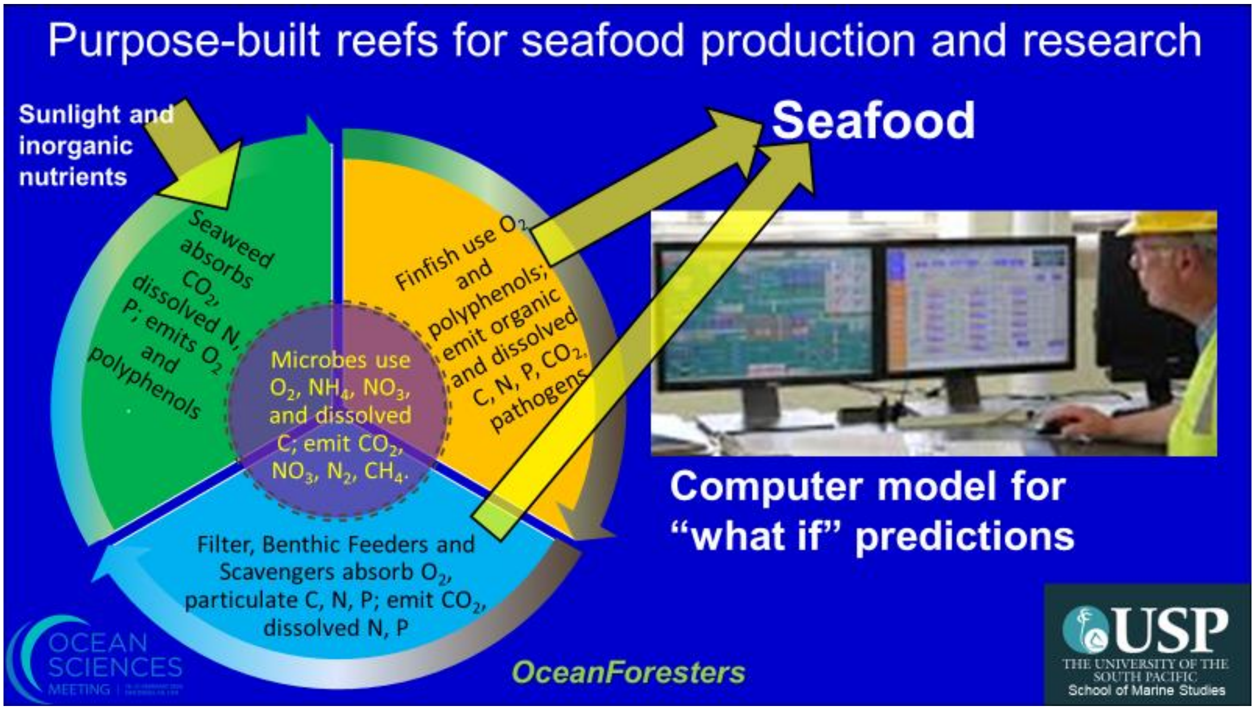
The Nutrient Recycling Seafood-Science Programme for the UN Decade of Ocean Science for Sustainable Development

Sustainable Seafood that supports Ocean Science
Ocean Science that supports Sustainable Seafood



An example Programme description for the
UN Decade of Ocean Sciences for Sustainable Development (2021-2030)

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Implementation Plan Discussion (unnecessary in actual programme write-ups)

The United Nations has proclaimed a Decade of Ocean Science for Sustainable Development (Decade) to be held from 2021 to 2030. The Decade's Implementation Plan Version 2.0, July 2020 (para 28, pg 11) identifies ten Ocean Decade Challenges.

The plan (para 37, pg 15) explains different levels of the tangible initiatives (Decade Actions) that will be carried out across the globe over the next ten years to fulfil the Decade vision:

A Decade programme is typically global or regional in scale and will contribute to the achievement of one or more of the Ocean Decade Challenges. It is long-term (multi-year), interdisciplinary and will consist of component projects, and potentially enabling activities.

A Decade project is a discrete and focused undertaking. It may be regional, national or sub-national and it will typically contribute to an identified Decade programme.

A Decade activity is a one-off standalone initiative (such as an awareness-raising event, a scientific workshop, or a training opportunity). It will enable a programme or project or directly contribute to an Ocean Decade Challenge.

A Decade contribution supports the Decade through provision of a necessary resource (e.g. funding or an in-kind contribution). A contribution can support either the implementation of a Decade Action or the coordination costs of the Decade.

Summarizing important concepts for implementing Decade Actions

- UN entities develop and register Decade Actions with the Decade Coordination Unit.
- Non-UN entities wait for and then respond to a Call for Action on a programme or project. (Per para 37, pg 16 "These will typically be launched twice per year by the Decade Coordination Unit via an online platform. Calls for Actions will not specify programmes or projects to be carried out as part of the Decade, but will target priority geographic areas or themes linked to the Ocean Decade Challenges.") Acceptable programmes are endorsed based on the advice of the Decade Advisory Board. Acceptable projects are endorsed by the Decade Coordination Unit after consultation with relevant decentralized coordination structures or endorsed by Decade programmes. (Fig. 2.3, pg 16)
- The Plan encourages actions that are coordinated with all stakeholders. Key stakeholders are identified in para 70, pg 24-26.
- From para 110, pg 35: "Firstly, in many cases, proponents of Decade Actions will take the lead in securing their own resources: in these cases, the endorsement of an initiative as a Decade Actions will increase its attractiveness to funders and resource providers that are supportive of the Decade. Secondly there will be funding and support opportunities that are exclusively available to Decade Actions and for which the Decade Coordination Unit will play a coordination role between priority needs and the commitments of funding and resource partners via the Ocean Decade Alliance and the Global Stakeholder Forum."
- The Ocean Decade Alliance acts to connect action proponents and resource providers (in-kind and funding). For example, a local community with an endorsed project may find the resources to implement the project within the Ocean Decade Alliance. (Mechanisms, pg 37-39)

1. Executive Summary

On a natural reef, life creates the conditions for more life. The wastes of animals become nutrients for plants and other animals and multiple species thrive. Plants use sunlight (photosynthesis) to turn a small amount of nutrients into a substantial amount of food, as shown in Figure 1. Each project in the Nutrient Recycle Seafood-Science Programme would use complete nutrient cycles to produce seafood on built reef ecosystems.

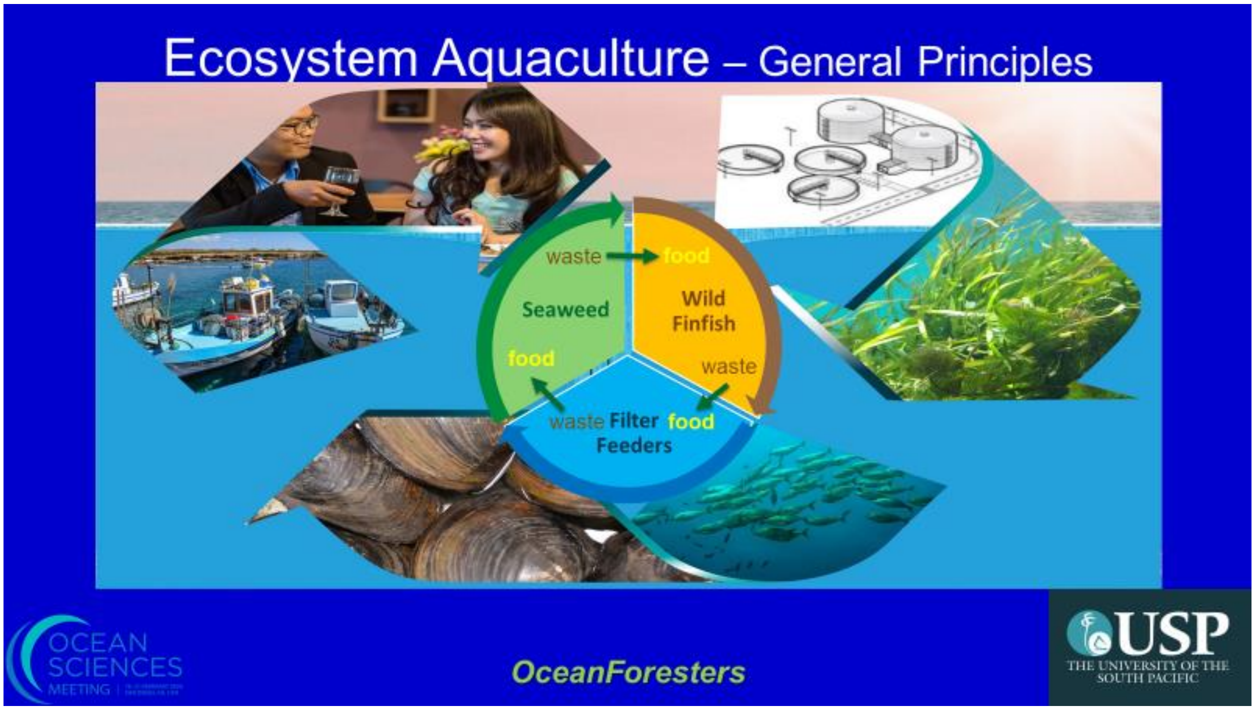

Fig. 1 – The large outer nutrient cycle shows how nutrients removed from the reef for food can be returned to the reef. The small inner circle represents nutrients cycling within the reef.

Distributed globally, seafood reefs can sustainably and economically produce a billion tonnes/yr of seafood, using a little of the ocean area that is less than 200-m deep and 20% of the nutrients from 10 billion people (in 2050). The Food and Agriculture Organization estimates current seafood production (including aquaculture and wild-caught) near 170 million tonnes/yr. Current meat and seafood combined is about a half billion tonnes/yr. The demand for seafood from purpose-built reefs might not exceed a doubling of meat and seafood, or a half billion tonnes, by 2050. The Nutrient Recycle Seafood Science Programme could target 100 million tonnes/yr by 2030.

Conditions for built reef ecosystems generally span between two extremes:

a. In sheltered shallow water with excess nutrients and sediment – Clarify the water with farmed filter feeders and sediment capture (mangroves, seagrass). Increase macroalgae substrate in the photic zone. The substrate may be a mix of bamboo and rope.

b. In the open ocean, as much as 200-m seafloor depth – Install permanent flexible floating fishing reefs at the optimum depth as the substrate for the desired native macroalgae, shellfish, and crawling sea creatures. Recycle nutrients from land matching the amount on nutrients extracted from the fishing reef.

Increasing seafood production from built reef ecosystems allows preservation of more marine protected areas. Nearby marine protected areas could be protected by the poaching prevention sensors on built reefs while also providing sea creature services that might not be available on the initial built reefs (spawning habitat, turtle shell cleaning station, etc.).

Human and livestock waste collection and recycling systems can maintain public health while recovering all freshwater, energy, and nutrients to produce more food. When nutrients are recycled effectively, the food-waste-food circular economy should cost less than current systems for "treating" human and livestock waste. That is, new water resource recovery systems will recover nutrients instead of using energy intensive oxidize-the-carbon and convert-ammonia-to-nitrogen gas technologies.

2. Ocean Decade Challenges Addressed

Challenge 1: Develop solutions to remove or mitigate pollution – Most (but not all) "pollution" is human urine and feces. Water resource recovery engineers are refining systems to recover and pasteurize the valuable plant nutrients and energy (carbon) in urine and feces. Purpose-built fishing reefs are only sustainable by returning the plant (inorganic) nutrients that were extracted from the purpose-built reef (as protein, organic nutrients).

Challenge 2: Develop solutions to monitor, protect, manage and restore ecosystems and their biodiversity under changing environmental, social and climate conditions – For example, some fish species will leave the tropics as tropical waters become too warm to reproduce. A purpose-built reef ecosystem allows research, large-scale experiments, and rewilding. For example, many cameras coordinated with acoustic sensing and occasionally providing cooler water on hot nights. As the number of purpose-built reef systems increases, the seafood production operation would pay for sensors and actions needed to maintain biodiversity.

Challenge 3: Develop solutions to optimize the role of the ocean in sustainably feeding the world's population under changing environmental, social and climate conditions – An additional 100 million tonnes/yr of seafood by 2030.

Challenge 4: Develop solutions for equitable and sustainable development of the ocean economy under changing environmental, social and climate conditions – Any coastal community, no matter how lacking in existing fishing resources or means to recover their waste resources, can have a purpose-built reef that matches their population.

Challenge 5: Build resilience to the effects of climate change across all geographies and at all scales, and to improve services including predictions for the ocean, climate and weather – In some cases, the structure is a mangrove forest or other kind of living reef. In all cases, the sensors on the living reef input to a computer ecosystem model. The reef operators use the model to predict if one species population will crash or explode based on forecasts of future conditions. That is, the reefs build resilience to the effects of climate change. Many purpose-built reefs each with many sensors will improve predictions.

Challenge 6: Enhance multi-hazard early warning services for all geophysical, ecological, biological, weather, climate and anthropogenic related ocean and coastal hazards, and mainstream community preparedness and resilience – Many purpose-built reefs each with many sensors will improve predictions. For example, some could include sensors that detect seismic or volcanic activity in addition to the geophysical, ecological, biological, and weather sensors used to optimize long-term productivity with biodiversity.

Challenge 7: Ensure a sustainable ocean observing system across all ocean basins that delivers accessible, timely, and actionable data and information to all users – The data from every reef could go to the cloud, with all the measurements and units organized for data mining. As income from seafood production allows, the reef operators will come to rely on real time data. That data can be made available on the web for school children to view and listen to activity on their local reefs or distant reefs. The acoustic systems on a reef might detect and provide an alarm for unauthorized activity in the reef or in nearby marine protected areas.

Challenge 8: Through multi-stakeholder collaboration, develop a comprehensive digital representation of the ocean, including a dynamic ocean map, which provides free and open access for exploring, discovering, and visualizing past, current, and future ocean conditions in a manner relevant to diverse stakeholders – Each purpose-built reef with its sensors provides a highly detailed representation of the ocean near it with a computer ecosystem model. The model might be viewed similar to the U.S. National Ocean and Atmospheric Administration's (NOAA) virtual ecosystem scenario viewer.

Challenge 9: Ensure comprehensive capacity development and equitable access to data, information, knowledge and technology across all aspects of ocean science and for all stakeholders – All reef systems would provide transparent public reports. In addition, philanthropic resources could provide support for online and direct interactions to share information and insights across all reefs. Philanthropies may also be needed to bring purpose-built reefs to small communities needing to sustain local food production but lacking (or not interested in) an export market.

Challenge 10: Ensure that the multiple values and services of the ocean for human wellbeing, culture, and sustainable development are widely understood, and identify and overcome barriers to behaviour change required for a step change in humanity's relationship with the ocean – The internet allows everyone to view the output of sensors on purpose-built fishing reefs. People will see where their food comes from, when their pasteurized urine and feces combine with sunlight to produce a wealth of biodiversity, how the non-food flora and fauna are important to the ecosystem's sustainable and robust food yields, etc. They will also see plastic and other trash, or clouds of sediment. They may see or hear people poaching from a reef or a nearby marine protected area. In short, each reef can be in everyone's living room or pocket. Some people may edit the most interesting moments to produce ocean documentaries and the ocean equivalent of funny cat videos.

3. UN Sustainable Development Goals Addressed

SDG #1. No Poverty: Ocean farming reefs are sustainable environmental community enterprises that create jobs especially for underserved communities. The jobs range from reef construction and maintenance to planting and harvesting to seafood processing and marketing.

SDG #2. Zero Hunger: Ocean farming rapidly grows a variety of sustainable and protein-rich food sources. Seaweed (the primary productivity and dissolved oxygen source, not an important crop) requires neither fresh water, pesticides nor land input to grow. The primary crops are high-protein free-range finfish, shellfish such as mussels, oysters, clams, etc., as well as invertebrates, including profitable sea cucumbers and sponges.

SDG #3. Good Health and Well Being: Fish and shellfish provide the healthiest source of protein, complete with micronutrients often lacking in terrestrial crops from depleted soils. In addition, seaweed (and creatures on its food chain) contains high amounts of iodine, potassium, magnesium, calcium and iron, as well as vitamins, antioxidants, phytonutrients, amino acids, omega-3 fats and fiber.

SDG #5. Gender Equality: Ocean farming enterprises can focus on training and advancing women as an economic development tool that serves the immediate family and ripples out to the community and nation. There are women-run co-operatives farming seaweed and adding value to the harvest. A built reef ecosystem would be a step up to higher income for existing seaweed (or fishing) co-operatives.

SDG #6. Clean Water and Sanitation: Coastal communities will come to value recovering the carbon and nutrients that had, in concentrated form, spread disease and overwhelmed local ecosystems. The productivity of built reef ecosystems depends on building human and animal waste collection systems that will pasteurize wastes and use them to fertilize seaweed forests.

SDG #8. Decent Work and Economic Growth: A permanent built reef ecosystem provides permanent quality jobs in ocean forestry. Ocean forestry is the more appropriate term because the reefs avoid mono- or duo-cultures. The reefs produce diverse income streams including: finfish, shellfish, crabs, snails, sea cucumbers, urchins, lobster. Managing the many product species and the ecosystem support species is like forestry but expanded to include fauna. (Seaweed harvests should be limited because of its low value and to avoid putting seaweed farmers out of business.) The quantity of jobs is only limited by the availability of suitable ocean area and recyclable nutrients. That means reefs could be built to provide permanent jobs for and recycle the nutrients from refugees and migrants.

SDG #10. Reduced Inequalities: A built reef ecosystem is a "new industry" for each community. As a new industry, the first built reefs lack an entrenched hierarchy of inequalities. The funding agencies can insist the new organizations structure for merit-based promotions and equal opportunity. The income from reef operations can fund education for everyone (online classes to improve one's certification level). Each reef has a wide range of manual, shop, and desk jobs from lifting nets full of fish, to maintaining sensors and communications, to maintaining the reef structure, to maintaining the fishing equipment, to processing the catch, to using the computer model when identifying how much of each species to catch that week.

SDG #11. Sustainable Cities and Communities: Cities and communities move toward sustainability when their food supply completes the nutrient cycle.

SDG #13. Climate Action: Built reef ecosystem seafood can scale to meet global high-protein food demand in 2050 even to displacing all meat and current seafood production. Any decrease in meat production would free-up land that is currently producing meat or grain for meat for other uses: grain for people, biomass-for-energy, permanent carbon-sequestering forests (or at least an end to deforestation). People whose livelihood depend on deforestation could become ocean foresters.

Mass weighted average meat GHG impact is about 17 tonnes of CO_{2eq} per tonne of meat (Ritchie & Roser 2019; Poore & Nemecek 2018). Seafood GHG impact is about three tonnes of CO_{2eq} per tonne of seafood (including both wild-caught and aquaculture) (MacLeod et al. 2020; Parker et al. 2018). A business-as-usual increase in both meat and seafood production would mean 13 billion tonnes of $CO_{2eq.}$ Continuing 2018 meat and seafood production levels and adding a half billion tonnes of built reef seafood would total eight billion tonnes of CO_{2eq}, a savings of five billion tonnes of CO_{2eq} (see SS tab 24). Although the macroalgae could be harvested for energy production, that is not within the Nutrient Recycling Seafood-Science Programme.

SDG #14. Life Below Water: Built reefs provide substrate for the aquatic version of rewilding. Rewilding is returning species to areas where humans caused their extinction: wolves, grizzlies, bison, and beaver to the U.S.; bison to Europe. Aquatic rewilding could include giant clams, seagrass, dugongs, sea turtles, clams, oysters, etc. over their pre-human range at their pre-human density.

Ocean waters around seaweed ecosystems have measurably lower acidity, which helps crustaceans and sea life of all kinds. Ocean reef ecosystem operators should manage to increase biodiversity because doing so should offer the most long-term and robust seafood production. Good management requires a calibrated computer model of nutrient flows, species populations, the effect of species populations on other species, the effects of changing temperature and ocean chemistry on species populations, etc. The model needs to cover a range of species sizes from virus to whale. (These points require substantial science.)

Scaling built-reef ecosystems allows more marine protected areas. 200,000 to 300,000 km^2 of floating flexible reef structures with total ecosystem aquaculture could produce a billion tonnes of seafood per year. A billion tonnes is 5 times current seafood production. Including space between reef structures to avoid overlapping mooring lines, they might occupy 1.5 million km^2 of continental shelf with seafloor depth less than 200 meters. That is about 13% of the 11 million km^2 of 0 to 200-m deep continental shelf that Gentry et al. (2017) found potentially suitable for fish and shellfish aquaculture. If all the non-indigenous ocean fishing and aquaculture were on floating flexible reef ecosystems, the entire deep ocean (deeper than about 200-m) and 87% of continental shelves (less than 200-m seafloor depth) could become marine protected areas or reserved for indigenous fishing.

Built reef ecosystems will diversify monitoring and maintenance funding for marine protected areas. The coastal community fishes the built reef for food and income. Most built-reefs will have acoustic sensing systems to detect poachers and monitor fish populations. The sensors on the built-reefs can detect poachers in nearby marine protected areas. When economic recessions or pandemics drop tourist income, the local community can survive on the built reef and still detect unauthorized activities in the marine protected areas.

SDG #15. Life on Land: The demand for meat, grain, and terrestrial plant biofuel is driving deforestation and overdrawing aquifers. Built reef ecosystem seafood can scale to meet global high-protein food demand in 2050 even to replacing all meat and current seafood production.

Other SDGs: While directly addressing the above eleven SDGs, ocean forests indirectly support the other five Goals by creating sound economic and social foundations so that everyone can participate in and gain from (4) Quality Education, (7) Affordable and Clean Energy, (9) Industry, Innovation and Infrastructure, (12) Responsible Consumption and Production, (16) Peace, Justice and Strong Institutions, and (17) Partnerships for the Goals.

4. Stakeholder Discussion

The local coastal community and its indigenous knowledge holders should design and operate their built reef ecosystem to suit local the local natural ecosystem, their ways of fishing, and their preferences for organizing. The only intrusion should be an understanding that funding depends on equalizing opportunities for everyone in the community. The local community must become "invested" in adapting the science to fit their resources. When communities are involved in the planning, they find ways to make the development successful. Development that is not planned by the community can be detrimental. See Saini, A. and Singh S.J., "The Aid Tsunami" Scientific American April 2020 for an example of adverse "help."

Scientists and engineers mentoring and coaching the local organizations will strive to leave the local reef-operating organizations with the skills to add more reefs independent of the initial scientists and engineers.

Likewise, scientists conducting research on built reef ecosystems will strive to leave the local organization with the skills to continue and expand research topics independently. Scientists might: (1) purchase data that the local organization gathers for its purposes; (2) pay for maintenance services, power, and communication connections on additional sensors; (3) work with the community to conduct research without affecting seafood production; (4) coordinate research with yield-enhancing experiments conducted by the local operator (submerge to cool, changing details of recycled nutrient distribution, and the like); and (5) offer to pay for difference in profit losses between the experiment reefs and the control reefs.

Resource providers (funding and in-kind) should find a funding mechanism that: (1) leaves the local community owning the built reef outright within 15 years; (2) does not saddle the local community with debt, should revenue minus expense be inadequate to repay; (3) collects more than the initial funding where revenue minus expense allows. Particularly in least developed countries, the lack of product transportation infrastructure may limit export revenue. The lack of export revenue may hamper purchasing some of the materials needed to maintain the structures.

5. Details of Ocean Science and Sustainable Development

5.1 Seafood Production and Science

Build on the understandings and recommendations of Hoegh-Guldberg, O., et al. 2019, particularly: "Conserving and protecting blue carbon ecosystems, … Restoration and expansion of degraded blue carbon ecosystems, … Expansion of seaweed (macroalgae) through aquaculture …". Seafood is addressed as a climate change mitigation: "There are two principal ways in which ocean-based foods can contribute significantly to climate change mitigation. One seeks to reduce the carbon footprint of ocean-derived food production. For example, changing fuel sources in vessels and technological advances in production techniques can alter the emissions associated with seafood from both wild-caught fisheries and ocean-based aquaculture. The other seeks to identify emission reductions from potentially shifting more GHG-intensive diets to those that include more GHG-friendly seafood options, if those seafood options can be provided on a sustainable basis."

Sustainable, eco-friendly seafoods require purpose-built new seaweed and sea animal ecosystems, as in Figure 2. OceanForesters' Total Ecosystem Aquaculture reefs (Lucas et al. 2019, Capron et al. 2020a and 2020b) present one such ecosystem. These are purpose-built Seafood-reefs. Each Seafood-reef involves installing artificial substrate for the growth of plants and sea creatures supported by the engineered return of nutrients equal to the amount of nutrients removed.

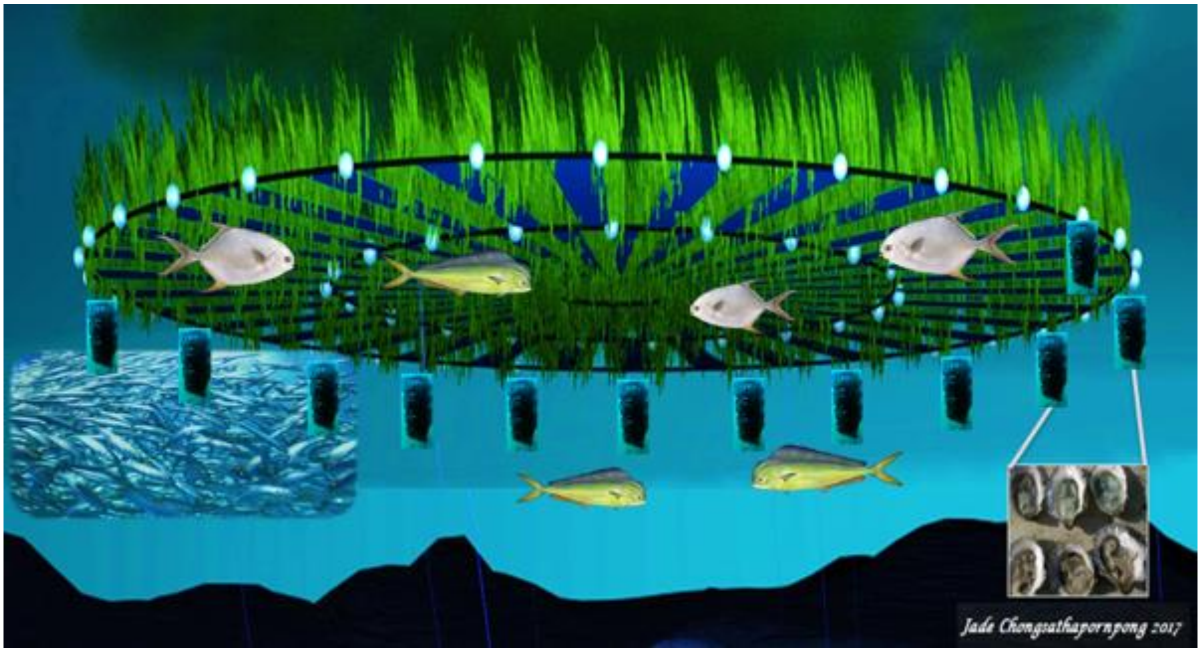

Fig. 2 – Artists' concept of a floating flexible fishing reef ecosystem

The nutrient return, planting, stocking, and harvest is managed to maintain a healthy biodiverse reef ecosystem. Tropical Pacific seafood species include: mud crab, giant clams, oysters, crabs, shrimps, lobsters, octopus, squid, sea urchins, sea cucumbers, sponges, and free-range finfish, including milkfish, perch, grouper, snapper, sea bream, and many more. Ecosystem support species (necessary but not typically harvested) include: seaweed, seagrass, mangroves, coral, worms, barnacles, snails, sea stars, anemones, microscopic creatures, bacteria, and much more.

Ocean science is essential to find ways to maintain tropical fisheries despite more and more urgent issues than are shown in Figure 3: (1) Flemming et al., 2020 found that embryos and adult fish when breeding are much more sensitive to warming than fish at other life stages. (2) Marine heatwaves are shifting ocean temperatures at similar scales to what is anticipated with climate change – but in much shorter time frames. The average climate change temperature shift in 2020 is about 20 kilometers per decade. Marine heat waves displace temperatures an average of 200-km in a few months (Jacox et al. 2020).

Plants in the ocean may respond to heat waves the same way land plants do. McGowan et al, 2020 studied subtropical coastal ecosystems in eastern Australia. They found the optimum temperature range for photosynthesis of 24.1°C to 27.4°C. Temperatures above optimum were accompanied with rapid decline in photosynthetic production, made worse if soil water content decreases. (The response of plants in the ocean will not be dependent on soil water content, but might be dependent on salinity, or nutrient availability, or some other parameter.)

Science could include intense data gathering on the built reefs with simultaneous measurements of environmental DNA in water samples and creature stomachs, automated flow cytometry, autonomous image recognition from stationary and mobile cameras, autonomous signal processing for active and passive sonar, and assorted chemistry and physical properties sensors.

Much of this science data pays for itself through increased seafood production. For example, the graph at upper right of Figure 4 shows that dissolved oxygen concentrations drop and fish need more oxygen as waters warm. Adequate sensors plus reefs may support accurate maintenance of macroalgal oxygen production for abundant fish production even as waters warm.

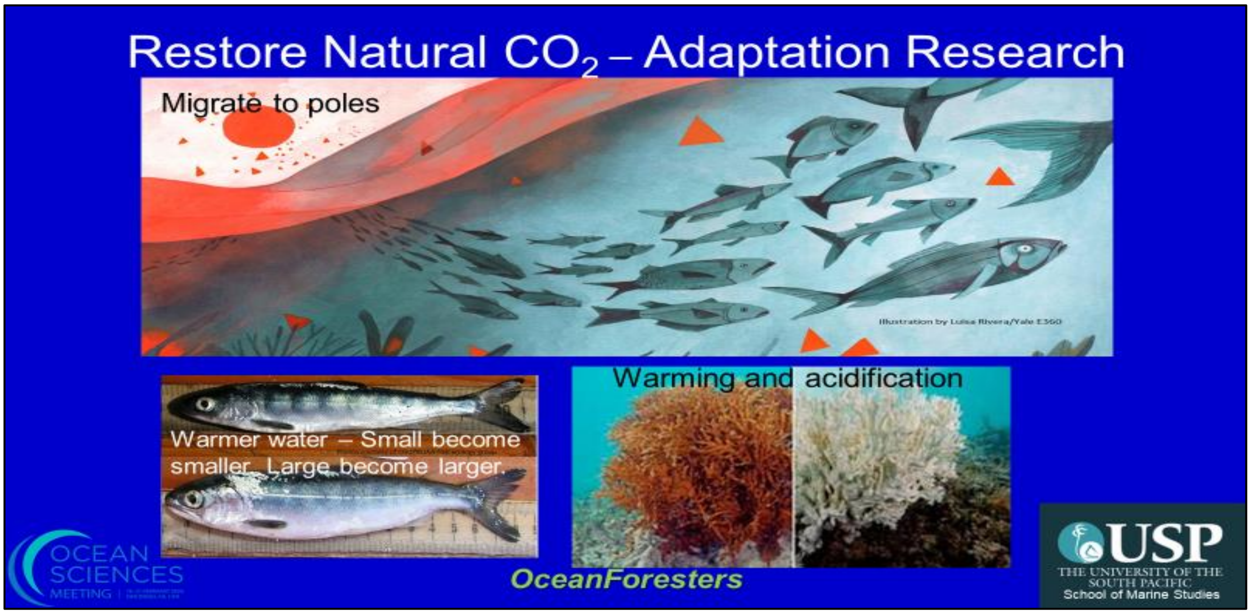

Fig. 3 – Changes in local ecosystems due to increased greenhouse gas concentrations (The debate on how and why fish size changes with warmer water is ongoing.)

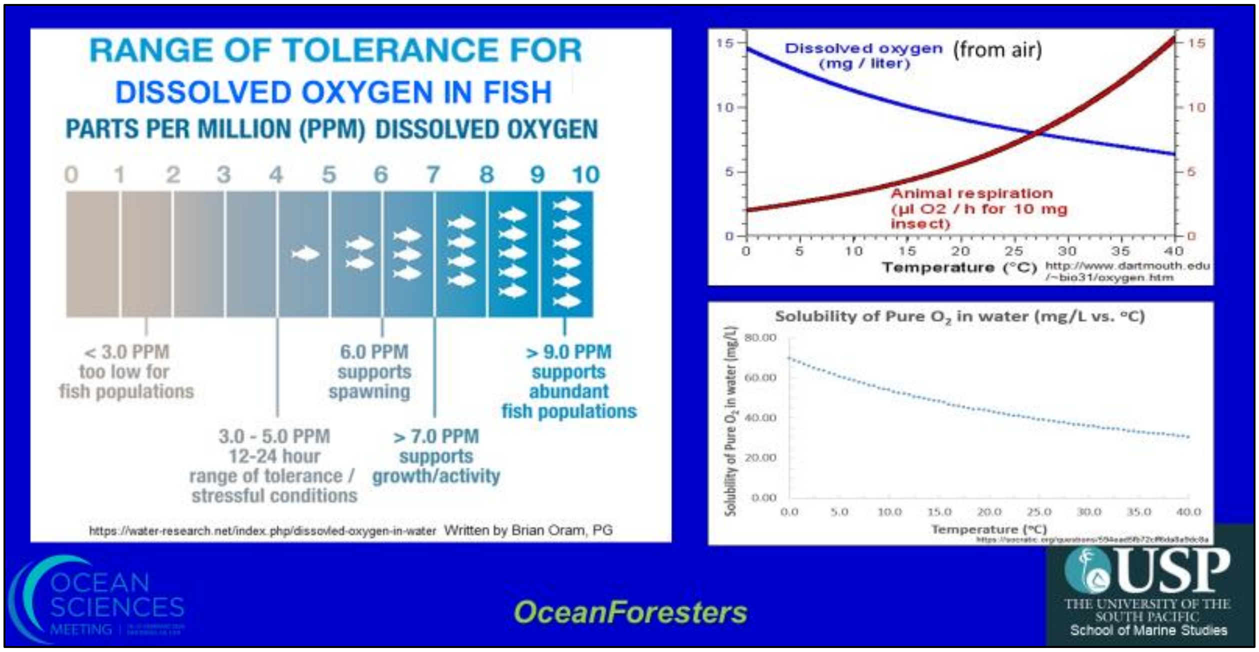

Fig. 4 – Shows the double whammy of equilibrium dissolved oxygen concentrations dropping while animals need for oxygen increases as water temperature increases

The simplified diagram in Figure 5 hints at the complexity of total ecosystem aquaculture. Each coastal community will need a computer model with information output like shown in the picture at the right to manage their ecosystem. The model should include at least the product species plus dozens of the other species important to ecosystem health, even including bacteria.

Fear of ecosystem crashes will motivate a global organization of Ecosystem Operating Communities to fund better and better computer models. The computer models would allow "what if" for actions when anticipating events. For example: 90% of Northern California's kelp forests disappeared when sea stars died-off and sea urchin populations exploded. Kelp and abalone populations both crashed. The computer helps predict the possible situation and allows trying many options, on the computer, months in advance. Do you harvest the sea urchins for sale to Japan or throw them into mangrove forests to feed mud crabs? Or do you find another community with an abundance of lobsters that you buy and stock to eat the sea urchins?

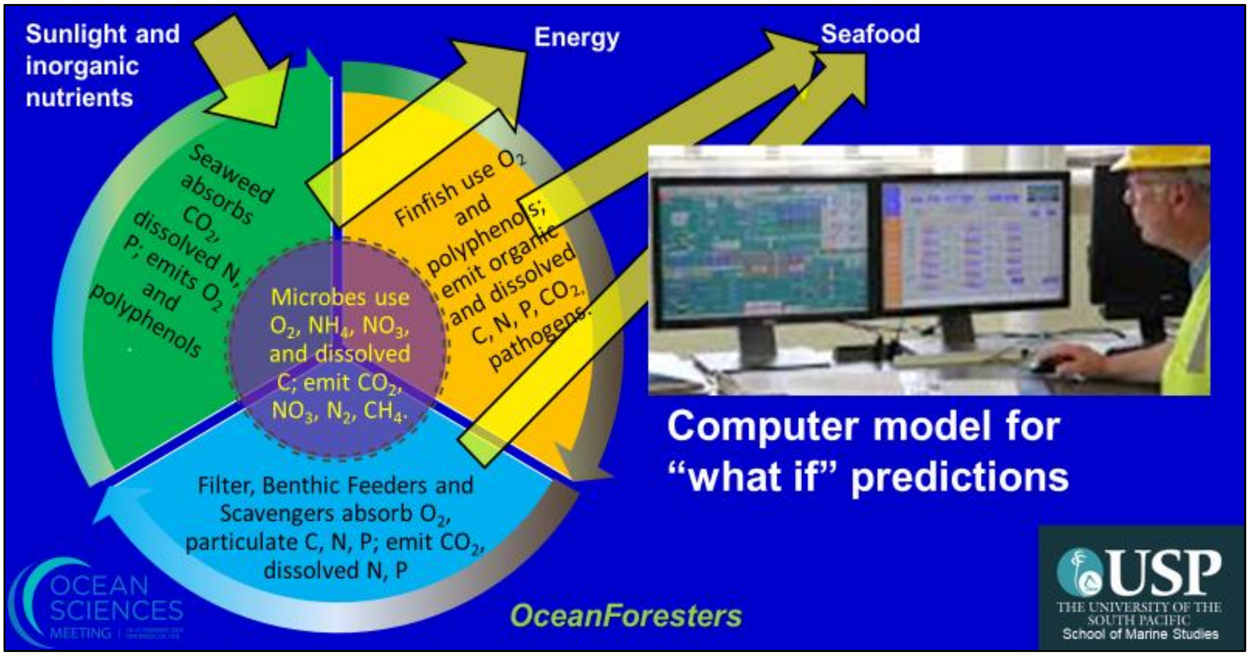

Fig. 5 – A schematic of nutrient, energy, and biomass flows into, within, and out of the built reef to the left of a representation for how a model of those flows might be displayed

Table 1 – Sketch of database with a few of the seafood species and a few of the parameters that would go into a computer model.

Species harvested for people food	Giant Clam	Rock oysters	Rabbitfish	Giant Trevally	Mahi Mahi	Red Snapper	other finfish	Crab	sea urchin	sea cucumber	gastropod	shrimp	lobster
Optimum standing biomass (tonne/ha)													
Typical yield (t/ha/yr)													
Typical dock value ($/kg)													
Time, larvae to harvest (days)													
Maximum temperature for successful completion of each life stage (ºC). Or perhaps this is some combination of temperature and dissolved oxygen concentration.													
Spawners													
Embryos													
Larva													
Adult													
Describe spawning timing (text)													
Describe embryo behavior (text)													
What it eats or limiting nutrients (text)													
How much it eats (kg food/kg body mass/day)													
How it eats, daily and seasonal variation (kg vs. time)													

Dissolved oxygen consumption or production (g O_2/kg body mass/hr)													
Variations in O_2 consumption or production with sunlight and temperature (g O_2 vs. light and temperature)													

Table 2 – Sketch of database with a few of the ecosystem maintenance species (not important for seafood) species and a few of the parameters that would go into a computer model.

Other important ecosystem species	Macroalgae	Macroalgae	Macroalgae	Seagrass	Seagrass	Parrot fish	barnacles	starfish	starfish	Anemone	Anemone	gastropods
Optimum standing biomass (tonne/ha)												
Maximum temperature for successful completion of each life stage (ºC). Or perhaps this is some combination of temperature and dissolved oxygen concentration.												
Spawners												
Embryos												
Larva												
Adult												
Describe spawning timing (text)												
Describe embryo behavior (text)												
What it eats or limiting nutrients (text)												
How much it eats (kg food/kg body mass/day)												
How it eats, daily and seasonal variation (kg vs. time)												
Dissolved oxygen consumption or production (g O_2/kg body mass/hr)												
Variations in O_2 consumption or production with sunlight and temperature (g O_2 vs. light and temperature)												

The food and science reefs are best placed where there is the most urgent need for seafood and science, along tropical coastlines where the seafloor depth is between 0 to 200 meters. If the seafloor is less than about 30 meters, the reef is best placed where the water has an excess of nutrients and/or sediment. That is, the natural situation is lacking biodiversity and productivity. Laucala Bay, Fiji would be typical for this situation. Specialists at the University of the South Pacific explain applying total ecosystem aquaculture in Figure 6 and at: https://challenges.openideo.com/challenge/food-system-vision-prize/open-submission/restorative-aquaculture-sustainable-seafood-production-for-the-world.

Fig. 6 – Possible substrate supporting structures, seafood products, and ecosystem support species for the situation of shallow water and excess nutrients

In seafloor depths between about 30 to 200 meters, the purpose-built reef would be flexible, floating, and permanent, as in Figure 2. Generally, the reef's plant-growing substrate would be 3 to 10 meters deep depending on the optimum depth for the local macroalgae or seagrass. The reef might submerge to 50-meter depth, when tropical storms pass nearby. Open ocean reefs are further described in this presentation by Don Piper at the International Symposium on Stock Enhancement & Sea Ranching, November 2019. Some of the research from the AdjustaDepth project for the U.S. Department of Energy, Advanced Research Project Agency-Energy's MARINER program can expand seafood production. AdjustaDepth project deliverables are available at ResearchGate or at: https://drive.google.com/drive/folders/1uIudPOFZi1qZCXSbQq_vSZuDFmkSqio_.

Each region of the world needs a research and training center (**Decade Collaborative Centre**) near a host university with access to seafloor, oceanographic, and nutrient conditions typical of a larger area. This because the nature of the structures, the storms, and the animals interacting with the structures vary greatly between regions. Example locations for the first food and science open-ocean reefs include: The Bay of Thailand; the Bay of Bengal; near Tanzania and/or Madagascar; near Ghana; Costa Rica (both Caribbean and Pacific); the Eastern Mediterranean Sea; and more. Each of these locations could showcase typical species and tropical marine ecosystems for many countries near them.

There are some non-tropical countries where food and science reefs are needed for general ocean health, adaptations for climate impacts, and/or peace. For example, nutrient recycling built reef ecosystems in the Eastern Mediterranean Sea (which is oligotrophic, Massa et al. 2017) could create jobs for migrants and Palestinians. Built reef ecosystems would not need recycled nutrients in the dead zones, such as the Danish Baltic Sea and the outlet of the

Mississippi River in the U.S. Gulf of Mexico. The area of Danish seas affected by low oxygen levels is double what it was in 2020 at about 3,300 km^2.

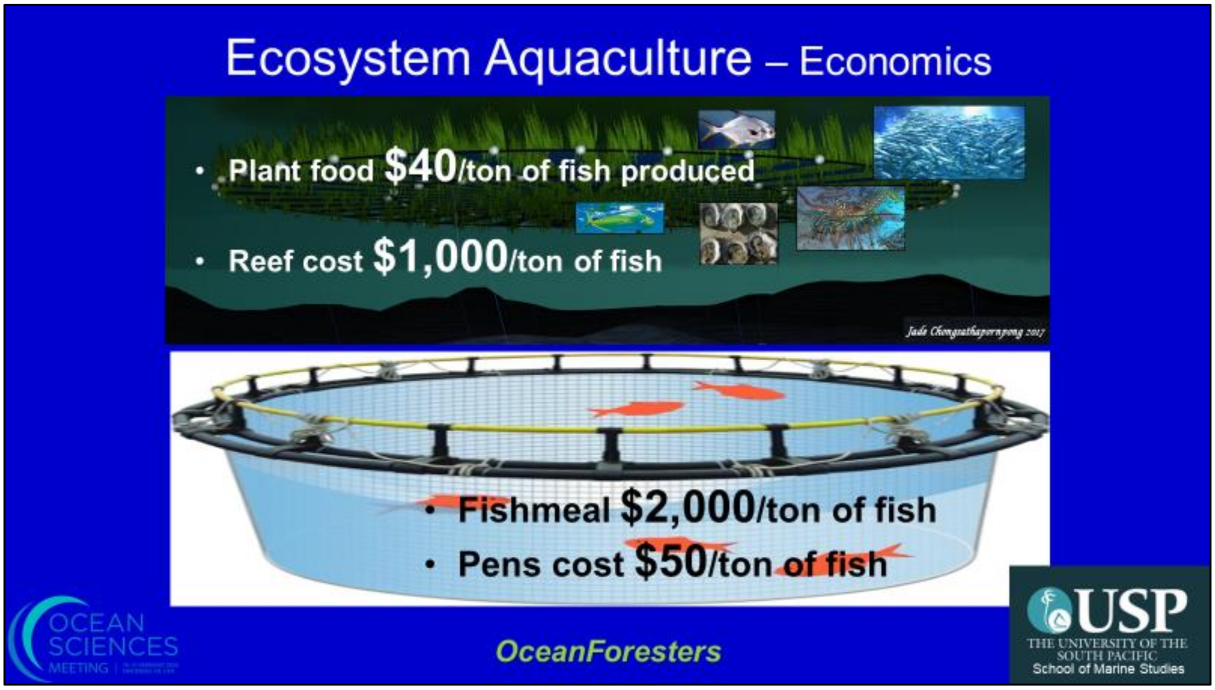

Fig. 7 – Comparing the economics of seafood from built reef ecosystems with seafood from penned finfish aquaculture

The OceanForesters were part of a team funded by the US Department of Energy to find inexpensive ways to grow and harvest macroalgae-for-energy. The team, led by aquaculture experts at the University of Southern Mississippi, University of New Hampshire, University of the South Pacific and others estimated the comparative economics of built reef ecosystems with free-range finfish relative to penned finfish aquaculture. Figure 7's graphic shows that built reef ecosystems are more like renewable electricity with a small operating cost and a larger infrastructure cost. The high cost of fishmeal and the low cost of infrastructure for penned finfish aquaculture is more like fossil fuel electricity.

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' MARINER program. The reef is built for 20-year service life while surviving hurricanes in 50 to 100-meter seafloor depths in the Gulf of Mexico. Sheltered locations like Laucala Bay, Fiji would be much less expensive. Some of the harvest would be exported to developed countries for values ranging from US$2,000 to US$4,000 per wet or shell-on tonne, with resulting large export revenues helping economic self-sufficiency.

Bottom line not including operating labor in either case: Fish products from an open-ocean flexible floating reef will cost about half as much as products from pens. Fish products from sheltered water built reef ecosystems, perhaps a fifth as much as products from pens.

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 $2 per wet kilogram, we'd have $30 million per year at the dock from one open-ocean 20-hectare reef.

5.2 Human resource recovery systems

Initially, human wastes were collected and treated as a public health measure. Diseases and parasites that kill many people are transmitted in feces and water that contacted feces: typhoid, cholera, polio, intestinal worms, etc. Therefore, public health is the top requirement for human waste resource recovery systems, followed closely by sustainability. True sustainability requires recycling the energy, the nutrients, and the water. True sustainability is exemplified by the "wastewater treatment" industry's move to "water resource recovery." Developed countries are burdened with systems that focused on public health and "treatment." The lack of infrastructure in some countries allows quick adoption of many existing and emerging safe and sustainable human waste collection and recycling systems including:

a. The Rich Earth Institute explains the benefits and "how-to" of collecting urine. Note that a developed country (Vermont, USA) utility found that collecting, pasteurizing, and selling urine as fertilizer was less expensive and uses less energy than removing the ammonia nitrogen at its wastewater treatment plant.

b. Feces can also be collected safely and effectively, if careful. Feces contain substantial carbon, which supports processes like anaerobic digestion or hydrothermal liquefaction (HTL) to produce biogas or biocrude oil separated from the recycle-ready nutrients. Because the HTL process can convert many plastics to biocrude and pasteurizes at 350°C, it may be particularly safe and effective for feces, medical wastes, and preventing epidemics.

c. Locations with existing collection systems and energy-intense treatment systems should consider pasteurizing the wastewater immediately downstream of screens and grinders. By using heat exchangers, pasteurizing can be accomplished with low grade (70 to 90ºC) "waste" heat from electricity production. HRS offers a heat exchanger system. PTG Water & Energy offers an integrated system of gas turbine and heat exchangers. After the waste is pasteurized, the existing treatment facilities could be converted to grow food (for animals, if not people). Options include: (1) growing filter feeders (shellfish) in the pasteurized water; (2) settling and/or filtering out the solids for consumption by black soldier fly larvae; and (3) distributing the pasteurized water on agriculture and/or built reef ecosystems.

d. ECOLOO is a Swedish odorless water-free toilet with special bacteria that digest both urine and feces producing a pathogen-free liquid fertilizer (plus some mineral-rich solid fertilizer).

e. Calysta makes high protein fishmeal pellets from methane. A similar process could be used to make high protein fishmeal pellets from pasteurized sewage. Either fishmeal pellets would be a good way to distribute nutrients into an otherwise oligotrophic (starved for nutrients) total ecosystem aquaculture system.

Ocean Science is essential for optimizing the distribution of nutrients on total ecosystem aquaculture systems to enhance yield, bio-diversity and sustainability. The rate of nutrient dose needs to be less than the capacity of the plants to supply dissolved oxygen to bacteria consuming the dissolved organic carbon. The plants' oxygen production will vary with sunlight. The nutrient dose rate needs to be adjusted each hour of the day and each season of the year depending on the amount of organic carbon and hour-to-hour variations in sunlight. At the same time, the rate of nutrient dose needs to support the biomass of the standing stock of plants to maintain ecosystem biodiversity. It may be important to stock (from hatchery) filter feeding shellfish and/or finfish to maintain water clarity as the bacteria consuming the organic carbon move up the food chain.

6. Supporting Stakeholders

Drs. Rajesh Prasad, Antoine de Ramon N'Yeurt, and Chinthaka Hewavitharane are professors at the University of the South Pacific (USP), Suva, Fiji. They are scientists with the mission of helping South Pacific people address food security and climate issues. Their Research and Training Project in Laucala Bay, Fiji would involve students, early career ocean professionals, local and indigenous knowledge holders, and local coastal communities from the twelve USP member countries and other island nations.

Luke Dallafior and Tricia Grant of Garrison Force are:

a. Supporting funding Blue Economy projects throughout Southeast Asia. Projects with the benefits of a Nutrient Recycling Seafood-Science Programme are particularly desirable. Technologies of interest, in addition to seafood: marine plant and algae extracts; ocean based alternative energy; blue carbon initiatives and ocean environmental analysis; and monitoring and data systems. Abundant Ocean Ventures will provide seed and growth capital for companies and technologies important to a sustainable blue economy.

b. Arranging projects in Bali, Indonesia that fit within a Nutrient Recycling Seafood-Science Programme. The projects will support mindful and synergistic ocean-based business ecosystems for coastal people throughout Indonesia. The projects can be scaled on a regional or global basis.

Mark E. Capron, Professional Engineer (P.E)., Jim R. Stewart PhD, Mohammed Hasan P.E., Don Piper, Graham Harris, Martin Sherman, and Jill Santos are core OceanForesters. OceanForesters is a private sector stakeholder with the mission of coaching, mentoring, consulting, and supporting local coastal communities to design, build, and operate the permanent built-reef ecosystems they desire.

7. **Possible Related Programmes and Projects**

Local coastal communities considering a project within the Nutrient Recycling Seafood-Science Programme may want to consider other options related to seafood, perhaps including:

Professor Ricardo Radulovich's Sea Farms

Professor Thierry Chopin's Integrated Multi-Trophic Aquaculture, explained in Ecosystem-based aquaculture: We need to stop thinking about aquaculture farm as something within the limits of a few buoys or GPS coordinates on a map

Sustained fishing of natural ecosystems to restore oceans to the way they were as suggested by the Oceans 2050, Rebuilding marine life, Seaweed Manifesto, and others. This can be accomplished with more marine protected areas, better fishing management, better policing of fishing, and reduced anthropomorphic impacts. These actions will make the oceans abundant, that is, full of life. But people cannot be extracting much of that life without recycling nutrients. Options include some nutrient extraction systems, such as farming seaweed and/or shellfish in areas of excess nutrients and some nutrient adding systems, such as penned finfish.

Dr. Flower Msuya, Zanzibar Seaweed Cluster Initiative

Professor Tian Tao, Dalian Ocean University, Marine Ranching in China and Podcast: Marine ranching off China's coast

Steve Willis' Herculean Climate Solutions and Ocean Orchards

Dr. Brian von Herzen's Enhancing Coastal Community Value Chains with Marine Permaculture (CVC-MPs) which made the top 100 solutions for the crowdsourcing contest MacArthur 100&Change:2020

Kelp farming, described in An ecosystem approach to kelp aquaculture in the Americas and Europe

The local communities might first check with the Decade Coordination Unit and the Decade Advisory Board to discover if there are Calls for Action and/or already endorsed programmes or projects similar to the project they envision. If similar projects are endorsed, they might coordinate with the Ocean Decade Alliance to find resource agencies for their project.

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