wave design. By altering the angle of the reef, a beginner section as well as an advanced section has been designed by altering the peel angle of the waves.

Conclusion

As has been demonstrated by Pratte's Reef and Narrowneck Reef, artificial surfing reefs can be a viable means to create a new surf site, while benefiting the local marine ecosystem and providing a measure of erosion control. But, are artificial surfing reefs the ultimate panacea for all of our coastal zone management woes? As with any solution, there are a number of issues regarding the ethics of artificially altering the natural environment.

One of the foremost issues is whether an artificial surf spot should be created at all. The two sides of this issue can be summed up quite easily. Proponents of artificial surfing reefs such as former world champion surfer Pam Burridge suggest that the reefs can alleviate the crowding problem that promises to get worse as more surfers take up the sport. As her husband said after he and Burridge were driven from the water during a session at Kirra in 1996, “It was just so crowded. I remember surfing that break with one other person in the late ‘60’s.” Or as professional surfer Shane Powell puts it, “The problem is that the crowds bring out the aggro factor in everyone.” Perth surfer John Balgarnie offers another perspective, “There are football fields, cricket grounds, basketball courts…we’d like a facility for surfers.”

Opponents to artificial surf reefs have several objections. Some believe that creating predictable quality surfing waves will only exaggerate the crowding problem. Others, like former world champion surfer Barton Lynch believe that the “artificialness” of the reefs detracts from the soul of natural surf breaks: “The beauty of a wave is in its fickle nature.” Perhaps the noteworthy objection to artificial surfing reefs comes from the environmental watchdog Surfrider Foundation which purports its opposition to artificial surf reefs as a viable alternative to naturally existing surf conditions (www.surfrider.org). The Surfrider Foundation goes on to recommend, however, that future man made additions to the coast consider other recreational and environmental uses such as surfing (www.surfrider.org).

Ultimately the decision to create an artificial surfing reef becomes a compromise between increasing the number of resources at surfers’ disposal and surfing losing some of its “soul”. Additionally, there is concern that if artificial surf reefs become technologically advanced enough to consistently produce quality surf, there may be an incentive to destroy naturally existing surf breaks since they can simply be mitigated as occurred at Pratte’s Reef.

A positive argument in favor of artificial surfing reefs is for their use in erosion control. While many additional studies are required, and each individual reef would need to be extensively studied regarding its effect on local coastal processes, submerged reefs may be a viable means for states to provide erosion control without coastal armoring. In 28 of 29 coastal states (Alaska being the sole holdout), shoreline stabilization is in some way restricted (Cohen and Gordon, 1998). This policy gives states and local communities incentive to find alternative means of erosion control. New Jersey constructed three artificial reefs in a pilot project to investigate their use as erosion control devices. As suggested by the Surfrider Foundation, it may be feasible to construct future artificial reefs in a manner that enhances the local surf conditions.

In addition to providing an alternative to shoreline stabilization, artificial surfing reefs may provide erosion control alternatives that do not negatively impact the aesthetics of the beach. With the increased environmental awareness of the public, tourists are increasingly interested in nature-based attractions (Prasetya and Black, 2003). This demand creates an incentive for beach based communities for which tourism is a significant portion of their income to seek alternatives to groins, seawalls, and other man made structures that may detract from the natural beauty of the beach. Submerged devices eliminate this dilemma while providing the added bonus of a recreation amenity.

The economics of an artificial surfing reef also presents an issue that must be addressed. The commercialization of a surf spot is a very touchy subject among surfers, and one which must be carefully considered. Many surfers are opposed to paying to use a "surf park" type artificial reef because they feel that restricting access to the ocean is unethical (www.surfline.com). However, there are other means by which a coastal community can benefit economically from an artificial surf reef besides the pay-to-use idea.

Increasing the recreational amenities offered at a beach may increase the number of people using the beach and the community (Weight, 2003). In addition to attracting more surfers, more families may be present, as well as fishermen, divers, and other tourists and their families. These additional users provide additional opportunities for businesses such as surf shops, bait and tackle shops, souvenir shops, and other tourist based businesses to earn additional income. This in turn can create additional jobs and provide other economical benefits to the community. While the study of how to place a value on an individual reef is beyond the scope of this paper, it is clear that a cost analysis of an artificial surfing reef goes beyond the simple costs of the construction of the reef versus the property it may protect. Constructing multiple use reefs opens up much wider monetary benefits to the coastal community.

While artificial surfing reef use is still in its infancy, the prospect of constructing multiple use coastal structures is one that is rapidly increasing. The cost benefits of attracting more money-spending tourists to an aesthetically pleasing, erosion controlled beach that provides recreational opportunities, is an idea which is gaining favor. As coastal use increases, we must carefully consider how we can protect the environment and still provide for the recreational needs of the public. Artificial surfing reefs are just one method that coastal communities can utilize to address coastal problems like erosion control while increasing the value of their shoreline. In each case, thorough research is necessary to study the effect on the environment such a reef may have, as well as any negative aspects to increased beach use in that area. As we seek to protect our natural resources, we should also seek ways in which we can concurrently improve the environment. This paper demonstrates how artificial surfing reefs can accomplish this task.

References

ASR Gold Coast Reef, www.asrltd.co.nz, 2000.

Breakwaters International, Beachsaver Reef.

Beamsley, Brett; Black, Kerry, The Effect of Offshore Reefs on Inshore Surfing Conditions. Proceedings of the 3rd International Surfing Reef Symposium, June 22-25, 2003.

Borrero, Jose C.; Nelsen, Chad, Results of a Comprehensive Monitoring Program at Pratte's Reef. www.surfrider.org.

Burgess, Scott C.; Black, Kerry P.; Mead, Shaw T.; Kingsford, Michael J., Considerations for Artificial Surfing Reefs as Habitat for Marine Organisms. Proceedings of the 3rd International Surfing Reef Symposium, June 22-25, 2003.

Cohen, Tina Bernd; Gordon, Melissa, State Coastal Management Effectiveness in Protecting Beaches, Dunes, Bluffs, Rocky Shores: A National Overview, March 1998.

Costello, Paul, Artificial Reef, ABC Television, March 9, 2000.

Dean, Cornelia, *Against the Tide*. Columbia University Press, 1999.

Dixon, Chris, Artificial Surfing Reefs. When Will We Get a Wave?. www.surfermag.com, October 30, 2003.

Executive Summary, Socioeconomic Study of Reefs in Southeast Florida Final Report, 2001.

Figley, Bill, Division Deploys 700 Reef Balls, News. New Jersey Division of Fish and Wildlife, January 11, 2000.

Harris, Lee E.; Woodring, Marsha Pardee, Artificial Reefs for Submerged and Subaerial Habitat Protection, Mitigation, and Restoration. www.artificialreefs.org.

Harris, Lee E., Submerged Reef Structures for Habitat Enhancement and Shoreline Erosion Abatement. www.artificialreefs.org.

Heller, Greg, Artificial Reefs. www.surfline.com, March, 2001.

Hiliau, Winston; Phillips, David, Artificial Surfing Reef Construction. Proceedings of the 3rd International Surfing Reef Symposium, June 22-25, 2003.

Mead, Shaw, Surfing Science. Proceedings of the 3rd International Surfing Reef Symposium, June 22-25, 2003.

Nybakken, James W., *Marine Biology- An Ecological Approach*. Benjamin Cummings, 2001.

Pattriaratchi, Charitha; Bandcroft, Stacey, Design Studies and Performance Monitoring of and Artificial Surfing Reef: Cable Station, Western Australia. Department of Environmental Engineering, The University of Western Australia.

Prasetya, Gegar; Black, K.P., Sanur and Kuta Beaches in Bali: Cases for Removing of Coastal Protection to Offshore Reef. Proceedings of the 3rd International Surfing Reef Symposium, June 22-25, 2003.

Raulerson, Gary E., Sarasota Bay NEP Restores Reef Habitat. *Coastlines*, Issue 13.2, April 2003.

Robinson, Simon, Making Waves- The Creation of Artificial Surfing Reefs May Offer Frustrated Board Riders New Breaks. *Time*, June 1, 1998.

Scarfe, B.E., Elwany, M.H.S., Mead, S.T., Black, K.P., The Science of Surfing Waves and Surfing Breaks- A Review. Proceedings of the 3rd International Surfing Reef Symposium, June 22-25, 2003.

Shaw, Robinson, Surf's Up: Artificial Reef Curbs Erosion, Improves Waves. *Environmental News Network*, May 18, 2000.

Surfrider Foundation, Pratte's Reef.

Weight, David, Economics of Surf Reefs. Proceedings of the 3rd International Surfing Reef Symposium, June 22-25, 2003.

www.bournemothcivicsociety.com

www.elporto.com.

www.reefball.com.