SURF TO TURF

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LINKING REGENERATIVE AGRICULTURE AND RESTORATIVE AQUACULTURE IN COASTAL FOODSCAPES

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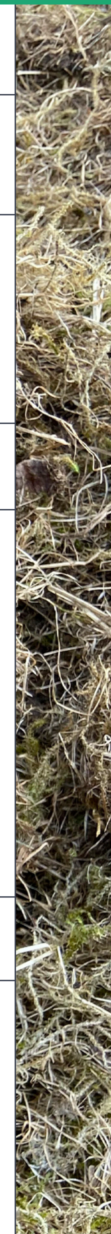


EXECUTIVE SUMMARY

From seaweed farming to oyster cultivation, our coasts represent some of the world's most dynamic and vital regions of food production. Yet, farmers and fishermen alike face an unprecedented array of ecological, economic, and societal challenges today. Circular practices involving restorative aquaculture and regenerative agriculture methods have garnered attention in recent years for their potential to combat climate change, enhance food system resilience, and promote worker and community wellbeing. Despite these shared stories of hope, marine-based foods and land-based agriculture are often considered and managed in silos. Implementing both traditional and innovative "surf-to-turf" practices —such as the integration of seaweed-based fertilizers and soil amendments— can help bridge this gap and, in doing so, simultaneously improve both soil and ocean health.

The connection between land and sea in our agricultural production systems has a deep and rich history. Indigenous ocean and land stewards and farmers along the coastline have used seaweed as a fertilizer for centuries. In New York, oysters were used as "sweeteners" for agricultural fields and whole oyster shells were scattered upon fields of wheat to enrich the soil.[1] Salt hay from tidal salt marshes was collected for use as mulch and fodder for cattle.[2] These agricultural practices brought nutrients from sea to soil, directly connecting terrestrial and marine environments in coastal foodscapes.

The emergence of industrial agriculture initiated a movement away from these traditional methods by the early to mid-20th century. The remnants of this link are often tales of environmental degradation: agricultural runoff contaminating water bodies, fish farms dependent on monoculture crops for feed, and sea-level rise threatening coastal farmland. This rupture in the historical connection between land and sea has also led to the omission of "blue foods" from contemporary regenerative food systems dialogues and the siloing of ocean-based and land-based food production systems.

In response to this separation, this report advocates a paradigm shift in our approach to food production along the coast. **Linking regenerative agriculture and restorative aquaculture practices can help strengthen the economic and ecological vitality of coastal foodscapes and generate new climate solutions.** Implementing an ecosystems-level approach to managing coastal foodscapes offers a pathway to contend with current challenges, while restoring the historical connections between ocean and soil health. Within the following pages, we first provide further history on the land-sea connection before cataloging best practices and the organizations who are forging robust collaborations that transcend conventional land-sea boundaries. Drawing on both past and present learnings, the report then offers unique opportunities to further strengthen, innovate, and reconnect us to this ancient relationship. Overall, it stresses that adopting an ecosystem-centric approach to managing coastal foodscapes lays the groundwork for nurturing and building upon a rich legacy of sea-to-soil agricultural practices while cultivating collaboration, fostering innovation, and growing resilience at the land-sea interface.

Linking regenerative agriculture and restorative aquaculture practices can help strengthen the economic and ecological vitality of coastal foodscapes and generate new climate solutions.

INTRODUCTION

Challenges on Land and at Sea

The world's coasts have long been important regions of food production both at sea and on land. Yet, coastal regions today face an unprecedented array of environmental and social challenges. In the United States, nearly 130 million people live in counties on the coast, representing a forty percent increase since 1970.[3] This has corresponded with increasing development pressure on open space, including farmland. Those farmers that have been able to keep their lands in agriculture must contend with the realities of climate change, including severe drought, more intense precipitation events, sea level rise, and flooding. In a 2022 report, the American Farmland Trust found that nearly 450,000 acres of farmland will be impacted by coastal flooding by 2040.[4] Saltwater intrusion and the salinization of soils further threaten the viability of low-lying coastal farmland. In the Chesapeake Bay, farmers have already begun introducing crops with increased salt tolerance in response to salt damaged fields from saltwater intrusion.[5] With this combination of development pressure, increased climate variability, and sea level rise, land-based farmers in coastal regions are facing new and mounting threats to the long-term viability of their farms.

At sea, the story is a similar one of ecological degradation and diminishing economic opportunity. In Newfoundland, the near collapse of the cod fishery and the consequential moratorium on cod fishing left nearly 30,000 people without work in the early 1990s and its effects on the province are still being felt today.[6] In Connecticut, a state built on its maritime heritage, only one commercial fishing fleet remains.[7] As early as the late 19th century, journalists in the Northeast were reporting on the decline of formerly flourishing fishing towns with headlines like "The Passing of the New England Fisherman," featured in an 1896 issue of Harper's New Monthly Magazine.[8] As wild fisheries were depleted, fin-fish aquaculture appeared to offer a solution, but this ultimately spurred its own suite of environmental issues, from disease outbreak and genetic mixing with wild fish to pollution of surrounding waterways.[9] As Bren Smith puts it in his seminal book *Eat Like a Fish*, fin-fish aquaculture replicated the methods of industrial animal farms and in doing so "accepted the trade-off of high yield at the expense of the ocean's health."[10]

With multiple crises facing our food system on land and at sea, it is imperative that we start thinking and acting differently in terms of how we produce food along the coast. By taking a socio-ecological approach to managing agricultural systems, we can use questions like "*what* should we grow?", "*how* should it be grown?", and "*who* should grow it?" to make decisions based on what the culture and ecology of a specific place supports. Several farmers, entrepreneurs, and other visionaries have already begun to ask questions like these and arrived at restorative aquaculture as a solution. The potential impact of restorative aquaculture extends beyond the shoreline, as regenerative ocean crops like shellfish and seaweed can be leveraged to enhance the sustainability of land-based agriculture. **Through restorative ocean farming, we have a singular opportunity to build a bridge between land- and sea-based food systems and, in doing so, enhance the overall resilience and vitality of both.** In the pages that follow, we will explore the history of sea-to-soil connections in food and agriculture, best practices and examples of these approaches at work today, and the opportunity they present for deep and meaningful food systems transformation on land and at sea.

Sea-to-Soil: Historical Connections

The idea of moving sea-based nutrients to the land is not new. Seaweed, fish, shells, and more have been used as soil amendments in coastal communities across the globe for centuries. Indeed, the first recorded use of seaweed as a fertilizer dates back to the first century A.D.[11] In the region that is present-day Rhode Island, the Narragansett people spent the summer months in coastal villages near the salt ponds and ocean waters of Narragansett Bay, where seaweed and fish was used to fertilize crops on land.[12] Seaweed continued to be an important fertilizer in New England through the 19th century. So significant was seaweed to the agricultural economy of New England that a holiday was recognized in the fall to allow farmers to gather and transport seaweed for application on their farms.[13] In Connecticut, the public's right to "gather seaweed between ordinary high and low water" dates to 1831 and remains part of public rights to the shore today.[14]

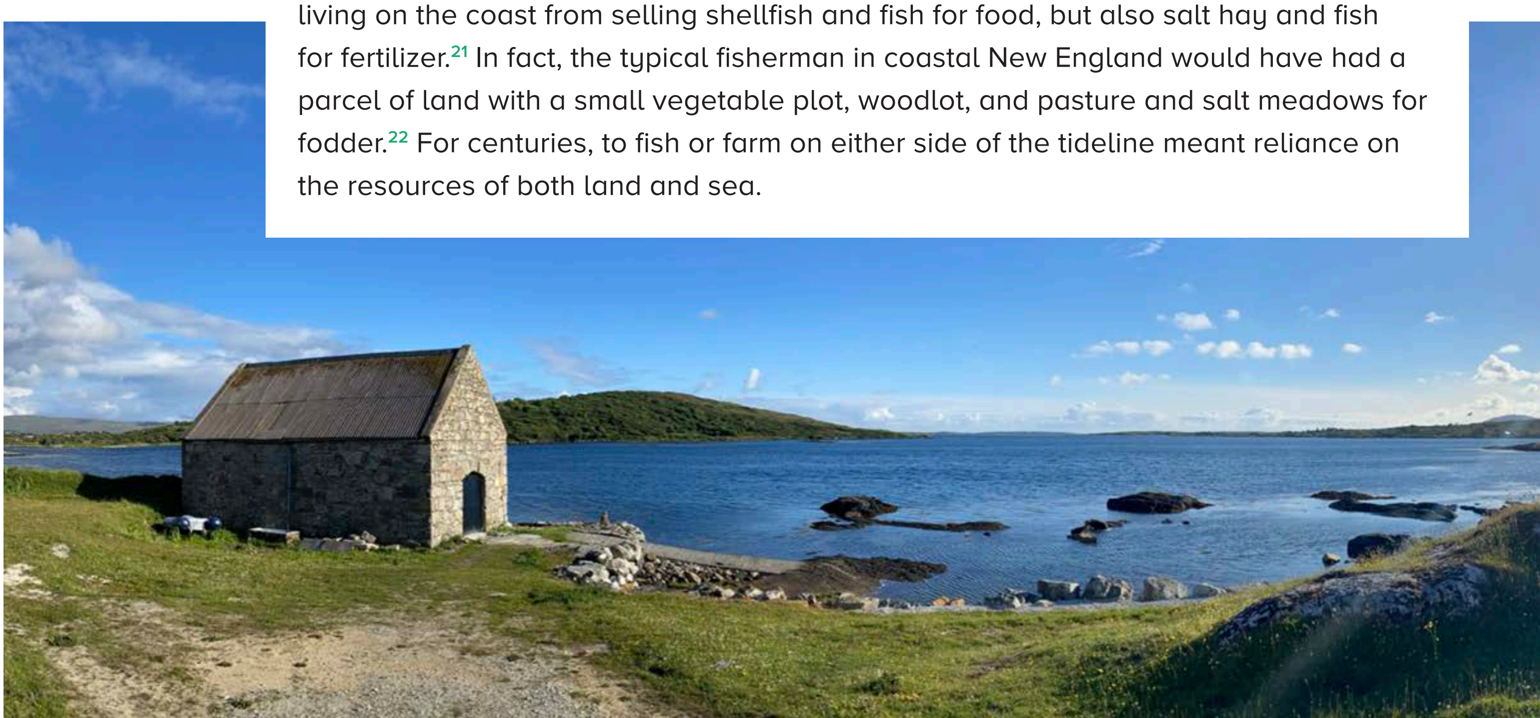
In Ireland, collecting seaweed for use as fertilizers and feed has helped propel the country's seaweed industry for over three centuries.[15] For farmers near the shoreline, annual applications of seaweed helped retain moisture and improve soil texture for the sandy soils of the coast. Many smallholder farmers and gardeners in Ireland continue this practice today. Seaweed was also used for livestock grazing and as fodder for pigs, cattle, and sheep.[16] The traditional Irish working song "Dúlamán" (Irish for channel wrack, a type of brown seaweed) pays tribute to the historic practice of gathering seaweed for fertilizer and food, and even puts forth the idea that feeding seaweed to sheep could help improve their coat.[17] In the 18th and 19th century, so-called "kelp houses" were constructed along the shoreline as storage facilities and remain a visible part of the shoreline in parts of the country today.[18]

"Gathering seaweed from beach, Eastern Point, for fertilizer." Source: Historic New England, Photographer Martha Hale Harvey, Date 1895–1920.

In the Northeastern United States, salt hay was a major cash crop until the early 1900s. The coastal town of Guilford, Connecticut was known for its "sea-meadows" — large expanses of tidal marsh whose salt hay was harvested each year as feed for wintering livestock. From the 1600s to the early 1900s "shore farmers" annually mowed saltmeadow cordgrass, *Spartina patens*, in late summer when the grass became more nutritious. In areas where pasture bordered salt marsh, cattle were allowed to freely graze the salt meadows.[19]

Like seaweed, oyster shells, fish, and other sea-based resources have a long history of use as soil amendments. One such example can be found in menhaden, a silvery, filter feeding fish whose name is derived from the Algonquin word for "fertilizer." Once abundant in the Long Island Sound, menhaden was used as a fertilizer by the Pequot, Niantic, Mohegan, Quinnipiac, and Wangunk peoples. This practice was imitated by colonists and later fueled the emergence of new industries. Founded in 1871 on Pine Island, located off the coast of Groton in Connecticut, the Quinnipiac Fertilizer Company processed menhaden to extract oil and milled the dried remains for use as fertilizer.[20] In 19th century Rhode Island, "fishermen-shore farmers" made their living on the coast from selling shellfish and fish for food, but also salt hay and fish for fertilizer.[21] In fact, the typical fisherman in coastal New England would have had a parcel of land with a small vegetable plot, woodlot, and pasture and salt meadows for fodder.[22] For centuries, to fish or farm on either side of the tideline meant reliance on the resources of both land and sea.

"The Kelp House" built around 1800 and used to store kelp. Doonreaghan, Ireland.

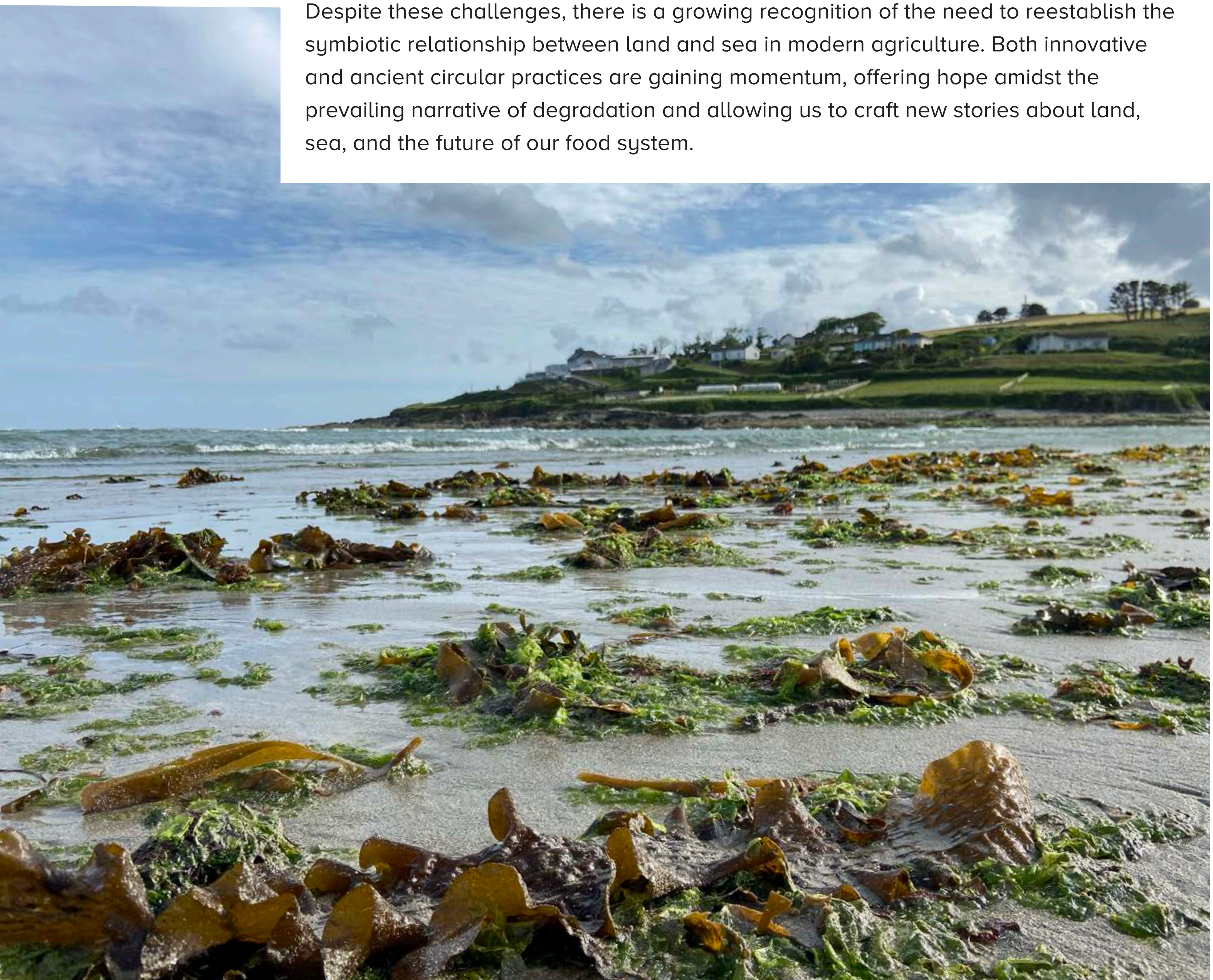


Seaweed, fish, shells, and other marine-based resources have been used as soil amendments in coastal communities across the globe for centuries.

Land & Sea Today

By the mid-20th century, the rise and ready availability of chemical fertilizers had made these practices of moving sea-based nutrients to land-based agriculture virtually obsolete. The connection between land and sea that had been so crucial to farmers and fishermen for centuries was largely forgotten in many parts of the world. So severe was this rupture that even in regenerative food systems discussions today, "blue foods"[23] are frequently left out or considered in siloes. The linkages that do remain between land and sea in the agricultural system of the United States are now too often narratives of degradation and harm: agricultural runoff from land-based farms polluting waterways and creating vast oxygen-depleted dead zones;[24] fish farms dependent on monocultures of soy, canola, and corn for feed;[25] sea level rise causing the salinization of soils and threatening the viability of coastal farmland.[26] Throughout this, farmers, fishermen, and farmworkers at the foundation of our food system have repeatedly experienced unhealthy working conditions, unfair labor practices, and exploitation.

Despite these challenges, there is a growing recognition of the need to reestablish the symbiotic relationship between land and sea in modern agriculture. Both innovative and ancient circular practices are gaining momentum, offering hope amidst the prevailing narrative of degradation and allowing us to craft new stories about land, sea, and the future of our food system.

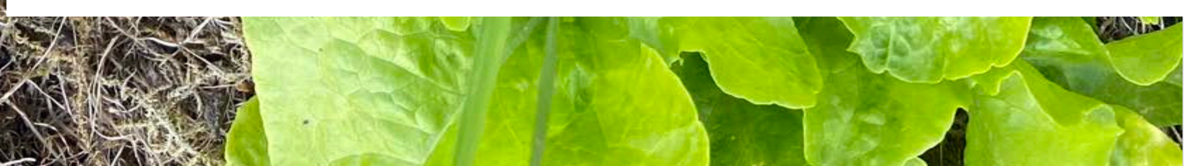


DEFINING RESTORATIVE AQUACULTURE

Along with regenerative agriculture, restorative aquaculture has received significant attention in recent years for its capacity to generate urgently needed climate solutions. But how is restorative aquaculture defined?

Also referred to as regenerative ocean farming, restorative aquaculture offers a promising path forward for coastal foodscapes. The Nature Conservancy defines restorative aquaculture as occurring when "commercial or subsistence aquaculture provides direct ecological benefits to the environment, with the potential to generate net-positive environmental outcomes."[27]

For the purposes of this report, we have chosen to focus on seaweed and shellfish, both of which are zero input crops, requiring no external water, fertilizer, or feed to grow. Some restorative aquaculture approaches, including GreenWave's regenerative ocean farming model, feature a polyculture of species that makes use of the entire water column to produce nutrient-dense ocean crops that help restore the surrounding ecosystem.[28]



Depending on the farm type and location, a restorative ocean farm can help to:

- **Improve water quality:** Shellfish such as oysters, scallops, clams, and mussels are filter feeding organisms that leverage the surrounding ecosystem for food. A mature oyster can filter as much as 50 gallons of water per day.[29] Both shellfish and seaweed take up excess nutrients in the water column, which can help mitigate the effects of eutrophication, including harmful algal blooms and hypoxic dead zones.[30] Seaweed can also be used in bioremediation to help reduce heavy metals and other coastal pollutants, though macroalgae grown for this purpose is not suitable for consumption.[31]

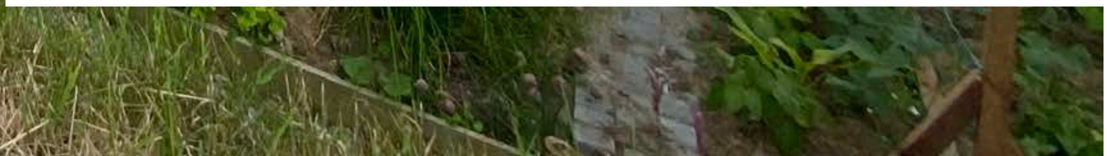
- **Protect shorelines:** Seaweed farms can help dampen wave energy during storm events, protecting against coastal erosion and increasing overall shoreline resilience.[32] Depending on their location, oyster reefs can also help decrease wave energy and mitigate erosion.[33] Other forms of farmed shellfish may also help enhance wave attenuation, though further research is needed.[34]

- **Enhance biodiversity:** The cultivation of shellfish and seaweed can enhance local biodiversity by providing habitat and food sources for fish and invertebrates.[35] A recent meta-analysis of 65 studies on the fish and mobile macroinvertebrate populations on farms and reference sites found that bivalve and seaweed aquaculture were associated with higher abundance and species richness of wild, mobile macrofauna.[36]

- **Mitigate climate change:** As a photosynthetic organism, seaweed can help absorb carbon dioxide and mitigate the local effects of ocean acidification.[37] Seaweed can also reduce methane emissions from cattle when used in feedstocks.[38] Further research is needed on the long-term carbon sequestration potential of seaweed aquaculture.

- **Create opportunities for equitable livelihoods:** Restorative aquaculture can create new job opportunities, enhance economic resilience in coastal communities, and revitalize working waterfronts. Ensuring the economic, social, and physical wellbeing of farmers and workers is a critical component of restorative ocean farming.

For more information on the benefits of restorative aquaculture, see the Urban Ocean Lab's Regenerative Ocean Farming Factsheet.

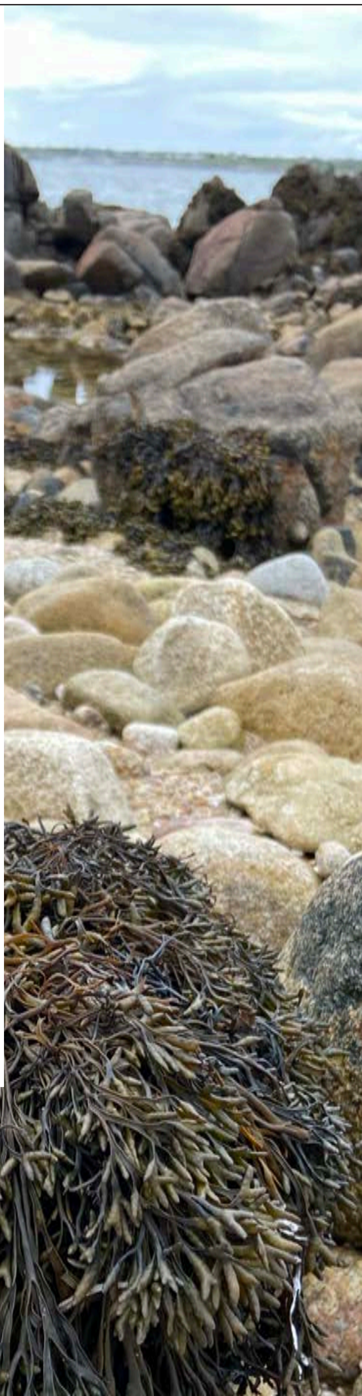


BEST PRACTICES

CONNECTING LAND-BASED AND OCEAN-BASED FOOD SYSTEMS

Connecting regenerative agriculture and restorative aquaculture through the "surf-to-turf" practices outlined in this report can help mitigate the impacts of climate change, enhance both soil health and ocean health, and create new economic opportunities for producers on land and at sea. The section that follows captures some of the key current practices that exemplify this systems-level approach to managing coastal foodscapes. While not exhaustive, we hope that through this cataloging, the versatile breadth of these comparatively untapped activities will be displayed and their immense potential exposed.

Importantly, while many of these practices are being rediscovered, these are mostly not new activities. Indigenous communities have been cleaning their waters, producing food for their families, fertilizing their crops, feeding their animals, and stewarding their shores for millennia. Although the below activities are at times portrayed as "new innovations" by scientists and media alike, they are actually built upon a rich foundation of indigenous practices and knowledge that has been developed over thousands of years that often goes unacknowledged.



Seaweed as an Animal Feed Supplement

Seaweed has long been used to feed livestock in various coastal areas across the world. In fact, references to the use of seaweed in animal feed can be traced back to ancient Greek myths and Icelandic sagas.[39] Interest in seaweed as an animal feed supplement has gained new traction in recent years for its potential to reduce methane emissions from ruminants and improve animal productivity and health.[40] While there is substantial variability in the nutritional profiles of different species, seaweeds can be a valuable source of proteins, complex carbohydrates and prebiotics, and minerals in animal diets.[41] Furthermore, seaweed has emerged as a potential way to reduce methane emissions from ruminants, a significant contributor to anthropogenic climate change. Initial studies have revealed promising outcomes, including a 67% decrease in methane reduction in dairy cows with the addition of 1% organic matter from *A. armata*, although further research is still needed.[42]

Despite the excitement surrounding the potential for significant methane reduction, many believe it is crucial to take a market-driven approach to drive the adoption of seaweed in animal feed. Simply reducing methane emissions may not be enough; seaweed must also improve the end product for continued strong adoption. Further research is also needed on topics such as toxicity as some seaweeds can be toxic to animals if eaten in large quantities. Although seaweed shows promise in helping to reduce methane emissions from livestock, it is important that this development does not distract from addressing the overarching negative impacts of intensive animal agriculture on people, animals, and the environment.

Seaweed as a Soil Amendment

The use of seaweed as an organic fertilizer and soil amendment has experienced a resurgence of interest from international donors, tech companies, and small-scale farmers. Numerous studies have demonstrated the potential of seaweed inputs to enhance plant growth, condition soil, protect plants from stress, and increase resistance to disease and pests.[43] Excitingly, seaweed-based fertilizers can also help reduce reliance on synthetic fertilizers and, in doing so, mitigate the harmful impacts of agricultural runoff in waterways, while creating opportunities for closed-loop nutrient cycling between land- and ocean-based food systems. In addition to these environmental benefits, the use of seaweed in fertilizers and soil amendments can create new market opportunities for restorative ocean farmers to sell their product. This is particularly important in the United States where the seaweed industry is still developing. Despite the promise of seaweed in fertilizer and biostimulant products, companies within the space noted barriers such as cost, knowledge, infrastructure, and local production sources that must still be overcome in order for the industry to progress.

Conservation Agriculture for Ocean Health

Conservation agriculture offers a suite of intentional, ecologically-minded approaches that farmers and landowners can employ to safeguard ocean health through land stewardship. These practices recognize the intricate relationship between land and sea, acknowledging that actions on land can have profound effects on aquatic environments. By implementing these practices, farmers aim to mitigate potential negative impacts from agricultural activities, such as nutrient runoff, sedimentation, and chemical contamination, all of which can harm nearby waterways and, ultimately, the broader ocean ecosystem. These practices often revolve around principles of soil health and conservation. Examples include cover cropping to reduce erosion and nutrient leaching, rotational grazing to provide periods of rest and regrowth that can reduce soil degradation and nutrient runoff, and buffer strips to act as natural filters to capture runoff before it reaches the water. Additionally, precision nutrient management strategies help farmers apply fertilizers in a targeted manner, ensuring that nutrients are utilized by crops rather than being lost to runoff.

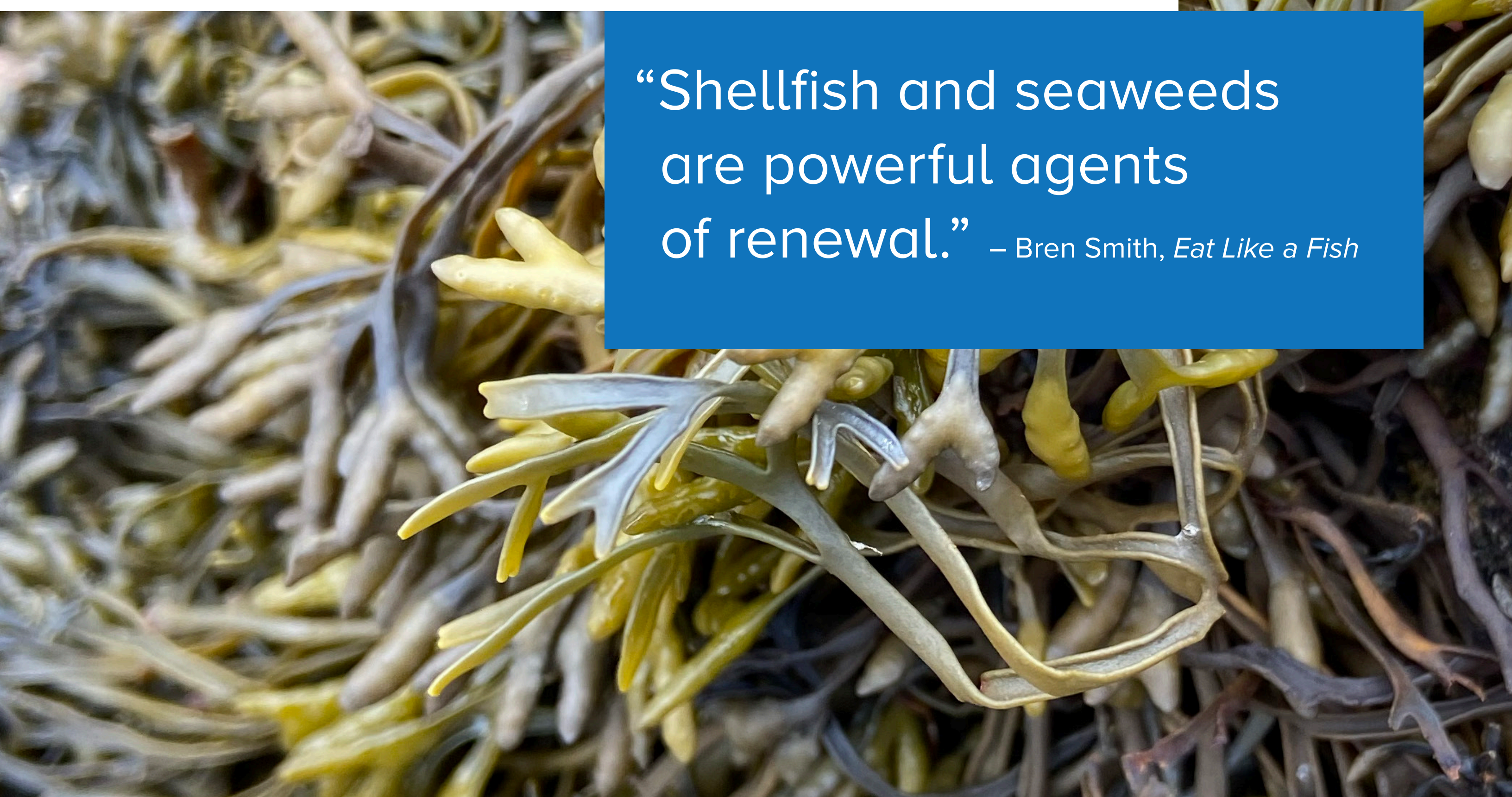
The USDA's recent $22.5 million investment in conservation assistance for farmers in the Chesapeake Bay region demonstrates a strong commitment to conservation agriculture as a tool to protect coastal waterways.[44] This initiative employs cover cropping, rotational grazing, and riparian buffers to reduce nutrient runoff, control erosion, and improve water quality. By prioritizing and funding these land-based practices, sustainable land-to-sea stewardship is both recognized and strengthened.

Seaweed and Marine Bivalves for Water Quality Improvement

Nutrient-enriched aquatic systems, often plagued by runoff from agricultural operations, sewage treatment facilities, or industrial sites, may exhibit excessive algae growth, decreased oxygen levels, diminished food sources and habitats for aquatic life, and water unsuitable for human recreation or use. To address these issues, seaweed and marine bivalves have emerged as highly effective agents for absorbing and filtering excess aquatic nutrients like nitrogen and phosphorus, leading to their increased use in water purification efforts. Bivalves naturally filter nitrogen from their environment by absorbing it into their tissues and shells as they grow. Similarly, seaweeds, such as kelp, absorb substantial quantities of these nutrients to fuel their growth and reproduction. Restorative ocean crops like shellfish and kelp have immense potential to clean up waterways and, in doing so, mitigate the impacts of nutrient runoff from land-based agriculture.

Blue Carbon: Seaweed and Marine Bivalves for Carbon Sequestration

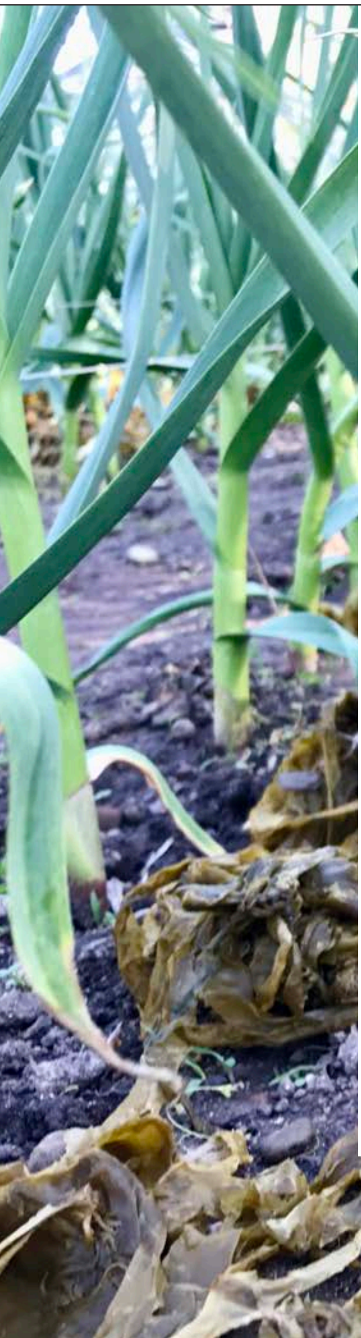
The global food system is responsible for an estimated one-third of anthropogenic greenhouse gas emissions, the majority of which can be attributed to agriculture and land use.[45] To combat this, there is growing interest in seaweed and shellfish farming as a potential climate solution through the sequestration of “blue carbon,” typically defined as carbon captured by coastal and oceanic ecosystems.[46] With shellfish, carbon sequestration occurs through the absorption of carbon as calcium carbonate within their shells as they grow. A recent study noted that shellfish farming implemented at the global scale could potentially sequester as much as 17.6% of total 2020 global CO_2 emissions.[47] Like terrestrial plants, seaweed captures carbon from the atmosphere through photosynthesis. A recent expert panel estimated that kelp, the most commonly used seaweed species for sequestration currently, has the potential to draw down around 1 to 10 billion tons of CO_2 per year.[48] Companies and farmers have already started to build and operate seaweed farms for carbon sequestration and are exploring storage options such as biochar, where seaweed is mixed with composted seaweed and soil and used as a soil enrichment supplement, or seabed storage, where seaweed is sunk to the ocean floor at a sufficient depth to remain captured in the sediment. While there is growing excitement surrounding these practices, numerous questions about the carbon sequestration potential of seaweed still need to be addressed, particularly around end-stage activities including the ecological impact of depositing billions of tons of dead biomass on the seafloor, the potential carbon emissions from seaweed-rich areas, and the longevity of deposited seaweed on the seabed.



> “Shellfish and seaweeds are powerful agents of renewal.” – Bren Smith, *Eat Like a Fish*

CASE STUDIES

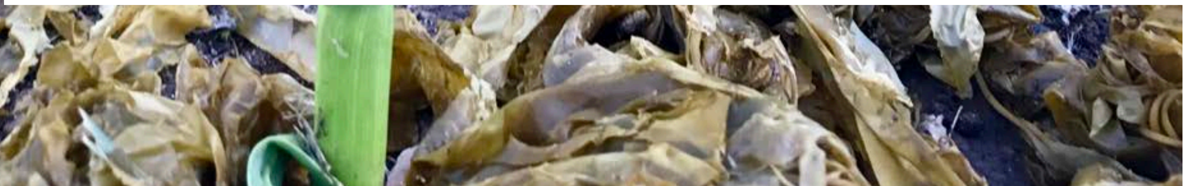
NORTHEAST INITIATIVES NAVIGATING THE NEXUS OF LAND AND SEA IN REGENERATIVE FOOD PRODUCTION



Several farms, businesses, and nonprofit organizations in the Northeastern United States are already at work helping to build regenerative food systems by bridging ocean health and soil health. Examples of these organizational leaders include:

Ocean Hour Farm: Founded in 2021 and located in Newport, Rhode Island, Ocean Hour Farm serves as a center for research, education, and demonstration of regenerative agricultural practices that highlight the critical connections between land and ocean health. A project of 11th Hour Racing, Ocean Hour Farm aims to improve ocean health through regenerative land stewardship. The farm partners with Clean Ocean Access to conduct regular water quality testing of the water that filters through the farm from over sixty surrounding acres and ultimately into Brenton Cove Bay. By trialing and demonstrating sustainable farming practices, like rotational grazing, creation of riparian buffer zones, and biointensive agriculture, Ocean Hour Farm intends to serve as a resource for farmers and land stewards and to help foster the land-to-sea connection for the agricultural community.

Earth Care Farm: Situated near Block Island Sound, Earth Care Farm has been producing farm-made compost for farmers, gardeners, and landscapers for over forty years. Earth Care Farm partners with local fisheries in Rhode Island to divert fish waste and creates compost using these fish scraps, shellfish, and seaweed, as well as food scraps from restaurants and institutions. The finished product contains shell fragments that act as a source of calcium to plants as they decompose over time.[49] Earth Care Farm's compost is used by farmers across the Northeast and beyond, bringing marine-based nutrients from Rhode Island's coast to agricultural fields.

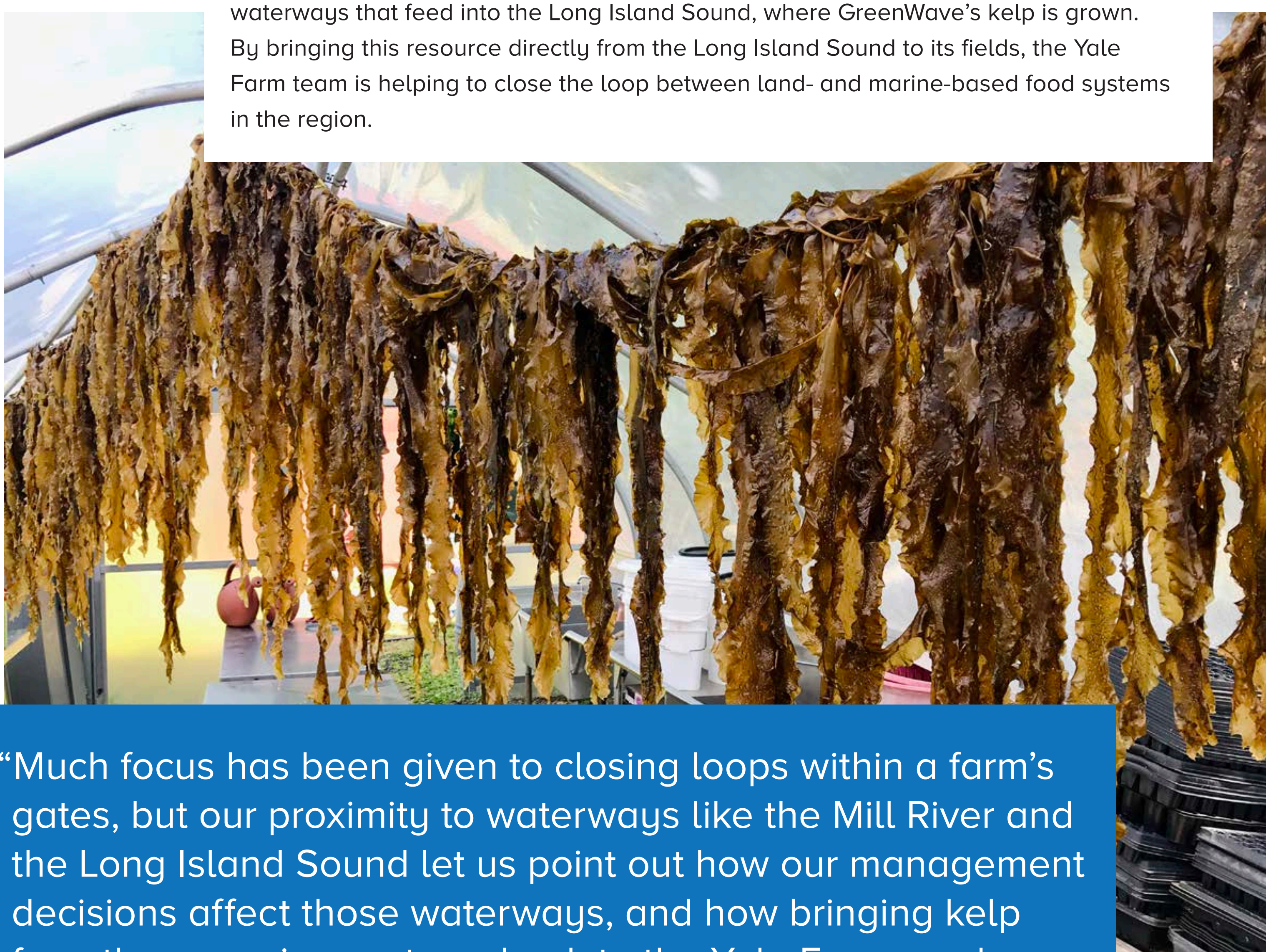


Montauk Seaweed Supply Co: The Montauk Seaweed Supply Co is New York State's only certified manufacturer of pure local fertilizer products sourced from the sea.[50] Established in 2021, Montauk Seaweed Co uses local kelp and seaweed to create healthy fertilizers and biostimulant products for use in farming, gardening, and landscaping. A core component of the company's mission is to "create a circular nitrogen loop" in which kelp farms can serve as phytoremediation for New York waterways and seaweed-based fertilizer products can return that nitrogen to the soil, ultimately reducing reliance on synthetic fertilizers.

Other organizations are using land and sea education as a tool to grow the next generation of young chefs, farmers, and food citizens. In partnership with the Mystic Rotary Club and Stonington Kelp Co, the Yellow Farmhouse Education Center has brought local, fresh kelp, accompanied by lesson plans and recipes, to classrooms across Connecticut and enabled family consumer science teachers to teach students about restorative ocean farming. Over the past two years, this program has reached over 1,110 students across 14 schools in Connecticut. In 2023, the Mystic Seaport Museum collaborated with the Mashantucket Pequot tribe to create a Three Sisters demonstration garden, using fish as fertilizer and layered with seaweed gathered from the local waterways. Education initiatives like this serve as important reminders of the deep history of these sea-to-land practices.

Bridging Land and Sea at the Yale Farm

Managed by the Yale Sustainable Food Program, the Yale Farm has been applying seaweed to its fields for the last ten years. The raw seaweed is sourced from GreenWave's restorative ocean farm in the Thimble Islands off the coast of Branford, Connecticut and then processed in a variety of ways once on site at the Yale Farm. These include dissolving the seaweed in water to make a kelp solution, decomposing it in the farm's compost bins, applying it directly to the fields as a mulch, and drying it in the farm's propagation tunnel to create a "kelp flake" soil amendment. As an educational farm, the Yale Farm's use of locally grown seaweed in its fields serves as an important example of closed-loop nutrient cycling at the watershed level. The farm is located near the Mill River in New Haven and thus its on-farm practices impact the waterways that feed into the Long Island Sound, where GreenWave's kelp is grown. By bringing this resource directly from the Long Island Sound to its fields, the Yale Farm team is helping to close the loop between land- and marine-based food systems in the region.



"Much focus has been given to closing loops within a farm's gates, but our proximity to waterways like the Mill River and the Long Island Sound let us point out how our management decisions affect those waterways, and how bringing kelp from those marine systems back to the Yale Farm can be part of a more productive definition of closing the loop."

– Jeremy Oldfield, Farm Manager, Yale Sustainable Food Program

BARRIERS

ADDRESSING THE HURDLES TO RESTORATIVE AQUACULTURE

In the barriers highlighted below, we chose to focus primarily on those facing the nascent seaweed farming industry. While several roadblocks remain in bridging the land-sea divide in food systems discussions, these cannot be effectively addressed without tackling the following challenges and setting the stage for the maturation of the restorative aquaculture sector. The barriers outlined here were also those mentioned the most frequently in stakeholder interviews, further emphasizing the need to direct resources to restorative ocean farming, and in particular, the emerging seaweed aquaculture industry. Some solutions to these barriers can be found in the following section.

Insufficient Knowledge and Training

While seaweed farming has a long history in many parts of the world, it has only recently emerged as an aquaculture practice in the United States. As such, technical training on the cultivation of kelp and other macroalgae is needed to support both new farmers entering the market and shellfish farmers or other fisherfolk looking to add seaweed to their production mix. While shellfish farming has a longer history in the US, as production is scaled and new farmers enter the market, knowledge gaps still exist on the "how to" and training on topics such as permitting, market development, and input costs, remains important. In addition to increased technical training and support for restorative ocean farmers, more efforts are needed to increase land-based farmer knowledge about the existence and multiple benefits of relevant marine products such as seaweed fertilizer, biostimulants, or feed amendments. Those already interested in incorporating ocean-based products also need additional training on how to better integrate them into their current practices. In this regard, extension agencies can play an important role.

GreenWave is leading the way in training this new wave of ocean farmers. Based in Connecticut but working globally, GreenWave supports farmers from "seed to sale" and offers a range of support mechanisms, including: online courses, farm design tools, and collaborative spaces for community building; climate subsidies, farmer infrastructure, and market development programs; and virtual and hands-on farmer workshops. With more than 6,000 users registered to date, GreenWave's online Regenerative Ocean Farming Hub was launched in 2022 and provides curriculum, tools, and networking opportunities to support emerging and experienced farmers from seed to sale. Greenwave's leadership in this space remains an integral resource for addressing knowledge and training gaps for new or transitioning farmers, and the organization's efforts should continue to be supported.

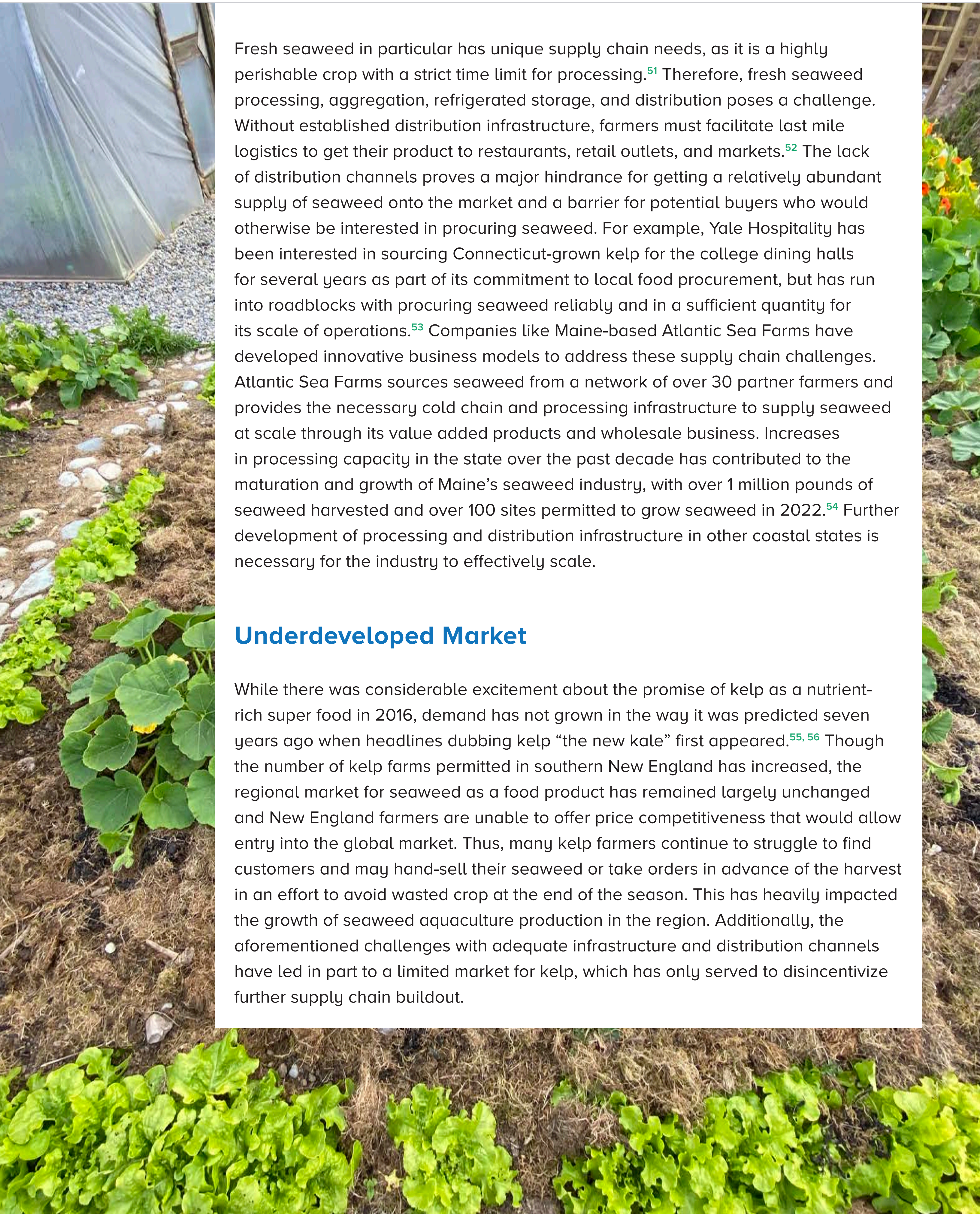
Inadequate Infrastructure

Seaweed can either be sold as a fresh (raw) or dried (dehydrated or desiccated) product. Drying extends the shelf life of seaweed, alleviating the time pressure to bring the crop to market once it is removed from the water. However, drying seaweed requires processing and storage infrastructure that many parts of the country, including southern New England, currently lack. As such, the only option for many kelp farmers is drying at the home scale, severely limiting processing capabilities. While the preservation process for seaweed is not technologically intensive, it does require adequate space where the crop can be washed, dried, and stored with appropriate food safety measures in place. Thus, the development of large-scale commercial processing facilities is critical.

Fresh seaweed in particular has unique supply chain needs, as it is a highly perishable crop with a strict time limit for processing.[51] Therefore, fresh seaweed processing, aggregation, refrigerated storage, and distribution poses a challenge. Without established distribution infrastructure, farmers must facilitate last mile logistics to get their product to restaurants, retail outlets, and markets.[52] The lack of distribution channels proves a major hindrance for getting a relatively abundant supply of seaweed onto the market and a barrier for potential buyers who would otherwise be interested in procuring seaweed. For example, Yale Hospitality has been interested in sourcing Connecticut-grown kelp for the college dining halls for several years as part of its commitment to local food procurement, but has run into roadblocks with procuring seaweed reliably and in a sufficient quantity for its scale of operations.[53] Companies like Maine-based Atlantic Sea Farms have developed innovative business models to address these supply chain challenges. Atlantic Sea Farms sources seaweed from a network of over 30 partner farmers and provides the necessary cold chain and processing infrastructure to supply seaweed at scale through its value added products and wholesale business. Increases in processing capacity in the state over the past decade has contributed to the maturation and growth of Maine's seaweed industry, with over 1 million pounds of seaweed harvested and over 100 sites permitted to grow seaweed in 2022.[54] Further development of processing and distribution infrastructure in other coastal states is necessary for the industry to effectively scale.

Underdeveloped Market

While there was considerable excitement about the promise of kelp as a nutrient-rich super food in 2016, demand has not grown in the way it was predicted seven years ago when headlines dubbing kelp "the new kale" first appeared.[55, 56] Though the number of kelp farms permitted in southern New England has increased, the regional market for seaweed as a food product has remained largely unchanged and New England farmers are unable to offer price competitiveness that would allow entry into the global market. Thus, many kelp farmers continue to struggle to find customers and may hand-sell their seaweed or take orders in advance of the harvest in an effort to avoid wasted crop at the end of the season. This has heavily impacted the growth of seaweed aquaculture production in the region. Additionally, the aforementioned challenges with adequate infrastructure and distribution channels have led in part to a limited market for kelp, which has only served to disincentivize further supply chain buildout.



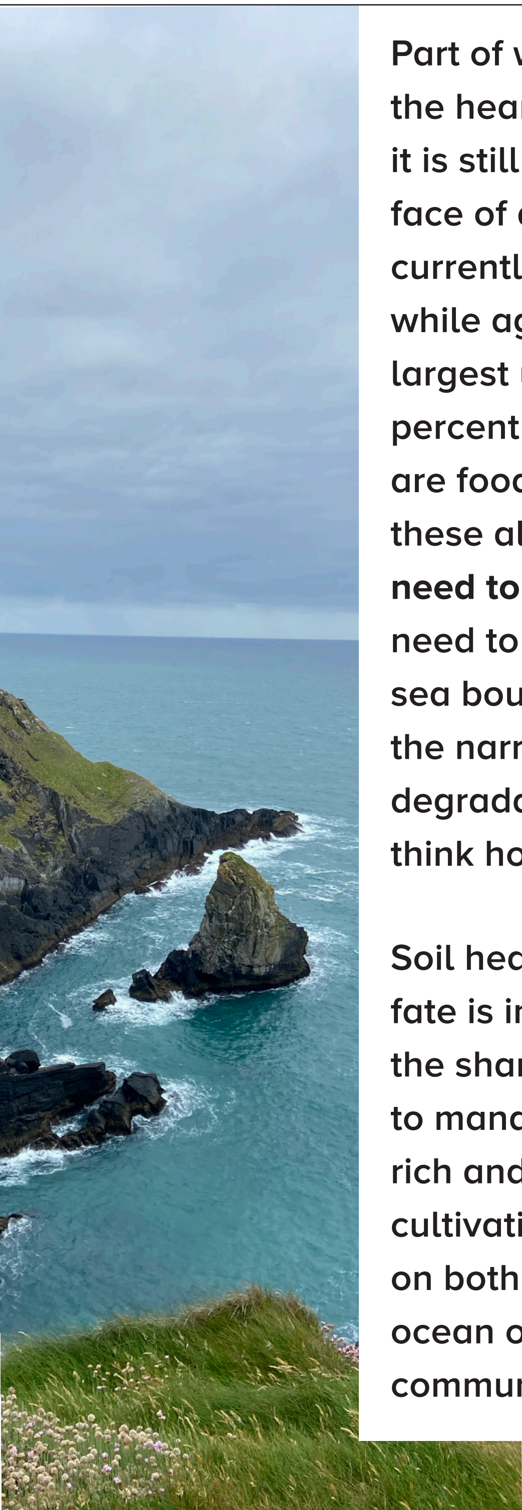
To contend with these challenges, ocean farmers have found creative avenues to grow their own market. As one such example, four farms located in Connecticut and Rhode Island - Stonington Kelp Co, New England Sea Farms, Block Island Shellfish Farm, and Rhody Wild Sea Gardens – formed the Sugar Kelp Cooperative and together organize the annual New England Kelp Harvest Week. Now in its third year, Kelp Harvest Week offers a way for seaweed farmers to sell their crop to participating restaurants, breweries, and distilleries at the end of April when the bulk of the crop is ready for harvest.[57] While this effort has helped raise awareness about seaweed in the regional culinary community, market development remains a significant challenge for seaweed farmers and additional resources are needed to support its advancement.

Strong Presence of NIMBYism

The prevalent and ever increasing attitude of NIMBYism (“Not In My Back Yard”) along expensive coastline real estate proves another barrier behind ocean farming infrastructure development. Interviewees talked about how affluent families are buying coastal properties and objecting to the “undesirable” views of current or planned shellfish or seaweed farms. This separation between “people working on the water and people looking at it”[58], can hinder the development of necessary coastal infrastructure as community complaints slow down the already timely process for permitting approval. In order to combat NIMBYism, there is a pressing need to help coastal homeowners deepen their understanding of and emotional connection to the beauty and historical depths of working landscapes within the places they call home.

OPPORTUNITIES

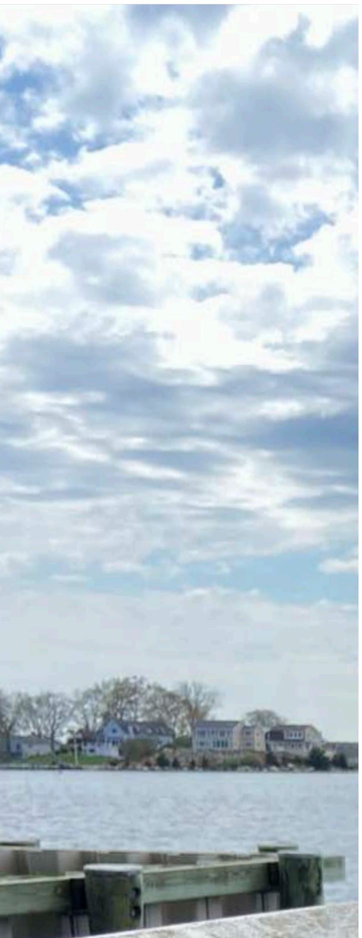
CULTIVATING HOPE AT THE LAND-SEA INTERFACE



Part of what has allowed regenerative ocean farming to capture the hearts and minds of the broader public in recent years is that it is still largely a story of hope, and hope is what we need in the face of a food system and climate in crisis. Our global food system currently contributes one-third of greenhouse gas emissions,[59] while agriculture is the leading driver of biodiversity loss[60] and the largest user of freshwater resources worldwide.[61] Roughly thirty percent of food is wasted globally,[62] yet over one billion people are food insecure.[63] Stories of hope are crucial to contend with these alarming realities, but **for hope to transform into action we need to think and grow differently than we have in the past**. We need to build deep and meaningful partnerships across the land-sea boundary between farming and fishing communities; to change the narrative of the connections between land and sea from one of degradation and harm to one of collaboration and innovation; to think holistically about building healthy soils and seas.

Soil health and ocean health are not separate objectives. Their fate is inextricably linked, and we have the opportunity to secure the shared future of both. Taking an ecosystems-level approach to managing coastal foodscapes offers a pathway to leverage a rich and storied history of sea-to-soil agricultural practices, while cultivating new and innovative ways to produce food sustainably on both sides of the shoreline. In doing so, we can unlock an ocean of opportunity for the health of our seas, soils, and the communities who depend upon both.

Revitalizing Working Waterfronts & Building Upon Coastal Heritage



With the decline of wild fisheries, once thriving working waterfront communities are now at risk of extinction.[64] On land, coastal farmers face ever-rising development pressures to sell or subdivide their farmland, while new and beginning farmers face major challenges with land access. Restorative aquaculture offers a pathway to protect these coastal livelihoods, while creating new economic opportunities for farming and fishing communities. As discussed above, one of the key barriers to the development of the seaweed industry, in particular, is the lack of suitable processing and storage facilities.[65] Protecting and investing in waterfront infrastructure, including docks, marinas, and warehouse spaces with shared equipment, can help address this hurdle.[66] In Maine, the Working Waterfront Access Protection Program provides matching funds to help fishing and aquaculture businesses, co-ops, and municipalities protect working waterfront properties for commercial fishing and aquaculture use.[67] This offers an important model for state policy that could be replicated elsewhere. Given the critical need for commercial processing infrastructure, investing in the preservation and revitalization of working waterfronts has the potential to significantly advance opportunities for restorative aquaculture.

The preservation of coastal heritage is a less discussed, but equally important potential outcome of strengthening the economic resilience of working waterfronts. Many of these communities have been feeding people from the land and sea for generations. As such, they possess a deep knowledge of coastal resources and are part of a culture centered around working on or near the water. Supporting regenerative agriculture and restorative aquaculture at the land-sea interface can provide avenues for farmers and fishermen to continue to live and make a living on the coast.

Developing Markets

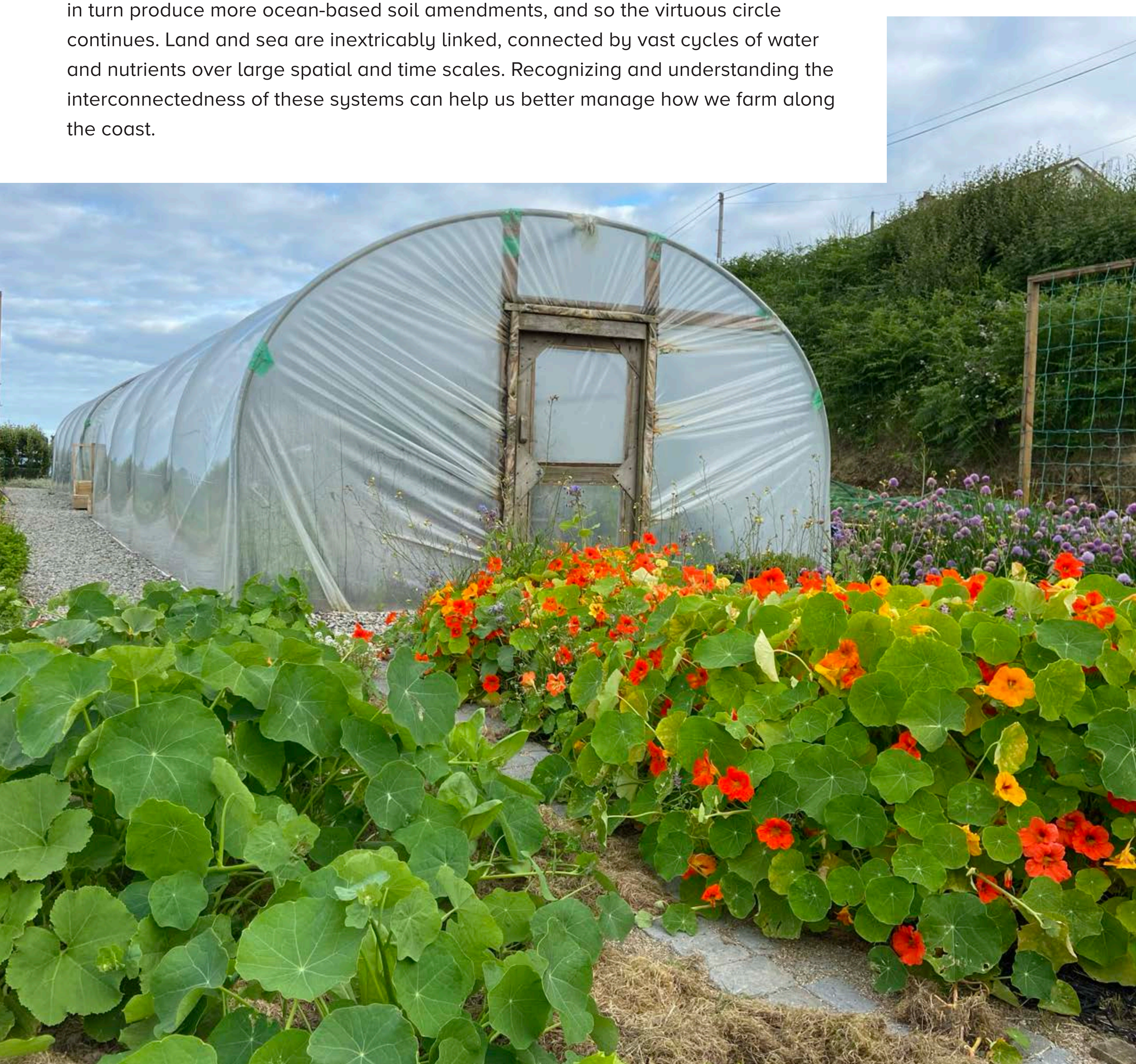
Under the leadership of organizations like GreenWave, there is now a well-established model for the production of restorative ocean crops like sugar kelp in the United States. Yet, while interest in kelp as a food product continues to grow steadily each year, the market for seaweed remains underdeveloped. In this regard, land-based agriculture offers an important market opportunity for the emerging seaweed industry through use as soil amendments and livestock feed. In southern New England, there is growing excitement amongst kelp farmers about the potential application of seaweed as a soil amendment to contend with the issue of biofouling at the end of the harvest season in May. In seaweed farming, biofouling refers to the growth and accumulation of aquatic organisms on the seaweed blades. Once the water warms, biofouling is a major challenge for seaweed producers, as the crop is difficult to clean and wash appropriately and thus unsuitable for human consumption.[68] However, it may still be used safely as a soil amendment, thereby effectively extending the season for the New England seaweed industry, while providing a sustainable "spoils-to-soil" fertilizer for farmers on land. Montauk Seaweed Company is one such company that has emerged to create new market opportunities for local kelp and seaweed through fertilizer and biostimulant products.

Forging New Partnerships

Taking an ecosystems-level approach to managing food systems can present new kinds of partnerships between practitioners on land and at sea. In New England, sugar kelp is the first ocean crop to come in and is ready for harvest by the end of May before the peak harvest season for land farmers. Given this complementarity, farm infrastructure could be used for drying kelp after harvest. During the COVID-19 pandemic, Yellow Farmhouse Education Center, a nonprofit food education center based at Stone Acres Farm in Stonington, Connecticut, worked with Stone Acres and local seaweed farm Stonington Kelp Co to find space in greenhouses for the kelp crop to be dried. Yellow Farmhouse has further deepened its partnership with Stonington Kelp Co by delivering kelp to schools across the state for culinary education teachers to use in their classroom, introducing a new generation of eaters to this restorative crop from the state's coastal waters. As regional food hubs are proposed and developed, consideration should be given equally to the storage and processing needs of ocean crops, as well as the typical row crops from land-based agriculture.

Closing the Loop

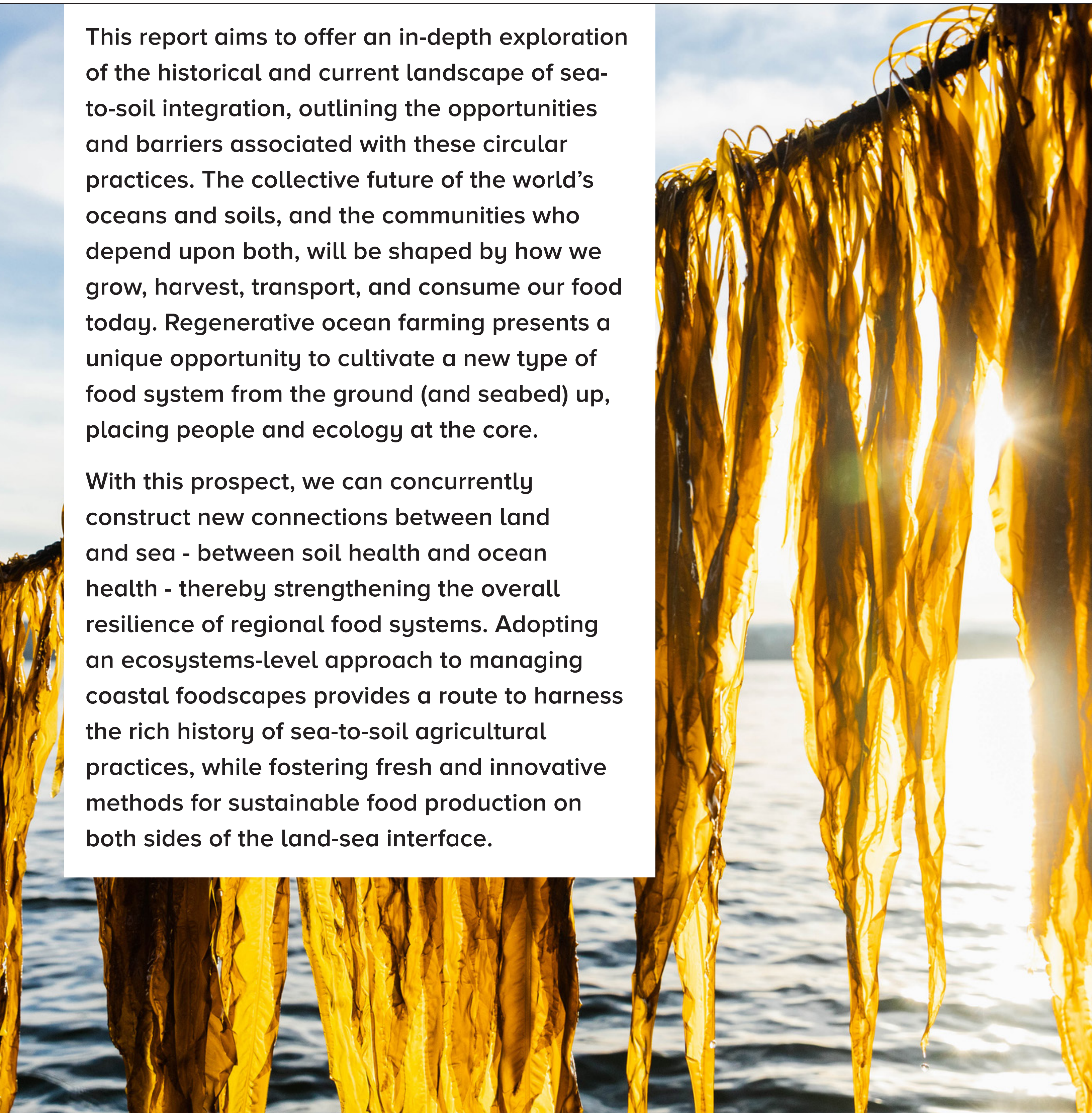
The use of restorative ocean crops as soil amendments for land-based agriculture offers a powerful way to bridge the nutrient cycle between land and sea. Applying liquid seaweed as a feed for agricultural crops, for example, can potentially help reduce the reliance on and overapplication of chemical fertilizers and, in doing so, lessen the degree of excess nutrient runoff in waterways. The corresponding improvement in water quality for coastal ecosystems can ameliorate the growing conditions for shellfish and seaweed farms downstream. These farms can then in turn produce more ocean-based soil amendments, and so the virtuous circle continues. Land and sea are inextricably linked, connected by vast cycles of water and nutrients over large spatial and time scales. Recognizing and understanding the interconnectedness of these systems can help us better manage how we farm along the coast.



CONCLUSION

This report aims to offer an in-depth exploration of the historical and current landscape of sea-to-soil integration, outlining the opportunities and barriers associated with these circular practices. The collective future of the world's oceans and soils, and the communities who depend upon both, will be shaped by how we grow, harvest, transport, and consume our food today. Regenerative ocean farming presents a unique opportunity to cultivate a new type of food system from the ground (and seabed) up, placing people and ecology at the core.

With this prospect, we can concurrently construct new connections between land and sea - between soil health and ocean health - thereby strengthening the overall resilience of regional food systems. Adopting an ecosystems-level approach to managing coastal foodscapes provides a route to harness the rich history of sea-to-soil agricultural practices, while fostering fresh and innovative methods for sustainable food production on both sides of the land-sea interface.



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Our hope is that this report can serve as a catalyst for conversation about the critical connections between land and sea in building regenerative food systems. We invite you to share your ideas and insights with us at cbey@yale.edu as we continue to build upon this work together.

The graphic design was created by HvADesign.

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- **Kelly McGlinchey** is a recent graduate of the Yale School of the Environment, where she received her Master of Environmental Management degree with a focus on sustainable agriculture and food systems. At Yale, Kelly served as a research associate with the Regenerative Agriculture Initiative, co-founded the Food Systems Graduate Network, and carried out her capstone research on building resilience in coastal food systems as a Berkeley Conservation Scholar. Prior to graduate school, Kelly founded Table & Tilth, a food sustainability consultancy dedicated to promoting an ecologically conscious, regenerative food system in partnership with our clients. Kelly has spoken on food entrepreneurship and sustainable food systems at New York University, Columbia University, Dartmouth College, the Institute of Culinary Education, and Google. Certified in permaculture design, Kelly has worked in gardens across six continents and savors any opportunity to get her hands in the soil. Kelly is a recipient of the Donella Meadows Prize for Promoting Sustainability and holds her BA in Environmental Studies from Dartmouth College.

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