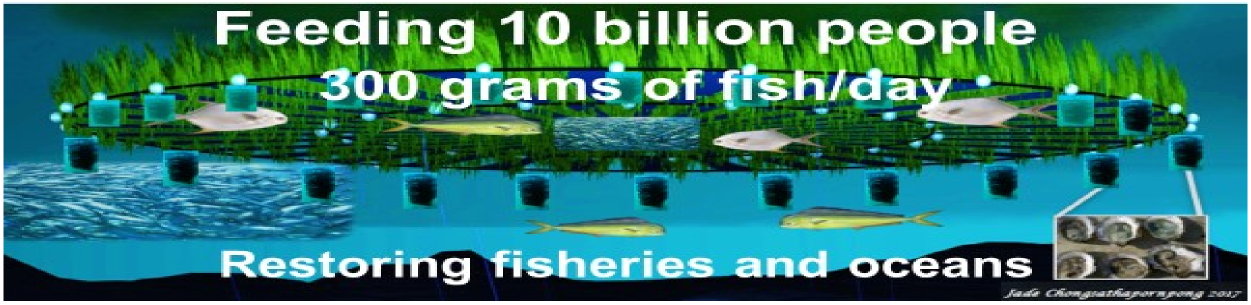
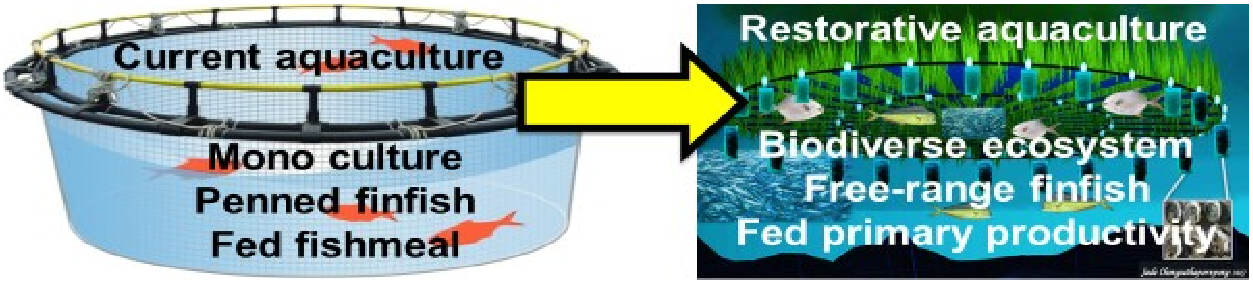


Global objectives – Give coastal people food, jobs, and hope for centuries. Food, jobs, and hope accomplish many UN Sustainable Development Goals. Centuries of food and job security allow coastal people stay home and welcome refugees to their community. Restorative aquaculture can scale beyond generating ocean health and global food security to producing biofuels and sequestering carbon dioxide.

Global issues – People become refugees when home becomes unlivable. Homes become unlivable for many interrelated reasons, often acerbated by climate change:

- Insufficient food – Crop failures, fisheries collapse, and associated job loss (drought or running out of groundwater/snow melt; floods; changing sea level)
- Violence and associated job loss – Wars, gangs, sometimes power and wealth-control struggles, but often traced back to crop failures and insufficient hope for a job.

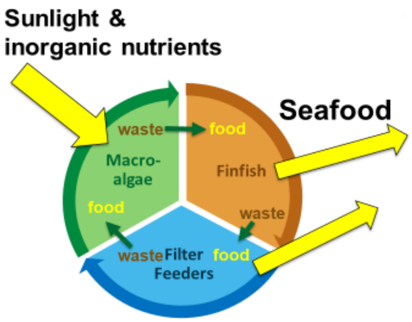
Starting the solution – Coastal communities can design, build, and operate their own fishing reefs as a new kind of aquaculture. As an example of a well-managed natural reef, consider the people of Punta Abreojos, Baja California Sur, Mexico. They manage abalone on nearby reefs for a sustainable developed-country quality of life. Every coastal community could have similar quality of life, if they had similar resources. Every coastal community could have similar resources in the form of a floating flexible reef. Every important natural reef could become a marine sanctuary with all the fishing on the natural reef moving to floating reefs.



Restorative aquaculture involves large (20-hectare growing area per reef[1]) floating flexible fishing reefs. The reefs are installed in the open ocean at seafloor depths between 40 and 200 meters. The reef's growing surface is normally at the ideal depth for local seaweed, 3 to 10 meters below the ocean surface. Some reefs may submerge to avoid storms. The reef's ecosystem can be left to nature or planted. Species that will volunteer or can be planted include seaweeds,

[1] This size is based on U.S. Department of Energy-funded hydrodynamic modeling of economical structures that can survive a category 5 tropical storm.

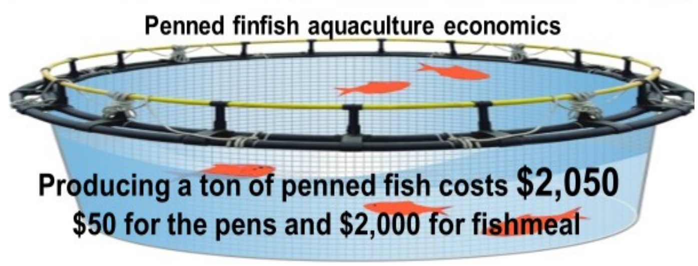
seagrasses, epiphytes, giant clams, oysters, mussels, conch, abalone, crabs, lobster, sea cucumber, sea urchin, sponges, herbivore finfish, filter-feeding finfish, sea turtles, aquatic mammals, predatory finfish, sharks, and more. Only some of the species on the reef will be harvested. Most of the species are left alone to reproduce, grow, and feed the harvested species.



Fishmeal is not required for fish production. Instead, plant nutrients replenish the nutrients harvested from the system. The plants combine the nutrients with sunlight through photosynthesis. Plant growth restores primary productivity. The restored primary productivity moves through the food chain, as in the figure at left, restoring ocean health and fisheries.

200,000 20-ha reefs could feed ten billion people 300 grams of fish per day (using nutrients from recycling all their pasteurized urine). Alternatively, people-produced nutrients could go to agriculture and a third of global artificial ammonia production replaces nutrients harvested from the reefs. The plants (macroalgae and/or seagrass) may also be harvested.

Economics – As the cost comparison at right suggests, most of the cost for restorative aquaculture is for infrastructure. Most of the cost for penned finfish is for consumables. Neither example includes boats, equipment and labor costs.



Open-ocean restorative aquaculture can be combined with Integrated Multi-Trophic Aquaculture (IMTA). For example, finfish pens may be attached to the flexible reef. Or the entire reef enclosed to be one huge pen. People could supply the penned finfish with fishmeal. The penned fish urine and feces becomes the plant fertilizer.

Due to its developed country perspective and the high the cost of fishmeal, the existing industry is not comfortable with free-range finfish, harvesting multiple species, or permanent rope structures. Restorative aquaculture appears better suited to developing country communities cooperating to protect and harvest many species in the area around their cluster of reefs.

Like a cluster of natural reefs, each new reef cluster will have a custom structure, custom substrate, custom sea creature shelters, custom harvest techniques, unique ecosystem, and custom economics. For example, some coastal communities may emphasize seafood selling for less than $1/kg at the dock. Other coastal communities may emphasize exports selling for $3/kg at the dock or restoring prehistoric fisheries such as Giant Clam in the Gulf of Thailand or Queen Conch in the U.S. Gulf of Mexico.

Next Steps: The components of this system have been prototyped or are in productive use, but they need to be integrated to deliver the full benefit. Possible first steps include:

- Feasibility studies/workshops in several locations combining local fishing knowledge and international experts. Blend digital and in-person attendance to match budget. ($50,000 to $300,000 per location.)
- Initiate operations plan and loan documents in several locations combining local fishing knowledge and international experts. ($1 - 4 million depending on location and level of detail.)
- Build the first few 100-hectare five-reef clusters ($7 to $15 million/cluster).

Understanding the relative scale of food, fuel, and reversing climate change

Food – Aim for globally robust food security using 200,000 flexible floating fishing reefs (including some close to shore (like Dr. Radulovich family-size sea-farms) and some offshore like OceanForesters model) operating by 2030. (Abundant and inexpensive seafood that displaces most of beef, chicken, and pork consumption.) Ideally, demonstration reefs built and operating by 2022. Then building at the rate of 80 reefs per day for seven years.

Biofuel, grow-harvest – Aim for commercial-scale robust seaweed grow-harvest equipment and operations by 2028. Aim for 3 times U.S. fossil oil demand by 2040 using 10 million flexible floating energy reefs. From 2020 to 2026, use the fishing reefs to refine growing, harvesting, storing, pre-treating, nutrient recycling, and other issues associated with maintaining a robust minute-to-minute, day-to-day, … year-to-year supply of biomass for the energy process. Then building at the rate of 2,000 reefs per day for fourteen years.

Biofuel, reversing CC – Build commercial-scale hydrothermal liquefaction (HTL) processes using waste organic biomass, plastics, and paper. Deploy the HTL units in developed and developing countries to eliminate marine plastic pollution by 2030. A commercial biofuel production facility requires biomass from at least 1,000 20-ha reefs. That implies building biofuel production facilities at the rate of two per day for fourteen years. The Allam Cycle power plant produces electricity and liquid CO_2. Its developers have tested at 50-MW and are siting a 300-MW facility. There are many options for sequestering CO_2. OceanForesters could revive a proposal to test a process that scales to safely store over 5 trillion tons of CO_2.

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[2] https://www.sciencedirect.com/science/article/pii/S0044848614005407