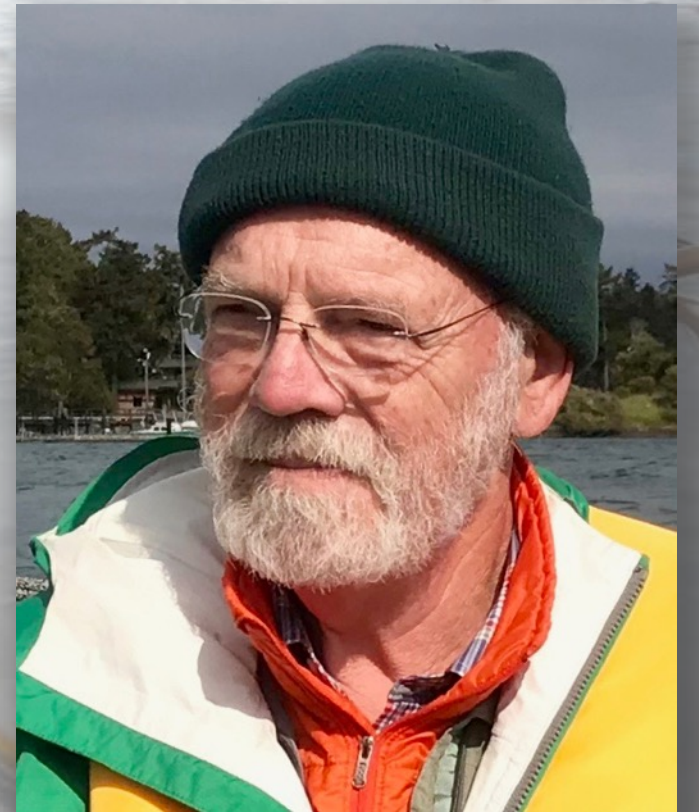


# Seaweed Aquaculture in Washington State

Thomas Mumford  
Marine Agronomics, LLC  
Olympia, Washington  
[tom@marineagronomics.com](mailto:tom@marineagronomics.com)

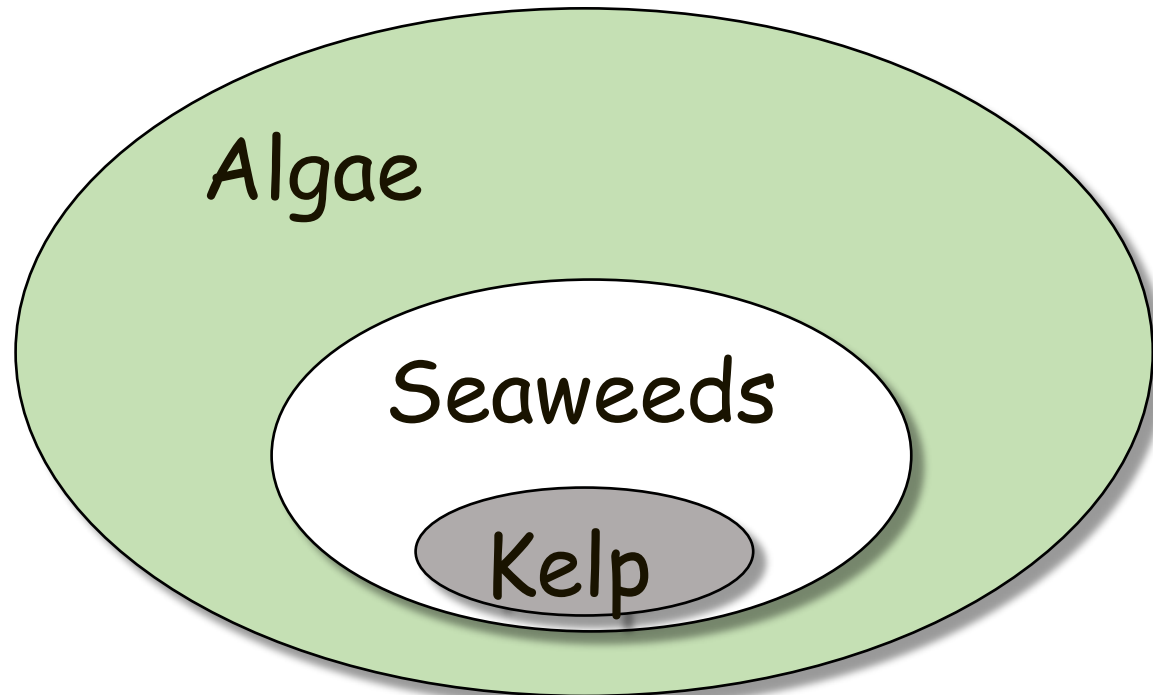


# Outline of Presentation

- What are seaweeds?
- Seaweeds of Washington
- Approaches to Seaweed Aquaculture
- Uses/products
- Overview of how to grow seaweeds
- Where are we going in the future?
- Resources

# What are seaweeds?

- Seaweed (a kind of alga)
- Kelp (a kind of seaweed)

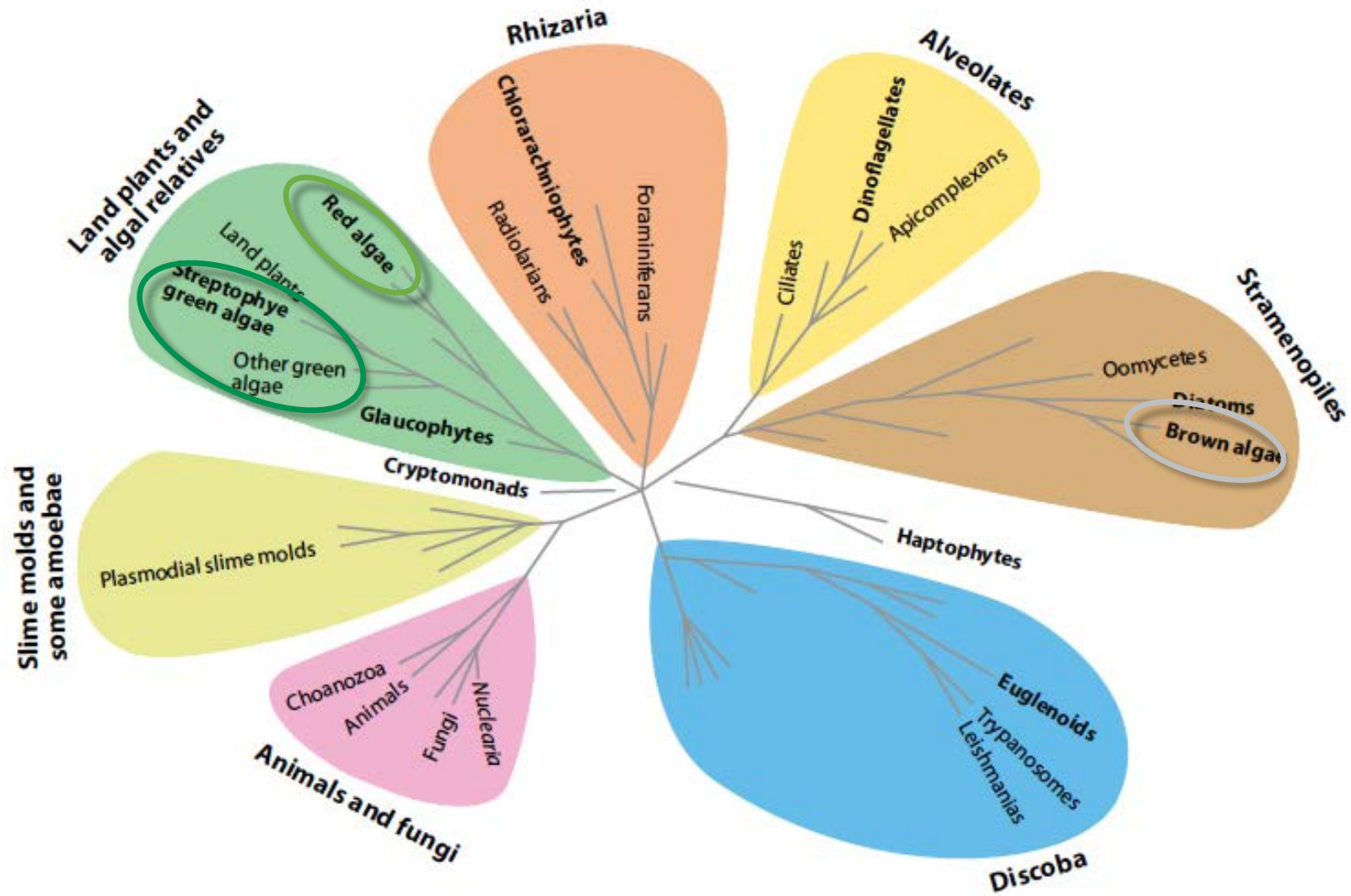


# Rhodophyta, Phaeophyta, Chlorophyta

- Red Seaweeds (Rhodophyta)
  - *Pyropia*, *Chondrus*, *Mazzaella*
- Brown Seaweeds (Phaeophyta)
  - Kelp
  - Sargassum
- Green Seaweeds (Chlorophyta)
  - *Ulva*

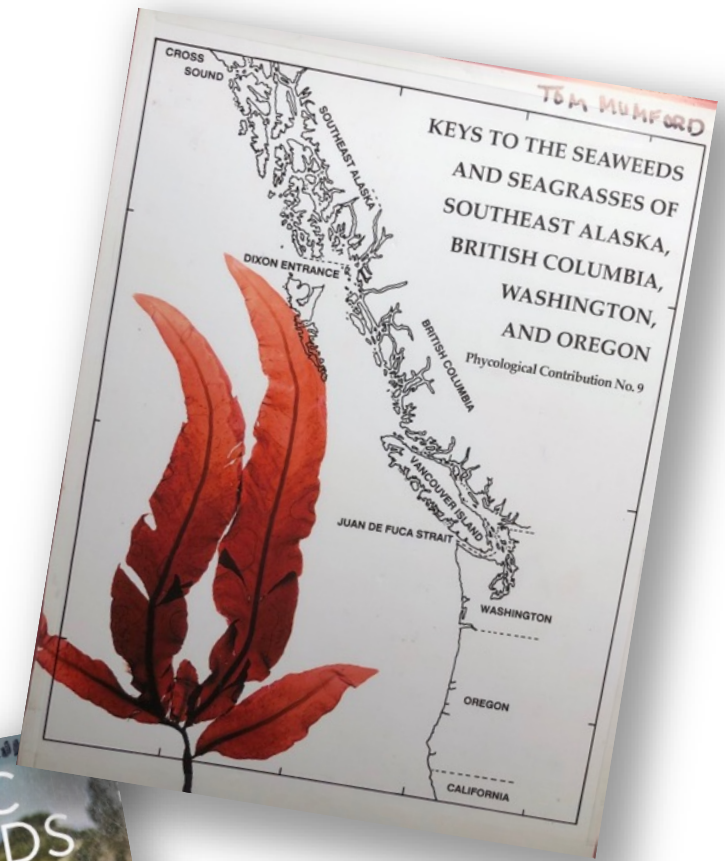
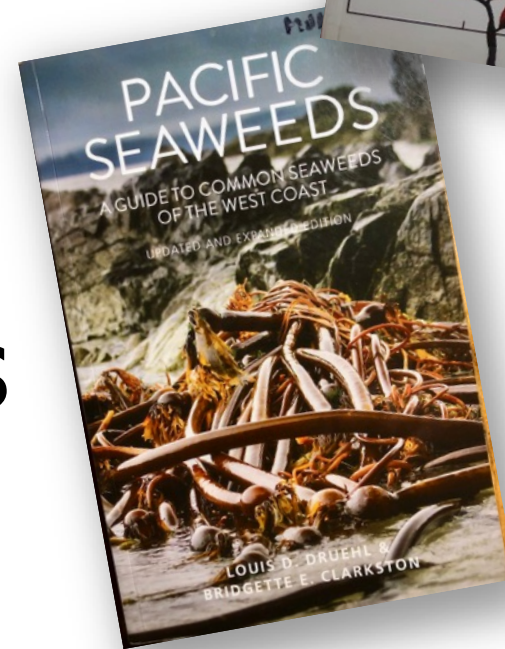


# Supergroups containing “Algae”



# The Bounty of Washington

- Over 600 species of seaweeds
- One of the most diverse kelp floras in the world- 22 species



# Seaweed Uses = Ecosystem Functions



## -Primary Producers

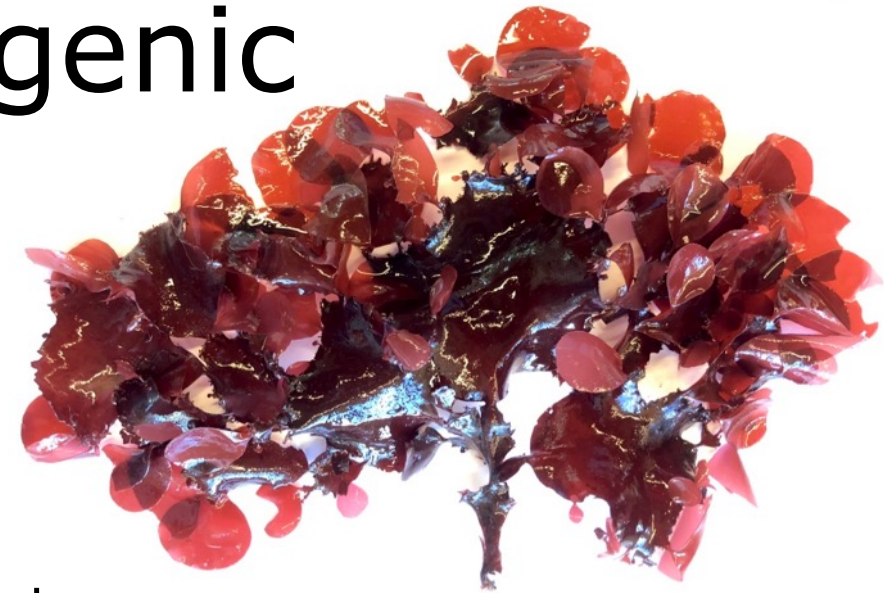
- Food Detritus Dissolved organic materials

## -Structuring Elements (biogenic habitats)

- Kelp beds

## -Biodiversity Function

- Seaweed species themselves
- Other species in, on and around seaweeds



# Traditional Coast Salish Uses

## Food, tools, culture



Fishing Line made from *Nereocystis stipes*



Herring roe on kelp (k'aaw) that is wind drying, Haida Gwaii, BC. Photo: Nancy Turner, date unknown

Herring-roe-on-kelp (*Macrocystis*)

Maiden of Deception Pass Story Pole,  
Tracy Powell. Rosario Beach.



Ko-kwahl-alwoot  
(Coast Salish)

Gunther 1921; Elmendorf 1961;  
Rector & Karsen 2015; Samish elders;



# Economic Seaweed Uses

- **Food** - nori, kombu, wakame, others
- **Fodder** – feed supplements, forage
- **Fiber** – alginate fiber, kelp baskets
- **Fertilizer and Soil Conditioners**– seaweed meal (kelp, rockweeds)
- **Drugs** – iodine, kainic and domoic acids
- **Chemicals** – “kelp”, potash, iodine, acetone
- **Biochemicals** – alginate, carrageenan, agar, agaros
- **Cosmetics** – alginate, carrageenan
- **Biomass** – for fermentation to methane, alcohols
- **Habitat** – for invertebrates, vertebrates, microbes
- **Carbon sequestration**
- **Nutrient remediation**
- **Restoration and compensatory mitigation**



The Real “Kelp”  
*Laminaria* was burned in pits to produce “kelp”, a solid brick of potash and soda, used in glass and soap making

# Seaweed As Food



From: Seriatim, Fall, 1976



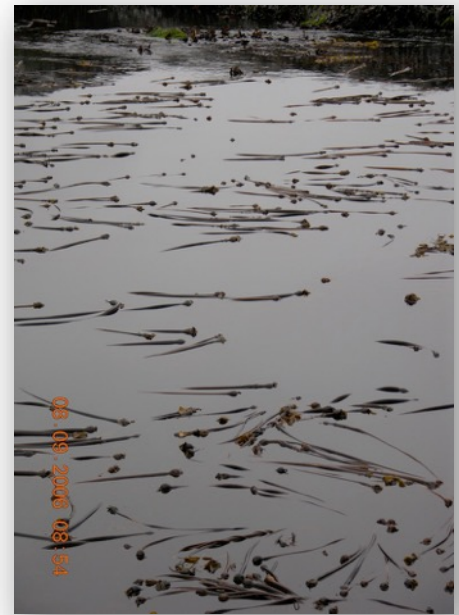
# Food

- Kelp species

- *Saccharina latissima*
- But *Nereocystis* and *Alaria* are more tasty
- What about the other 19 species of kelp?

- Nori (*Pyropia* spp.)

- Ogo (*Gracilaria* spp.)



# Historical Uses of Seaweed



Sheep that live entirely on seaweed  
North Ronaldsay, Orkney Islands.



Lazy Beds in the British Isles

# FODDER

## Benefits of feeding organic seaweed animal feed to your animals

17 October 2008

How to have Healthy and Contented Animals

### Growth

- Can improve growth rates in lambs
- Increase wool production in sheep
- Increase milk yields in cows, sheep and goats
- Pigs put on less fat and more meat, and do not feel the cold so much!
- Chickens breed better and grow fat and fast if have 5% seaweed in their diet, especially if yeast is added as well

### Defence

- Can reduce intestinal parasites in pigs
- Can reduce incidence of mastitis in cows
- Can reduce baldness in Gouldian Finches
- Reduce loss of lambs to white muscle disease
- Seaweed fed to horses reduces the incidence of inflammation in tendons and nerve sheaths and prevents cracked hooves
- Mineral and iodine deficiencies in animals can be remedied by feeding seaweed

### Nutrition

- Gives higher iodine levels in eggs and milk
- Gives brighter coloured egg yolks
- Gives healthy hooves and coats in horses
- Increases fertility
- Gives overall health and well-being



# “Adding Seaweed to Cattle Feed Could Reduce Methane Production by 70%”



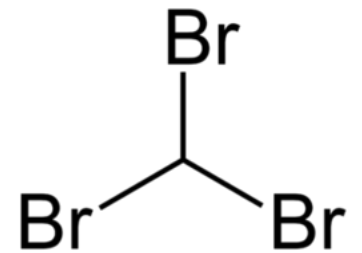
- Livestock responsible for 44 percent of all human-caused methane
- Add dried seaweed to 2 percent of sheep and cattle feed
- Halogenated metabolites in the seaweed disrupt the enzymes that are responsible for the cattle and sheep producing methane in the rumen (stomach).
- Cuts methane emissions by more than 70 percent



*Asparagopsis taxiformis*

Most popular *Limu* in Hawaii

- bromoform
- dibromochloromethane
- bromochloroacetic acid
- dibromoacetic acid
- dichloromethane



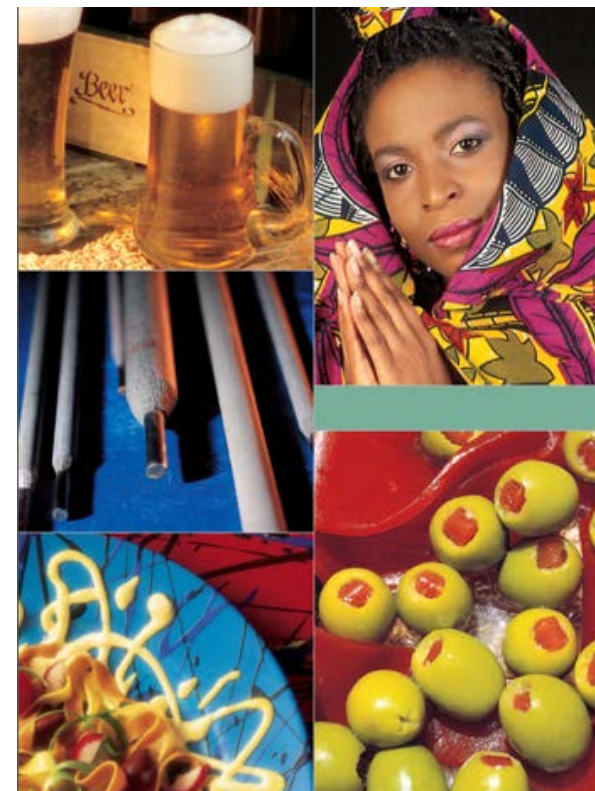
## FOOD

Application	Functions and Benefits
<b>Bakery Cream and Filling</b>	<ul style="list-style-type: none"> <li>Instant gelling and thickening; heat stability; range of different textures; good mouthfeel and flavor release</li> </ul>
<b>Beer</b>	<ul style="list-style-type: none"> <li>Improves and maintains foam levels</li> </ul>
<b>Dressing</b>	<ul style="list-style-type: none"> <li>Thickening, stabilizing, emulsifying; good mouthfeel; acid stable</li> </ul>
<b>Fruit Juice</b>	<ul style="list-style-type: none"> <li>Stabilizing, emulsifying</li> </ul>
<b>Fruit Filling and Preparation</b>	<ul style="list-style-type: none"> <li>Gelling, thickening, stabilizing; prevents syneresis; excellent heat stability; cold and hot process; wide range of textures; available for low to high brix systems</li> </ul>
<b>Dry Mix Dairy</b>	
<b>Ice Cream and Sorbet</b>	<ul style="list-style-type: none"> <li>Stabilizing; controls viscosity; prevents crystal formation and shrinkage; contributes to even and slow meltdown</li> </ul>
<b>Low Fat Spread</b>	<ul style="list-style-type: none"> <li>Stabilizing; good mouthfeel, texture and flavor release</li> </ul>
<b>Meat</b>	
<b>Petfood</b>	<ul style="list-style-type: none"> <li>Gelling; produces heat-resistant and retortable, meat-like chunks</li> </ul>
<b>Restructured Food</b>	<ul style="list-style-type: none"> <li>Excellent gelling ability; heat stability; easy to form</li> </ul>
<b>Yogurt</b>	<ul style="list-style-type: none"> <li>Stabilizing; good mouthfeel, texture and flavor release</li> </ul>

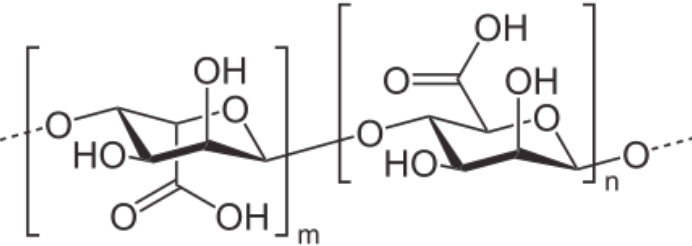
## SPECIALTY

Application	Functions and Benefits
<b>Textile Printing</b>	<ul style="list-style-type: none"> <li>Gives the desired rheology to print pastes; is inert to dyes and fibers; has excellent wash-out properties; is extremely pure</li> </ul>
<b>Paper</b>	<ul style="list-style-type: none"> <li>Enhance greaseproof properties, oil resistance, and solvent holdout; improves rheology, water-retention, runability, ink holdout, and printability</li> </ul>
<b>Welding</b>	<ul style="list-style-type: none"> <li>Lubricant stabilizer and “green strength” agent in the extrusion of high quality welding rods</li> </ul>

# Chemicals Phycocolloids Alginates



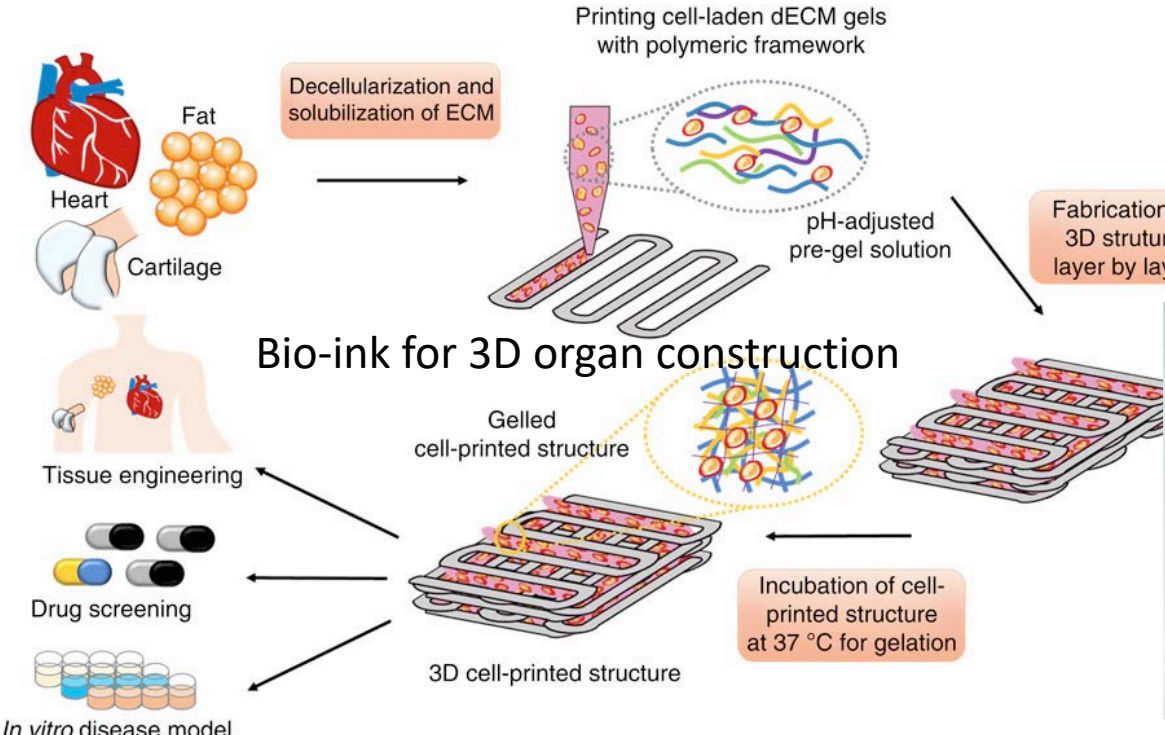
# Alginate Acid in Your Life



-Gelling  
-Stabilizing



Textile Printing



Wound Dressing



"New Gastronomy" - spherification



# Algal Bio-plastics



## Making Seaweed Bio-Plastic

Our project made of seaweed and We are trying to decrease the pollution by making bioplastic to protect the community from plastic's side effects and we should provide the manufacturers use this idea to help them make bioplastic products.



<https://www.slideshare.net/Albairaq/biodegradable-making-seaweed-bioplastic-idm12>

[https://www.washingtonpost.com/technology/2019/04/29/london-marathons-method-reducing-plastic-bottles-edible-seaweed-pouches/?utm\\_term=.5ba1fefda83a](https://www.washingtonpost.com/technology/2019/04/29/london-marathons-method-reducing-plastic-bottles-edible-seaweed-pouches/?utm_term=.5ba1fefda83a)

# Chemicals

## Phycocolloids

### Carrageenan

**Desserts**, carrageen, ice cream, cream, milkshakes, yogurts, salad dressings, sweetened condensed milks

**Sauces**: to increase viscosity

**Beer**: clarifier to remove haze-causing proteins

**Pâtés and processed meats** (e.g., ham): substitute for fat, increase water retention, increase volume, or improve slicing

**Toothpaste**: stabilizer to prevent constituents separating

**Fruit Gushers**: ingredient in the encapsulated gel

**Fire fighting foam**: thickener to cause foam to become sticky

**Shampoo and cosmetic creams**: thickener

**Air freshener gels**

**Marbling**: the ancient art of paper and fabric marbling uses a carrageenan mixture on which to float paints or inks; the paper or fabric is then laid on it, absorbing the colours

**Shoe polish**: to increase viscosity

**Biotechnology**: to immobilize cells and enzymes

**Pharmaceuticals**: used as an inactive excipient in pills and tablets

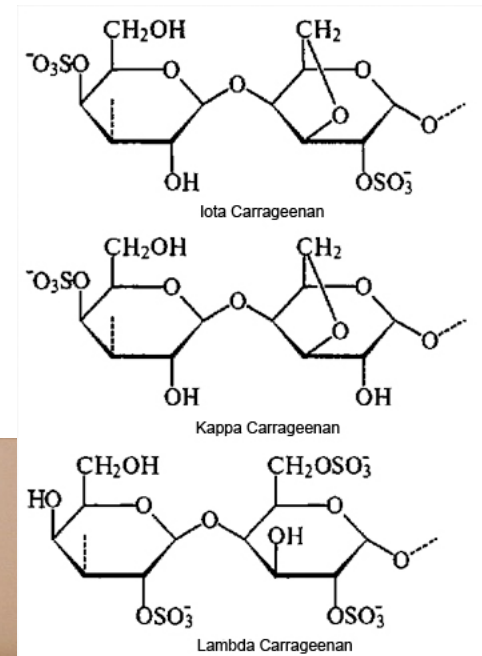
**Soy milk and other plant milks**: to thicken

**Diet sodas**: to enhance texture and suspend flavours

**Pet food**

**Personal lubricants**

**Vegetarian hot dogs**



“It’s Everywhere,  
it’s Everywhere!”

# FMC BioPolymer Brochure- Carrageenan



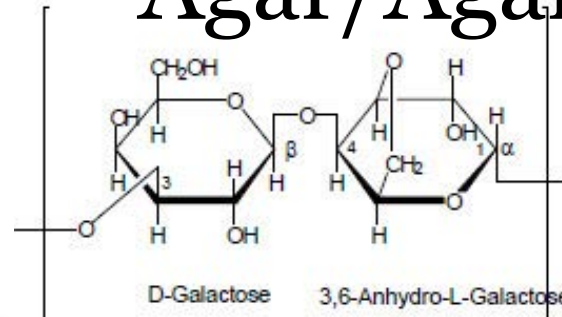
RED ALGAE

- SOURCE OF AGAR

*Gracilaria/Gracilariopsis*  
*Gelidium*  
*Pterocladia*  
*Ahnfeltia*

# Chemicals Phycocolloids

## Agar/Agarose

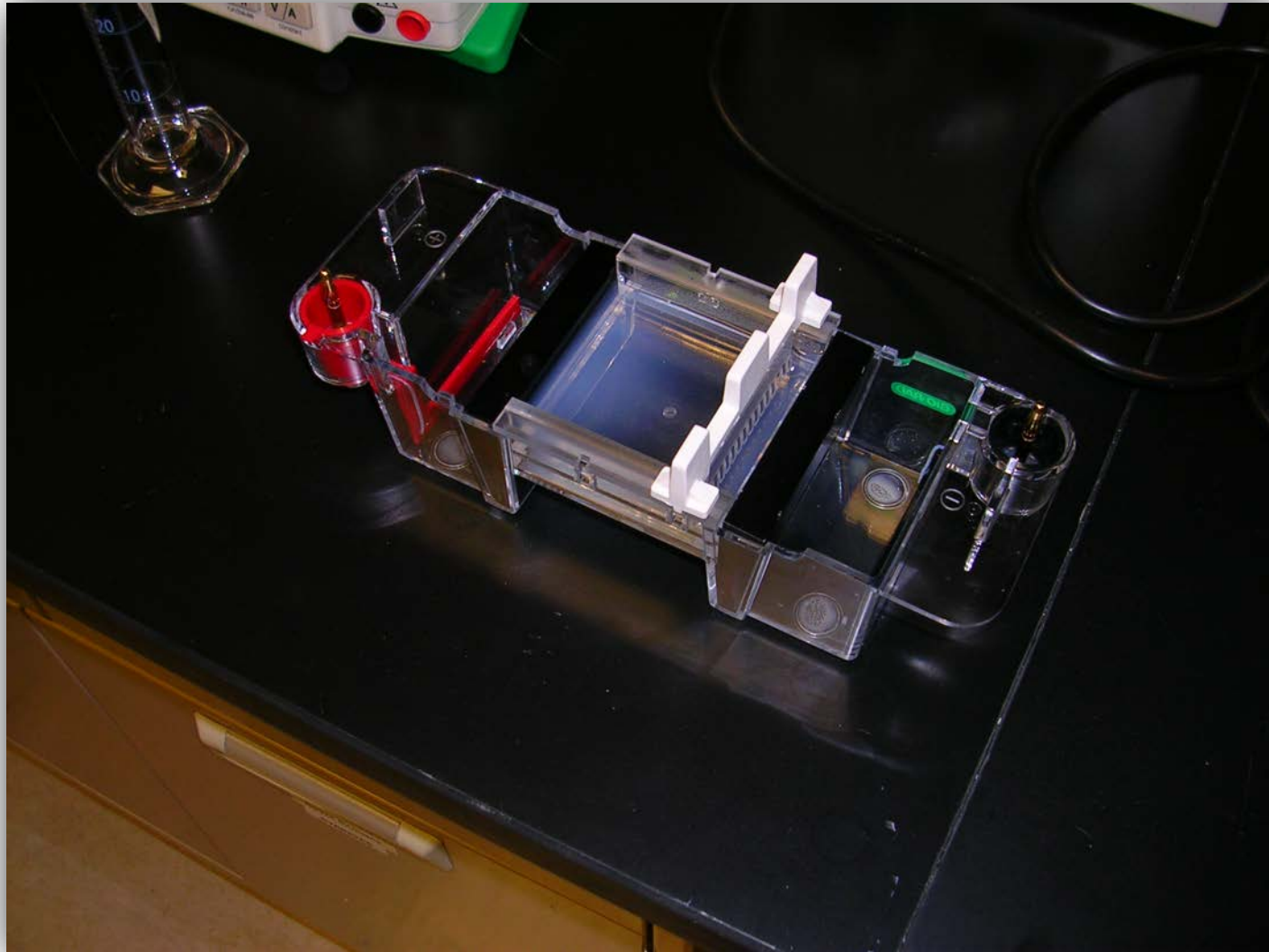


Gel for Vegetarians

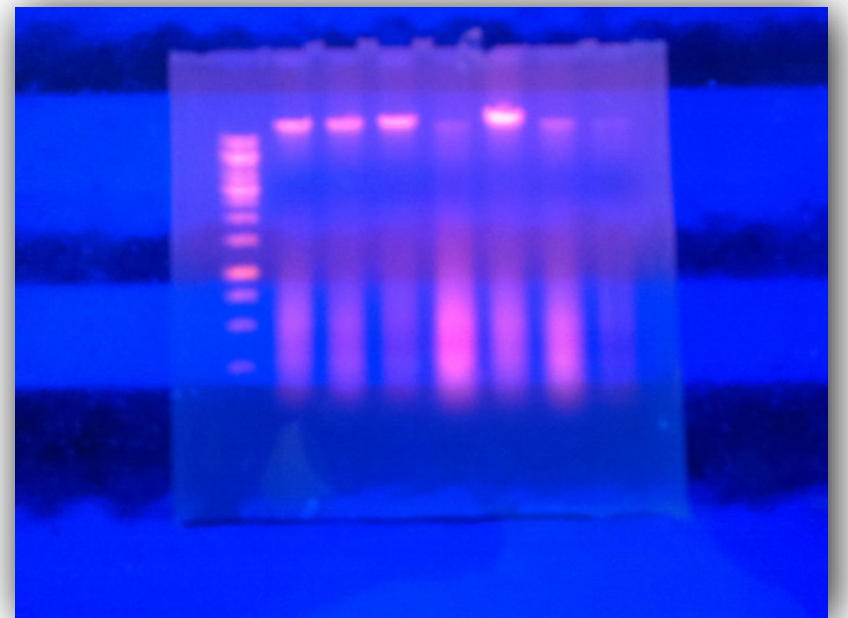


Bacteriological plates



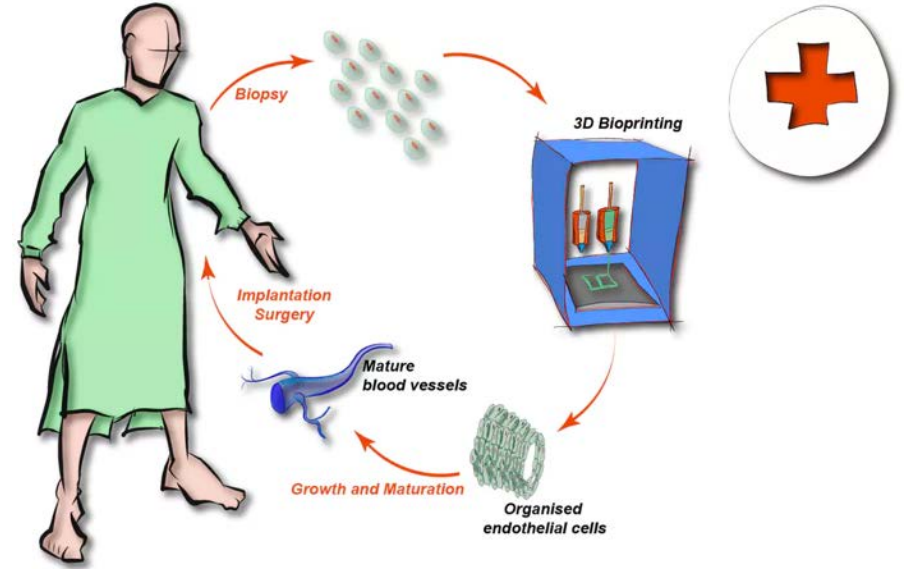
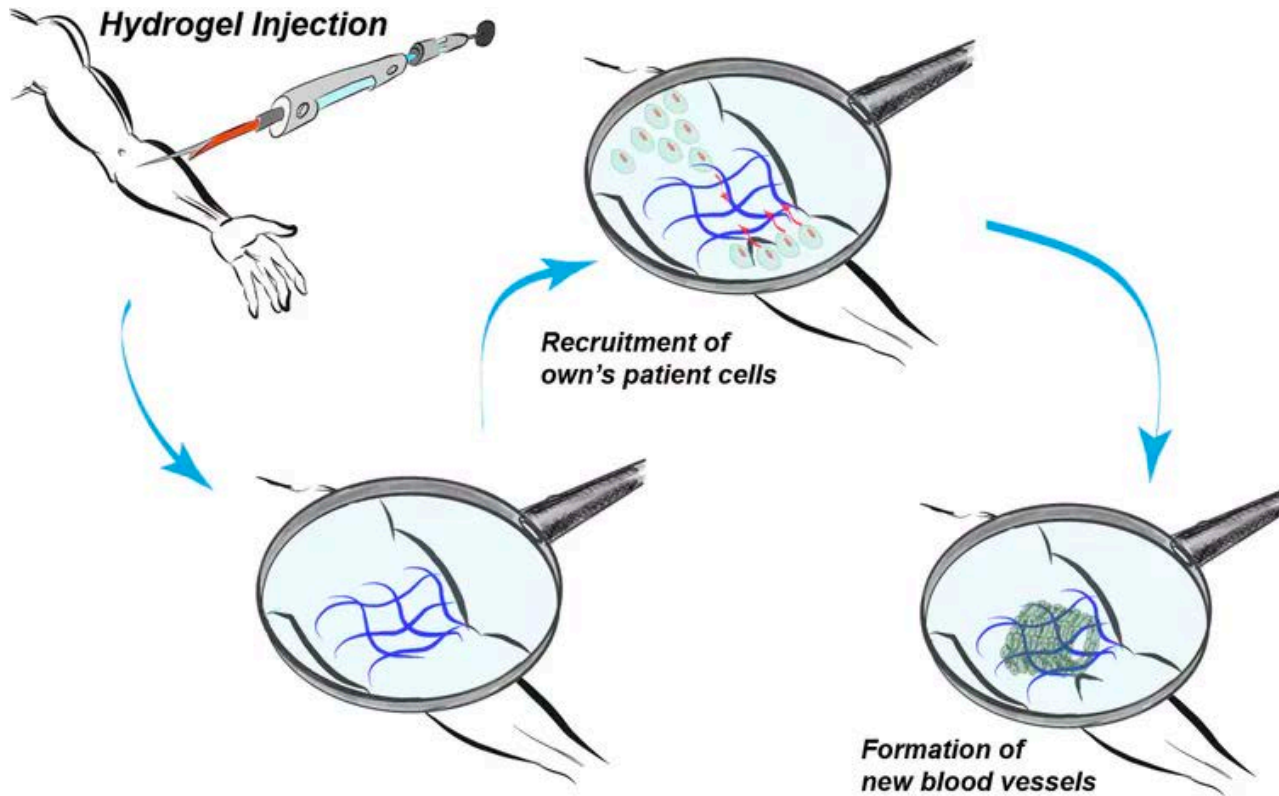


# Gels for Electrophoresis



# Agarose used to grow Blood Vessels in Human Body.

Alginate for tissue culture scaffolding



<https://theconversation.com/edible-seaweed-can-be-used-to-grow-blood-vessels-in-the-body-112618>

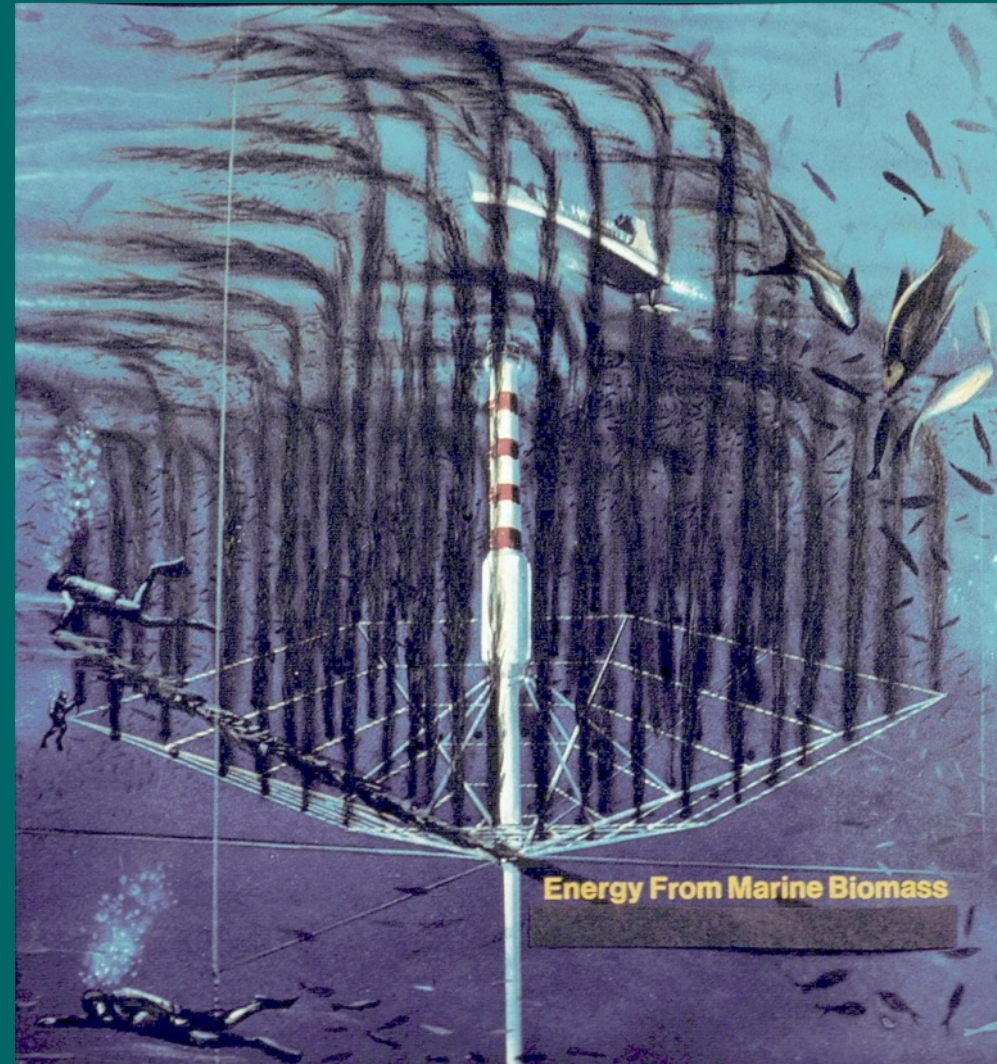
Forget, A., Roberto Gianni-Barrera Andrea Uccelli Melika Sarem Esther Kohler Barbara Fogli Manuele G. Muraro Sandrine Bichet Konrad Aumann Andrea Banfi V. Prasad Shastri. 2019. Mechanically Defined Microenvironment Promotes Stabilization of Microvasculature, Which Correlates with the Enrichment of a Novel Piezo-1+ Population of Circulating CD11b+/CD115+ Monocytes Advanced Materials First published: 29 March 2019. <https://doi.org/10.1002/adma.201808050>

# Kelp as Source of Biomass for Energy Production



Figure 9: Scoubidou System Used in France (CEVA)

From: A Review of the Potential of Marine Algae as a Source of Biofuel in Ireland February 2009. Report prepared for Sustainable Energy Ireland by: Tom Bruton, Henry Lyons Yannick Lerat, Michele Stanley, Michael Bo Rasmussen .



# Nautical Offshore Macroalgae Autonomous Device (NOMAD)

*Michael Huesemann, Pacific Northwest National Laboratory*

ARPA-E funds: \$3.94M

Cost share: 11%

## Technology Summary

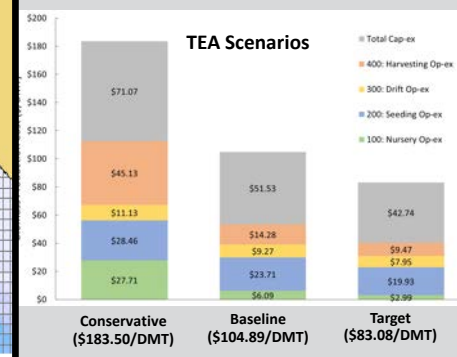
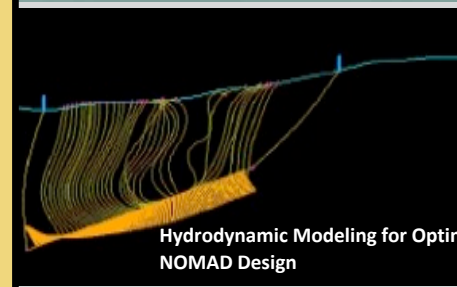
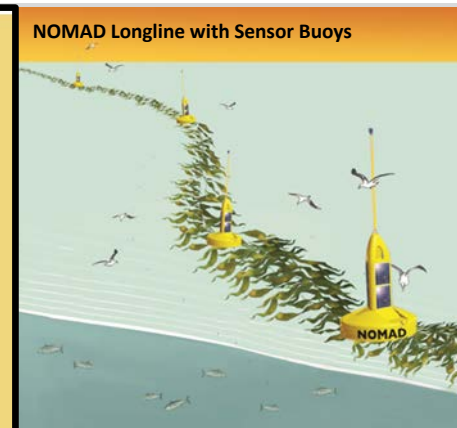
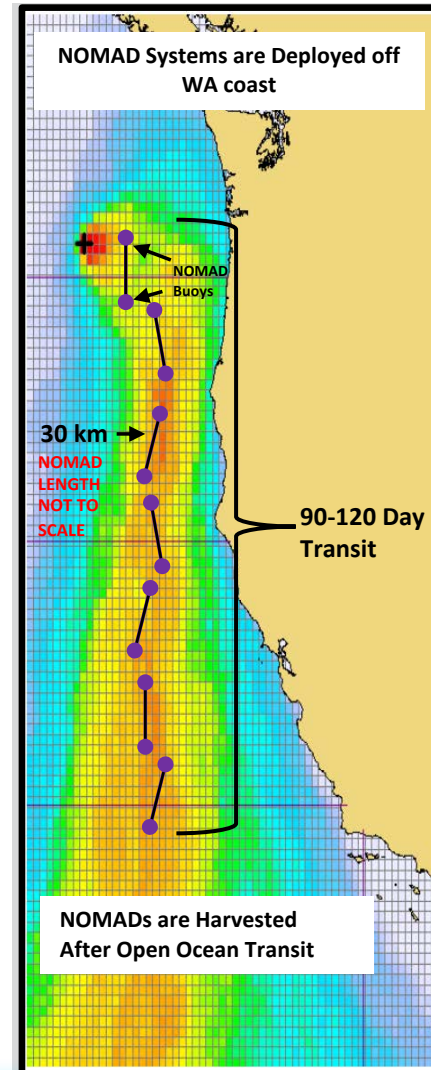
- NOMADs are free-floating, sensor equipped, carbon-fiber (CF) seaweed longlines (30 km, 6 tethered 5 km CF lines).
- NOMADs are released offshore WA and float south for ~3 months along nutrient rich currents as determined by hydrodynamic and biomass growth modeling.
- A complimentary binary culture of bull and sugar kelp is used to optimize yields and resilience.
- NOMADs pose no entanglement risks to marine life due to the large designed bending radius of CF.

## Technology Impact

- ▶ Reduces cost of biomass from ~\$250/DMT to \$83/DMT
- ▶ Enables disruptive biomass production in the US EEZ
- ▶ Is scalable by deploying NOMADs in different ocean regions potentially leading to significant liquid biofuel production

## Proposed Targets

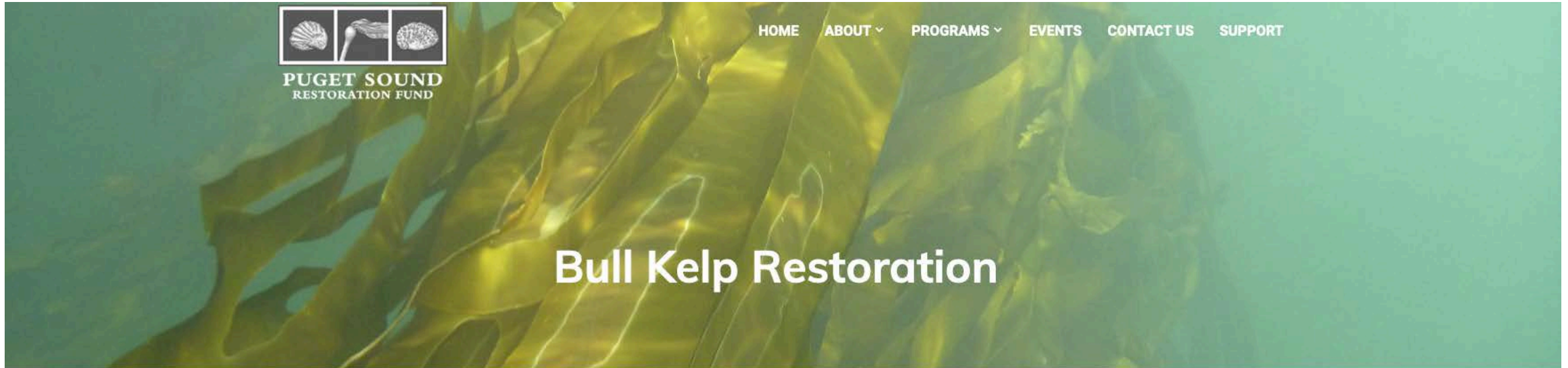
Metric	State of the Art	Proposed
Seeding/Harvest	Slow, manual	Fast, automated
Inoculum Production	Slow manual hatchery lifecycle	Rapid, adhesive clonal propagation
Cultivation	Monoculture-Fixed	Polyculture-Floating
Biomass Cost	\$250/DMT	\$83/DMT



*NOMADs Produce Seaweed at 3 Times Lower Cost While Minimizing Environmental and Operational Impacts*



# Restoration/ Compensatory Mitigation



**Our goal is to reverse declines in canopy kelp forests in Puget Sound and develop viable solutions to recover the essential habitat they provide.**

---

# Seaweeds Used

## Brown Algae

- Food, Alginate, Fertilizer: Kelps: *Laminaria*, *Macrocystis*, *Nereocystis*, *Alaria*, etc.
- Alginate, Fertilizer: *Fucus*,

## Red Algae

- Nori: *Porphyra*, *Pyropia*
- Agar: *Gelidium*, *Pterocladia*, *Gracilaria*, *Agarophyton*
- Carrageenan: *Mazzaella*, *Chondracanthus*, *Mastocarpus*

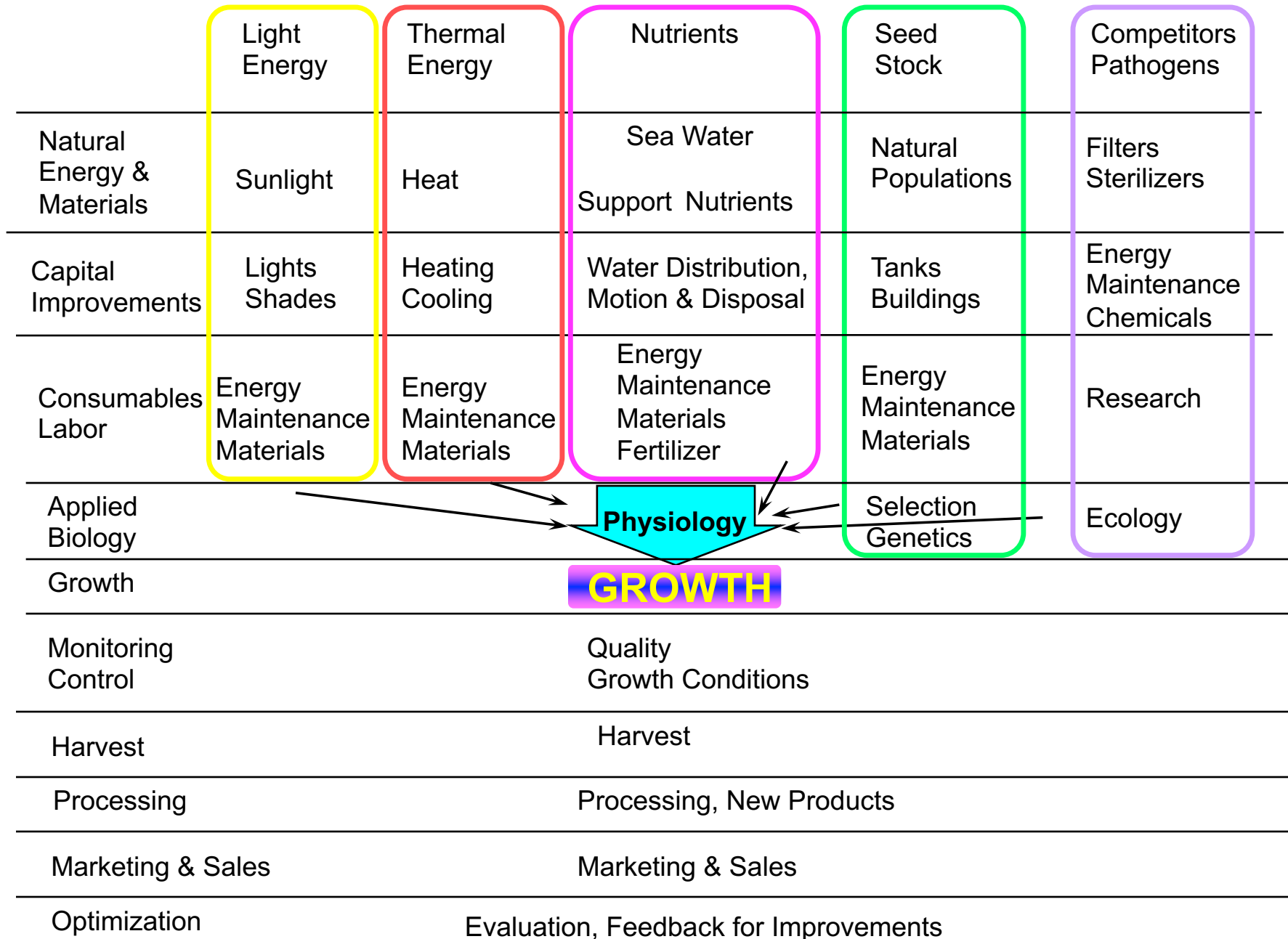
## Green Algae

- Food: *Monostroma*, *Ulva*, *Dunaliella* (phytoplankton)

# What are you going to grow?

- Really your first question should be-
  - what product do I want to produce.
    - can I sell it? What's the market, competition?
- Then figure out economics of production
- Then chose species and cultivation method
- Get Permits underway or secured

# Aspects of Intensive Seaweed Cultivation



# Seaweed Aquaculture

Seed Stock Selection (species, cultivars)

Propagation (net seeding, cuttings)

Outplanting (long lines, nets, tanks, ponds)

Harvesting (depends on culture method)

Processing (depends on product)

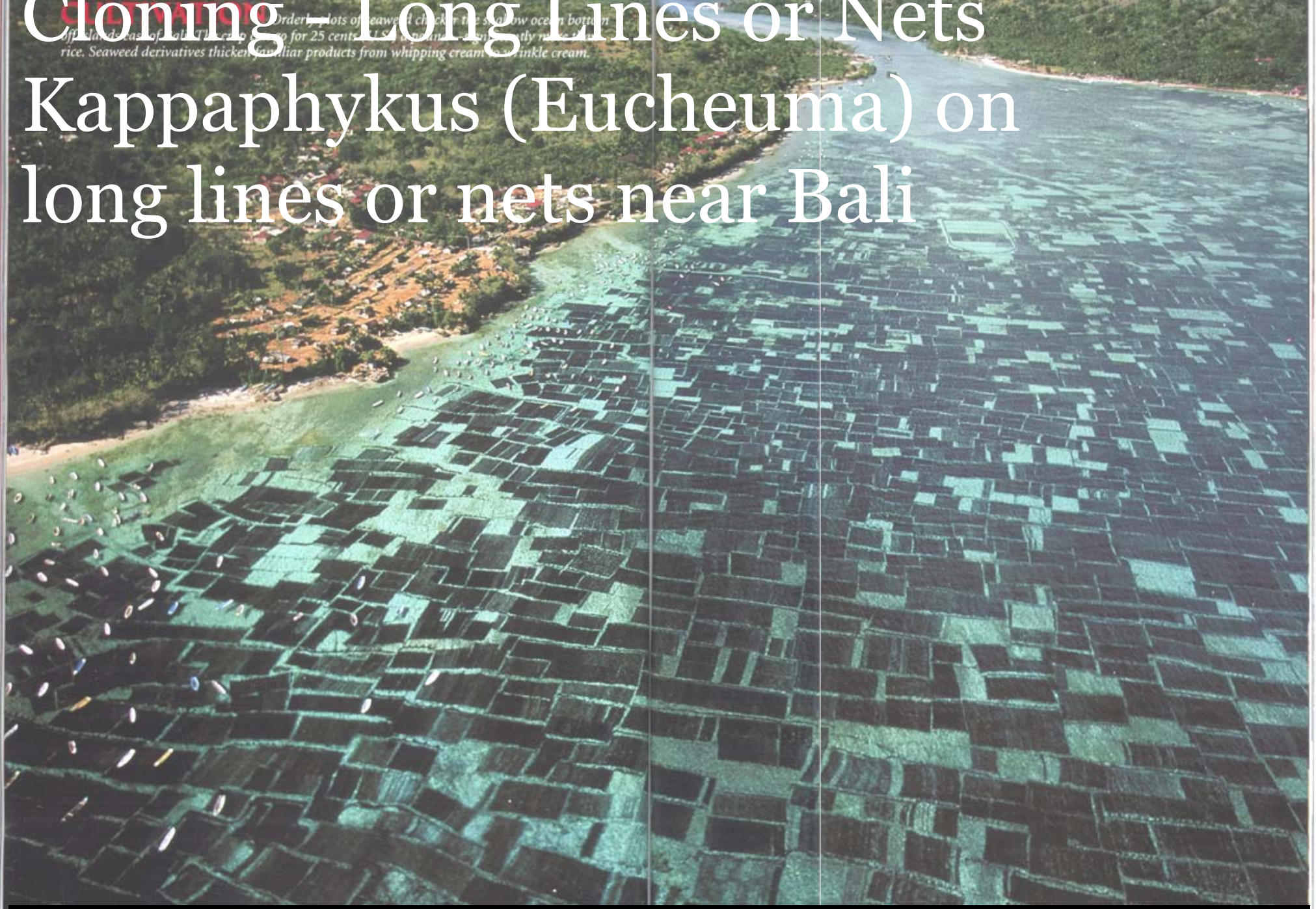
Marketing (depends on product)

# Cloning - Long Lines or Nets Kappaphykus (Eucheuma) on long lines or nets Carrageenan source



Order - lots of seaweed checked the shallow ocean bottom  
off the coast of Bali, Indonesia for 25 cents a US pound. Significantly more than  
rice. Seaweed derivatives thicken familiar products from whipping cream to vanilla cream.

# Cloning - Long Lines or Nets Kappaphykus (Eucheuma) on long lines or nets near Bali



# Tank Culture

(See John Colt's talk)

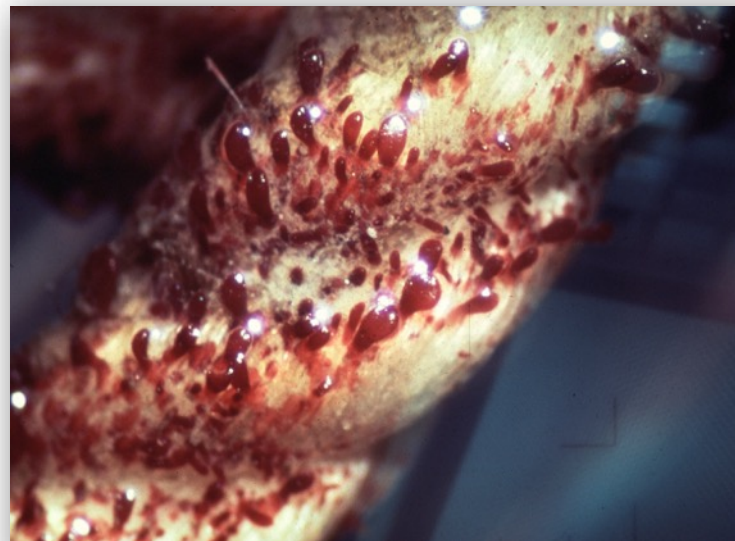
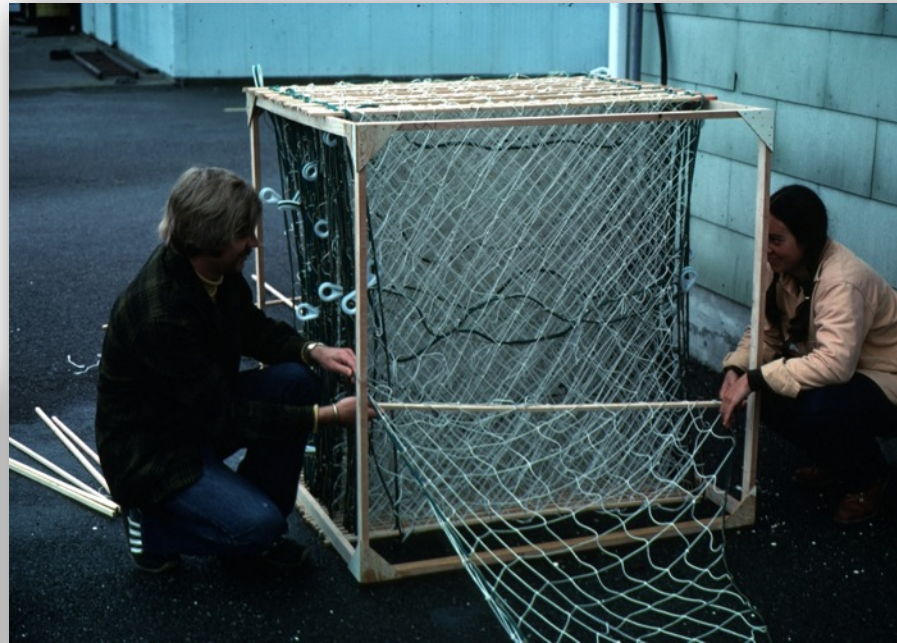
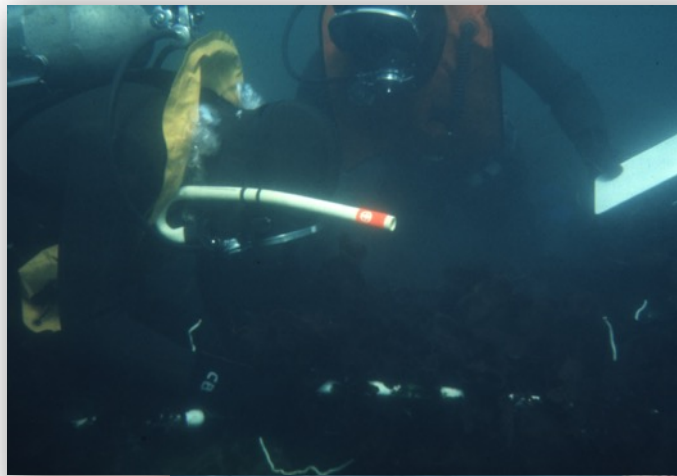






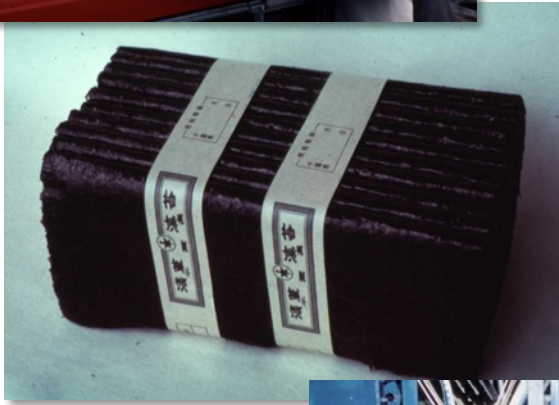
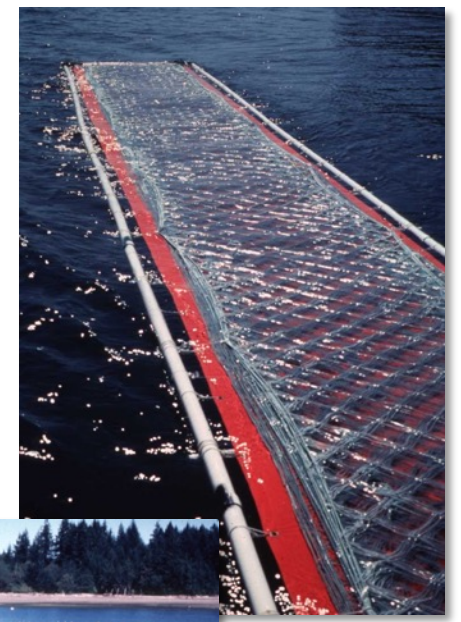
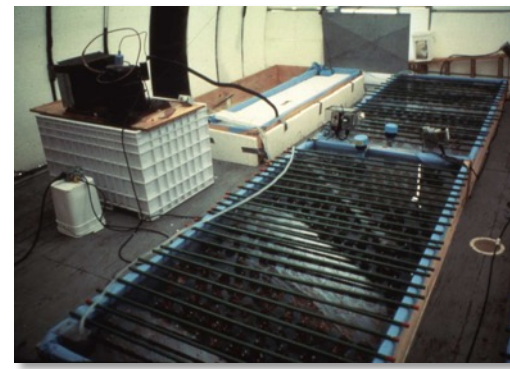
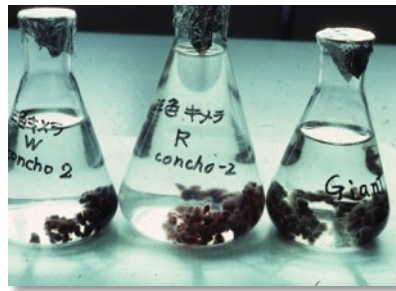
# Cloning - Long Line (or Net):

also used  
with  
Gracilaria  
on long lines  
or net bags

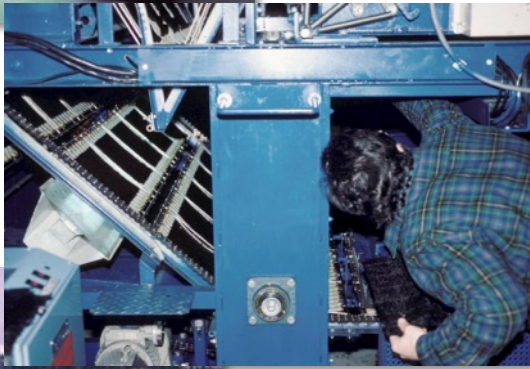


# *Mazzaella* for the production of carrageenan

Dept. Natural Resources  
1978-81



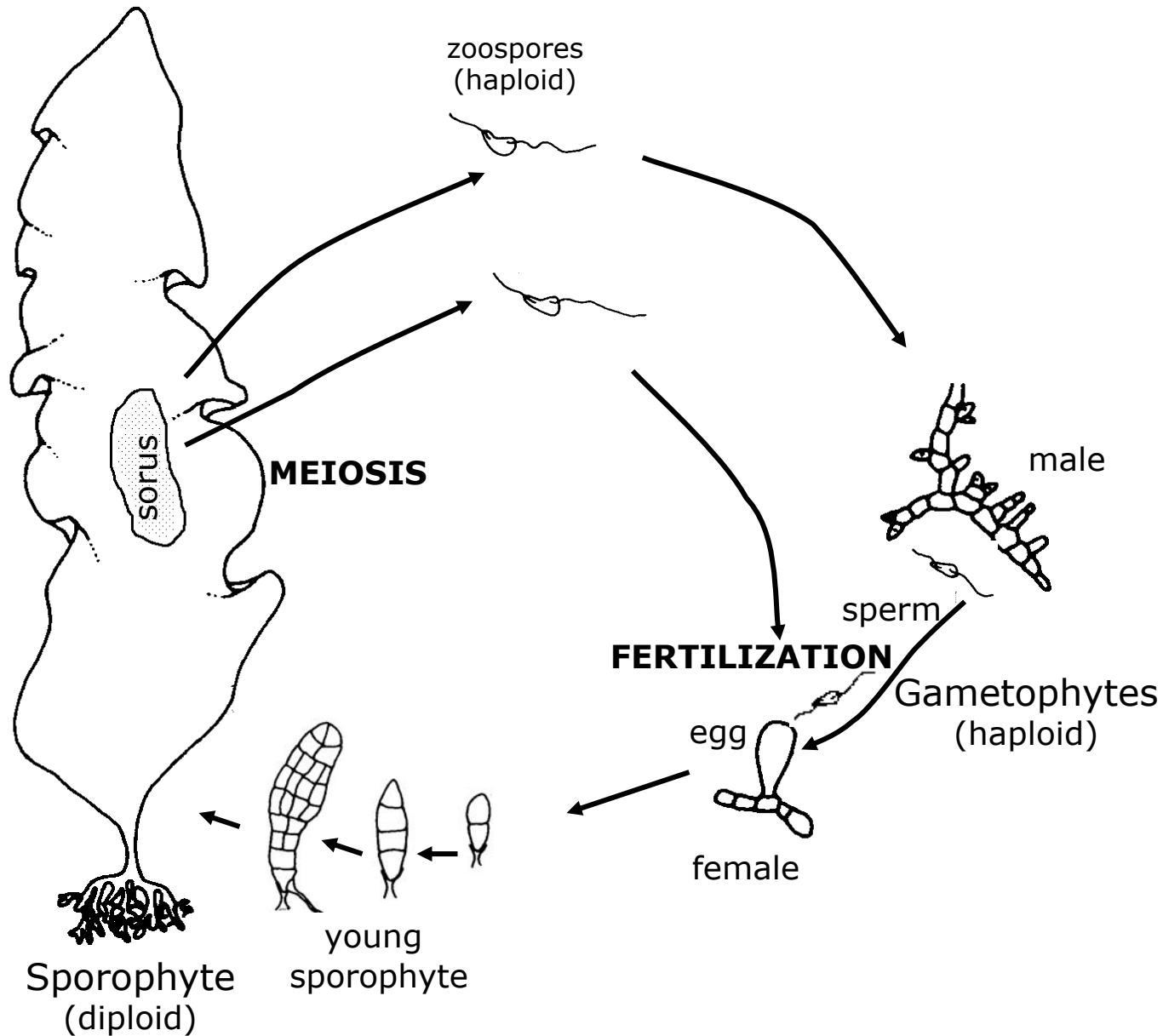
*Porphyra*  
(*Pyropia*)  
Cultivation for  
Nori  
In Washington  
State



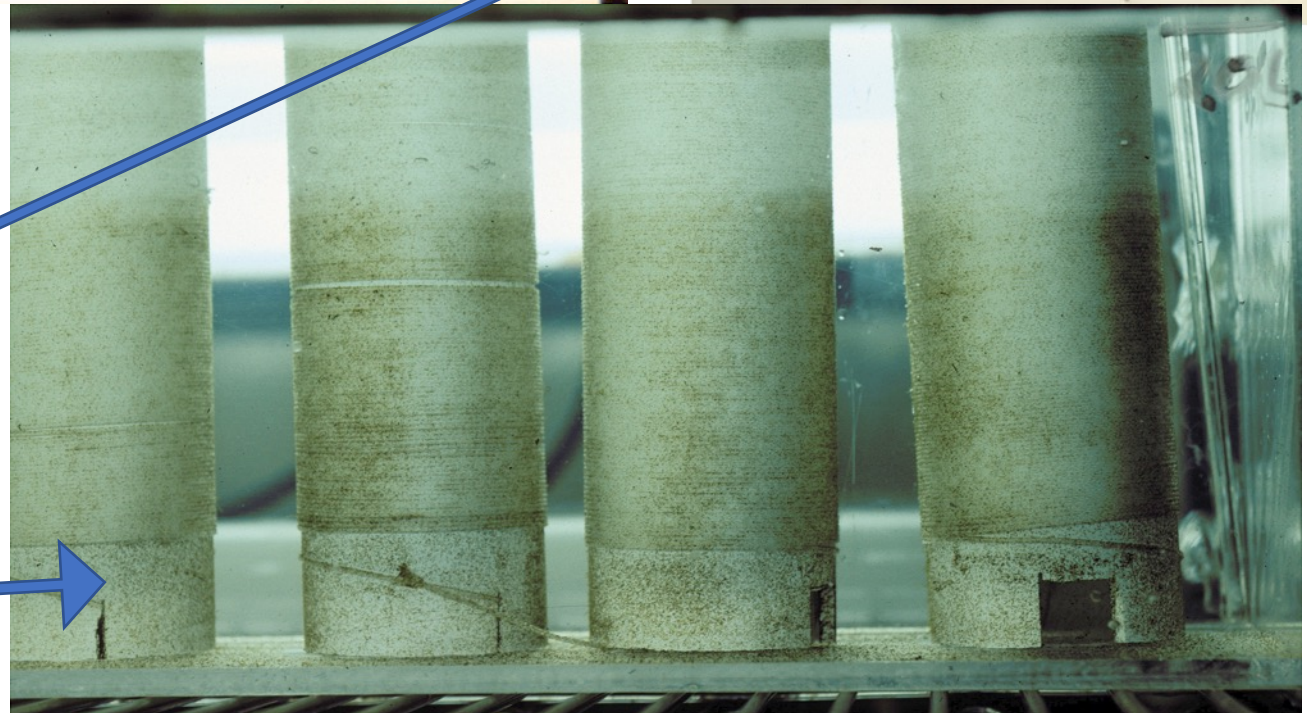
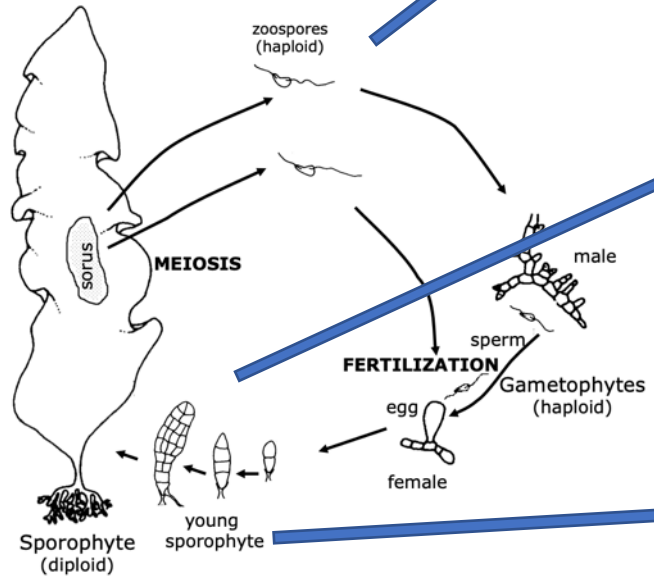


# Kelp Life History

“Alternation of heteromorphic generations”



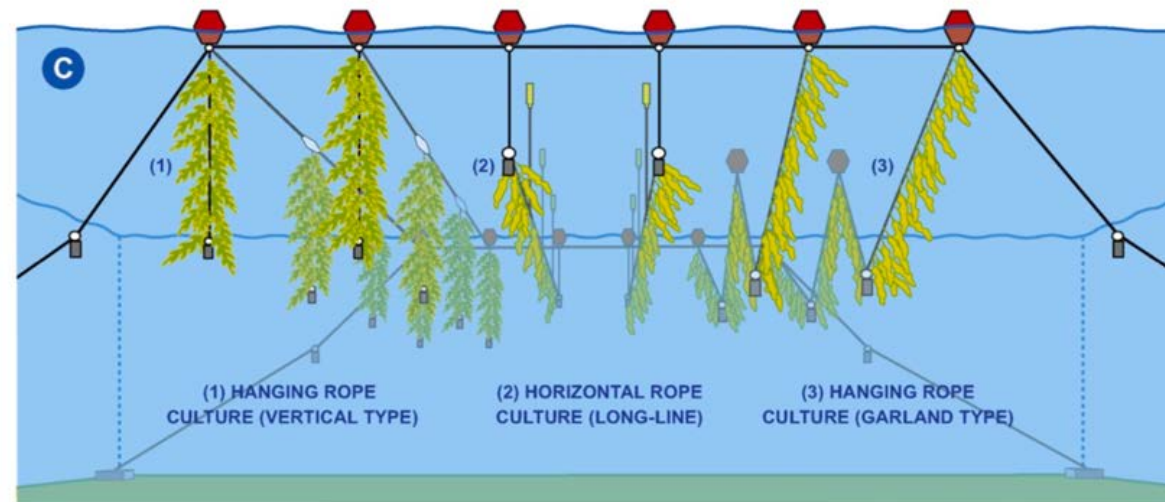
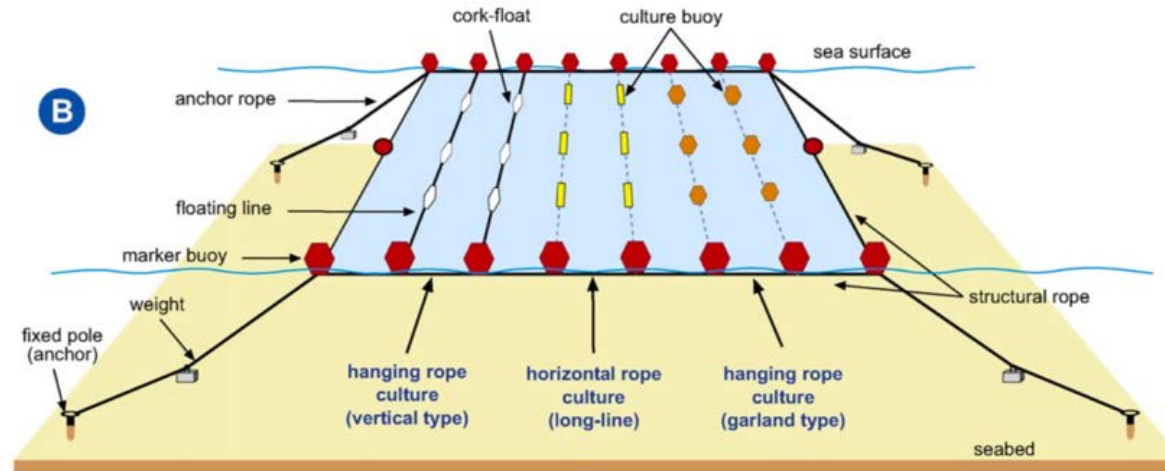
# Kelp Farming





# Modern Kelp Cultivation

## Examples of rope culture



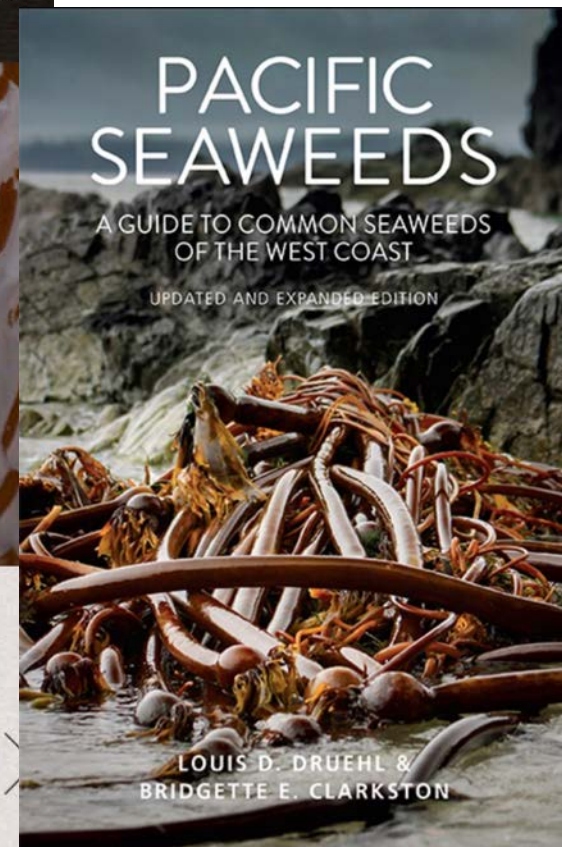




# Modern Seaweed Cultivation

## US & CAN: independent

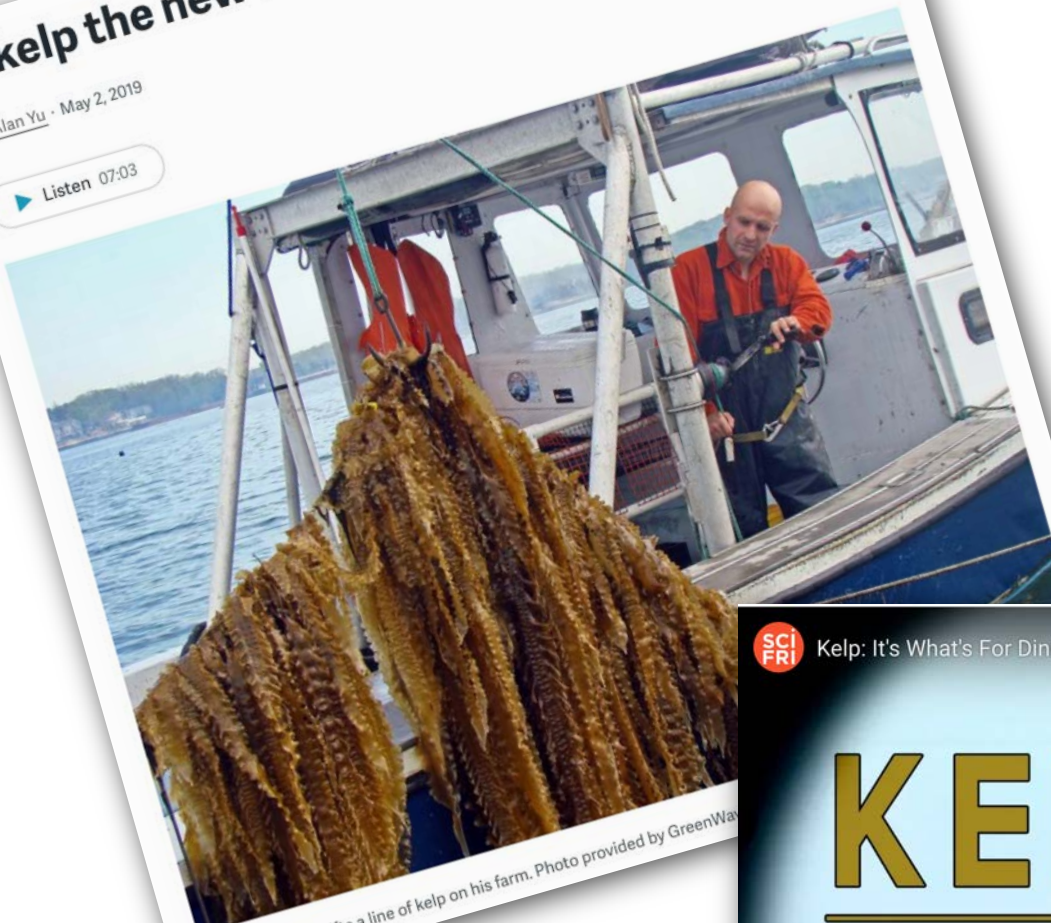
The screenshot shows the Canadian Kelp website homepage. At the top is a navigation bar with the following links: HOME, PRODUCTS, GIFT SHOP, CONSULTING, WHY KELP, ABOUT US, MEDIA, CONTACT. The main header features the brand name "Canadian Kelp" in a white script font. Below this is a large hero image of seaweed with the text: "The ocean is our world and our job is to bring the *purest sea vegetables and seaweed products* from nature's door to your family's table." and the hashtag "#findyourkelp". At the bottom of the page, there is a row of five product packages: "MACHO KELP", "KELP FLAKES", "KELP TWISTS", "SUGAR KELP", and "KOMBU".



# Is kelp the new kale? It was supposed to be

By Alan Yu · May 2, 2019

Listen 07:03

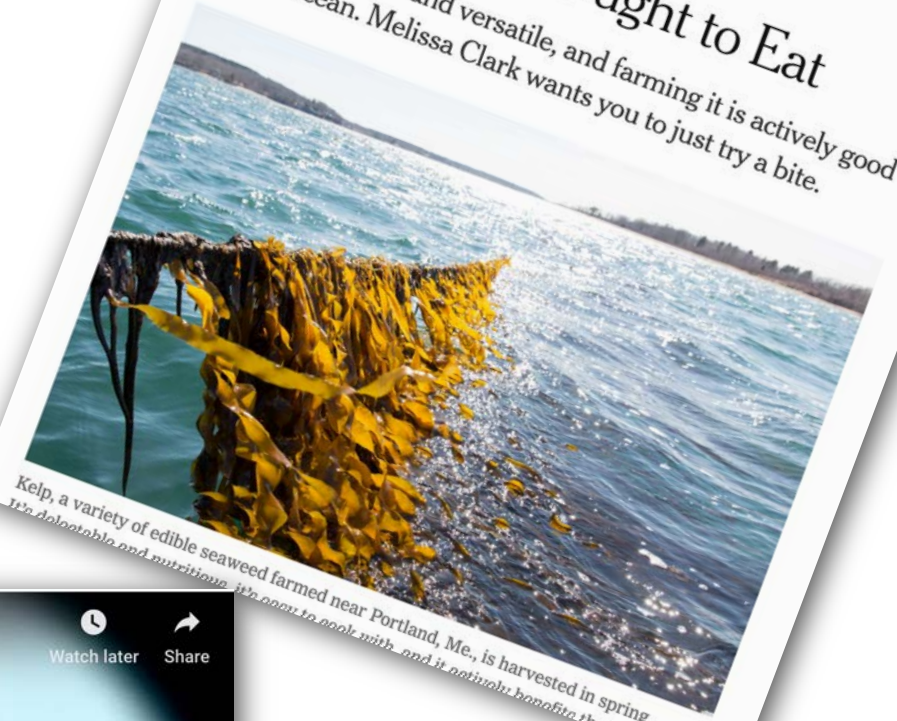


Bren Smith lifts a line of kelp on his farm. Photo provided by GreenWay

The New York Times

# The Climate-Friendly Vegetable You Ought to Eat

Kelp is delicious and versatile, and farming it is actively good for the ocean. Melissa Clark wants you to just try a bite.



Kelp, a variety of edible seaweed farmed near Portland, Me., is harvested in spring. It's delicious and nutritious, and it naturally benefits the ocean's

SCIFRI Kelp: It's What's For Dinner

Watch later Share

# KELP

It's What's For Dinner

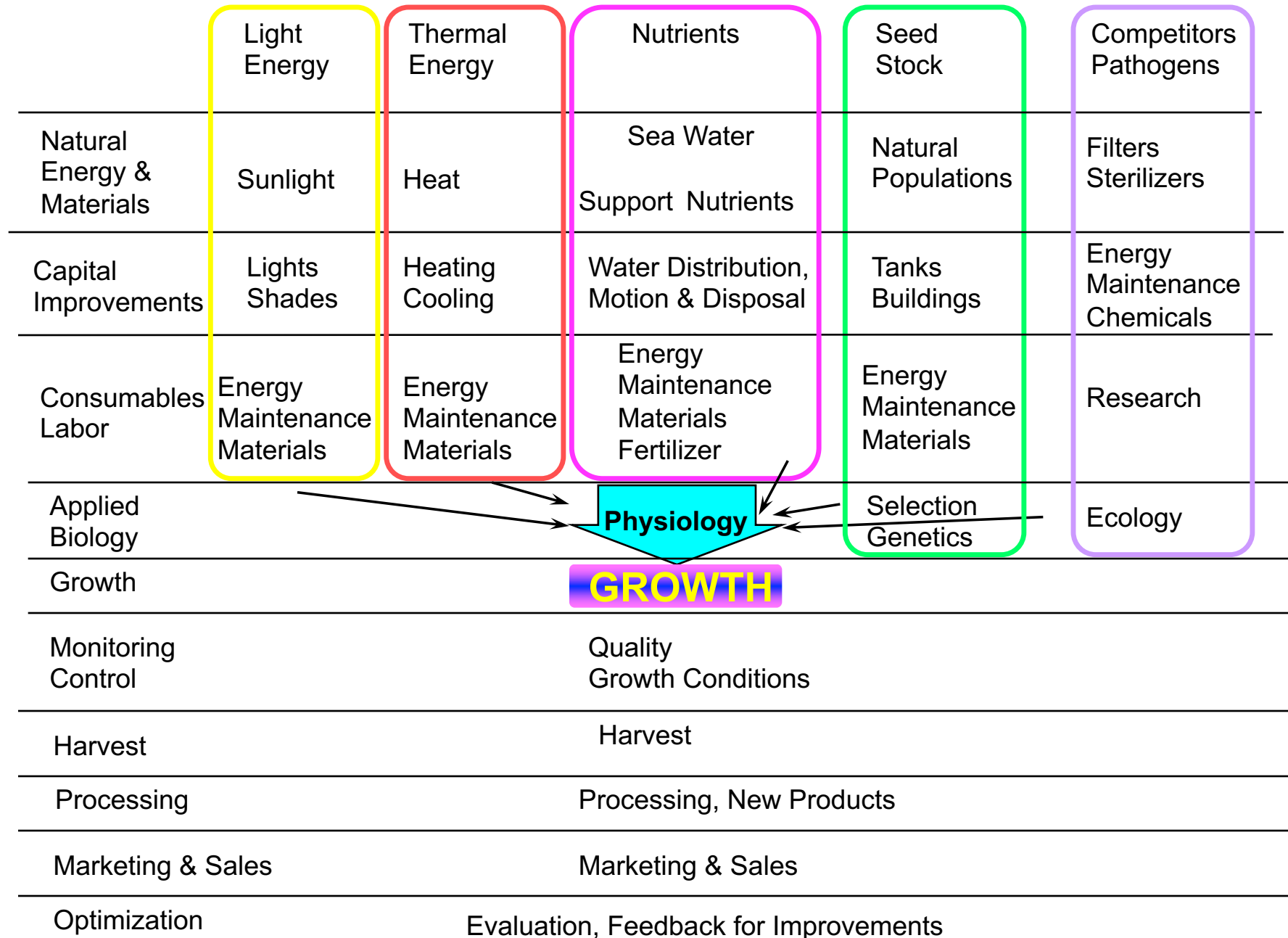
# Modern Seaweed Cultivation

- Europe: industrial scale for ~~biofuel~~ higher-value



***The Seaweed Carrier:** SES patented the first ever modern structure to enable mass seaweed cultivation on an industrial scale, called the Seaweed Carrier. It is a sheet-like structure that basically copies a very large seaweed plant, moving freely back and forth through the sea from a single mooring on the ocean floor, which allows seaweed cultivation in deeper and more exposed waters.*

# Aspects of Intensive Seaweed Cultivation



# The Future of Seaweed Aquaculture

## Macroalgae that have been sequenced

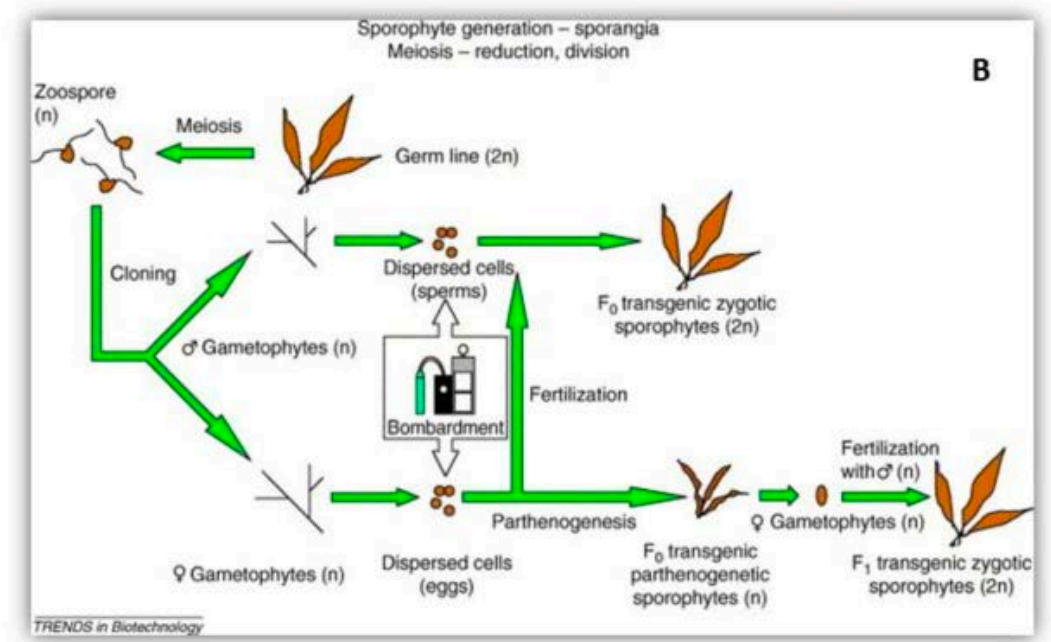
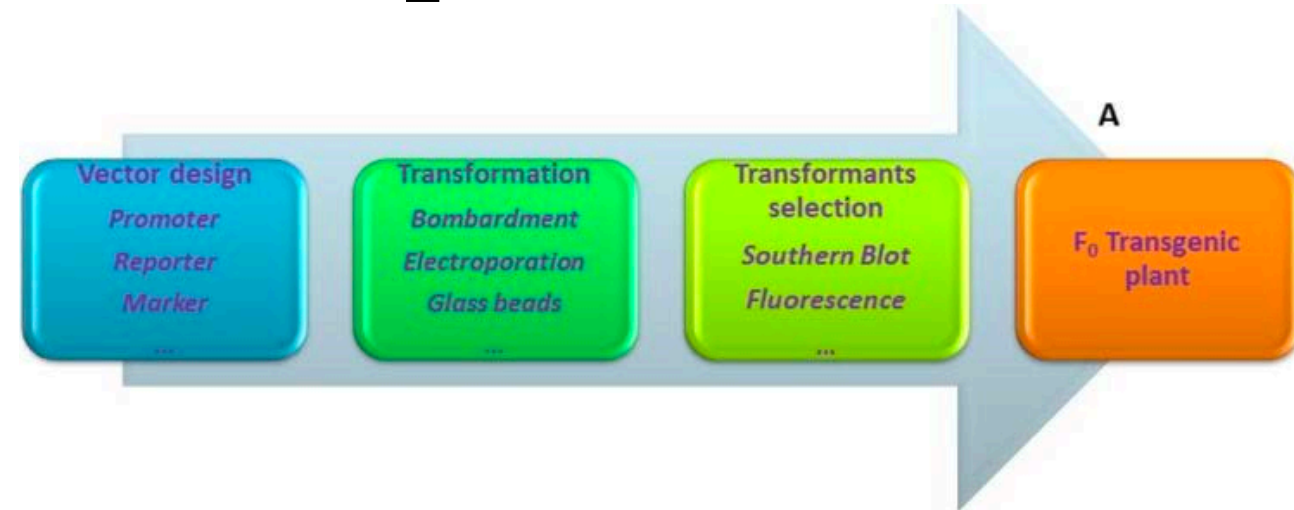
- *Chondrus crispus*
- *Gracilariopsis chorda*
- *Porphyra umbilicalis*
- *Pyropia yezoensis*
  
- *Ectocarpus siliculosus*
- *Saccharina japonica*



# ISS

**International Seaweed Symposium 2019**

23rd International Seaweed Symposium  
Date: 4/28/2019 - 5/3/2019  
Venue: ICC Jeju, Jeju, South Korea



# Resources

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