Meeting Protein & Energy Needs for 10 billion People while Restoring Oceans

Scott Lindell and Hauke Kite-Powell

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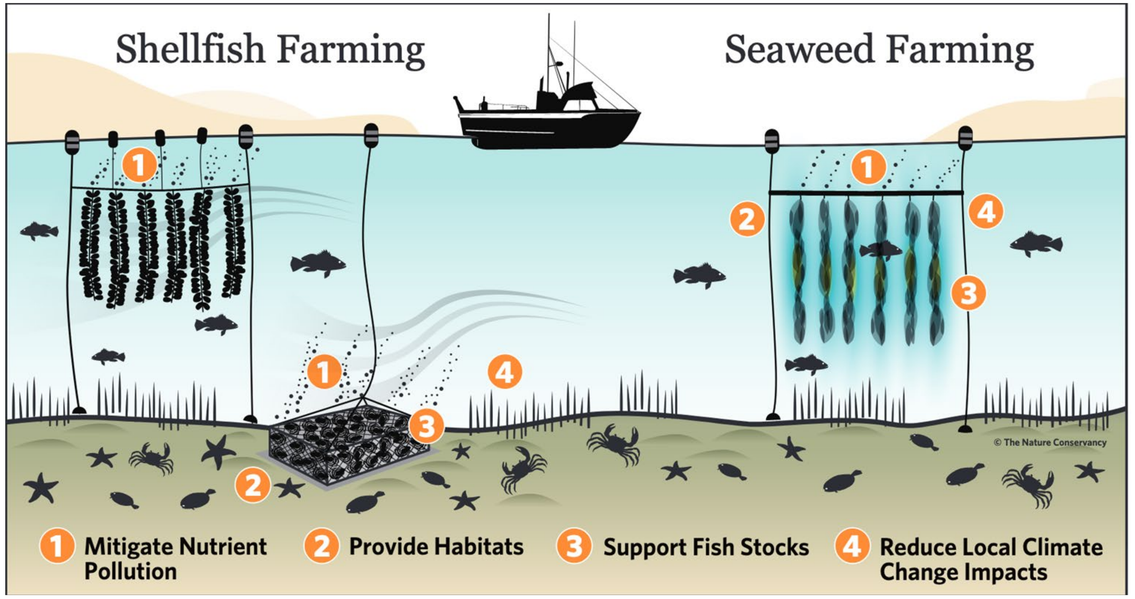
Abstract

- Shellfish and seaweed farming provide resources, opportunities, and solutions to address a wide range of seemingly intractable global problems. Properly placed and managed, aquaculture operations can be restorative to ocean environments, counter climate change, and relieve pressure to farm sensitive terrestrial environments. For these reasons, there is growing social acceptance and political pressure for marine aquaculture expansion, and State, Federal, and International, as well as eNGO-led initiatives are underway. Now is the time to invest in multi-disciplinary science-based teams that can signpost the sustainable pathway for marine aquaculture by developing monitoring and modeling tools and protocols for measuring associated ecosystem impacts and beneficial services. The yield on that investment will be healthy food and more carbon-neutral bio-fuels grown in ways that help heal our oceans. A sustained commitment by the US now to develop the science and technology for future ocean farms will find an enthusiastic audience in young researchers and technologist around the world, who seek better ways to improve peoples' lives through their science and problem-solving.



Human needs: Shellfish produce healthy proteins, while seaweeds produce complex carbohydrates and micronutrients important to human and livestock health, and potential feedstocks for bio-fuel.

Economic advantages: sustainable jobs, improved trade balance

Ecosystem benefits: Carbon and nutrient removal

Leveraging technology:
- automation
- integration with ocean energy production (wind farms)
- monitoring to ensure ecological integrity

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Challenges

Food and Energy Production

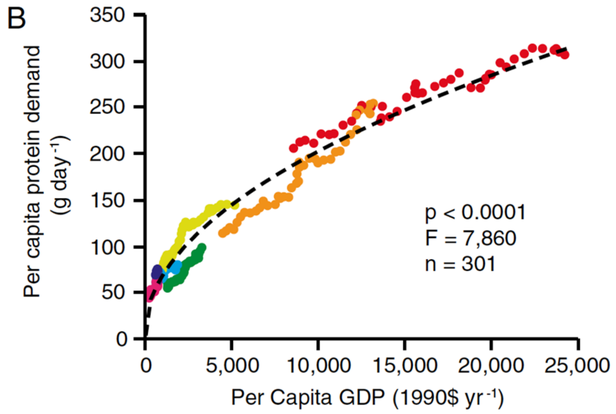
- We need to double protein production by 2050 as population and incomes rise.
- Most suitable farmland is already in use.
- We will also need at least 50% more energy by 2050.

Climate

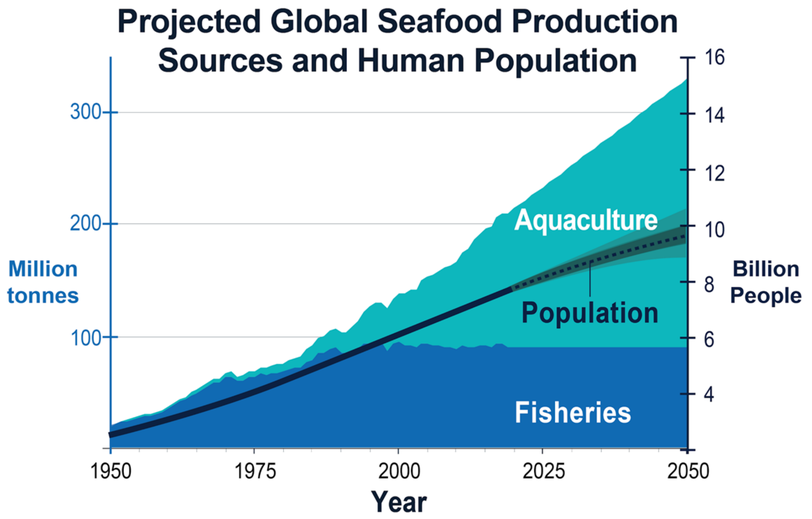
- Climate change and freshwater scarcity hinder food production on land.
- Climate change will reduce yields for many land crops
- Agriculture accounts for 20% of global GHG emissions, and is highly dependent on fossil fuels.

Oceans

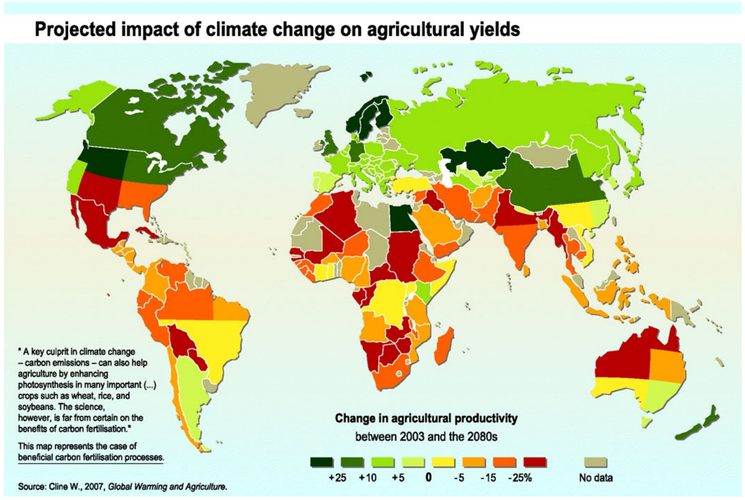
- Climate change is stressing ocean systems via higher temperatures, and acidity.
- Wild fisheries are over-fished or at sustainable maximum yield. Aquaculture must make up the difference between demand and supply.
- Marine aquaculture can help restore environments AND supply human food, feed and bio-fuels.



Source: Tilman et al. (2011)



Adapted from Source: Waitt et al., World Resources Institute, 2014, and United Nations, https://population.un.org/wpp/Graphs/Probabilistic/POP/TOT/900



Source: Cline et al. (2007)

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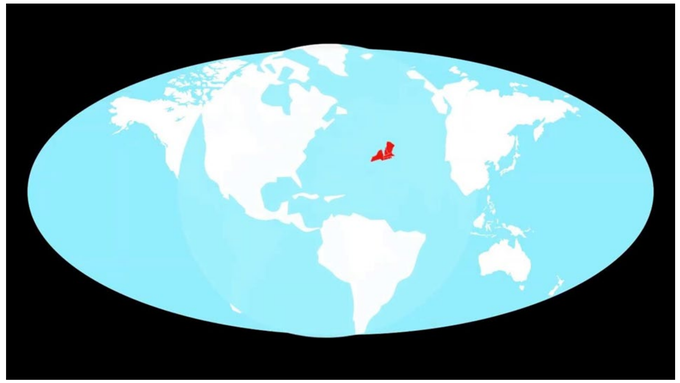
Vision: Restorative Ocean Farming

Ocean real estate is largely underutilized today

Farming the oceans, or marine aquaculture, is a logical step to enhance production of protein, feed and bio-fuel feedstocks with a smaller ecological footprint than is possible on land.

Currently most aquaculture happens in freshwater. The oceans cover 70% of our planet yet provide only 2% of human nutrition.

Discover how small an ocean area we need to farm to meet the world's needs by 2050 in the **animation below.**



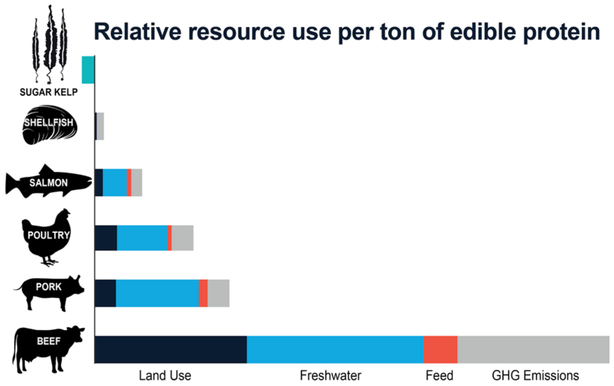
Ocean farming is ecologically superior to land agriculture

Only sunshine, labor and love!
Bivalve shellfish and seaweeds require few inputs:

- NO feed.
- NO freshwater
- NO arable land
- NO fighting gravity

This means they are more efficient and contribute far fewer greenhouse gases than agriculture.

Example: GHG emissions from beef production is 20 times that for bivalve shellfish farms



Source: Waite et al, World Resources Institute, 2014 and Pahlow et al. 2015

Ocean farming can restore damaged marine ecosystems

Seaweeds and shellfish absorb or remove excess nutrient sources, and improve seawater quality.

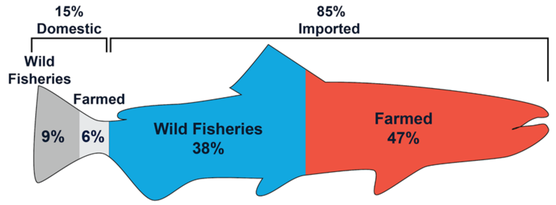
Seaweeds also absorb CO2, and release oxygen, thereby helping reverse ocean acidification.

Ocean farms provide ecosystem benefits as "reefs" or structures that support other valuable marine life.

Ocean farming creates jobs

Despite many years of moderate scale aquaculture, there are still scientific questions to be answered and social barriers to be overcome before marine aquaculture can fulfill its full potential. Overcoming those, we can create more sustainable jobs and reverse the US seafood trade imbalance.

Sources of all seafood consumed in the U.S.



Data Source: National Marine Fisheries Service, 2020

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Connections to infrastructure, technology, and partnerships

Technology is key

US research and technology development has enabled much global aquaculture growth, even as US aquaculture production has lagged behind the global industry. Currently, shellfish and seaweed aquaculture are a small fraction of US agriculture production but, shellfish farming has quintupled regionally in the last 10 or 15 years, while seaweed production has doubled every year or two over the last five.

Technology, mechanization, and automation will be critical to making open ocean farming economical and safe via cost-effective monitoring and maintenance, prevention of adverse interactions with protected species, and efficient harvesting, transport, and processing of harvested products.

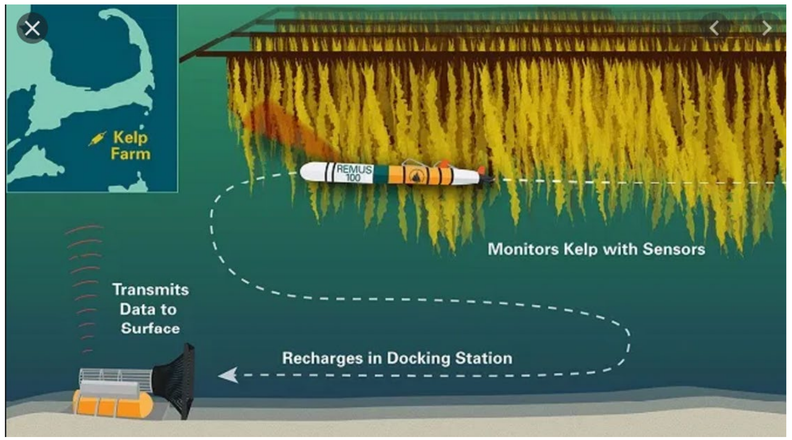
Infrastructure linkages: wind farms, working waterfronts

Marine farms can be co-located with offshore wind farms to make more efficient use of ocean real estate. They can provide the economic drivers to keep America's working waterfronts healthy, such as in places where commercial fishing is in decline.

Partnerships with the offshore energy, fishing, and robotics industries can leverage areas of US expertise to support the development of a robust, sustainable, and profitable US ocean aquaculture industry.

New policies and investment help pave the way

A recent Executive Order prompted NOAA to streamline regulations and create Aquaculture Development Areas in Federal waters. The AQUAA Act now pending in Congress will provide more resources for marine aquaculture expansion, including aquaculture research. The DOE has invested about $50M in the last three years in the MARINER Program to develop tools and networks for fostering sustainable seaweed aquaculture. Members of this Ocean Shot have designed and implemented aquaculture projects in the US and internationally.



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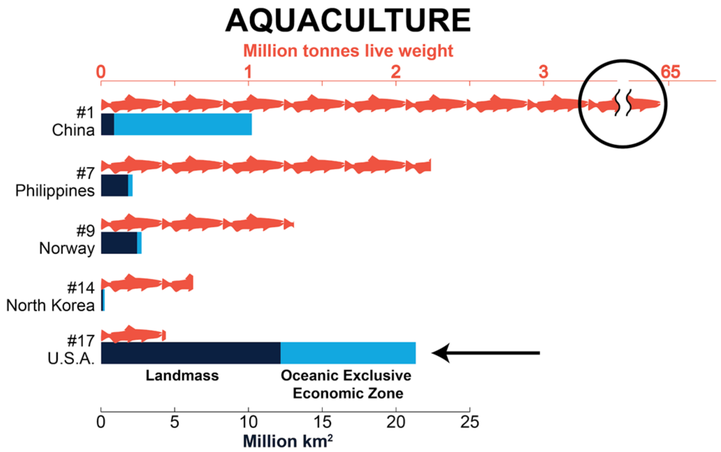
Opportunities for national and international capacity-building

eNGOs are leading the way

International eNGOs like The Nature Conservancy and World Wildlife Fund are investing in initiatives to promote shellfish and seaweed aquaculture as nature-based climate solutions.. Oceans 2050 is a collaborative international initiative that cites Regenerative Ocean Farming and Blue Carbon Sequestration as two of its objectives. Ocean Visions is a consortium to jump-start a community that designs and deploys equitable and scalable ocean solutions to climate change. All these initiatives and several more in Europe and Asia-Pacific regions require tools this Ocean Shot proposes to verify or certify the intended environmental benefits derived from aquaculture projects. **The U.S. has a lot of catching up to do despite having one of the largest oceanic Exclusive Economic Zones!**



Source: UN Food and Agriculture Organization 2019

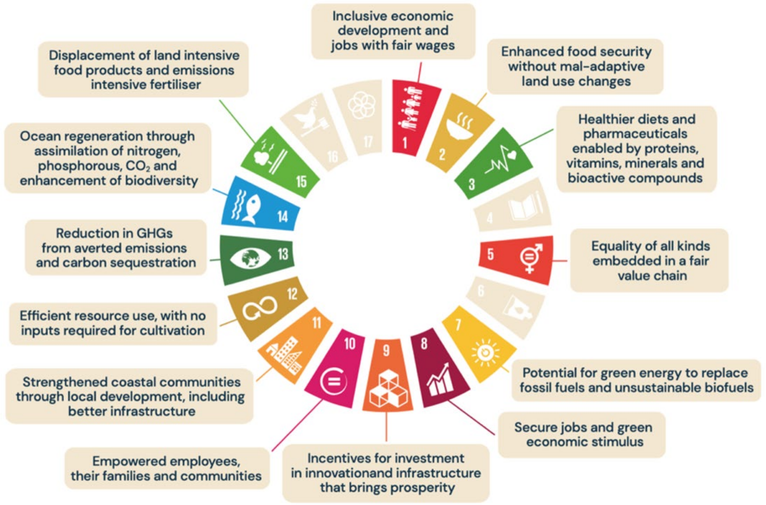
Multi-disciplinary approaches

Optimizing the siting, design, engineering, husbandry, and ecosystem stewardship of large-scale future ocean farms will require collaboration across many disciplines and industries. Sectors outside the traditional ocean sciences that can play a key role include breeding and genetics, robotics, and biofuel processing, as well as naval architecture and offshore industries. Multi-disciplinary teams can signpost the sustainable path by early development of monitoring and modeling tools and protocols for measuring ecosystem impacts and services (e.g. ocean acidification, nutrient extraction/deposition, carbon sequestration, impact or enhancement of fishery resources) associated with marine aquaculture.

UN sponsored initiatives

The UN has declared 2021 to 2030 the **Decade for Ocean Science and Sustainable Development.** Recently a UN document entitled, "A Seaweed Manifesto" was published which defines a vision: a scaled-up, responsible and restorative seaweed industry which plays a globally significant role in food security and climate change mitigation, supports the marine ecosystem, and contributes to job creation and poverty alleviation. The Manifesto explores the challenges and barriers for responsible development of the industry, of which many are similar for the shellfish farming industry.

Seaweed and shellfish farming contribute to UN Sustainable Development Goals



Source: Seaweed Manifesto, 2020

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Examples of Collaborations

MARINER Program

The projects that comprise ARPA-E's MARINER program seek to develop the tools to enable the United States to become a global leader in the production of marine biomass. Presently, seaweed is primarily used as food for human consumption, but there is a growing opportunity for the production and use as feedstock for fuels and bio-compounds like bio-plastics, as well as animal feed. ARPA-E estimates the United States has suitable conditions and geography to produce at least 500 million dry metric tons of macroalgae per year. Such production could yield ~10% of the nation's annual transportation energy demand.

MARINER teams are developing technologies such as cultivation and harvesting systems, modeling tools, aquatic monitoring tools, and advanced breeding and genomic tools. WHOI is leading or cooperating in four of the funded projects.

U.S.: ARPA-E's MARINER Program

MacroAlgae Research Inspiring Novel Energy Resources

Macroalgae Biomass:
No Land
No Freshwater
No Fertilizer

MARINER creates new biomass production opportunities for the vast ocean resources of the United States.

- Launched in 2016
- 20+ Projects
- US$50+ Million

Metric	Primary Design Targets
Full System Size	≥ 1,000 hectares
Range of Deployment	≥ 100,000 hectares
Biomass Production Cost	≤ $80/dry metric ton
Net Energy Return	≥ 5:1

World Wildlife Fund partnership

Woods Hole Oceanographic Institution and others have teamed with international eNGOs like WWF to develop the science and engineering required to farm seaweeds and shellfish sustainably. Below describes stretch goals for the seaweed farming industry fostered by such partnerships over the next 10 years.

The Seaweed Solution

Potential Climate Benefits from Scaling Seaweed Production

	Commodities replaced by seaweed (million tons)	Emissions avoided through commodity displacement (mt CO_2 eq)	Avoided land use through commodity displacement (hectares)	Potential sequestration benefit of avoided land use (mt CO_2 eq)
Human consumption (displacing vegetables)	2,800,000	1,900,000	160,000	520,000
Animal feed (displacing soy or corn)	2,000,000	5,100,000	540,000	1,800,000
Bioplastic (displacing petroleum)	1,600,000	4,100,000	440,000	1,400,000
Total	6.4 million tons commodities displaced	11 mt CO_2 eq avoided	1.1 million hectares/yr avoided	3.8 mt CO_2 eq/yr potential sequestered

*Numbers are based on the methodology from Poore and Nemacek (2018) "Reducing food's environmental impacts through producers and consumers" and updated by the upcoming WWF's upcoming "Food Matters: Strategic Actions to Restore the Planet and Feed Humanity" publication.

GreenWave partnership

Woods Hole Oceanographic Institution has teamed with GreenWave to conduct research that support the mission of developing farming systems growing a mix of seaweeds and shellfish that require zero inputs while sequestering carbon and rebuilding reef-like ecosystems. Their ten year goal is to provide training, tools, and support to a baseline of 10,000 regenerative ocean farmers to catalyze the planting of 1 million acres and yield meaningful economic and climate impacts.

National and State Shellfish Initiatives

NOAA established the National Shellfish Initiative in partnership with shellfish farmers and shellfish restoration organizations with the goal to increase populations of bivalve shellfish in our nation's coastal waters - including oysters, clams, and mussels - through both sustainable commercial production and restoration activities. Now nine State and regional initiatives are actively meeting the growing demand for seafood, adding jobs and business opportunities while they provide for cleaner water and nutrient removal, and habitat for important commercial and recreational species.

Now is the time…

US scientists and engineers are global leaders in the discovery and understanding of fundamental ocean processes, and have partnered with agencies, researchers and indigenous people around the world to advance aquaculture technologies. A sustained commitment by the US to develop the science and technology for future ocean farms will find an enthusiastic audience in young researchers and technologist around the world, who seek better ways to improve peoples' lives through their science and problem-solving. Helping feed and power the world while restoring the ocean will be a clarion call to some of the best minds of this and future generations.

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