Integrated Multi-Trophic Approaches in Seaweed Farming: Prompting Native Sea Vegetable Production and Consumption to Ameliorate Hypoxia in the Gulf South

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Looking at South Korea's Seaweed farms from Space (NASA Earth Observatory image by Jesse Allen, using Landsat data from the U.S. Geological Survey)

ABSTRACT:

Every summer, the US coastal waters of the northern Gulf of Mexico face lethal hypoxia levels that threaten community and ecosystem health as a result of natural and anthropogenic processes (Rabalais, 2002). The Mississippi River receives 41% of the nation's contiguous watershed, making the gulf a sink for high nutrient fertilizers and pesticide run-off from the midwest that cause algal blooms and eventual eutrophication (Pareira, 1990). Between Florida and Texas, these red tides are driven by extensive growth of phytoplankton *Karenia brevis* (Walsh et al, 2010). Last year, the National Ocean and Atmospheric Administration reported the largest ever "dead zone" recorded in the area, a total of 8,776 sq miles (Shashvatt, 2017). In addition to receiving high inputs of run-off nutrients from upstream agriculture, the northern Gulf of Mexico is also the highest contributor to aquafarm production in the United States--the state of Louisiana alone holds 873 aquafarms, double any other state (Treece, 2008). Fecal matter and excess feed create point-source pollution in and near these aquafarms as nutrient overload that can often trigger and exacerbate coastal hypoxia. Integrated Multi-Trophic Aquaculture serves as a possible and unexplored remedy to coastal hypoxia in the

northern Gulf of Mexico, where seaweed cultivation can provide benefits in the forms of nutritional food delivery, carbon sequestration, nutrient regulation and intake, aquafarm disease reduction, and sustained marine biodiversity (Cottier-Cook, 2016). This project will identify 5 native seaweed species that can be cultivated reliably and have human consumption appeal. These species will be evaluated by growth, nutrient uptake, and nutritional value to determine their feasibility for production, bioremediation, and health potential respectively. With information collected from these preliminary results, we will establish expanded replicates in 4 locations: 2 off shore sites and 2 coastal sites near productive aquafarms with high DIN (dissolved inorganic nitrogen) to TP (total phosphorus) ratios. Water quality measurements will be taken weekly to evaluate if local DIN and TP levels are reduced with increased seaweed growth. After one year, we will compare the disease concentration rates of aquafarmed organisms with the historical data provided by the aquafarm, and disseminate our results to regional aquafarm networks.

RATIONAL AND LITERATURE REVIEW:

Despite our planet's surface being 70% comprised of water, our land food capacity (10 billion tons/year) is 2 orders of magnitude greater than that of our oceans (100 million tons/year) (Mouritsen, 2017). As the primary recipient of solar energy, the oceans are a storehouse of potential for the cultivation of autotrophic seaweed. Some cultivated species, like *Enteromorpha prolifera,* have been measured to grow at a rate of 10-37% per day in the field (Liu, 2009). Seaweed production makes up about 49% of total mariculture production, valued at $6.4 billion USD (Cottier-Cook, 2016). The market share is overwhelmingly dominated by China and Indonesia, who produced over 23 million tons in 2014, where the only country in the Americas to make the international chart was Chile, who produced 12,836 tons of *Gracilaria* in 2014 (Buschmann, 2017). While the Western world is growing in appetite for "nutritious" health foods like protein and omega-3 fatty acid-filled seaweed, the production in US has still faltered (Buschmann, 2017). Ecological services provided by co-culturing seaweeds and other finfish or invertebrates like oysters or abalone are well-documented both in regulating nutrient cycles, provisioning, and cultural services (Nobre, 2010; Neori, 2008; Troell, 2009).

This paper will examine the potential benefits of native seaweed (*Porphyra leucosticta, Gracilaria tikvahiae, Percursaria percursa, Ulva compressa, Sargassum natans*) through integrated multi-trophic aquaculture in rectifying the hypoxic and nutrient-rich waters of the US coastline Gulf of Mexico, diversifying farmer economic opportunities, and supporting a healthy human dietary food source. As many as 10 million residents in coastal communities in the Gulf South of the United States live under the poverty line (Hotez, 2014), sharing many demographic qualities with communities of the Global South. One study in Tanzania demonstrated the efficacy of seaweed farming to provide alternative income and help lift women out of the cycle of subsistence farming (Myusa, 2006). Edible seaweed harvest and cultivation makes up a mere 1% of the total seaweed biomass produced, as they are most often used for other purposes like agar, carrageenan, and hydrocolloids (Buschmann, 2017).

There are over 10,000 different types of edible seaweeds (Felder, 2009), but the top 5 genera make up 98% of the world's cultivated production (Buschmann, 2017). Due to this propensity to cultivate seaweeds of similar genera, there is growing concern for epiphyte spread and disease introduction into new ecosystems via monocropped, non-native seaweed settlement (Cottier-Cook, 2016). For this reason, the project will center native seaweed species as options for cultivation rather than seek to introduce well-researched cultivars from other marine geographies.

As global harvest of natural sea kelp forests increases for countries like Norway, Chile, Japan, and Morocco, this threatens the longevity of wild kelp survival, particularly if means of cultivation do not keep up (Buschmann, 2017). Our need to commence a more balanced global production of seaweed outside of the usual suspects of historical seaweed producers is both necessary and likely. The European Commission makes the case that seaweed has so much production potential that, by 2054, algae cultivation could account for 18% of the global alternative protein market, a production equivalent to 56 million metric tons of protein (European Commission, 2012).

Many studies suggest that seaweeds offer a unique nutritional balance for human consumption, containing densely-packed omega-three fatty acids, fiber, phytonutrients, as well as protein concentrations (Schiffman, 2016). One study's results claim that regular consumption of seaweed can reduce incidence of cardiovascular disease and assist with healthy brain development and maintenance (Cornish, 2017). In North America, the US market for seaweed has filled the "food for health" niche due to these touted nutritional benefits, but aside from this slim demand, US consumers have little to do with the sea vegetable.

While primary food production and nutritional requirements may be a first motivator for increasing seaweed's yield capacity, seaweed farming can provide two other non-provisional ecosystem services in the form of regulating natural cycles of oxygenation, nutrient loads, and carbon sequestration as well as cultural services that humans derive benefit from like supporting marine biodiversity. Some estimates suggest that algae fix up to half of the world's carbon, and that its continued usage may be implicated in furthering efforts to rectify greenhouse gas emissions (Chung, 2011). Others have marveled at the ability of sea kelp forests to bioremediate excess nutrient runoff when positioned near secondary waste treatments and salmon farms (Handå, 2013). Both N and P are concentrated about 100,000 times more in seaweed than in ambient seawater (Harrison, 2001), where nitrate is stored intracellularly in the vacuole and cytoplasm of the seaweed. The kelp forests of South Australia provide an ecosystem service of biodiversity and ecosystem stability, which is in turn valued at $7.7 billion annually through tourism and fishing (Bennet, 2015).

Intensive mariculture production (finfish and shrimp farms) has skyrocketed due to global fishery catch declines (Cottier-Cook, 2016). Organic pollutants arise in these systems as uneaten foods or feces are degraded and accumulated as inorganic pollutants that severely increase the nutrient loads of the water (Maroni, 2000). A broad body of literature suggests that integrated multi-trophic aquaculture (IMTA) can serve to utilize the excess nutrients created by intensive mariculture, where seaweeds absorb the dissolved nutrients to grow. As seaweed types have varied nutrient uptake rates depending on water properties and time of year, the ratio of marine organisms to seaweeds in ITMA systems often determines the efficacy of excess nutrient removal. This project will uncover some of the possible socio-cultural obstacles to seeing more abundant seaweed production (and consumption) in the Gulf South US coastline, while assessing certain areas of critical importance for trialling seaweed farming where excess water nutrients already exist.

QUALIFICATIONS:

I hold a master's degree in Earth Systems with a focus on Marine Biology. While studying at Stanford's Hopkins Marine Research Station in Monterey, I monitored and catalogued invertebrate larval developments across 11 different marine species. This entailed collecting specimens from walking the rocky intertidal zone (*Pachygrapsus crassipes*) and snorkeling for other submerged invertebrates (*Pisaster giganteus*, *Sepia sepia*) to sample. Once our male and female individuals were placed in tanks, we stimulated gamete release in certain individuals with potassium chloride injection, and would mix sperm and eggs to form fertilized zygotes that could be routinely cleansed in fresh water and documented every three days. I have worked in marine conservation planning and advocacy as a contract data collector for the Save our Seas Foundation and media manager of the Bimini Biological Field Station.

At the research station, I collected data for several PIs related to shark migration pathways using acoustic telemetry, and recorded shark social behavior and daily movement patterns. I also was selected to serve as a citizen scientist for TheOceanCleanup to survey micro and macro plastic accumulation in the Pacific Gyre. As I lead a plant-based lifestyle, I hope to intersect my passion for marine systems with plant-based foods, and this is where my research with seaweed farming begins to take shape.

RESEARCH OBJECTIVES:

Research Objective 1: To identify which native seaweed species are most amenable to cultivation, growth, and human consumption for the Northern Gulf of Mexico (Gulf Coast, US).

Research Objective 2: To determine the nutrient removal uptake and nutritional value of species chosen.

Research Objective 3: After expanding replicates from former results, to evaluate the various benefits of seaweed cultivation alongside coastal aquafarm production sites through nutrient uptake.

Research Objective 4: To understand socio-cultural obstacles to the implementation of seaweed polyculture and explore pathways to implementation.

METHODS:

Site selection and set up: The first two sites are chosen from NOAA measurements of local hypoxia, taking high-output aquafarms' locations into account based on proximate DIN concentrations. The two aquafarms surveyed are Bowers Shrimp (TX) and Motivatit (LA). The two open ocean locations are approximately 10 miles offshore, selected based off water flow rates as control sites where DIN concentration will not be a determinant factor impacting seaweed growth rate. Five 3x2 m structures reinforced with PVC will be attached to floating buoys and weighted to rest below ocean surface to reduce wave or surface water disturbance on seaweed growth. These open ocean structures will be anchored via deeplines and equipped with GPS satellite tracking devices to ensure their recovery in case there is disruptive weather. We will attach native seed stock for each seaweed at .5 m intervals along the PVC structure where they can grow through passive solar radiation using ambient water nutrients.

Water DIN content analysis: The daily water qualities (pH, salinity, temperature, chemical oxygen demand, dissolved oxygen) of each site will be measured with buoyed passive readers similar to YSI. We will also measure concentrations of ammonium, nitrate, nitrite, and phosphate at 2 m depth in the water column on a weekly basis through the research methods used by Parsons et al, 1984.

Native seaweed selection: 5 macroalgae seaweed natives to Gulf of Mexico of different genera are selected: *Porphyra leucosticta, Gracilaria tikvahiae, Percursaria percursa, Ulva compressa, Sargassum natans*. Three of the five of these genera are among the most commonly cultivated seaweeds globally for foods. These seaweeds will be distributed among the top chefs and food distributors in the Bowers Shrimp (TX) and Motivatit Oysters (LA) network for consumer marketability, which includes texture, taste, and nutrient value.

Growth rate and seaweed tissue content analysis: The growth rates of each seaweed will be recorded both on and off shore to determine the most amenable species for expanded cultivation. We will take samples of the tissue of the seaweeds to determine nutrient breakdown with CHNS/o Elemental Analysis methods as used by Chung et al, 2002. In the LUMCOM marine research lab of coastal Louisiana, we will also place acclimated seaweed in saltwater beakers of varying DIN molarities for short periods of time and record the resulting DIN molarity after 20 minutes. Measurements of the resulting DIN molarity in the beakers will allow us to reverse-calculate the amount of DIN uptake by the seaweeds in this short duration, where we will extrapolate seaweed nutrient intake at larger scales and the impacts on the ecosystem. These informations will serve two purposes: we can observe the nutritional breakdown of the seaweed tissue, which can better inform human consumption benefits of each species, and we can also record the nitrogen and phosphate content uptakes of the seaweeds per unit of time to determine their potential efficacy at remediating hypoxia and nutrient excess on a grander scale.

Integrated Multi-trophic Approach for seaweed trials: Having identified the original aquafarm sites near Bower Shrimp (TX) and Motivatit Oysters (LA), we will place three 15 m rows of seaweed seed stocks for the 2 top performing seaweed species of growth and DIN uptake. These expanded replicates will be placed adjacent to coastal aquaculture farms that see high DIN concentration during the summer, where they can grow for a year. Each month, the water properties will be surveyed as well as DIN and phosphorus concentrations sampled to notice if there is any significant nutrient concentration differential between areas with and without seaweed cultivation taking place nearby. These will be compared to historical monthly DIN concentrations of the region. After one year, the disease rates of aquafarmed oysters and shrimps will be surveyed and compared to the company's historical records of productivity lost to disease.

Survey Aquaculturalists for Seaweed Potential: Before the project begins, we will liaise with marketing and consumer branding experts for each company to determine the feasibility of incorporating seaweed sales into their branding strategy. We will conduct interviews with aquafarmers and fishermen on business characteristics to assess qualitative metrics such as one's motivations for farming and fishing, sense of place to Gulf Coast, considerations of ocean health, considerations of animal welfare, effect of dead zones on business, etc. We will also survey them on socio-economic demographics like race, class, and predominant food intake within family to assess whether they depend on aquaculture for their own food sources. The last portion of the survey is to determine the farmers' consumer attraction, neutrality, or aversion to seaweed as a food source, to ask preliminary questions as to whether or not they would consider seaweed as edible and nutritive, or if they would consider selling seaweed to supplement their income. Results of our preliminary growth and nutrition studies will be shared across a network of Gulf South aquafarmers and fishermen, aimed at building rapport and brainstorming solutions to issues of food insecurity, poverty alleviation, habitat restoration and bioremediation. If there is a significant reduction in aquafarming disease rates with correlation to proximity to these native seaweed plots and supplemental native seaweed feed for oysters and shrimp, these results will also be shared with aquafarmers in the Gulf South region.

RESEARCH OUTCOMES AND IMPACTS:

The project hopes to inform coastal aquafarmers of the underutilized and undervalued role of native seaweed cultivation. The results will reveal how IMTA practices with seaweed polyculture can contribute to economic diversity for aquafarmers as sources of human food during off-harvest season, aquafarming supplements, disease resistance, and also as ecosystem services through nutrient cycling management and bioremediation for excess nutrient loads near sinks of fertilizer runoff or fecal deposition in aquafarms.

By testing water quality of high and low DIN sites, we hope to learn more about the efficacy of seaweed nutrient uptake and determine which of the numerous species may be best adapted for locations along the northern Gulf of Mexico. We hope to inform farmers on the preferred species of seaweeds to be cultivated in their regions, in order to reduce non-indigenous seaweed proliferation and their resulting epiphyte and potential pathogenic introductions that can alter ecosystem functionality.

Seaweed cultivation may possibly ameliorate common issues of eutrophication or brown blood disease caused by excessive nutrient loads that prompt algal blooms and coastal hypoxia. We hope to identify the types of IMTA organismal combinations and spacings that respond in culturally sensitive ways to farmer's practice while also mitigating environmental consequences of business as usual methods. As eating diverse arrays of native seaweeds has also been linked to reduced disease outbreak in aquafarming case studies, we hope this informs farmers on ways to reduced economic loss.

More idealistically, an overarching goal is to increase domestic human production and consumption of diverse sea vegetables as a response to the negative environmental consequences associated with terrestrial, industrial agriculture that is still very much dependent on deforestation, land transformation, fertilizers, and pesticides. These sea-plants store 1/2 of the globe's carbon and can absorb greenhouse gases at 5 times the rate of land-based plants, helping potentially mitigate ocean acidification (Schiffman, 2016). We hope to demonstrate native seaweeds undervalued in the role they play in solving nutritional deficiencies as well as abating carbon emissions in the anthropocene.

RESEARCH OUTREACH AND RESULTS DISSEMINATION:

Within each of the 2 regions of aquafarms and hypoxic regions in the Gulf of Mexico, we will catalog a list of the top aquafarmers and coastal fishermen who could benefit from this approach.

Based on preliminary research, we will reach out to the Gulf South aquafarming companies Bowers Shrimp and Fish (TX), Frugé Seafood (LA), Elkstrom Enterprises (TX), and Motivatit (LA). We will include networks of coastal marine stations through universities like LUMCOM, LSU, University of Alabama, Florida Gulf Coast University and Texas A&M.

As findings are determined, we will post updates on multiple social media accounts, including facebook, twitter, instagram, and blogger, engaging the public and the companies with their social media accounts for increased engagement. By linking with vegan and vegetarian communities through social media on the research findings, this will also open up the market for direct seaweed consumption in the Gulf South US that is not currently being used to its fullest potential.

Eventually, if these companies choose to experiment with a portion of IMTA, we will assist them in setting up coastal farms that center seaweed cultivation as a means of marine habitat biodiversity, bioremediation, carbon sequestration, finfish and marine invertebrate feed, as well as human food. Ultimately, through publishing these results in peer-reviewed journals and collaborating with local universities like LSU and Texas A&M, this information can reach aquafarmer scientists who otherwise ignore the possibility of seaweed cultivation as a necessary part of the mariculture economy.

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