Sustainable Seaweed Aquaculture

Exploring how to grow, sell, and consume native seaweed

in the emerging culinary market

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SCRIPPS INSTITUTION OF OCEANOGRAPHY

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Executive Summary

The sustainable seaweed aquaculture capstone project describes the process of discovery connecting the production, distribution, and consumption of sustainable seaweed in the Southern California region. Increasing the supply of safe, sustainably produced domestic seafood is a stated priority of the State Legislature, the National Oceanic and Atmospheric Administration (NOAA), and the Department of Commerce; however, the aquaculture industry of California is still in its nascency. Site visits and interviews of business leadership revealed that California seaweed aquaculture is primarily a boutique industry consisting of a relatively small group operations cultivating relatively few species for culinary use at high end seafood restaurants. To gather qualitative understanding of operational management and consumer attitudes towards consuming native seaweeds, we visited regional distribution outlets focusing on fresh, high quality, local seaweed. Next, consumption of seaweed was explored through collaborative food events with six different chefs spanning Northern Baja California to San Luis Obispo. A series of four scientific growth experiments was designed for two high value native culinary seaweeds *Gracilaria pacifica* (Ogo) and *Palmaria palmata* (Dulse), which were subsequently funded by an E.W. Scripps Associates grant via the Director's Office. Finally, a series of business resources was leveraged to begin the process of venture creation, including the Rady Micro MBA program, Rady Lab to Market SPARK program, Triton Innovation Challenge, and Rady Social Venture Accelerator. Ultimately, the project resulted in the creation of the California Seaweed Co., which is in active development as an early stage startup. The company seeks to

provide a platform for ongoing research and development of seaweed aquaculture and production at scale in order to supply the Southern California market with safe, sustainably produced domestic seafood.

Introduction & Background

The earliest written record of human usage of algae (seaweed) originates from China, about 1700 years ago (Li-En Yang, Qin-Qin Lu & Juliet Brodie European Journal of Phycology Vol. 52 , Iss. 3,2017). The word macroalgae is used interchangeably with seaweed in addition to both scientific and common cultural names often used by chefs and consumers. Today 96% of commercial seaweeds globally are produced by aquaculture(FAO, 2016). The global commercial seaweeds market was valued at USD $10.31 billion in 2015 and is expected to reach USD $22.13 billion by 2024, growing at a compound annual growth rate (CAGR) of 8.9% from 2016 to 2024 (Grandview Research 2016). In a parallel to food production in the terrestrial space, humans are shifting from a mode of hunting and gathering of wild seafood to one of strategic production. Strategic production implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. In particular, aquaculture is the breeding, rearing, and harvesting of animals and plants in marine and aquatic environments, including ponds, rivers, lakes, and the ocean, and shares many similarities to agriculture. Agriculturists carefully select areas with rich soil and favorable weather conditions for farms or create them indoors in controlled environments like greenhouse. Aquaculturists can locate environments with the required temperature, light, salinity and nutrient densities which allow organisms to flourish or

they can create managed conditions in a contained water environments on-shore. World aquaculture production of fish and plants combined reached 101.1 million tonnes in live weight in 2014, for an estimated total farmgate value of USD $165.8 billion. Farmed aquatic plants alone contributed 27.3 million tonnes (USD $5.6 billion) to this total. The Food and Agriculture Organization of the United Nations (FAO) tracked a total of 580 species and/or species groups farmed around the world in 2014. These species items include 362 finfishes, 104 molluscs, 62 crustaceans, 6 frogs and reptiles, 9 aquatic invertebrates, and 37 aquatic plants. (FAO 2016).

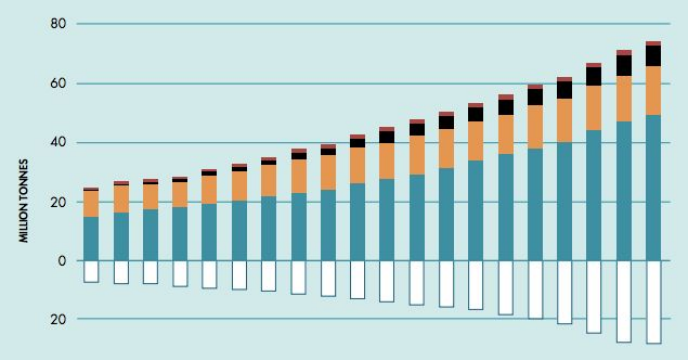

Figure 1. World Aquaculture Production Volume and Value of Aquatic Animals and Plants (1995–2014). Source: FAO 2016

While the majority of ocean-based aquaculture is focused on fish and invertebrate species (shellfish, crustaceans, and cephalopods), there is increasing interest in farming marine plants or seaweeds (Kim, Yarish et al. 2017)

Global Seaweed Market

Seaweed aquaculture is practised in about 50 countries with output more than doubling in the past decade with annual production now exceeding 27 million metric tons. (FAO

2016). Asian countries represent the top aquatic plant production with China, Indonesia, Philippines and South Korea representing top global producers. In some instances aquaculture farms are so large they are visible from space (FAO 2016).

Production of Farmed Aquatic Plants

	2005	2010	2013	2014
		(Thousand tonnes)		
Kappaphycus alvarezii and *Eucheuma* spp.	2 444	5 629	10 394	10 992
Laminaria japonica	4 371	5 147	5 942	7 655
Gracilaria spp.	936	1 696	3 463	3 752
Undaria pinnatifida	2 440	1 537	2 079	2 359
Porphyra spp.	1 287	1 637	1 861	1 806
Sargassum fusiforme	86	78	152	175
Spirulina spp.	48	97	82	86
Other aquatic plants	1 892	3 172	2 895	482
TOTAL	13 504	18 993	26 868	27 307

Source: FAO 2016

The modern global seaweed business market is segmented on the basis of product type, form type and application. The seaweed biomass produced from aquaculture activities has varied uses/markets: It is directly consumed by humans, used in feed for fish and livestock, applied as thickening and gelling additives for foodstuffs and pharmaceuticals. Importantly, the demand for human food production has continued to increase (Chopin, Buschmann et al. 2001). Red seaweed emerged as the leading product segment and accounted for 52.5% of total market revenue in 2015. Red seaweeds are also projected to grow at the highest CAGR due to their unique functional qualities, high diversity of species, ease of culturing for many species, and their use in almost all industrial sectors(e.g. *Pyropia* (Nori) for sushi and *Gelidium* for agar production). Human consumption has recently become the leading application segment

and accounted for 81% of total revenue in 2015. This segment is also expected to witness the highest growth of ~9.0% over the forecast period 2016-2024 (Grandview Research 2016).

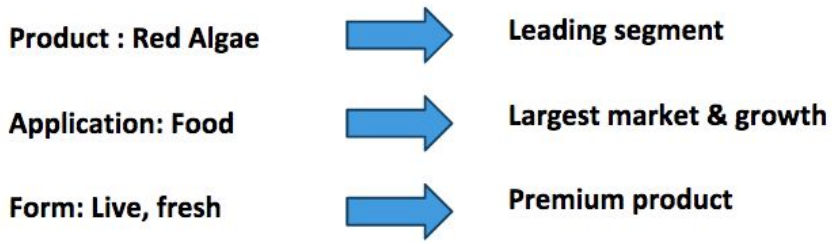

Figure 2. Red Algae produced for food represents a large market opportunity

In contrast with the large scale production in Asia, California seaweed aquaculture is a boutique specialty market consisting of a relatively small group of species being cultivated for culinary use for high end seafood restaurants. However, the lack of domestic seaweed production is not due to a lack in demand. In 2014 the US became the largest importer of Korean farmed seaweed, spending more than USD 67 million per annum and surpassing Japan, which spent USD 58 million. This value is expected to hit $100 million annually by 2017 as the popularity of seaweed continues to increase (The Korea Times, 2014). Two species with existing culinary use markets and which grow well in onshore aquaculture environments in Southern California's oceanographic conditions and climate are *Gracilaria pacifica (Ogo)* and *Palmaria palmata (Dulse)*. *Gracilaria pacifica* is a native red alga with a range that extends from Baja California to British Columbia. *Gracilaria* species are commonly cultivated for a variety of uses including agar production, as the culinary ingredient known as "Ogo" which is commonly found in raw fish salad (or Poke), as food for ornamental aquarium fish and feed for

farmed abalone. Dulse (*Palmaria palmata)*, is another red seaweed used as food that has been marketed and popularized as “tasting like bacon”. It is dried and sold in whole pieces, usually eaten without cooking, or as a powder that is used as a condiment. It grows in cold waters and is collected off the West Coast of the United States, Ireland, Iceland and the east coast of Canada. There is a small industry domestic between the Pacific Northwest and Central California working to expand the market for dulse. (DJ McHugh - 2003)

Nutritional contribution of seaweeds

Seaweeds are high in vitamins, minerals, and plant-based proteins yet low in calories and are becoming increasingly popular as a source of food (Rioux, Beaulieu et al. 2017). The primary chemical and nutritional constituents of seaweed varies according to the species, harvest location and time, wave exposition and water temperature (Laurie-Eve Rioux Lucie Beaulieu Sylvie L.Turgeon 2017). The nutritional quality of seaweeds is noteworthy due to the abundance of key nutrients such as dietary fibers, minerals (especially iodine) and certain vitamins (e.g., B12). Seaweeds can also contain important proteins and polyunsaturated fatty acids (omega-3) (Cardoso, Pereira, Seca, Pinto, & Silva, 2015). Studies have consistently associated lower incidences of cancer with diets rich in seaweeds in Asian countries (Cian, Drago, de Medina, & Martínez-Augustin, 2015). Beneficial cardioprotective, anti-inflammatory and neriprotective effects have also been noted in addition to improved gut microbiota and function. (Cian et al., 2015; Liu, Banskota, Critchley, Hafting, & Prithviraj, 2015).

Culinary Characteristics

Marine macroalgae are unique. They can provide texture and flavor to food, two outstanding characteristics that may open up to new culinary innovation (LE Rioux, L Beaulieu, SL Turgeon - Food Hydrocolloids, 2017). The umami taste was first described in 1908 in a traditional Japanese seaweed broth called dashi which is made from Kombu (*Saccharina japonica*) and other ingredients including shitake mushrooms and fermented bonito (katsuobushi). Its common utilization started during the Edo period (1603–1868) is still used almost every day in Japanese households (Y Osawa - Ecology of food and nutrition, 2012). The word “Umami” and its concept were coined, in the early twentieth century, by a Japanese chemist named Kikunae Ikeda. The Japanese word for delicious, *umai*; umami translates roughly to “deliciousness.” Taste research confirms that molecular compounds in glutamic acid—glutamates—bind to specific tongue receptors to create the “fifth taste” (Goldfield, 2015). Growing trends in American food preferences which incorporate seaweeds are the expansion of sushi popularity, Asian fusion restaurants, and Polynesian inspired foods such as Poke which has surged in popularity in recent years. A search of southern california restaurants on yelp returned over three thousand businesses with the word “Poke” in their name, menu or in listed reviews. One poke recipe made popular by self proclaimed godfather of poke” Chef Sam Choy calls for 2 ounces of Ogo per serving.

Problem and Opportunity

The lack of domestic seaweed production is not due to a lack in demand. In fact, in 2014 the US became the largest importer of Korean farmed seaweed, spending more

than USD $67 million and surpassing Japan, which spent USD $58 million; this value is expected to hit USD $100 million annually by 2017 as the popularity of seaweed continues to increase (The Korea Times, 2014). There are currently only two onshore aquaculture operations growing seaweeds for culinary use in Southern California in spite of a large potential market and favorable climate. Substantial barriers to entry in terms of cost and time investment if seeking a new seawater intake and discharge permit are a likely limit to proliferation of the seaweed industry. Additionally, coastal real estate in Southern California is cost prohibitive in areas adjacent to clean seawater. However, the existing operations are instructive examples of what is possible for the future of California culinary seaweed production. One operation in Moss Landing, California is a family owned boutique producer of high quality seaweed with an on-shore flow through seawater system. The private company, Monterey Bay Seaweeds, is nested within the facility of public research institution at Moss Landing Marine Laboratories. This model could be replicated at Scripps Oceanography or other research institutions that already have permits and ocean water access and circulation infrastructure. Seaweed product is shipped live in sterile seawater to both local and out of state restaurants, at time fetching prices between USD $25 and USD $50 per pound.

Capstone Project

a) Market Analysis
b) Exploration of Local Industry
c) Culinary Networking and Qualitative Market Outreach
d) Business Model Discovery
e) Proof of Concept Growth and Optimization Experiments
f) Scientific Research In Progress

Market Analysis

Total Available Market (TAM) | Global Seaweed Consumed | $5 Billion

Serviceable Addressable Market (SAM) | Annual U.S. Imports | $100 Million

Serviceable Obtainable Market (SOM) | Southern California Underserved Market $110 Million

Figure 3. Estimated production capacity of onshore flow through seaweed growth system Ogo (*Gracilaria pacifica*)

Exploration of Local Industry

Seven aquaculture production and research sites were visited and/or management interviewed in California and Oregon in order to compile a qualitative assessment of the strengths, weaknesses, opportunities and threats to the seaweed industry. We visited a combination of seaweed, finfish and shellfish aquaculture sites, to get a complete picture of the challenges involved in operating and maintaining aquaculture facilities. The site visits are briefly described below in geographic order, from south to north.

Hubbs Seaworld Research Institute (San Diego, CA)

Aquaculture efforts are primarily focused on breeding finfish (Yellowtail Jack, White Seabass and Striped Bass) onshore and raising to market size offshore. Don Kent,

President and Chief Executive Officer of Hubbs Seaworld Research Institute (HSRI) granted an in person interview, tour of the aquaculture facility and was a guest speaker at an aquaculture panel presented at the inaugural SIO 286 Sustainable Seafood course. HSRI strengths exist in their connection to a well funded publicly traded company, SeaWorld Entertainment Inc., (NYSE: SEAS) with over 50 years of experience and a research equipped facility with seawater access. However, weaknesses may lie in the brand affiliation and physical proximity to SeaWorld due to animal rights concerns, especially those related to husbandry of marine mammals. The opportunity to be a well supported offshore aquaculture partner to private industry may help mitigate this brand image liability. Threats to success of the aquaculture program initiatives include uncertain regulatory environment for cost and timeline of securing offshore production and distribution permits.

Carlsbad Aquafarm (Carlsbad, CA)

Thomas Grimm granted an introductory meeting and toured the facility. This was the first site meeting on the project and illustrated some of the promise and difficulties with conducting aquaculture production *in situ*, even when working in a protected embayment environment. The minority stake partners on the project Norm and Rebecca Abell are now offsite splitting time between their new operation overhauling Glausen Oysters, currently the largest oyster farm in Oregon. Rebecca Abell also joined the SIO 286 Sustainable Seafood aquaculture panel as a representative of the aquaculture industry.

Catalina Sea Ranch (Long Beach, CA)

I conducted several full day visits to CSR and shadowed CEO Phil Cruver. The operation is the only shellfish farm on the west coast operating offshore in federal waters. This operation was well funded and boasted a well connected board of directors with successful background in a number of various industries. I reviewed several of their awarded grants and also brainstormed with the CEO about future potential funding to incorporate a larger algal component to the operation. At the time seaweeds weren't their main focus but they have since received research funding to pursue offshore kelp cultivation.

The Ventura Shellfish Enterprise (Ventura, CA)

The Ventura Shellfish Enterprise (VSE) is a multi-party initiative that seeks to permit twenty 100-acre plots for growing the Mediterranean mussel (*Mytilus galloprovincialis*) via submerged long lines within the Santa Barbara Channel near Ventura Harbor.This project highlighted the difficulty of achieving progress forward with a plan in California state waters. As envisioned, the Ventura Shellfish Enterprise positions the Ventura Port District (VPD) to hold all entitlements for the group of offshore aquaculture leases that will then be subleased to individual producer-fishermen for shellfish farming. These sublease opportunities will be marketed to both existing Ventura Port District commercial fishermen, commercial shellfish businesses and startups. Without such a pre-permitting structure, these entities would be less likely to entering the business given the uncertain regulatory pathway. As a requirement of their tenancy, sub-lessees will agree to operate under robust environmental monitoring guidelines and best

management practices adopted from third party certification agencies. The project is currently moving through the community outreach, planning and permitting stages. I attended numerous public workshops in Ventura county to understand how the formative process of creating an offshore aquaculture collective functions. The VSE team expanded it's identified candidate area search for site to include a new option in federal waters after a combination of public comments and stakeholder response on the initial plans. On November 15, 2017 the proposed plan was presented to the Board of Port Commissioners a 2,000 acres of sea water bottom in federal waters near Ventura Harbor. The Ventura Port District (VPD) received a substantial sub-award from a $300,000 NOAA 2015 Sea Grant for the proposed project in support of the project. The Cultured Abalone (Gaviota, California)

Doug Bush, the general manager of the Cultured Abalone granted an interview and site tour of their facilities.The Cultured Abalone raises the native red abalone, *Haliotis rufescens*, through their entire life cycle from spawning and larval rearing in their on-shore hatchery through to the harvest. The system utilizes a continuous flow through of raw seawater drawn in from a depth of 40ft. Doug Bush also provided live seaweed that we transported to Scripps Oceanography to begin the project's hands-on aquaculture testing phase. The Cultured Abalone became the primary partner of the project providing Ogo and Dulse for both experimental biomass and marketing samples and larger scale deliveries to the partner chef food events.

Monterey Bay Seaweeds (Monterey, California)

Monterey Bay Seaweeds (MBS), a private venture nested within a public research institution at Moss Landing Marine Laboratories, could be a model for future aquaculture venture creation in the University of California system. Dr. Mike Graham is a professor of phycology at California State University Monterey Bay, Moss Landing Marine Laboratories who also runs an on-shore seaweed farm with his family. They are growing several species native to California including *Palmaria palmata* (Dulse), *Gracilaria pacifica* (Ogo), and *Ulva lactuca* (Sea Lettuce). MBS is producing approximately 50 lbs per week per 1,000 gallon tank. Given the market price up to $50 per pound this gives an possible revenue generation of $2,500 per tank per week.

Clausen Oysters (Coos Bay, Oregon)

Clausen Oysters is the largest oyster farm in the State of Oregon. Pacific Oysters are grown on 600 leased acres in Coos Bay and harvested year-round. Fresh and shucked oysters are shipped to seafood distributors for the wholesale market and sold locally to restaurants and to the public. The company is run by Norm and Rebecca Abell, two experienced aquaculturists who previously operated the largest on-shore culinary seaweed production in San Diego. Norm is also the president of the Tuna Harbor Dockside Market and granted in person interviews discussing the potential of reinvigorating the seaweed farming potential in San Diego.

Culinary Networking and Qualitative Market Outreach

Qualitative market research was conducted via educational boothing, in person interviews with executive leadership and sample distribution at points of sale. Catalina

Offshore Products and The Tuna Harbor Dockside Market were the primary San Diego distribution locations visited. To compare qualitative public interest and general response to consuming southern california cultivated native seaweeds I set up educational booths during peak market hours (10am-12pm) on two Saturdays at Catalina Offshore Products and Tuna Harbor Dockside market. These two operations both serve the same niche of local, fresh, high quality seafood to the San Diego market. The display included Sea Grant produced flyers containing information on seaweed biology, serving sizing and recipes for the two native native seaweeds *Gracilaria pacifica* and *Palmaria palmata* Additionally, a tank with live seaweeds was used to showcase tumble aquaculture production.

To validate the opportunity apparent in the economic review of the seaweed aquaculture industry chef visits were arranged. Starting locally in North Park San Diego at Saiko Sushi, a kitchen that prides itself on sourcing the freshest ingredients possible. Head Chef Anthony Pascale primarily sources Catalina Offshore Products for his kitchen's menu. The first visit with Chef Pascale involved bringing several pounds of live Ogo to his kitchen where he experimented with several seaweed salad combinations, including deep frying the Ogo into crispy sticks and placing it on top of their regular seaweed salad (rehydrated imported Asian seaweed of unknown species composition).

> *"The quality of the local seaweeds far surpasses the closest substitute. It has a rich and distinctive flavor that compliments everything on our locally sourced progressive Japanese menu."*
>
> -Chef Anthony Pascale | Saiko Sushi

A cross-border trip to visit with chefs from restaurants in Baja, Mexico proved to be the most significant culinary breakthrough of the project. While visiting the restaurant Deckman's En El Mogor I delivered live Ogo (*Gracilaria pacifica*) to Michelin Star Chef Drew Deckman. During the meeting he showed the local foraged seaweeds he was cooking with but acknowledged the supply was not consistent and the exact location, species and harvest practices were occasionally unknown to him.The success of that first meeting opened the door to a series of food events in San Diego and resulted in the first complete dish by a chef from the project using our target seaweeds. Chef Deckman sources as many of his ingredients from the Guadalupe Valley as possible, including from the Mogor Ranch itself. He personally meets with the fishermen he purchases his seafood from. Chef Deckman voiced enthusiasm and support for the ideals of the project -- building a steady supply of high quality sustainably grown native seaweeds. The following week live Ogo (Gracilaria pacifica) was used in the creation of multiple dishes by Chef Deckman as the final round of dishes for an event featuring cadre of Baja California chefs brought to Bitter Brothers Brewing in San Diego. Northern Baja California flavors were paired with a variety of San Diego beers to create an cross-border food fusion.

Figure 5. Chef Drew Deckman dish featuring Ogo.

The following week Chef Deckman while preparing for a benefit dinner for Tuna Harbor Dockside Market along with an all-star group of sustainable seafood specialists across Southern California at The Land and Water Co. restaurant. Owner ,Chef Rob Ruiz. Rob Ruiz was named “Best Chef” is San Diego for 2016 and was also awarded the 2016 World Oceans Award for his campaign to conserve the vaquita porpoise and promotion of using shrimp caught without use of gillnets.

> *"What an incredible and sustainable ocean product. The Ogo is totally versatile from salads to cooked to sauces and vinaigrettes. I enjoy using the Ogo, and look forward to every chance I have the opportunity in the future."*
>
> -Chef Drew Deckman | Deckman's en el Mogor

Ogo was sourced from The Cultured Abalone and delivered to Bill ‘Butter’ Joyce for the 2017 San Diego Pokefest. The winning group had a seaweed blend of at least four species that were flown in from Hawaii for the event.

Chef Rob Ruiz was the featured chef for lunch break snack served immediately following the sustainable seaweed project presentation as part 2016-17 MAS Marine

Biodiversity and Conservation cohort. The dish featured U.S. hook and line caught Wild Eastern Pacific bigeye tuna which was locally offloaded in San Diego, hand cut and proton frozen by Catalina Offshore Products (COP) in San Diego. Proton freezing is an emerging technology that combines an environment of evenly distributed electromagnetic waves and cold air. This quick freeze method reduces ice crystal formation and therefore reduces cell membrane damage. Unlike most frozen tuna sold in the U.S., proton-frozen tuna is not CO-treated. Because of this, its signature red color will naturally turn brown after about 30 days if left in a traditional home freezer. If consumed within a short window after freezing, color will look as fresh as when it was first cut (COP 2016). Proton frozen tuna is a natural alternative to frozen saku blocks of gassed tuna that are common in poke restaurant chains. Fresh live Ogo sourced from The Culture Abalone completed the dish. The public response was overwhelmingly positive. Locally produced seaweeds pair perfectly with new these new food preservation techniques developed by COP, that if combined at scale could find a market beachhead by servicing the large and growing Poke restaurant sector in Southern California.

> *"Over the last decade a void has appeared in the Culinary World, as consumers demand natural, responsibly harvested products. Specifically, a lack of having access to locally grown, nutrient rich seaweed species, limu, and edible algaes. These seaweeds, like Ogo and Dulse, not only offer access to underutilized natural food sources, but also blue tech jobs, and opportunity for innovation."*
>
> -Chef Rob Ruiz | Land and Water Co

Business Model Discovery

The project outreach and food event collaborations with top sustainable seafood chef revealed one clear problem: despite being one of the most sustainable and nutritious seafoods on the planet, restaurants, chefs and consumers in the United States do not have consistent, high volume access to live culinary seaweeds.The solution of land based aquaculture of a native seaweed superfood emerged as a result of exploring the strengths, weaknesses, opportunities and threats to the California aquaculture industry.

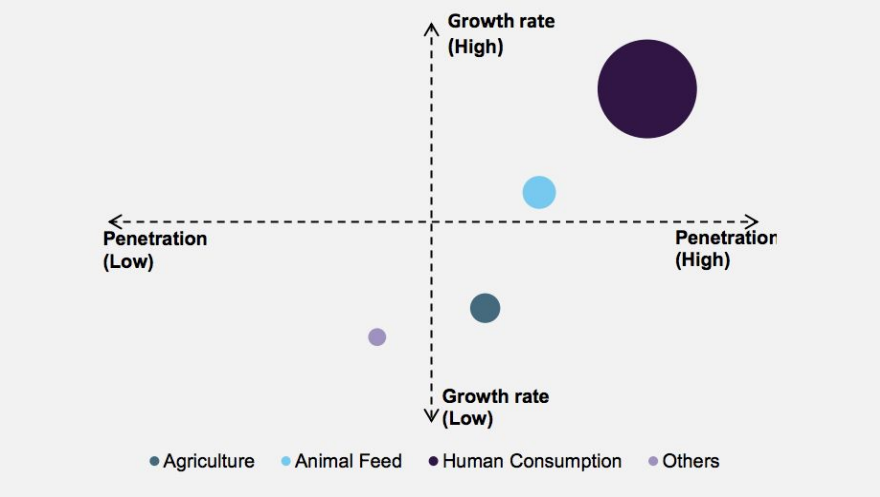

Figure 5. Commercial Seaweed Opportunities *Source: FAO, International Seaweed Association, SIA, Primary Interviews, Grand View Research*

Seaweed is an optimal crop for aquaculture for human food use due to:

- Controlled on-shore operation
- Short crop time to harvest
- No freshwater or fertilizer inputs

The environmental sustainability component of on-shore aquaculture is another factor which make seaweed aquaculture a viable and attractive business opportunity. With the global human population forecast to surpass nine billion by 2050 there is a clear and growing need to identify sustainable sources of food. The increasing threats of climate change, social and economic instability and competition for natural resources leads many nations to prioritize investment in aquaculture as an emerging food resource (Folke and Kautsky 1992). The recurring inputs of fertilizer needed for terrestrial agriculture production are not required for onshore algal aquaculture: no fresh water, fertilizer or soil is necessary for successful seaweed production when raw, filtered seawater is utilized. In contrast with offshore projects, onshore aquaculture does not require extensive production equipment in the ocean, therefore sensitive marine ecosystems and coastal habitats are not negatively impacted. When using a shore based flow through seawater system the ocean use footprint is limited to only the point of seawater intake and discharge. Shore based projects have a greater likelihood of success by eliminating expensive and complicated ocean spatial planning processes, engineering and permitting procedures across a multitude of agencies and stakeholders. Further because seaweeds take up large amounts of Nitrogen & Phosphorus from the environment, they can be used in a bioremediation context to improve water quality.

Business Model Development

Multiple business development programs and management training resources were applied to exploring venture creation of a sustainable seaweed aquaculture company.

This included start-up business focused management modules for aspiring entrepreneurs, a condensed Masters of Business Administration curriculum, Social Venture Accelerator and the Triton Innovation Challenge sustainability innovation competition.

Rady SPARK, Rady School of Management

The Rady Spark program follows the “innovator’s journey” utilizing a condensed version of the full year (3 quarter) Lab to Market Rady School of Management course led by Dr. Vish Krishnan and Dr. Ricardo Santos. The spark program consists of three modules : Discover, Validate and Launch.

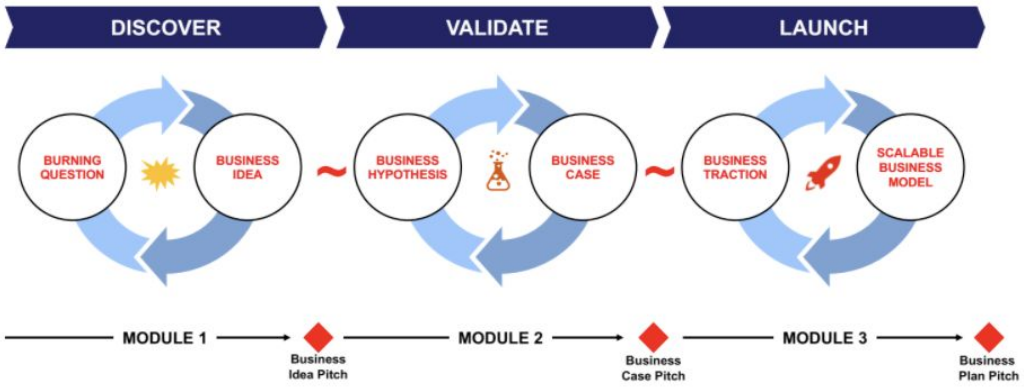

Figure 6. The Innovator’s Journey. Source: Rady Spark Discover, Prof. Ricardo dos Santos

I led a sustainable seaweed project team through the curriculum with the goal to use the course as a vehicle to begin exploring the possibility of creating an algal aquaculture program. The course theory centers on Steve Blank’s “Lean Startup” model with one key tool of the course being the business model canvas. In the first “Discover” model our team used a staged approach to iteratively build out the business model canvas with sub-canvases such as the business idea canvas.

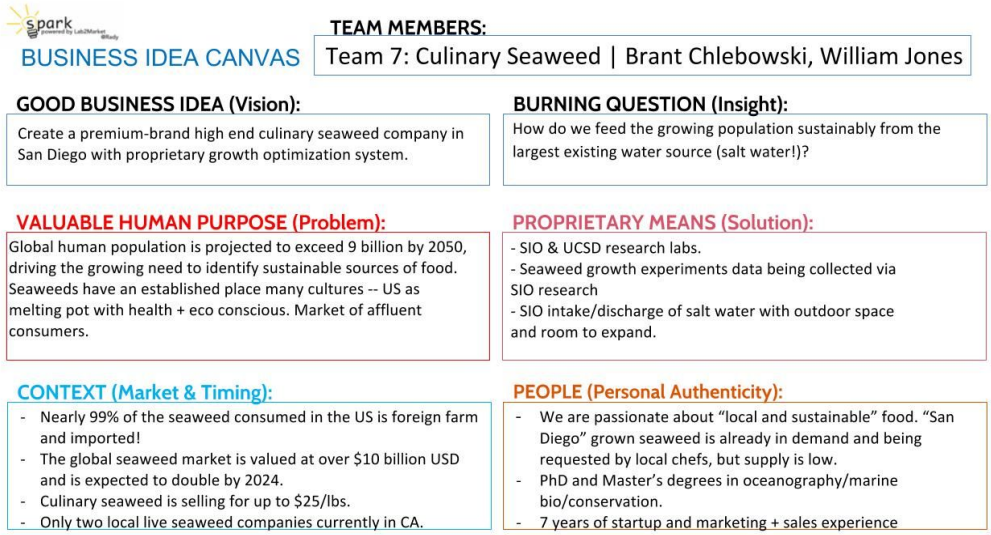

Figure 7. SPARK Business Idea Canvas.

The Rady MicroMBA course filled the gap between the Spark 'Discover' and 'Validate' modules. The Rady School of Management organized MicroMBA Course to provide Phds, Postdocs and graduate students the opportunity to gain an introduction to business concepts, network with business professionals, and become a part of the entrepreneurial science/tech community. The twelve-session course covered topics ranging from strategy, financial decision analysis and leadership to business analytics. Weekly structured coffee chats with top tier local business professionals facilitated small group dialogue about specific topics of interest especially to students motivated by personal entrepreneurial projects.

Triton Innovation Challenge, Scripps Oceanography

The project entered the Triton Innovation Challenge (TIC), a business competition that spotlights commercially promising, environmentally focused technologies between the Jacobs School of Engineering, Rady School of Management and Scripps Institution of Oceanography. The competition was a vehicle which allowed the sustainable seaweed

project team to deploy principles learned in earlier business-focused training to the campus wide business competition. Our team completed the National Science Foundation funded Scripps Innovation Bootcamp, a three-week pitch and business development course taught at Scripps by staff from the Jacobs School of Engineering Institute of the Global Entrepreneur. Mentorship from experienced business professionals and entrepreneurs worked with the team to refine the product, market, business concepts, and pitch presentation. The bootcamp forced a rapid brand development and the *California Seaweed Co*. was formed including logo, website and other marketing collateral.

Figure 8. The first California Seaweed Co logo

Achieving a third place finish in the TIC finals, including the top finishing team from Scripps Oceanography solidified the California Seaweed Co's confidence in the viability of continuing the research and development of the sustainable seaweed aquaculture venture.

Figure 9. Brant Chlebowski presenting during the Triton Innovation Challenge pitch Photo: Erik Jepsen/UC San Diego

Social Venture Accelerator, Rady School of Management

Following the success with the TIC business competition, the California Seaweed Co was accepted into The Social Venture Accelerator (SVA). The Rady program is designed to support students who are interested in creating social impact through entrepreneurship. SVA teams participate in workshops where we explore social entrepreneurship and focus on the various aspects of launching a startup. We are supported by a team of mentors and advisors with experience in social entrepreneurship.

Scientific Research In Progress

Dr. Jennifer Smith led drafting a proposal for an Internal SIO development grant via the director's office and the EW Scripps Associates. The proposed scientific work plan builds on the qualitative market research completed in the first half of project via

outreach to seaweed producers, distributors and consumers. We proposed to conduct a series of eight experimental manipulations to identify conditions that optimize growth rates (e.g., temperature, light and stocking density) for market two market ready seaweed species of red algae, Ogo (*Gracilaria pacifica)* and Dulse *(Palmaria palmata).* Growth rate is an important factor to consider for optimizing production and yield in seaweed aquaculture.

For each experiment, we will use a regression-based approach where 10 unique treatments will be used to gradually increase or decrease the specific parameter of interest. Irradiance values will range from 50-1000 μM m-2 s-1 spanning typical values determined from PAR sensors in coastal CA. We will vary inorganic nitrogen concentrations from 1-100 μM which covers conditions mimicking El Nino through to extreme upwelling. Temperature treatments will range from 55-70o F, spanning the natural thermal range present in San Diego surface waters. Lastly, we will alter initial stocking densities for each species by an order of magnitude across the 10 treatment tanks. As stocking density is known to significantly alter growth rates due to self-shading and alteration of boundary layer dynamics due to crowding, this is a key component of this experiment and will allow our team to identify conditions that optimize growth potential.

A total of eight experiments will be run, four for each seaweed species. For each experiment, three replicates of each treatment level will be used to quantify within treatment variability in algal responses. All experiments will be conducted in the Smith Lab's aquarium room in Hubbs Hall using 2 L aquaria with LED lighting (12/12 light dark

cycle) and flow through seawater and outdoors at Tank two.

All experiments will run for 2 weeks and specific algal responses that will be quantified include: 1) change in growth weight (g), 2) % change in weight, 3) pigment concentrations (Chl a, carotenoids, phycobilins) and 4) photosynthetic efficiency (measured with a diving PAM fluorometer). All algal response data will be explored using model fitting approaches to determine optimal conditions for growth and physiological performance. Finally, once conditions have been optimized we will explore the grow-out of the two species in larger (500L) outdoor circular aquaria installed on the platform at Tank #2 at SIO (behind the Sea Grant building). Temperature, irradiance, stocking density and nutrient concentrations will be maintained at values determined to optimize growth from the experiments outlined above. These data will allow for determination of doubling times or time to harvest for these species in more typical aquaculture setting, which can then be used to inform development of a business plan for future scaling and commercialization of these and potentially other species in the future.

Proof of Concept Growth and Growth Optimization Experiments

To date we have successfully Species cultivated - Ogo (*gracilaria pacifica*) using both indoor and outdoor flow through system with raw seawater sourced from the Scripps Oceanography main supply drawn from the end of the pier. Approximately 5 kilograms of *Gracilaria pacifica* were acquired from the production stock at the Cultured Abalone aquaculture facility in Goleta California in March 2017. The biomass was transported in sealed plastic bags without seawater to Scripps Institution of Oceanography and placed

in clear sided aquaria outdoors with a raw seawater flow through system at tank 2. The experiment specimens were selected from this transferred stock which was cultivated with a flow through seawater system drawn from the Scripps pier. A tumble culture was achieved with a combination of directed water jets from a perforated PVC pipe placed on the bottom on one side of the aquaria lengthwise. This imparted a water flow across the bottom of the aquaria. Compressed air emitters were placed on the bottom opposite the PVC pipe to encourage water movement upward toward the surface of the tank. When functioning correctly a vigorous and continuous tumble of biomass was achieved with the excess seawater flow through spilling over the top edge of the aquaria on the outdoor water table. The aquaria were cleaned weekly at which time the entire contents of the individual tanks were cleaned of epiphytes, diatoms and other contaminants were brushed away and dead or damaged Ogo biomass was removed.

Figure 10. Outdoor cultivation of Ogo. Photo: Nina Rosen

Indoor used small rectangular flow through tanks with air stone bars (8”-12”) to assist with tumble due to flow through restrictions on the indoor wet lab table drains. After using larger (12-18”) air stones for the higher volume aquaria it became clear that the water flow rates could be reduced if air flow was used to drive water circulation and according biomass movement.

An outdoor experimental setup was constructed using 15 gallon opaque circular plastic tubs with stand pipes inserted vertically to maintain a constant water level. The tubs were drilled through the bottom to allow drainage out the center of the bottom in order to avoid biomass losses due to overflow of the tanks/tubs. This loss of biomass due to fragmentation (likely due to grazers) and subsequent clogging of the indoor tank drains caused the tanks to overflow and biomass was lost down the drain. This confounded the first indoor density experiment with *Gracilaria pacifica* (Ogo). This experiment will be repeated on the improved outdoor system with circular tubs and vertical stand pipes. The final experimental setup included 10 tubs in 2 rows of 5 arranged on top of a water table outdoors at Scripps sea water storage tank number two.

Conclusions and Next Steps

Today 96% of commercial seaweeds globally are produced by aquaculture with a market valued at over USD $10 billion in 2015, forecast to more than double by 2024. The U.S. is one of the largest importers of seaweed globally, with the 2017 figure forecast to reach USD $100 million. Red Algae produced for food represents a large market opportunity as it is the leading product segment and accounted for over half of total market revenue. Red seaweeds are also projected to grow at the highest CAGR

and furthermore human consumption is now the leading application segment and accounted for 81% of total revenue in 2015. This segment is also expected to witness the highest growth of ~9.0% from 2016-2024. (Grandview Research 2016).

California seaweed aquaculture is a boutique specialty market consisting of a relatively small group of species being cultivated for culinary use for high end seafood restaurants. One successful business model embeds private ventures within the facility of public research institution with seawater access and infrastructure. This model could be replicated at Scripps Oceanography or other research institutions that already have permits and ocean water access and circulation infrastructure. The timing of this market is favorable as asian and polynesian seafoods are enjoying a surge of popularity and consumers are increasingly concerned about nutrition, sustainability and responsible sourcing of their diets. Seaweeds are high in vitamins, minerals, and plant-based proteins yet low in calories and can provide unique textures and flavors to food -- all qualities that invite culinary innovation. Locally produced seaweeds pair perfectly with new food preservation techniques developed in San Diego, that if combined at scale could find a market beachhead by servicing the large and growing Poke restaurant market in Southern California. Our project demonstrates that many local chefs don’t have access to a consistent, high volume supply of live culinary seaweeds, one of the most sustainable and nutritious seafoods available. California Seaweed Co. is driven by the vision to supply live native Californian seaweeds to the United States culinary market through land-based aquaculture, with a strong emphasis on the sustainability and nutritional content.

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