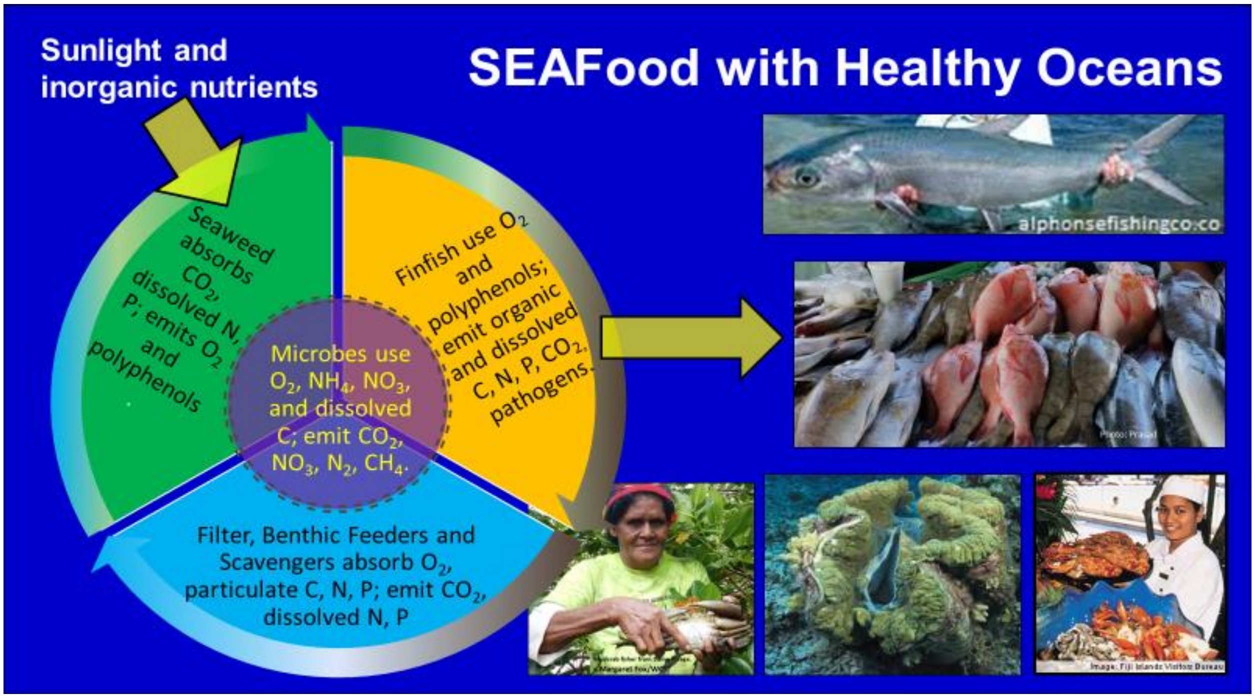
Science Enables Abundant Food (SEAFood) with Healthy Oceans
Tropical Pacific Region, University of the South Pacific
A Proposed Programme Description for the
UN Decade of Ocean Science for Sustainable Development (2021-2030)



January 2021

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1. Executive Summary

The University of the South Pacific's (USP) SEAFood (short title for this Decade Programme) goals include: (1) improved quality of life in participating communities and (2) improved ocean productivity, health, and biodiversity. The goals are accomplished using science to increase sustainable seafood production and networking between communities. Each member community selects fisheries management techniques networked with each other and USP's Research and Training Center. Networking and benchmarking ensure best practices are identified, shared, and adopted. The Center will restore Laucala Bay, Fiji while demonstrating best fisheries management techniques. By 2030 USP member countries could produce an additional US$100 million/yr of seafood with some of that income maintaining digital connectivity and science. The initial estimated total budget for Tropical Pacific SEAFood is US$100 million. 2% funding secured.

The USP mission includes:

- Achieving excellence in research by addressing consequential and multidisciplinary scientific questions which appreciate the distinctiveness and richness of Pacific Island Communities (PICs), culture, environment and biodiversity.
- Contributing effectively to the sustainable use and governance of the PICs' natural resources for the advancement, prosperity and development of the people and for the conservation of its rich biodiversity and environment.
- Preparing human resources capable of generating excellent scientific data and use such information for making informed and rational decisions based on factual evidence for the welfare of people and nature of PICs.
- Increasing the visibility of university research and to inform the public about its importance for the management and conservation of the PICs' natural resources.
- Attracting more international students as a result of the growing reputation of USP as a centre of excellence for research and knowledge creation in Oceania.
- Conducting theoretical, applied and comparative research to assist Pacific Island peoples meet their needs and aspirations and, at the same time, achieve international recognition in those areas that reflect the University's unique geographical location and multicultural contexts.

As Lead Institution for the Tropical Pacific SEAFood with Healthy Oceans Programme, USP strives to individualize the science and development each coastal community needs for the oceans each coastal community wants. USP will support tasks common to every community such as networking, training, research, ecosystem model development, data visualization, data standardization and data management. Accomplishments will depend on initial funding. USP has a financial accounting system and people management systems to support projects throughout its local coastal communities. By the end of Ocean Decade, USP would like to have established such robust biodiversity and seafood production that the income from seafood production can fund USP's globally accessible research and training indefinitely.

USP has 14 campuses in its 12 member countries spread across 33 million square kilometers of ocean. There are also 4 affiliate countries. All are within the Tropical Pacific Region. Other countries/communities may join the Tropical Pacific Region as USP and the other country agree.

USP and its member communities are most interested in truly sustainable aquaculture integrated with living reefs and adaptations. Adaptations are essential for continued biodiversity and seafood production over future centuries of anthropomorphic impacts: warming oceans; changing climate; ocean acidification; pollution; sediment loading; etc. USP plans a research and training centre to model sustainable aquaculture systems for the tropical Pacific and distribute "how to" knowledge to interested communities. Techniques may include: establishing marine protected areas and policing fisheries rules; farming macroalgae; farming shellfish; integrated multitrophic aquaculture with penned finfish; and SEAFood built-reef ecosystems, both sheltered and open ocean.

The terms "Science Enables Abundant Food (SEAFood) ecosystem", "SEAFood ecosystem lifeboats", "lifeboat ecosystems", and "built-reef ecosystems" all refer to truly sustainable aquaculture that operates like a natural reef. On a natural reef, life creates the conditions for more life. The wastes of animals become nutrients for plants and other animals so multiple species thrive. Plants use sunlight (photosynthesis) to turn a small amount of nutrients into a substantial amount of food, as shown in the inner circle in Figure 1.

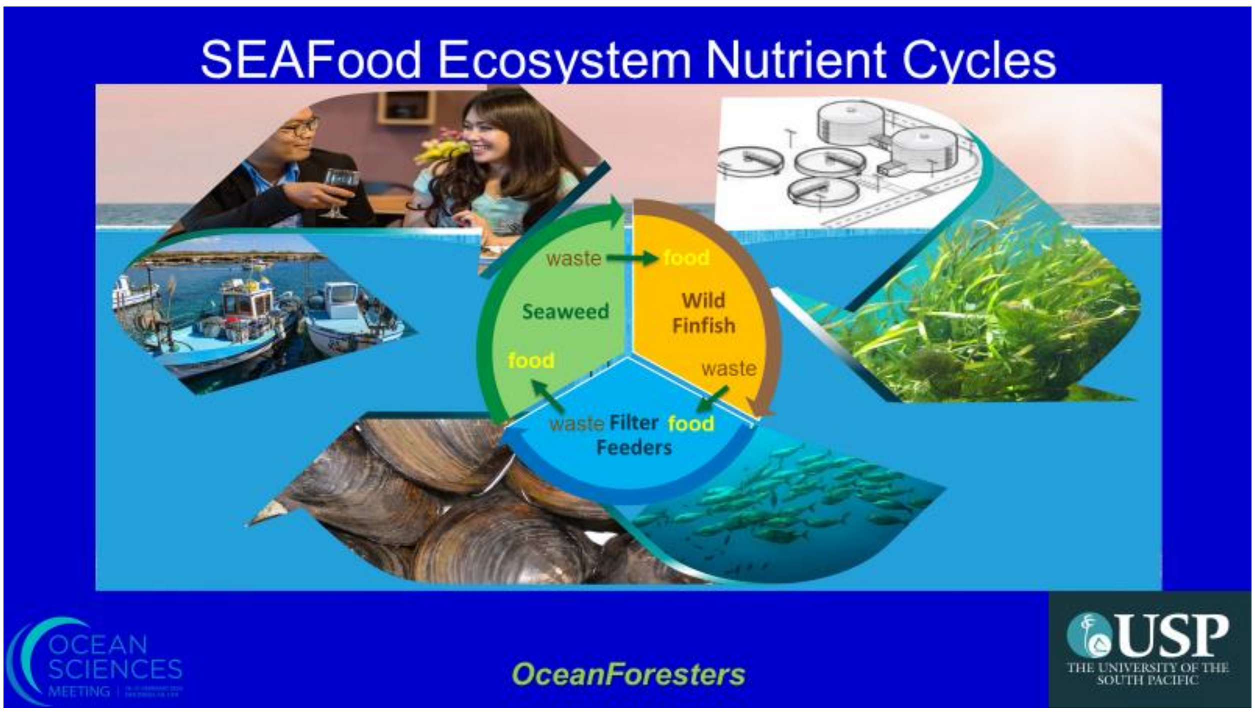

Fig. 1 – The large outer nutrient cycle shows how nutrients removed from the reef for food can be returned to the reef. The small inner circle represents nutrients' cycles within the reef.

SEAFood built-reef ecosystems would be built outside of existing and future marine protected areas (MPAs), in areas where there is currently low biodiversity and low productivity, and even inside a dead zone or other polluted area. The new reef ecosystems include science-based adaptations to support continued biodiversity and productivity for centuries. With vastly increased seafood production on their own new reef ecosystems, built and managed to their specifications, coastal communities can more readily accept vastly increased MPAs. SEAFood reefs can also clean up dead zones and other areas with excess nutrients.

Seafood income means that coastal communities, investors, and MPAs would not rely solely on tourist income. The income from seafood produced on the built reef would pay for science and poaching prevention sensors. The sensors will be on the built reef, managed by citizen-scientist-fishing-people, and also in the MPA. Nearby MPAs would be managed for tourist income while also providing sea creature services that might not be available on the initial built reefs, such as spawning habitat, turtle shell cleaning stations, etc.

Conditions for SEAFood built-reef ecosystems generally span between two extremes:

a. In sheltered shallow water with excess nutrients and sediment (Fig. 2) – Clarify the water with farmed filter feeders (shellfish, some finfish) and sediment capture (mangroves, seagrass). Increase macroalgae substrate in the photic zone. The substrate may be a mix of bamboo, rope, and nets. Where native, giant clams are both filter feeders and primary productivity.

Fig. 2 – Possible substrate supporting structures (upper left), seafood products, and ecosystem support species for the situation of shallow water and excess nutrients

b. In the open ocean, as much as 200-m seafloor depth (Fig. 3) – Install permanent flexible floating fishing reefs at the optimum depth for the desired native macroalgae, filter feeders, shellfish, and crawling sea creatures. Recycle nutrients from land (people and livestock) matching the amount on nutrients extracted from the fishing reef.

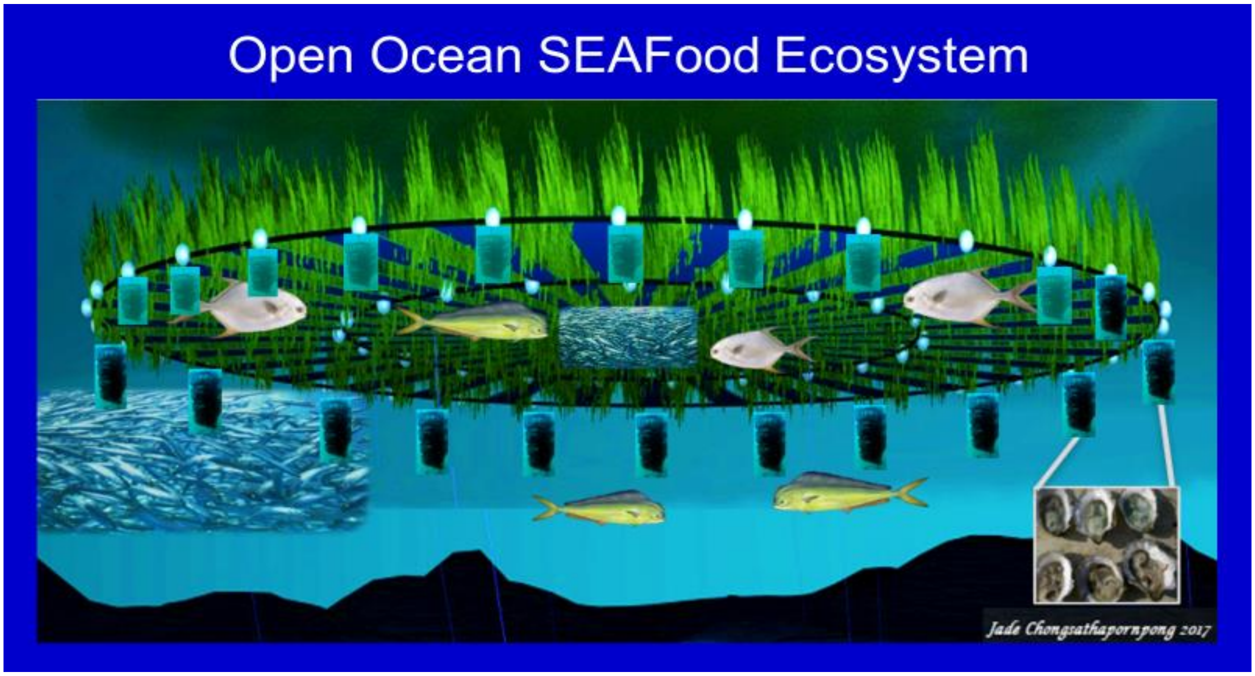

Fig. 3 – Artists' concept of a SEAFood floating flexible fishing reef ecosystem

Projecting a 2050 demand of 500 million tonnes of seafood per year suggests the 2030 goals for both Sustainable Development and the UN Decade of Ocean Sciences for Sustainable Development should be 100 million tonnes/yr of seafood from built reefs by 2030. This amount of seafood replacing meat would save 1.5 billion tonnes/yr of CO_{2eq} plus conserve more freshwater than the flow of the Mississippi River. The seafood would be worth about $200 billion/yr at the dock. Ten percent of ten years of income implies $200 billion may be available for ocean conservation and research to sustain ocean ecosystems through a century of climate change.

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 that are commonly used in developed country wastewater treatment.

2. Lifeboats – Recent research supporting urgency for SEAFood programme

September 2020 – "Half of resources in threatened species conservation plans are allocated to research and monitoring" Lead author Rachel Buxton: "In some ways, it's like we're counting the deck chairs on the Titanic," [rather than actually saving species]. More nuanced analogy from a discussion with Dr. Phillip Williamson – The monitoring and predictive modeling of environmental science updates our ability to avoid hazards, like providing radar to the lookouts on the Titanic and ensuring the radioed "ice ahead" warnings from other ships reach the ship's captain. The Titanic's lifeboat capacity could have saved only a third of the people aboard, if loaded efficiently. Like the Titanic, Earth lacks adequate and sufficient lifeboat (ecosystems). See Figure 4.

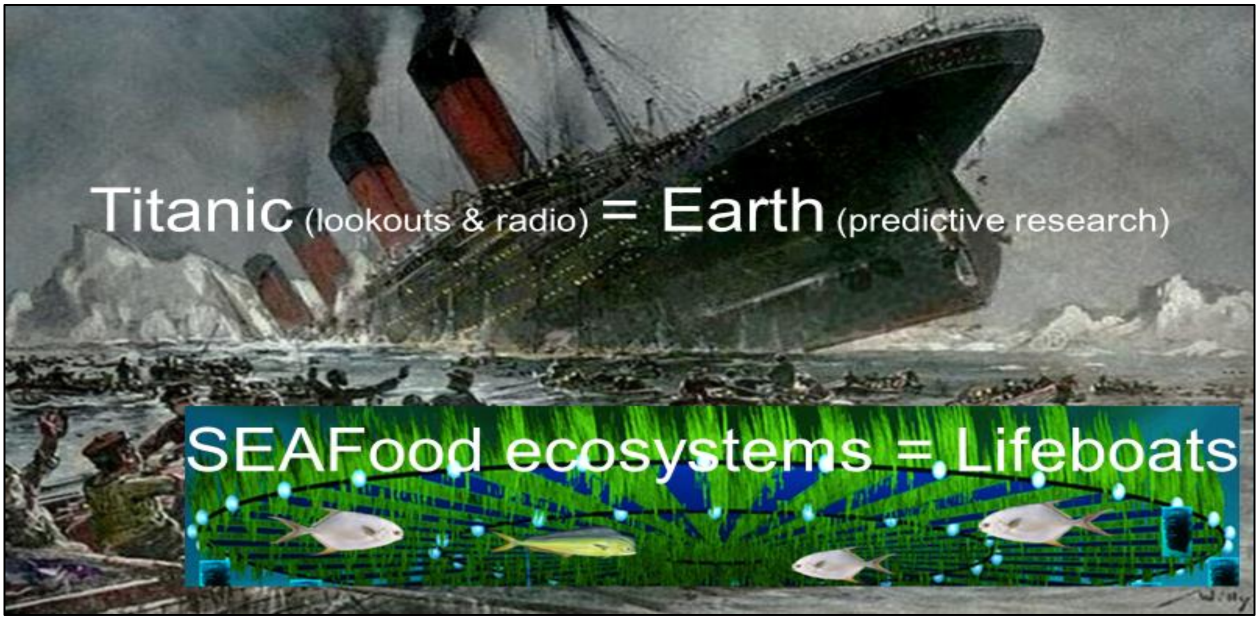

Fig. 4 – Great loss of life could have been avoided, if the Titanic had carried sufficient lifeboats.

Lifeboats are needed to support ecosystems and feed/shelter people in place. Ocean SEAFood lifeboat ecosystems are self-rescuing in that seafood production can pay for monitoring, modeling, adaptation (cooling the ecosystem, increasing dissolved oxygen during heat waves, and reducing ocean acidification), and mitigation.

September 2019 – SEAFood ecosystems can employ concepts in "Harnessing global fisheries to tackle micronutrient deficiencies" to provide the most needed micronutrients locally and in an alliance of globally dispersed local coastal communities.

April 2020 – A quote from "Rebuilding marine life" "Rebuilding fish stocks can be supported by market-based instruments, such as …the growth of truly sustainable aquaculture to reduce pressure on wild stocks." SEAFood builds truly sustainable aquaculture while building the science to ensure true sustainability with robust biodiversity and species survival.

July 2020 – Oceans become more acidic (lower pH, ocean acidification) as more CO_2 is dissolved in water. Sea plants raise pH by removing CO_2 during photosynthesis. Plants can raise pH so much that nano particles of calcium carbonate form and drift down current. See "Chesapeake Bay acidification buffered by spatially decoupled carbonate mineral cycling." Sea creatures can more easily form and maintain their shells in the higher pH near sea plants and where particles of calcium carbonate buffer the pH. Growing sea plants counters ocean acidification locally, as in the water in and down current of a kelp forest. Decomposing plant material and animal respiration could put CO_2 back in the water (lowering pH). However, removing carbon from the water (in the form of either sea plants or sea creatures) provides a long-term, if local, antidote to ocean acidification. Also, because seafood has much lower carbon footprint than does meat, producing and consuming more seafood instead of meat means less ocean acidification globally.

September 2020 – 110 aquatic scientific societies, representing over 80,000 scientists, suggest the urgent need for SEAFood in the American Fisheries Society's "Statement of World Aquatic Scientific Societies on the Need to Take Urgent Action Against Human-Caused Climate Change, Based on Scientific Evidence."

3. Details of Ocean Science and Sustainable Development

3.1 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 3. 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.

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.

In the tropics, throughout their pre-historic range, giant clams may be the keystone species of built-reef ecosystems and nearby natural coral reef ecosystems. Per Noe (2015), giant clams' internal algae can provide more net primary productivity than coral or most macroalgae. Giant clams provide food for local organisms directly through their tissue and indirectly through the discharge of feces, gametes (reproductive cells), and zooxanthellae (photosynthetic algae). Noe et al. 2015 and references therein goes on to explain that giant clams control eutrophication (in areas of excess nutrients) two ways: (1) filtering large quantities of seawater, clearing the water of microalgae; and (2) assimilating inorganic nutrients. All this means tropical built-reef ecosystems could employ nutrient recycling to increase fish harvest productivity while improving the health of nearby natural coral reefs. The typical tropical built-reef might have a few hundred mature (+20 years old) giant clams and a few hundred thousand juvenile (less than 10 year old) giant clams.

Ocean science is essential to find ways to maintain tropical fisheries despite more and more urgent issues than are shown in Figure 5: (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.

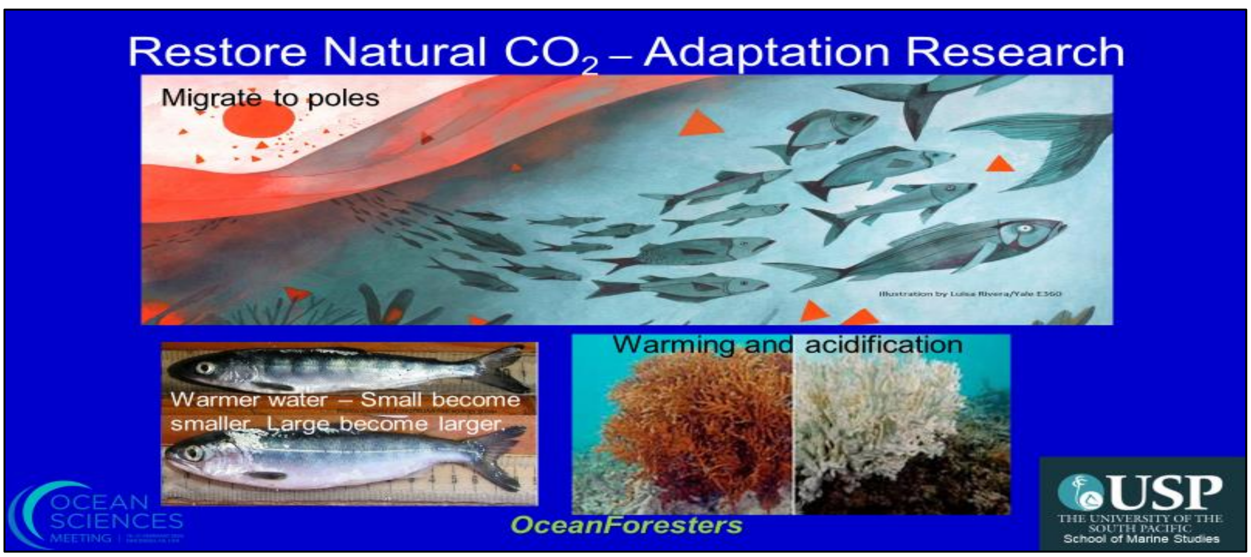

Fig. 5 – Changes in local ecosystems due to increased greenhouse gas concentrations (The debate on how and why fish size changes with warmer water is ongoing.)

Much of this science data pays for itself through increased seafood production. For example, the graph at upper right of Figure 6 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.

The simplified diagram in Figure 7 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.

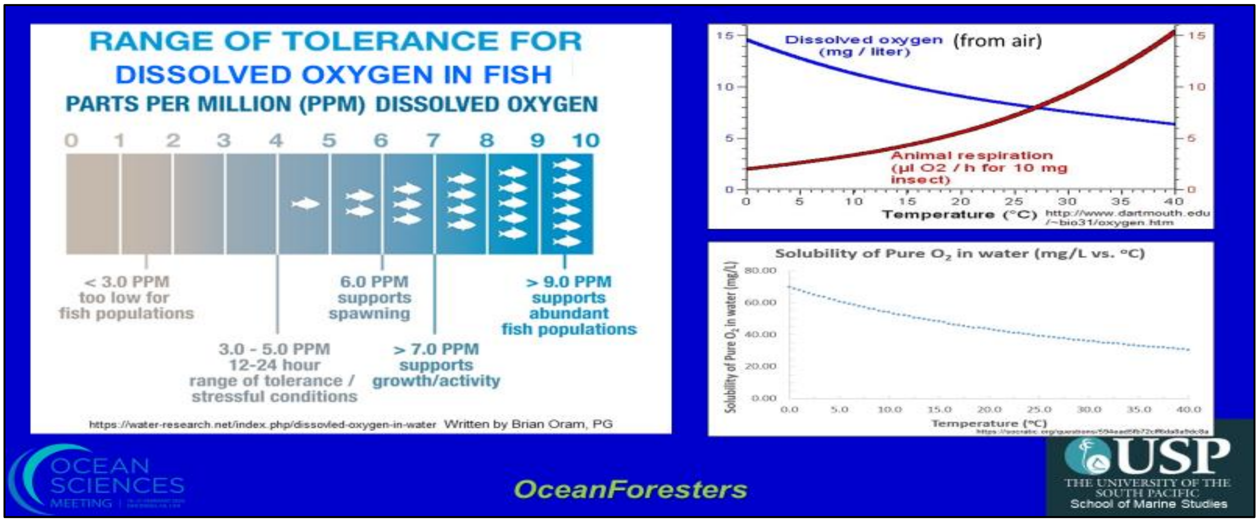

Fig. 6 – Shows the double whammy of equilibrium dissolved oxygen concentrations dropping while animals need for oxygen increases as water temperature increases

USP will reduce the risk of ecosystem crashes by developing computer models for tropical Pacific built-reef ecosystems. 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. You give them urchins to feed their lobsters. They give you lobsters to eat your urchins.

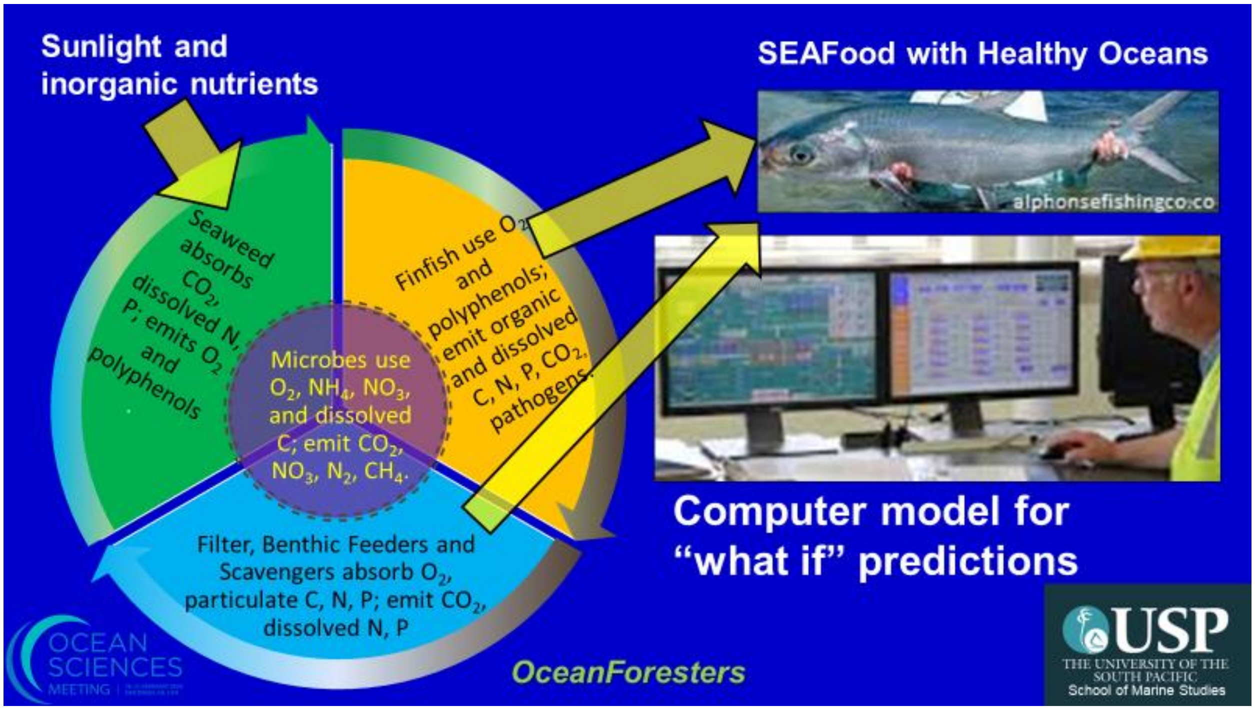

Fig. 7 – A schematic of nutrient, energy, and biomass flows into, within, and out of the built reef to the left of a representation for how a model of those flows might be displayed

Table 1 – Sketch of database matrix with examples of 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 (rarely harvested 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)												

Ideally, the model of nutrient flow, species populations, and harvests can be extended to include the interrelationships amongst food systems (e.g., production, processing, distribution, waste), health (consumption), the environment (sustainability), and public policy. Every built-reef ecosystem could benchmark its environmental benefits and impacts with to-be-developed methodologies and techniques to calculate, model, and simulate these benefits and impacts. Operators of SEAFood may raise the bar for healthy food and ecosystem services. They may need new metrics so that food consumers and governments can distinguish the merits of eating wild-caught, free-range SEAFood seafood from penned aquaculture with IMTA, penned aquaculture without IMTA, etc.

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. Professors at USP explain applying shallow water built-reef ecosystems in Figure 2 and at: https://challenges.openideo.com/challenge/food-system-vision-prize/open-submission/restorative-aquaculture-sustainable-seafood-production-for-the-world.

In seafloor depths between about 30 to 200 meters, the purpose-built reef would be flexible, floating, and permanent, as in Figure 3. 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 (perhaps a **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: Fiji, 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, per 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 2000, now at about 3,300 km^2.

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 8'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.

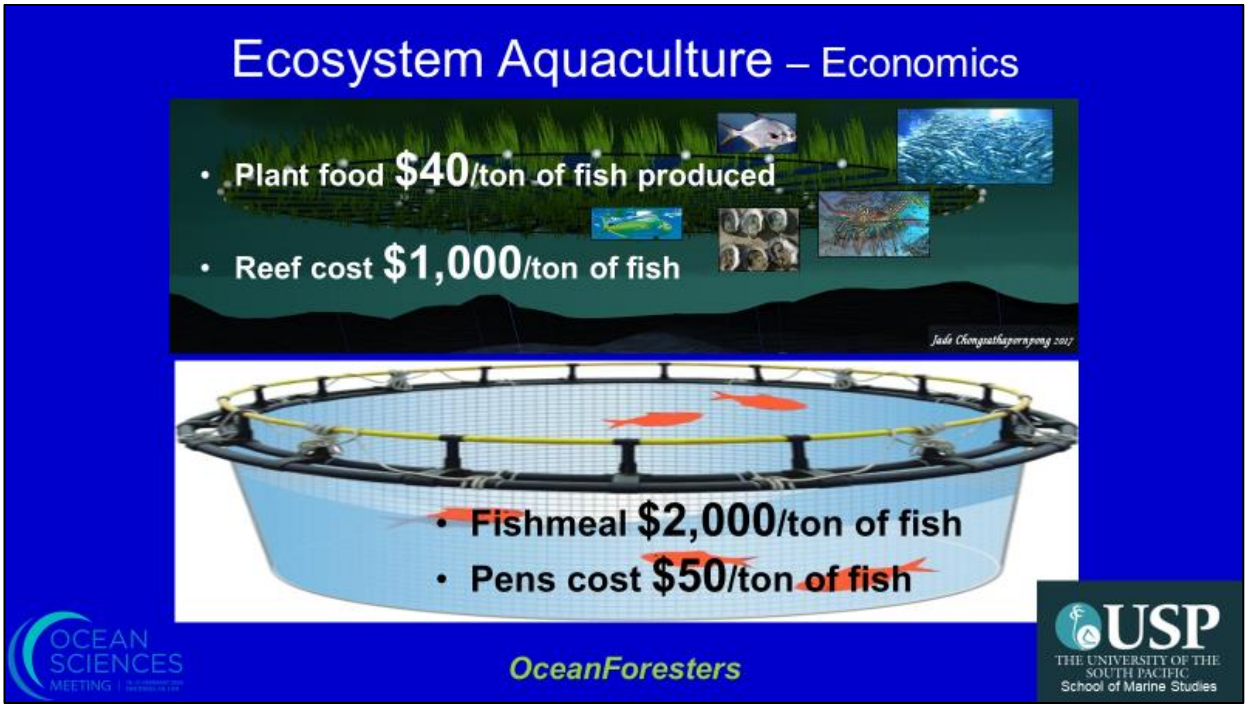

Fig. 8 – SEAFood – Economics Comparing the economics of seafood from built reef ecosystems with seafood from penned finfish aquaculture

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 OceanForesters' techno-economic analysis prepared for the U.S. Department of Energy Advanced Research Projects Agency-Energy MARINER program. The reef designed for a 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, the projection is $30 million per year at the dock from one open-ocean 20-hectare reef.

3.2 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 otherwise oligotrophic (starved for nutrients) total ecosystem aquaculture.

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.

4. Ocean Decade Vision and Mission

In the name "UN Decade of Ocean Science for Sustainable Development," every word matters. USP's Programme is Sustainable Development (increased sustainable seafood production infrastructure). Ocean science and indigenous knowledge combining to produce a computer model of the ecosystem is essential for the sustainable development.

The Decade Vision is: The science we need for the ocean we want," and the Mission: "Transformative ocean science solutions for sustainable development, connecting people and our ocean." USP's Programme provides the "Science USP member communities need for the ocean USP member communities want." The combination of no-take reservoirs with built reefs will be truly transformative ocean science solutions for sustainable development.

The approach is also consistent with the Decade context to "harness, stimulate and coordinate interdisciplinary research efforts at all levels, in order to support delivery of the information, action and solutions needed to achieve the 2030 Agenda for Sustainable Development.

The USP Programme emphasizes delivery of the information, action and solutions needed to achieve the 2030 Agenda for Sustainable Development to the communities in need all across the Tropical Pacific. This effort is supported by utilizing all seven science components.

1. It will develop scientific knowledge, build infrastructure and foster relationships for a sustainable and healthy ocean. The two initial regional Programmes: the University of the South Pacific's Tropical Pacific SEAFood and Western Indian Ocean SEAFood are models for the world.
2. USP scientists are already focused on critical ocean priorities for Agenda 2030, but this program can inspire other scientists across the world.
3. Both Programmes will synthesize existing research and identify knowledge gaps and priorities for future research.
4. Both Programmes will synthesize results and support development of user driven solutions.
5. Both Programmes could inspire new joint research and cooperation within and across ocean basins.
6. By making data broadly available, both Programmes will support science, policy and societal dialogues.
7. Close interaction with fishing communities will result in new co-designed research strategies.

5. Ocean Decade Outcomes

Outcome 1: A clean ocean where sources of pollution are identified and reduced or removed. The USP Programme reduces pollution from land by diverting, pasteurizing and recycling human wastes, plus reducing pollution in the ocean with carefully managed ecosystems that absorb many pollutants (such as excess nitrogen) as food (as discussed above in Section 3.1).

Outcome 2: A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed. The managed ecosystem approach is discussed above in

Section 3.1 supports a healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed to optimize both diversity and food production.

Outcome 3: A productive ocean supporting sustainable food supply and a sustainable ocean economy. Artificial reefs have great potential to support a sustainable food supply and a sustainable ocean economy, as discussed above in Section 3.1 and below in Section 10.

Outcome 4: A predicted ocean where society understands and can respond to changing ocean conditions. Constant data fed into a computer model combined with regular communications with other communities supports responding to changing ocean conditions. More in Section 3.1.

Outcome 5: A safe ocean where life and livelihoods are protected from ocean-related hazards. Fishing on built-reefs closer to shore is less expensive and much less dangerous than fishing on the high sea. More in Section 3.1.

Outcome 6: An accessible ocean with open and equitable access to data, information and technology and innovation. Our theory of change and multi-dimensional communications strategy support an accessible ocean with open and equitable access to data, information and technology and innovation. More in Section 3.1 and in Section 10.2.

Outcome 7: An inspiring and engaging ocean where society understands and values the ocean in relation to human wellbeing and sustainable development. Live videos of animals and harvesting operations on the reefs show where food comes from, how reefs support a wealth of biodiversity, with sustainable and robust food yields, etc. More in Section 10.3.

6. 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. Any aquaculture, including purpose-built fishing reefs, is only truly sustainable by returning to the plant the inorganic nutrients that were extracted from the purpose-built reef as protein, and other organic nutrients.

Challenge 2: Develop solutions to monitor, protect, manage and restore ecosystems and their biodiversity under changing environmental, social and climate conditions – Our productivity is based on restored ecosystems; thus seafood production operations pay for sensors, analyses, and actions to maintain biodiversity. 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. (Rewilding is bringing back native species made rare by humans. Perhaps giant clams near Zanzibar.) That is, many cameras coordinated with acoustic sensing and occasionally providing cooler water on hot days. 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, as much as a billion tonnes/yr by 2050, only limited by human demand.

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 currently lacking means to recover their waste resources, can have a purpose-built reef that matches their population under changing environmental, social and climate conditions.

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, giant clams to reinforce coral reefs, or other kind of living reef. In all cases, the sensors (including temperature, nutrients, acidity, etc.,) 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 reefs 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 can 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 will 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.

7. Achieving Decade Objectives

The goal of 100 million tonnes of seafood by 2030 implies newly built seafood reefs involving 10,000 to 100,000 local coastal communities. Built-reef seafood productivity/area depends on the nutrient recycling/area and ecosystem health. Operators (fishing people) need to track many parameters (temperature, pH, nutrient concentrations, disease, species population, individuals' health, etc.). In addition to instruments (maintained by the operators) the fishing people will be citizen scientists with smart phones.

Each built-reef operator will use information to foresee changes in species populations (due to harvesting, heat waves, disease, …). Foreseeing changes means long-term (decades) of seafood production security. All of the thousands of coastal communities (globally) have reason to share information and costs.

Each local community will select a governance arrangement in concert with their funding agency. Individual governance arrangements might be: local government (a community or special district); a fishing cooperative; a private company. The individual communities can collaborate for economy of scale.

1.1 Regularly assess the state of the ocean: An alliance of coastal communities can provide management software to operators that automatically produces a continuous report on the state-of-the-ocean near each built reef. The local information can be rolled up into regional summaries, or provided individually, as desired.

1.2 Promote new technology and access to it: The alliance of coastal communities can set up a program for several communities to provide resources to one community to try new technology and conduct experiments of interest to all.

1.3 Expand ocean observing systems: Each built-reef is an ocean observing platform.

1.4 Support community-led science: Local coastal communities will develop the capabilities to design, build, operate, and maintain their new reef ecosystems. They might retain outside consultants, materials, and construction equipment initially. All the knowledge (local, indigenous, and contemporary) for each built-reef will be compiled and shared. Each built-reef is likely to be unique.

1.5 Overcome barriers to diversity and promote investment: The value of seafood is such that each seafood reef should generate the income needed to pay back construction loans while increasing the quality of life in the community. The funding agencies can incentivize equity.

2.1 Comprehensive understanding of ocean-land-atmosphere-cryosphere-people: During design, construction, operation, and maintenance each built-reef provides big data to understand the ocean and interactions of ocean-land-atmosphere-cryosphere-people.

The global demand for built-reef seafood by 2050 might be near 500 million tonnes/year implying 50,000 to 500,000 built-reefs supplying big data.

2.2 Understanding thresholds and tipping points: Every built-reef is an instrumented experiment requiring operators to detect and communicate thresholds and tipping points. Threshold and tipping point detection is critical to sustaining seafood production and biodiversity on each built-reef.

2.3 Use historical knowledge to support SDGs: Yes! Use indigenous, historical and pre-historic knowledge while restoring the density of species that were over-fished to near-extinction locally: giant clams in the tropical Pacific and Indian Oceans, conch in the Caribbean, etc.

2.4 Improve ocean models: Every built-reef needs a three dimensional model including oceanographic data, nutrient flows, multiple species (from as small as microbes to as large as whales) populations, and human actions.

2.5 Improve predictions: Collecting big data allows artificial intelligence mining the data to find correlations and improve predictions, which will benefit local adaptation, productivity, and economics.

2.6 Expand ocean-related collaboration: Local communities with similar oceanographic conditions and species can improve their productivity by sharing research and training centers. For example, the University of the South Pacific might host a research and training center for tropical Pacific Ocean communities employing giant clams for primary productivity.

3.1 Communicate the role of ocean science for sustainable development: This programme promises to reach local fishing people, particularly those with indigenous knowledge. Built-reefs will be successful when the local fishing people have adjusted the design to conform to their fishing and cultural norms. Without such adjustment, failures (population crashes, reduced biodiversity) become likely.

3.2 Open access connecting knowledge generators and users: The goal is an Alliance of local communities to maintain a wiki that is accessible globally. The wiki would contain and organize all the information and data from every built-reef and the associated nutrient collection and seafood distribution systems.

3.3 Multi-stakeholder co-design and co-delivery: The complexity of built-reef ecosystems requires interdisciplinary multi-stakeholder collaboration.

3.4 Spatial planning for sustainable development across regions: Built-reefs can be positioned with spatial planning across regions and scales. Note that some communities will produce only local seafood (no exporting). Some areas will produce less expensive yet higher quality seafood for local consumption and export. Regional and global spatial planning can help prevent conflicts (trade wars, monopolies) as supply eventually exceeds demand.

3.5 Management to maintain ecosystems and adapt within community values and needs: The built-reef ecosystem includes habitat and substrate such that the vast majority of species volunteer. Relatively few species might be farmed or stocked such as: oysters, giant clams, and conch.

3.6 Prepared for multiple stressors and hazards: Maintaining seafood production requires tools for preparing and adapting to stressors and hazards.

3.7 Expand tools that integrate knowledge of ocean-related capital: Each reef is likely to have passive acoustic sensors. Acoustic data can help track the location and quantity of species, the movements of people and larger animals, and the actions of people and larger animals. These movements and actions can be tracked in nearby boat channels and marine protected areas. The acoustic data might be matched with people's locations and purchases.

8. Achieving Sustainable Development Goals

SDG #1. No Poverty: Ocean farming reefs are truly sustainable environmental community enterprises that create jobs especially for underserved communities. The jobs range from reef construction and maintenance to planting, nutrient collection and distribution, seafood harvesting, and 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. An alliance of reef operators can employ concepts in "Harnessing global fisheries to tackle micronutrient deficiencies" to provide the most needed micronutrients locally and to share micronutrients among globally dispersed communities.

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. Replacing 100 million tonnes/yr of the current about 300 million tonnes/yr of meat production with 100 million tonnes of seafood, saves about 600 million acre-feet/yr of freshwater (800 km^3/yr, 30,000 m^3/sec). For perspective, the average flow of the Mississippi River is about 20,000 m^3/sec.

SDG #8. Decent Work and Economic Growth: A permanent built reef ecosystem provides permanent quality jobs in ocean forestry. "Ocean forestry" is a more accurate term than "farming" 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 that includes flora and 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}. Although the macroalgae could be harvested for energy production, that is not within the SEAFood Programme.

SDG #14. Life Below Water: "Rebuilding marine life" suggests that, "Rebuilding fish stocks can be supported by market-based instruments, such as …the growth of truly sustainable aquaculture to reduce pressure on wild stocks." This program can move beyond truly sustainable aquaculture to 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. restored 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. In fact, submerged plants can facilitate the formation of calcium carbonate minerals, which are transported down current, buffering pH wherever they go (Jianzhong Su et al., 2020). 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. Replacing 100 million tonnes/yr of the current about 300 million tonnes/yr of meat production with 100 million tonnes of seafood, saves about 600 million acre-feet/yr of freshwater (800 km^3/yr, 30,000 m^3/sec). For perspective, the average flow of the Mississippi River is about 20,000 m^3/sec.

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.

9. Decade Criteria

The USP Programme contributes to all Decade criteria as summarized below:

Re: "**Accelerate the generation or use of knowledge and understanding of the ocean, with a specific focus on knowledge that will contribute to the achievement of the SDGs and complementary policy frameworks and initiatives." And "Is co-designed or co-delivered by knowledge generators and users, and does it facilitate the uptake of science and ocean knowledge for policy, decision making, management and/or innovation.**"

The USP Programme will involve local coastal communities and researchers as co-equal designers on three fronts: (1) The local fishing communities are designing systems to sustainably and inexpensively provide their food supply (thereby helping achieve SDGs), in coordination with researchers who assist in the design and installation of structures, sensors, and a computer model of the ecosystem. As operators, the local fishing communities will trial actions that sustain their ecosystem through climate change. (2) The researchers use the data and the computer models to analyze the ecosystems in almost real time and suggest experiments and refinements to the fishers to improve productivity and profitability while restoring ocean ecosystems. (3) The researchers (with the permission of the operators) make data available to the worldwide community to globally improve ocean science for sustainable development.

That is, the local fishing community continually refreshes and improves their understanding of "the ocean they want." The researchers continually improve and make available to the world "the science the fishing community needs for the ocean they want."

Re: "**Will provide all data and resulting knowledge in an open access, shared, discoverable manner and appropriately deposited in recognized data repositories consistent with the IOC Oceanographic Data Exchange Policy or the relevant UN subordinate body data policy**."

USP sees Data Management as part of its Communications Plan and attaches in #40 a Communications and Data Management Plan. Data Management consistent with the IOC Oceanographic Data Exchange Policy is sketched in the Plan. Ideally, a global Lead Institution would provide most of the actions listed in the Communications and Data Management Plan, but if funding is provided, USP can do it.

Re: **Strengthen existing or create new partnerships across nations and/or between diverse ocean actors, including users of ocean science**.

Features in the Communications and Data Management Plan will strengthen existing and create new partnerships as communities imitate each other's successes.

Many coastal communities will have somewhat similar key primary production species in their ecosystems. For example, giant clams are native on the coasts of Madagascar, East Africa, Red Sea, Arabian Sea, Bay of Bengal, Indonesia, Gulf of Thailand, North Australia, Philippines, and the Western Tropical Pacific. Kelp forests are found globally in temperate climates and cool ocean currents off every continent and island except Antarctica and the Arctic Ocean.

But partnerships are not limited to areas of similar ecology. Concepts for research, business, education, marketing, etc. will be shared even into and from terrestrial agriculture.

Re: **Contribute toward capacity development, including, but not limited to, beneficiaries in Small Island Developing States, Least Developed Countries and Land-locked Developing Countries.**

USP's Programme creates permanent jobs for people in the fishing community to maintain sensors and operate their built-reef ecosystem using a computer model. While the computer model is initially developed by others, people from the fishing communities should be making many of the model calibrations and improvements by 2030. All 16 USP members and affiliates are Small Island Developing States and four Least Developed Countries

Re: **Overcome barriers to diversity and equity, including gender, generational, and geographic diversity. Collaborate with and engage local and indigenous knowledge holders.**

The Communications and Data Management Plan has two barrier hurdling concepts, Ombudspersons and Benchmarking, built into the community-to-community networking. Benchmarking allows communities to compare themselves on diversity and equity, including gender, generational, and geographic diversity with others. Funders can compare communities. Ombudspersons ensure the reports are real.

Engaging local and indigenous knowledge holders is key to sustained increased seafood production with healthy happy communities.

10. Knowledge uptake, data sharing, partnerships, capacity development, diversity, local and indigenous knowledge

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.

11. Lead Institution, Tasks, and Partners (as of 4 December 2020)

1. Lead Institution: The University of the South Pacific

2. Type: University
3. Lead Institution physical address: Laucala Campus, Suva, Fiji (for hard-copy mail)
4. Contact person: Dr. Rajesh Prasad
5. Contact details:
   School of Marine Studies, The University of the South Pacific
   Laucala Campus, Suva, Fiji
   Office Phone: 32 32952
   Mobile Phone: 970 7749
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   Email: rajesh.prasad@usp.ac.fj

Tasks are suggested in the Ocean Decade Challenges Addressed, Achieving Decade Objectives, and Achieving Sustainable Development Goals. The scope of this effort is such that several Partners may be needed for each task. Except for data management, different regions and different communities can take different approaches to each task. Only funded tasks will be accomplished. Once through the learning curve, income from seafood production can pay to continue and refine each task. Each task contributes to centuries of robust sustainable equitable seafood production, justifying the coastal communities' continued investment in each task.

10.1 Data management – Physical science, financial/business, social, safety, and other kinds of data will be collected and archived in a way that allows everyone (globally) to access, download, and research the data.

10.2 Program Management with amplified networking – Program management involves organizing the tasks common to most Projects to support the communities and researchers. Supporting Projects via amplified networking can include:

- **Transparent suggestion box** and suggestion evaluation system – Generate and spread innovations by rewarding innovators who share their innovations with other communities and reward communities for adopting innovations. The suggestion box is a continuous crowdsourcing operation. It might include aspects of the Technology Approval Group and the Water Research Foundation-Water Environment Federation's Leaders Innovation Forum for Technology. Both operate in the water resources recovery community and are directly useful for sanitation with resource recovery. Their networking techniques can be applied to the SEAFood lifeboat ecosystems.
- **Ombudspersons** with a physical presence in every coastal community and at least a virtual presence in every research community – Ombudspersons should be convenient for to everyone in the community and research teams for rapidly correcting corruption, abuse of power, unsafe practices, inequalities, etc.
- **Product-market coordination** – Best practice food-safety certification and branding free-range products of SEAFood ecosystems – For example, suppose a dozen coastal communities are occasionally harvesting lobster. The local communities could coordinate to match local weekly supply with global weekly demand and their individual situation.

- **Coordinated tool testing** – Groups of communities or researchers interested in trying a new tool (innovation, fish trap, no-take reservoir, sensor, software, etc.) fund and oversee testing of a new tool by one coastal community and/or researcher.
- **Benchmarking** – Coastal communities and researchers should be able to compare their performance with other communities and researchers. Comparison areas should include occupational safety, product safety, productivity and biodiversity (aka ocean health) per area, change in productivity and biodiversity per area (over a year, year-to-year, decade-to-decade), expense and income per tonne of product, financial transparency, gender/disabled/tribe/income origin equity, sustainability, etc.
- **Connectivity hardware and software** – Many communities need better links to the worldwide web and associated devices (smart phones, tablets, computers). Ideally, every fishing person or boat will have a smart phone to reference for at least weekly updates on timing and positioning nutrient recycling, what fish what size/condition of that fish to harvest (or put back), what sensors need what maintenance, situations to report, etc.
- **Education** – Develop and disseminate digital tools (videos, games, virtual ecosystem scenario viewers, real-time remote viewing and listening) for everyone to see and understand where their seafood is growing. Build an Oceanwiki with all the information and data from every built-reef and the associated nutrient collection and seafood distribution system.

10.3 Process and Technology – These tasks support centuries of robust sustainable equitable seafood production at the community and researcher level:

- Operating fisheries ecosystems with integrated research.
- Conducting research in built-reef ecosystems with more benefit than harm to fishery income and the ecosystem.
- Designing fisheries ecosystems, which include: no-take reserves with managed fishing outside the reserve; seaweed farming; long-line shellfish and seaweed farming; SEAFood built-reef ecosystems; regional and global spatial planning for no-take zones and activities outside the no-take reserves; etc.
- Training and/or behavior modification for operating the fisheries ecosystem.
- Organizing the community and research effort to suit the community's culture. Organizing can be as simple as changing behaviors to respect a no-take reserve. The reef ecosystem operator might be a fishers' cooperative, a local government, a private company with employees, or other.
- Designing and installing safe sanitation which mitigates nutrient pollution with resource recovery.
- Designing and manufacturing equipment hardware and software: sensors, computer model of the ecosystem; substrate supporting structures and materials.
- Installing, using, maintaining, and teaching people how to use the hardware and software.
- Developing and calibrating computer models of each ecosystem with associated multi-hazard early warning (months in advance), ocean observing, and linking to form a comprehensive digital representation of the ocean.

10.4 Marketing Systems – Communities will benchmark for local high-quality safe food to ensure local health and well-being. Product-market coordination will ensure they are eligible for top prices on the international market.

- USP will consider the whole value-chain – Growing, harvesting, moving products to end consumers, government facilitating (public-private arrangements, permits, regulations), etc.
- As lead institution, USP will work with international food-safety certification and marketing agencies and companies to help local communities appropriately brand free-range products of SEAFood ecosystems for maximum long-range profitability.
- USP's networking will facilitate steady availability of products.

10.5 Partners

Lead Institution for the Tropical Pacific Region

The University of the South Pacific's (USP) member countries and communities are Partners for the Tropical Pacific Region

USP: Dr. Rajesh Prasad, School of Marine Studies, The University of the South Pacific

Laucala Campus, Suva, Fiji; Office Phone: 32 32952, Mobile Phone: 970 7749, International Calls: Fiji Country code (+679); Email: rajesh.prasad@usp.ac.fj. Dr. Prasad is coordinator of the Aquaculture Program at USP. He and his colleagues 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.

USP: Dr. Antoine N'Yeurt, Pacific Centre for Environment & Sustainable Development (PaCE-SD), Office of the Vice-Chancellor | The University of the South Pacific, Private Mail Bag | Suva, Fiji, Tel. : (679) 32 32 023 - nyeurt_a@usp.ac.fj; Dr. N'Yeurt is the leading macroalgae expert of the South Pacific, essential to the macroalgal component of the Programme.

USP: Dr Chinthaka Hewavitharane, School of Marine Studies, The University of the South Pacific, Laucala Bay, Suva, Fiji. Tel: (679) 323 2927 Mob: (679) 925 9413 chinthaka.hewavitharane@usp.ac.fj, is an expert on aquaculture. He and his colleagues 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.

USP: Dr. Jack Dyer, jack.dyer@utas.edu.au, (+0027) 076 973 2765, Durban, South Africa is joining USP this year. Dr. Dyer just completed his PhD in Maritime Logistics and Management (Blue Economy and Climate Change) to investigate potential climate change impacts on Pacific marine ecosystem resources, Ports, Shipping and Maritime Supply Chains, which is essential to ensuring successful marketing of the seafood.

USP South Pacific Regional Herbarium: Marika Tuiwawa, Curator, Institute of Applied Science, Faculty of Science and Technology, Private Bag, Laucala Campus, Suva, Fiji. marika.tuiwawa(at)usp.ac.fj, +679 32 32970. Expert on mangrove ecosystems. His team also includes specialists in a wide range of taxa including vascular plants, bryophytes, birds, bats, freshwater fish and invertebrates, insects, reptiles and amphibians, many of which are important to mangrove ecosystems.

USP expects to involve many faculty and staff, certainly those in the:

- Pacific Centre for Environment & Sustainable Development
- School of Marine Studies
- Graduate School of Business
- School of Education
- School of Computing, Information and Mathematical Sciences
- School of Engineering and Physics

Regions, communities, organizations, and researchers that share the same (giant clam) ecology as USP's Tropical Pacific region. Networking for: same-native-species already adapted to higher water temperatures (or needing adapted native species); science and approach innovations; marketing coordination; etc.

Initial Western Indian Ocean Region Partners

Lead Institution: International Ocean Institute – African Region (IOI-SA) represented by Shannon Hampton - the Program Manager (shampton@ioisa.org). The IOI-SA specializes in ocean governance and capacity development. IOI-SA is also the coordinating partner of the WIOGEN (www.wiogen.org) project which aims at developing enhanced networking and knowledge sharing amongst partners in the Western Indian Ocean region, with the goal of achieving improved ocean governance. WIOGEN is a MeerWissen Initiative with ZMT and IOI-SA as implementing partners. Tel: (+27)829289577, (+27)217998830. Postal address: C/O SANBI, Private Bag X7, Claremont, 7735, Physical address: 18 CBC Building, SANBI, Kirstenbosch, Newlands.

Dr. Flower Msuya, fmsuya1@gmail.com, is the founder and leader of the Zanzibar Seaweed Cluster Initiative (ZaSCI), Mizingani Road, P.O. Box 3794 Zanzibar, Tanzania Mob: +255 777 490807. The ZaSCI started with women farming seaweed. Dr. Msuya, with funds from WIOMSA www.wiomsa.org researched on a new way to farm seaweed in deep (cooler) water and then with help from Sea PoWer implemented the new method. She also led ZaSCI into processing seaweed into 50 value-added products and placing fish traps in the seaweed farm.

Love The Oceans, represented by Francesca Trotman francesca@lovetheoceans.org, Founder and Managing Director, Guinjata Bay, Jangamo District, Inhambane Province, Mozambique. Love The Oceans is working to protect and study the diverse marine life found in Jangamo, including many species of sharks, rays and the famous humpback whales. LTO's ultimate goal is to establish a Marine Protected Area for the Inhambane Province in Mozambique, achieving higher biodiversity whilst protecting endangered species. LTO scientists collect data on: coral reefs, humpback whales, whale sharks & manta rays, ocean trash and fisheries. They work with active fishing communities helping them transition to more sustainable practices and run two other community conservation outreach projects.

Comoros Directorate General of the Environment and Forests, represented by Mme Abdallah Fatouma, Coordinator of the project ANCAR II, alifat89@gmail.com, BP 860 Moroni Comores. The Directorate of the Environment and Forests, which includes the coastal zone, desires to integrate living shorelines and ocean ecosystems with managed fisheries supporting adequate standards of living and sustainable ecosystems with mitigation and resilience in the face of climate change.

Initial communities, organizations, and researchers that share the same (giant clam) ecology, but lack a regional SEAFood Lead Institution as of 14 January 2021. Networking for: same-native-species already adapted to higher water temperatures (or needing adapted native species); science and approach innovations; marketing coordination; etc.

Seadling, Dr. Simon Davis, sd@seadling.com, Phone: +60 139876209, Biotechnology Research Institute, University of Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia, is a social and environmental impact seaweed biotechnology firm based in SE Asia that enhances the productivity of community-led seaweed farming and produces high-value seaweed nutritional products. Seadling seedlings are proven to grow faster with higher yields and greater disease resistance than those currently used. Seadling will provide faster growing seaweeds that will enhance the entire programme.

Luke Dallafior, luke@garrisonforce.com, of Garrison Force, and Tricia Grant, tricia@triciagrant.com, 6/275 Harbord Road, Dee Why, Australia, 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.

Dr. Mohammad Badran is an active independent researcher with diverse knowledge of Red Sea Environmental management and Professor Mohammad al Zibdah is a manager of an experimental aquaculture unit for the University of Jordan in Aqaba. Their interest is in tackling challenges of nutrient recycling while protecting the coastal environment and enhancing biological productivity of the (oligotrophic) ecosystems near and in the nutrient-sensitive coral lifeboat ecosystem habitats in the Gulf of Aqaba and wider Red Sea.

Dr Imran Ahmed Khan, Assistant Professor, Department of Geography, University of Karachi, Karachi 75270, Pakistan, imrank32@uok.edu.pk. Dr. Khan analyzes remote sensing data to produce Spatial pattern, Monthly, Seasonally, annually and inter-annually trends of SST and Time series statistical model monthly assessment with 4 km spatial resolution. The model will be fitted to the observed data that describes the annual SST pattern with near future (monthly) prediction.

Initial institutions, researchers, communities, and businesses with appropriate expertise (from outside both Tropical Pacific and Western Indian Ocean region)

OceanForesters: Mark E. Capron, Professional Engineer (P.E.), 2436 E. Thompson Blvd. Ventura CA 93003-2730, Cell: 805-760-1967, markcapron@oceanforesters.com Additional team members include: Jim R. Stewart PhD, Mohammed A. Hasan P.E., Don Piper, Graham Harris, Martin Sherman, and Jill Santos. OceanForesters, a California corporation, 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. Using a design developed with funding from the U.S. Department of Energy, modeled to withstand a direct hit from a Category 5 cyclone, OceanForesters will provide engineering and other expertise.

Vincent Doumeizel, Director-Food Programme, Lloyd's Register Foundation, Vincent.Doumeizel@lr.org, 71 Fenchruch Street, London, EC3M 4BS, United Kingdom. Lloyd’s Register Foundation has identified seven pressing challenges within their mission to protect the safety of life and property. Two challenges are particularly important for an Ocean Decade Nutrient Recycling Seafood-Science Programme: safety at sea and safety of food.

Engineers Without Borders USA, 1031 33rd Street, Suite 210, Denver, CO 80205, Call: 303-772-2723, kevin.andrezejewski@ewb.org and info@ewb-usa.org. EWB leverages a skilled network of nearly 10,000 engineer members to work with communities around the world on various engineering projects. Within EWB-USA is the Engineering Service Corps, which partners with outside agencies, foundations and other implementing partners to deliver consulting services that utilize our most seasoned engineers. These engineers have both the engineering background but also the cultural experience, which is critical in the humanitarian sector. The Engineering Service Corps roster represents engineering disciplines ranging from water resources (including sanitation and water resource recovery) to civil and structural experts along with agriculture and energy experts. They will provide high quality, low cost engineering services.

Bradley Kennedy, bradley@richearthinstitute.org, Rich Earth Institute, 355 Old Ferry Road, Brattleboro, Vermont 05301, USA. Rich Earth Institute research suggests that collecting, pasteurizing, and using urine as a fertilizer in the United States can be cost competitive with conventional systems for removing nutrients from wastewater, while using less energy than synthetic fertilizer production.

Anthony Johnson Akpan, President, Pan African Vision for the Environment (PAVE), WANGONET 7, Raymond Street, Sabo, Yaba, Lagos, Nigeria, ajakpan@yahoo.com, PAVE offers: (1) insights for implementing safe convenient sanitation with energy/food and nutrient resource recovery, particularly in Africa; and (2) Organizing the African Ocean Literacy Civil Society Action Network to address Ocean Decade Challenge 10, Objectives 3 and 3.1. (2) is a proposed large-scale marine environmental education Programme. PAVE deals with human settlement issues including Agricultural Value Chain promotion, Gender, Disaster

Risk Reduction (DRR), Climate change and Clean Energy promotion, Waste Management including E-Waste, plastic, and Chemical Management, and Stakeholder Engagement.

Dr. Kevin Hopkins, hopkins@hawaii.edu, (808) 937-8310, Professor of Aquaculture at the University of Hawaii, 200 W. Kāwili St., Hilo, HI 96720-4091, teaches aquaculture engineering, fisheries science, and water quality analysis. His research interests include business aspects of aquaculture and the application of fisheries and ecological models. He has been the primary organizer of the international Marine Agronomy Group.

Dr. Reginald Blaylock is the Assistant Director of the Thad Cochran Marine Aquaculture Center, University of Southern Mississippi, 703 East Beach Dr., Ocean Springs, MS 39564, Phone: 228-818-8003, reg.blaylock@usm.edu. Center research focuses on building partnerships with industry, government, and non-profit organizations to address the zootechnical, environmental, regulatory, structural, and logistical bottlenecks constraining the sustainable production of marine organisms. Specific programs address molecular and mathematical aspects of aquatic health, development of selective breeding programs, management of genetics impacts of aquaculture, development of captive spawning protocols, maximizing the environmental and economic sustainability of production systems ranging from closed, land-based recirculating systems to offshore systems, and optimization of procedures for large-scale production of marine algae, finfish, crustaceans, and mollusks.

Scott James, SC_James@baylor.edu, (925) 518-4940, is an Associate Professor in the Departments of Geosciences and Mechanical Engineering, One Bear Place #97354, Waco, TX 76798-7354 USA. His research interest is the intersection of water and energy, which includes modeling and optimizing macroalgae growth.

Dr. Kurt Rosentrater, karosent@iastate.edu, 515-294-4019, is an Associate Professor at Iowa State University, 3327 Elings, 605 Bissell Rd. Ames, IA 50011-1098 USA. He teaches courses in food and process engineering as well as economic and environmental assessment. His research program uses life cycle assessment and techno-economic analysis for a variety of bio-based systems and processes. He will provide techno-economic analysis support.

Dr. Ali Fuat Canbolat, Associated Professor in Hacettepe University, Chairman of the Board, Ecological Research Society (EKAD), Mustafa Kemal Mahallesi 2119. Cadde, No: 9/21 Çankaya/ANKARA, Turkey, canbolat@hacettepe.edu.tr. EKAD organizes many academics coaching volunteers in maintaining biodiversity while conserving ecosystems mostly in the Eastern Mediterranean Sea. Dr. Canbolat and many EKAD projects spread understanding and conservation of sea turtles.

Dr. Ant Türkmen, researcher, Mustafa Kemal Mh. 2128sk. 4/11 Ankara-Turkey,antturkmen@gmail.com, is developing projects about improving data literacy around ocean-based transformative technologies and jobs of the future with Italian National Institute of Oceanography and Applied Geophysics (OGS) and University of Trieste. He is one of the founder members of the Ecological Research Society leading projects on marine protected areas and ecosystem-based management of fisheries in the Eastern Mediterranean Region. He is also a member of EU-COST Action “Unifying Approaches to Marine Connectivity for improved Resource Management for the Seas” (SEA-UNICORN, CA 19107) work groups and a thematic expert for Intergovernmental Oceanographic Commission of UNESCO.

Dr. Carla Palma, carla.palma@hidrografico.pt is the Head Division of Marine Chemistry and Pollution at the Portuguese Hydrographic Institute (IHPT), Rua das Trinas 49, 1249-093 Lisboa, Portugal. She leads a team of marine geochemists whose main focus is the study of the marine environment (inorganic nutrient flows, toxics, pH, etc.) IHPT is Portugal's primary hydrographic survey resource, an agency of the Portuguese Navy working closely with Ministers of Education, Science, Agriculture, Sea, Environment, and Spatial Planning. Most international projects are in countries of Portuguese official language, particularly those located in the African continent, such as Cabo Verde, Guinea-Bissau and Angola.

Mr. Gaspard Durieux, gaspard.durieux@sp.ismar.cnr.it works as an expert in oceanographic metadata management for the Italian National Research CNR-ISMAR department on PNRA Antarctic database and contributes to build standards and make data available for investigation of ocean/atmosphere, contaminant fluxes and biodiversity dynamics modeling. Gaspard is a specialist in water sciences, engaged in a multidisciplinary network aiming to build innovative technical and social solutions to the climate challenges. Gaspard has experience in the fields of political and social science and developed an expertise in project management, network coordination and social innovation. He collaborates as a mentor with the networks Climate KIC, Impact Hub, and Water Innovation Lab to translate research ideas into impactful and scalable projects.is an international consultant. Participating in the Ocean Decade represents for him the opportunity to integrate his skills and passion into a major collective work.

Jessie Turner, Cascadia Law Group (Jturner@cascadialaw.com), 606 Columbia St. NW, Suite 212 Olympia, WA 98501 USA. Through her role at Cascadia Law Group, Jessie is the Secretariat for the International Alliance to Combat Ocean Acidification, helping to set its strategic direction, develop annual programming, establish partnerships across a wide variety of disciplines and coalitions, and support governments and affiliate members in the development of practicable and implementable adaptation and resiliency strategies to the threat of climate-related changing ocean conditions, including ocean acidification.

Nikia Solutions LLC, Phil Santoni, 2202 N. West Shore Blvd., Tampa, FL 33607. Phil.Santoni@nikiadx.com, designs and installs the digital hub systems used for Nikia's African Digital Hub Initiative. These intranet systems provide access to digital cloud solutions with affordable service models that support rapid deployment, free local access, & long term successful communications, training and support everywhere (even where there is no internet availability).

Stingray Sensing, Rae Fuhrman, rae@stingraysensing.com, (310) 463 – 5601, 7642 Newport Drive, Goleta CA 93117, heads a restorative aquaculture consulting firm and tech start-up based in Goleta, California. By developing responsible oceanographic monitoring requirements along with the equipment to achieve real-time monitoring of regenerative marine farms, large-scale cultivation of beneficial and harvestable ecosystems becomes possible.

AquaDam, 121 Main St., Scotia, CA, Mathew Wennerholm, matthew@aquadam.net, (707)-764-5099 manufactures water-filled tubes that can be as large as 3 meters high. The tubes can be used in ocean structures, for movable on-land aquaculture or hatchery ponds, and as levees to contain floods.

Chris Webb, CEO of [AI Control Technologies](), chris.webb@ai-ctec.com, (415) 867-5163, 121 North State Street, Third Floor, Suite 500, Jackson, MS 39201, USA. AiCT makes remote and precise buoyancy control electronics and AI software for aquaculture. Precise buoyancy control allows submerging to avoid parasites, avoid storms (less damage to crop or structure), and avoid impeding endangered species. Also, lobster (and other) traps could be deployed and retrieved electronically under a flexible floating fishing lifeboat ecosystem without having to pass through the lifeboat ecosystem.

Miguel Hoffman, miguelito.elsalvador@gmail.com, rama.elsalvador@gmail.com, 503-7896-0687, is the Founder of RAMA (Rescate al Medio Ambiente) [Environmental Rescue], San Salvador, El Salvador, a non-governmental organization of El Salvador. RAMA believes that our blue planet requires blue solutions to the most pressing crises of our epoch: environmental degradation, climate change and deep, institutionalized poverty. RAMA will help organize SEAFood projects (both sheltered and open ocean versions) as well as projects clearing El Salvador's freshwater lakes and rivers of their hyacinth infestations.

12. Area of similar ecology

USP's tropical Pacific SEAFood with Healthy Oceans Programme shares a key species, giant clams with a larger region. Giant clams are a keystone primary productivity species, perhaps more important than macroalgae for producing food and oxygen within its native area. See Figure 9.

Projects within the giant clam area are described in Appendix A.

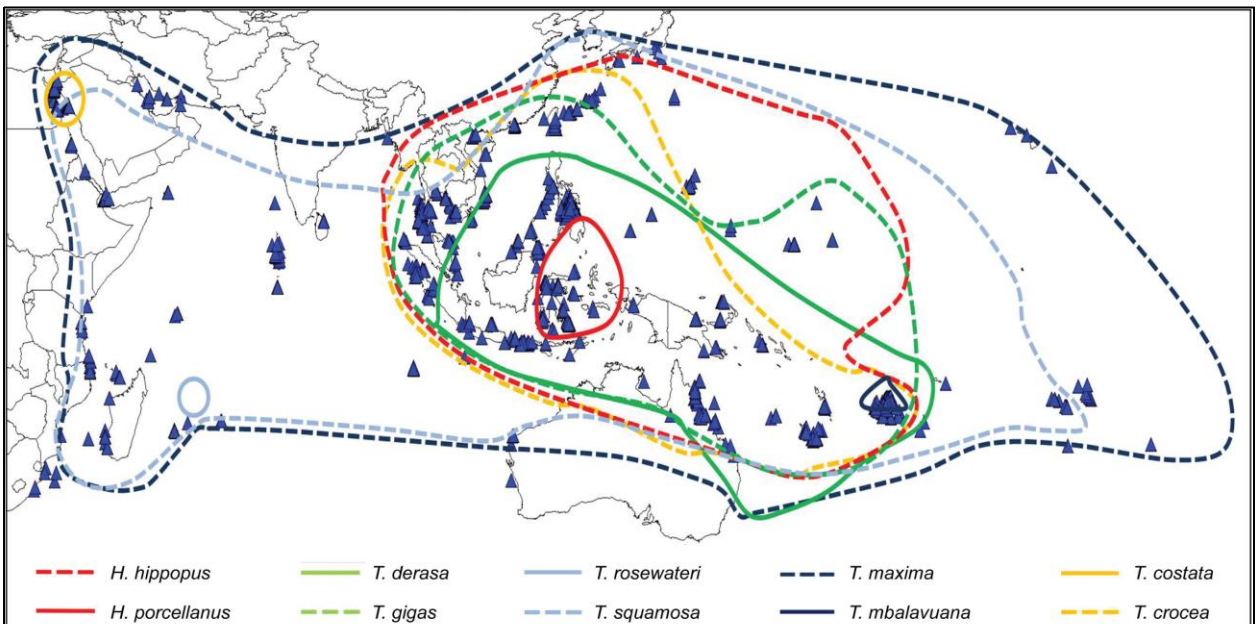

Fig. 1. Distribution of giant clams. Adapted from Rosewater (1965, 1982); Lucas (1988); Howard (1988); Zann & Ayling (1988); Gomez & Mingoa-Licuanan (2002) and Richter et al. (2008). The blue triangles represent Reef Check records and therefore the species are unknown. Abbreviation used for genera: *T.*, *Tridacna*; *H.*, *Hippopus*.

Fig. 9 – A map of the geographic extent of giant clams from Othman et al. 2010

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Appendix A
Typical Projects for the tropical West Pacific and Indian Oceans

The tropical West Pacific and Indian Oceans are likely to have somewhat similar SEAFood built-reef ecosystems. This is because the area is home to a possible key primary producing species, giant clams. See main document map Figure 9. Giant clams, like coral, contain significant symbiotic algae. Neo et al. (2015) provides details.

Table 2 in Neo et al (2015 shows giant clams natural population densities can range from 36 to 909,000 individuals per hectare. The latter density is mostly juvenile clams producing the highest biomass (on the table) of 238 kg/ha/yr dry weight. This means that we might expect to harvest about 2 tonnes/ha/yr wet weight of all species in the ecosystem (with nutrient conditions similar to Fangatau and Tatakoto atolls). The productivity/area might be substantially improved when nutrients equal to those extracted are returned to the ecosystem. Even with only background nutrients, a 20-ha ecosystem would produce $80,000/ha/yr with seafood worth $2/kg at the dock. The 500-m diameter circle of Figure A1 encloses 20-ha. With ample nutrients and more photosynthetic species, productivity can be over ten times higher.

OceanForesters research with the U.S. Department of Energy Advanced Research Projects Agency-Energy's MARINER program suggests productivity with optimum nutrients could be between 300 to 1,000 tonnes/ha/yr wet weight of all harvested species.

The easiest way to recycle nutrients to a SEAFood ecosystem is to locate it where people are placing too many nutrients. This is the situation for the University of the South Pacific's project in Laucala Bay (which receives discharges from the main Suva sewage treatment plant). The challenge becomes installing and managing the filter feeders, macroalgae, and giant clams to maintain sufficient dissolved oxygen for a healthy ecosystem.

When an area has less-than-optimal nutrients, the easiest way to recycle nutrients is to collect and pasteurize people's urine. Pasteurization requires only 55ºC for 2 hours. (Or longer times and higher temperatures when dealing with more problematic materials.) All the urine from 100 people could in theory convert to 10 tonnes/year of wet shell-on blend of all harvested species (finfish, shellfish, seaweed, mollusks, etc.). Actual production will be much less, perhaps less than half. When recycling nutrients to support a seaweed monoculture, 100 people's urine could theoretically add 20 wet tonnes/yr to the crop.

When preserving or restoring coral reef ecosystems, SEAFood can emphasize giant clams for primary productivity and filtering (water clarity). That is, the aerial view could resemble Figure A1, but with less seaweed. The growth of native macroalgae, recycling of inorganic nutrients, distribution of inorganic nutrients should be managed such that increased seafood productivity is compatible with healthy nearby coral reef ecosystems.

When coral is not a concern, such as over a muddy or sandy seafloor, farmed and volunteer macroalgae can be the key primary productivity. This especially when recycling substantial inorganic nutrients. The plan could resemble Figure A1, but with more seaweed.

Only the primary producers are shown in Figure A1. The ring of seaweed around the circle filled with giant clams may be useful to define the boundary of the fished SEAFood ecosystem. Hopefully, the host country's laws and culture will acknowledge that all the species, biomass, and shell mass inside the ring belong to the people who built (seeded) and maintain the SEAFood ecosystem. Most of the ecosystem biomass will volunteer. Many "planted" or "stocked" species will be managed to become self-seeding, such as giant clams. Much of the SEAFood ecosystem may spread downstream.

Managing and harvesting the SEAFood ecosystem is more like forestry than farming. There are many harvested species. A species is harvested before its population boom threatens a crash of that species or the ecosystem. All species are harvested in moderation, sparing especially individuals with the largest reproductive capacity. A one-species example – A few giant clams (the survivors of heat waves and other stressors) are allowed to age until their reproductivity declines. Most giant clams become food for other creatures. Science includes genetic testing to find those young giant clams susceptible to heat waves. Some of them might be harvested and sold before predicted heat waves.

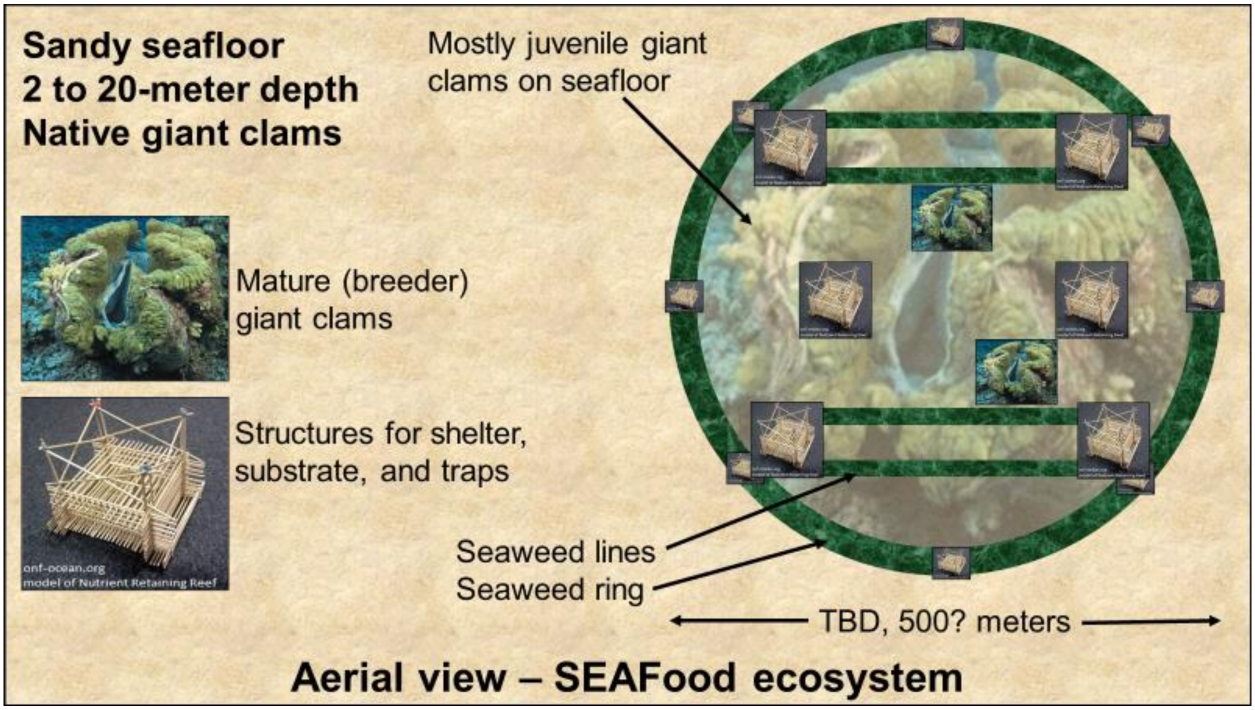


Fig. A1 – Concept plan of a SEAFood ecosystem in shallow water where giant clams are native (Structures, giant clams, and seaweed inside the ring are not to scale.)

Growing seaweed monocrops (sometimes with shellfish) is becoming a hot topic. See the Seaweed Manifesto and the MARINER Program. Seaweed production via large farming operations could depress prices, although some hope for carbon sequestration fees. In a built-reef ecosystem, seaweed may be more valuable for ecosystem services such as: dissolved oxygen, in-situ food for other species, shelter, and reproductive habitat than if harvested.

Where seafloor depth is greater than about 20 meters, flexible floating reef structures become necessary to support macroalgae and symbiotic algae in the photic zone.

The University of the South Pacific's Tropical Pacific Region Science Enables Abundant Food (SEAFood) with Healthy Oceans Laucala Bay Training and Research Center

Dr. Rajesh Prasad[1], University of the South Pacific, Fiji, with the OceanForesters[2]

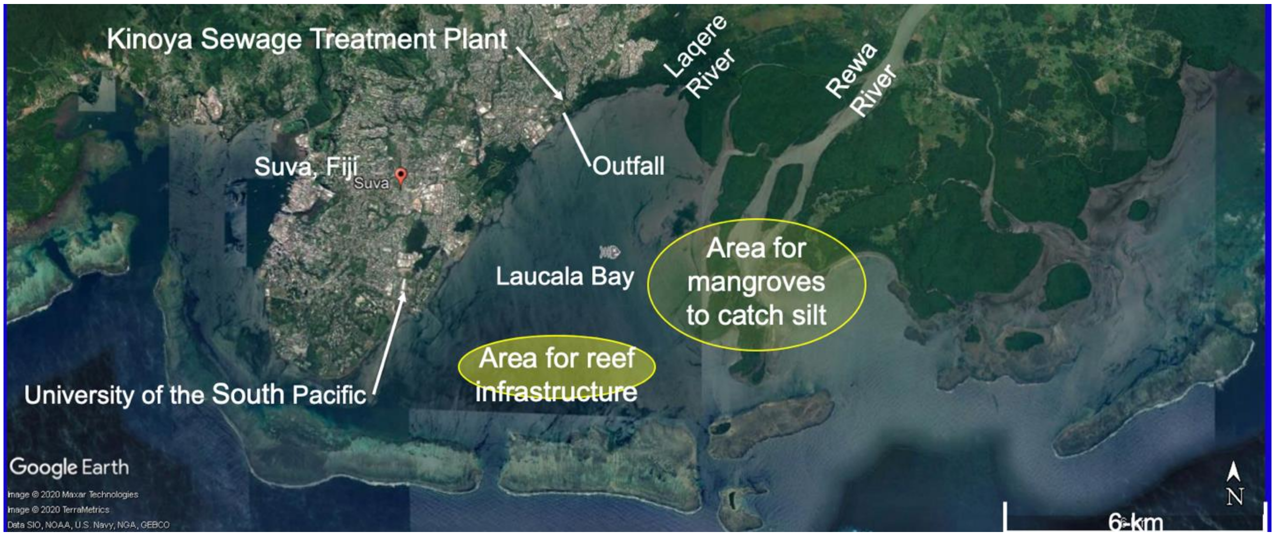
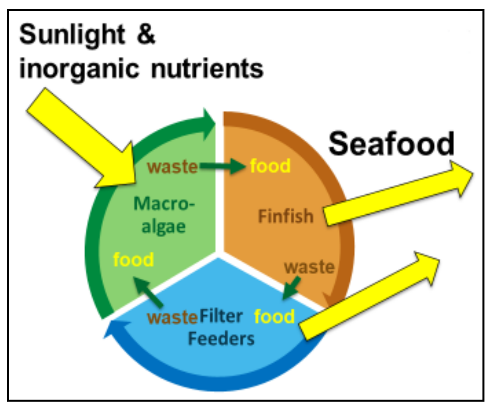


Fig. A2 – Locations of project components

Summary: The University of the South Pacific's (USP) member and associate countries[3] need a research and training center. The shallow sheltered water center locations are shown in Figure A2. Eventually, research and training can be expanded to the open ocean. Fiji is mentioned in Gentry et al. (2017) for its abundance of open ocean area with less than 200-m seafloor depth.

Need: Most urgently, island nations that relied on tourism for jobs and subsistence have had to relax fishing management rules. People need to feed themselves during the pandemic. Over the not-so-long term island nations and their coastal ecosystems are vulnerable to the impacts of climate change which are exacerbating the issues of food security, poverty, land shortages as populations increase, declining wild fisheries, and pollution, especially in their sheltered bays and lagoons.



SEAFood with Healthy Oceans: The Tropical Pacific SEAFood Training and Research Center would be based at the USP Suva campus and would provide students from across the Pacific examples of SEAFood facilities.

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[2] Includes: Engr. Mark E. Capron, MASCE*, Engr. Mohammed A. Hasan, FASCE*, Jim Stewart, PhD, Don Piper, and Graham Harris. Contact: markcapron@oceanforesters.com, California 805-76-1967

[3] Member countries: Cook Islands, Fiji, Kiribati^, Marshall Islands, Nauru, Niue, Solomon Islands^, Tokelau, Tonga, Tuvalu^, Vanuatu^ and Samoa. Associate countries: East Timor^, Federated States of Micronesia, Palau, Papua New Guinea (Note that ^ indicates a least developed country.)

SEAFood involves establishing a complete ecosystem that cycles 'waste' nutrients into increased seafood production, while cleaning up pollution and restoring the natural environment.

Candidate species for fisheries restoration include: giant clams, oysters, mussels, conch, abalone, mud crabs, lobsters, sea cucumbers, sea urchins, sponges, herbivore finfish, filter-feeding finfish, predatory finfish, and more. Supporting species needed to maintain a robust ecosystem and improve yield include: seaweeds, seagrass, mangroves, epiphytes, and many tiny sea creatures. USP and OceanForesters will seek indigenous ocean knowledge to help ensure a robust ecosystem.

Why Laucala Bay: Laucala Bay, adjacent to the USP campus, will provide an excellent demonstration and teaching site, since it presents an extreme example of the excess nutrient issues found in many countries. (See Figure 2 in the main document.) The water is clouded with sediment from the rivers and microalgae growth from the Kinoya Sewage Treatment Plant outfall and fecal coliform. Supplying a million or so filter feeders (oysters, mussels, clams, giant clams, plus volunteer filter feeding finfish) along with planting mangroves and perhaps seagrass will clarify the water. The shellfish and finfish can thrive when they are near underwater plants. Plants raise pH (and thus locally reverse ocean acidification) and increase oxygen levels. The plants can thrive when the water is clarified (they are not covered by sediment).

Laucala Bay is also ideal because giant clams are native, the seafloor is less than 15 meters deep, and its natural condition is coral reef. Giant clams have symbiotic algae, like coral. That is, they are both a nutrient absorbing plant and a filter feeding animal. They are the ideal keystone species for SEAFood projects that can also restore coral reef ecosystems. Giant clams are native throughout the eastern tropical Pacific and Indian Oceans. (See Figure 9 in the main document.)

Dr. Prasad and OceanForesters are currently designing a trial combining USP labor with $5,000 from OceanForesters for materials. The trial might quantify giant clam performance:

a. How many logs of fecal coliform removal the shellfish accomplish? (You can adjust the flow-thru rate proportional to the shellfish's filtering rate. If funds allow, check for other wastewater borne microbes.)
b. Do the giant clams absorb nitrate and ammonia/urea from the water? (They might get all the N their symbiotic algae need from digesting organic N the clams filter out of the water. If they do not remove inorganic N from the water, we can arrange the ecosystem to feed them microalgae.)
c. If funds allow, check for a daytime dissolved oxygen and pH increase, perhaps night-time dissolved oxygen and pH decrease.

Self-Sustaining: Eventually, income from seafood sales can be used to expand and sustain USP's Research and Training Center. Many island nations will install SEAFood projects for both local consumption (reducing imports) and export income, improving their diet and economies and increasing resilience to climate issues.

Open Ocean Future: Fiji is one of three places singled out in Gentry et al. (2017) for its large area of seafloor that is less than 200 meters deep. Open ocean SEAFood structures around Fiji would be in water at least 50 meters deep. The macroalgae and giant clams would normally be near the ocean surface, but would submerge during typhoons.

Funding and Governance: Training and proof-of-concept research can start with as little as US$5,000 for materials. Any amount up to about US$2 million over a few years can be leveraged into a first-rate SEAFood Training and Research Center. The reef and mangrove ecosystems, along with seafood yield data and calibrated fisheries models, could provide collateral for bank loans to expand a SEAFood business.

USP and OceanForesters would like the Laucala Bay SEAFood business to fit the Fijian culture and UN Sustainable Development Goals. This means involving USP's social and business departments plus all the stakeholders around Laucala Bay.

OceanForesters' bio-ecological-engineering analysis suggests the Laucala Bay SEAFood business could have US$10 million/yr net revenue after full expansion (five to ten years). That is, the Laucala Bay business should have ample revenue to fund USP's Laucala Bay Training and Research Center. The business would fund the Center because the business needs trained employees and knowledge to manage the SEAFood operations for robust biodiversity and yields.

Long Range Benefits: With minimal initial foundational funding, students trained at the Fiji Center can bring this profitable system to the open ocean and sheltered water of many countries across the Pacific, helping them to remain self-sufficient in seafood, while some of them generate income from surplus international sales. The micronutrients in seafood will improve the diets and health of thousands of people. Thousands of hectares of mangrove restoration will not only improve water quality but also protect islands against tropical storms. The income will give them more options to adapt to sea level rise.

The following projects are outside USP's tropical Pacific region. USP and its coastal communities will be networking outside their area. Features in these projects may be adopted in the Tropical Pacific.

The Zanzibar Seaweed & SEAFood Cluster Initiative

Dr. Flower Msuya[4] and the OceanForesters[2]

The warming ocean forces the Zanzibar Seaweed Cluster Initiative (ZaSCI) to move operations a few kilometers offshore. The ideal seafloor depth of 6 to 10 meters of rarely too warm. The red circled area in Figure A3 includes mud, sand, and coral reef seafloors with maximum depth near 80 meters. The offshore move requires boats. Boats are expensive, which means the operation must earn more per year and more per boat trip. Needing boats is one of the reasons ZaSCI is already trapping fish that visit their seaweed farming operation.

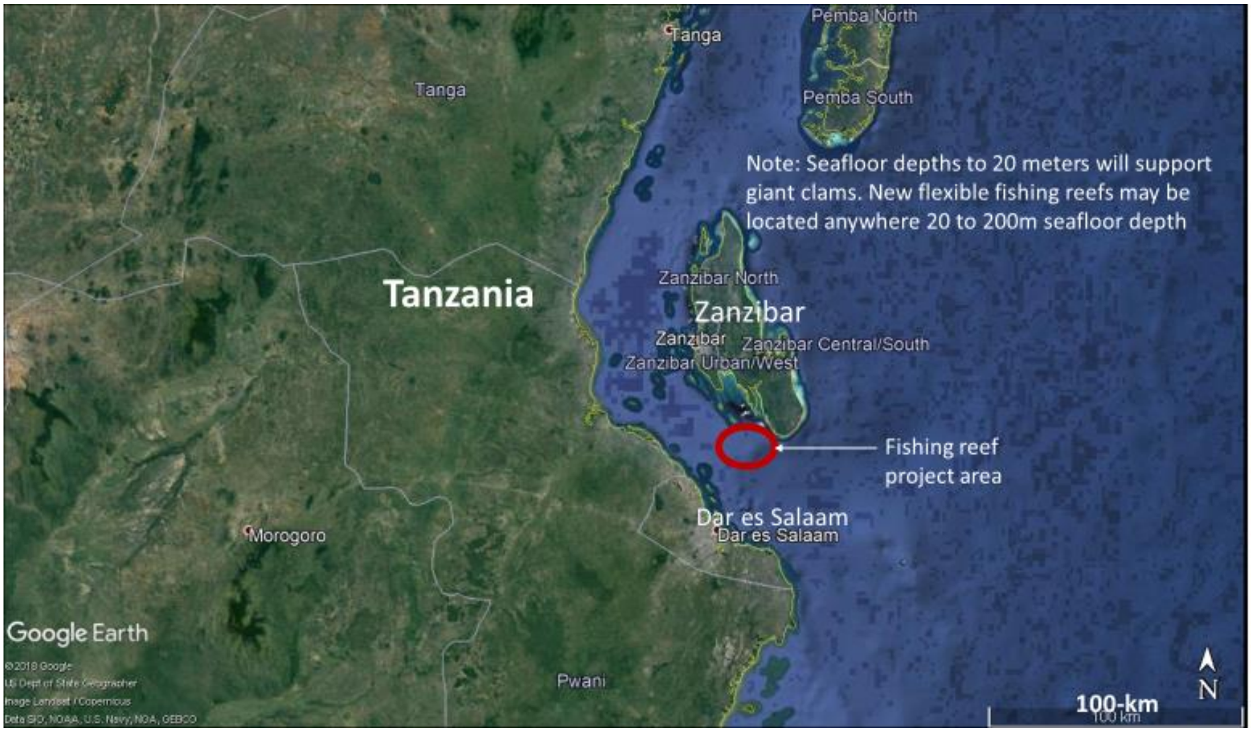

Fig. A3 – Planned location for _________________(name)

ZaSCI plans to add the SEAFood ecosystem depicted tin Figure A1 to its current seaweed farming operation. The planned SEAFood operating area (red circle in Figure A3) contains all three conditions allowing them to adjust between mostly seaweed and shellfish to mostly giant clams.

ZaSCI will start pasteurized urine recycling with 20 people using techniques refined at the Rich Earth Institute. Twenty people should boost monocrop seaweed production about 2 tonnes/yr or sea creature production about 1 tonne/yr.

The Institute of Marine Sciences will coordinate research activities on the ZaSCI SEAFood ecosystems. The minimum participation of ZaSCI members would be as citizen scientists and sensor maintenance. ZaSCI needs science to develop the full ecosystem model with operator interface mentioned in the main document.

[4] Founder and leader of the Zanzibar Seaweed Cluster Initiative (ZaSCI), Tanzania

Malaysia and Indonesia SEAFood Projects

Dr. Simon Davis[5] and the OceanForesters[2]

Seadling has strong relations with four seaweed farming communities:

- Kota Belud and Semporna, Sabah, Malaysia
- Nunukan, Kalimantan, and Sulawesi, Indonesia.

Dr. Davis feels that seaweed farmers in the indicated communities may be interested in participating in the Ocean Decade. Their minimum participation would be as citizen scientists and sensor maintenance while conducting their current seaweed farming operations. Their science could include testing Seadling's seaweed seedlings for:

- Sustained production of high-value seaweed nutritional products through marine heat waves.
- Continued and further improved robust disease resistance through changing ocean conditions.
- Increased local day and night dissolved oxygen and pH by seaweed species and breeding.

Some of these communities may elect to transition their seaweed farming operations to SEAFood ecosystems. Doing so implies building their capacity to conduct the science needed to personalize SEAFood ecosystem model.

Seadling's Expanded Seaweed Hatcheries Project

Dr. Simon Davis[5] and the OceanForesters[2]

Seaweeds used in farming need to adapt to warming and other changing conditions. Or the seaweed farmers will need to move farther offshore. Seaweeds cannot migrate fast enough when marine heat waves can cause migrations of finfish a hundred kilometers in a few months, Jacox et al. (2020). See the urgency discussion for more issues needing directed evolution and the lifeboat analogy.

Seadling will provide adaptions by expanding breeding and hatchery operations with: more science and more hatchery locations.

[5] Founder and Managing Director of Seadling.

Budget - Science Enables Abundant Food (SEAFood) with Healthy Oceans: Tropical Pacific Region, University of the South Pacific											
Initial Programme High Level Budget (US$ millions)	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	**Total**
A. USP Training and Research Centre, Laucala Bay, built-reef ecosystem infrastructure and operation.	1	2	1	1	1	0	0	0	0	0	**6**
B. Regional Computer Model, Program and Data Management with amplified networking (in-region expense).	2	2	0.5	0.5	0	0	0	0	0	0	**5**
C. Computer Model, Program and Data Management with amplified networking (a share of global expense)	1	0.5	0.5	0.5	0.5	0	0	0	0	0	**3**
D. Business and Marketing Systems (includes in-region and a share of global expense)		1	0.5	0.5	0.5	0.5	0.5	0	0	0	**3.5**
E. USP Training and Research Centre, Fiji, Open Ocean built-reef ecosystems infrastructure and operation			2	6	5	2	1	1	1	0	**18**
F. Construction and initial operation of sheltered water no-take reserves and built-reef ecosystems across partner countries		1	3	4	4	4	4	4	3	0	**27**
G. Construction and initial operation of open water no-take reserves and built-reef ecosystems across partner countries					6	8	8	8	4	0	**34**
H: Installing safe and convenient sanitation systems with resource recovery		0.5	0.5	0.5	0.5	0.5	0.5	0.5	0	0	**3.5**
Total by year	**4**	**7**	**8**	**13**	**18**	**15**	**14**	**14**	**8**	**0**	**100**
High Level Budget Rationale – Excel with 12 tabs available showing potential profitability of a shallow water SEAFood built-reef ecosystem available on request.											

This chart presents an initial overview of a High Level Budget for the entire Programme. It would start with the USP Training and Research Centre, Laucala Bay, Project, which is detailed in the next ten tabs of this spreadsheet. **Activity A: USP Training and Research Centre**, Laucala Bay budget for the sheltered water systems, including built-reef and mangrove ecosystems infrastructure and operation as a demonstration of the technologies for the region. For details, see the remaining tabs in the Excel file. Once the Laucala Bay and other sheltered systems are demonstrating profitability, likely by year 3, the reefs can expand with bank loans and investor funding as shown in the OngoingEconomics tab. However, it would be desirable to have some continued donor funding for an additional 2-3 years for USP staff, graduate students, student trainees, and their expenses, including sensors, until the reef buildout and seafood production in the Bay is large enough, hopefully by year 6, to generate sufficient extra income to support those expenses.
Activities B & C: Regional and Global Computer Model, **Program and Data Management** with amplified networking includes developing and calibrating computer programs that model as many as possible of the important species in each reef ecosystem. The models also provide predictions for health, development, life and death of the important species. The computer models will be integrated with local and global ocean observing sensors and satellites, and linked to form a comprehensive digital representation of the local ocean and ecosystems to produce concrete recommendations for optimizing any given ecosystem in real time, including associated multi-hazard early warnings (hopefully weeks or months in advance) of heat waves, etc. The computer model of the ocean ecosystem gradually includes more species, more inputs, more accuracy, longer range forecasts, better calibration, etc. over time. The computer networking system also includes capability to process and integrate data from sensors from each reef and no-take ecosystem to feed the computer models, as well as provide operational data for each community. In addition, the networking system reports the relative successes of each ecosystem, along with its parameters so that other communities can learn what works best and apply those lessons locally. It will also have a search and Q&A capability to access the knowledge base as well as experts. Initially, donor funding for Row 2 finances the USP Tropical Pacific Regional and Global Computer Model, Program and Data Management. It is expected that by year 5 reef production will generate sufficient extra income to support those expenses. Ideally, donor funding for Row 3 could also finance a Global Computer Model, Program and Data Management system providing the data outlined above linking and supporting each Regional Programme. Within a few years, the operation and improvement of each community's computer models and networking are expected to prove, to each community, that their value exceeds their cost. Also within a few years, each community's additional seafood production is expected to generate sufficient income to support a fair share of continuing networking and model operation/improvement so no more donor funding is needed.
Activity D: Business and Marketing Systems – Communities will benchmark for local high-quality safe food to ensure local health and well-being. Product-market coordination will ensure eligibility for top prices on the international market, including the whole value chain: growing, harvesting, moving products to end consumers, government facilitating, etc.; working with international food-safety certification and marketing agencies and companies for maximum long-range profitability; and networking to facilitate steady availability of high quality products. It is expected that before year 8 regional reef production will generate sufficient extra income to support this component.

Activity E: USP Open Ocean built-reef ecosystems infrastructure and operations ideally would have initial donor funding, but it is possible that the profitability of the Bay operations by year three could attract investor funding for the open ocean systems. Once operational, as the profitability is demonstrated, likely by year 6, the reefs can expand with bank loans and investor funding, similarly to the Bay systems. However, it would be desirable to have some continued donor funding for an additional few years for USP staff, graduate students, student trainees, and their expenses, including sensors, until the reef buildout and seafood production is large enough, expected before year 9, to generate sufficient extra income to support those expenses. **Activity F**: **Sheltered water no-take reserves and built-reef ecosystems across partner countries** construction and initial operation will likely need substantial donor funding until those show profitability and become self-supporting by year 9. **Activity G**: **Open water no-take reserves and built-reef ecosystems across partner countries** construction and initial operation will likely need substantial donor funding until those show profitability and become self-supporting by year 9.
Activity H: Places with an excess of nutrients and safe convenient sanitation won't need to build a new system (Laucala Bay, for example). The donor funding shown is aimed at selecting designs and installing demonstration toilets and resource recovery pickup and pasteurization systems in many USP region communities to show it works and gain public approval. Expansion of the resource recovery systems will be paid for by the reef seafood sales because they need the nutrients to gain maximum production and profits.

Logic Framework - University of the South Pacific, Tropical Pacific SEAFood			
Logic hierarchy	**Verifiable indicators**	**Means of verification**	**Important assumptions**
Goal 1: Most of the people in each participating coastal community experience improved quality of life.	Percentage of households reporting improved quality of life as measured by income, health, education opportunity, and happiness indices.	Household and health clinic surveys in each community, initially annually. Data Source: surveys analogous to https://worldhappiness.report/	People spend additional income in ways that increase personal and community happiness.
Goal 2: Ocean productivity, health, and biodiversity improve near each participating community.	For the areas within 1-km of new no-take reservoirs and built-reef ecosystems: biodiversity and biomass both double within 5 years of no-take establishment and/or built-reef construction.	Ocean observation. Data Source: ocean observation sensors, scientists, and citizen-scientist fishing/touring people	The combination of no-take reservoirs and built-reef ecosystems increases biodiversity and biomass.
Strategic Objective (SO 1.1): Coastal communities increase their sustainable seafood	Increased seafood production by 50 kg/yr/community member within 5 years of joining the network of communities.	Observation of and by fish markets and fishing people. Data source: community digital data collection, pre-2019 records/estimates for baseline	Local and global paying markets are able to utilize the increased seafood production.

production quantity.			
SO 1.2: Coastal communities increase their sustainable seafood production value per kg. (Value includes both health effects and $/kg.)	Local health effects/kg improves 20%. Exported $/kg doubles. Both within 5 years of establishment/construction.	Observation of and by fish markets and fish samples. Data source: laboratory and sensor analysis, community digital data collection	Local seafood replacing less healthy imported processed food has beneficial health impacts. Export markets are feasible and available.
SO 1.3: Coastal communities maintain seafood production quantity and value for decades.	Maintained SO 1.1 and 1.2 seafood production quantity and value.	5-yr rolling average. Observation of and by fish markets and fishing people. Data source: community digital data collection	Science (computer models), local innovations, and networking identify adjustments to deal with climate and other changes.
SO 1.4: Coastal communities maintenance of ocean resources is funding self-sufficient for decades.	Within 3 years of operations starting, 70% of communities are generating sufficient profits from their ocean resources to fund continued science and whole-community quality of life improvements for decades.	Fiscal management observations Data Source: transparent accounting combined with data from other strategic objectives and activities.	The increased seafood production does not exceed paying demand locally or globally.
SO 1.5: Combined no-take reserves and built-reef ecosystems are sufficiently profitable that they attract bank and investor funding.	Within 3 years of operations starting, 50% of communities are generating sufficient profits from their ocean resources to attract bank and investor funding for expansion.	Fiscal management observations Data Source: transparent accounting	Science (computer models) and networking help most communities to repay loans or investments.

SO 2.1: The communities constantly improve their ocean resources for decades.	Biodiversity and biomass in the community's ocean resources increase to an abundant steady state.	5-year rolling averages. Observation of community's ocean resources. Data source: community digital data collection, ocean observation sensors, scientists, and citizen-scientist fishing/touring people.	Science (computer models), local innovations, and networking identify adjustments to deal with climate and other changes.
Note on Activities: Due to the interrelated systems approach of this Programme and the high-level nature of this Logic Framework, most activities feed into every strategic objective.			
Logic hierarchy	**Verifiable indicators**	**Means of verification**	**Important assumptions**
Activity A: USP Builds and operates its Laucala Bay Training and Research Centre.	Installed in-bay and mangrove built-reefs and training and research infrastructure producing salable seafood. Conducting training and research.	Observation Data Source: Teachers, researchers, students, sensors, sales reports, transparent accounting	The built-reef ecosystem will transform the ecology of Laucala Bay.
Activity B: USP implements in-region ecosystem computer model, Program and Data Management and amplified networking.	USP regional computer models produce more value (biodiversity, yield, sustainability) then they cost. All networking communities have similar (+- 30% of the average or median) performance on all benchmarked parameters, which include equity.	Observation of computer model "what if" and forecast accuracy. Observation of communities' participation and results from networking. Data source: Computer model use, networking data, community digital data collection, ocean observation sensors, scientists, and citizen-scientist fishing/touring people	Individual-to-community, community-to-community, community-to-researcher data privacy and data security issues are resolved.
Activity C: The global Program implements the global ecosystem computer model(s) and global Program and Data Management, and amplified networking.	Global computer models produce more value (biodiversity, yield, sustainability) then they cost. All networking communities have similar (+- 30% of the average or median) performance on all benchmarked parameters, which include equity.	Observation of computer models "what if" and forecast accuracy. Observation of communities' participation and results from networking. Data source: Computer model use, networking data, community digital data collection, ocean observation sensors, scientists, and citizen-scientist fishing/touring people	Country-country, region-region, region-global data privacy and data security issues are resolved.

Activity D: Communities increase economically beneficial export income with business and marketing refinements (in-region and globally).	In more than 70% of communities, increased income from seafood exports exceeds the funds needed to import materials, equipment, and knowledge to accomplish strategic objectives and activities.	Observation of and by fish markets and fiscal management observations Data Source: community digital data, market reports, transparent accounting combined with data from other strategic objectives and activities.	Most communities actively collaborate.
Activity E: USP Builds and operates its Open Ocean Training and Research Centre.	Installed open ocean training and research infrastructure producing salable seafood. Conducting open ocean training and research.	Observation Data Source: Teachers, researchers, students, sensors	Demand for seafood exceeds capacity of sheltered water operations.
Activity F: USP communities in partner nations establish, instrument, and manage no-take reserves integrated with construction and operation of sheltered water SEAFood built-reef ecosystems.	The area of no-take reserves (many as living reefs protecting the community) exceeds 1-ha per community member. The area of SEAFood built-reef ecosystems for 70% of communities is appropriate for producing at least 50 kg of seafood/yr/member from the community's human resource recovery system.	Ocean, fish market, and fishers observations. Data Source: community digital data collection, ocean observation sensors, scientists, and citizen-scientist fishing/touring people	SEAFood built-reef ecosystems are sufficiently productive for 70% of communities to produce at least 50 kg of seafood/yr/member.
Activity G: USP communities in partner nations establish, instrument, and manage	The area of no-take reserves (many as living reefs protecting the community) exceeds 1-ha per community member. The area of SEAFood built-reef ecosystems for 70% of communities is appropriate	Ocean, fish market, and fishers observations. Data Source: community digital data collection, ocean observation sensors, scientists, and citizen-scientist fishing/touring people	Demand for seafood exceeds capacity of sheltered water operations.

no-take reserves integrated with construction and operation of open ocean SEAFood built-reef ecosystems.	for producing at least 50 kg of seafood/yr/member from the community's human resource recovery system.		
Activity H: Communities install safe and convenient sanitation systems with resource recovery for all.	Percentage of households safely recovering waste resources. Quantity, quality and utilization of the recovered resources.	Observation of community dwelling and resource recovery and utilization records. Data source: Google Earth and Resource Recovery Team	The value of recovered resources pays for building and operating the resource recovery systems.