Coral Reef Arks

—a proposal to preserve and restore coral reefs through the Anthropocene—

Coral Reef Arks White Paper

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Coral reefs are some of the world's most beautiful and valuable ecosystems. Unfortunately, microbialization and climate change are contributing to their global decline. These problems will worsen over the next century. The loss of coral reefs means the loss of an exceptional source of food, medicine, coast line protection, and human pleasure. We are proposing an policy for restoring and expanding coral reefs.

Imagine massive floating structures in the open ocean colonized with luminescent corals, anemones, crabs and urchins, and circled by giant schools of fish. These are Coral Reef Arks. We have previously used a tool, called ARMS, that aggregates millions of reef species into one-square-foot structures. Like building blocks, hundreds of ARMS will be aggregated onto Coral Reef Arks to assemble large reef communities from the ten coral reef regions of the world. These Arks will be placed in sites less vulnerable to climate change and other stressors, ensuring the survival of the entire ecosystem.

This project will establish a global system of Coral Reef Arks. The Arks will generate immediate economic benefits in the form of fisheries, tourism, and the storehouses of pharmaceutical molecules. The Arks will also create a new way to study coral reefs. Arks will serve as floating zoos and reservoirs for of flora and fauna to restore reef communities, as well as provide the means to expand coral reefs into new regions of the world's oceans.

Statement of the Problem and Proposed Solution

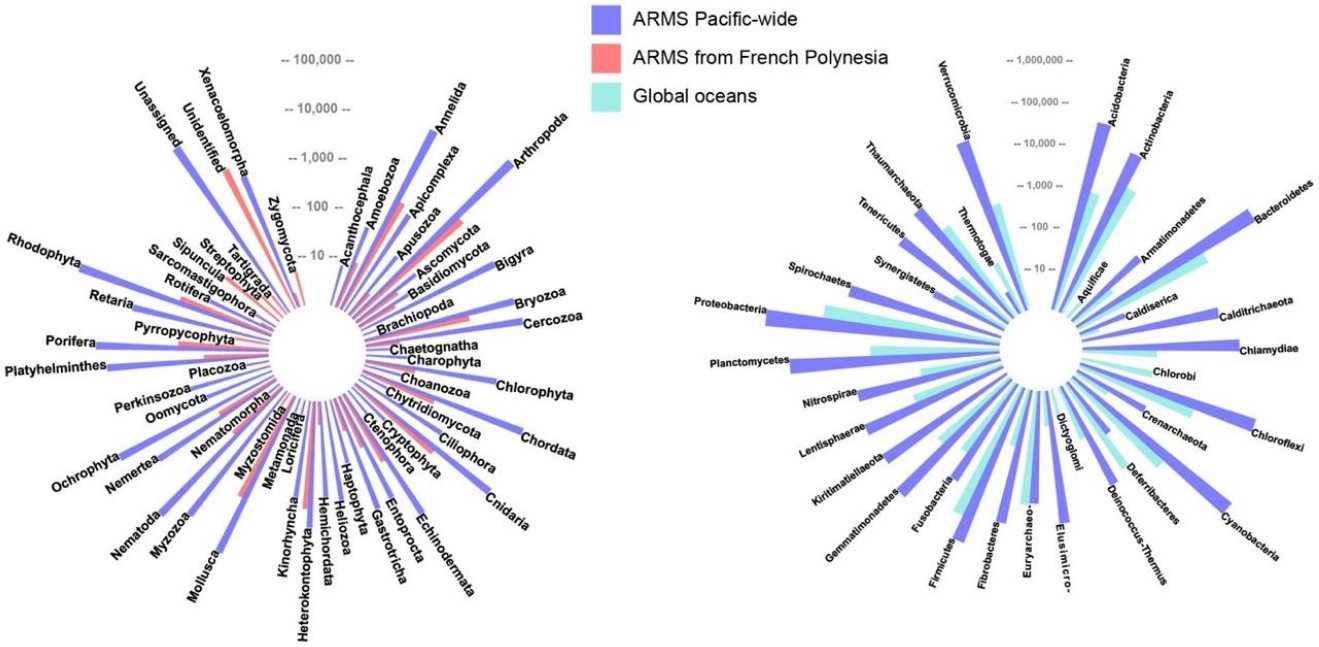
Coral reefs have the dual distinction of being the world's most valuable ecosystems and its most threatened. Coral reefs provide immense economic benefits—on the scale of trillions of US dollars. They provide large amounts of food (particularly protein), are unique sources of molecules used to fight diseases, serve as natural breakwaters, and draw massive numbers of tourists. Given this list, we are all impacted by the loss of coral reefs, even those of us who have never visited a reef. It is the people who live near reefs, however, that depend on them the most and have the most to lose. Food security and storm surges from hurricanes are acute threats. Many tropical economies are built on tourism and are severely diminished when reefs disappear and completely collapse when storms destroy infrastructure.

Arks will provide an active insurance policy for reefs worldwide by maintaining representative pieces of reefs in safe zones. The Arks will be essential for restoring reefs after catastrophic events, like mass coral bleaching that is becoming more frequent. Further, the Arks will develop their own fisheries, providing a valuable and novel source of food. These floating coral reefs will be tourist attractions, helping build local economies while preserving biodiversity.

Currently, we are seeking collaboration and financial support for the Coral Reef Arks project. So far, we have raised nearly $10 million to lay the scientific foundations for this project. Now we are looking for experts in marine law, business, and Global Information Systems (GIS). We are also seeking funds to purchase materials, support travel, and support personnel.

Current Research and Funding for Arks Development

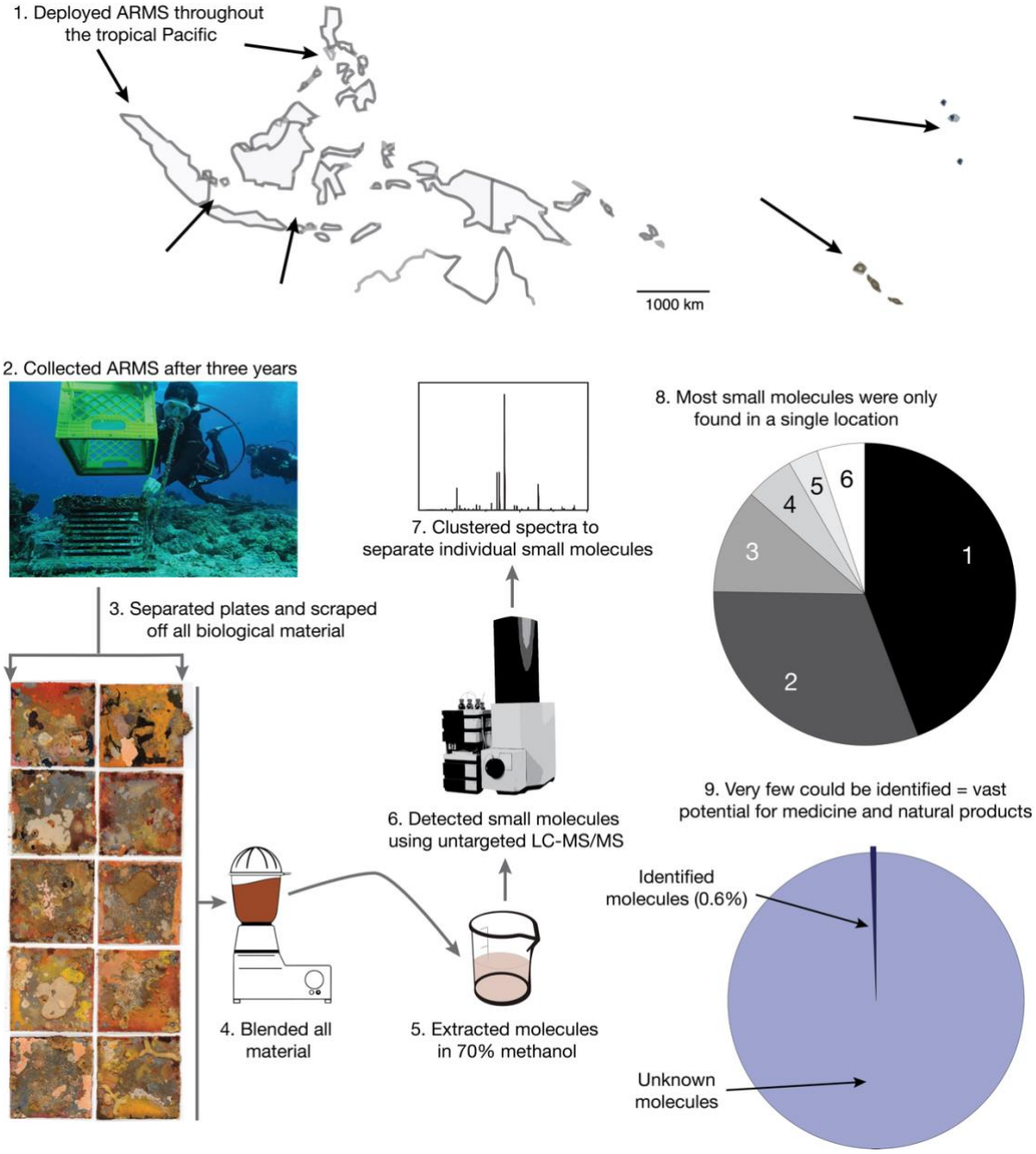
***1) Census the extreme species diversity on coral reefs ($5 million; US National Science Foundation)*:** We performed the first census of species biodiversity on coral reefs in a collaboration with the Smithsonian Institution, National Oceanic and Atmospheric Administration, UCLA, Moss Landing Marine Laboratories, and many international collaborators. Our research group invented and deployed one-foot cubed structures called Autonomous Reef Monitoring Structures (ARMS) on coral reefs throughout the world. Using next generation sequencing, we detected over 1 million species from 100 ARMS and found that at least 10% of the organisms that settle on ARMS were unknown to science and represent new species. Among the species known to science, ARMS attracted a staggering ~85% of the biodiversity found in the entirety of the planet's oceans, including invertebrates, small eukaryotes, bacteria, and archaea. Among the bacteria, in particular, ARMS diversity was higher than that of bacteria previously found throughout the global oceans (figure below). The recapitulation of reefs on ARMS allowed us to dig deeper into the diversity of life than ever before and suggests that Arks have a high probability of harboring functional reef communities in perpetuity. To learn more about this project please visit infinitediversity.org.



Eukaryote Biodiversity

Bacteria Biodiversity

***2) Discover new medicines and natural products on coral reefs ($3.5 million; National Institutes of Health, Gordon and Betty Moore Foundation)*:** In collaboration with chemists at the University of California San Diego, we used ARMS to census small molecule diversity on coral reefs throughout the Pacific. Coral reefs are exceptional sources of groundbreaking medicines used to treat diseases from cancer to HIV. Within just one class of potential drugs, we found thousands of unique molecules on ARMS. Only 0.6% of these molecules could be matched with known molecules. The rest were completely unknown and represent an untapped source of potential new medicines. Almost half of the small molecules we detected were only found on coral reefs in a single region, highlighting that it is important to preserve reef biodiversity from many areas of the world.



***3) Enhancing coral recovery with engineered surfaces ($825k; National Science Foundation)*:** We are collaborating with materials engineers at the University of Illinois and coral biologists at the CARMABI Foundation Curaçao to engineer surfaces that attract coral larvae and promote their subsequent survival. In doing so, we hope to speed up coral reef recovery. Optimized surfaces will be placed on ARMS in order to attract even more corals than are attracted by the current ARMS design. Attracting as many corals as possible will bolster ecosystem health and value on Arks.

***4) Tracking microscopic succession on coral reefs (e.g., bacteria, viruses, molecules) to understand how these unseen players help make healthy reefs ($500k; Gordon and Betty Moore Foundation)*:** We are studying how coral reefs form at a microscopic level, as we allow an aquarium reef to take shape—starting in an environment of sterile saltwater. This study allows us to see how the communities of bacteria, viruses, and molecules grow on healthy coral reefs, which we will then track on Arks.

Microbes and viruses control the life and death of corals. The goal of this project is to determine how the microorganisms can be used like probiotics to build a healthy coral reef.

***5) Enhancing herbivore abundance to speed up coral growth and settlement ($50k, Spruance Foundation)*:** In collaboration with coral ecologists at Scripps Institution of Oceanography (UC-San Diego), we are restoring urchins to coral reefs to remove algae that compete with corals. Most urchins have been lost from coral reefs due to disease and overharvesting. This project is quantifying the extent to which we can restore coral-dominated, healthy reefs by placing these animals back on reefs. Preliminary data suggest that urchin restoration is tipping the ecological balance towards corals. In just three weeks, grazing by urchins completely removes algal turfs around corals and promotes colony growth. We will use this restoration approach on Arks and will use Arks to restore natural reefs, as we are doing with urchins.

Our Plan: Place ARMS on Arks in safe areas to preserve the coral reefs of the world

We will deploy 10,000 ARMS, 1000 in each of the ten coral reef regions of the world. ARMS will be colonized for three years, creating representations of worldwide coral reef biodiversity, then will be placed on Coral Reef Arks. Based on our global ARMS dataset we expect ARMS to recruit millions of species to these 10,000 ARMS.

ARMS will be moved to a superstructure called an Ark. A line from the ocean floor to a surface buoy. The Arks will be suspended from this surface buoy. The Arks will be designed to last for at least 100 years.

Curaçao (southern Caribbean) is an optimal site for testing the first Arks because the location confers a strong suite of logistical advantages including advanced engineering facilities. Curaçao is also one of the most extensively inventoried reefs in the world and has some of the most diverse and healthy coral reefs in the Caribbean. Once designs for the Arks have been tested and optimized, colonized ARMS will be placed on Arks moored in the oceanic regions projected to be least affected by temperature and pH changes.

The final phase of this project will be to create the Reef Ark Parks to house, protect, and propagate global coral reef biodiversity. Candidate sites include: the Mesoamerican Reef, the northern Great Barrier Reef, the Indian Ocean – Seychelles/Madagascar, the Coral Triangle – Indonesia, Micronesia (Palau), and the Red Sea. Stakeholder groups for these Parks (e.g., tourists) will also be identified during this period. At the completion of this project, we will have established a global system of ten Reef Ark Parks, each containing at least 85% of the biodiversity found on the coral reefs of the world.

Ecosystem Goods and Services Created by Arks

Sustain reservoirs of yet-to-be discovered pharmaceuticals: A disproportionate number of molecules for pharmaceutical applications come from coral reefs. Thus, the loss of reefs also takes away opportunities to discover new medicines. Arks will protect these resources and give scientists time to isolate new molecules and apply them to human medicine.

Create fisheries: Placing large structures like Coral Reef Arks in desolate regions of the ocean will create fisheries. This is important because fish protein is a major food source for humanity and most of the world's oceans produce almost no fish biomass.

Attract tourists: The Coral Reef Arks will be beautiful, suspended coral reefs in crystal-clear water. These structures will become floating zoos and will create an entirely new venue for tourists to see, snorkel, and SCUBA dive on. Revenues from tourism will stimulate local economies and facilitate commercial investment to build more Coral Reef Arks.

Create new conservation and restoration technologies: Arks represent an entirely new platform for marine conservation and restoration. This technology can be applied to any marine ecosystem, which will become increasingly useful as other ecosystems come under threat. Arks will be used to re-seed reefs after they are damaged by disasters such as storms, or even to move existing reefs to new areas. The success of Arks as a conservation and restoration tool will be measured based on the levels of biodiversity they maintain and the health of the communities living on them, particularly when these metrics are compared to the communities from which they came.

Create opportunities for scientific discovery: Arks will allow us to build on our earlier work and understand how reefs are "put together" at a new level of detail. We will watch the succession of the fledgling reef communities on ARMS as they become reefs on Arks. Arks will also provide a new way to census marine life, thereby creating a zoo of reef biodiversity. Arks will allow us to take these and other studies to the natural environment, providing the first ever reef-scale experimental laboratory in the ocean.

Seeking Collaboration

Maritime lawyer: We are seeking a maritime lawyer. The lawyer will provide the legal background of the rights and responsibilities to deploy Reef Arks Parks in different countries' EMZs and in international waters. The lawyer will work in close collaboration with a GIS scientist (described below) to select a subset of the most optimal sites for Reef Arks Parks based on environmental conditions, legal jurisdiction, and avoiding navigational hazards.

GIS scientist: We are seeking a GIS scientist to map the seamounts and other sites best suited for 100+ year of reef survival based on current and projected levels of temperature and pH change, and cross these locations with anchorage potential (e.g., depth).

Environmental economist and business people: We are seeking an environmental economist or business leader to assess and quantitative the economic benefits of Arks and with the goal of building a sustainable business model.

Seeking Financial Support

We have secured $9.875 million USD in support of scientific research and development. We are seeking additional financial support to implement the remainder of the plan in a number of key areas outlined below.

(1) Deploy the first restoration-aimed ARMS and Arks in Curaçao. Estimated cost: $1 million USD

(2) Deploy 10,000 ARMS units in the ten coral reef regions of the world. Estimated cost: $10 million USD

(3) Fabricate, assemble, and implement ten Reef Arks Parks. Estimated cost: $50 million USD