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U.S. Seaweed Farming: How We Can Remedy and Revolutionize our Industrialized Food System

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Revolutionize and Remedy our Industrialized Food System

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Abstract

This paper explores the potential that regenerative kelp farming along the U.S. coasts can have to remediate environmental degradation caused by our industrialized food system. In chapter 1, using quantitative data from various peer-reviewed journal articles, I explain the ways in which the widespread use of petrochemicals in fuel and fertilizers have contributed to environmental degradation in the form of nitrogen pollution on land and in water, soil erosion, and ocean acidification. Chapter 2 examines the political figures and events that led to our decades-long dependence on petrochemical farming. Then, I discuss seaweed fertilizers as a sustainable alternative for the future and potential political hurdles to making this happen. Chapter 3 delves into the significance of seaweed's impact on the health of marine ecosystems. Then, I consider the extent to which the ecosystem services provided by such underwater forests and other natural seaweed formations can be replicated through the creation of a network of small to medium scale regenerative seaweed farms. Chapter 4 details the many health benefits that can come from increased seaweed farming and consumption in terms of human nutrition, reduced pollution, and economic opportunities. Finally, in chapter 5 I depict the current reality of kelp farming in the U.S. based on interviews with sustainable kelp farmers and marine biologists. I share their forecasts for the industry and their policy recommendations for bolstering further development of it. Building on these, I also make recommendations of my own on how we can make sure this sustainable-seaweed-farming revolution happens as soon as possible. Keywords: seaweed farming, regenerative aquaculture, food system, environmental politics, environmental history, public health, United States.

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Introduction: Climate Change and the Ocean

Word Count: 780

A Warming Ocean. The ocean The impacts on ocean ecosystems and human societies are primarily driven by regional trends and by the local manifestation of global-scale changes.[1] At these smaller scales, the temperature, acidification, salinity, nutrient and oxygen concentrations in the ocean are also expected to exhibit basin and local-scale changes.[2] However, the ocean also has significant natural variability at basin and local-scales with time scales from minutes to decades and longer, which can mask the underlying observed and projected trends.[3] The most severe impacts of a changing climate will typically be experienced when conditions are driven outside the range of previous experience at rates that are faster than human or ecological systems can adapt. Unfortunately, the ocean will continue to take up heat in the coming decades for all plausible scenarios. Some studies have estimated that "the top 2000 m of the ocean will take up 935 ZJ of heat between 2015 and 2100".[4] By 2100 the ocean is very likely to warm by 2 to 4 times as much for low emissions and 5 to 7 times as much for the high emissions scenario compared with the observed changes since 1970.[5] It is virtually certain that the ocean will

[1] Bindoff, et al. 2019: Changing Ocean, Marine Ecosystems, and Dependent Communities. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate, IPCC, https://www.ipcc.ch/srocc/chapter/chapter-5/
[2] Bindoff, et al.
[3] Ibid.
[4] Ibid.
[5] Ibid.

continue to take up heat throughout the 21st century, and the rate of uptake will depend upon the emissions scenario we collectively choose to follow.[6]

Coastal blue carbon ecosystems, such as mangroves, salt marshes and seagrasses, can help reduce the risks and impacts of climate change, with multiple co-benefits.[7] Around "151 countries around the world contain at least one of these coastal blue carbon ecosystems and 71 countries contain all three".[8] There is reported to be a medium level of confidence that a successful implementation of measures to maintain and promote carbon storage in such coastal ecosystems could assist several countries in achieving a balance between emissions and removals of greenhouse gases. Conservation of these habitats would also sustain the wide range of ecosystem services they provide and assist with climate adaptation through improving critical habitats for biodiversity, enhancing local fisheries production, and protecting coastal communities from storm events.[9]

Expected coastal ecosystem responses over the 21st century are habitat contraction, migration and loss of biodiversity and functionality.[10] Pervasive human coastal disturbances will limit natural ecosystem adaptation to climate hazards. Global coastal wetlands will lose between 20–90% of their area depending on emissions scenarios with impacts on their contributions to carbon sequestration and coastal protection.[11] Kelp forests at low-latitudes and temperate seagrass meadows will continue to retreat as a result of intensified extreme temperatures, and their low dispersal ability will elevate the risk of local extinction. Intertidal rocky shores will continue to be affected by ocean acidification, warming, and extreme heat exposure during low

[6] Ibid.
[7] Ibid.
[8] Ibid.
[9] Ibid.
[10] Ibid.
[11] Ibid.

tide emersion, causing reduction of calcareous species and loss of ecosystem biodiversity and complexity shifting towards algae dominated habitats.[12] Salinisation and expansion of hypoxic conditions will intensify in eutrophic estuaries, especially in mid and high latitudes with microtidal regimes.[13] Sandy beach ecosystems will increasingly be at risk of eroding, reducing the habitable area for dependent organisms.[14]

Human impact on aquatic life. Human domination of nature has now reached the world's vast oceans with an accelerating impact. Approximately 90% of the fish living in the ocean spawn on coral reefs, in coastal wetlands and marshes, in mangrove forests, or in rivers that empty into the sea.[15] A 2009 study revealed "that 58% of the world's coastal sea-grass beds have been degraded or destroyed, mostly by dredging and coastal development". Sea-bottom habitats are also greatly harmed by human activities. They are often threatened by dredging operations and trawler fishing boats. Trawlers drag huge nets weighted down with chains and steel plates over the ocean floor to harvest a few species of bottom fish and shellfish. Each year, thousands of trawlers scrape and disturb an area of ocean floor many times larger than the annual global total area of forests that are clear-cut. These ocean-floor communities could take decades or centuries to recover. According to marine scientist Elliot Norse, "Bottom trawling is probably the largest human-caused disturbance to the biosphere."[16] Coral reefs serve as habitat for many hundreds of marine species. Coastal development, pollution, ocean warming, and ocean acidification -- the rising levels of acid in ocean waters due to their absorption of carbon dioxide from the atmosphere -- threaten them. The Coral Reef Alliance reported in 2010 that more than a quarter

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[12] Ibid.
[13] Ibid.
[14] Ibid.
[15] Miller and Spoolman, et al. *Living in the Environment,* Cengage Learning, ch. 11
[16] Miller and Spoolman, et al.

of the world's shallow coral reefs had been destroyed or severely damaged. A 2011 study by the World Resources Institute estimated that currently 75% of the world's shallow reefs are threatened by climate change, overfishing, pollution, and ocean acidification, and that by 2050, some 90% will be threatened.[17]

Chapter 1: Dirty Food (1,113 words)

The modern U.S. agricultural sector is immense in so many ways it is almost unfathomable. The average size of a farm today is around 434 acres whereas in 1935 the average farm size was around 155 acres.[18] This contributes to around $1.109 trillion to the U.S. GDP annually. All of this is accomplished by only 1.5 percent of the population who work on 2 million farms -- a drastic reduction since the peak of 6 million farms run by 70% of the population in 1933.[19] This huge unprecedented level of crop production is possible because of U.S. Agriculture's dependence on petrochemicals. While petrochemicals provide us with the ability to grow massive amounts of food, come with detrimental consequences to ecological and human health. In this chapter, I will outline the many ways in which petrochemicals are used in the agricultural, negative impacts of their production and use, and introduce seaweed as a viable alternative.

Introduction to Petrochemicals. Petrochemicals are a set of very specific chemical compounds derived from oil, natural gas, coal, plants or other sources.[20] In the U.S., 99 percent

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[17] Ibid.
[18] Norman J. Vig and Michael E. Kraft. *Environmental Policy.* (Green Bay, Wisconsin: University of Wisconsin -- Green Bay, 2019), 497.
[19] Norman J. Vig and Michael E. Kraft. *Environmental Policy*, 497.
[20] "What are Petrochemicals?," American Fuel and Petrochemical Manufacturers, https://empower.afpm.org/products/what-are-petrochemicals

of petrochemicals used are derived from oil or natural gas.[21] They are produced using extreme temperatures (over 1400 F) and pressures (over 2000 psi) in a process called cracking which takes place at oil refineries.[22] Four main ways in which petrochemicals are used are: fertilizers, pesticides, plastics, and fuel. I will now go through each of these types of function and discuss their negative impacts.

Fertilizers.There are three broad categories of fertilizers: nitrogen, phosphorus, and potassium (NPK) - based. The combined applications of these types amounts to around 130-140 pounds per acre of U.S. farmland (that is farmed "conventionally" as opposed to organic farming, which still only makes up around 1 percent of U.S. farms).[23] Nitrogen-based fertilizers are applied the most out of the three nutrients as it accounts for 59 percent of total fertilizer weight.[24] Phosphorus and potassium-based fertilizers account for "20 and 21 percent of total fertilizer treatments respectively and both nutrients maintain rates between 25 and 36 pounds per acre per year".[25] Corn, soybeans, wheat, and cotton combined receive approximately 60 percent of all NPK fertilizers.[26] Approximately "40 percent of total commercially applied NPK is put on corn, whose production is largely concentrated in the Midwestern states".[27] Most soybeans are produced in this region as well, but the crop accounts for less than 10 percent of total NPK use (this is because soybeans are legumes which are nitrogen-fixing organisms meaning that they add their own nitrogen into the soil while they are growing).[28]

[21] "What are Petrochemicals?"
[22] "What are Petrochemicals?"
[23] "A Look at Fertilizer and Pesticide use in the US," Gro Intelligence, https://gro-intelligence.com/insights/articles/a-look-at-fertilizer-and-pesticide-use-in-the-us
[24] "A Look at...US"
[25] "A Look at...US"
[26] "A Look at...US"
[27] "A Look at...US."
[28] "A Look at...US"

Pesticides. Under the umbrella term of 'pesticides' there are three major categories based on the organism that one is trying to keep away from crops. There are those that control weeds called herbicides, those that protect against insects and animals called insecticides or rodenticides, and fungicides that protect against fungus and mold diseases.[29] Pesticides come in a variety of formulations, depending on their target and purpose. For example, "fumigants are applied as gases to the soil, and 'systemic' pesticides are absorbed by leaves before spreading through the rest of the plant."[30] While all pesticides are harmful to the environment, "some chemicals can harm a wide variety of non-target species, and some application methods have high potential to drift off target".[31] This means that pesticides damage the natural ecosystems around the farm and damage the populations of not just the organisms they were manufactured to hurt. For this reason primarily, pesticides are one of the leading threats to biodiversity and the general health of the environment at large. One well-documented and well-known example of the detrimental effects that pesticides have on unintended organisms is the way in which atrazine (a chemical found in herbicides) disrupts the reproductive capabilities of amphibians, and specifically many frog species. This is greatly contributing to the alarmingly rapid decline of frog species around the world. Nevertheless, despite all of the terrifying research being done about the damages caused by pesticides, its use remains extremely high and it keeps on growing due to the unintended creation of 'superweeds' that evolve to be ever more resistant to the chemicals. The most recent report on pesticide sales and use from the US Environmental Protection Agency (EPA) "puts US pesticide use at 1.1 billion pounds in both 2011 and 2012, which amounts to 23 percent of the nearly six billion pounds used worldwide".[32]Agriculture

[29] "A Look at...US"
[30] "A Look at...US"
[31] "A Look at...US"
[32] "A Look at...US"

accounts for "nearly 90 percent of pesticides in the US, with industry/commercial/government and home and garden use making up the rest".[33]

Plastics. It is no secret that almost every industry nowadays relies on plastics in some form or another. It is a material that likely every American, possibly even everyone around the world, interacts with on a daily basis. The agricultural industry is no exception as "more than a billion pounds of plastic is used annually in U.S. agriculture alone".[34]These plastics are made from various petrochemicals including polyethylene, ethylene-vinyl acetate and ethylene-butyl acrylate.[35] They are used in the production of various items including "plastic mulch, greenhouse covers, and tunnels."[36] Additionally, "other plastics, including polyolefin, Polypropylene (PP), Ethylene-Vinyl Acetate Copolymer (EVA) and others are also used in irrigation, silage, twine, and tubing.[37] Since thes plastics are often used in outdoor settings where they are subject to all kinds of weather conditions, farm machinery, and animal interactions, they slowly get broken down over time into microplastics that will never (on a human timescale) biodegrade as non-oil-derived chemicals do; this means that they will continue to disrupt the ecosystems they enter long after that particular area has ceased being farmland.

Transportation. The U.S. is part of a global food system that relies heavily on airplanes and trucks for the transportation of crops across nations. This contributes greatly to air pollution specifically in terms of carbon dioxide being released. While the most effective (and the most

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[33] "A Look at...US"
[34] AFPM Communications, "From Farm to Table: The Role of Petrochemicals in Agriculture," American Fuel & Petrochemical Manufacturers, https://www.afpm.org/newsroom/blog/farm-table-role-petrochemicals-agriculture
[35] AFPM Communications
[36] AFPM Communications
[37] AFPM Communications

sustainable) means of addressing this problem is shortening the distances that food travels from the farm to the plate by increasing the amount of local small farms for every region (like how we used to interact with food for thousands of years!), changing the way that these transport machines run could still help us significantly reduce our emissions in the meantime. Certain vehicles like cars and some trucks have the ability already to run on solar power. Unfortunately, we are still a ways away from being able to use this type of technology on airplanes. For airplanes, more research is coming out pointing to the possibility of running them on biofuels. This includes biofuels made from seaweeds -- which are immensely less ecologically damaging to produce than those made from corn (which is what most biofuels currently in use are made from).

Chapter 2: Politics of Industrial Agriculture (449 words)

World War 2 brought with it much experimentation with chemicals for war but then this turned into research into chemicals for farming and household products as well. We started becoming obsessed with chemicals and thought they were the future of all industries. With the invention of chemical fertilizers and pesticides in these years, the green revolution was jump-started. Contrary to what its name suggests, this agricultural development started us off on our journey of destruction of the environment on the massive scale in which we have done since this time and going forward (the past 50 or so years). The United States government, particularly the USDA strongly supported use of these new chemicals because of the much larger crop output per acre for a wide variety of crops. One politician in particular is largely responsible for the industrial transformation of agriculture in the U.S. -- Earl Butz. He became the USDA Secretary under the Nixon administration in 1971. He had a vision of turning the agricultural industry into "a hyper-efficient, centralized food system, one that could profitably and cheaply 'feed the world' by manipulating (or 'adding value to') mountains of Midwestern corn and soy".[38] Previous to his coming into this role, there were many New Deal policies still in place that were meant to protect farmers and the land (which is understandable considering that the ecological and economic effects of the Dust Bowl still haunted the memories of countless communities). For example there were limits to the sizes of farms and the quantities that farmers could produce in any given year. These restrictions were meant to protect not only the price of crops but also to protect the soil quality of the farmland. He convinced farmers that they no longer need to worry about over-producing because he promised that any amount of food that did not sell domestically could be sold internationally. Butz was not concerned about soil health or protecting small farmers and he very openly advocated for new policies that would directly benefit agribusiness companies (many of which he had served on the boards of previously and had other personal and economic ties to). His infamous motto for U.S. farmers was, *"Get big or get out!"* as he advocated for farmers to increase the sizes of the farms and plant fence to fence tightly packed rows of wheat, corn, and soy (these were in high demand due their ability to be converted into "mass-produced convenience fare" such as cereals and snack foods). This led to tens of thousands of small farmers losing their livelihood as they became in debt from trying to keep up with Butz' demands and giving way to the "deepest rural crisis since the Depression."[39]

Marine Aquaculture in the United States. The term 'marine aquaculture' refers to the "breeding, rearing, and harvesting of aquatic plants and animals" in saltwater either directly in the ocean or in large ponds and tanks (understanding NOAA). In the United States, marine aquaculture provides economic opportunities for coastal communities in every coastal state in the nation

[38] Tom Philpott, "A reflection on the lasting legacy of 1970s USDA Secretary Earl Butz," Grist.com
[39] Philpott, 1.

(NUA).The products of these diverse working waterfronts around the country contribute around $397 million to the annual GDP (NUA - the first chart). The main organisms farmed are bivalves (such as clams, mussels, and oysters), shrimp, and salmon (understanding). As of 2017, the majority of marine aquaculture production in the U.S. were the bivalves specifically. That year, the U.S. produced 36 million pounds of oysters (valuing at $186 million), 9 million pounds of clams ($129 million), and 0.9 million pounds of mussels ($10 million). The US is not a major aquaculture producer (ranking 17th in 2017 globally), but it is the number one *importer* of "fish and fishery products". (NUA). When measured by weight, about 90 percent of seafood eaten in the US was either farmed or wild-caught from abroad. (NUA). Even though the US is a relatively small aquaculture producer, this nation still plays a significant role in seafood production around the world as we supply "a variety of advanced technology, feed, equipment, and investment capital" to other countries (NUA). Marine aquaculture production in the US is very regionally diverse with about 39 percent of value being produced in the Pacific (including Alaska and Hawaii), 39 percent in the Atlantic, and 22 percent in the Gulf of Mexico (NUA). The marine aquaculture industry has been growing faster than the nation's economic growth in general in recent years.

Chapter 3: Kelp's Essential Roles in Oceanic Ecosystems (2,319)

Although we call them 'seaweeds', this name is not always the most accurate description of them because not all seaweeds are found in the *sea* and they are not *weeds* in the way that we conceptualize that term. While the majority of them are found in the salty ocean, there are some seaweed species that grow in freshwater lakes and ponds around the world. They commonly grow and reproduce very rapidly, perhaps *like* a weed; however, while weeds are usually thought of as invaders of a space where desired plants grow, seaweeds are extremely more likely to bring immense *benefits* to the areas they inhabit rather than damage. Furthermore, a common misconception about seaweeds is that they are aquatic plants -- they are not! While both plants and seaweeds photosynthesize and can have similar-looking structures (for example, many seaweeds appear as though they have leaves), seaweeds are actually a type of marine macroalgae. Once you take an extra second to examine their parts closely, their differences really jump out at you. Generally, the basic parts of a plant are the root system, stems, and leaves. Seaweeds do not have any of these parts. Instead of roots that anchor a plant into the soil, seaweeds have holdfasts that help them grip onto rocks, ropes, and any other structures around them. From the holdfast grow the stipes and blades. These are unlike the stems and leaves of plants because they greatly differ functionally. While plants' various parts are made up of differentiated cells that work together to maintain the organism (i.e. the roots take up water and nutrients from soil, the stem transports them, and the leaves are the site of photosynthesis), the majority of seaweeds are made of undifferentiated cells that are individually self-sufficient -- each cell generates what it *alone* requires.[40] This is possible because of the aquatic environment in which they grow; the cells do not need to move nutrients around because each cell is always in direct contact with water from which they absorb all the nutrients they need.[41] The only exceptions to this basic structure are a few species of seaweeds that have evolved to transport salts and products of photosynthesis, but again these species are rare.[42] To photosynthesize as much as possible, many seaweed species have pockets of oxygen among their blades to help them float to the more shallow (and therefore sunnier) parts of the ocean.[43] In nature, this need to stretch upward from their deeper undersea rock (for example) to which they are fastened is what

[40] Mouritsen, *Seaweeds: Edible, Available, and Sustainable,* 3.
[41] Mouritsen, 3.
[42] Mouritsen, 3.
[43] Mouritsen, 3.

allows them to serve as key habitat structures for an endless amount of different organisms that live in various depths within the euphotic zone.[44] For this reason it can be said that seaweeds are "to the sea what forests, undergrowth, bushes, and groundcover are on land".[45] Since they also produce and release oxygen as a result of photosynthesis, it is clear why seaweeds are a *vital* member to almost all coastal marine ecosystems across the planet.

Seaweeds were one of the first multicellular organisms to evolve during the Proterozoic period -- they have been around for over 600 million years! Today, we have been able to document around 12,000 species of seaweed, but of course there may be thousands more to be discovered as oceanic research continues throughout the century with ever more sophisticated technologies. Seaweeds come in a wide variety of shapes, sizes, and colors but are mainly broken down into three categories: brown, red, and green algae.[46] There are around 2,000 species each of brown and green species, with the majority of them (around 6,000 species) belonging to the red category.[47] Their sizes greatly vary, with some being only a couple of millimeters or centimeters long and others reaching enormous lengths. For example, the Giant Kelp (*Macrocystis pyrifera) "*can regularly attain lengths of 60 meters and form enormous 'kelp forests' in the ocean.[48] The diversity of seaweed is why it is able to live in so many parts of the world, playing key roles in countless marine ecosystems.

Where is Seaweed Found Naturally? Seaweeds have evolved in so many different ways over hundreds of millions of years because they have been able to adapt to a wide range of oceanic climates. Many species of seaweeds are much more hardy than they appear; "some

[44] Mouritsen, 3.
[45] Mouritsen, 3.
[46] Mouritsen, 4.
[47] David Thomas. *Seaweeds*. (United States: Smithsonian Institution Press in association with The Natural History Museum, London, 2002), 11
[48] Mouritsen, 4.

tolerate being dried out completely, being exposed to frost, or being subjected to great fluctuations in temperature".[49] They are constantly subject to the movement of the ocean, and oftentimes have to withstand "rapid ocean currents, violent tidal changes, foaming surf, and mighty waves pounding against cliffs and coastlines".[50] They can be found in all coastal waters around the planet and in all climatic zones as some thrive in warm waters and others thrive in icy polar regions.[51] Even though they are everywhere, have been a part of humanity since the very beginning as a food source, and continue to hold significance for many cultures, seaweed is still largely a mystery. The global distribution of seaweeds "has not been comprehensively mapped, the full details of their habitats are unknown, their taxonomic classification is incomplete and their biodiversity is not yet understood".[52] A large number of seaweed species have even adapted to life in the intertidal zone in which they are exposed to air two times a day as the tide ebbs and flows.[53] Despite there still being much research that needs to be done on their whereabouts, oceanographers estimate that "seaweeds take up an area that corresponds to about 8 percent of the total area covered by the world's oceans".[54] Because they are found almost everywhere, it is no wonder why so many different countries have centuries-long traditions of foraging and farming seaweed for various uses.

Where is Seaweed Farmed? Although many people could often forget about this humble algae, especially in Western cultures as it is eaten far less than it is in many Eastern nations, seaweed cultivation is actually quite extensive on a global scale. In fact, "in terms of overall quantity the cultivation of seaweeds is currently more extensive than any other single form of

[49] Mouritsen, 2.
[50] Mouritsen, 4.
[51] Mouritsen, 2.
[52] Kaori O'Connor. *Seaweed: A Global History*. (London: Reaktion Books Ltd., 2017), 8.
[53] Mouritsen, 4.
[54] Mouritsen, 4.

aquaculture, including fish farming".[55] China is the biggest producer of *konbu* (*Saccharina japonica*), with a yearly output of about 2.5 billion tons.[56] *Saccharina japonica* alone accounts for 40 percent of the total world production of seaweed.[57] But in economic terms, this is overtaken by the Japanese aquaculture of *nori* (*Porphyra yezoensis*), which is worth about US $2 billion annually.[58] While approximately 13 million tons of wet seaweeds are harvested each year in about 40 different countries around the world, 95 percent of the total yield comes from just ten of them: China, North and South Korea, Japan, the Philippines, Chile, Norway, Indonesia, the United States, and India.[59] About 80 percent of seaweed production originates in Asia, with the balance coming primarily from Europe and North and South America.[60]

Seaweed serves many key functions for the multitude of ecosystems they are found in and help create. One way in which seaweed supports ecosystems is by serving as a nutrient-rich food source for a wide variety of organisms. They are eaten in many different ways. For example, "many finer seaweeds are grazed upon, while the larger seaweeds are not grazed to a great extent".[61] For example, *Laminaria* is a seaweed in which "only 1 percent of the thallus is directly eaten by herbivores such as gastropods, fish, and sea urchins".[62] Another species that feeds upon seaweed while it is in its whole form is the green sea turtle. The main way kelps of this size are eaten is when they are broken up into tiny pieces, from the few times they are grazed, and then float around to be swallowed by debris feeders.[63] Specifically, organisms such

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[55] Mouritsen, 42.
[56] Mouritsen, 42.
[57] Mouritsen, 45.
[58] Mouritsen, 45.
[59] Mouritsen, 45.
[60] Mouritsen, 45.
[61] Thomas, 54.
[62] Thomas, 54.
[63] Thomas, 54.

as crabs, sea cucumbers and amphipods rely on kelp in this way.[64] Once the small fragments break down further into tinier, even microscopic, sizes, they serve as "rich supplies for filter-feeding organisms such as mussels, barnacles, tunicates, anemones, and polychaete worms."[65] Every part of the seaweed is important, even the mucus it produces (which is what makes it so slippery!) The mucus or slime (made of polysaccharides) dissolves into the surrounding water, enriching the waters with nutrients.[66] Seaweeds also "release amino acids into the water as a result of damage or due to regulation of their metabolism in response to environmental stress."[67] These substances are called dissolved organic matter (DOM) and it is thought that up to "30 percent of the carbon assimilated by *Laminaria* may be released in the form of DOM."[68] This fraction is very ecologically important because "bacteria and fungi and some protozoans feed on DOM."[69] "The seaweeds, therefore, play a role in the regulation of bacterial activity within coastal waters." "As the bacteria break down the DOM, nutrients such as nitrogen and phosphorus are released back into the water and can be taken up again by the seaweed for new growth." David Thomas describes how many species use kelp both as food and habitat— he describes a subtidal kelp environment as such having “[kelp] covered with filter-feeding sponges and anemones, and teaming with worms, crustaceans and brittlestars. Snails and sea slugs also graze on the fronds themselves, or more frequently, the biofilms of microalgae and bacteria that accumulate on the seaweed surfaces."[70] The benefits of kelp do not stop at this strata of the food chain, but go on to be carried even further up; Grey whales depend heavily on the plentiful

[64] Thomas, 55.
[65] Thomas, 54.
[66] Thomas, 54
[67] Thomas, 54.
[68] Thomas, 54.
[69] Thomas, 54.
[70] Thomas, 55

invertebrates that kelp species support. The ecosystem benefits of kelp go on even further as seaweeds wash up on shore and support coastal terrestrial environments[71]— Thomas gives an example of how rotting seaweed is key to the survival of sand hoppers, which in turn feed seabirds.[72]

Seaweed is also known to be a place of shelter for a number of different organisms. The dense growths of seaweed attracts various species of fish as it serves as a refuge, or hiding, from large predators such as dolphins or birds,"Shoals of plankton-eating fish hide amongst stands of seaweed, coming out of cover to feed only at certain times of the day."[73] . Some species have even evolved to be camouflaged specifically within the leafy, dark strands of seaweed such as the sargassum fish (*Histrio histrio),* an anglerfish that shares its eponymous name with the sargassum seaweed species in which it resides. The long, leaf-like appendages of the Saragassum fish provides the perfect manner for the fish to hide within its seaweed home. The weedy and leafy sea dragons (*Phyllopteryx taeniolatus* and *Phycodurus eques)* also claim shelter within strands of seaweed, as their colorful, fleshy fins seamlessly aid the fish into melting into their environment through visual camouflage. Even more spectacular, the Giant kelpfish (*Heterostichus rostratus)* are found in kelp beds any where from the southern tip of California to the north of Canada where their slender, elongated bodies aid them to hide within the seafloor among seaweed. A more curious creature, the common octopus, has been known to use pieces of seaweed to cover themselves from intimidating predators such as pyjama sharks as a manner of concealment, additionally ocotopi have been document to imitate the motion of seaweed floating in currents as a way to throw off predators. As if their disguise could be any better, these fish are

[71] Thomas, 55
[72] Thomas, 55
[73] Thomas 56

also able to *change color* as a way to mimic their surrounding environment which would consist of a background of seaweed stalks and dark, murky water. Additionally, seaweed goes beyond the ocean currents to the shore where scraps of seaweed strands are utilized by seabirds to pad their nests for their eggs.

Special Relationship: Giant Seaweeds and Otters. One of the most well-documented seaweed-based food webs is the one involving the otters, sea urchins, and giant *Macrocystis* kelp off the coasts of California and Alaska. In this region, *Macrocystis* is "harvested in vast quantities for the seaweed processing industries"[74]. The otters do not eat the seaweed but rather they rely on the abundance of life found living among the giant fronds (and it is also noteworthy that they use the kelp to anchor themselves when they float on their backs while resting).[75] This includes the populations of various invertebrates, notably that of sea urchins.[76] Sea urchins graze on seaweeds voraciously; "a dense swarm can effectively strip an area of attached seaweeds" and "the damage they cause has been compared to the devastation left by a forest or bush fire".[77] While the majority of sea urchin species feed on "fragments of seaweed that they catch with their tube feet," several species also feed on the holdfasts and fronds directly.[78] Researchers in this area have carried out experiments in which divers periodically removed significant portions of urchins from the kelp forests and discovered that the kelp not only increased in numbers but they also grew to be noticeably longer.[79] Along the southern region of the Californian coast, *Macrocystis* populations have been documented experiencing vast decreases in population in

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[74] Thomas, 57.
[75] Thomas, 57.
[76] Thomas, 57.
[77] Thomas, 57.
[78] Thomas, 57.
[79] Thomas, 57.

several instances during the past two centuries "due to extensive grazing by sea urchins".[80] Humans have tried to help the kelp population numbers increase again in the past with "horrific schemes" involving "burning the urchins with quicklime, (which unfortunately also damaged many other marine organisms) and simply smashing the urchins with hammers".[81] The destruction of the *Macrocystis* forests was correlated with a decline in sea otter populations for that region.[82] During the 1960s, the sea otter populations began to increase again "the kelp beds soon started to re-establish".[83] Experts believe that "the feeding activities of the otters lowered the sea urchin population to the extent where the kelp beds were able to recover".[84] This is a logical conclusion when one takes a look at the sheer amount of food otters consume! A study done over only a two month period along the Monterey coast recorded that 50 of them ate "5000 red sea urchins, 300 mussels and 400 abalones."[85]

Chapter 4: Health Benefits of Kelp Word Count: 1808

Seaweed the Superfood. When most people think of 'superfoods' they might think of leafy greens and other vegetables and fruits like blueberries and cauliflower. What about seaweeds? They are arguably the most super of all! Although there are varying amounts of nutrients found within different species (and even intraspecies based on its location and season), "generally seaweeds are extremely nutrient-rich, having a mineral content ten times greater than that found in land plants".[86] It is claimed that seaweed has "ten times more calcium than milk, eight times more iron than red meat, and more protein than eggs, wheat, or beans".[87] Also significant,

[80] Thomas, 57.
[81] Thomas, 57.
[82] Thomas, 57.
[83] Thomas, 57.
[84] Thomas, 57.
[85] Thomas, 57.
[86] Kaori O'Connor. *Seaweed: A Global History*, 14.
[87] O'Connor, 14.

"seaweeds are high in non-nutrient phytochemicals known as secondary compounds, which are antioxidant and anticholesterolemic, which epidemiological studies suggest can reduce the risk of coronary heart disease, stroke and cancer".[88] Vitamin A, the B vitamins (B1, B2, B3, B6, B12, and folate) and vitamins C and E are found abundantly in seaweed, as are the minerals iodine, calcium, phosphorus, magnesium, sodium, potassium, iron and chlorine, along with the trace elements of micro-minerals manganese, copper, zinc, selenium, chromium and molybdenum.[89] These minerals have many key roles in helping the body maintain homeostasis "including oxygen storage, thyroid hormone generation, enzyme formation, energy production and support of immune and insulin functions".[90] Seaweeds also contain large amounts of vitally important protein, "the body's primary building blocks for muscle, skin, hair, bone, and much else".[91] While many Americans believe that red meats, poultry, and fish are the greatest sources of protein (which, to be fair, is largely due to the careful-crafted ad campaigns of the meat industry), these protein sources come with negative consequences as research has been increasingly showing that consumption of these foods contribute to the development of cardiovascular disease.[92] Due to seaweed being fat-free and high in protein content "it is increasingly described as the perfect 'heart-healthy' food".[93] Seaweed wins as the top choice for many even when pitted against high-protein land plants such as legumes (soybeans, chickpeas, kidney beans, etc) because the cultivation of plant proteins "puts a heavy burden on the terrestrial environment, and some of them contain high levels of carbohydrates, while the small amount of

[88] O'Connor, 14.
[89] O'Connor, 14.
[90] O'Connor, 14.
[91] O'Connor, 15.
[92] O'Connor, 15.
[93] O'Connor, 15.

carbohydrates in seaweeds are not digested by the human body, and so do not add undesired empty calories".[94]

It has long been known that in places where people eat large amounts of seaweeds and other seafoods on a regular basis, there are "lower incidence[s] of cardiovascular disease and high blood pressure".[95] People in these areas also tend to have greater longevity; this fact was known already back in 1927 when Japanese professor Shoji Kondo of Tohoku University was doing research on the "correlation between lifespan and diet in various areas of Japan".[96] His research showed that people who live in southern Japan "where consumption of seaweed is high" had greater life expectancies (this was especially true for women) and this finding has been supported by many other researchers over the following decades.[97] Seaweeds are truly unique in their ability to greatly nourish the human body!

Millennia of Food and Medicine. Kelp is over 500 million years old and it was a key source of nutrients for early humans, (even though this is often left out of history books!) continued to be throughout history across many cultures, and continues to be so today. Although the large majority of ancient Greek and Roman naturalists were primarily interested in studying the potential medicinal properties of terrestrial plants, there are a few early records of seaweed experimentation from them as well.[98] The famous Roman author Pliny the Elder wrote in his best-preserved piece, *Natural History*, that seaweed could be used topically to treat various ailments such as gout and ankle swelling; the Greek poet Nicander claimed that seaweed could

[94] O'Connor, 15.
[95] Mouritsen, 101.
[96] Mouritsen, 101.
[97] Mouritsen, 101.
[98] O'Connor, 31.

be used to cure certain snake bites.[99] The most significant history of seaweed use however is not found in these cultures, but rather in several Asian cultures where they have been used for thousands of years as food and medicine.

One country that has a long and well-known cultural history with seaweed is Japan where it is mostly used as a food. The Japanese island chain is surrounded by two currents, the Black and the Okhotsk. The Black Current brings cold waters and the Okhotsk brings warm waters. Due to this unique oceanic location, there is a plethora of diverse "nutrient-rich marine ecosystems from the subarctic to the subtropical".[100] These waters are home to a thriving population of marine life, boasting thousands of different species of animals, algae, and plants. In terms of seaweeds alone, there are around 2,000 species in Japanese waters.[101] Since many of these are edible, it is no wonder why seaweed has been a key ingredient in Japanese meals for thousands of years. In fact, a traditional Japanese diet consists of eating seaweed "every day, often at every meal".[102] The most popular seaweeds in Japan are wakame, nori, and kombu (kelp).[103] Kombu has been harvested in the waters surrounding the island of Hokkaido (the farthest north main island) "since prehistoric time".[104] While found in subarctic oceanic areas around the globe, kombu from this region is widely regarded as being the cream of the crop due not only to its exquisite texture and flavor, but it's exceptionally high nutrient content as well.[105] Today, the overwhelming majority (over 95 percent) of kombu eaten in Japan is harvested from Hokkaido; it is commonly either made into a stock or even simply eaten as a main ingredient

[99] O'Connor, 31.
[100] O'Connor, 41
[101] O'Connor, 41
[102] O'Connor, 41
[103] O'Connor, 41
[104] O'Connor, 41
[105] O'Connor, 41

without much preparation.[106] Since seaweed has virtually always been a part of the Japanese diet, people have been able to craft delicious meals with it in hundreds of different ways over the years. Therefore it is no surprise that at the turn of the 17th century, the Japanese seaweed cuisine had already developed to be relatively "elaborate and sophisticated" when compared to other cultures' consumption of the super algae.[107] The *Kan'ei* Cookbook, which was written around 1640, "mentioned 21 seaweeds in common use and a variety of techniques for preparing them, including baking, toasting, pan-frying, vinegaring, using in soup and preparing raw in salads".[108] The most important one within this book was wakame (*Undaria pinnatifida*) and it is still an "indispensable part of the traditional Japanese diet".[109] What makes it so enjoyable is its "sweet taste and soft texture" and this is the seaweed that is usually found in miso soup, a cultural staple.[110]

Perhaps no other type of seaweed is more important in Japan, and around the world, than nori (*Porphyra*). This is a type of red seaweed that is found in temperate waters. Even during ancient times, nori was "highly esteemed" and "as a highly valued wild-gathered product, was specified on the earliest tax and tribute lists".[111] This seaweed, like many others, was originally dried naturally used as an ingredient for soups or turned into a paste.[112] During the Edo period (1603-1868) seaweed producers in Asakusa (now a part of theTokyo metropolitan area) figured out how to turn nori into a paper-like form by "boiling, shredding, and then drying [them] on frames" (such as how paper itself was produced); this form of nori became renowned as an Edo

[106] O'Connor, 42
[107] O'Connor, 52
[108] O'Connor, 52
[109] O'Connor, 52
[110] O'Connor, 52
[111] O'Connor, 57
[112] O'Connor, 57

(now Tokyo) specialty.[113] Although the Japanese had developed successful farming methods for various types of seaweed for centuries, the cultivation of nori remained a mystery as farmers could not figure out why their attempts kept failing. For this reason, even though there was a high demand for this specific seaweed, there was usually always little supply as it was only harvested naturally. This changed in the 1940s when British scientist Dr. Kathleen Drew-Baker introduced her Japanese colleagues to her soon-to-be world-changing discovery: she had unravelled the complexities of the nori reproduction process. She mapped it out back in the 1930s, but her research was not met with enthusiasm or even much interest at all in the West, and then World War II broke out which of course caused her work to seem even less relevant at the time. So, after the war, she shared her findings with scientists in Japan who very quickly realized that her research was ground-breaking and was the key to the mystery of nori cultivation. Thanks to her work and the following work of Japanese scientists and cultivators, nori was finally able to be reliably farmed after centuries of confusion.With this new ability, nori production boomed and helped Japan greatly in rebuilding its post-war economy and improving national health which were both "at a low ebb" in the aftermath of the war.[114] Due to this newfound availability of nori, the Sushi Revolution was born as it became a popular everyday snack in Japan first and then took the world by storm in the 1970s and 80s. [115] Dr. Drew-Baker is still honored every year during a ritual at a shrine at Ariake Bay in Kumamoto Prefecture that overlooks an important nori-producing area.[116] The ceremony honors her as 'the Mother of the Sea' and commemorates

[113] O'Connor, 57
[114] O'Connor, 62.
[115] O'Connor, 62.
[116] O'Connor, 62.

her contribution "to the Japanese seaweed industry, to the global Sushi Revolution, and to nori".[117]

Another country with a long history of seaweed usage is China. While the Japanese focus has always been primarily on seaweed as food, in China seaweed was originally "thought of and treated as medicine".[118] Traditional Chinese medicine is based on "a complex system of balances and correspondences attributed to the mythic Yellow Emperor, said to have reigned from 2696 to 2597 B.C."[119] In *Huangdi Neijing* (Classic of Internal Medicine), a journal that is attributed to this figure, was "only compiled in around 200 B.C., but it contains material that was handed down orally from much earlier".[120] Within this intricate web of medicinal cures and beliefs, seaweed was believed to have "invigorating and cooling" properties, was associated with yang (as in yin and yang, yang representing male/sun/darkness energy), and with "both bitter and salty flavors".[121] While many of the cures have been found to be less than effective due to them having little support from biological data, there have also been many cases in which the cures were actually very effective. For example, there is a condition known today as goitre that causes disfigurement and muscle stiffness. There are several ancient Chinese writings that prescribe seaweed consumption (specifically *kon bu*, which is a *Laminaria* kelp species) as the cure for this bodily "hardening" and "stagnation" due to its power to invigorate.[122] It is now known that goiter is caused by an iron deficiency, so when people ate the seaweed they were replenishing their iron levels and therefore truly were healing.[123] This is an example of seaweed being used as

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[117] O'Connor, 62.
[118] O'Connor, 65.
[119] O'Connor, 65.
[120] O'Connor, 65.
[121] O'Connor, 67.
[122] O'Connor, 67.
[123] O'Connor, 67.

a form of reactive care, but the Chinese had an even greater emphasis on preventative care, which is why they recommended eating seaweed (of course, this then led to the development of another unique seaweed cuisine).

Chapter 5: Farmers in Action (word count: 1091)

GreenWave. GreenWave is a non-profit organization that has been advocating for and helping bring about a regenerative-ocean-farming revolution in the U.S. since its founding in 2014. Co-founders Bren Smith and Emily Stengel's goals have been described as "laying the foundation for a just, restorative and resilient ocean economy that meets the needs of both people and the planet".[124] The future of marine aquaculture that GreenWave helps us imagine is one that involves a network of small, independently-owned by members of the communities to whom they primarily sell their products. This structure, as opposed to the industrialized reality discussed in previous chapters, could potentially allow people, especially those living in coastal communities around the United States, to create and support millions of jobs in the fields of aquaculture, restaurants, groceries, food pantry/charity work, recreation, and marine education. There are three main types of work that GreenWave does: "farmer training, policy development, and R&D".[125]

- Breakdown of GreenWave's Work:
  - Farmer Training Program - GreenWave helps people interested in becoming regenerative ocean farmers kickstart their farms by assisting them with "permitting support, hands-on technical assistance, donated Patagonia gear, free

[124] "GreenWave", Draper Richards Kaplan Foundation, https://www.drkfoundation.org/organization/greenwave/#:~:text=GreenWave%20was%20founded%20in%202014,%2C%20policy%20development%2C%20and%20R%26D.
[125] "GreenWave"

seed, small startup grants, and introductions to guaranteed buyers".[126] The deal with the guaranteed buyers is significant as well -- with a partnership with large corporations like Google promising to purchase at least 80 percent of the new farmers' seaweed crops to be used as ingredients for food during large employee events.[127] Their goal is to train 30,000 farmers by 2030 and they depend on individuals' financial donations and grants.[128] Currently there are over 5,000 on the waitlist, which is why they also are working on expanding to meet the high demand for their services.

- Policy development and R&D programs - From the way representatives like Bren Smith, who currently serves as the Executive Director and is the owner of the Thimble Island Farm, GreenWave seems to act with the perspective that we are on the cusp of bringing about a new era of sustainable aquaculture that can play a key role in adapting to and addressing climate change.[129] His engaging and thought-provoking presentations and interviews for TED talks, 60 Minutes, RollingStone, Time, National Geographic and more all leave one feeling like we are very much on the cusp of something very promising! Being at this cusp, the organization strives to build a new, sustainable ocean economy keeping justice in mind from the start. GreenWave "believes this is the first opportunity in generations to “do food right” by embedding justice, equality and climate mitigation into the DNA of the new ocean economy".[130] Therefore, this is why they partner with countless public and private institutions to try to ensure that they and

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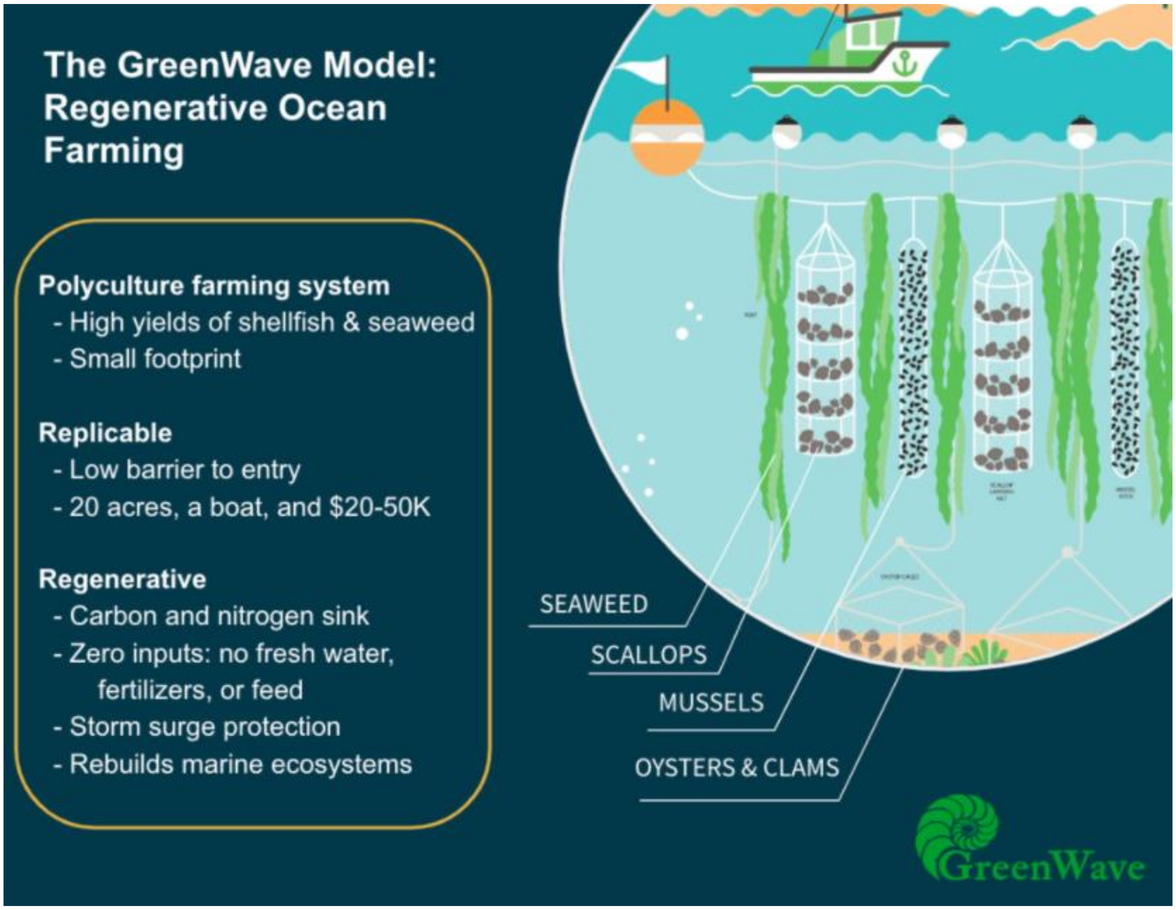
[126] "GreenWave"
[127] "GreenWave"
[128] "GreenWave"
[129] "GreenWave"
[130] "GreenWave"

other players in this developing field learn from the mistakes of the industrial agriculture and aquaculture industries of the past several decades.



GreenWave's regenerative ocean farm model. (greenwave.org)

Stonington Kelp Co. I had the pleasure of interviewing Susie Flores, owner of Stonington Kelp Co. The farm is owned solely by her and her husband, and they have been running it for four years, beginning in 2016. GreenWave assisted this farm in getting started! They are located in Stonington, Connecticut, which is exciting because they are one of the region's few seaweed farms. They grow only sugar kelp. They cultivate their seaweed as a food-grade commodity intended for human use, and they are aggressive in their marketing campaigns, claiming that this is how they aggressively seek out new customers. When I inquired about Stonington Kelp Co.'s partnership with other farms, Ms. Flores said that they do "cooperate across farms and state lines.

Collaborations that are most successful are typically those that are regionally close because they face common challenges and opportunities as a result of their shared environments. We partner on a variety of tasks, including packaging, marketing, and general harvest support." According to Ms. Flores, the industry's problems in the New England area in general (excluding Maine, presumably due to Maine's long and illustrious history of seaweed farming over the last century) stem from a lack of processing facilities for the raw material seaweed. Additionally, she stated that this is a problem not only in this area, but throughout the country. Susie Flores, in addition to running the farm, speaks and presents at colleges and environmental organizations about seaweed farming. Regarding policy proposals, she states that she is in favor of policies that benefit small farmers and promote sustainable business development.

Sugar kelp crop at farm in Stonington, Connecticut

Photograph by Stonington Kelp Co. (@stoningtonkelpco)

Buoys marking the farm (the real show is underwater of course!)

Photograph by Nit Noi Provisions (@nitnoiprovisions)

Seagrove Kelp Co. Seagrove Kelp Co. is located in Alaska and they are having their second harvest this May 2021. They are a hundred acre site with expansion plans in the works. They are operated by 10 to 20 employees, including the nursery and laboratory staff. They have grown seaweed from the very beginning. Specifically, they grow Nereocystis Luetkeana (bull kelp), Alaria marginata (ribbon kelp) and Saccharina latissima (sugar kelp). I interviewed Mr. Markos, the CEO of the company. He says that the motivation for starting this farm was because seaweed is a "terrific, sustainable, versatile crop". He says that "most goes into value added food products, followed by fertilizer and then pet food. Pet food is the growing trend area." When I asked about collaboration between his farm and others he said, "There is some collaboration across the space, particularly when prompted by the Sea Grant programs, but there is some silo effect. It would help when there is a national trade group where common problems can be addressed." When I asked him about industry challenges, he said that "all of the above are challenges. It is a nascent industry and we are all looking for that magic sauce of scale and value, which will include consistent yields, more efficiency across the span and product development."

When I asked him what policy recommendations he has he said that he supports: "USDA crop insurance. A federal aquatic farming policy, which includes streamlined site lease and permitting structures, more engaged and funded marketing, product development and market development, access to capital for start up operations and investments in infrastructure necessary for scaling will expedite the development of the industry." To future farmers he gives the advice of being diligent, patient, and persistent as this is hard work. He also says that the industry has not yet reached its potential and he says together we will mostly reach that potential!

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