GLOBAL CORAL REEF ALLIANCE

A non-profit organization for protection and sustainable management of coral reefs

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BIOROCK® TECHNOLOGY:

Cost-effective solutions to major marine resource management problems including construction and repair, shore protection, ecological restoration, sustainable aquaculture, and climate change adaptation

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INTRODUCTION

BIOROCK® technology is a innovative technology that uses safe, very low-voltage, electrical "trickle" charges to grow and repair marine structures at any scale and to rapidly grow or restore vibrant marine ecosystems.

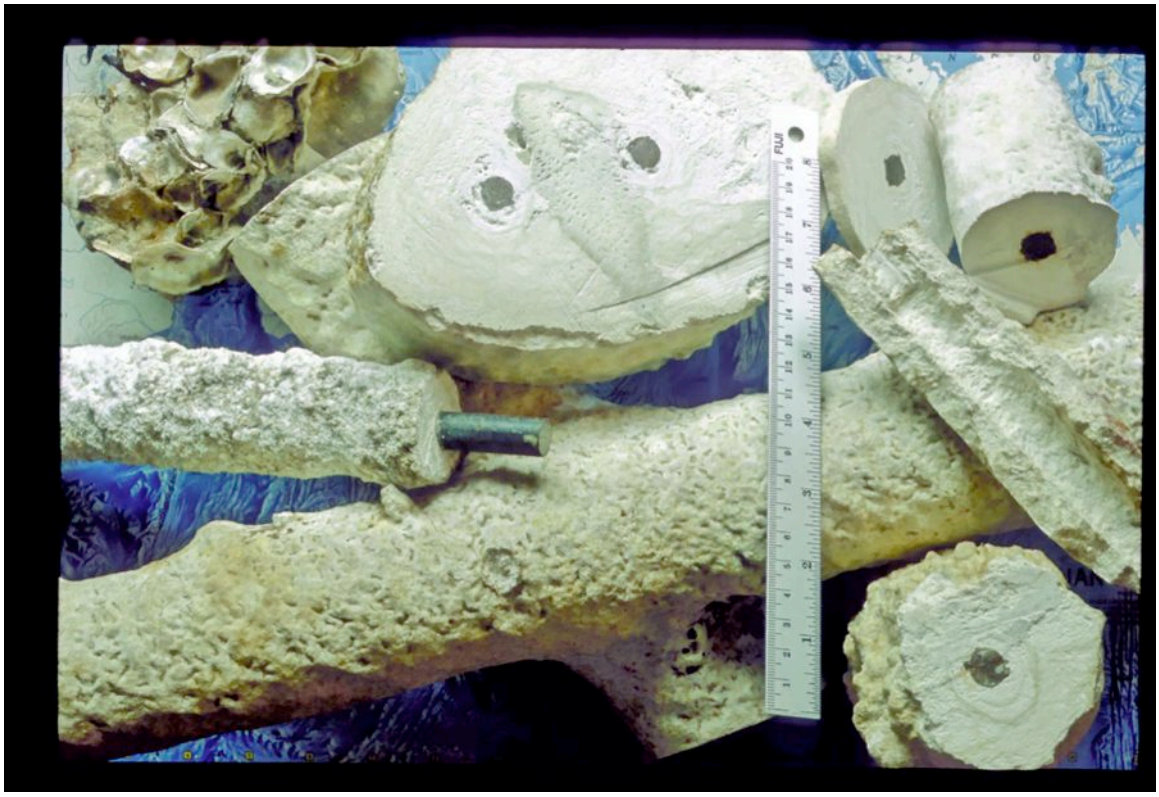
The **BIOROCK®** process was originally invented by the late architect Professor Wolf Hilbertz to produce natural building materials in the sea (also known as Seacrete, Seament, and Mineral Accretion), and developed by him and biogeochemist Dr. Tom Goreau to restore degraded marine ecosystems, fisheries, and beaches.

BIOROCK® provides greater benefits, faster results, and lower costs than any other alternative to solve a wide range of crucial marine management problems:

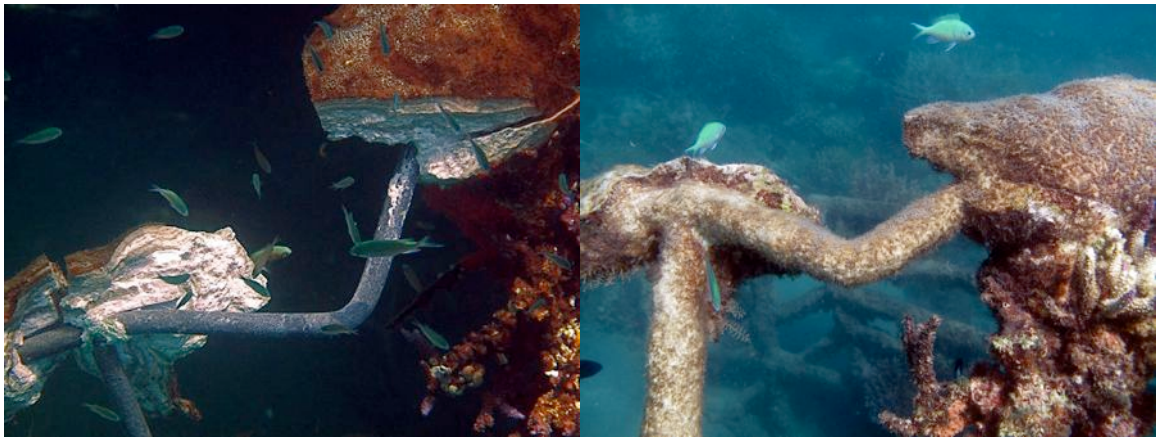
1) MARINE CONSTRUCTION

The **BIOROCK®** process uses electrically conductive materials like ordinary steel, the cheapest and most widely used construction material, to build structures of any size or shape in the sea. During the **BIOROCK®** process the steel is completely protected from corrosion. Rusty steel is first un-rusted as red rust quickly turns grey and black and is converted back to iron. Then the structure turns white as limestone minerals that are naturally dissolved in seawater grow over the surface, producing a constantly growing hard rock coating. When grown slowly (less than 1-2 centimeters per year) this material is around three times stronger than concrete made from ordinary Portland cement. The **BIOROCK®** process produces the only marine construction material that gets stronger and harder with age. It is also the only marine construction material that is self-repairing: if the mineral layer is broken, the damaged area grows back first. All other marine construction materials deteriorate with age and eventually need to be removed and replaced. **BIOROCK®** structures save money by never needing replacement, and are many times cheaper to build than concrete or rock structures of the same size. They can easily be added onto later or changed to meet evolving needs. **BIOROCK®** cements grown from salt water under different conditions are even harder after they set than primary **BIOROCK®** materials. Moreover they actually absorb CO_2 from the atmosphere as they set (Portland cement manufacture produces about 5-10% as much CO_2 as fossil fuel combustion), and can be cheaper than cement in many places.

Two years of Biorock material growing on iron bar. Photo Wolf Hilbertz.



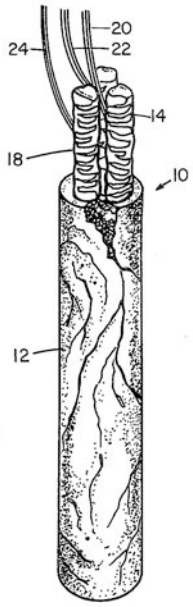
Various pieces of Biorock cut out of structures, showing un-rusted original steel inside, covered with limestone rock grown over them. Photo Wolf Hilbertz.



On the left a Biorock structure in Bali right after the rock coating was broken off when a large boat smashed into it. There was no rusting on the steel after 12 years in the water. One year later new material had filled in the broken area, seen at right. Photos by Rani Morrow-Wuigk.

2) DOCK, PIER, JETTY, & SEAWALL REPAIR

The **BIOROCK®** process repairs rusted, cracked, and crumbling steel-reinforced concrete structures like docks, piers, and sea walls. Rusting of interior reinforcing bar is stopped, and the cracks and holes in concrete fill in with rock-hard limestone, from the inside out. Deteriorating structures that would have to be destroyed and replaced can be permanently repaired at low cost. Conventional concrete “repair” methods hide the outer appearance of damage by sealing it in, while internal deterioration continues. The **BIOROCK®** process internally repairs and permanently stops rusting of steel pilings and bulkheads below the high tide line. Shipworms do not attack **BIOROCK®** treated wood, and wood structures such as pilings can be impregnated with limestone: turning “sticks into stones”.



The process of repairing cracked concrete structures from the inside out. Figure by Wolf Hilbertz.

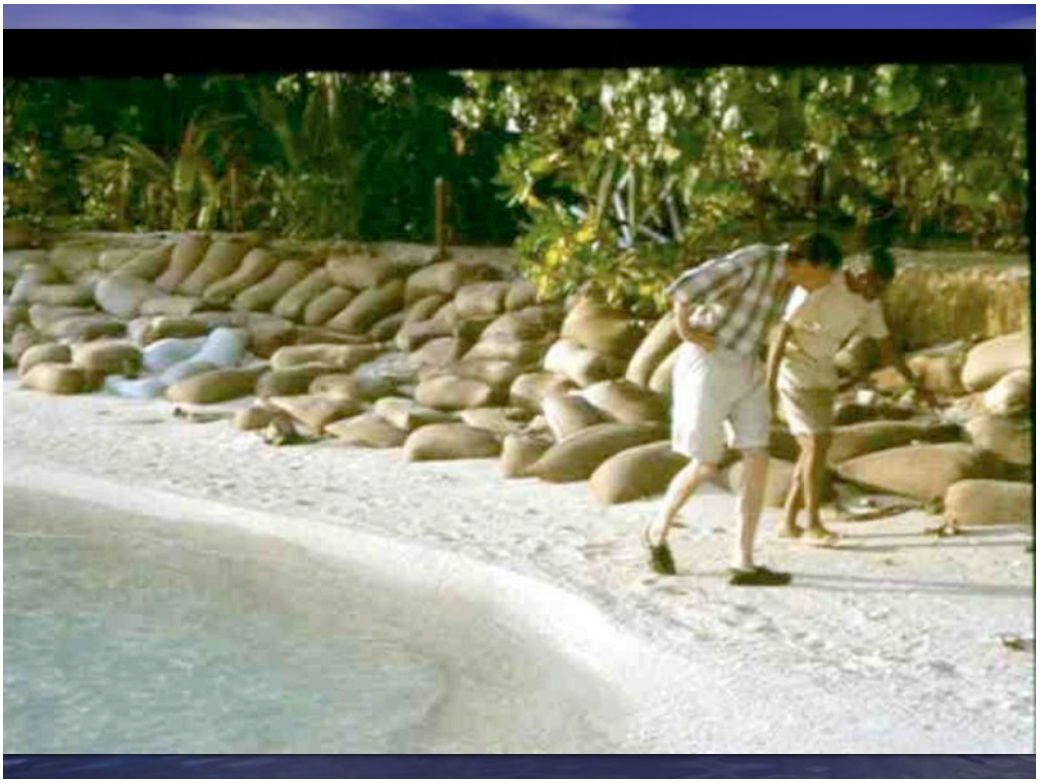
3) SHORE PROTECTION

BIOROCK® provides the ideal breakwater material because it grows stronger with age and repairs itself if damaged by heavy waves. **BIOROCK®** structures can be powered by wave energy generators that produce the most energy and fastest growth precisely when wave erosion is highest. **BIOROCK®** shore protection structures are designed and engineered in a site-specific way to withstand maximum wave energies. They are faster and cheaper to build than concrete or rock structures of the same size. **BIOROCK®** breakwaters are designed and constructed as open frameworks that allow waves to pass through them, slowing them by friction. They operate under completely different physical principles than conventional breakwaters, using refraction instead of reflection. Waves passing through the structures reach the shore with less energy, so they deposit sand on beaches instead of eroding them. **BIOROCK®** breakwaters avoid increased scour and erosion caused by solid breakwaters, which washes away all the sand in front, and then underneath them, accelerating undermining, cracking, settlement, and collapse. Rock and concrete module breakwaters can be armored over and cemented together with limestone, forming massive units that prevent rocks and concrete modules moving apart in heavy storms, and having to be reset with cranes at great cost. **BIOROCK®** breakwaters gain strength with age, becoming more effective over time as surface area increases and corals, oysters, and mussels proliferate. **BIOROCK®** structures in shallow water, sitting unattached on sand, un-welded and held together only with binding wire, withstood some of the strongest hurricanes ever recorded in the Caribbean with only minor damage because waves were able to pass through them, while massive structures were overturned or ripped apart.

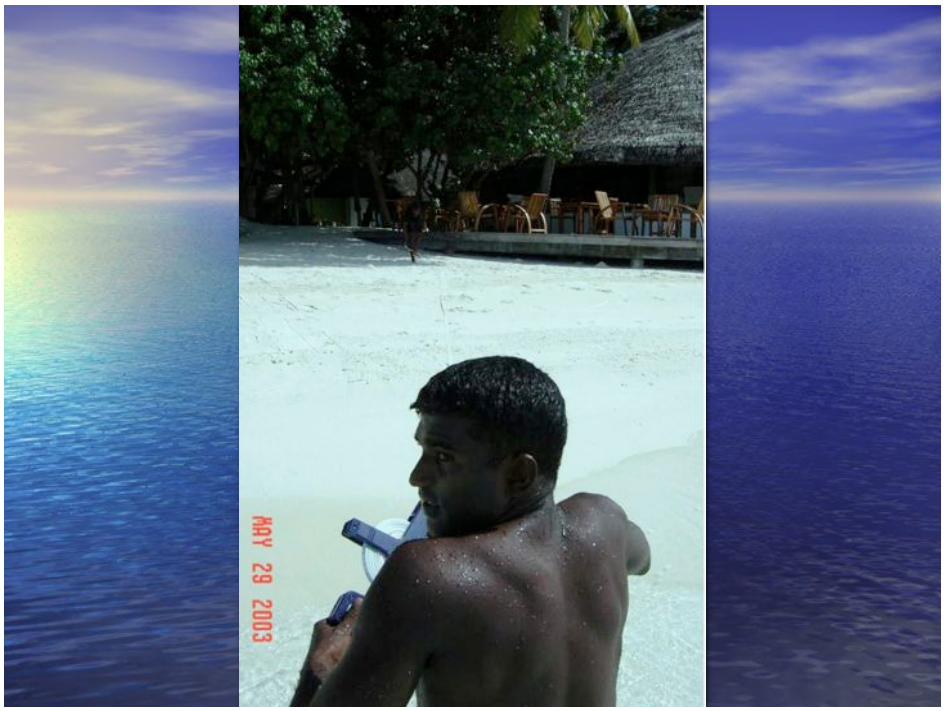
Conventional shore protection structures in Male, Maldives on left cost $13 million per kilometer. Photo Wolf Hilbertz. Biorock structures shown offshore at low tide in Gili Trawangan, Indonesia are cheap and effective, breaking up waves offshore and building beaches. Photo Tom Goreau.

4) RE-GROWING ERODING BEACHES

BIOROCK® shore protection reefs naturally re-grow severely eroded beaches faster and more cheaply than any other method. The vast majority of beaches worldwide are disappearing due to global sea level rise and increased storm wave energy caused by global warming. **BIOROCK®** reefs have the best, cheapest, and fastest results growing these beaches back. For example in the Maldives, one of the lowest lying countries in the world, a **BIOROCK®** coral reef was grown in front of a beach that had disappeared. Trees were falling into the sea and buildings about to collapse. A new beach 50 feet (15 meters) wide grew behind the **BIOROCK®** reef in 2-3 years, and has remained stable for more than 15 years. The beach and reef were not damaged by the Asian Tsunami, which washed right over the island. **BIOROCK®** shore protection structures on a severely eroding low island in Indonesia caused new beach growth that could be clearly seen on Google Earth satellite images after only 8 months. A sea wall that was undermined and about to fall was half buried in new sand a year after the **BIOROCK®** shore protection structures were placed offshore, while new sea walls on nearby properties that were not protected by Biorock reefs were undermined and collapsed in a year.



Ihuru, Maldives, before, severe erosion, trees falling into the sea. Photo Wolf Hilbertz.



Ihuru, Maldives. Two years afterwards, 15 meters (50 feet) of new beach growth. When we began the building was about to collapse into the sea, and the hotel said they would have no choice but to demolish it. Photo Azeez Hakeem.

New beach grown behind Biorock reef at Ihuru, Maldives (dark line in front of beach). Photo by Azeez Hakeem.

5) ADAPTATION TO SEA LEVEL RISE

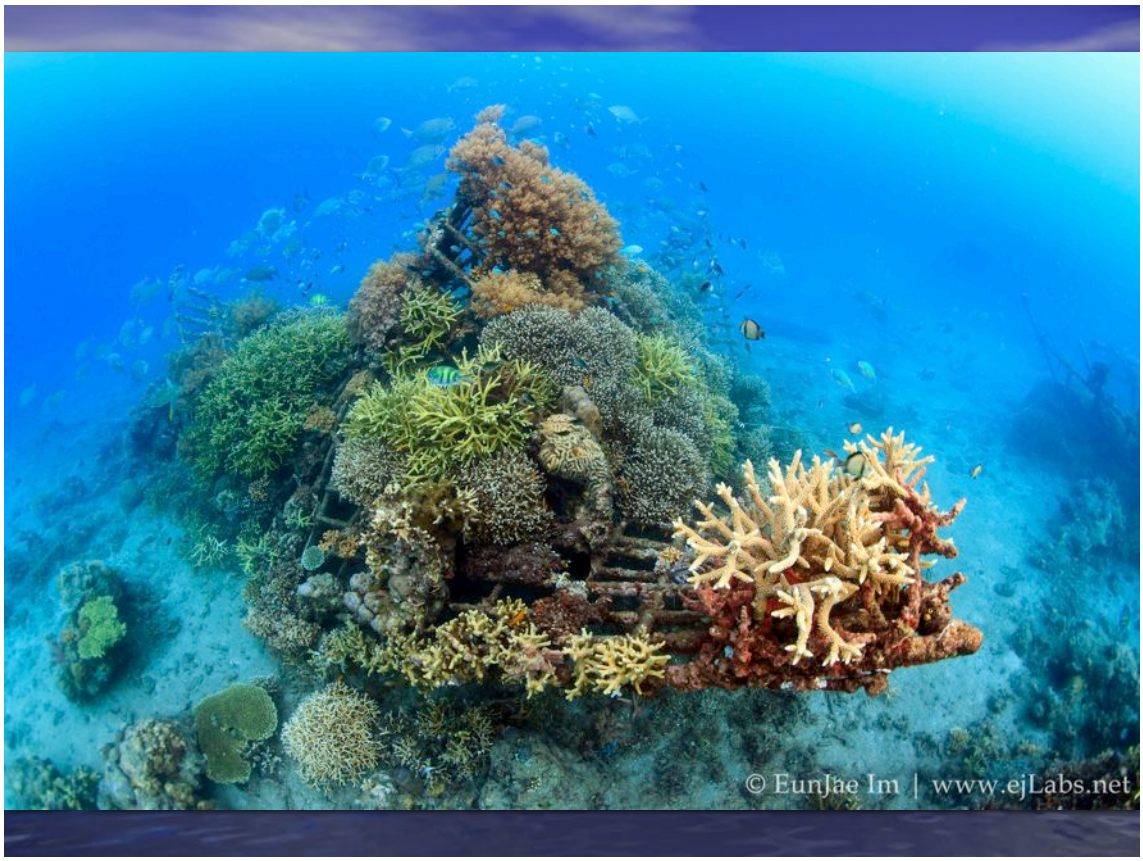
BIOROCK® shore protection structures are the most cost-effective solution for protecting low-lying coasts and islands from global sea level rise, which is currently 3-4 mm/yr and projected to rise sharply in the future. The price of protecting existing populations and infrastructure from sea level rise, and the cost of mass abandonment and relocation away from coastal areas, will likely be the largest future expense of global climate change. **BIOROCK®** structures can grow upwards at around 20 mm/year, and much faster when growth of corals and oysters on them is taken into account, so they provide the only opportunity for growing shore protection that can keep up with sea level rise. Conventional concrete or rock seawalls cost around $15 million per kilometer, **BIOROCK®** shore protection reefs gain strength with age, are self-repairing, cost much less than conventional structures, and provide many more benefits. Whole islands can be protected from submergence.

Erosion of low-lying islands. Left Helen Reef, Palau by Wolf Hilbertz. Right Gili Trawangan, Indonesia, by Tom Goreau.

6) TOURISM

BIOROCK® reefs attract tourists from all over the world to see beautiful corals and fishes right in front of hotel beaches; they come back again and again to see them evolve, and tell family and friends. **BIOROCK®** projects have won many major international ecotourism and environmental awards. Almost all tropical tourist resorts have unattractive dead reefs in front of their beach, and guests go hours by boat to see corals and fishes. If hotels grew **BIOROCK®** reefs in front of their beaches they would attract guests, grow back their beaches, and help restore the fisheries of surrounding areas, eliminating conflicts with displaced local fishermen. **BIOROCK®** reefs can be at any depth, and can be designed for snorkelers or for SCUBA divers. Shipwrecks, the most common tourist dive sites, are all rusting and collapsing, and rarely turn into what any marine biologist would call a coral reef. **BIOROCK®** technology can stop their deterioration and turn them into real coral reefs and extraordinary dive attractions.

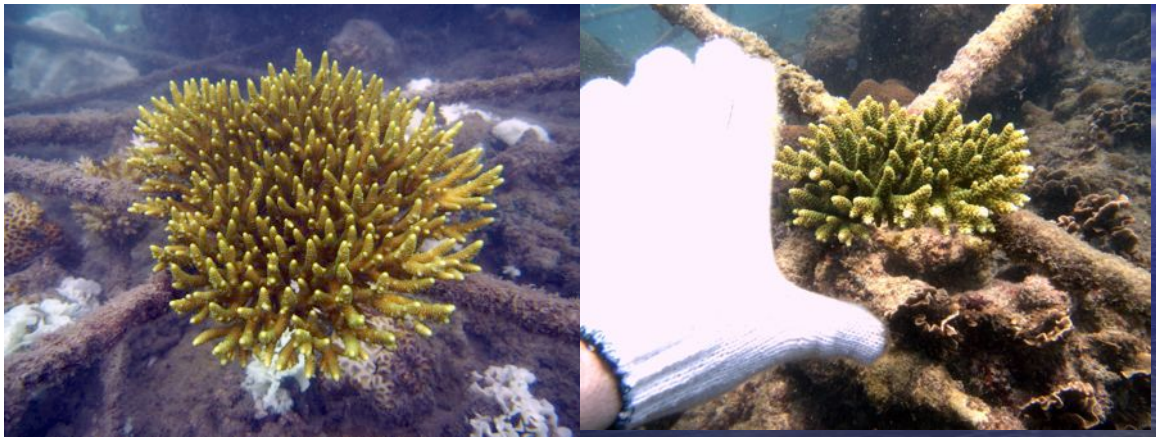
Biorock reef covered with rapidly growing corals and swarming with fish. Karang Lestari Project, Pemuteran, Bali. Photo by EuenJae Im.



Rapidly growing coral and abundant fish in area that had been barren sand. Karang Lestari Project, Pemuteran, Bali. Photo by EunJae Im.

7) CORAL REEF PROTECTION AGAINST GLOBAL WARMING

BIOROCK® technology is the only sustainable method of protecting coral reefs from mass extinction from global warming. Every coral reef region of the world has already suffered from severe high temperature coral bleaching and mortality, and any further warming will destroy the little coral that is left. Corals growing on **BIOROCK®** reefs have 1600% to 5000% times higher survival after severe bleaching than corals on nearby reefs. There is no other method known to protect corals from global warming, which is worsening as governments fail to reduce atmospheric greenhouse gases. **BIOROCK®** Coral Arks, designed to save coral reef species from local extinction, are currently growing around 80% of all the coral reef genera in the world. There is an urgent need to establish them in all major reef areas and include all coral reef species, as this may be the only hope when global warming intensifies.



Biorock coral in Koh Samui, Thailand completely unaffected by the high temperatures that have turned all the corals around it white and then killed them (background). The same coral a year earlier, showing growth. Photos by Thomas Sarkisian.

8) CORAL REEF RESTORATION

BIOROCK® coral reefs turn barren dead and dying areas into pristine reefs swarming with fishes in a few years, even where natural recovery is impossible. All other coral reef restoration methods work well only under perfect water quality conditions (but **BIOROCK®** grows coral 2-10 times faster), but all fail when water becomes too hot, muddy, or polluted. **BIOROCK®** corals continue to thrive when others die, and **BIOROCK®** reefs cost less than other methods. **BIOROCK®** technology greatly accelerates coral settlement, growth, healing, survival, and resistance to environmental stresses such as high temperature, sediment, and pollution. All other marine organisms examined also benefit. These amazing results happen because the **BIOROCK®** process creates the ideal biophysical conditions that all forms of life use to make biochemical energy. This also has enormous implications for medicine and agriculture that we will develop.

Before the Biorock project the reef was dead with only a few percent live coral cover. 10 years afterwards the bottom at the same site is completely covered with pristine reef. Photos from Karang Lestari project, Pemuteran, Bali by Rani Morrow-Wuigk.

Spontaneous settlement of corals has nearly covered a Biorock reef in 3 years. Koh Samui, Thailand, by Thomas Sarkisian.

9) OYSTER REEF RESTORATION

BIOROCK® oysters grow up to 10 times faster in length (1000 times faster in volume) and have up to 10 times higher survival under severe stress. The first **BIOROCK®** project was completely overgrown by spontaneously settling oysters that grew to adult size in a few months. **BIOROCK®** allows oyster reefs to be rapidly grown in habitats where there has been no previous recovery. Oyster reefs play a critical role in shore protection, water purification, fisheries habitat, and food supplies in cold waters, but almost all have been destroyed. Conventional oyster restoration techniques have failed because they lack the increased growth rates and survival that **BIOROCK®** methods provide. Floating oyster and mussel reefs can be grown to filter and clarify polluted water.

Oysters growing in bags above increase in length 10 times faster in mesh bags on Biorock projects, and there is dense spontaneous settlement of oysters on rocks in front of it, at a severely polluted site in New York City where oysters are normally unable to grow. Photo by Rand Weeks.

10) SEA GRASS RESTORATION

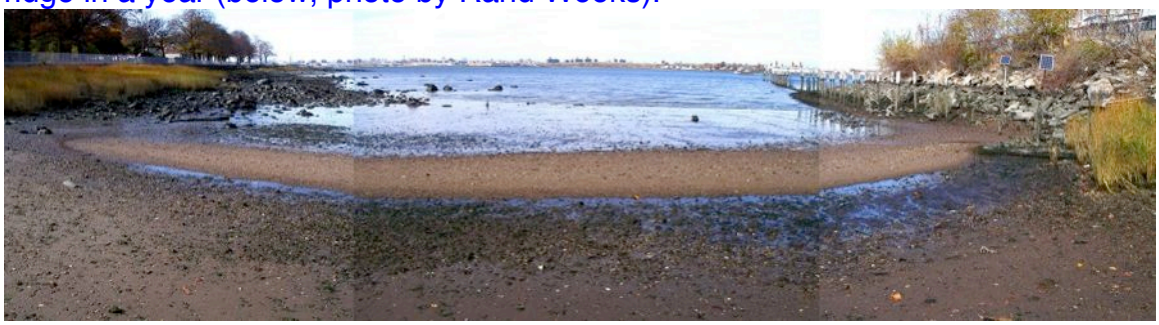
BIOROCK® methods increase sea grass growth and survival, even promoting growth and proliferation of roots on hard rock bottom where they are normally unable to survive. Sea grasses are critical juvenile fish and shellfish habitat. They also provide crucial shore protection services by stabilizing sand. Sea grasses are rapidly being destroyed worldwide, and **BIOROCK®** technology provides the fastest way to restore them.

Seagrass growing with Biorock on bare rock in the Mediterranean where it could normally not survive. Fish are attracted to the habitat (left) and roots grow densely. Photos by Raffaele Vaccarella.

11) SALT MARSH RESTORATION AGAINST SEA LEVEL RISE

BIOROCK® technology greatly accelerates growth and budding of salt marsh grass, and allows the grass to survive in water deeper than its normal limit. As a result, salt marsh that has been damaged by pollution and oil spills can be rapidly regenerated. Even more importantly, **BIOROCK®** technology allows salt marsh to be extended seawards, deeper than it would normally grow, adding land where the coast is vanishing. Salt marshes provide critical shore protection services and essential habitat for juvenile fish, shellfish, and birds, but salt marshes worldwide are rapidly vanishing. Louisiana salt marshes are currently disappearing at rates up to hundreds of meters a year. **BIOROCK®** provides the only hope to restore them, along with oyster and mussel reefs, and naturally regain land that has been lost to the sea.

Dense growth of saltmarsh at previously barren polluted site in New York City (above, photo by Tom Goreau). The new saltmarsh has grown a new sand beach ridge in a year (below, photo by Rand Weeks).



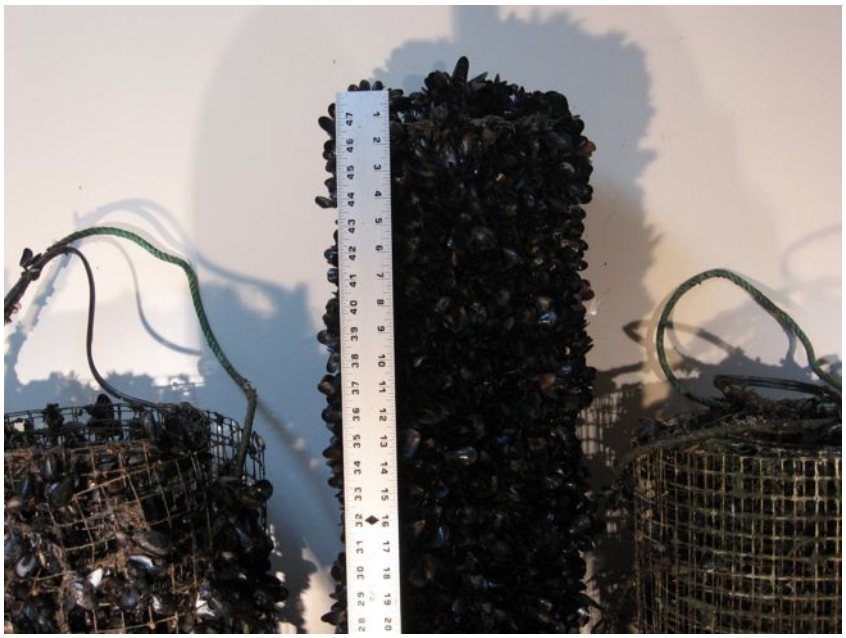
12) FISHERIES RESTORATION

BIOROCK® methods create ideal habitat to restore damaged fisheries, especially on barren sand, mud or rock, where there are no reefs or seagrass to provide nursery habitat for baby fishes to hide in. Populations of fish, oysters, mussels, lobsters, crabs, and giant clams rapidly increase around **BIOROCK®** projects, generating enormous fish schools. Indonesian fishermen report increased numbers, sizes, and diversity of fish in areas near **BIOROCK®** projects. Each species needs habitat with different size and shaped spaces to attach to or hide in. **BIOROCK®** habitat can be made in shapes that certain desired species prefer. **BIOROCK®** reefs can be restocked with baby fishes collected in the open sea, turning >95% mortality into >95% survival, and is the fastest possible way to restore coastal fisheries, eliminating limitations caused by lack of juvenile recruitment, habitat, and food. Floating **BIOROCK®** habitats moored in deeper water create floating reefs in deep blue water and can increase populations of valuable open ocean fish like tuna and mahi-mahi.

Dense fish populations around Biorock structure at Karang Lestari project, Pemuteran, Bali. Photo by Rani Morrow-Wuigk.

13) SUSTAINABLE AQUACULTURE

BIOROCK® habitats specifically designed for economically valuable marine species greatly increase their populations, growth, and health. For example, spiny lobsters crowd densely into **BIOROCK®** lobster habitat, greatly increasing their populations. These structures create a new paradigm for sustainable aquaculture: rapid growth of highly diverse marine ecosystems that grow their own food, eliminating pollution and the need for costly imported feeds. This is diametrically opposed to current practices that grow single species, usually single clones, promoting parasites, disease, genetic pollution of wild stocks, and harmful algae blooms that damage surrounding ecosystems and fisheries. **BIOROCK®** methods avoid these problems, at lower cost.



Dense spontaneous settlement of mussels on Biorock, British Columbia (center) with little or none on controls on either side. Photo Eric Vanderzee.

Giant clams glow with color due to Biorock. Majuro, Photos by Tom Goreau.

14) REVERSING EFFECTS OF OCEAN ACIDIFICATION

The **BIOROCK®** process reverses ocean acidification by creating alkaline high pH local conditions. It is the best way to grow acid-vulnerable species at accelerated rates. Acidification is killing oyster larvae in the northeast Pacific, severely damaging the oyster industry on the west coast of North America. In New York City 93% of control oysters died over winter, and the few survivors shrank because cold acidic water dissolved their shells. **BIOROCK®** oysters nearby had 100% survival, grew over the winter when they would have otherwise been dormant, and their shells were shiny with no signs of dissolution.

15) MARINE SUSTAINABLE ENERGY DEVELOPMENT

BIOROCK® technology can be powered by energy from the sun, winds, waves, and ocean currents, generated directly at the site. Ocean energy reduces global warming caused by oil, coal, and natural gas. Ocean wave and current energy could meet many times human energy needs, but are not being seriously developed, especially in poor coastal countries. Pioneering innovators in wave and tidal current energy work with us, providing their prototype devices to build demonstration **BIOROCK®** pilot projects to demonstrate the vast potential of clean and unutilized ocean energy.

Biorock structures powered by wind and sun (left, Bali, by Rani Morrow-Wuigk), or by wave generators (right, Marshall Islands, by Tom Goreau).

CONCLUSIONS

The **BIOROCK®** process uniquely provides cost-effective solutions to many critical marine resource management problems. The inventors and developers of Biorock collaborate with all serious partners worldwide to apply the revolutionary new methods to solve their problems. We have built hundreds of projects all over the world. We work with a full spectrum of partners: indigenous people, fishing communities, divers, hotels, non-profit environmental management groups, businesses, and local and national governments, to make these solutions available to those who need them. The **BIOROCK®** process is elegantly simple, and easily executed by those with special training and materials, but will fail if imitated without authorized expertise and maintenance.

BIOROCK® TECHNOLOGY was founded the original inventors and developers. It donates a large proportion of its profits back into helping poor coastal communities, especially in tropical island nations and indigenous fishing communities, who need it the most.

REFERENCE LIST AND LINKS:

For more information please see, or contact us directly:

For before and after video showing long-term results:
http://www.youtube.com/watch?v=Rx8TV9Kd0ns

For information on the engineering, physical, and structural applications:
http://www.globalcoral.org/InTech-Marine_electrolysis_for_building_materials_and_environmental_restoration.pdf

http://www.globalcoral.org/IEEE_JOUR_1979small.pdf

For information on the biological benefits:
http://www.crcpress.com/product/isbn/9781466557734

For information on fisheries benefits:
http://www.globalcoral.org/Coral%20Reef%20and%20Fisheries%20Habitat%20Restoration%20in%20the%20Coral%20Triangle.pdf

For information on community-based marine resource management:
http://www.globalcoral.org/karang_lestari_equator_award.pdf

For information on tourism benefits:
http://www.globalcoral.org/Ecotourism%20Biorock%20complete.pdf