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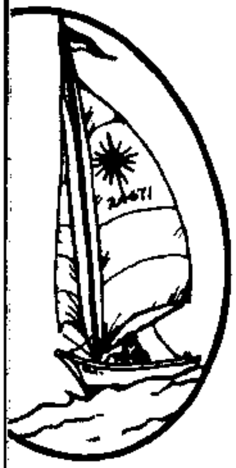
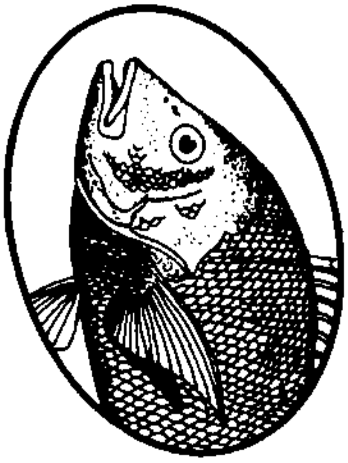
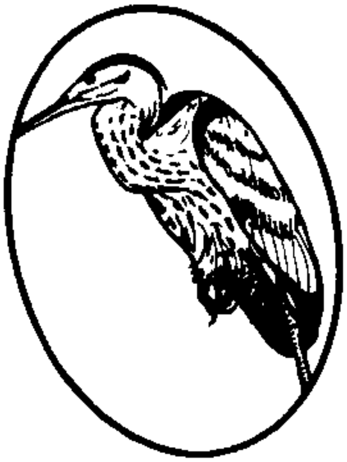
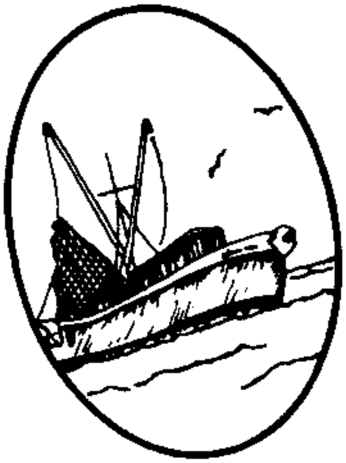
Artificial Seaweed for Shoreline Erosion Control?

Spencer Rogers Jr.









UNC Sea Grant College Program
105 1911 Building
North Carolina State University
Raleigh, NC 27650

ARTIFICIAL SEAWEED FOR SHORELINE EROSION CONTROL

by

Spencer Rogers Jr.

Department of Civil Engineering, North
Carolina State University and UNC
Sea Grant, Marine Advisory Service
Kure Beach, North Carolina 28449

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Over the last few years, artificial seaweed has been loudly hailed as a cure for oceanfront shoreline erosion control problems. This paper summarizes the history, theory and actual documented results of erosion control projects using artificial seaweed.

EUROPEAN DEVELOPMENT

The early development of artificial seaweed for erosion control purposes has been reported to have started around 1962, either in Denmark (Brashears, 1967) or England (Linear Composites, 1986). The first reported field installation took place on the Danish shoreline near the North Sea in 1963 (Brashears, 1967). Further development took place through work conducted independently by three fiber/fabric firms: Avisun, a subsidiary of Sun Oil in Denmark; Royal Dutch/Shell and Nicolon in the Netherlands; and Linear Composites, a subsidiary of Imperial Chemical Industries in England. All three products were similar. The artificial seaweed was composed of polypropylene tape, 1/8" to 3/8" wide, connected edge to edge to form a continuous serrated sheet. Or in some cases, dozens of tapes were bundled together to form individual tufts of seaweed. Both types of tapes are called "fronds." Bundles of monofilament fibers, with a diameter of 0.01 to 0.0001 inches, were also tested but later abandoned. Fronds varied from 3 to 8 feet in length.

All three groups initially found anchorage on the bottom to be a difficult engineering problem. Avisun lost three of their early tests due to anchorage failure. Two other tests of their product took place in the United States and have been reported previously in this journal (Rankin, 1965; Wicker, 1966; Brashears, 1967; and also Sivard, 1975; Bradfish, 1966). The first two articles reported on a test conducted with the New Jersey Department of Conservation and Economic Development off the Atlantic shoreline of Ocean City, NJ. Dense bundles of artificial seaweed were placed in 15 feet of water, approximately 800 feet offshore. A bed of material 90 feet wide (perpendicular to the shoreline) was placed along 900 feet of shoreline. The equivalent of 31 rows of seaweed with 3 feet between rows, were placed parallel to the shoreline. Fronds of seaweed were placed every five feet in the row along the shoreline. Each frond consisted of about 2,000 individual tapes, 6 feet long. Each was attached to a rope grid, which was anchored with individual lead weights and concrete anchors. Over 3,000 feet of shoreline around the installation was to be monitored. Wicker (1966) reported that the anchorage system failed within several months, after either being cut by commercial fishing gear or by natural causes. No conclusions could be made on its effectiveness.

Avisun tried again, in the Atlantic this time with NASA, along Wallops Island, VA, just south of Assateague Island (Brashears, 1967). Water depths and distance offshore were about the same, but this time, the bunched fronds were anchored to steel frames. The frames were placed in V-shaped arrays pointed offshore with three different densities of seaweed. The project was destroyed within several months by northeast storms. The connection between the individual bunches and the steel frame failed. Most of the seaweed was washed ashore (Figure 1). No other more recent record of Avisun's product was found. No other research on this side of the Atlantic was reported for over 10 years. Research continued in Europe.

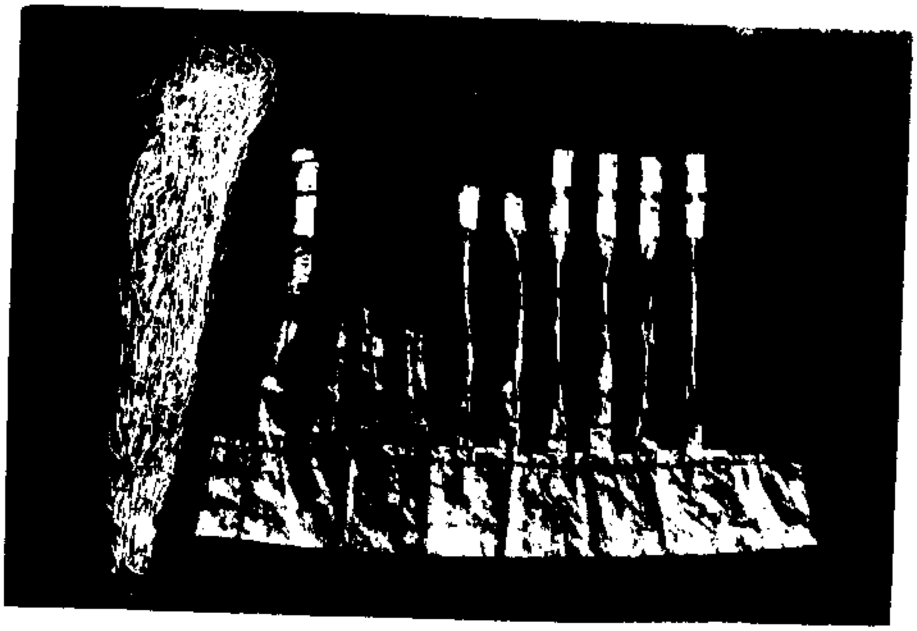

Figure 1. Avisun seaweed from Wallops Island, VA, installation (left). Note ring where anchorage failed. Deteriorated Seascape unit from Cape Hatteras (right).

After several years of work, the two remaining manufacturers settled on differing anchorage methods. Shell/Nicolon developed an anchor consisting of a fabric tube, approximately 6 to 12 inches in diameter, filled with either sand or gravel (Nicolon, 1985). Individual tapes are attached edge-to-edge to the length of the tube, providing, in effect, a serrated sheet of seaweed. Both tube and seaweed frond are generally 5 to 8 feet long. Linear Composites (1986) eventually settled on two different designs depending on the application. For free standing applications, bundles of polypropylene tape are attached to a filter fabric base on roughly a 1.5' grid. The fronds are available in variable lengths. The fabric is then anchored with steel beams or concrete. For use around offshore structures, the free end of the seaweed is weighted and the fixed end is supported from above on welded steel frames attached to the structures. The fronds are 5 to 8 feet long. These anchorage methods were developed relatively early and were sufficiently successful to conduct specific tests on artificial seaweed as an erosion control method.

Erosion problems are caused by a wide variety of natural and man-made phenomena. European research concentrated on two specific erosion problems: excessive tidal scour in secondary inlet channels and localized scour around man-made offshore structures (Angus, 1982). Unlike the two early U. S. tests, shoreline erosion was only an indirect concern. Field testing has been conducted in the Netherlands, England, Denmark, West Germany, the French Mediterranean, Norway and the United States.

In the Netherlands, research on artificial seaweed has been conducted in cooperation with the Shell Plastics Laboratory, Nicolon and the Dutch Ministry of Transport and Waterways. Research has concentrated on the use of seaweed as a low-cost alternative to rock mattresses to control tidal scour in secondary channels of tidal inlets (Bakker 1972, 1973). These secondary channels have been found to be a significant threat to both natural shorelines and to the coastal protection of some of the major land reclamation projects. In 1964, Shell developed a gas injected polypropylene material that has much greater buoyancy. Polypropylene normally has a specific gravity of 0.9. Gas injection during manufacture reduces the specific gravity to 0.2, substantially increasing the buoyancy. The added buoyancy was found to reduce sinking when the material fouled with marine organisms or debris. Shell provided the polypropylene. Nicolon manufactured the seaweed. The Ministry installed and monitored the tests.

Several methods of installation were developed depending on the water depth, current velocity and wave climate. The material was placed in channels, perpendicular to the direction of flow, in hopes of trapping enough sand to form a dam across the channel. Water depths most frequently ranged 10 to 50 feet. Several were placed in intertidal locations at low tide. One test was placed around a submarine pipeline at a depth of 100 feet. Peak current velocities were 3 to 5 feet per second. The seaweed fronds varied in length from 5 to 7 feet. Fifteen to 50 rows of units were installed. Early tests had fewer rows than those that followed. Eleven large scale tests were evaluated by 1978 (de Boer, 1975; Nicolon, 1978).

Results of the experiments were mixed. Two of the tests resulted in deeper channels and increased erosion. Five sites, including the deep water pipeline showed shallower, more stable channels after 3 to 6 years of monitoring. It was concluded that the artificial seaweed could be reasonably judged to have been the cause of the deposition. In the remaining cases, major deposition or relocation of the channels occurred. The size and configuration of the changes led to conclusions that they were naturally occurring changes, far beyond the capacity of the seaweed. These tests were therefore inconclusive. The researchers noted the difficulty of separating 1 to 3 feet of change, potentially caused by the artificial seaweed from equal or larger changes naturally occurring along the shoreline.

Overall, the Dutch tests indicated that artificial seaweed could be effective in controlling current scour in secondary tidal channels and localized scour around man-made structures. It may be a lower cost alternative to rock control structures, however, it has seen only limited use in recent years. While several of the tests were conducted in significant wave climates, the effect was primarily on the current and did not show any effects on wave-induced currents or shoreline erosion.

Linear Composites (1985) has reported successful installations at three offshore oil platforms where weighted artificial seaweed is suspended from above by metal frames securely attached to the platform. Three other installations of their sea bed system, bundles of fronds attached to a filter fabric mat, have been deployed around offshore pipelines. As with the Dutch tests, all of the erosion problems were caused by current scour, in these cases, around man-made structures. A field trial to test the material's effectiveness against shoreline erosion was conducted on the English Channel in 1965. Bundles of seaweed fronds 8 feet long, spaced on 3-foot centers, were placed 480 feet offshore in a grid 400 feet long and 150 feet wide. While beach profiles showed a buildup of the beach, the grid was severely damaged by storms within six weeks after installation. The effects of the seaweed were undetermined.

Ocean Industry (1979) reported on the installation of Linear Composite's erosion mats at Saintes Marie de la Mer, France, on the Mediterranean coast near the mouth of the Rhone River in 1978. Nearby beaches have serious erosion problems, but the actual installations were for scour problems adjacent to rock jetties and other man-made structures (Geomidi, 1979). Erosion at the site was apparently caused by current scour although at least some sea swell was present. Five separate test mats, 33 x 7 feet, were installed. Bundled fronds were located in a grid every 1.5 feet. The first two mats failed immediately due to anchorage problems. The other three were re-sited to more sheltered locations and were anchored by heavy chain. Up to 10 inches of fine sediment was deposited after seven months. The project monitors recommended heavier anchorage of the filter fabric mats, increasing the density of bundled fronds, lengthening the fronds and increasing the size of the beds. The report concludes that the seaweed should help protect the base of rock structures from current scour.

LABORATORY AND THEORETICAL STUDIES

The early development of artificial seaweed took place by trial and error. It was 5 or 10 years later that theoretical and laboratory studies were used to aid in product design and application.

Early flume studies by the Dutch Hydraulics Laboratory, De Voorst (Bakker, 1972) for Nicolon indicated that continuous screens of seaweed, perpendicular to the current were more effective than tufts of seaweed at intervals. It was theorized that the seaweed reduced sediment transport by absorbing part of the turbulent shear stress with the fronds. The reduced shear stress transferred to the bottom sediments resulted in reduced bed load. A similar reduction in turbulent vertical mixing within the boundary layer established by the seaweed reduced suspended sediment transport as well. Tufts were found to have little effect on the current velocity because of increased turbulence between the tufts. Separate flume studies at the River and Harbor Laboratory of the Norwegian Institute of Technology (Linear Composites, 1986) and by the Royal Spartan Manufacturing Company (1985) found that fiber bundles or tufts could be used effectively to reduce current scour and localized scour around sea bed structures. Current velocities near the bottom were significantly reduced, particularly with multiple rows of closely spaced bundles.

While few of the European field studies directly addressed wave attenuation or wave-induced currents, the majority of the laboratory tests looked at those effects. Bakker (1972) reported that Ertel had developed theoretical estimates of wave attenuation by natural seaweed beds. A dense seaweed bed was theoretically capable of reducing steep waves (7 feet, 5 seconds) by 88 percent within 130 feet of seaweed bed and 99 percent within 260 feet. Bakker judged Ertel's work to be "very rough and arbitrary." While such significant wave attenuation has been found to be substantially too high, Ertel's early work offered promise for artificial seaweed.

Wave channel studies were conducted at the Hydraulics Research Station in

Wallingford, England (Price, 1968) for ICI. In the first series of tests, bundles of seaweed 3 inches long, spaced on a 3.5-inch grid in 10 inches of water, were tested under waves 3 inches high at 1.33 second periods on a coal beach. Beginning with an equilibrium beach, the seaweed was installed and changes were monitored for 140 hours. Net bottom velocities appeared to be shifted landward increasing onshore transport. Only a 4 percent reduction in wave height, considerably less than was predicted by Ertel, was measured. It was proposed that the effect of the seaweed modeled as a more viscous bottom boundary layer. Later work, (Price, 1970) using 1-foot long bundles on 2- to 6-inch grids in 1.4 feet depths under waves 2 to 6 inches and up to 2.5 seconds, found just the opposite. Landward transport was retarded by the seaweed. Wider spacing of the bundles reduced the amount of coal accumulated by the seaweed. The report concluded that the material may be useful as a sediment trap in one directional flow.

The Koninklijke/Shell Exploration and Production Laboratory (1974) conducted small-scale wave tank tests in the Netherlands. Forty continuous rows of seaweed screens, 1 foot long were placed on a fixed bed, 6 inches apart (2ft^2 of screen/ft^2 of bottom). In waves 8 inches high with 2.5 second periods, the breaking wave height was reduced by up to 30 percent. However, the report notes that the 1:10 scale modeling did not correctly model the seaweed material, but represented seaweed 10 times larger in diameter than it would be in actual practice.

The most recent and largest scale tank study of artificial seaweed was conducted in the large wave tank at the Corps of Engineers Coastal Engineering Research Center, formerly in Fort Belvoir, VA (Ahrens, 1976). Seven rows of Nicolon seaweed, 10 feet apart with fronds 7.5 feet long were placed perpendicular to the waves in 7.5 feet of water. Wave heights and periods were varied between 0.7 to 3.4 feet and 2.6 to 8.2 seconds. A maximum wave height reduction of 12 percent was found for the steepest waves tested (2.6 feet, 2.6 seconds). Wave height reductions were not significant in any tests of waves higher than 3 feet or longer than eight seconds. The report concludes that the artificial seaweed was not an effective wave attenuator at common ocean wave periods.

Related research sponsored by the Gas Research Institute has been conducted in response to proposals to plant large kelp beds on the U. S. Pacific coast for biomass (i.e. energy) production (Wang, 1982). These large kelp beds, in 50 feet of water, are envisioned to be more than half a mile wide and extend for several miles along the shoreline. Plants would be anchored in a grid every ten feet with potentially a substantial length of the plant floating on the surface. Unidirectional current reductions of 45 to 75 percent have been measured in existing kelp beds (Jackson, 1983). Dalrymple (1983) mathematically modeled the drag forces on individual kelp fronds and calculated the effects on waves as well as onshore and longshore sediment transport. Roughly a 50 percent reduction in wave height is anticipated half a mile into the field with waves 20 feet high and 10 to 20 second periods. The proposed kelp projects in the report are compared to porous offshore breakwaters and are judged likely to alter the wave climate sufficiently to modify the shape of adjacent shorelines.

While early theoretical and laboratory work offered optimism that artificial seaweed could be used effectively to protect shorelines from wave activity, larger scale tests did not confirm earlier expectations. The research indicates that only with dense expansive artificial seaweed installations, approaching the scale of the proposed kelp farms, is the method likely to be effective in controlling shoreline erosion.

ARTIFICIAL SEAWEED IN THE UNITED STATES

Interest in the use of artificial seaweed to control shoreline erosion was rekindled in the United States sometime around 1976. Seascape Technology Incorporated of Greenville, DE, developed Seascape (1984), a product similar to that of Nicolon, but with several obvious differences (Figures 1 & 2). The units are made with Dupont's Typar spun-bound filter fabric, a nonwoven polypropylene fabric, felt-like in appearance, intended for use primarily as a gravel underlayer in road construction and as carpet backing. The fabric anchor tube is 5 feet long and 6inches in diameter. The tube is filled with 50 to 100 pounds of sand or gravel and tied closed at the site. Attached to the tube are fronds 4 feet long and 3 inches wide. Polypropylene has a specific gravity of 0.9, which is not very buoyant, so a foam pad is stitched to the top of each frond for added flotation. Seascape (1984) reports that it acts as an underwater sand fence trapping suspended sand to form an offshore sand bar or reef. Its sand trapping ability is reported to have been tested as "several fold greater" than one of the unnamed early European seaweeds. No documentation of those tests was provided.

Figure 2. Underwater photograph of Seascape seaweed unit showing anchor tube, fronds and flotation.

Plastic SeaLeeves were developed by Beach Builders of America Inc. (Beach Builders, 1985) from Schaumburg, IL. Their anchors are 4 feet long and 18 inches in diameter. Beach Builder's reports the use of polyethylene sheets 2 to 4 feet wide, forming fronds 4 feet long. Narrower, individual fronds are sometimes used, however. Flotation is provided by either foam pads or floats that look like miniature ping pong balls. Materials and frond size have varied greatly from site to site. SeaLeeves are reported to precipitate suspended sand to form offshore bars, building until the fronds are buried. Product literature reports 30 installations in the Great Lakes, all successful, in waves of 6 to 10 feet. No further details or documentation were provided on most of those installations.

Sea Grid has been developed by Erosion Technology Systems Inc. (1985) in Wilmette, IL. An anchor tube 9 inches in diameter and 5 feet long is attached to fronds 5 feet long and 6 inches wide with added flotation. It differs from the previous products in that, after placement, the individual anchor units are interlocked by a diver to form a single, large grid. Sea Grid is also reported to treat erosion by forming energy-absorbing offshore sandbars.

At least 27 installations of these three artificial seaweeds could be documented since 1981. More than 20 others have been reported by the manufacturers but could not be identified. Several sites have had more than one installation. Several others groups have received state or federal environmental permits, but have not yet been constructed. Eight installations were identified in Wisconsin, and five each in North Carolina and Florida. Others were found in New York, New Jersey, Maryland, Delaware, South Carolina, Michigan, Wisconsin and California. All of the installations were intended to control existing shoreline erosion problems on moderate to high wave energy beaches. Unlike the European installations, current scour was seldom a factor. No laboratory studies have been reported on any of the United States products.

MONITORING OF SHORELINE CHANGES

Over many years and with many studies, general observations of shoreline changes on sandy beaches have shown that high levels of variability should be expected. For instance, erosion rates are often reported as so many feet per year and averaged over many years. The actual change each year is always much higher, either from eroding or accreting. Years of high erosion are balanced by years of high accretion. The average annual conditions are seldom, if ever, seen. In addition to these annual changes, variation in wave heights and direction cause even larger changes in a matter of hours or days. For example, shorelines in North Carolina that appear to have changed little when inspected once a year, have been shown to have shifted back and forth over 100 feet horizontally every year. The normal high level of variability on a beach complicates the evaluation of any erosion control method. It is not necessary to observe only that the beach changed, but to separate the effect of the method from the normal changes that would have occurred anyway. One of the best ways to evaluate an erosion control method is to survey profiles of the beach before and numerous times after installation. Profiles are taken within the protected area as well as other nearby control areas expected to be outside the influence of the installation. Profile comparisons can indicate positive and/or negative effects of the method and how they differ from the control profiles. Longer periods of comparison are desirable, with at least one year preferred. Repetitive tests at different sites are useful. Relatively predictable test sites are better than shorelines with complex features and high variability from year to year. Comparison of scaled aerial photography can also be used to evaluate shoreline changes but provide less information than profiles. Photography does not generally reveal underwater changes in any useable detail.

Observers trained in coastal processes, geologists, engineers and others can often form opinions on an erosion control method based on shoreline observation alone. But they would much prefer to more accurately judge the method on surveyed results. The majority of artificial seaweed installations have not been evaluated by other than periodic, visual observations. However, relatively detailed survey information has been compiled on seven projects.

The most widely publicized seaweed installation and its most frequently claimed success story occurred at the Cape Hatteras Lighthouse in North Carolina. The shoreline has a long history of high erosion averaging 20 to 24 feet per year since 1823. Three groins were constructed in 1969 to protect the adjacent Coast Guard Station to the north which was at that time a U. S. Navy facility (Figure 3). The groins have effectively stabilized the intended shoreline, but at the expense of increased downdrift erosion to the south. Unfortunately, the southern groin is just seaward of the lighthouse, and the groins were not very well designed for local conditions. Several major repairs have been conducted since initial construction. In 1980, the landward end of the south groin was flanked allowing the shoreline to rapidly move to as close as 70 feet from the lighthouse. Major repairs were again conducted to reattach the groin and construct a seawall around the foundation to reduce the chance of flanking. Several large beach fill projects were also completed since the 1960s but were relatively short-lived due to the net longshore transport rate of 1.5 million cubic yards per year (Corps of Engineers, 1984).

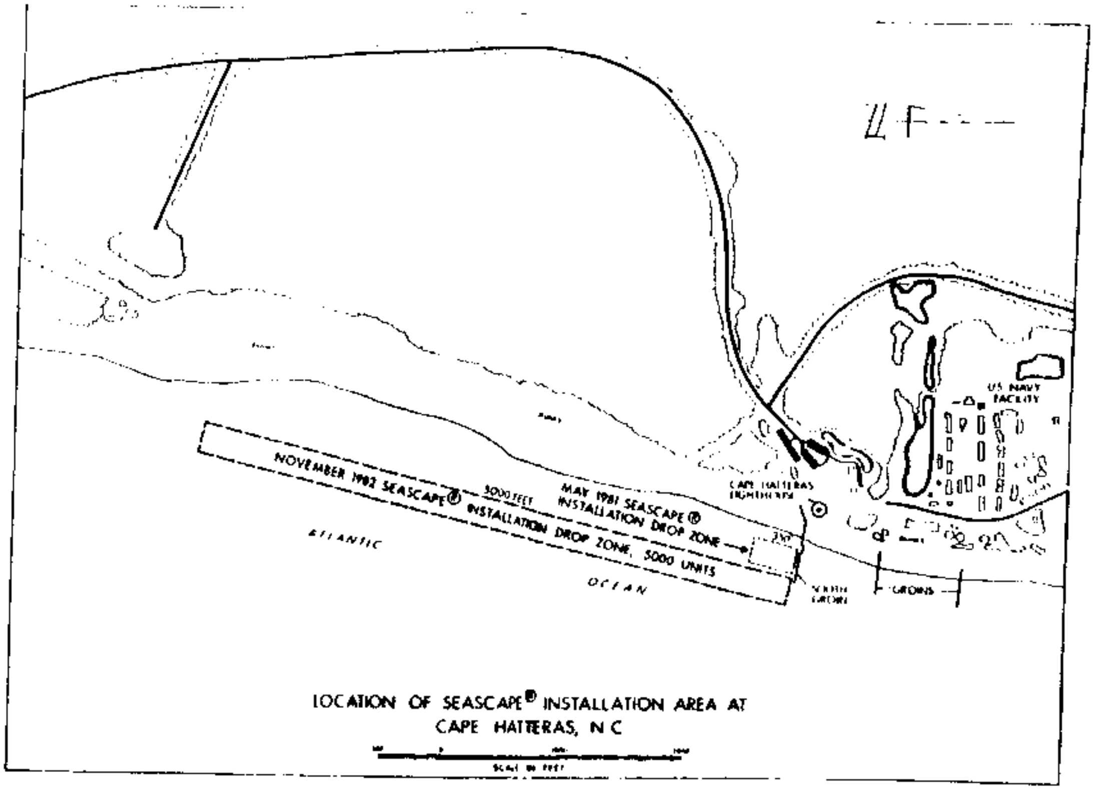

Figure 3. Cape Hatteras Lighthouse installation (from the Corps of Engineers, 1984)

The lighthouse is part of the Cape Hatteras National Seashore, managed by the National Park Service. In early May of 1981, 500 units of Seascape were donated and installed by the manufacturer. Five parallel rows, each 350 feet long, were placed in roughly 4 to 7 feet of water, about 350 feet offshore. The rows were 40 feet apart. The fronds were 4 feet long. In response to a buildup in the beach, private donations collected by the Committee to Save the Lighthouse were used to construct a larger installation with park service permission in November of 1984. Five rows, 10 feet apart were placed in 6 to 10 of water, roughly 500 feet offshore and extending 5,000 feet, almost a mile south from the southern groin.

Four months after the initial installation, one profile was taken across the seaweed site (Terchunian, 1981). By the end of August, an offshore bar had moved landward depositing as much as 6 feet of sand over the seaweed installation area. Accretion occurred on the beach as well. The mean high water line was located 190 feet seaward of the May location. Deposition of sand on the beach continued after the second larger installation. The governor of North Carolina was pictured widely on TV and in the newspapers measuring 245 feet of new beach. The beach was obviously wider, but what caused it? The manufacturer claimed it was the seaweed, but provided only a pair of before and after photographs as evidence.

A group of coastal specialists from several universities and agencies, including the author, who had previous experience with the Cape Hatteras shoreline, conducted a workshop to evaluate the natural fluctuations of the shoreline and the variety of erosion control methods that had been previously used (Benton, 1983). The group reviewed a variety of earlier studies of the area and conducted detailed shoreline comparisons from historical aerial photography. The workshop concluded that the shoreline near the lighthouse was dominated by high erosion rates, averaging 20 or more feet per year. But several periods of substantial accretion had occurred due to natural or as in the case of the groins and beach fill projects, man-made causes. The group concluded that the accretion following the artificial seaweed installation was most likely due to the natural shoreline fluctuations. As evidence, the report noted that the mile north of the seaweed also accreted during the same time period. Only the groins appeared to have consistently altered the shoreline for any length of time.

As part of a continuing design project to protect the lighthouse, the park service requested that the Corps of Engineers assess the effectiveness of the seaweed after it had already been installed (Corps of Engineers, 1984). Several sets of beach profiles were conducted, but pre-installation data was not available. The study also compared aerial photography and used divers to inspect the seaweed. The Corps concluded that the deposition behind the seaweed was part of a general accretion averaging 25 feet over six miles of shoreline that could not, in any way, be attributed to the seaweed.

The site has a history of other periods of major shoreline accretion. The lighthouse was abandoned and the light reestablished on another tower farther inland in 1935 when threatened by erosion. The erosion trend reversed. The light was returned to the lighthouse in 1950. Profiles within the seaweed area did not indicate any specific areas of stability that could have been caused by the seaweed. The report also noted a rapid disappearance of the units after installation, tangling, abrasion and wave damage to the fronds as well as a general deterioration of the fabric. The report concluded that there was no evidence that the seaweed caused the accretion and that the unit anchorage and fabric were inadequate for the wave exposure at Cape Hatteras.

The most positive report of any surveyed artificial seaweed installation has come from the Pacific coast of Long Beach, CA. An area of chronic erosion exists in a gap between the Alamitos Bay entrance jetties and the Long Beach offshore breakwater (Department of Public Works, 1983). Several major beach fill projects have been conducted using fine sand from the bay, but erosion has frequently threatened upland development and the recreational beach. Erosion rates averaged 5 to 10 feet annually since 1957, but were closer to 40 or 50 feet in 1976-78. In May of 1983, the city installed 1600 units of Seascape in three rows, 10 feet between rows, along 2150 feet of shoreline in depths of -6.0 MLLW. Fronds were 4 feet long. The sand-filled units weighed roughly 60 pounds. An extra row of SeaLeeves 100 feet long with fronds 3 inches wide was placed 10 feet farther seaward in a deeper area near the center of the project. The units were placed in calm seas by city employees and accurately aligned by divers. One month prior to the seaweed placement, a $781,000 beach fill project was completed immediately landward of most of the seaweed. Beach profiles were taken before installation and repeated six times in the following 11 months. The Long Beach Department of Public Works prepared a report on the history of the area and the seaweed installation (Department of Public Works, 1983). Results of the monitoring studies were later released as appendices (Department of Public Works, 1983; 1984). Evaluation by the city engineer after nine months concluded "cautious optimism," reserving judgment on the project's effectiveness until a full storm cycle.

A summary report containing the last profiles was prepared by a group that included a Long Beach councilwoman and the former Director of Public Works, who had overseen the previous city reports (Hall, J., 1984). The report concludes that there were "spectacular shoaling rates within the kelp (artificial seaweed) field." "A relatively permanent offshore bar of reinforced earth formed over the seaweed." "Beach erosion rates have been reduced to manageable proportions." "The general line of the beach appeared to be fairly constant throughout the report period." Divers located and excavated one of the Seascape units that was reported to be completely buried the full 4 feet of frond length. The authors of the report clearly indicate the seaweed was successful in controlling the shoreline erosion.

However, a closer inspection of the beach profiles and shoreline change data in the same report indicate different conclusions. Divers had difficulty locating many or any of the seaweed units and were unable to confirm the location of the installation after diving began three months following installation. Contrary to the report's conclusion, the beach profile showed no shoaling on or landward of the seaweed. Several profiles showed little change, others showed consistent vertical losses of 2 to 2.5 feet where the seaweed was placed. The only offshore bar found after 11 months was located on a control profile 600 feet outside the seaweed bed and much closer inshore. The crest of the beach berm, one of the most easily identifiable features for visual comparisons, showed consistent erosion in the profiles, losing between 45 to 60 feet in 11 months. The most stable profile was 600 feet outside the seaweed bed. The -6.0 feet MLLW contour also moved closer to the shoreline, an average of roughly 45 feet. A volume estimate of the sand stored in the berm, tabulated in the report, indicates that more than 55,000 cubic yards of sand were lost from the berm during the study period.

The profiles show a general flattening of the offshore profile with time. Sand was eroded from the berm and deposited offshore, beyond the seaweed. The changes are typical of beach fill projects, like the one completed a month before the seaweed was placed. Since sand is most easily and economically placed high on the beach, the beach profile is too steep, making it substantially out of equilibrium. Shoreline erosion, offshore deposition and a general flattening of the offshore slope are expected as adjustments occur for the new fill, new grain size and wave climate.

Hall's (1984) conclusion that the artificial seaweed created offshore bars and reduced shoreline erosion in Long Beach are not supported by the survey data in the report or in previous city reports. The data, in fact, clearly indicate high shoreline erosion rates, no recognizable bar formations or areas of stability near the seaweed and several feet of erosion where the seaweed was placed. The profiles indicate that if seaweed disappeared, it was not due to deposition but rather to settlement or structural failure. The beach behaved as expected after the beach fill project. No identifiable effects, either positive or negative are apparent from the Long Beach monitoring studies.

Two artificial seaweed installations were constructed on eroding shorelines in Delaware. As a state environmental permit requirement, a monitoring project including beach profiles was conducted. The results were evaluated by the Delaware Division of Soil and Water Conservation (Pratt, 1984). In Bethany Beach during January 1983, 350 Seascape units were placed in five rows parallel to the Atlantic shoreline with 14 feet between rows. The 70'x 400' bed was located in depths of about 15 feet, 400 feet offshore. The fronds were 4 feet long. The beach behind the seaweed and adjacent shorelines were monitored for 14 months. Also, in January, 300 Seascape units were placed 350 feet in the Atlantic, offshore of Dewey Beach, in water 15 feet deep. Eight rows, spaced every 12 feet, built a 100'x 350' bed. The adjacent beach was monitored for 13 months. The final evaluations of both projects indicate no measurable accumulation of sand at either site due to the seaweed. There were no significant differences between the beach profiles through the seaweed bed and profiles 500 feet on either side of the installation. During periods when offshore bars formed they were visible in all of the profiles for that date, in and out of the bed, and were located considerably inshore of the seaweed. Artificial seaweed had no effect on shoreline erosion at either Bethany or Dewey Beach.

The State of New Jersey installed and monitored an installation of artificial seaweed in the Atlantic Ocean at Stone Harbor Point. The area is a complex shoreline roughly 3/4 mile north of Hereford Inlet and at the south end of a substantial, rock-armored bulkhead and groin field in the Borough of Stone Harbor (Figure 4). The area has a history of wide fluctuations, but since 1972, the major problem has been caused by the cutoff of the normal sand supply from the north by the bulkhead and groins. The south end of the bulkhead has been flanked. The unarmored shoreline has eroded more than 500 feet behind the bulkhead. In recent years, a large offshore bar has formed roughly along the alignment of the bulkhead, seaward of the eroding shoreline. The bar gradually moves ashore, welds to the beach and a new bar reforms farther offshore. In November 1983, five rows of Seascape were place approximately parallel to the shoreline, 50 feet seaward of the last groin, 400 feet seaward of the bulkhead and 1,000 feet from the eroding shoreline. The existing offshore bar was roughly 500 feet offshore. The 2,000 feet of seaweed bed extended from 500 feet north to 1,500 feet south of the south groin, in water depths 8 to 10 feet. Anchor tubes were filled with 75 to 100 pounds of sand. The project was monitored for one year by Rider College (Hall, M., 1985) and evaluated by the NJ Division of Coastal Resources (Halsey, 1985). Beach profiles, aerial photography and divers were used to document the shoreline changes. The reports indicate the existing bar moved and reformed as normal. There was no evidence that the artificial seaweed altered the shoreline changes. Shoreline erosion continued south of the bulkhead and groin. A significant deterioration of the fabric fronds and the inadequate anchorage was noted. Burial of the units was reported to have taken place by either loss of flotation of the fronds or by rolling of the anchor tubes after localized bottom scour. While the offshore bar moved through the survey area, no bar was stabilized near the artificial seaweed. The project was judged to be clearly unsuccessful.

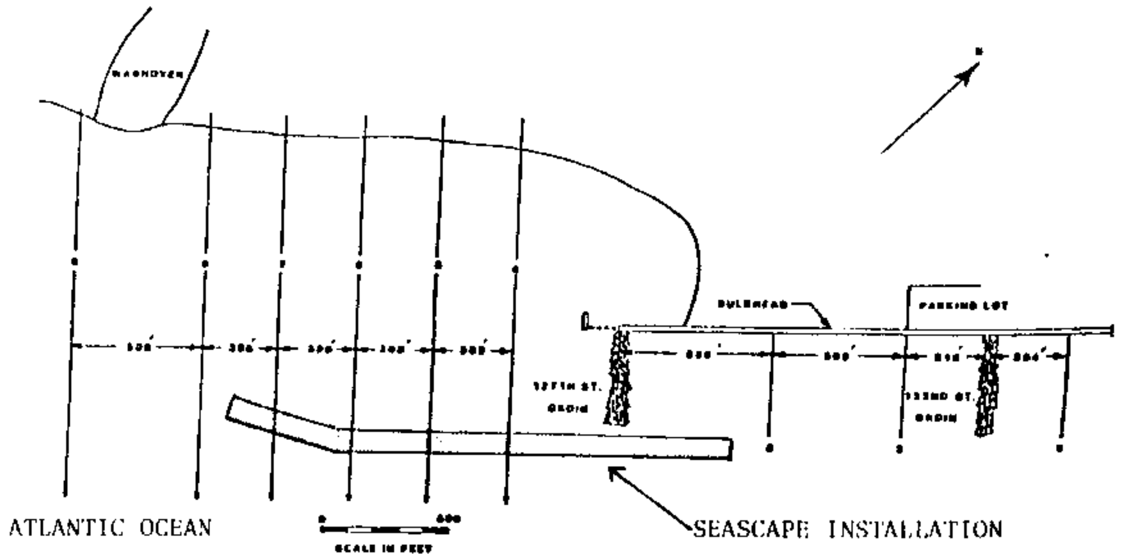

Figure 4. Stone Harbor Point, New Jersey (from Halsey & Hall, 1985)

Several artificial seaweed installations have been monitored in Florida as part of construction permit requirements by the FL Division of Beaches and Shores. In July of 1983, six to eight rows of SeaLeeves were installed in the Gulf of Mexico 150 feet offshore Keewaydin Island, just south of Naples, FL (Stephen, 1983). The rows, 500 feet long, were placed 5 feet apart. The fronds were 4 feet long. Three different plastic materials were installed. One of the three types was ripped from its anchor tubes between three and nine months into the study (Coastal Engineering Consultants, 1984). Two rows of seaweed were washed ashore leaving four to six rows for the rest of the study. After nine months, erosion occurred over most of the intertidal and near shore regions that were monitored. No significant offshore bar formations were observed near the seaweed. The seaweed was reported to be showing no discernable effect on the shoreline. After 18 months, erosion had continued at the site due to normal shoreline changes (Leadon, 1985). It was concluded that the seaweed was clearly ineffective and removal was recommended.

A second installation was completed in May 1984 near the south end of Longboat Key, FL. A field of Sea Grid units, 30'x700' was placed approximately 300 feet offshore along the crest of an existing offshore bar in 4 feet of water (Dean, 1984). Monitoring included extensive beach profiles and direct observation by diving. After three months, an estimated 40 to 60 percent of the fronds had sunk and were not functioning as intended. Analysis of NGVD (formerly MSL) contour changes and sand volume changes show no identifiable effect of the seaweed. Monitoring will continue.

Other monitoring studies are in progress in Florida and New York. Laboratory experiments are planned at Scripps Institute. As previously indicated, most of the other installations have not been systematically monitored with beach profiles, scaled photography and/or controlled comparisons with adjacent shorelines. Most installations occur with wide media coverage and are watched by both local scientists and the general public. Attempts were made to gather the informal observations by geologists, engineers and others specializing in shoreline processes. One of the more thorough examples was conducted in Illinois. Staff from the IL Division of Water Resources, the Illinois Geological Survey and the North Central District Corps of Engineers regularly observed eight installations and conducted inspection dives (Vonnahme, 1983). They concluded that the several different brands of artificial seaweed they observed did not work as claimed by the manufacturers. No offshore bars were found that could be attributed to the seaweed. Where bars were found, they were also present on adjacent unprotected beaches and were created by natural processes. The bars were found to move regularly and/or disappear completely depending on the season. The seaweed units were also reported to deteriorate, tear apart and move intact along the bottom due to normal lake wave action.

Similar results have been observed by the author in the four other Seascape installations in North Carolina besides Cape Hatteras. No shoreline changes could be attributed to the seaweed. Offshore bars, when present, moved regularly and were unrelated to the seaweed placement. There have been no discernable differences between the shorelines protected with artificial seaweed and adjacent unprotected shorelines. The materials appear to be inadequate to survive moderate to high wave activity.

POTENTIAL IMPROVEMENTS AND APPLICATIONS

If artificial seaweed is ever to be successfully developed as an erosion control method in waves, it is apparent that there are two potential ways that the seaweed can work, based on ocean wave mechanics and previous lab studies. The first mechanism by which seaweed could potentially affect the shoreline is by the "underwater sand fence" theory mentioned frequently by the U. S. manufacturers. It is probably the most difficult mechanism to apply in practice. The aerodynamics of the wind are considerably different from the oscillating hydrodynamics of a wave, but basically the seaweed must reduce the oscillating current velocity very near the bottom below some threshold velocity unique to the bottom sediments. The stabilized bottom or bar then must cause waves to break offshore more frequently. The remaining smaller waves reaching the beach would cause less erosion of shoreline.

The laboratory studies in steady currents show that seaweed can perform that function when placed with sufficient accuracy and density. The difficulty lies not in velocity reduction but in maintaining the seaweed in a stable position where it can perform that function. In the successful current applications, bottom changes around the seaweed beds were very gradual. Most beach profile changes show substantial rapid fluctuations on a seasonal or individual storm basis. At Cape Hatteras the vertical change as the winter bar moves ashore has been measured to exceed 12 feet as the inshore trough is filled by the landward moving bar over a period of several months. The offshore bar movement can reverse the process in a matter of hours during a typical storm.

Thin layers of rock have traditionally been used to prevent current scour. In effect, the rock increases the surface roughness reducing the bottom currents and increases the threshold velocity of the sediments. On an active beach, thin layers of rock have consistently been found to settle rapidly, primarily beginning at the edges of the layer. Sand is eroded from the edges. The rock gradually settles to the lowest limits of the beach profile changes. The rock gives the impression of disappearing. The anchor system of a seaweed unit can reasonably be expected to do the same thing. The settled seaweed is then incapable of maintaining the velocity reduction at the desired location or elevation to stabilize the bottom or bar and therefore cannot increase the offshore breaking of larger waves. Based on the current studies, a large dense bed of seaweed is necessary for adequate current reduction on a stable bottom. The rapid changes in the surf zone would require stabilizing the entire area of significant sand movement. Such a massive undertaking is probably impossible with any soft structure such as seaweed, but even if possible, it would be inordinately expensive compared to other already costly erosion control alternatives.

The second and more attractive mechanism by which artificial seaweed can protect the shoreline is to directly reduce the incoming wave heights rather than alter the nearshore bottom to perform that function. Artificial seaweed can be used to break incoming waves, functioning in much the same manner as natural kelp beds and man-made floating breakwaters. The seaweed, like breakwaters, would be best placed seaward of the surf zone in deeper water. The most serious anchorage problems, discussed in the preceeding case, could be avoided by placement in relatively stable bottom sediments farther offshore. For instance, the kelp beds can grow in 50 feet of water. The effectiveness of a floating breakwater for a given wave condition is influenced by the breakwater's weight, its effective drag on the oscillating wave currents and several other factors. The seaweed must be light for flotation, but dense multiple fronds can provide a large surface area to increase drag. Wave currents are lowest near the bottom and highest at the water surface; therefore, seaweed effects are greatest near or on the surface. Most floating breakwaters are relatively shallow, affecting only 3 to 5 feet from the surface. Research on floating tire breakwaters has shown that sinking a second layer of tires under the surface layer only marginally improves the wave protection. Unharvested kelp beds have a substantial length of fronds floating on the surface. The width of a breakwater limits its effect on long wave lengths. Long wave lengths pass through narrow breakwaters with minimal effect. A very wide bed of artificial seaweed, perpendicular to the shoreline, would be necessary to attenuate typical ocean storm waves. Any bed would probably be hundreds, if not, thousands of feet wide.

Wave tank tests indicate that seven rows of seaweed floating to the surface can have measurable effects on wave heights with lower heights and short wave lengths. As heights and wave lengths approach, even open-bay conditions, the seaweed becomes ineffective at reducing wave heights. A very dense and wide field would be necessary to significantly reduce wave heights sufficiently to protect a shoreline.

A variety of problems must be solved for such a seaweed field to be effective. The structural loads on the seaweed are substantial, and effective anchorage remains a formidable problem. The experimental kelp projects on the West Coast have already shown the difficulty of proper anchorage even in deep water. Material development is presently inadequate. Both the United States and European seaweeds are sensitive to ultraviolet light. Like most plastics and fabrics, their lifetime is limited in direct sunlight floating on the surface. Such a seaweed field would present substantial hazards to both navigation and swimmers but would be a significant fish attraction. While somewhat more feasible than the first nearshore case from an engineering perspective, the seaweed density and width of an effective field again would undoubtedly be far more expensive than other erosion control alternatives.

As a final observation, it should be noted that even at the remote chance that seaweed could be developed as an effective, cost-competitive method of controlling shoreline erosion, its function either nearshore or offshore is as a breakwater, reducing wave heights on the shoreline. Effective artificial seaweed would act as a sand trap, stabilizing the shoreline at the expense of adjacent higher energy beaches. Just as with other sand trapping methods, groins and offshore breakwaters, a functional artificial seaweed installation would have significant adverse effects on adjacent shorelines which may or may not be acceptable at any particular site.

CONCLUSIONS

European experience indicates that artificial seaweed can be used to reduce current scour in certain conditions. The seaweed must be well anchored, densely placed in large beds having stable flotation sufficient to allow normal fouling for extended periods of submergence and be strong enough to withstand substantial forces and abrasion in the marine environment. Field results have shown both successes and failures. Successes have been reported in reducing tidal scour in secondary inlet channels and controlling localized scour around offshore structures such as oil production platforms and submerged pipelines. The two European seaweeds appear to be substantially stronger and better designed than the more recent United States products.

To date, every documented seaweed installation has been shown to be ineffective in controlling shoreline erosion by waves. No effect on the shoreline, either positive or negative, has been found. On several occasions, shorelines have accreted such as at the Cape Hatteras Lighthouse, but those same changes have clearly occurred on adjacent beaches beyond the area potentially affected by the seaweed. No offshore bar or any identifiable deposition has occurred within a seaweed bed at any of the sites or even in any individual profile in the published studies. Deterioration of the units by abrasion and wave activity has been a consistent problem with all three of the recently promoted brands of seaweed in the United States. Anchorage methods have been frequently found to be inadequate in higher wave exposures. Artificial seaweed has consistently proven ineffective in controlling shoreline erosion. The engineering and financial requirements of an effective design appear to be insurmountable.

Artificial seaweed has, at several times, been offered as an interesting method of potentially controlling shoreline erosion. Unfortunately, all of the evidence to date indicates it is not an effective alternative.

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