9.30 am - 9.50 am
Keynote Presentation

CHARLES YARISH

Professor Emeritus
The University of Connecticut
USA

1st International Seaweed Conference USA
Seagriculture
7 - 8 SEPTEMBER 2022
PORTLAND (ME), USA

Seaweed Aquaculture in the USA: Opportunities, Challenges and Future Directions

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Global Seaweed Production (MT) by Species (2016)

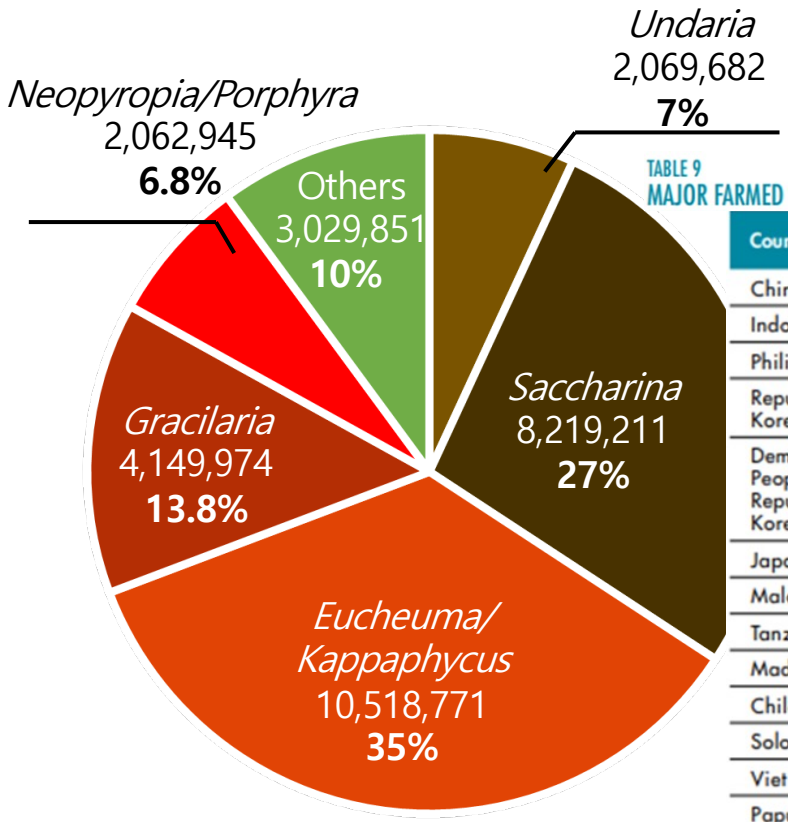
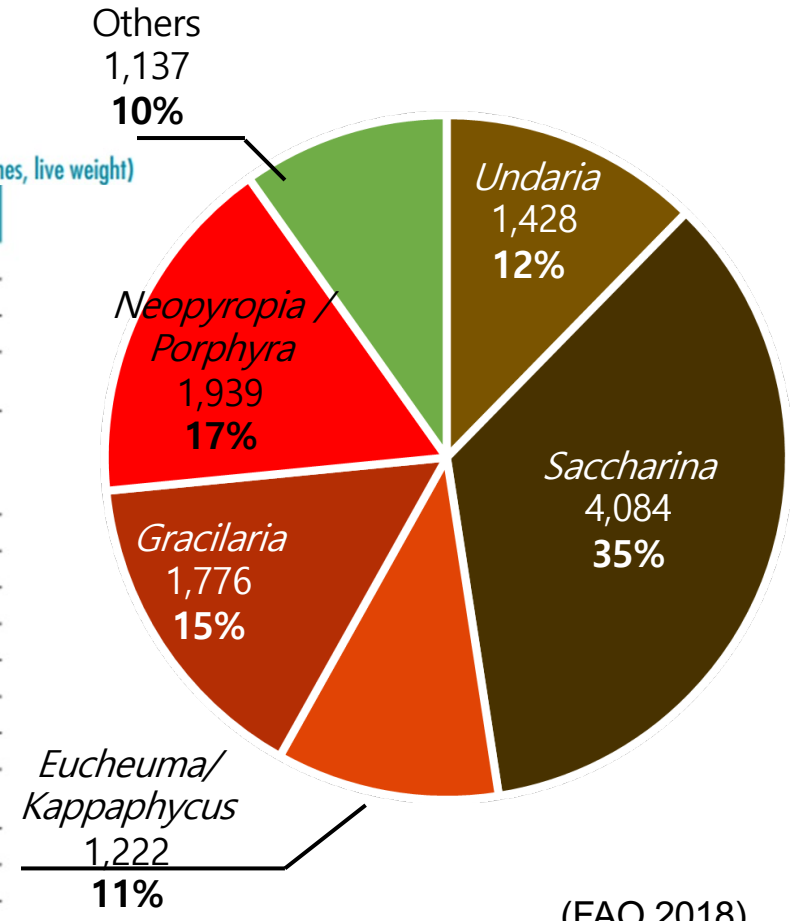


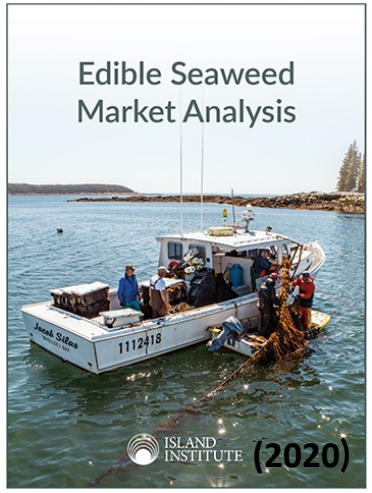
TABLE 9
MAJOR FARMED SEAWEED PRODUCERS (thousand tonnes, live weight)

Country	2016	% of total, 2016
China	14 387	47.9
Indonesia	11 631	38.7
Philippines	1 405	4.7
Republic of Korea	1 351	4.5
Democratic People's Republic of Korea	489	1.6
Japan	391	1.3
Malaysia	206	0.7
Tanzania	119	0.4
Madagascar	17	0.1
Chile	15	0
Solomon Islands	11	0
Viet Nam	10	0
Papua New Guinea	4	0
Kiribati	4	0
India	3	0
Others	8	0
Total	**30 050**	

Economic Value (million dollar) by Species (2016)



(FAO 2018)



USA ESTIMATED SEAWEED MARKET (2022)

SOURCE	ESTIMATED DRY POUNDS
Net Imports	**16,000,000**
Domestic Aquaculture	**106,390 - 130,000**
Domestic Wild	**30,000 – 1,600,000**
Total	**1,736,390 – 1,765,000**

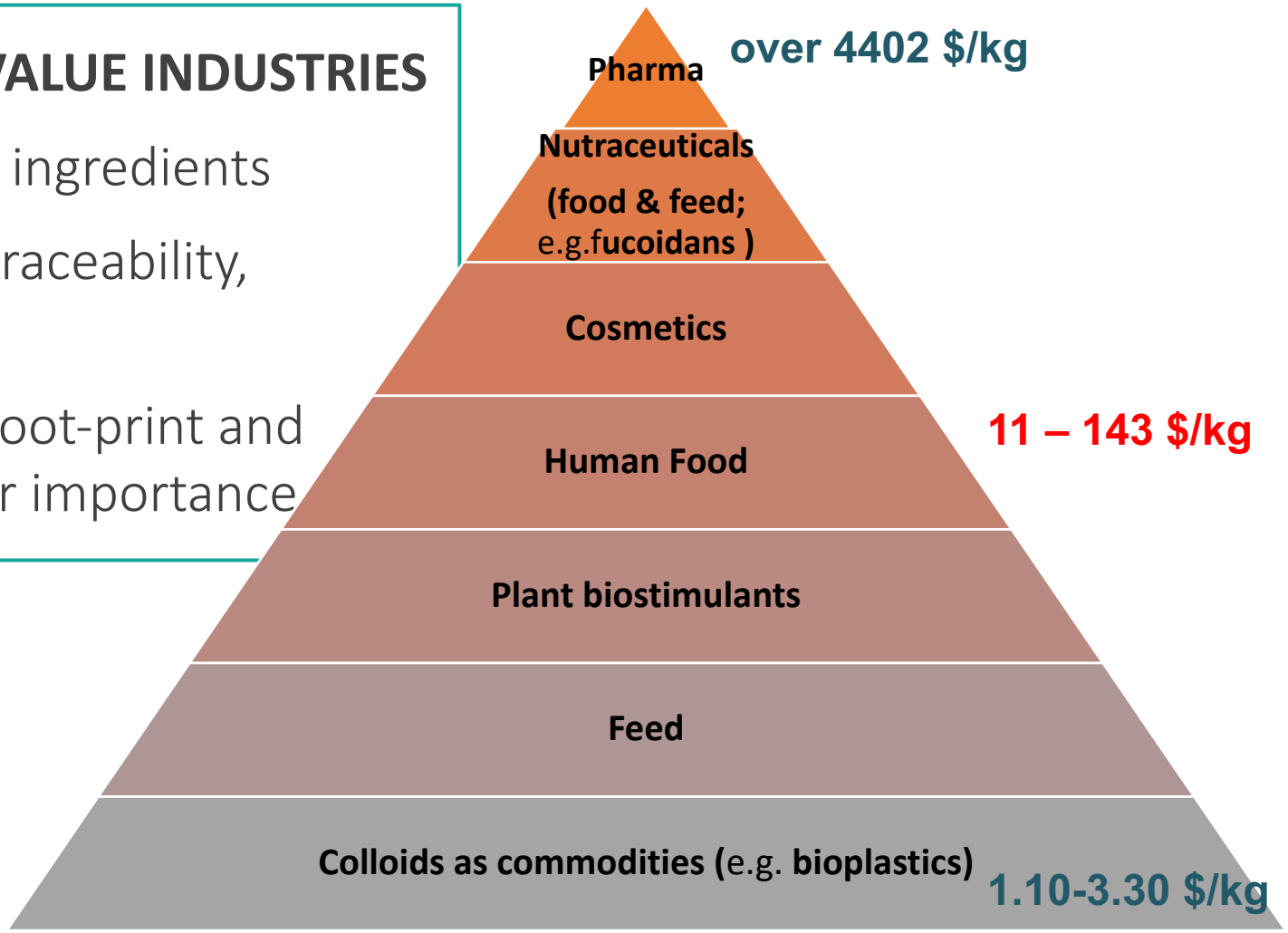
Source (US)	Estimated Wet Pounds	Equivalent Dry Pounds
Aquaculture	1,063,900-1,300,000	106,390- 130,000
Wild	300,000 – 350,000	30,000 – 35,000
	16 million (2022; Seaweed Hub)	1,600,000 -(2,000,000?)
Total	**17,363,900 – 17,650,000**	**1,736,390 – 1,765,000**

~95-98% of edible seaweed products found in the U.S. are currently imported

OPPORTUNITY: There is a need for farmed seaweed because wild harvested can't meet market demand for "high-quality."

WESTERN HIGH VALUE INDUSTRIES

- ✓Seek for natural ingredients
- ✓Quality, safety, traceability, standardization
- ✓Environmental foot-print and origin are of major importance



Biofuels

Courtesy of ALGA+

Obstacles to the Growth of Seaweed Aquaculture in the USA

- Coastal zone use conflicts

✓The **Social License** from the Public to Support Permitting

  ✓Nutrient bioextraction, water quality improvement, habitat restoration, new habitat & diversity enhancement

- Permit, licensing, lease application processes
- Compliance with environmental regulations

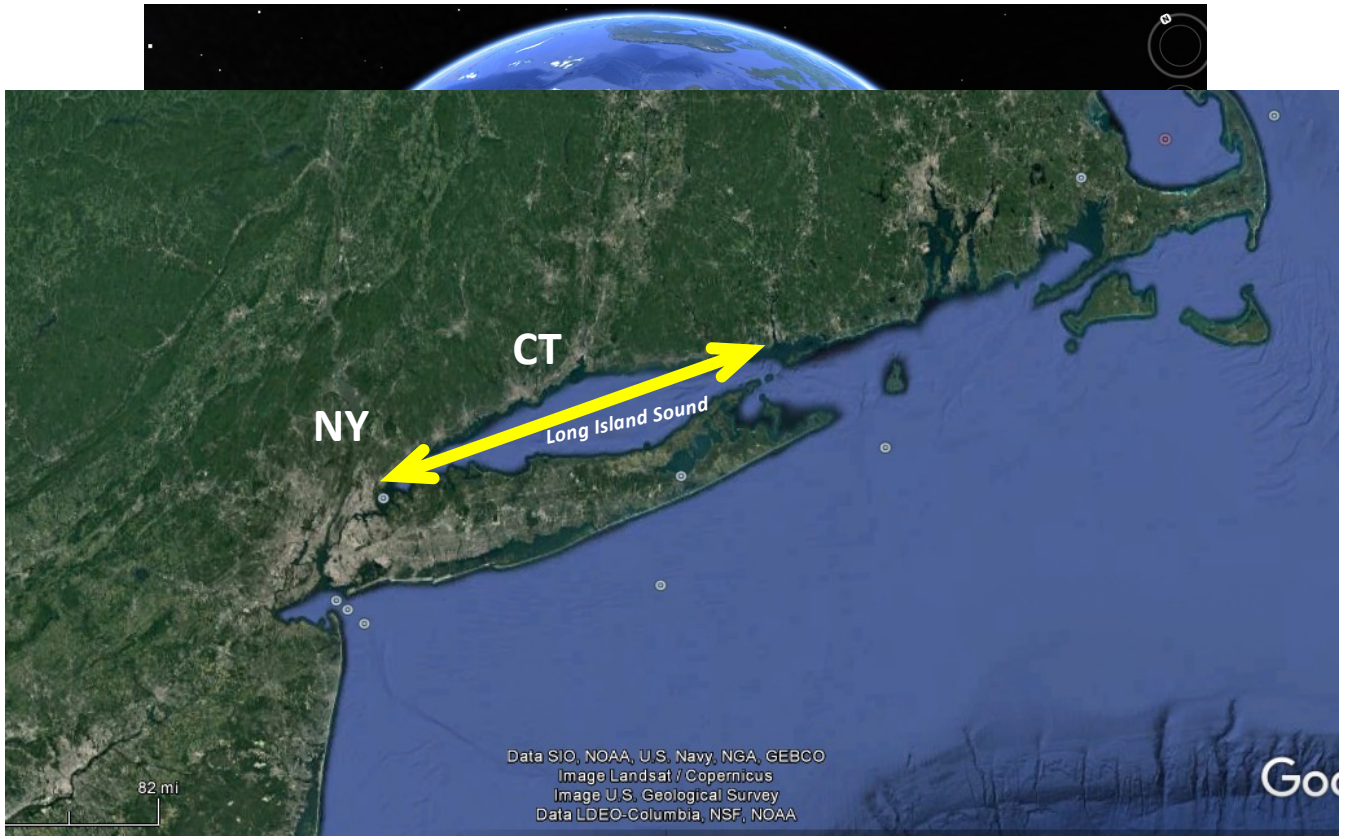
✓Cost effectiveness of the aquaculture (culture & breeding technologies; scale of production; survive open ocean conditions; maximize biomass yield; & increase automation)

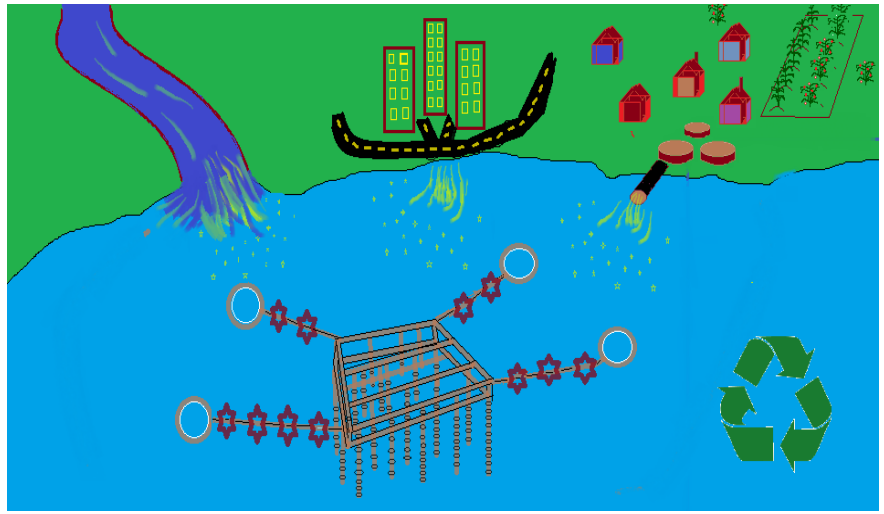
✓Processing

✓Food safety (development of science to inform regulatory agencies)

✓Workforce Development (working waterfront/education)

Long Island Sound Estuary





Ecosystem services approach to overcome NIMBY: Nutrient Bioextraction

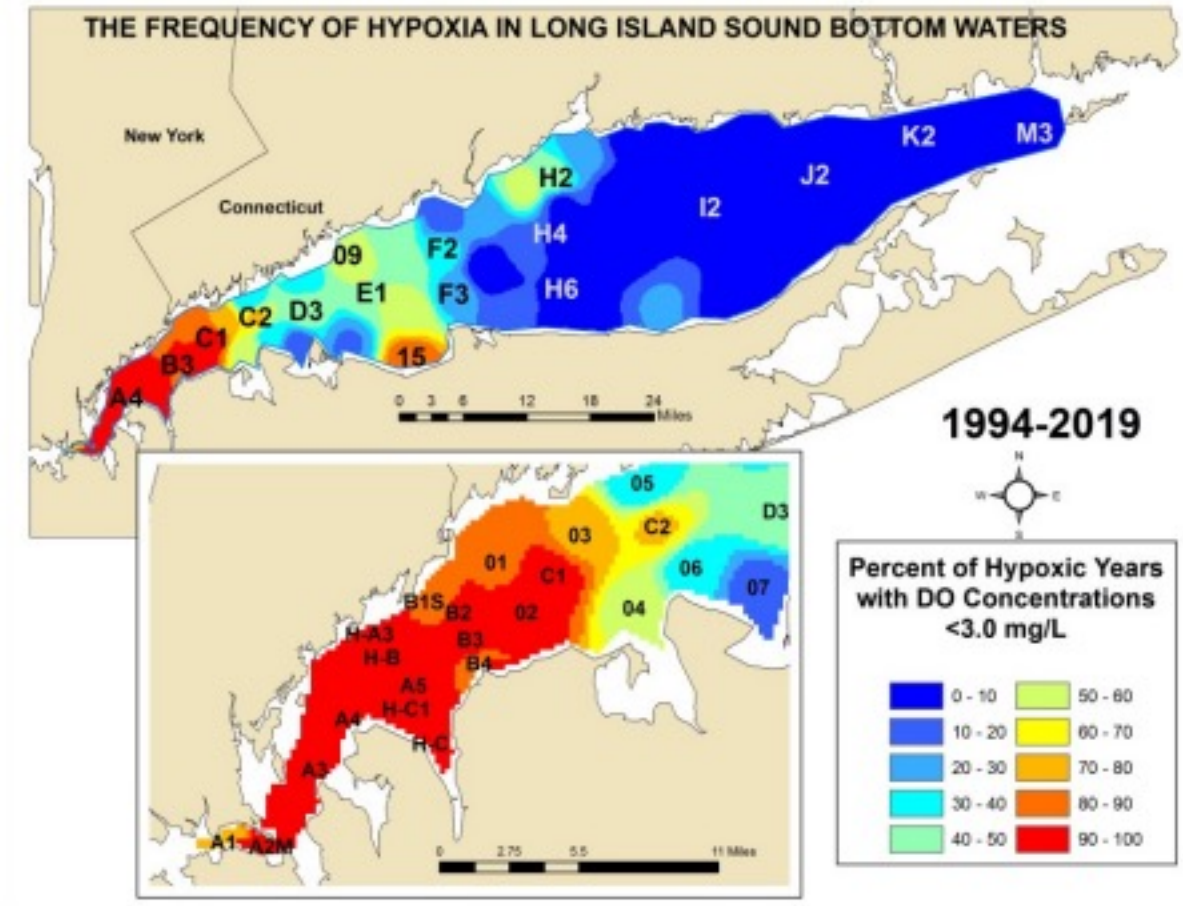
How does nutrient bioextraction work?

- **Cultivation and harvest of seaweed and shellfish**
- Nutrients are taken up either directly (seaweed-inorganic nutrients such as nitrate and ammonium) or indirectly (shellfish, via plankton-organically bound nutrients)
- Removal of biomass removes nutrients from the ecosystem

Frequency of Hypoxia in Long Island Sound Bottom Waters

(CT DEEP and EPA Long Island Sound Study)

Ecosystem services approach



Why was nutrient bioextraction being conducted in Long Island Sound & Bronx River estuary (East River)?

- Longtime focus of nitrogen management has been on point sources (i.e., wastewater treatment plant upgrades)
- Growing recognition that nonpoint source pollution is also a substantial problem that needs to be addressed
- Nutrient bioextraction may also address legacy pollution in the water column and sediments

Objectives

To design, demonstrate, and promote the bioextraction of inorganic nutrients from urban coastal waters using native seaweeds (*Gracilaria tikvahiae* & *Saccharina latissima*)

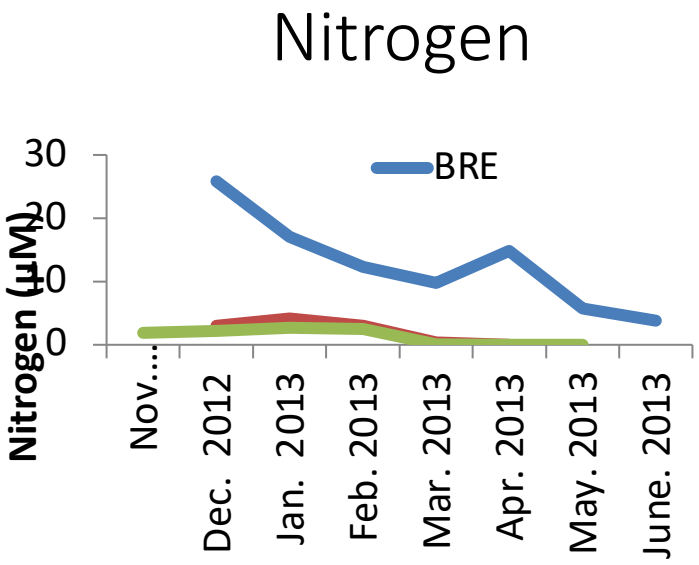
Nearshore seaweed farms

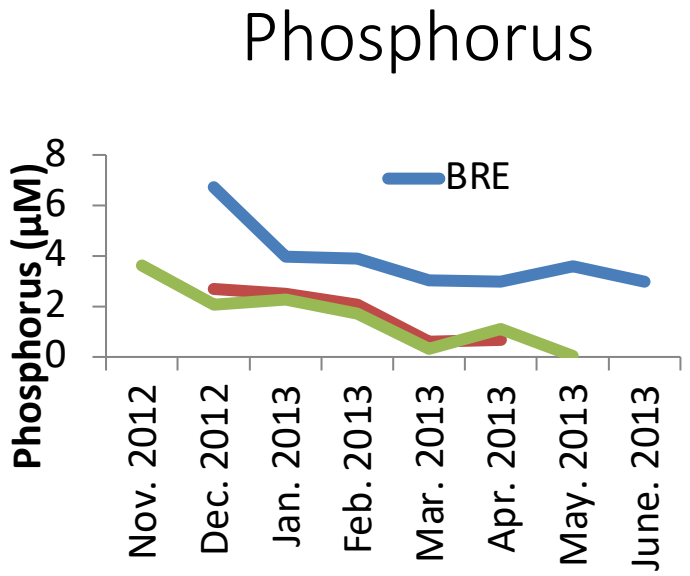
Bronx, NY (BRE)

Western LIS
(Fairfield, CT)

Central LIS
Branford, CT

Inorganic Nitrogen and Phosphorus





Gracilaria tikvahiae (red seaweed, a summer crop)*

- Growing season: June – Oct. (> 15 °C)
- Commercial value of *Gracilaria* ~ $1.78 billion annual value, FAO 2018

Rocha et al. 2019. Characterization of agar from cultivated *Gracilaria tikvahiae*:… Food Hydrocolloids 89:260-271. https://doi.org/10.1016/j.foodhyd.2018.10.048.

Productivity (*Gracilaria*)

Bronx, NY

~ 365 kg per month
per 100 m longline
(July)

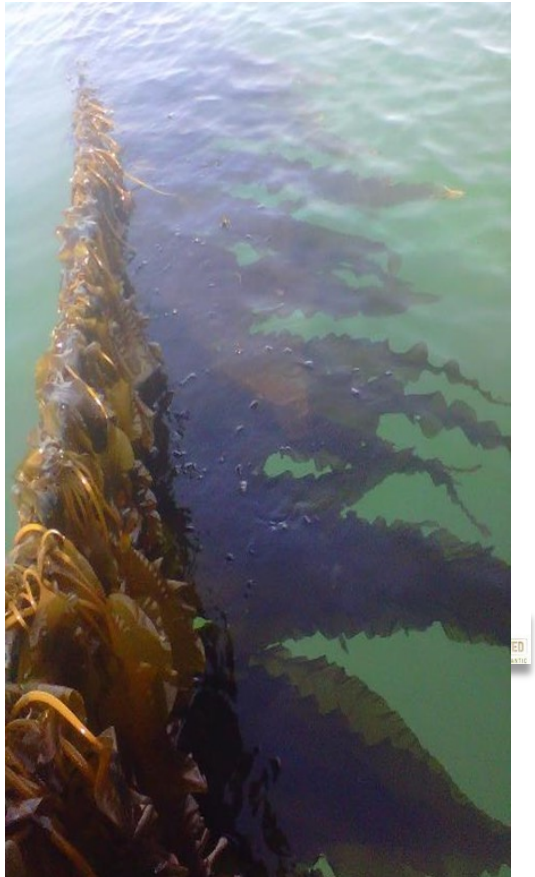
Long Island Sound

~ 73 kg per month
per 100 m longline
(July)

Kim et al. 2014, Aquaculture

Saccharina (sugar kelp, brown seaweed, a winter crop)

- Kelp is the most widely cultivated species in the world (~$5.53 billion annual value)
- Human food and source of alginates (colloid & biomedical)
- Growing season: Nov. – May (< 15 °C or < 60 °F)
- Nutrient bioextraction (ecosystem services)
- Biofuels (US MARINER Program, ARPAe, DOE)

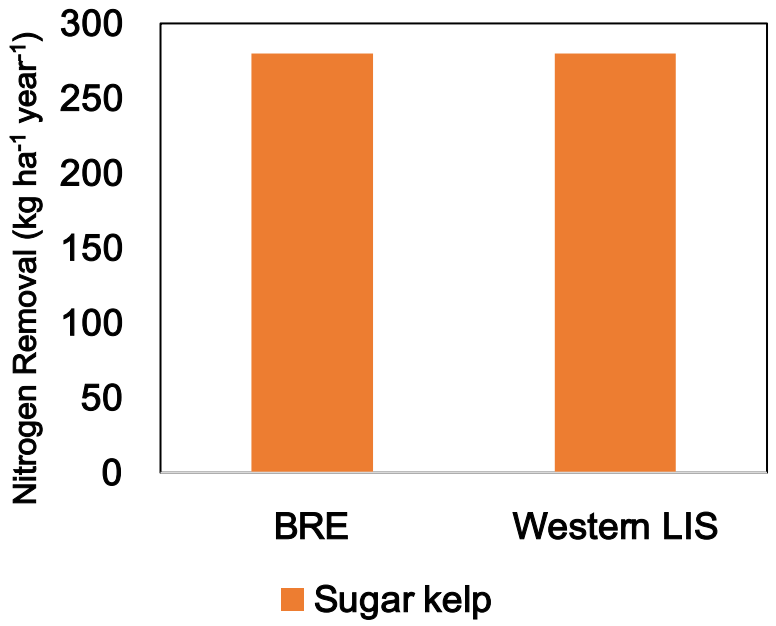


~ 1,752 kg per 100 m longline (Dec. – May growing season)

Kim et al. 2015, Marine Ecol. Prog. Series

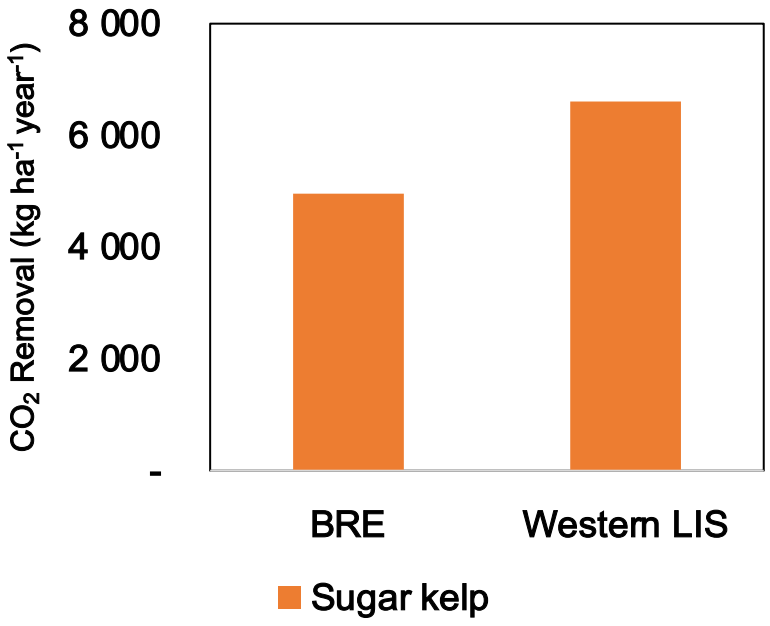
Nutrient Bioextraction by Kelp

Nitrogen Removal



9 – 24 kg FW m^{-1}

CO_2 Removal

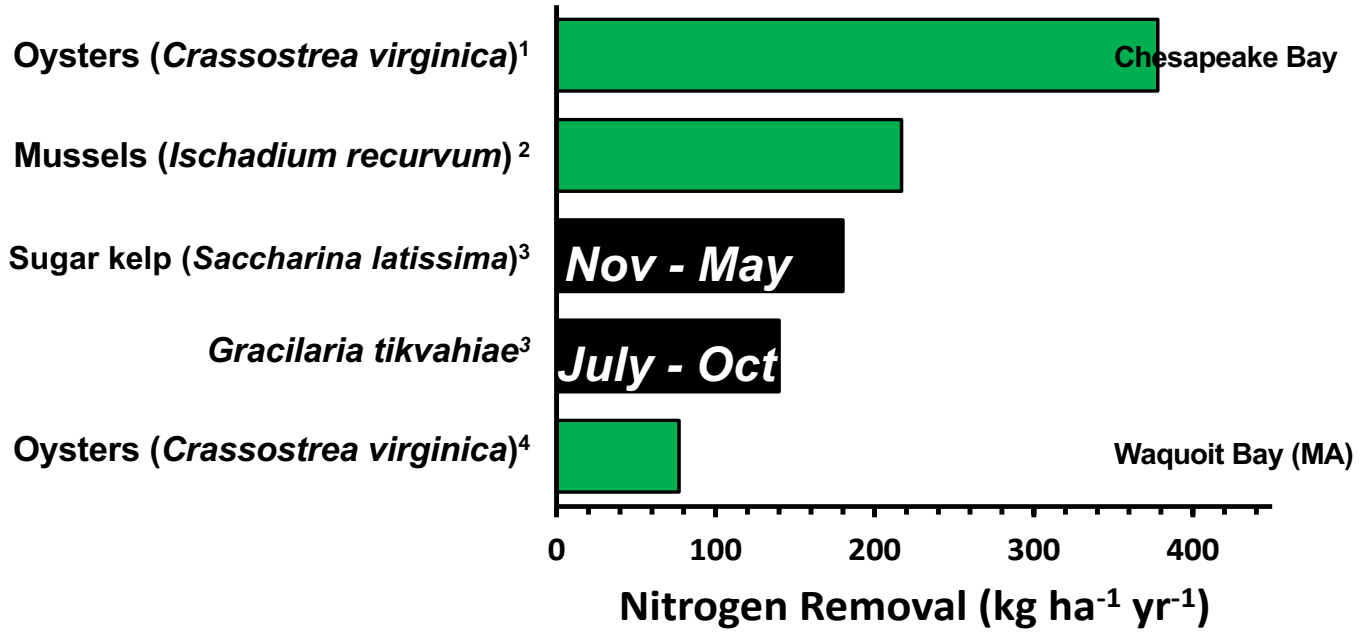


1,100-1,800 kg C ha^{-1}

38-180 kg N ha^{-1}

Kim et al. 2015, Marine Ecol. Prog. Series

Nutrient bioextraction: comparison



[1]Higgins et al. (2011)
[2]Kellog et al. (2013)
[3]this study
[4]Kite-Powell et al. (2006)

Going **Really** Green: *Sea Farming for Environmental and Economic Benefits*

Brief Description:

The key elements of this best practice are: 1) key partners' recognition of the need for a comprehensive approach that combines traditional water pollution control methods with innovative strategies in a cost-effective and economically sustainable manner; 2) the vision to foresee a different approach that combines science and business in synergistic partnerships to achieve mutual goals—clean water and economic benefits, including new jobs; 3) the willingness and ability to use limited resources to conduct on-the-ground scientific empirical experiments in cooperation with the business community; and 4) moving from [illegible] experimentation to actual implementation and development.

This multi- [illegible] highly urbanized waters is feasible and practical. Conflicts with recreation can be minimized or avoided. Farming seaweeds and shellfish species improves water quality while developing new consumable and nonconsumable products and markets that enhance the economic value of the water-

Subobjective:

Long Island Sound

Type:

Nutrient Reduction—Ecological Services

Highlights:

- **What:** This best practice demonstrates the potential for sea farms, shellfish, and seaweeds to improve water quality in coastal areas of the United States. Pilot projects on Long Island Sound are evaluating the feasibility of sea farming in coastal waters, quantifying the potential for nutrient bioextraction, evaluating use conflicts, and researching new markets for products, considering suppliers and consumers. Enhancing sea farming can reduce nutrient pollution, have ancillary ecosystem benefits by creating habitat, support sustainable jobs, and potentially reduce the national seafood trade deficit.

New England
Seaweed Culture Handbook

Nursery Systems

Sarah Redmond, Lindsay Green
Charles Yarish, Jang Kim, Christopher Neefus
University of Connecticut & University of New Hampshire

CTSG-13-03
Connecticut Sea Grant 2013

Video Series Shows How to Start Growing Seaweed

Ever wonder what it would be like to grow seaweed? Connecticut Sea Grant has posted a six-part educational video playlist series on YouTube, to show people how to culture and grow four different species of economically important seaweeds. Part One, the introduction to the "Handbook for Seaweed Culture in New England" offers a broad overview of seaweeds and uses in New England. Other chapters describe how to set up a laboratory to culture seaweed, and seaweed nursery culture for native New England species of Kelp, *Gracilaria*, *Chondrus*, and *Porphyra*. The videos are close captioned for accessibility.

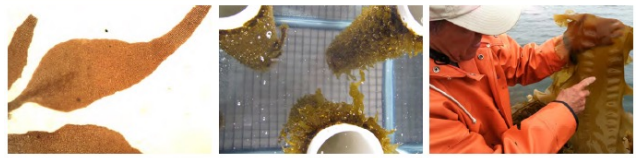
This project was funded through NOAA's Sea Grant programs in Connecticut and New Hampshire. Research was conducted at the UConn Marine Biotechnology Laboratory in Stamford (Charles Yarish) and at the University of New Hampshire, Durham (Chris Neefus).

Link for the entire Seaweed Handbook playlist: http://s.uconn.edu/seaweedplaylist

Links to Individual Chapters:

Part 1 Introduction http://youtu.be/zQt-ZoYu1SE
Part 2 Laboratory http://youtu.be/7Ay0NFSIOIg
Part 3 Kelp http://youtu.be/y-k3seeEJFs
Part 4 *Gracilaria* http://youtu.be/cd5jDPbn63g
Part 5 *Chondrus crispus* http://youtu.be/AKEkzMQ9fHs
Part 6 *Porphyra* http://youtu.be/RGUrPJx_Vj8

Kelp Farming Manual
A Guide to the Processes, Techniques, and Equipment for Farming Kelp in New England Waters



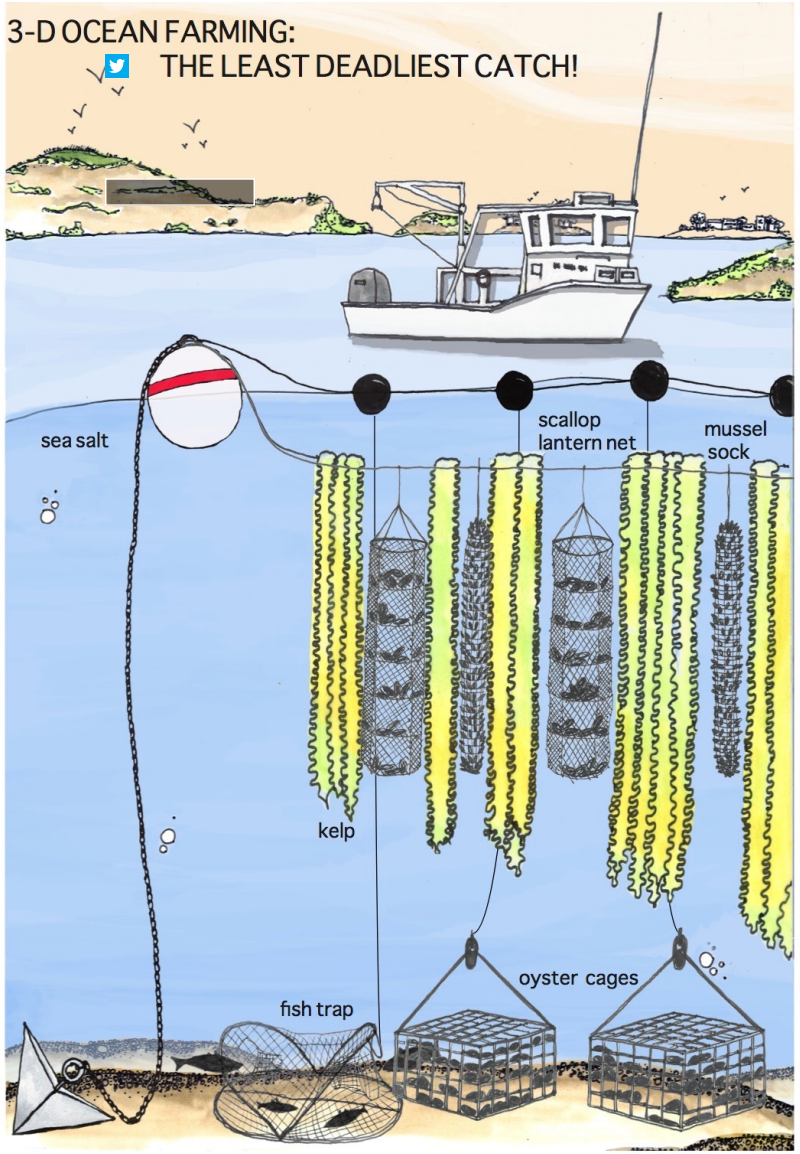
Katie Flavin
Nick Flavin
Bill Flahive, PhD

Ocean APPROVED
FARMING THE NORTH ATLANTIC

ATEC
ALGAE TECHNOLOGY EDUCATIONAL CONSORTIUM

thealgaefoundation

- ATEC* (post K-12 education)
  - Algae Cultivation Extension Short Courses
  - Massive Online Open Courses
  - Biotechnology Curriculum
  - Algae Cultivation Degree program
- K-12 education
  - Summer Algae Science Institute
  - Algae Camp
- Scholarships
- Algae Prize*



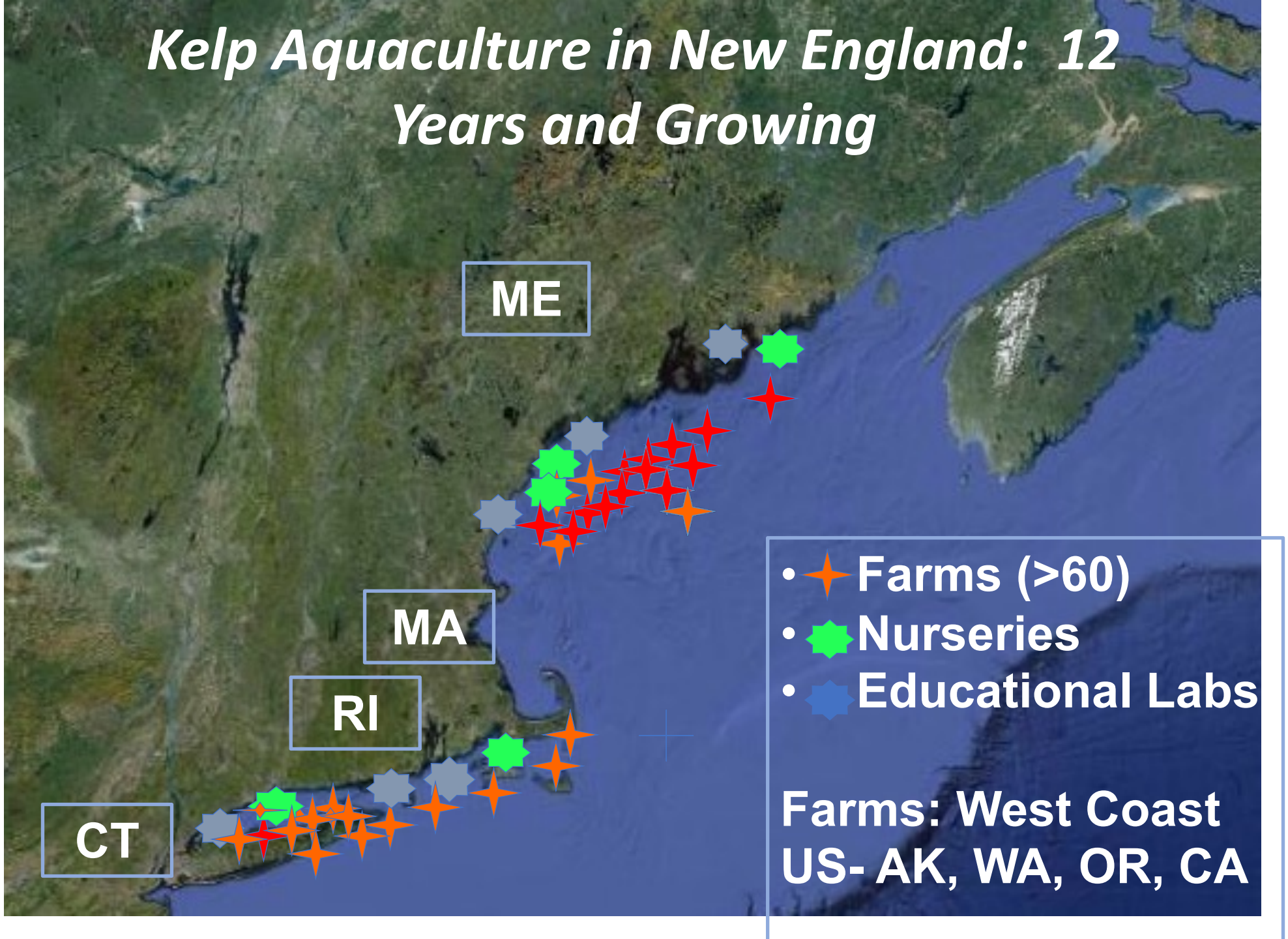
Courtesy of GreenWave

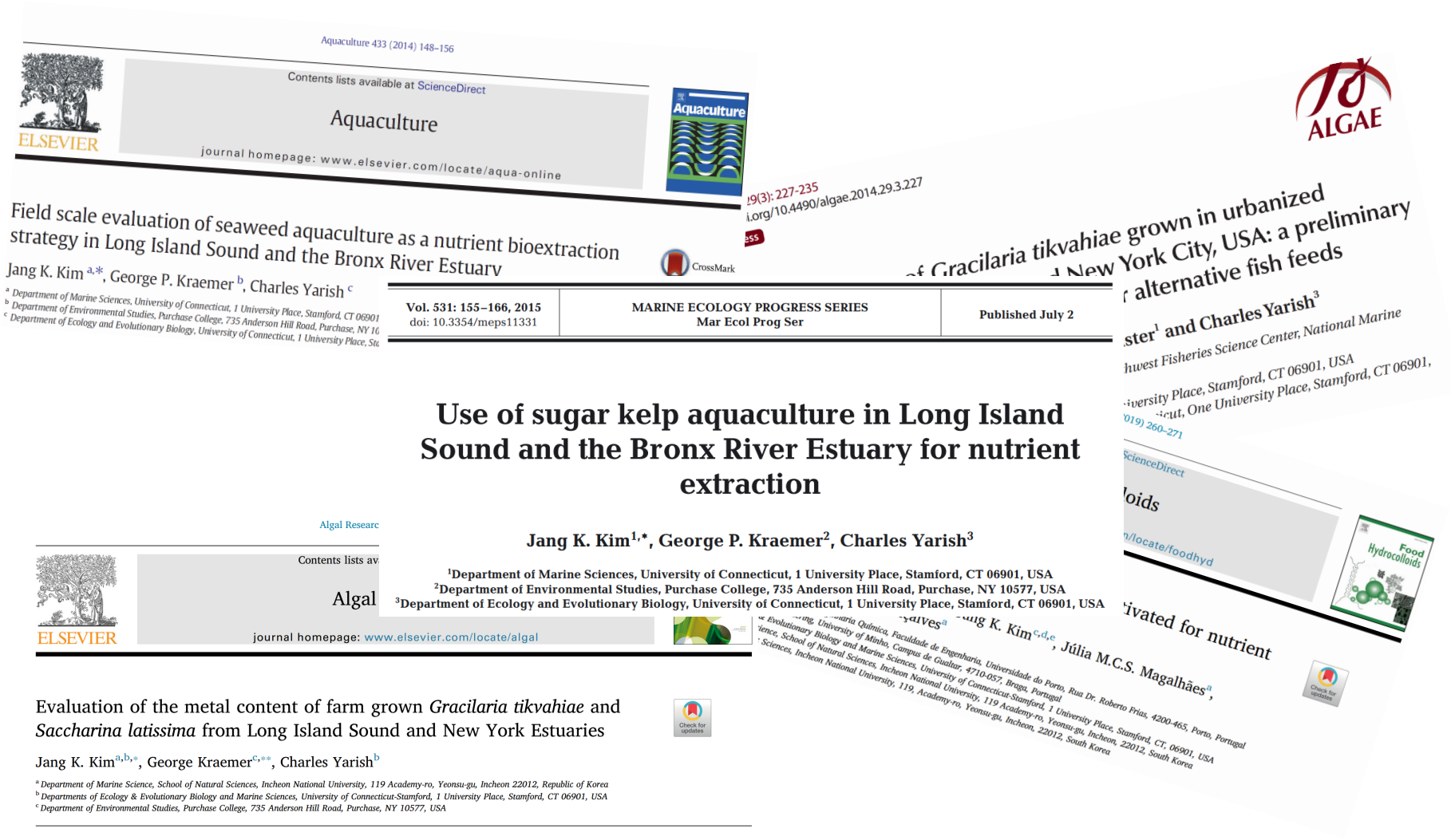
CBS' 60 Minutes reports on **seaweed** farming and its surprising possibilities (Apr 29 & Jul 15, 2018)

It's nutritious. It keeps the ocean healthy. It's good for the environment. There's very little not to like about **seaweed**, a commodity that offers healthy solutions to some of the Earth's most vexing problems. Lesley Stahl reports on a new type of farming, "ocean farming," including an interview with a ...

Huffington Post online: "American Fishermen Need A Little Kelp."

https://www.huffingtonpost.com/entry/7466-tnw-kelp_us_5b7f08cbe4b09b05561880e0


Kelp Aquaculture in New England: 12 Years and Growing
ME
MA
RI
CT
• Farms (>60)
• Nurseries
• Educational Labs
Farms: West Coast US- AK, WA, OR, CA



Aquaculture 433 (2014) 148–156

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aqua-online

Field scale evaluation of seaweed aquaculture as a nutrient bioextraction strategy in Long Island Sound and the Bronx River Estuary

Jang K. Kim [a,*], George P. Kraemer [b], Charles Yarish [c]

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29(3): 227-235
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Vol. 531: 155–166, 2015
doi: 10.3354/meps11331

MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser

Published July 2

Use of sugar kelp aquaculture in Long Island Sound and the Bronx River Estuary for nutrient extraction

Jang K. Kim[1,*], George P. Kraemer[2], Charles Yarish[3]

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ALGAE

of Gracilaria tikvahiae grown in urbanized
New York City, USA: a preliminary
alternative fish feeds

ster[1] and Charles Yarish[3]

hwest Fisheries Science Center, National Marine

iversity Place, Stamford, CT 06901, USA
icut, One University Place, Stamford, CT 06901,

019) 260–271

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Food Hydrocolloids

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Algal Researc

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Algal

journal homepage: www.elsevier.com/locate/algal

Evaluation of the metal content of farm grown *Gracilaria tikvahiae* and *Saccharina latissima* from Long Island Sound and New York Estuaries

Jang K. Kim[a,b,*], George Kraemer[c,**], Charles Yarish[b]

[a] Department of Marine Science, School of Natural Sciences, Incheon National University, 119 Academy-ro, Yeonsu-gu, Incheon 22012, Republic of Korea
[b] Departments of Ecology & Evolutionary Biology and Marine Sciences, University of Connecticut-Stamford, 1 University Place, Stamford, CT 06901, USA
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valves[a]

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ience, School of Natural Sciences, Incheon National University, 119 Academy-ro, Yeonsu-gu, Incheon, 22012, South Korea
Sciences, Incheon National University, 119, Academy-ro, Yeonsu-gu, Incheon, 22012, South Korea

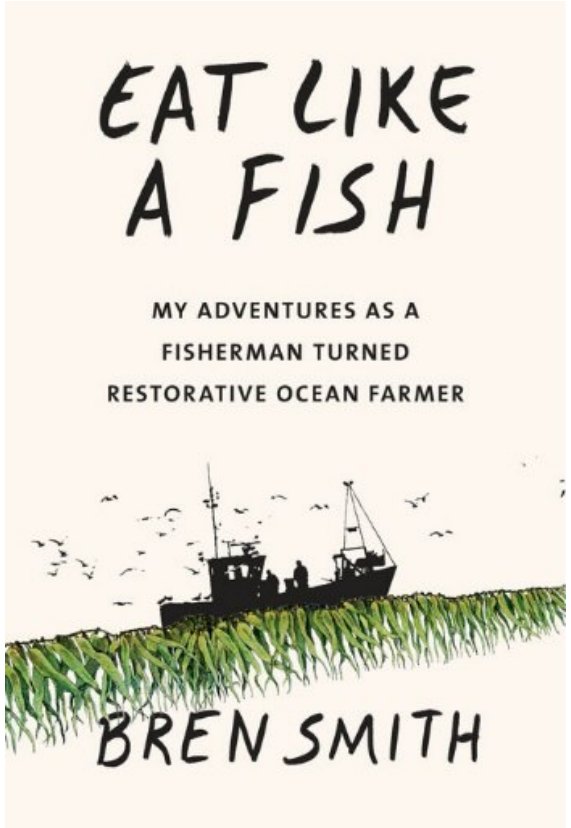
CURRENT FOOD TRENDS

1) More and diversified foods produced with **high environmental sustainability** standards
2) Adoption of healthy food habits:
    1) more plant-based food
    2) reducing animal fat intake
    3) reducing salt, sugars
3) Food products customized to target consumers needs:
    1) nutritional daily routines & convenience
    2) organoleptic features in line with the normal diet
    3) Natural or organic designation

Courtesy of Blue Evolution & Ocean's Balance

- **Atlantic Sea Farms (‘Ocean Approved’): Maine**
- **Thimble Island Oyster Co. (Thimble Island Ocean Farm): Connecticut**

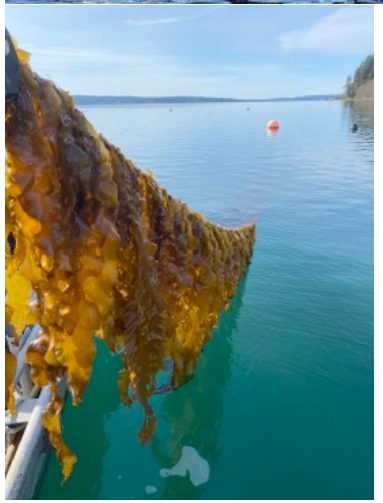
atlantic SEA FARMS™

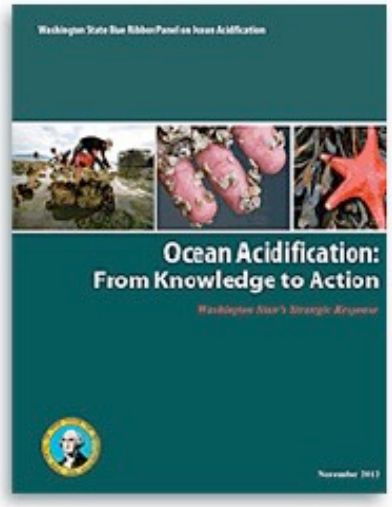


GreenWave Org.

barnacle FOODS

akua





https://bluedotseafarms.com

20 grow lines @ 150 M long
4 kg fw production per meter
12,000 kg fw annual production

Blue Dot Sea Farms established and producing sugar kelp and Pacific oysters (Indigos) marketed through Baywater Shellfish Company
100% of BDSF's sugar kelp goes into the production of **Seacharrones**

WA State Blue Ribbon Panel on Ocean Acidification recommended an adaptation strategy based on growing seaweeds for nutrient storage and removal including carbon and nitrogen

SPRINGTIDE SEAWEED

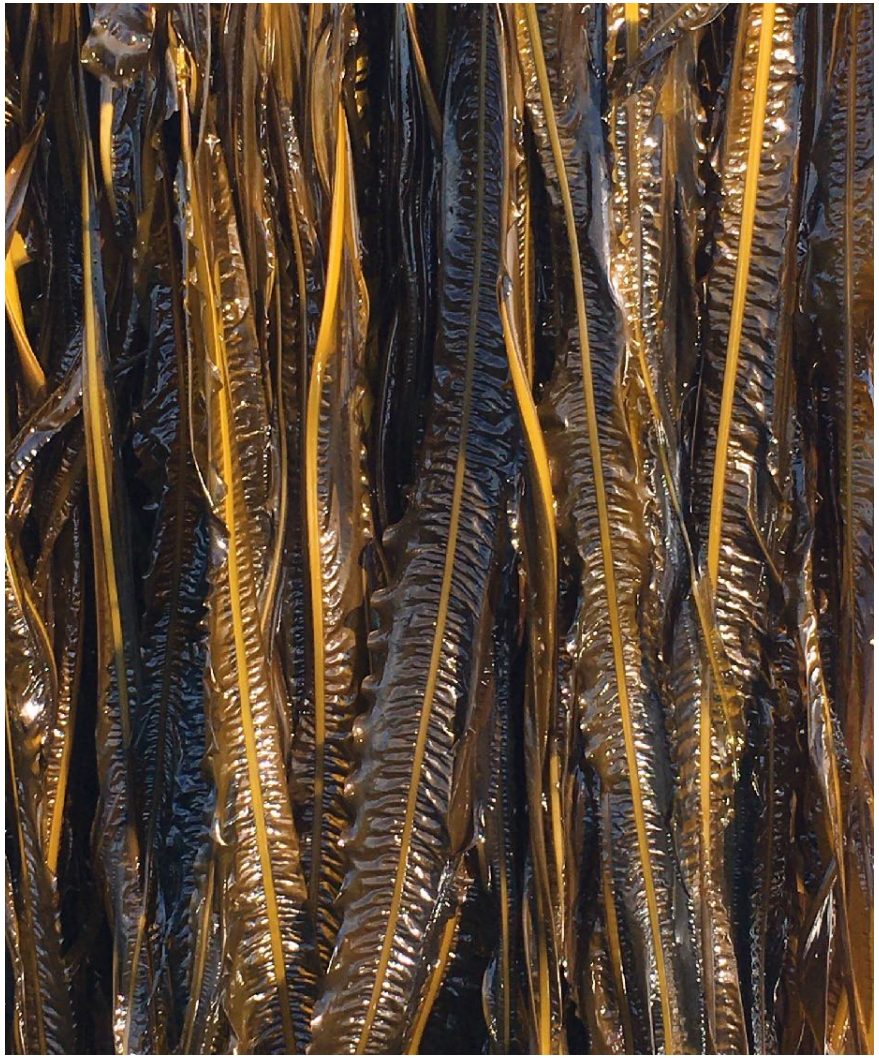
High Quality, Certified Organic Farmed Seaweed Ingredients for the Food Industry

Maine, USA

Developing new crops and products for the seaweed farming industry

Brown Seaweeds (Kelps)

Winged Kelp (Atlantic Wakame)
(*Alaria esculenta*)



Sugar Kelp (Atlantic Kombu)
(*Saccharina latissima*)

Courtesy of Springtide Seaweed

Red Seaweeds (New Crops)

Dulse (*Palmaria palmata*)

Gim / Laver/ Nori

Courtesy of Springtide Seaweed

Future of US Seaweed Industry

ANIMALS

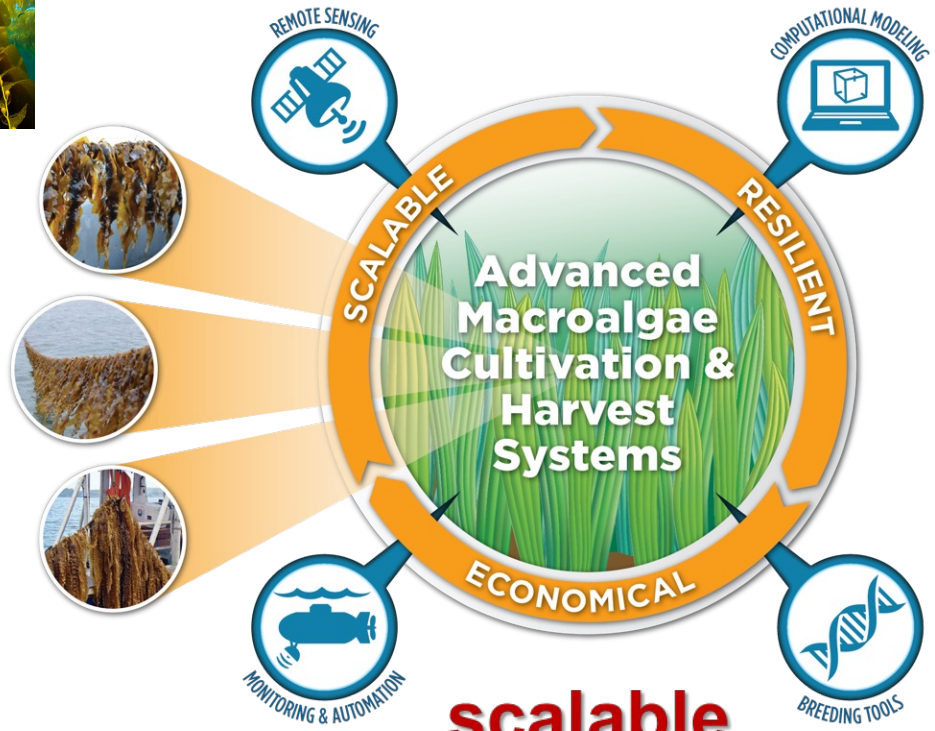
Study: Seaweed in Cow Feed Reduces Methane Emissions Almost Entirely

An Australian study found 99% methane reduction with 2% (feed DM) *Asparagopsis taxiformis* *in vitro*

Seaweeds have a wide range of potential uses:

antibiotic, anti-oxidant, anti-inflammatory, immunostimulants, prebiotics, etc. **Different species of macroalgae differ in their anti-methanogenic efficiency.** **Stefenoni et al.& Vijn et al. 2020**

The ARPA-E MARINER Program (MacroAlgae Research Inspiring Novel Energy Resources ~ $62 Million, 20+ projects)



Macroalgae Biomass:

No Land

No Freshwater

No Fertilizer

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

Photos copyright (top to bottom): Daria Barbour/National Geographic; The Island Institute; Bren Smith/Huffington Post

scalable, cost-competitive, and sustainable biomass production

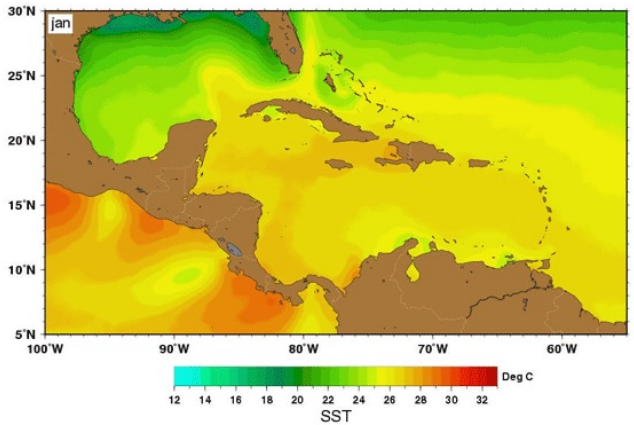
Courtesy of ARPA-E

THE UNIVERSITY OF CHICAGO
MARINE BIOLOGICAL LABORATORY

Tropical seaweed cultivation & harvesting

Project Vision (P.I. Roberson)

Mechanized cultivation and harvesting of tropical seaweeds resistant to climate change using *Eucheumatopsis isiformis* as a model



Project Impact

Production of biomass and ecosystem services year-round using carrageenan production as a step in the pathway towards viable conversion of macroalgal biomass to fuel

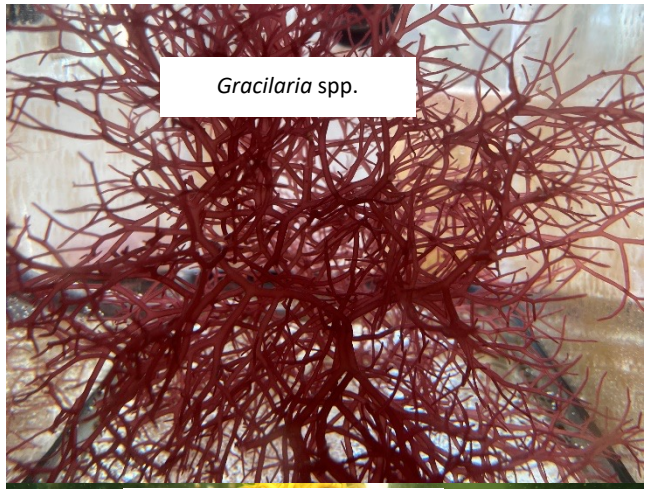
Eucheumatopsis isiforme

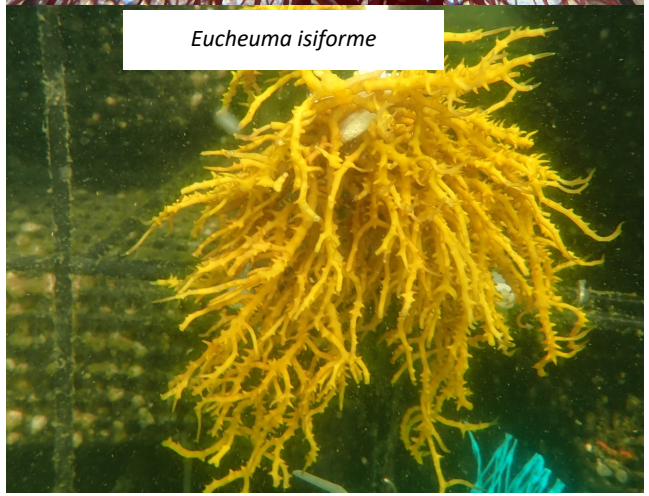
C.A. Goudey & Associates

WOODS HOLE OCEANOGRAPHIC INSTITUTION

UCONN STAMFORD

Developing novel insight on the best cultivation techniques for tropical seaweed species native to the tropical U.S. and Caribbean





Our team (15 partners) is actively engaged in:

- Culture isolation
- Laboratory growth trials
- Field cultivation
- Molecular analysis
- Compositional profiles (carrageenan/agar, carbon, nutrients,

The Nature Conservancy

TWO DOCKS SHELLFISH, LLC

UNIVERSIDAD DE PUERTO RICO UPR

Cinvestav

Pacific Northwest NATIONAL LABORATORY

THE UNIVERSITY OF CALIFORNIA IRVINE

Sea Grant Puerto Rico

MAKAI OCEAN ENGINEERING

Cascadia Research Collective non-profit research and education since 1979

CariCOOS

RUTGERS

UNIVERSITY OF ALASKA FAIRBANKS

TendOcean

WOODS HOLE OCEANOGRAPHIC INSTITUTION

Development of Scalable Coastal and Offshore Macroalgal Farming

Project Vision (P.I. M. Stekoll)

Develop replicable farm system for seaweed production that when combined with innovative seed planting and harvesting technologies results in affordable biomass production

Project Impact

An affordable pathway to produce temperate kelps at a scale that will have meaningful impact on both near-term seaweed mariculture practices and future US energy needs

Blue Evolution

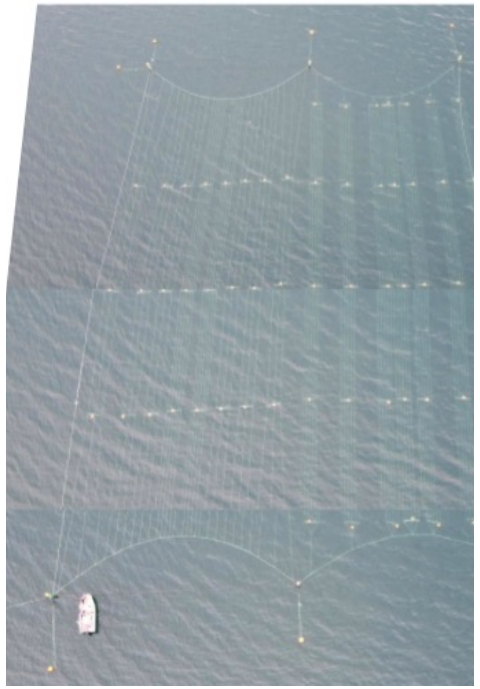
GreenWave

AFDF Alaska Fisheries Development Foundation, Inc.

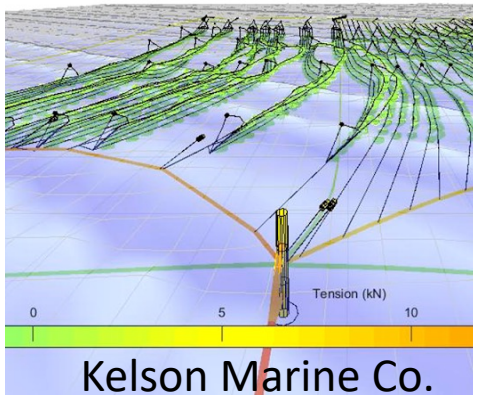
C.A. Goudey & Associates

THE UNIVERSITY OF CHICAGO MARINE BIOLOGICAL LABORATORY

UCONN UNIVERSITY OF CONNECTICUT




Technology Prog


Tension (kN)
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Kelson Marine Co.


AUTION
P FARM

Selective Breeding Technologies for Scalable Offshore Seaweed Farming

Project Vision (P.I. S. Lindell)

Develop tools to identify and breed superior sugar kelp cultivars, improving productivity 10 to 20% per generation.

Project Impact

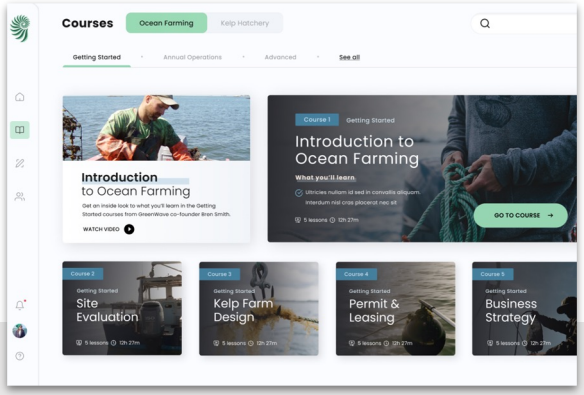
Tools and methodologies created and tested will be broadly applicable to rapid improvement of seaweed breeding and cultivation in the U.S.

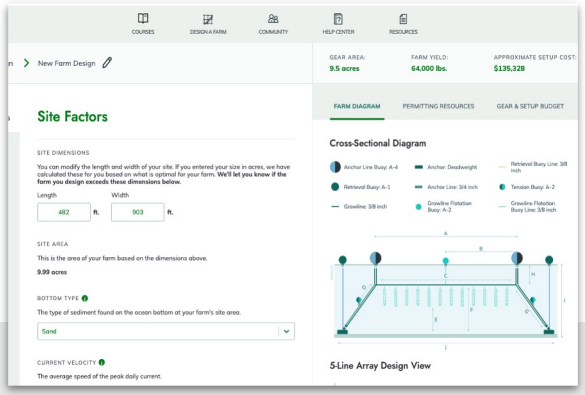
USDA/ Cornell University
University of Alaska
HudsonAlpha, NOAA
Fisheries NEFSC

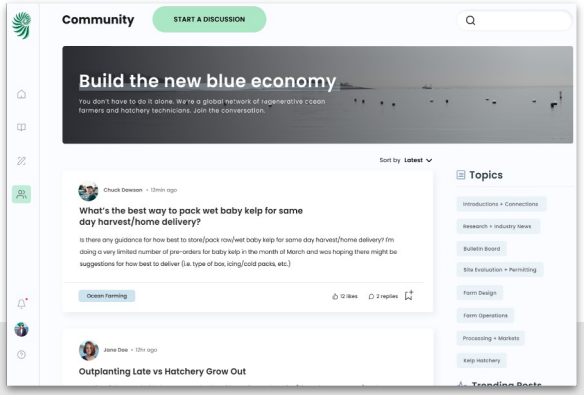
Ocean Farming Hub & Climate Fund

Scaling Training & Support for Regenerative Ocean Farmers (>2400 users, 90 countries)

Established a climate fund (13 cents/pound,US)







COURSES

How-to videos and courses to launch and grow your ocean farm or hatchery

TOOLS

Interactive farm designs, budgets, and gear lists to build your farm

COMMUNITY

Collaborative space to solve technical questions and innovate

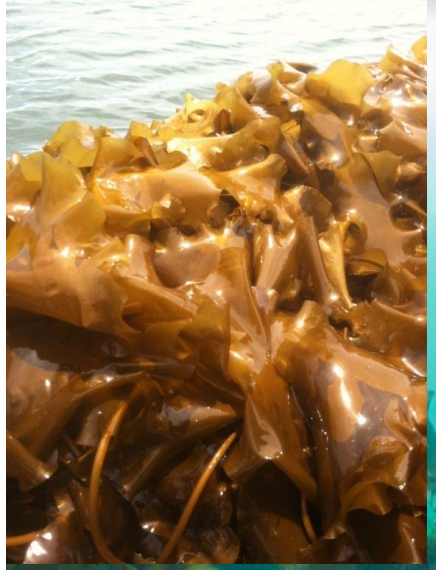
GREENWAVE

www.greenwave.org/hub

Seaweed Bio-refinery

Courtesy: J. Forster

- Bio-active compounds
- Human food – fresh or dried
- Hydrocolloids mannitol, other carbohydrates
- Minerals
- Protein, fats, other nutrients
- Biochemical feed-stocks (Bio-plastics)
- Fermentation to Bio-fuel
- Animal and aquaculture feeds
- Soil conditioner
- Biomass > feed
- Waste



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- Maine Aquaculture Innovation Center
- U.S. Department of Agriculture, National Institute of Food and Agriculture (NIFA)
- To all my many colleagues, post-doctoral scholars and former students