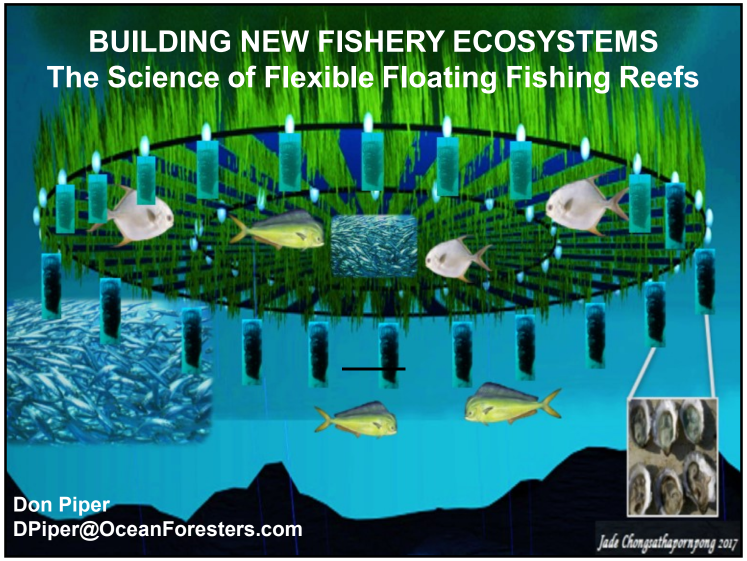
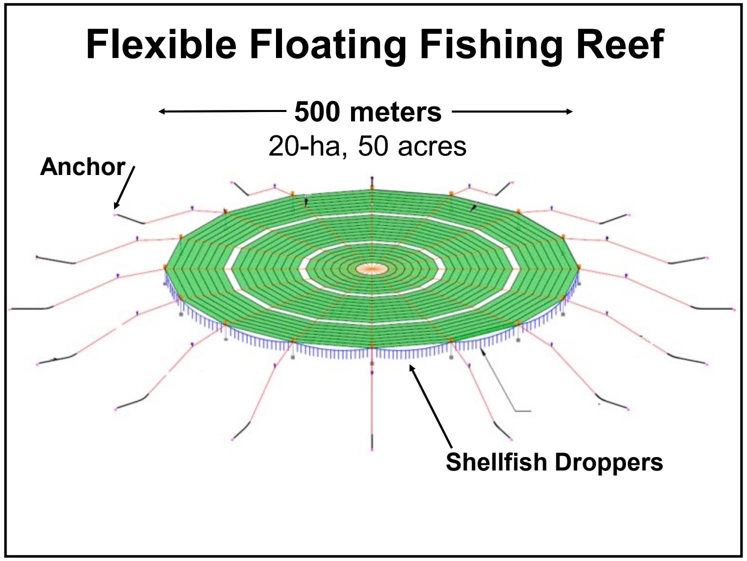



Good Morning! My name is Don Piper. I'm with OceanForesters, a network of more than 100 scientists, engineers and business partners committed to feeding the world, fueling the world, and sequestering carbon in the ocean and atmosphere.

Using a grant from the Advanced Research Projects Agency U.S. Department of Energy (ARPA-E) our team learned how to grow seaweed-for-biofuel inexpensively and sustainably. We also found a way to feed the world with shellfish and finfish grown on huge floating flexible reefs without using fishmeal and while simultaneously growing seaweed.

Over the next ten minutes I will

1. Introduce you to the concept of flexible floating fishing reefs
2. Share aspects of the science behind the concept
3. And outline the scalability and impact flexible floating fishing reefs could have



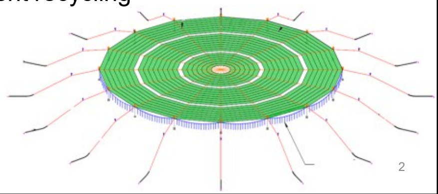

*A "flexible floating fishing reef" is a reef made from rope and floating at the optimum depth for primary productivity.*

This is the Spiderweb, a depth adjusting reef we have developed for the Department of Energy. The green area provides a substrate for growing seaweed, finfish shelters, and hanging shellfish. The substrate is normally 2 to 6 meters deep when growing *Gracilaria Tikvahiae* in the Gulf of Mexico. If a storm approaches, the entire structure submerges to at least 40 meters deep. The system is designed for seafloor depths between 50 to 100 meters.

All the components of the Agricultural Revolution are here. In addition to operating with more nutrients, we envision a new machine for autonomous mowing and harvesting of our perennial *Gracilaria*. The reef is larger than current aquaculture systems. We will have many crops growing simultaneously, a form of fast, continuous crop rotation. Unlike the agricultural revolution, the reef is definitely not a mono-culture farm. It more resembles a multi-culture forest populated by free-range fish.

## Building Flexible Floating Fishing Reefs

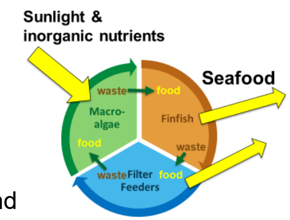
- Another tool for fisheries managers
- Increasing and optimizing ecosystems
- Reduce the pressure on degraded fisheries
- Yield depends on nutrient recycling



2

Building flexible floating fishing reefs is another tool for fisheries managers – increasing and optimizing fisheries ecosystems.  New reefs reduce the pressure on existing degraded ecosystems.  Existing ecosystems can become marine sanctuaries while fishing moves to the new <u>artificial</u> reef.  The new fishing reef yield is <u>increased by </u>its primary productivity.

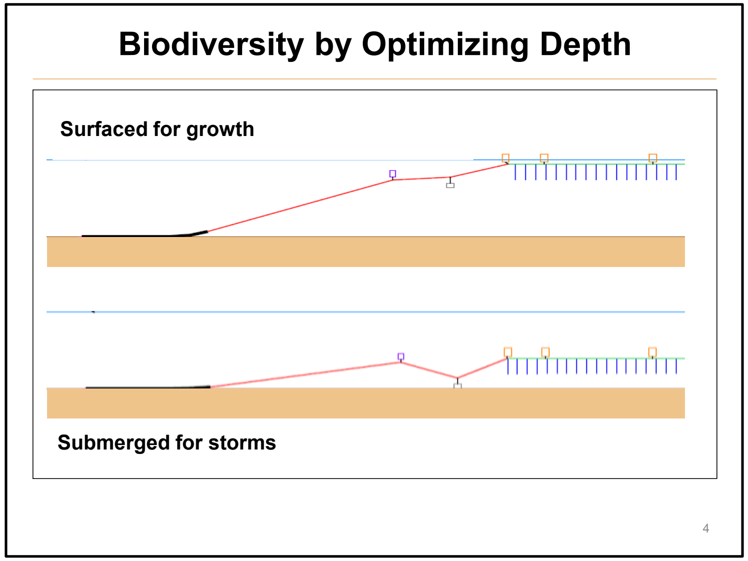
## Building Flexible Floating Fishing Reefs




- Reef operators can ensure
  - Much greater **productivity** and
  - **Biodiversity** by optimizing depth and nutrients
    - *Depth* controls photosynthesis
    - Inorganic *nutrient return*
      - Controls primary productivity
- Timing primary productivity controls dissolved oxygen

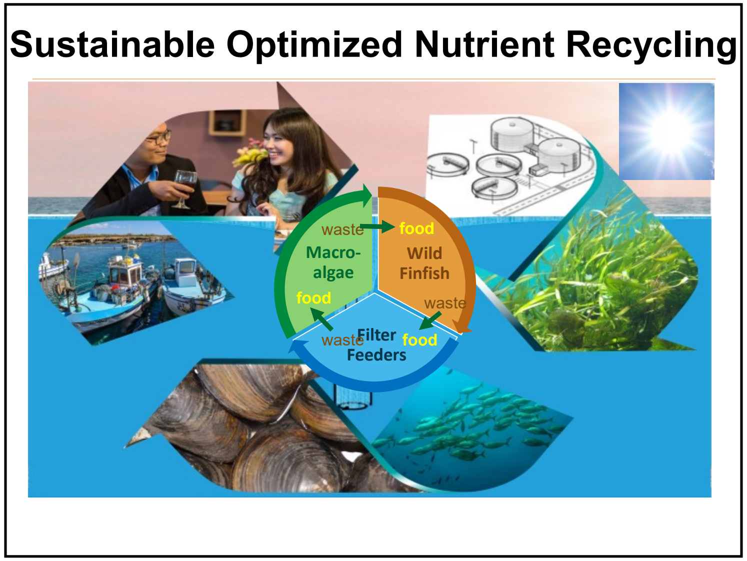
3

Reef operators can ensure much greater productivity and biodiversity by optimizing the new reef's depth and nutrient return. The depth controls photosynthesis. Inorganic nutrient return controls primary productivity. Timing primary productivity controls dissolved oxygen concentration.




Funding from the ARPA-E program allowed several teams to develop open-ocean structures/systems for growing macroalgae. <u>Our team designed the flexible floating reef to withstand a Category 5 hurricane by submerging to near the ocean floor.</u>

We can build fishing reef ecosystems out of rope. We can optimize nutrient supply for optimum primary productivity that feeds an ecosystem of fish production that appears to generate fish at half the cost of penned finfish aquaculture.

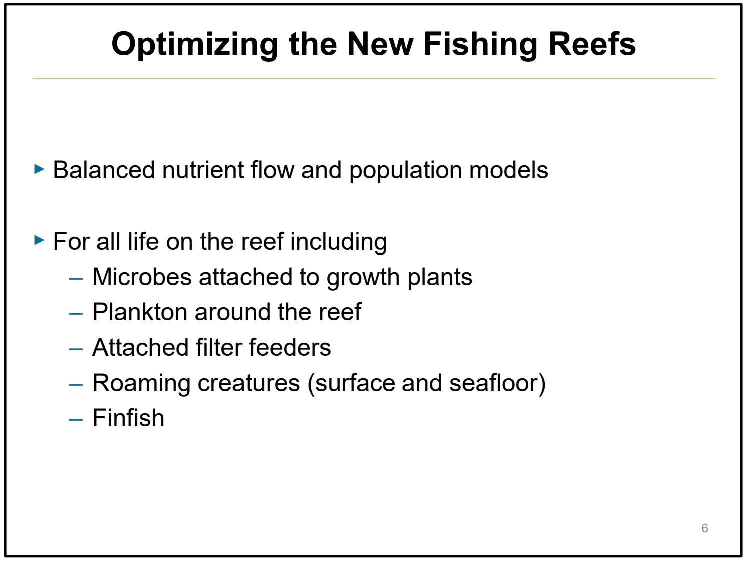



The key to sustainability is recycling the nutrients. We do two types of recycling. One is the natural internal system recycling in the center diagram in which some of the fish eat the seaweed, while the fish release urine which feeds the seaweed. The shellfish can get nourishment from the fish feces. And they also release urine to nourish the seaweed.

The outer diagram shows how nutrients are recycled on a large scale, in which people eat the fish and shellfish. Their urine goes to a sewage plant, which pasteurizes it and distributes it to feed the seaweed and keep the whole system sustainable and much more productive.

We can increase the output of the ocean forest aquaculture ecosystem using the outer recycling loop. This outer loop is what makes ocean forestry a completely different kind of Aquaculture, a significant move beyond Integrated Multi-trophic Aquaculture. In the upper right you see the seaweed using sunlight to produce food for fish and shellfish in the lower figures. The people in the upper left eat the fish and shellfish and produce plant nutrients, which are then pasteurized and recycled to feed the seaweed. Aquaculture becomes **reef-to-reef production**, which is the holy grail of sustainability usually expressed as **cradle-to-cradle manufacturing.**

Nutrient recycle from people is unnecessary in some locations. For example, our first few structures may use the excess nutrients from the Gulf of Mexico dead zone, cleaning it up.




In order to operate the new fishing reefs, we use ecosystem nutrient-flow and population models for all the life on reef. Reef life includes microbes, attached growth plants; the plankton around the reef; attached filter feeders; roaming creatures (structure and/or seafloor); and finfish.

## Open Ocean Systems for Growing Macroalgae

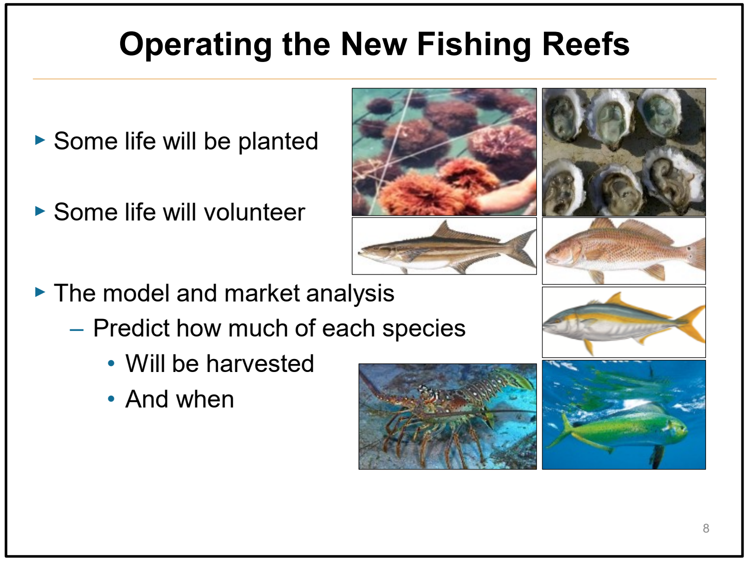
Our MARINER team included:

- Species
- Nutrient flow
- Economic and
- Scaling analysis using

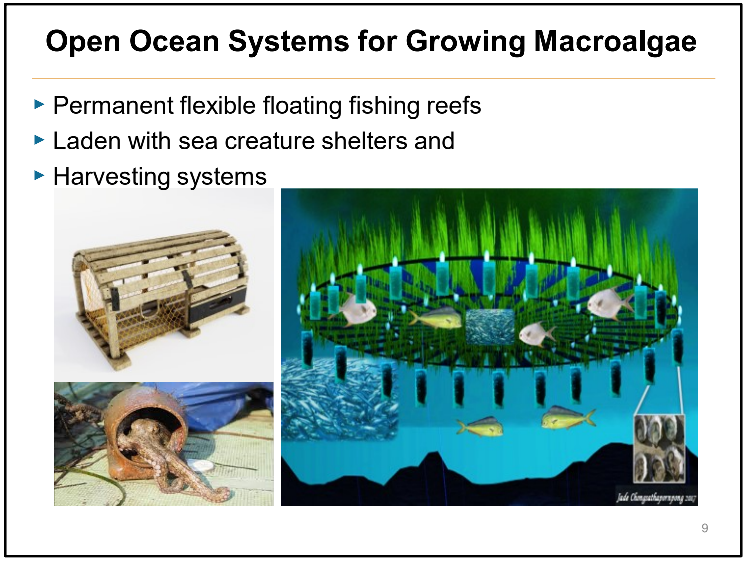
- The macroalgae reef as a new form of aquaculture

7

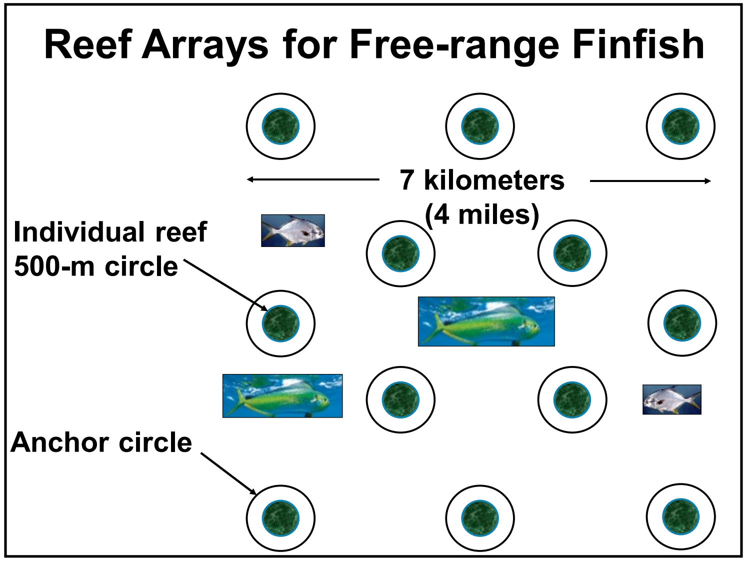
*Our MARINER team included a preliminary species, nutrient flow, economic, and scaling analysis when using the macroalgae reef as a new form of aquaculture. For example, reefs in the Caribbean might harvest: queen conch, lobster, Caribbean king crab, octopus, squid, sea urchin, sea cucumber, bivalves, sponges, in addition to free-range finfish –, cod, snapper, jacks, kingfish, mackerel, whiting, bonefish, barracuda, tarpon, wahoo, grouper, flounder, tripletail, and more…*




Some life will be planted and/or stocked. Some life will volunteer. Reef operators will use the model and market analysis to predict how much of each species will be harvested and when. We work with the local people in each situation to help them identify the optimal native species to plant and harvest for maximum profits consistent with sustainability.

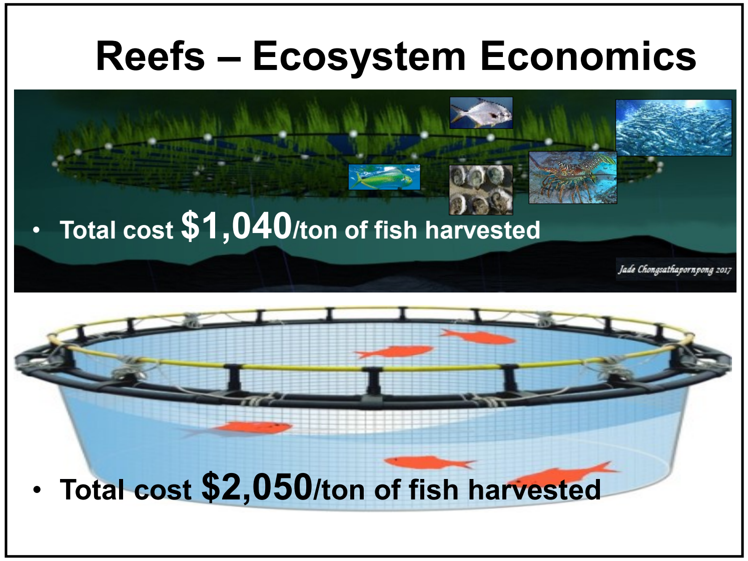



Over time, these structures evolve into permanent, sustainable flexible floating fishing reefs laden with sea creature shelters and harvesting systems




*Our scaling and economic analysis suggest that 60,000-km$^2$ of new fishing reefs could feed 10 billion people 300 grams of seafood every day. The seafood would cost US$1 to $2 per kilogram at the dock. At feed-the-world scale, reef operators would be returning/distributing nutrient volumes equivalent to either 10 billion people's wastes or a third of global artificial nitrogen production.*

How free-range finfish can be practical:
Permits are granted by the seafloor area occupied by the anchors or the watch circle of the structure. If we pack the Spiderweb structures tight with 10 meters clear between anchors, then five 20-ha reefs would occupy about 100-ha of seafloor. (More seafloor in deeper water.) But why not adjust the permit laws so that five 20-ha reefs are allowed (or required to occupy not less than) 1,000-ha? The requirement comes with ownership of the free-range fish within the 1,000-ha seafloor area. This slide shows an example with a dozen reefs. Any finfish caught or sea cucumbers grown on the 16 square miles (nearly 5,000-ha area) on or above the seafloor would be the property of the permit holder. With lots of room to grow, ocean forestry fish can obtain a market premium as "wild-caught." Perhaps even a new category as "organic ocean forest wild-caught" or even better "regenerative ocean forest wild caught."




If we buy ammonia to start our ocean forest operation before recycled nutrients are available, the economics are like renewable energy. That is a high initial cost for the structure followed by low annual cost.

For penned finfish, the big cost is fish feed, about $2,000/ton of harvested fish. But in a flexible floating ocean forest only $40/ton of fish would be spent on the plant food (based on supplying nitrogen as ammonia at 1.5 times the current cost of ammonia). The cost assumes only 50% of the supplied nitrogen gets into a fish product. Our fish products include finfish, shellfish, mollusks, crustaceans, seaweed, … everything that will grow over, in, and around our floating flexible reef. Approximately $1,000/ton of fish harvested from a flexible floating reef will be spent on the structure itself based on our techno-economic analysis prepared for ARPA-E. The reef is built for 20-year service life while surviving hurricanes in 50 to 100-meter seafloor depths in the Gulf of Mexico, so it is pricey.

Bottom line: Fish products from a flexible floating reef will cost about half as much as products from pens; $1,040/ton of fish harvested from a flexible floating reef versus $2,050/ton of penned fish.

A thousand people provide sufficient nutrients to grow about 700 wet tons of seaweed per 20-hectares of reef per year. Allowing for the difference in protein density, about half that seaweed productivity would give about 150 wet tons of non-seaweed high-value seafood. Our ARPA-E research suggests the first 5-pack of reefs, custom designed for the location, will cost about $20 million installed. They would have 100-ha of reef area and occupy about 1,000-ha of seafloor area. We estimate 15,000 wet tons of seafood worth $15 million per year from the 5-reef array.

## Flexible Floating Ocean Forests

**Benefits**

- **Restorative aquaculture**
- **Clean up pollution and dead zones**
- **Sustainable – reef-to-reef production**
- **More habitat – increase ocean productivity**
- **Climate change resilient – no freshwater, < acidification**
- **Safer automatable harvesting, more profit**

The Aquacultural Revolution can restore ocean health and biodiversity. Friends of the Ocean can become our allies. Our desire for jobs, food, and profit aligns with maintaining a biodiverse and healthy reef. Plus, by recycling nutrients, we have the holy grail of sustainability – cradle-to-cradle manufacturing. More accurately: reef-to-reef production.

We also:
Clean up pollution and dead zones
Increase ocean productivity
Address resilience to climate change and
Create safer fishing because the reefs are closer to shore and generate more profits than fishing on the high seas.

# Flexible Floating Ocean Forests

**Challenges**

- ❖ **Climate change – warmer water, bigger waves …**
- ❖ **Fish less concentrated for harvest**


- ❖ **Expense of floating flexible reef**
- ❖ **Difficulty managing dozens of species**
- ❖ **Turtles and marine mammals eating products**

Of course there are some unknowns and challenges.  Fish grow smaller in warmer water or migrate toward the poles. Waves will be larger.

But most challenges are of the kind humanity can overcome with practice and innovation.  For example, Cobalt Intelligence is using lights to aggregate fish. (Slide 20)


In conclusion:

- The economics favor ocean forestry
- The sustainable social and environmental benefits favor ocean forestry
- Every coastal community can have their own flexible ocean forest
- Nutrient recycling favors this approach
- Everyone in this room can help bring about an **aquacultural revolution**!!


Thank you.  I look forward to your questions and collaboration opportunities.

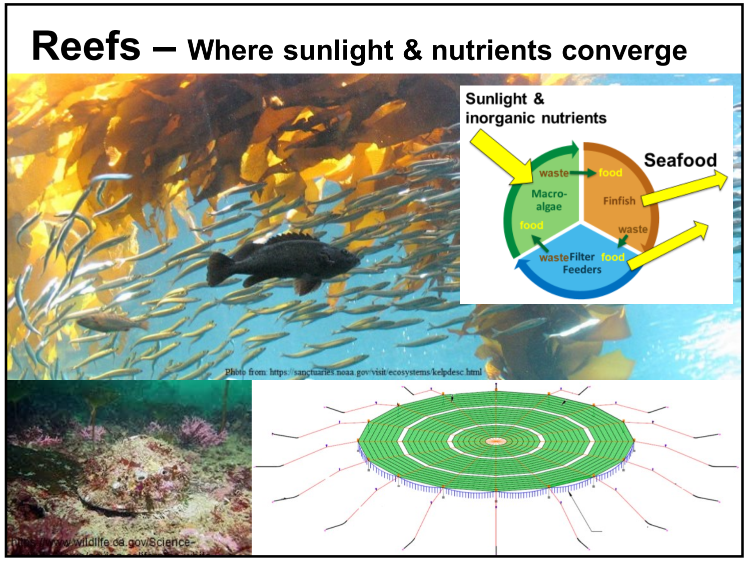
## How does our reef differ from a FAD?

- We optimize the primary productivity by recycling nutrients.
- We are actively managing the ecosystem.
- Therefore we are a ***Fish Multiplying Device***!

Traditional seaweed and shellfish farms are “extractive” as are FAD’s and all wild caught fishing.  They remove nutrients from the ocean.

16

Reference Mike Rust, NOAA




Ocean productivity and biodiversity flourish where sunlight and nutrients converge on surfaces with attached growth – natural (and artificial) reefs. Natural reefs , and our floating flexible reef, contain an intricate food and nutrient chain, simplified in this diagram. There are dozens of tasty human food products on every reef. Good ocean forest reef management practices can recycle human-provided nutrients into a pound of finfish, shellfish, lobster, and the like 365 days per year per person. Good reef management involves:

**One.** If nutrient exports and imports don't match, bad things happen.

**Two.** If the nutrients are too concentrated in time or space, bad things happen.

**Three.** But if you supply more nutrients, you can export more food.

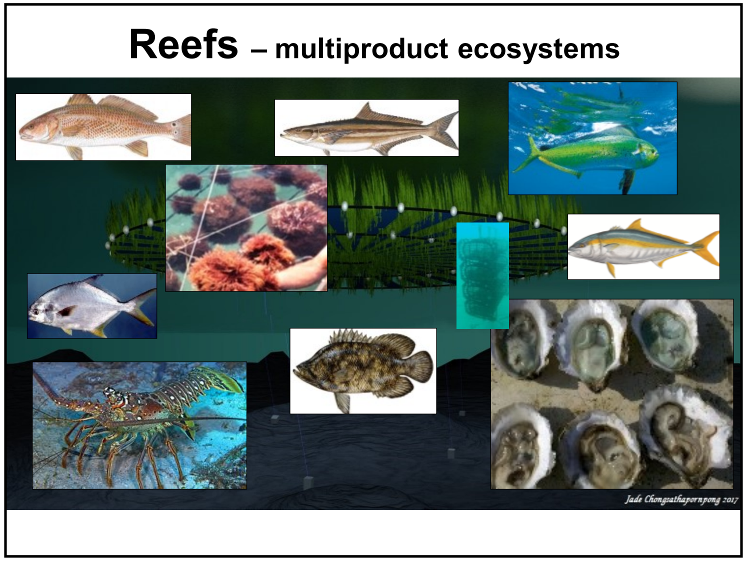
**Four.** If you supply inorganic nutrients, photosynthesis will increase their food value **for free!** Actually not completely free. You have to install and maintain a reef!

## Reefs – manage for wealth and biodiversity


This is a photo in a *National Geographic* article about managing natural reef resources. A town in Mexico's Baja California manages the abalone harvest from their natural reef so well they can afford to educate their children and send them to college.

If a managed natural reef can provide that much wealth, consider what should be possible on our artificial reefs with their benefits of:

- Ideal depth for maximum sunlight, independent of seafloor depth;
- Ideal substrate for attached plants and animals (not too soft or sandy for dense sealife);
- Ideal wave energy, never too strong because we can submerge;
- Ideal nutrient supply and distribution, as we will learn in the next slide.



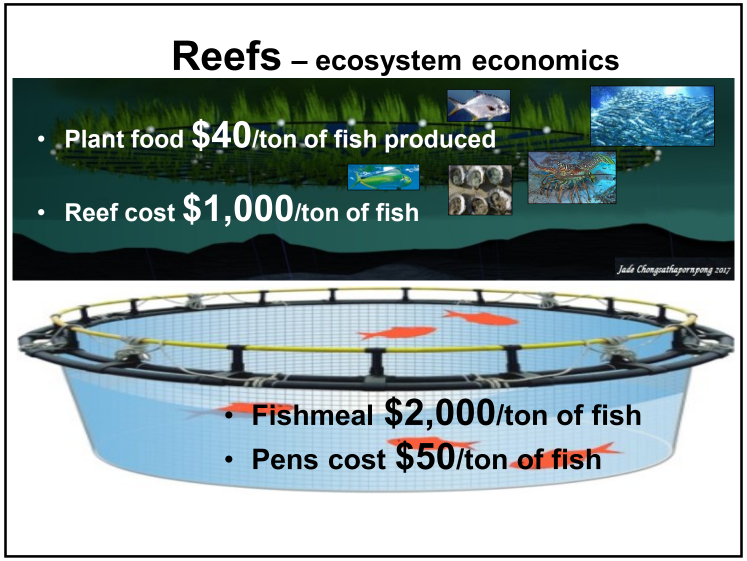

Aquaculturists have been focusing on one or two products for many of the same reasons that terrestrial agriculture favors mono-crops. It is difficult to achieve economies of scale when managing the reef entire ecosystem. But the ocean is more difficult to fence and its not practical to enforce a mono-crop with pesticides, herbicides, and antibiotics.

*For example, **reefs in the Caribbean might harvest**: queen conch, lobster, Caribbean king crab, octopus, squid, sea urchin, sea cucumber, bivalves, sponges, and free-range finfish – lionfish (over-fish them to local extinction), cod, snapper, jacks, kingfish, mackerel, whiting, bonefish, barracuda, tarpon, wahoo, grouper, flounder, tripletail, etc.*

The system allows reef owners to grow a suite of products appropriate for an ocean forest. In the Gulf of Mexico, our products might include:

- *Gracilaria*
- Oysters hanging in cages
- A wide variety of finfish
- Not pictured potential species include: scallops, mussels, barnacles, sea cucumbers, crabs, octopus, and more …

The finfish will hide in the structure when young and hang out in the shade as they become larger.  Occasional swarms of small finfish are likely to attract large fish, such as tuna.




If we buy ammonia to start our ocean forest operation before recycled nutrients are available, the economics are like renewable energy. That is a high initial cost for the structure followed by low annual cost.

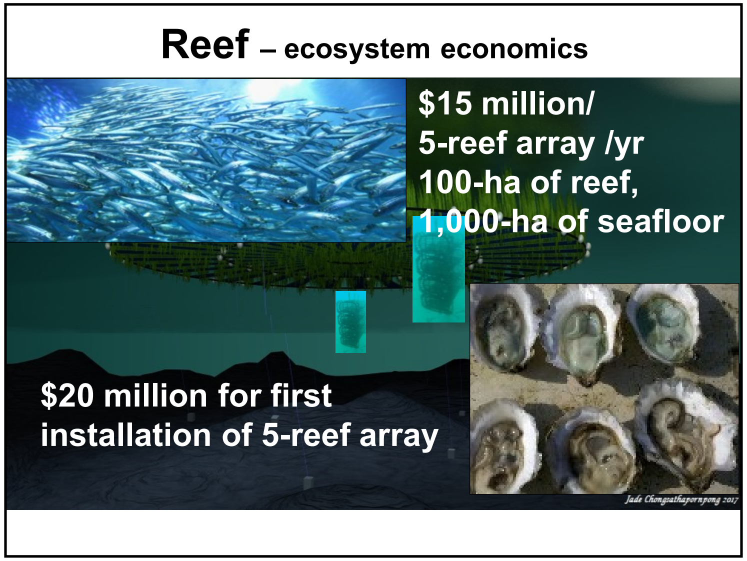
The $40/ton of fish for the plant food is based on supplying nitrogen as ammonia at 1.5 times the current cost of ammonia. The cost assumes only 50% of the supplied nitrogen gets into a fish product. Our fish products include finfish, shellfish, mollusks, crustaceans, seaweed, … everything that will grow over, in, and around our floating flexible reef.

The $1,000/ton of fish for the structure is based on our techno-economic analysis prepared for the U.S. Department of Energy Advanced Research Projects Agency-Energy. The reef is built for 20-year service life while surviving hurricanes in 50 to 100-meter seafloor depths in the Gulf of Mexico, so it is pricey.

Bottom line: Fish products from a flexible floating reef will cost about half as much as products from pens.
*Optional additional text*
A thousand people provide sufficient nutrients to grow about 700 wet tons of seaweed per 20-hectares of reef per year. Allowing for the difference in protein density, about half that seaweed productivity would give about 150 wet

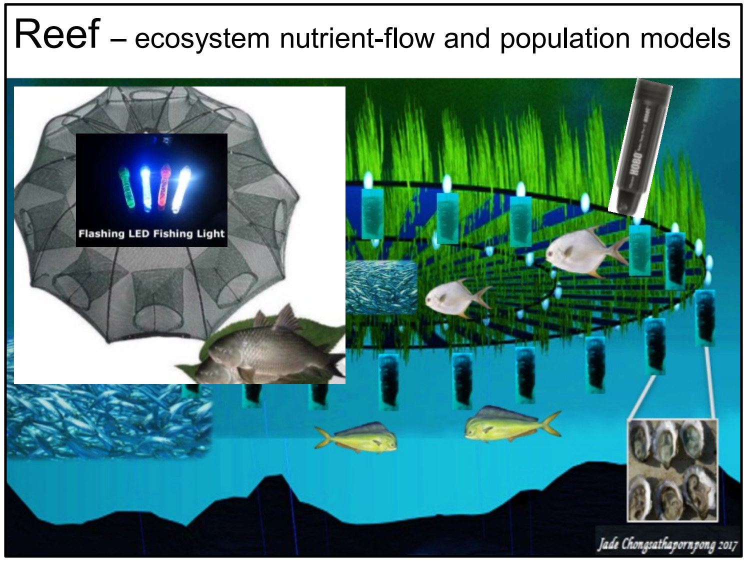
tons of non-seaweed high-value seafood.  At $1 per wet kilogram, we'd have $15 million per year at the dock from one of our 20-hectare reefs.

Our Department of Energy research suggests the first 5-pack of reefs, custom designed for the location, will cost about $20 million installed.  They would have 100-ha of reef area and occupy about 1,000-ha of seafloor area.  We estimate 15,000 wet tons of seafood worth $15 million per year from the 5-reef array.




A thousand people provide sufficient nutrients to grow about 700 wet tons of seaweed per hectare per year. Allowing for the difference in protein density, about half that seaweed productivity would give about 150 wet tons of non-seaweed high-value seafood. At $1 per wet kilogram, we'd have $15 million per year at the dock.

Our Department of Energy research suggests the first 5-pack of reefs, custom designed for the location, will cost about $20 million installed. They would have 100-ha of reef area and occupy about 1,000-ha of seafloor area. We estimate 15,000 wet tons of seafood worth $15 million per year from the 5-reef array.




*In order to operate the new fishing reefs, we will need **ecosystem nutrient-flow and populations models** for all the life on the reef. Reef life includes microbes, attached growth plants; the plankton around the reef; attached filter feeders; roaming (structure and/or seafloor) creatures; and finfish. Some life will be planted and/or stocked. Most life will volunteer.*

The models will combine with built-in sensors, fish-attracting, and fish- harvesting systems.

## OceanForesters Team for Dept. of Energy

**Coordination, Permitting, Techno-Economic Analysis**

- Kelly Lucas, University of Southern Mississippi
- Reginald Blaylock, University of Southern Mississippi
- Stephan Howden, University of Southern Mississippi
- Mark Capron, OceanForesters
- Jim Stewart, OceanForesters
- Martin Sherman, Seavac Ltd. UK
- Anthony T. Jones, Intake Works

**Biology and Nutrients**

- Michael Chambers, University of New Hampshire
- Scott James, Baylor University
- Maureen Brooks, University of Maryland
- Stacy Krueger-Hadfield, University of Alabama Birmingham
- Suzanne Fredericq, University of Louisiana at Lafayette
- Brian Lapointe, Florida Atlantic University
- Antoine N'Yeurt, University of the South Pacific
- Ricardo Radulovich, University of Costa Rica
- Alejandro Buschmann-Rubio, University of Lagos, Chile

**Oceanography and Technology**

- Steven DiMarco, Texas A&M University
- Kerri Whilden, Texas A&M University
- Tony Knap, Texas A&M University
- MH Kim, Texas A&M University
- Kristen Thyng, Texas A&M University
- Brian von Herzen, Climate Foundation
- Alyson Myers, Fearless Fund
- Chris Webb, AI Control Technologies
- Alberto Mestas-Nunez, Univ of Texas, San Antonio

**Structural Modeling**

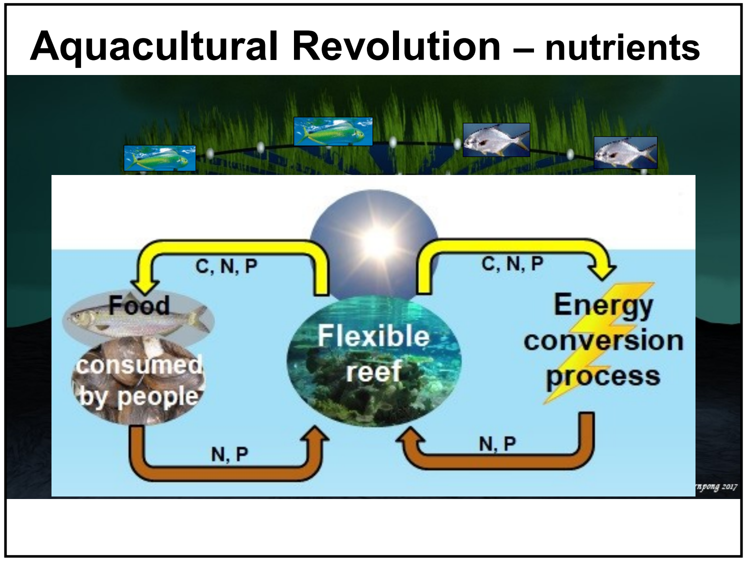
- Rob Swift, University of New Hampshire,
- Zach Moscicki, University of New Hampshire
- Igor Tsukrov, University of New Hampshire
- Corey Sullivan, University of New Hampshire
- David Fredriksson, U.S. Naval Academy
- Toby Dewhurst, Maine Marine Composites
- Andrew Drach, Callentis Consulting Group

**Technology Advisors**

- Samson Rope
- Applied Fiber
- Aquuai Robofish
- Synthetik-Technologies

OceanForesters assembled a large interdisciplinary international team to combine the biology, oceanography and structural engineering to develop innovative approaches to meet the US Department of Energy ARPA-E push to grow economical seaweed-for-energy.

In addition to our 30 funded people, we benefited from the knowledge of Ricardo Radulovich, Alejandro Buschmann, Samson Rope, Applied Fiber, Aquaai, and Synthetik-Technologies.




The previous slide showed how that the aquacultural revolution can sustainably feed the world without synthetic fertilizers. But what about the Department of Energy's interest, fueling the world with biofuels?

Conveniently, all the processes that convert wet seaweed to energy at less than 400 degrees Celsius produce ammonia, phosphate and micronutrients as by-products. That means we can operate both loops on the same ocean forest reef. A "Feed the world" loop and a "Fuel the world" loop. The "Fuel" loop will be cycling ten to a hundred times the biomass and nutrients of the "Food" loop, if seaweed satisfied global demand for both food and fuel.

With sufficient funding, this table shows how soon each goal could be achieved:

| **Funding, initial** | **$10 M** | **$1 B** | **$100 B** |
|---|---|---|---|
| Feed the world (all 9 billion people) | 2050 | 2040 | 2030 |
| Fuel the world (replace all fossil fuels) | 2100 | 2080 | 2050 |
| Reverse climate to 1980 (350 ppm) | 2300 | 2200 | 2100 |

An investment of $10 million could start the movement toward these three goals, more investment would move faster.

**Figure 5: Provisional global assessment of NETs: scale, cost and readiness**

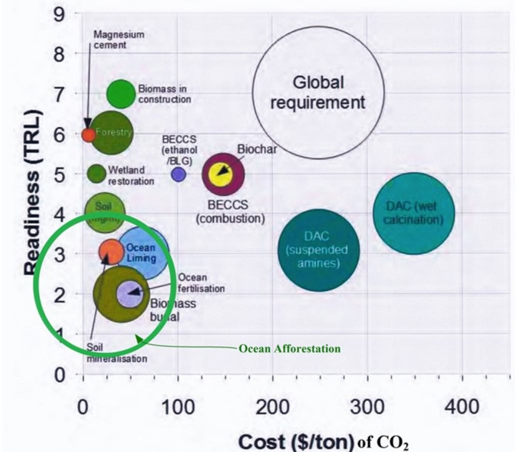



Figure 5 is from McLaren , "First, Stop Digging", Sept. 2011, https://sites.google.com/site/mclarenerc.
Mark Capron, PODenergy, estimated and added the Ocean Afforestation circle, Feb. 2013