Blue Economy Cost-Benefits Spreadsheet Explanations and Assumptions

**Comoros' Women for Sustainable Development and Food Security,
Blue Ventures and Ocean Foresters (Team)**

August 7, 2016

Cost and benefits overview

Our team treats each island as a closed nutrient recycle system with loss of nutrients from exports and lost fish as a deficit that has to be made up or production will eventually decline. We anticipate that incoming nutrients from deep ocean water upwelling are in use and not available to increase primary productivity. Our calculations are based on the fact that the growth of the basis of the food chain, seaweed and other plants and algae is limited by the availability of bio-available nutrients: first nitrogen, then phosphorous. We also counter the tendency for excess nutrients to create ocean deadzones. As a result, ocean forests are a self-sustaining increase in primary productivity and biodiversity that does not need fertilizer or feed imports.

Our spreadsheet shows how nutrient management can monetize 20-year benefits summing to near $200 million on less than half the costs. We feel the costs are overestimated for reasons explained below. We feel the benefits are substantially understated because we have only valued food/farming/wastewater benefits. We have yet to monetize the benefits of climate change adaptation, energy with complete resource recovery, biodiversity and primary productivity, education, hope, migration prevention, virtual water, pollutants-to-resources, pausing and then reversing climate change, tourism, immigration, and greenhouse gas benefits.

We have to determine the costs of operating both a water-cleaning farm and a clean-water forest. Assume each initially up to 10 ha for the A$250,000. We are listing benefits only from the clean-water forest under the assumption that people may not buy the water-cleaning seaweed and mollusks. If it turns out that we can purify sufficiently that people will buy (and remain healthy) eating water-cleaning products, we'll check the economics of alternative uses for those products.

We collect nutrients with water cleaning seaweed and mollusk farms near wastewater discharges. This harvest goes to feed the clean-water forest.

The harvested water-cleaning seaweed is exposed to the sun for a few days to destroy pathogens. We plan to purify mollusks in a bleach-seawater solution for human consumption, but the market is uncertain.

The benefits are from the many products of the clean water forest in proportion to the nutrients available to drive primary productivity. We will have underestimated the benefits from some products and overestimated the benefits from others. Given all the other uncertainties and our conservative assumption on the available nutrients, this initial spreadsheet approximates that the N and P nutrients in a wet ton of the water-cleaning seaweed are the same as those in a wet ton of octopi, sea cucumbers, fin fish, mollusks, or clean-water seaweed.

Blue Economy cost-benefit assumptions (for tab 1)

1 Cost details are in the Blue Econ Tasks tab. We assume the water is free of industrial pollutants (heavy metals, dioxin, etc.) but has raw sewage from animals and humans. Some species of seaweed will grow well on ropes in the local conditions with 2.5 meter tides, water which is warming and may be brackish. More nutrients reach the seaweed growing area during the rainy season. If warming has made the water too warm to grow, the seaweed at least absorbs nutrients during the

wet, warm, and longest daylight season (December-April). Or farmers can work the rope-growing technique in deeper/cooler water. The seaweed grows vigorously on stored nutrients to extend harvests over the cooler May - November for time-staggered beach-drying operations during the cool dry season. We can seed the ropes with seaweed without available electricity, using only manual labor and hand tools. Cyclones are not frequent, but the equipment will be arranged such that a cyclone washes seaweed and equipment ashore without excessive loss of equipment. The water-cleaning and clean-water operations are economically synchronized because the high-value clean products would not be growing without the nutrients returning from the people who consumed the high-value products, which would not be high-value without barrier of separate growing areas to separate and neutralize pathogens. Estimate a third of annual production rate in first year for start-up.

2 Cost details from Blue Econ Tasks tab. We assume beach drying is adequate pathogen reduction when in series with a month or so of detention time in pristine coastal water. Some fish will eat dried-chopped seaweed and stay in the 10-20 ha seaweed forest releasing ammonia, phosphate, and calcium carbonate pellets. Dried-chopped seaweed will be put into porous "teabags" to provide an environment where bacteria degrade the seaweed into food products for other creatures; shellfish; crabs; and small fish. Plastic debris serves as "spacers" in the tea bag to allow distribution of water, dissolved oxygen, and small creatures throughout the tea bag. Some of the detritus falling from the tea bags is consumed by sea cucumbers. Our nutrient release and uptake is time and temperature synchronized such that we avoid creating a microalgae bloom, especially a toxic one. Estimate a third of annual production rate in first year for start-up.

3 The water-cleaning seaweed is grown and processed the same for terrestrial or aquatic use: let dry somewhat on the beach, chop and haul to new location. Therefore there is no specific cost for this option. Seaweed with no additional human processing adds C, N, and P to the soil or protein for livestock. We will investigate diverting some seaweed production to terrestrial fertilizer when sufficient seaweed is available. A lot depends on economic cooperation with the terrestrial uses. After achieving some scale, anaerobic digestion could be employed to extract energy and concentrate the nutrients.

4 If we were able to use 100% of the nutrients from Grand Comoros' 400,000 people, we could grow 350,000 wet tons of seaweed on 2000 ha. However, our conservative calculation begins with capturing the nutrients from 7% of the nutrients from the Moroni sewer. The synchronized operation ramps up linearly over ten years to a maximum of 30% the nutrients from all 400,000 people, employing the same $/wet ton of the first year operation. In subsequent years, funds spent on initial design in the first year are instead spent on maintenance, trials of new techniques, increased biodiversity to avoid a crop growth problem or market crash, marketing to increase demand (training chefs, making new products, etc.), and the like.

5 After ten years, biodiversity, production, techniques, species, market demand, continuous adaptation, integration with living shorelines, and the like have been optimized for food production. The operations can proceed for another ten years exporting and trading their expertise such that the net expense for Comoros continually re-thinking is zero.

6 This sum of income from Blue Econ Tasks tab over 20 years is based on a linear ramp-up over ten years followed by steady-state operation for another ten years. The steady-state ocean forest covers

about 300 ha relying on 30% of the nutrients from the island population. Note that, if we captured 100% of Comoros' nutrients, the farm and the forest would each cover 2,000 ha, providing about half a kilogram of food per person per day, if all consumed locally. There are bound to be some products sold to the global market, which are likely to increase the dollar benefits for Comoros. In the long term, some of the money earned from exports must go to replace the nutrients exported, either by importing food or importing fertilizers or biologic soil amendment to increase local food production.

7 Californians in urban environments spend roughly $100 per person per year to collect and treat wastewater to a level felt to be safe for stream discharge. The spreadsheet uses a value of $5 per capita per year for Comoros. Even if one earns only a few dollars per day, the value of people and their loved ones not getting sick from coastal ocean contact and food should be more than $5 per year. On the other hand, the California expense sets an upper limit near $100 per year because most California water is treated more than needed on Comoros. The full benefit is the sum of annual benefits with ten years ramping up to water-cleaning most of the ocean discharges for the full island population and then ten years at steady state.

8 Spinoff jobs - Wikipedia (https://en.wikipedia.org/wiki/Local_multiplier_effect) reports research has shown a local job multiplier effect from 0 to 5 jobs are created for each job created by a new local business. We assume each job created in the aquaculture sector creates one more local island job of equivalent pay, thus doubling the direct impact, but it could well be greater.

9 Climate change adaptation - For example, we may want a living reef of mussels filtering particulates from the wastewater. Seagrass dunes, mangroves infilled with dredged sand, are other possibilities to consider. Ocean acidification would make shellfish or coral reefs unsustainable unless those reefs are surrounded by growing and harvesting seaweed which remove dissolved CO_2 and increase pH. That is, unless future aquaculture and living shoreline techniques address ocean acidification and hypoxia, their useful life is short. We are also going to find techniques to keep seaweed, shellfish, coral, and all coastal species growing in warming water.

10 Energy with complete resource recovery - Here-to-fore seaweed has been more valuable as a food or feed source and sometimes directly for fertilizer. However, energy crops can be sustained at any level (up to global replacement of fossil fuels) in a manner which increases biodiversity and primary productivity, if the energy transforming process separates the carbon from the nutrients and recycles the nutrients to grow more seaweed. For example, the U.S. Pacific Northwest already needs several times the potential of local food production of seaweed to maintain ocean chemistry for food production and for living shorelines. Other areas have a decade or two before needing a seaweed operation in order to continue harvesting food from the sea. Anaerobic digestion and hydrothermal liquefaction are energy process which recycle nutrients. Anaerobic digestion is immediately available and economic when the "wastes" exceed those produced by about 50,000 people. Hydrothermal liquefaction is just now (July 2016) looking for its first commercial use, but may need wastes collected from near 500,000 people to be economic because of high capital costs.

11 Biodiversity and primary productivity - We can keep the operation more like forestry management and less like terrestrial mono-crop farming or penned aquaculture.

12 Education, hope, and migration prevention - Reduced food importing will allow agencies supporting Comoros to divert funding to education, even while people are given hope. Hope for a better future inspires people to invest for the long term: education and infrastructure. Hope with education and infrastructure will keep people on the coast with sea level rising beneath them. Growing food in the coastal ocean can reverse the internal migration of villages up hill. Villages on Comoros have been migrating uphill following slash and burn agriculture. The geology makes clean water less available up hill. Jobs on the coast will pull villages back to the coast by providing the means to sustain farming in one location.

13 Virtual water, virtual desalting of seawater - Comoros is a relatively new volcanic island with thin soils, porous rocks, and no rivers. It is extremely difficult to store freshwater from the rainy season to irrigate crops over the 7-month drier season. Growing sea food reduces reliance on soft rain for irrigation without floods. Virtual water is a term coined to describe when a water-poor country (Saudi Arabia) buys land in Africa to grow wheat and ships the wheat to Saudi Arabia.

14 Pollutants-to-resources - The Comoros do not have groundwater to pollute but may eventually have industrial spills. Such spills will move quickly to the ocean where micro or macro algae can hyperaccumulate the pollution and can be harvested for the energy and resource recovery process.

15 Pausing and then reversing climate change - Eventually, the Comoros will be producing bio-energy. The bio-energy production process may have a CO_2 by product, at no extra cost. When the bio-energy is combusted, the exhaust will include substantial CO_2. Comoros might be paid for bio-CO_2 capture and sequestration services at lower cost than other locations.

16 Tourism and immigration - Comoros may experience an uptick in tourism because of clean beaches, sustainable activities, adapted coastal infrastructure, and unusual foods. With an improved economy, Comoros could become an immigration destination for people fleeing the terrestrial effects of climate change. People like the Syrians fleeing violence caused in part by bad freshwater policies and extended drought. Other countries would provide funding for immigrants because doing so is much better for everyone than long-term refugee camps or resettling to places without sufficient jobs to accommodate them.

17 Greenhouse gas (GHG) benefits include the reduction of methane release from untreated human and animal sewage undergoing anaerobic digestion in septic tanks, outhouses, and feedlots; reduction of shipping emissions from fewer imports; eventual replacement of fossil fuels by biofuels; and others TBD.

Blue Econ Tasks (tab 2)
(Basis letters and numbers in column D)

a. Blue Ventures and Ocean Foresters have over a hundred people experienced in components of ocean farming, ocean forests, conventional fish aquaculture, community fisheries management, exporters relationships, and more. Some of them may need to fly to Comoros from the US at about $6,000 round-trip each, others will come from Madagascar, Fiji, and other locations. One of our objectives is to conserve on this category, if that can be done while improving outcomes.

b. Reasonably paid manager “white collar” jobs is essential for recruiting the best people and enabling them to give their best with the prospect of greatly increased responsibilities.

c. Paying farmer/forester-trainees is helpful for recruiting the best people. Some of these initial trainees need the qualities of future teachers, marketers, and managers for expansion. Others will soon become self-supporting by selling the products.

d. If the water-cleaning farm covers 10 ha, and the clean-water forest covers 10 ha, this equipment cost represents an unusually low A$0.4 per square meter, because only some of it will have ropes for seaweed. The cost of sea cucumber pens will be advanced against the income from the sales.

1 The production of water-cleaning seaweed is imported from the "Seaweed tons per yr" tab, which also calculates associated numbers, such as the size of the water-cleaning farm when it is N limited. Subsequent calculations are based on nutrient-limited concepts and our approach of a) capture polluted nutrients in a seaweed/mollusk farm, b) kill pathogens, c) distribute clean nutrients in the clean-water "forest." We forecast 1,000 tons of seaweed the first year of operation and build up over ten years to handle the full 53,000 tons.

2 We use 50% as the fraction of water-cleaning seaweed available because that allows us to divert half the nutrients to terrestrial fertilizer/feed and still have nutrients left over from clean-water operations. This is more conservative than it first appears because: a) initially there are plenty of background nutrients (conventional seaweed farming-harvesting relies on background nutrients, eventually limiting farm size and density); and b) the ocean forest also has internal recycle of nutrients in a food chain such as seaweed-bacteria-fish-seaweed.

3 Calculated.

4 - 9 – Export Sea Cucumbers

4 Because product production is nutrient-limited, we cannot exceed utilization of 100% of the nutrients available, in fact we need to be well under 100%. We have initially adjusted this fraction to arrive at a forest harvesting area not to exceed 10 hectares, using past results from team member projects and other published information.
Blue Ventures has established relationships with the private venture Indian Ocean Trepang (IOT), an offshoot of Copefrito, southwest Madagascar’s largest seafood collection company, for export. Juvenile sea cucumbers will be reared in a hatchery and placed in growth ponds until they’ve reached a couple of centimetres in length. The young sea cucumbers are then transferred to enclosures where they are tended by teams of farmers. The farmers agree to clean, dry and sell the full-grown sea cucumbers back to IOT after about 9-12 months.

5 Calculated

6 Based on Blue Ventures Madagascar report of density about 0.6 kg/sq m.

7 Calculated

8 Based on Blue Ventures Madagascar report of aquafarmers receiving about $2 per wet kg.

9 Calculated

10 to 15 – Molluscs – Mme Abdallah reports that people on Grand Comoros do not regularly consume mollusks, but are likely to do so if safe. Fish is regularly smoked, so smoked (in the same fire) mollusks would be a good introduction. Mussels are relatively easily purified such that we could produce mussels from both clean-water forest and water-cleaning farm for local consumption. Due to uncertainties in demand and value we include only the forest production in the benefit calculation. The clean-water operation must initially be heavy on shellfish and sea cucumbers and the like. See the co-growing picture in the article on Professor Charles Yarish: http://www.nbcnews.com/news/us-news/red-tape-slows-bloom-seaweed-farming-s-green-revolution-n613526 Estimate of % of nutrients that would supply 10 ha at low density of mollusks. Published yields are at least 10 t/ha/yr and could be as much as 100 t/ha/yr. Note excess nutrients are available to support 100 t/ha/yr. Because mussels are grown in the Philippines and India, we expect they will grow even as the water around Comoros warms. Based on prices paid to farmers in the Philippines, $0.06 to $0.36 per kg. Strategies for improving survivorship of hatchery-reared juvenile *Holothuria scabra* in community-managed sea cucumber farms, *Antoine Rougie, Mebrahtu Ateweberhan and Alasdair Harris,* BV Publication SPC Beche-de-mer Information Bulletin #33 – May 2013, p. 14. (https://blueventures.org/impact/publications/?wpv-conservation-programme=Aquaculture&wpv-locations=0&publication-year%5B%5D&wpv_aux_current_post_id=55&wpv_view_count=88569-TCPID55)

16 to 21 – Octopi – Mme Abdallah indicates that octopi are consumed locally. Octopi are quite mobile and a little higher on the food chain. Prior to acquiring better data, we are using similar wet tons/ha as for fin fish. Half the low-end market price for fin fish on Comoros, comparable to what fishers are getting in Madagascar.

22 to 27 – Local Seaweed – Mme Abdallah is uncertain of local seaweed consumption (directly). However, she suggests that inexpensive healthy food will be purchased and consumed. Estimating at a third of the high-end yield for seaweed farms. This is the low-end of exported seaweed, 10 cents per kilogram. As a fresh product it should actually command a price between vegetables and meat. If we can make an inexpensive staple product which people would recognize as a sort of high-protein rice or noodle substitute, it should sell for much more.

28 to 33 – Export Seaweed – The numbers are typical of Blue Ventures experience on Madagascar. Export seaweed is not a high priority because the global market fluctuates and is competing low-income people against each other. Also, warming water is making the globally desired species more difficult to farm.

34 to 39 – Free-range fin fish harvested in the ocean forest – Typical number for free range cod farmed by feeding trash fish.

40 to 45 – Forest ecosystem – This is a catch-all food benefit, not likely to be an income. The ocean forest will "shed" nutrients in the form of increased biodiversity and quantity of sea creatures all around it. The wet tons of products are driven by the mass of "left over" nutrients. The area over

which the products spread is not relevant to this benefit value. A $200 per wet ton is a fraction of the low-end value for fin fish.

46 Total annual benefit value of the initial ~10 ha operation built with AU$250,000 (after the first year).

47 This shows we project using 89% of the 1,000 wet tons of water-cleaning seaweed derived nutrients brought over from the water-cleaning farm. We know that some of our nutrients are lost, but assume that they are made up with nutrients coming in on the tide, etc.

48 The ocean forest produces several products within the same area. (The Forest ecosystem area is not included in the average.)

49 Complete island build-out, calculated in "Seaweed tons per yr" using 30% of the human waste nutrients from 400,000 people.

50 Average annual cost for the first ten years is calculated as the initial A$250,000 times the steady-state water-cleaning seaweed production of 53,000 tons divided by the initial 1,000 wet tons per year, building up to 53,000 tons by year ten.

51 Annual cost in the second ten years is calculated the same as above, but without the A$80,000 initial consultant costs.

52 Annual benefit is based on the same ratio of 53,000:1,000.

53 to 64 – Terrestrial fertilizer/feed – We use typical N and P concentrations in seaweed with typical global fertilizer values (generally artificial ammonia or nitrate made from natural gas). We are familiar with the developed country value of biochar (carbon and water sponge effects). The terrestrial fertilizer value of seaweed grown on Comoros may be much higher due to the thin soils which are driving villages to migrate uphill following slash and burn agriculture.

Seaweed tons per yr (tab 3)

1 to 5 – This section estimates the nutrients produced by people which get into the ocean and become available for the water-cleaning seaweed farm. The wastewater volume is typical for a developed country 50 gallons per person per day inclusive of laundry, stores, schools, showers, as well as flushing which generates the indicated 60 mg/L of N and 10 mg/L of P. If the water volume per person changes, the N and P concentrations would change proportionally, so these values are constant per person, no matter how much the dilution.

6 to 12 – This calculates the mass per area uptake of N, P, and CO_2-C given the selected seaweed growth rate. Seaweed growth per area is a function of sun light energy and available nutrient flow. Other factors include how well the species is adapted to ambient water temperature. Growth rates range from 10 to 60 dry metric tons per ha per year (we are using a conservative value of 20). Note the seaweed does uptake much more CO_2-C than either N or P.

13 to 20 – This a calculation of the mass of seaweed which can be produced by the above amount of nutrients and the associated area. We are using typical numbers which actually range about 25% more or less depending on the species. Generally the seaweed will not be growing so as to remove every last bit of nutrients. Also the seaweed is giving off mucilage slime which prevents herbivores from attaching to it. Microbes convert the slime into food of larger organisms. Note that if the seaweed growth were not limited by the available N, it would become limited by the available P.