

# *Opportunities for Seaweed Mariculture in Northeast America*

**A Sea Grant Success Story!**

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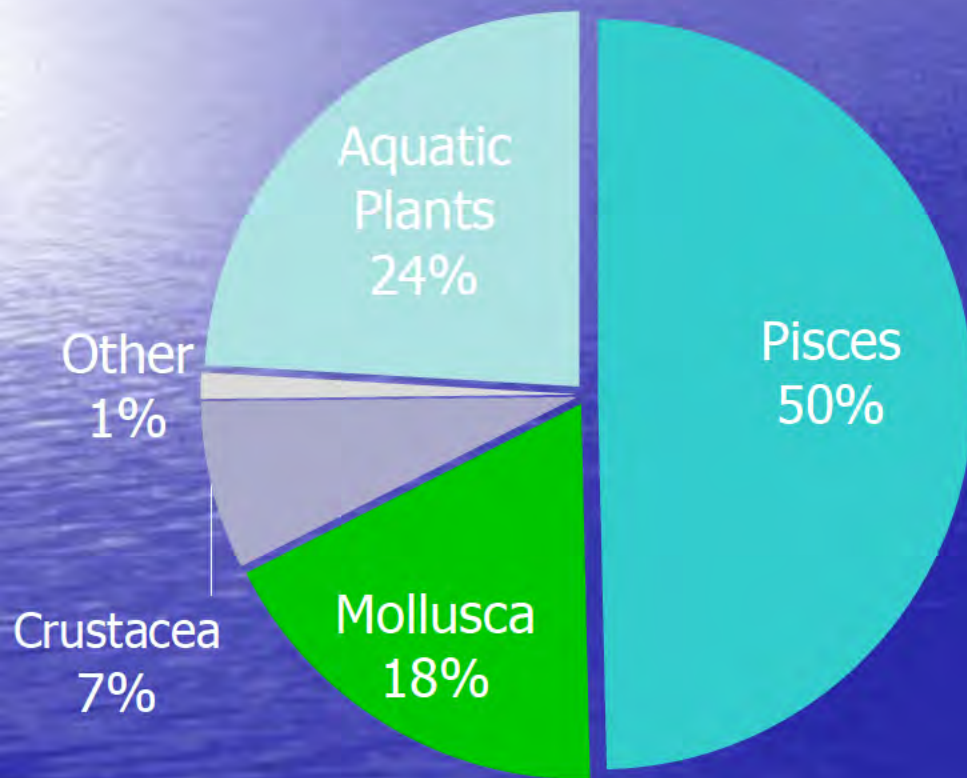
# Why Grow Sea Vegetables?

- US\$ 5.9-7.1 Billion Global Market
  - US >\$ 35 Million US Market
  - Emerging Local Industry for Northeast
- Extractive Component in IMTA
  - Coastal Farms
  - Recirculating Systems

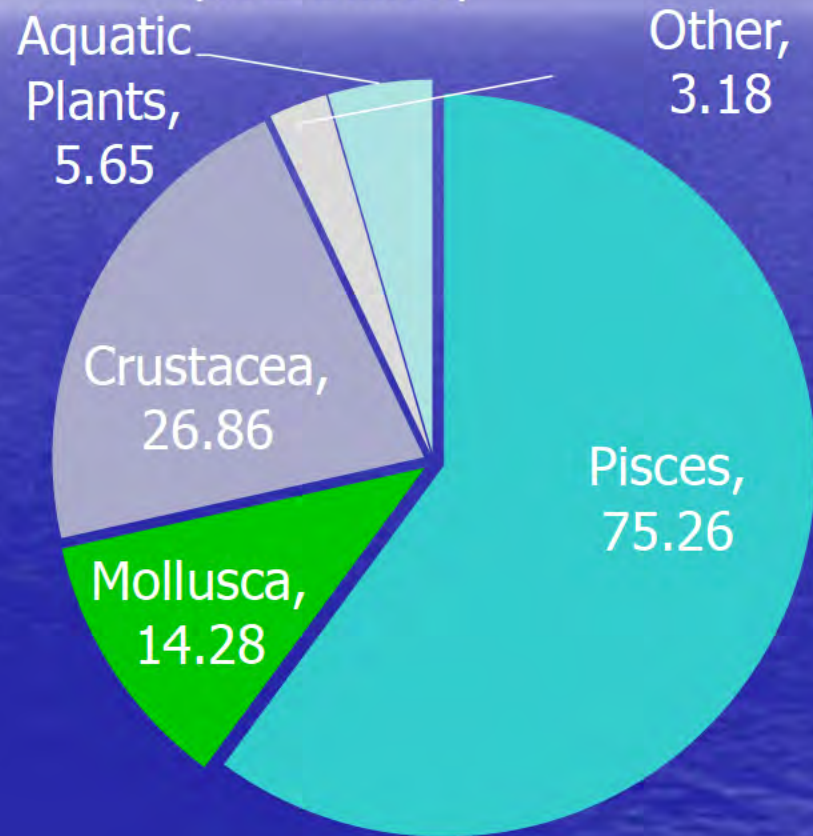


# Marine Aquaculture by Species Group

## Production by Weight



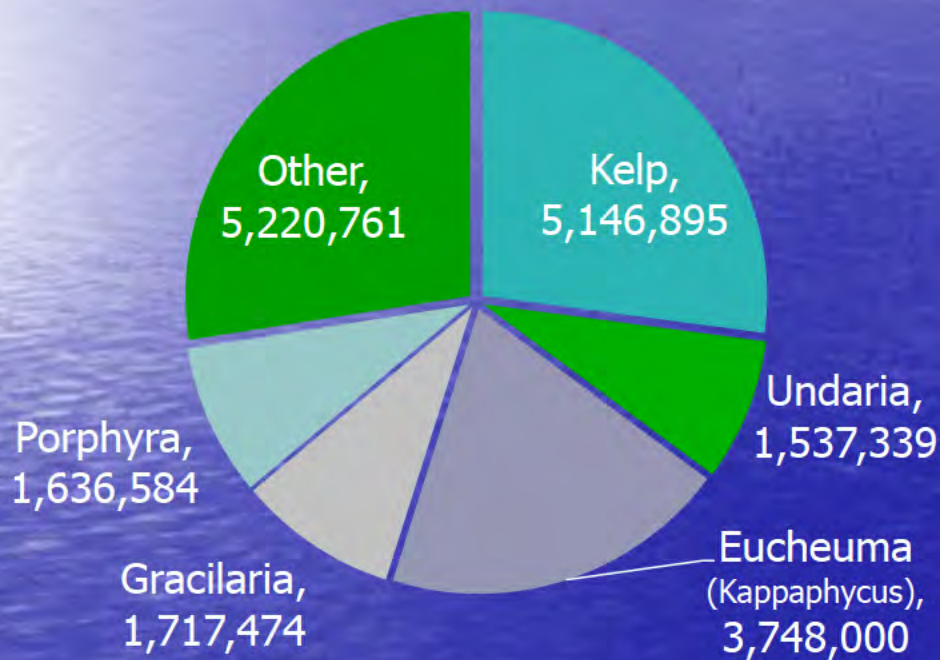
## Economic Value (\$US Billion)



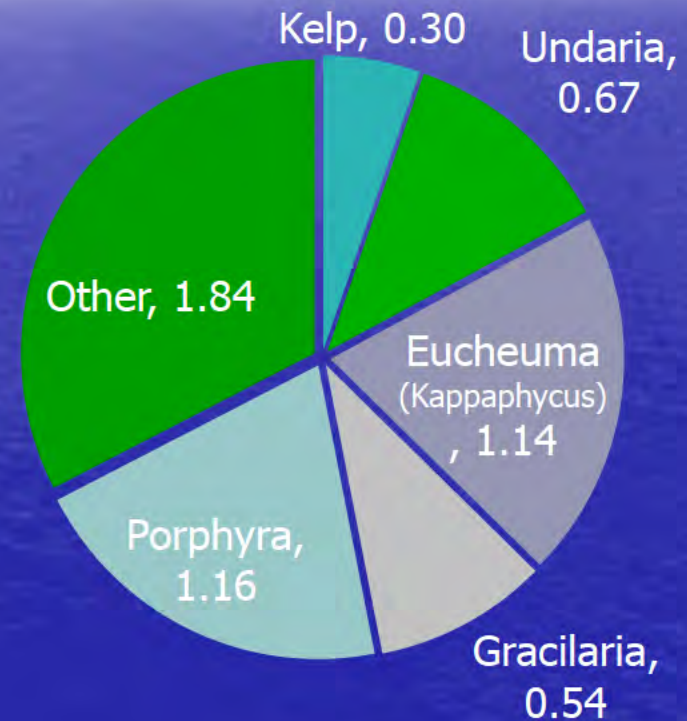
Source: FAO Fisheries and Aquaculture Information and Statistics Service. 2012

# Production of Seaweed Aquaculture

## Production by Weight (ton)



## Economic Value (\$us Billion)



Source: FAO Fisheries and Aquaculture Information and Statistics Service. 2012

# Uses of Seaweeds

- Food
- Feed
- Fertilizer
- Medicine
- Cosmetics
- Textile
- Paper
- Leather
- Major sources of phycocolloids  
(alginates, carrageenans & agars)
- Biofuel



# Food Value of Seaweeds

## Nutritional value

**1 kg fresh vegetables = 100 gm of seaweeds**

- Average percentage of protein: 5 – 10 %
- Average percentage of fat: 0.5 – 1.5 %
- Average percentage of ash: 10 – 18 %
- Average percentage of fiber: 3 – 6 %
- Average percentage of carbohydrate: 40 – 60 %
- Rich concentration of minerals, vitamins and trace elements

# Nutritional Value of Seaweeds

**100 g of Seaweed Provides:**

- **30 – 40 gm Proteins**
- **Vitamin – A**
- **Vitamin – B<sub>2</sub>**
- **Vitamin – B<sub>12</sub>**
- **Vitamin – C (67%)**
- **Vitamin – E and**
- **Na, K, Mg**



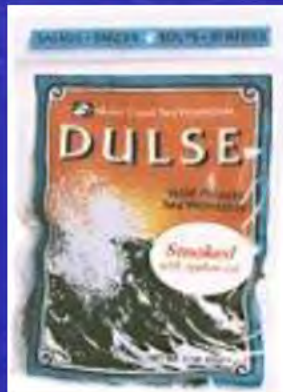
# Various products of seaweeds





# Emerging Local Industry

- Maine Coast Sea Vegetables (Franklin, ME)
  - Dried Wild Harvested Sea Vegetables
    - Retail and Direct Sales (\$2.8 million/yr)
    - Best Sellers – Nori, Dulse, Sugar Kelp
    - Demand is Greater than Supply
      - 14 tons (\$700k) Unfulfilled Orders in 2011



# Emerging Local Industry

- Ocean Approved LLC (Portland ME)
  - Fresh Frozen Kelp Grown on Longlines
    - Only US Commercial Kelp Nursery
      - Developed with Technology from UConn/UNH Sea Grants Projects and NOAA SBIR Projects
      - Cultivated 1 mile of Kelp Longlines in 2011
      - >9 miles in 2012
    - Sold through Whole Foods and other retail markets
    - Marketing Includes Recipe Development, In-Store Demos, Cooking School Workshops (Johnson & Wales).
      - [www.oceanapproved.com](http://www.oceanapproved.com), [www.facebook.com/oceanapproved](http://www.facebook.com/oceanapproved)

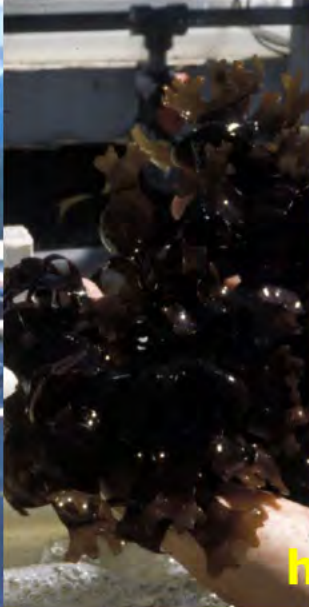


# How Do You Grow Sea Vegetables?



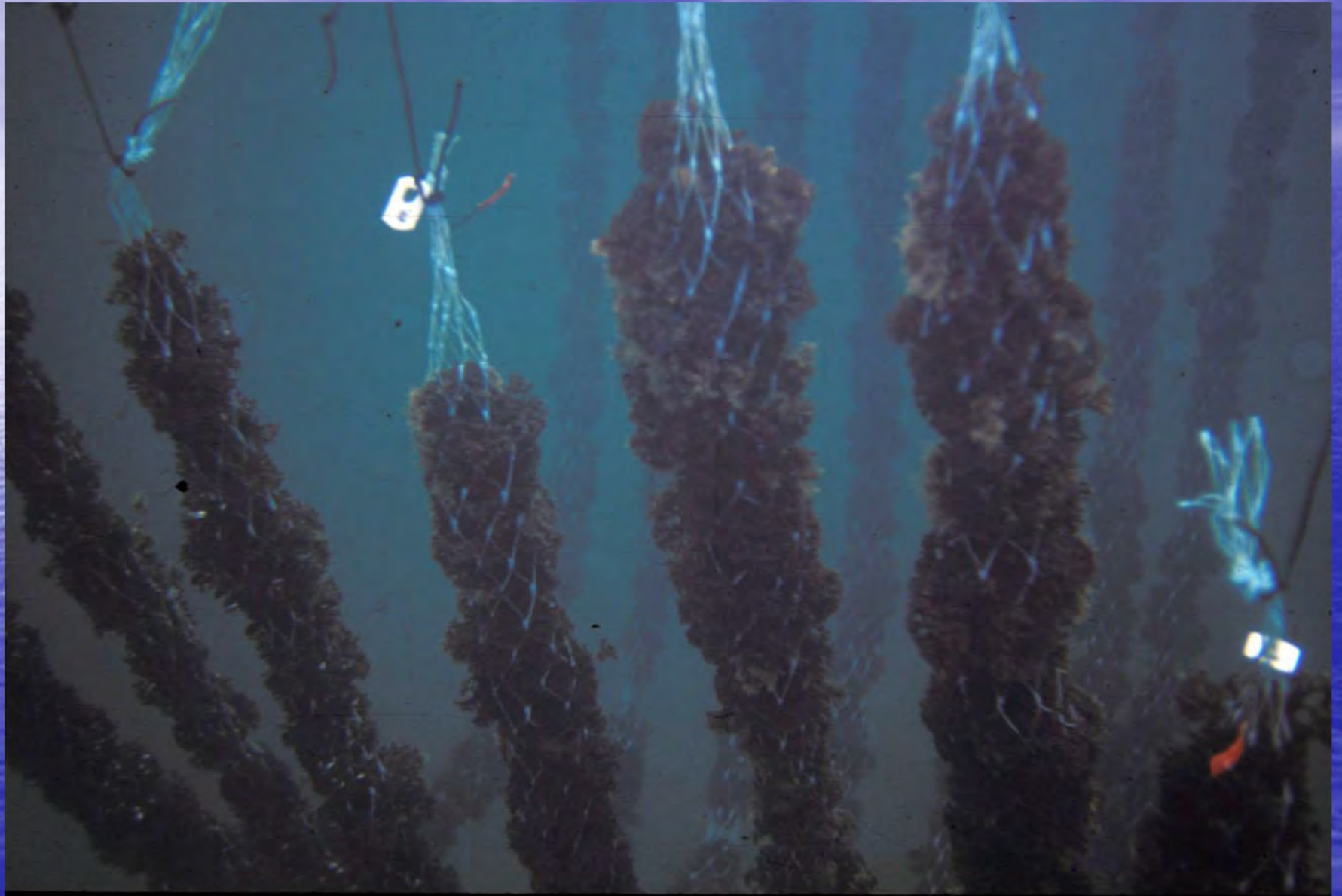
- Initiate Laboratory Cultures
  - Collect Wild Specimens with Desirable Characters
  - Isolate Spores
  - Produce Mass Cultures of Appropriate Life History Stage
- Induce Spore Release
- Seed Lines for Outplanting
- Grow Out
- Harvest

# *Chondrus (Irish moss)*



<http://www.acadianseaplants.com/index.html>

# Tube Net or Mussel Socks





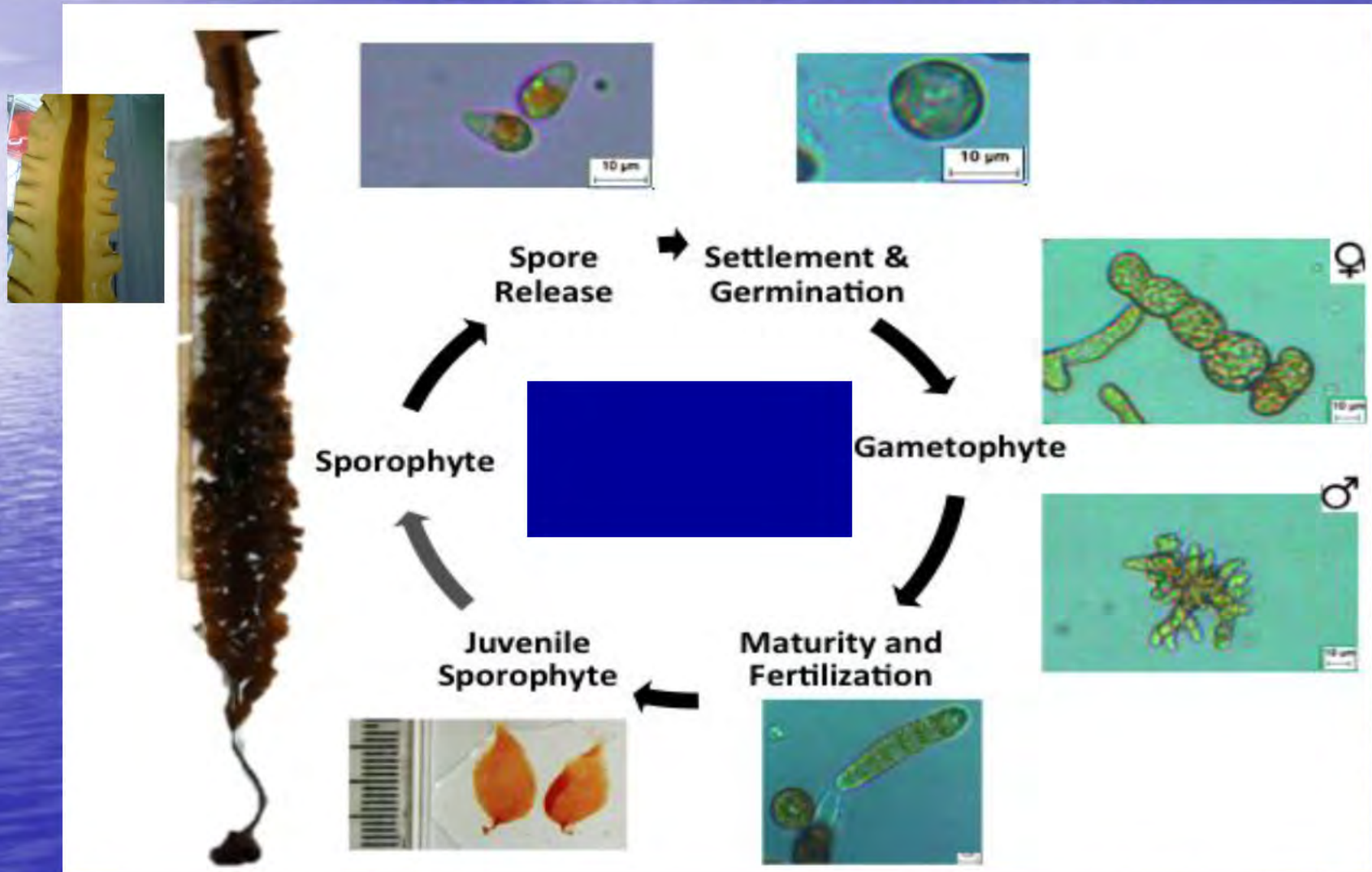
## **Hana-nori™**

The land-based cultivation system developed by **Acadian Seaplants** to grow its **Hana-nori** product line is unique in the world. Likewise, the all-natural pink, green and first-ever bright yellow seaweeds produced at the facility are also unique in the world and are sold exclusively to the Japanese food market.

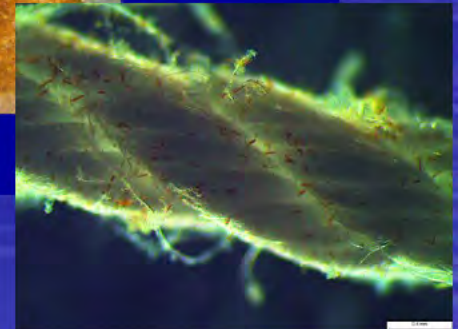
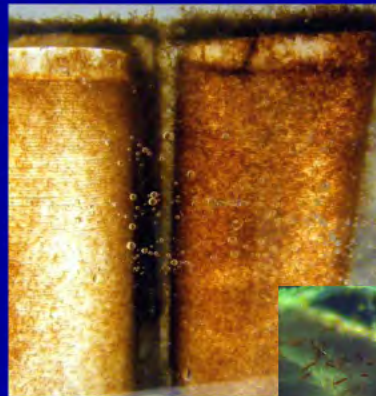
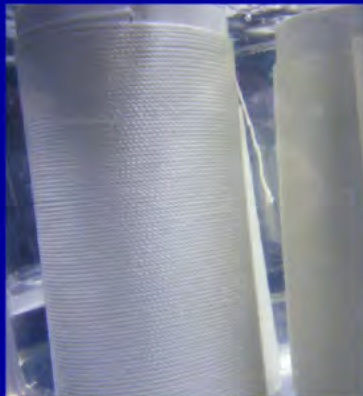
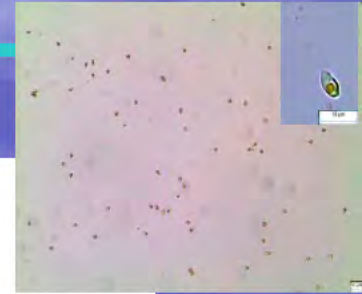
<http://www.acadianseaplants.com>

# Sea Vegetable Biology

## *Saccharina latissima* Life History



# Development of a reliable "seed" nursery modular system of *Saccharina latissima* for the mass production





# Kelp Open water cultivation trial in LIS

December 2011



April 2012



# Sugar Kelp (*Saccharina latissima*)

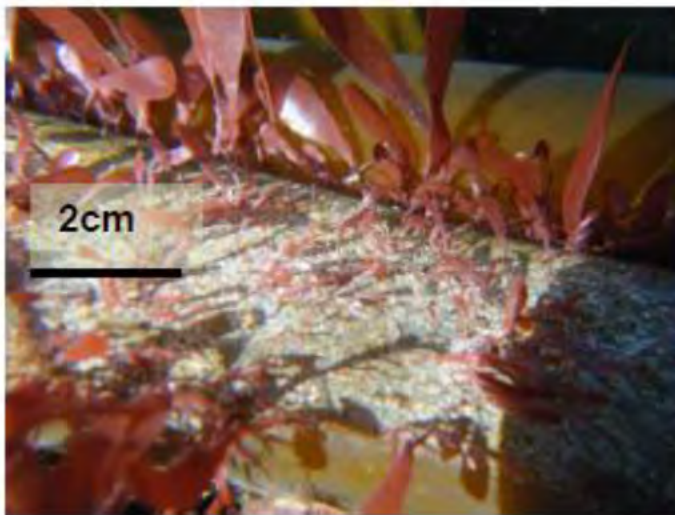
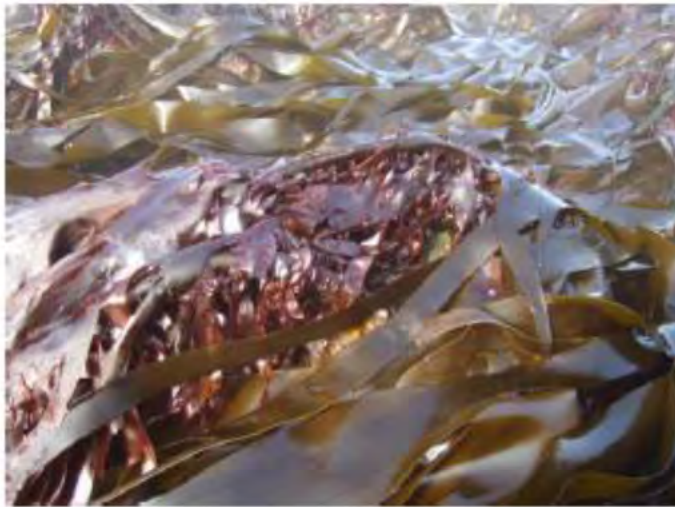
- Growing season: Nov. – May ( $< 15^{\circ}\text{C}$  or  $< 60^{\circ}\text{F}$ )
- Productivity:  $\sim 18\text{ kg/m/}$  growing season



# What Do You Do With Sea Vegetables?



# *Palmeria* ("dulse")



(Werner and Dring, 2011)  
(<http://www.bim.ie/our-publications/>)



(Werner and Dring, 2011)  
(<http://www.bim.ie/our-publications/>)



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# ***Porphyra*** (Nori = Japanese)

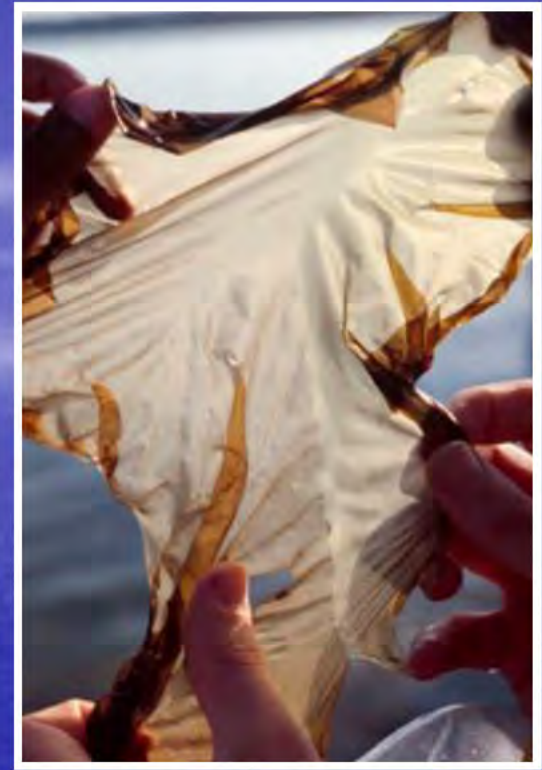


# Porphyra Products

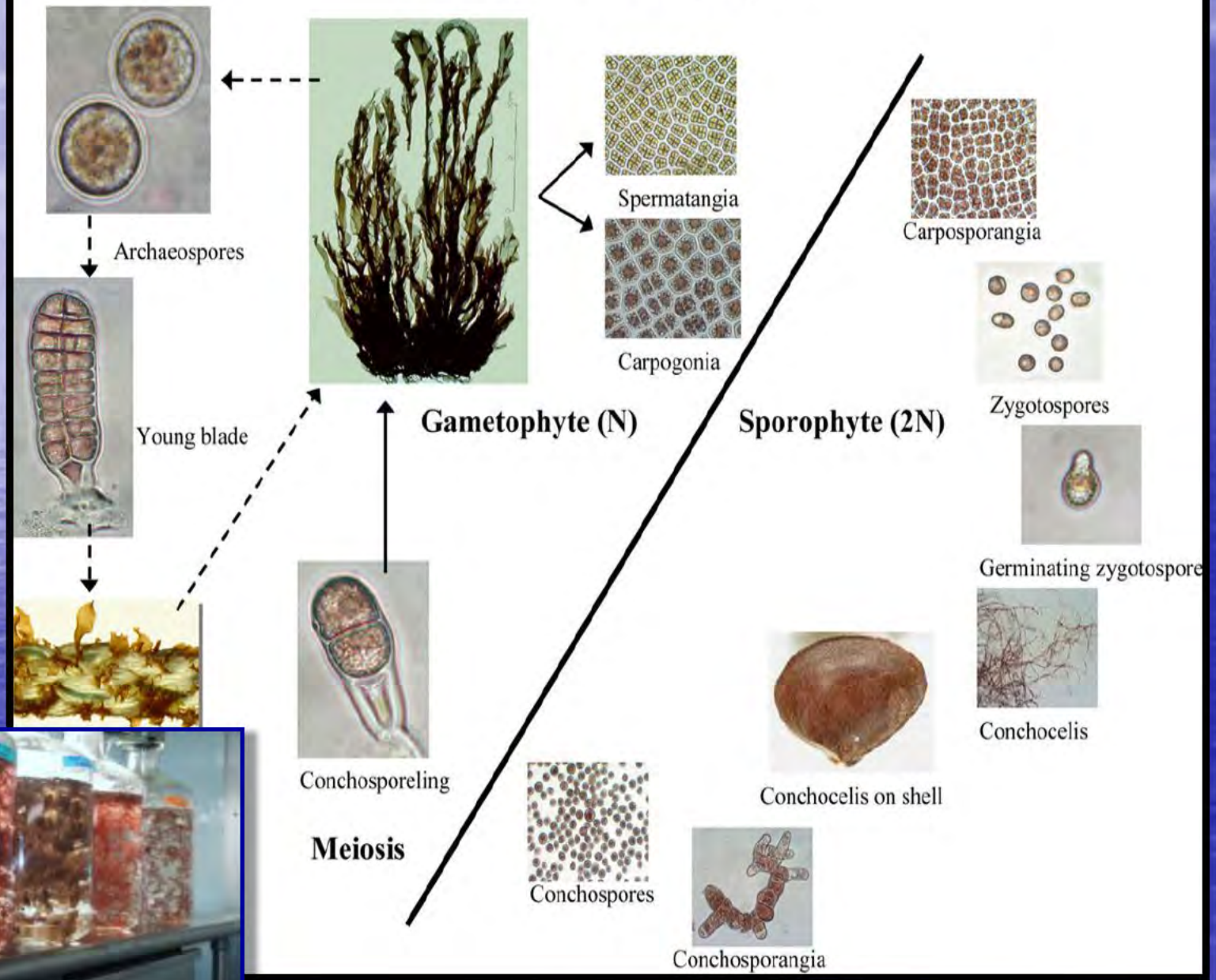


# *Porphyra* species

- Simple, flat sheet gametophyte (high SA/V)
- 1-2 cell layers: all productive
- fast growth (up to 48% d<sup>-1</sup>)
- high nutrient accumulation (possibility of 6-8% N DW)
- high protein content (up to 50% DW)
- salable harvest (nori, high-value r-phycoerythrin )

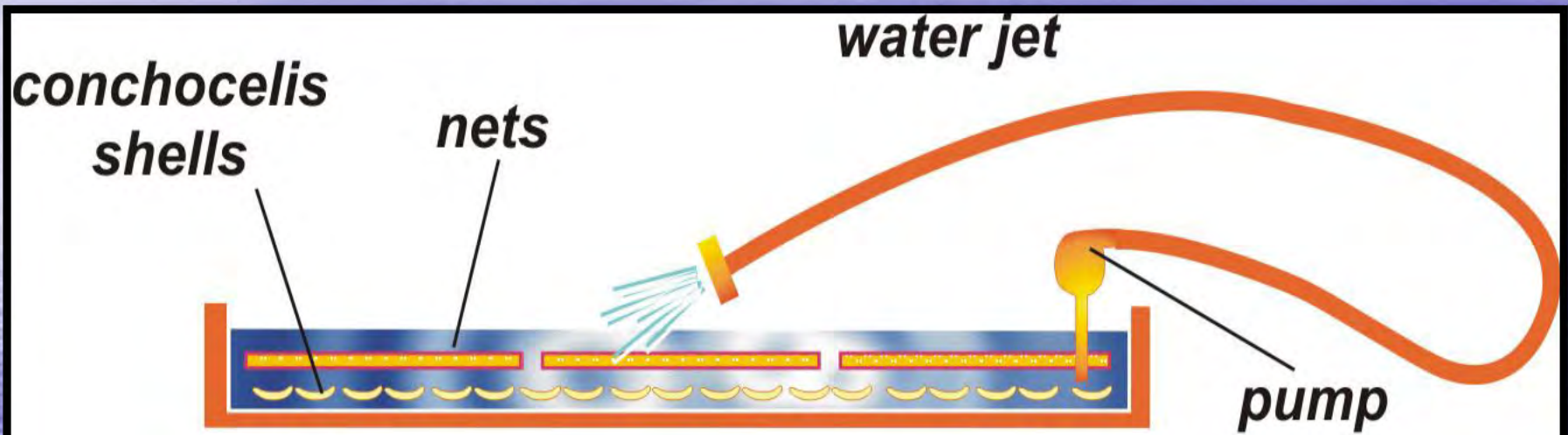


# Life Cycle of *Porphyra*





Culture of conchocelis on oyster shells and rotary wheels for seeding of nets.

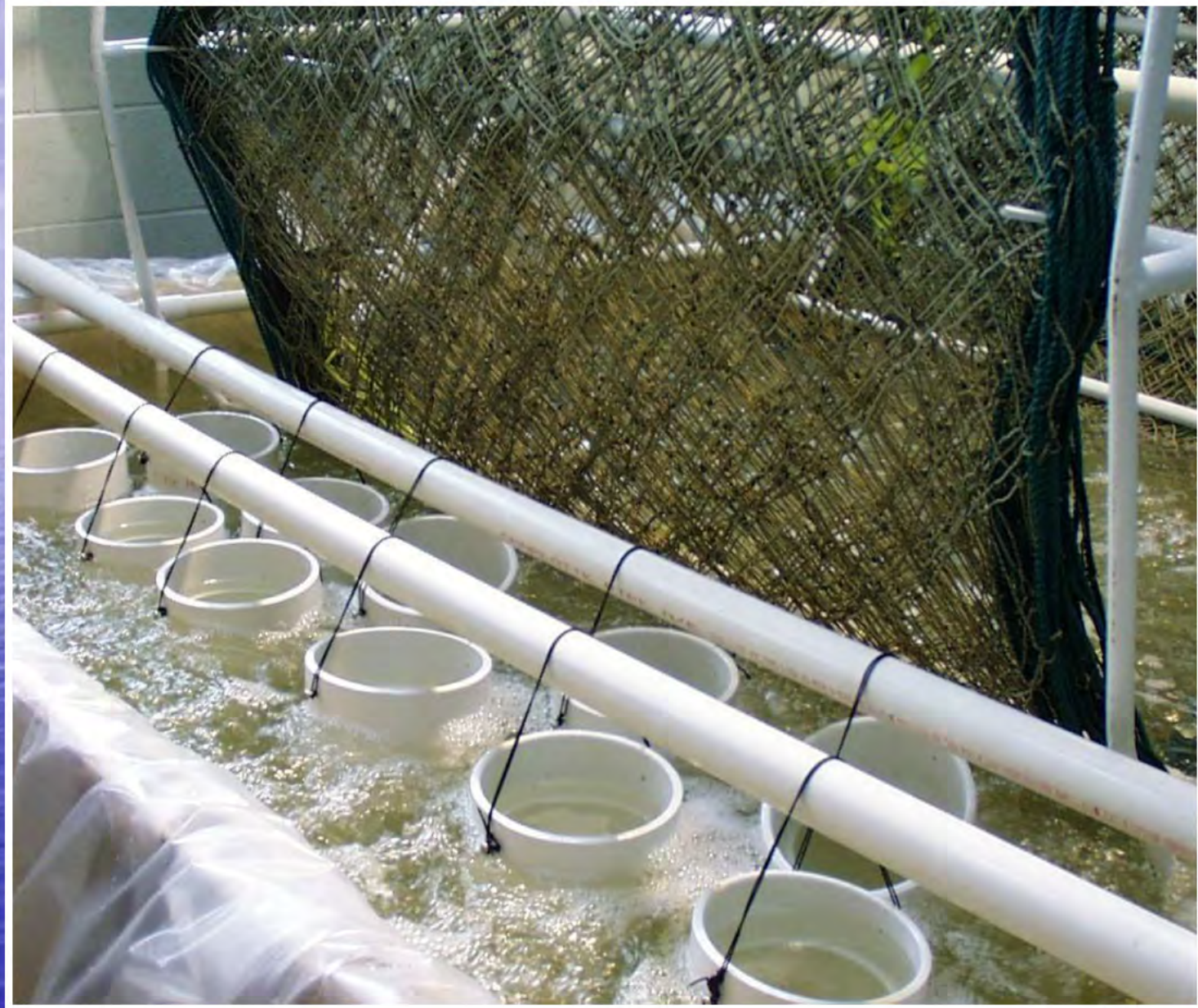


***Water jet agitation type spore-collecting method***

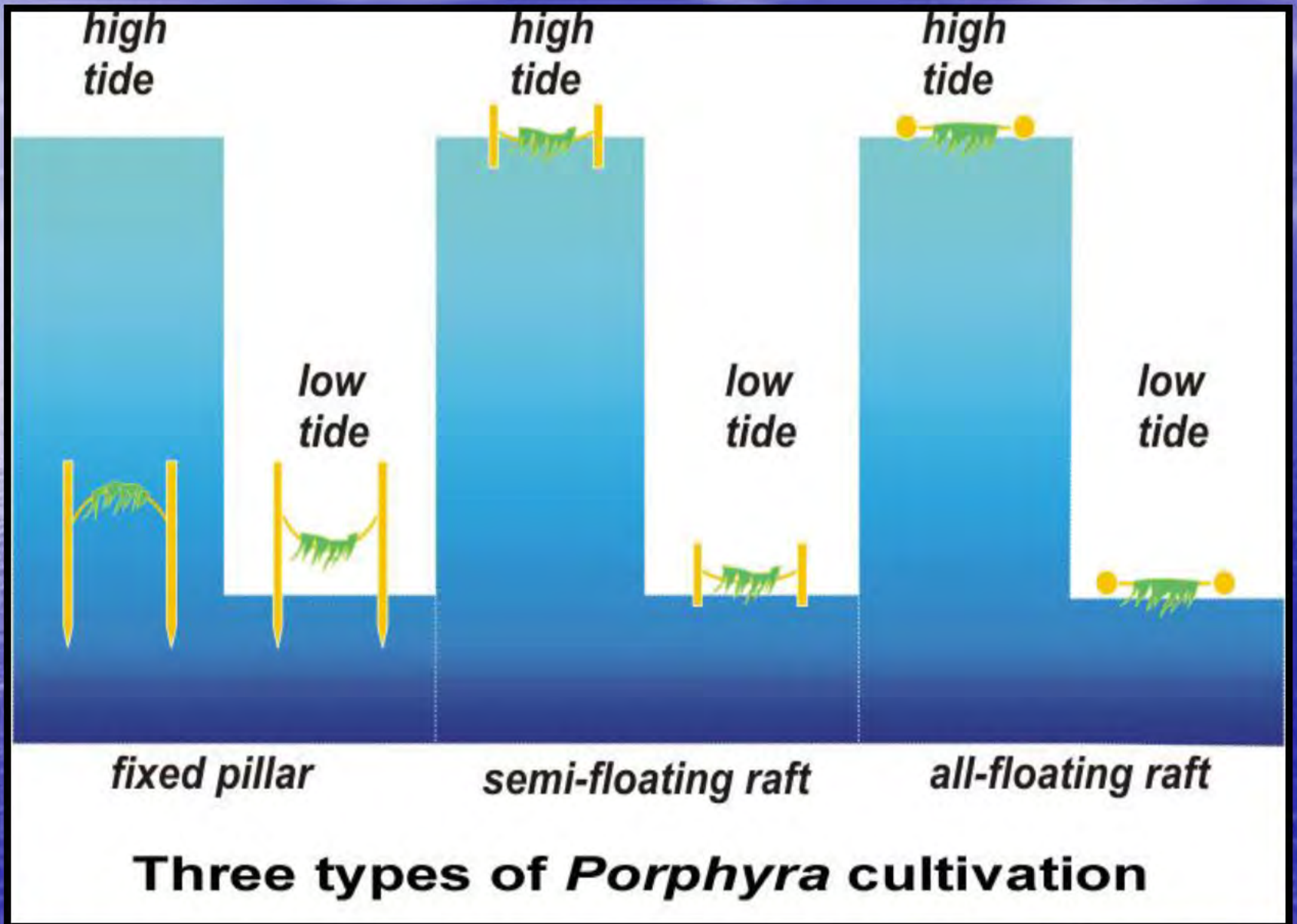
# Free conchocelis culture



# Spore collection and inoculation of nets







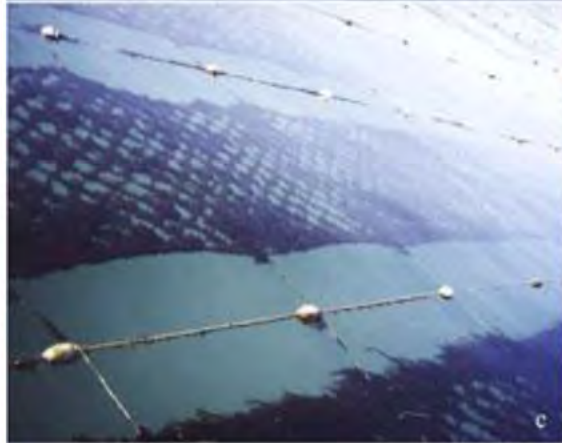
(Sahoo and Yarish, 2005)

# Modern *Porphyra* cultivation

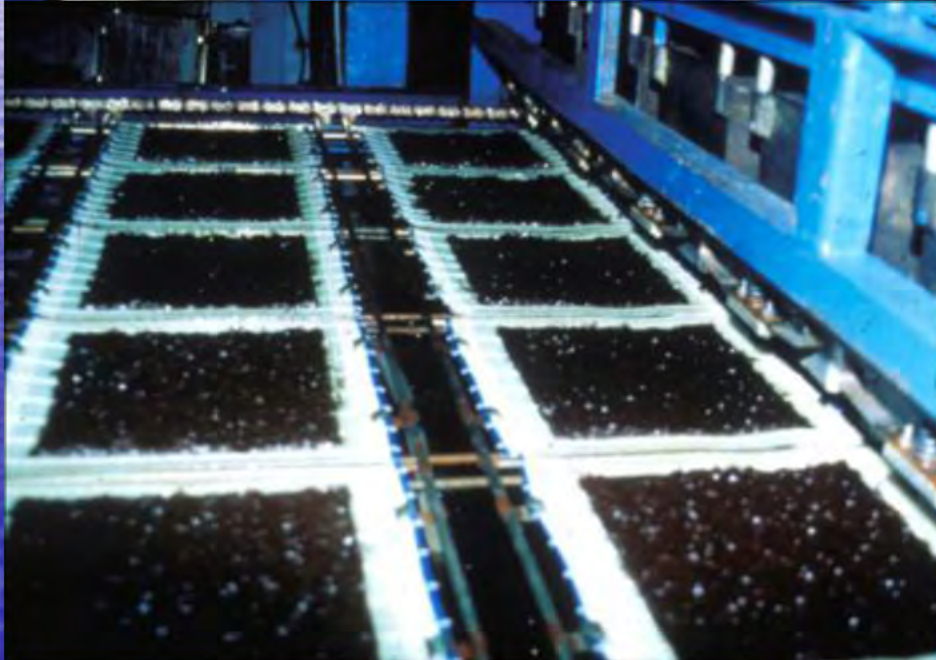


Ariake Bay, Japan

# Cultivation and harvesting of *Porphyra*



Sheet making  
machine



# Sheet-forming

Forced hot air drier



Photos: Dr A Hurtado SEAFDEC

Sheets ready to  
be roasted

# Sorting *Porphyra* sheets

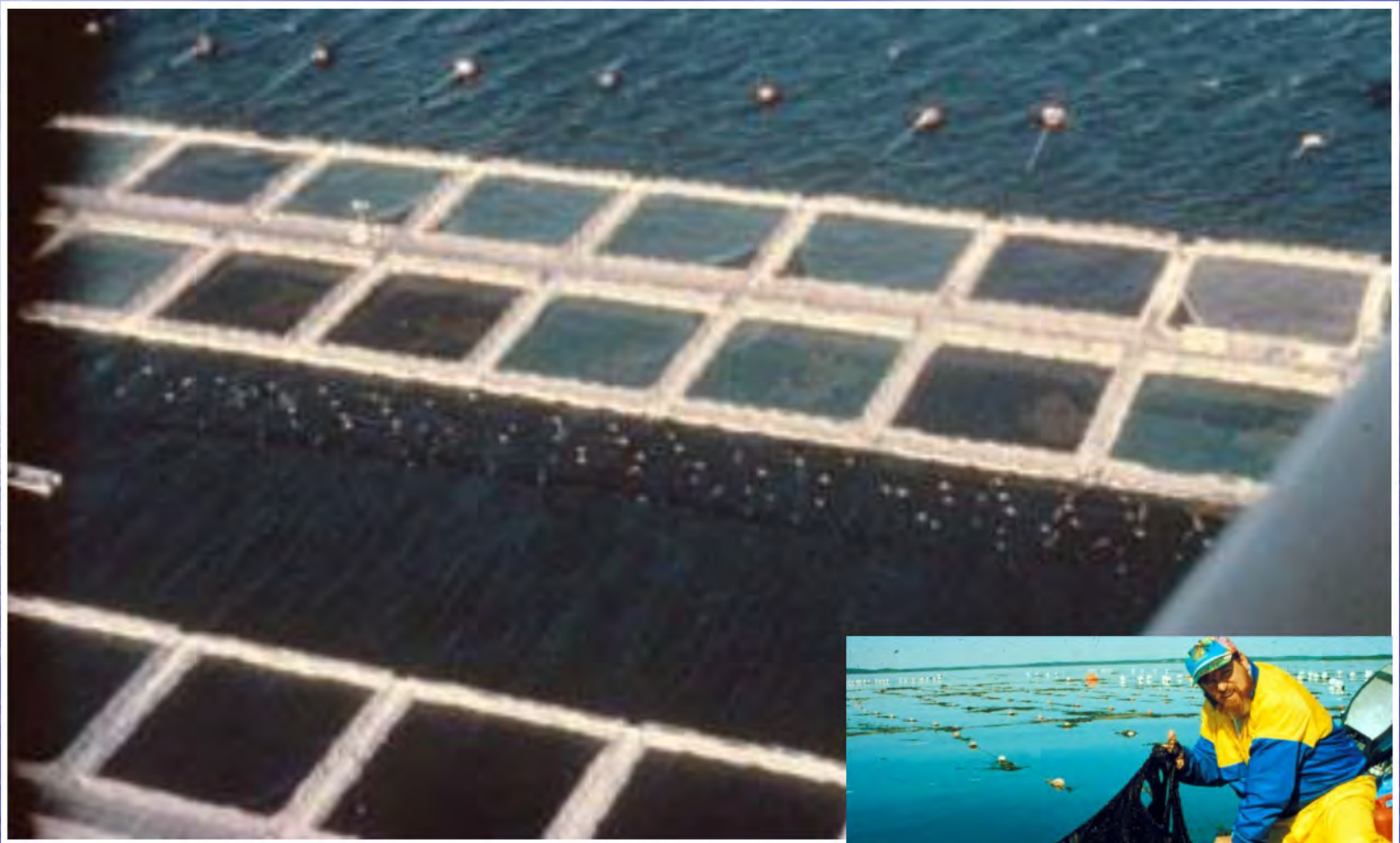


Forced hot air drier



Photos: Dr A Hurtado SEAFDEC

# *Porphyra* – Salmon (courtesy of I. Levine)



(McVey et al. 2002)

# Integrated Multi-Trophic Aquaculture (IMTA)

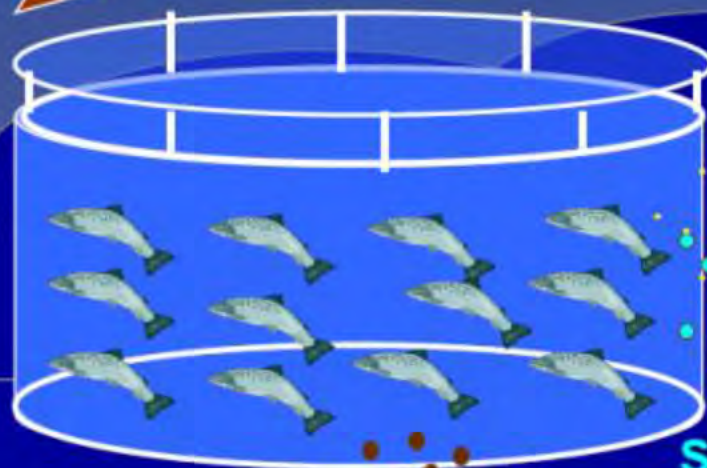
Fed Aquaculture  
(Finfish)

+

Suspension Extractive Aquaculture

Organic  
(Shellfish)

Inorganic  
(Seaweeds)



Large POM

Small  
POM

Nutrient Zone

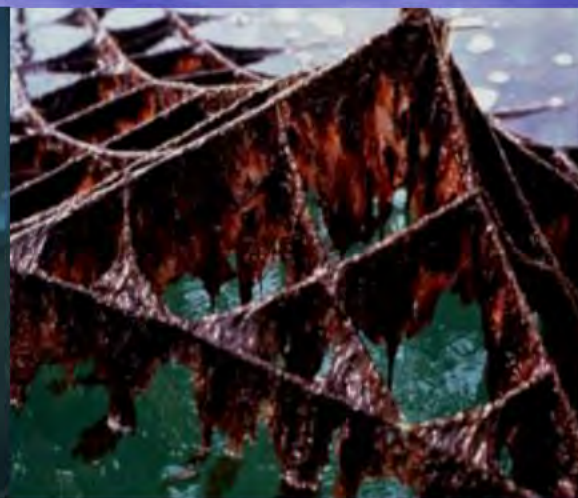
DIN

F&PF

Deposit Extractive  
Aquaculture (Invertebrates)



(Source: T. Chopin)

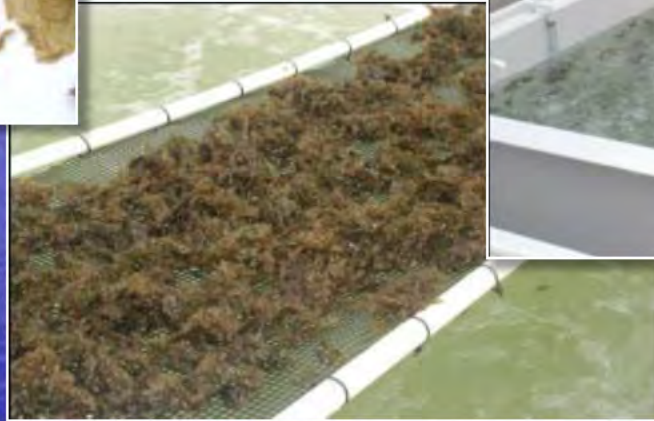
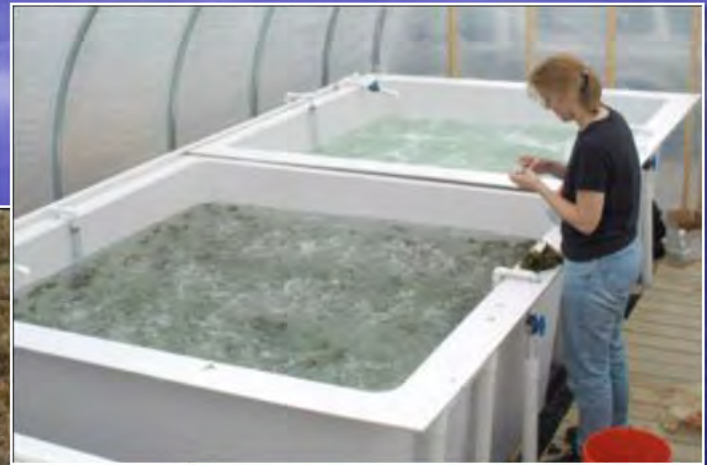


**Balanced Ecosystem Approach**  
fed aquaculture of finfish (or shrimp)  
with extractive organic aquaculture of  
shellfish and extractive inorganic  
aquaculture of seaweed (IMTA)

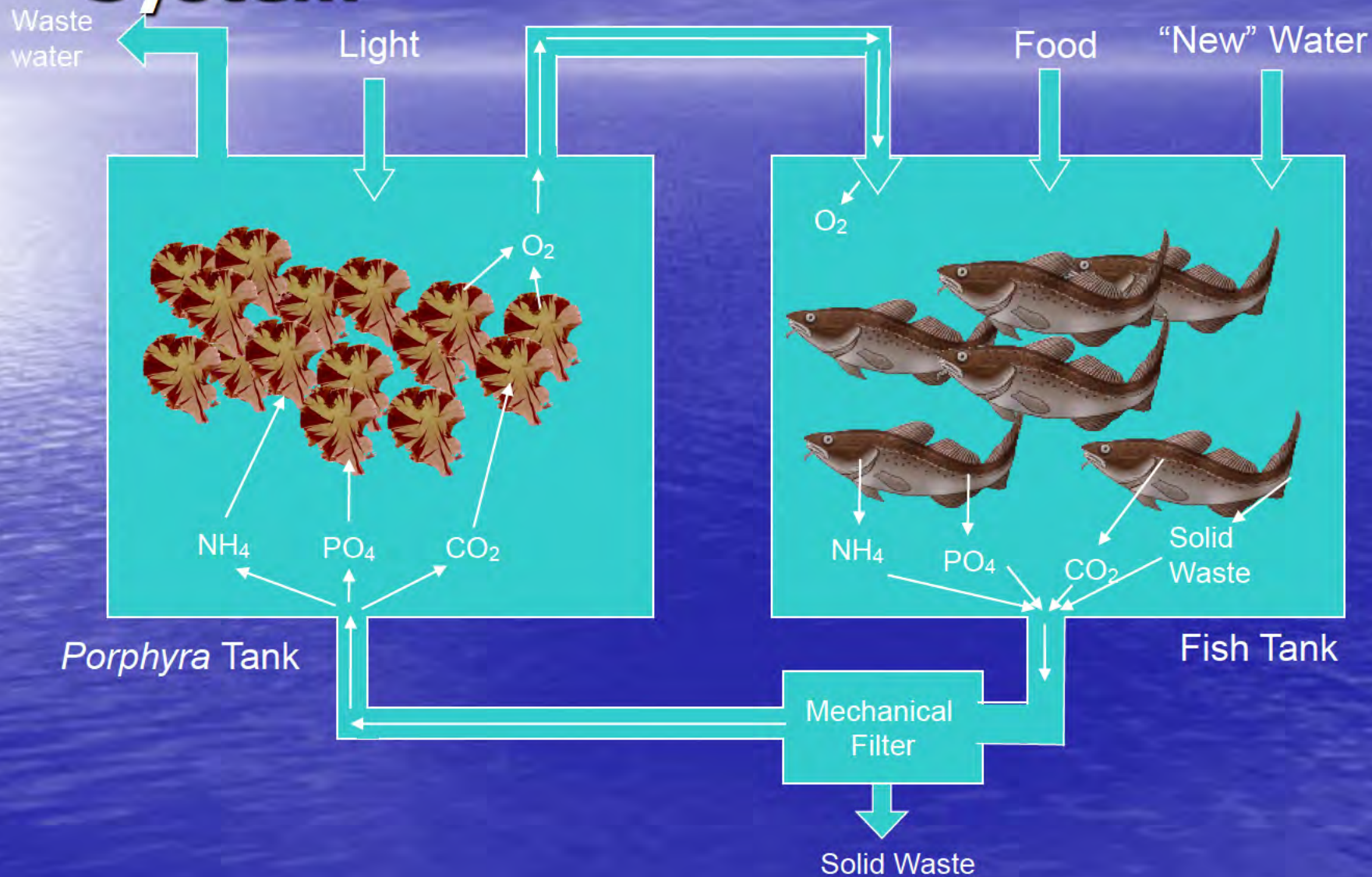


# Integrated Cod/Nori Aquaculture

UNH / Great Bay Aquaculture / Local Ocean LLC

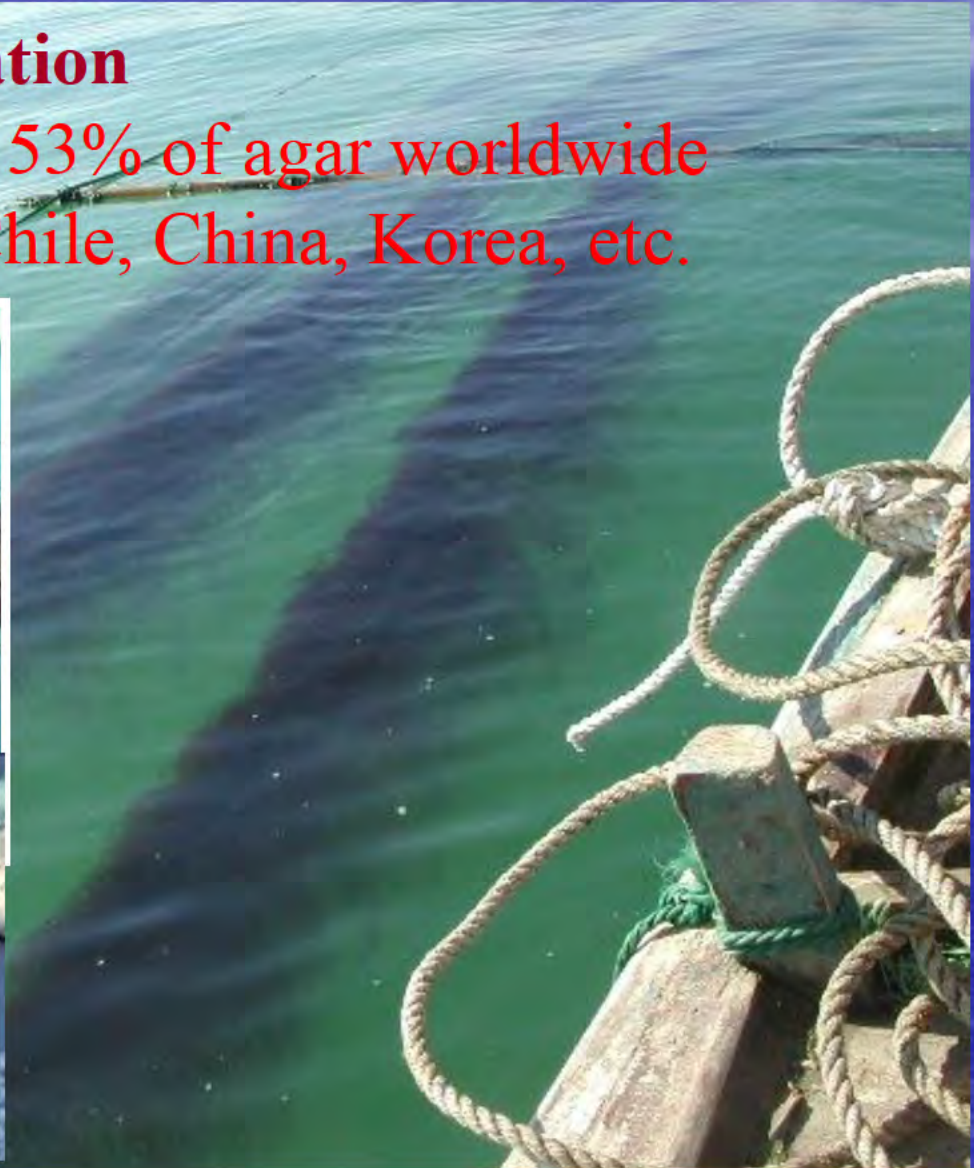


# Integrated Finfish/*Porphyra* Recirculating Aquaculture System



## *Gracilaria* Cultivation

Most production  $\approx$  53% of agar worldwide  
Grown in Brazil, Chile, China, Korea, etc.



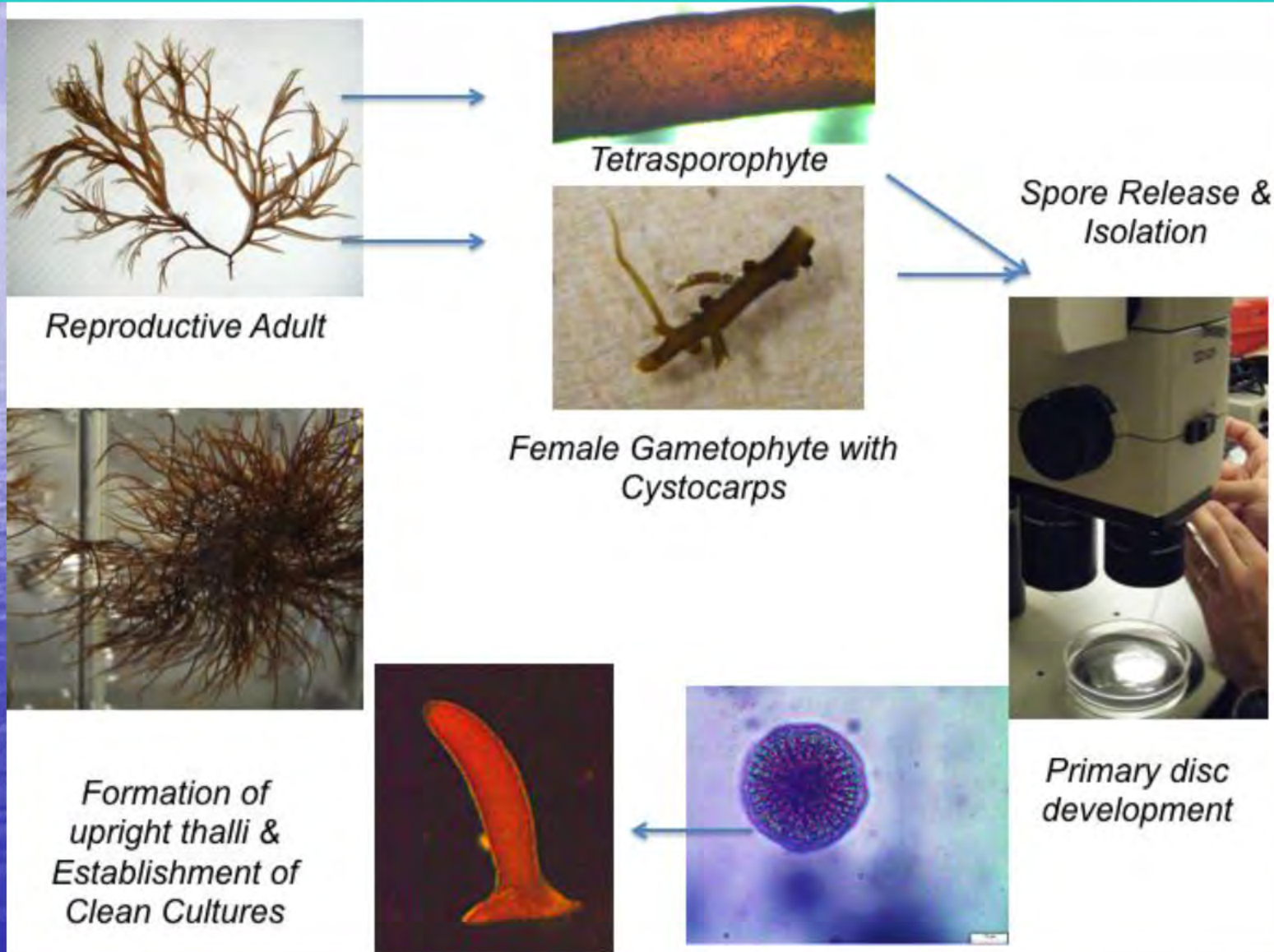
# *Gracilaria* Cultivation (Chile)



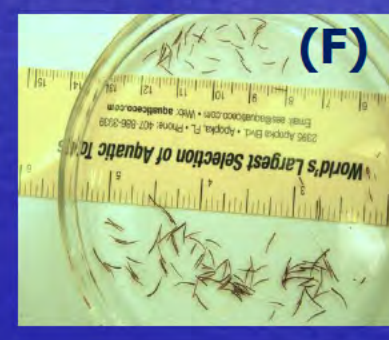
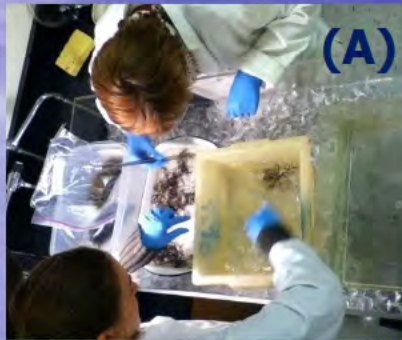
# *Gracilaria* – Harvesting (Chile)



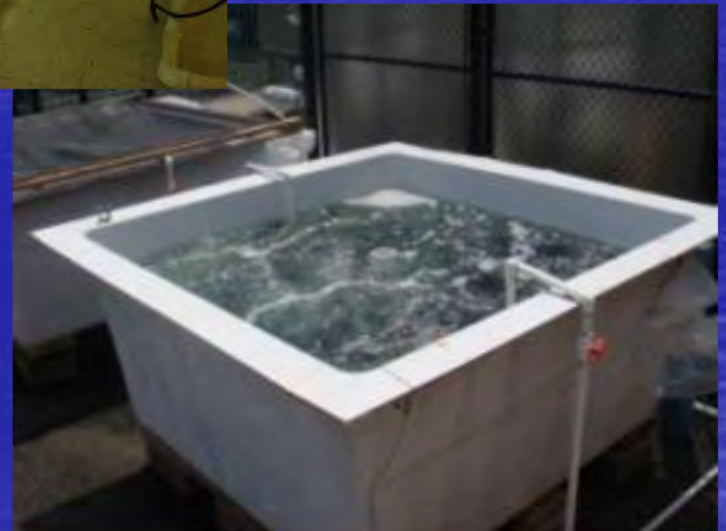
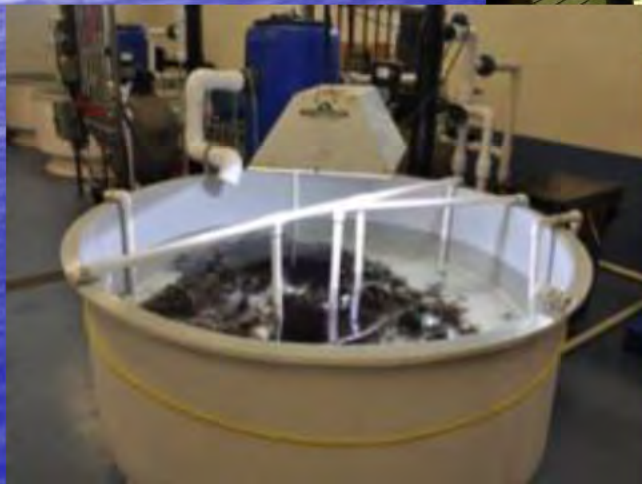
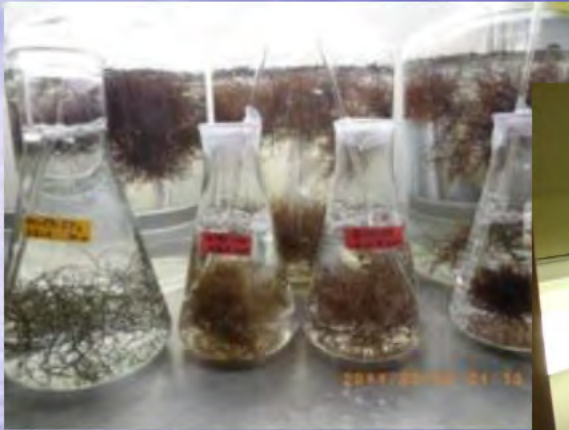
# Establishment of clean *Gracilaria* laboratory cultures - Spore Isolation



# Establishment of clean *Gracilaria* laboratory cultures - Tip Isolation



# *Gracilaria* Nursery Systems





# Gracilaria Open water cultivation trial in LIS & Bronx River



# *Gracilaria*

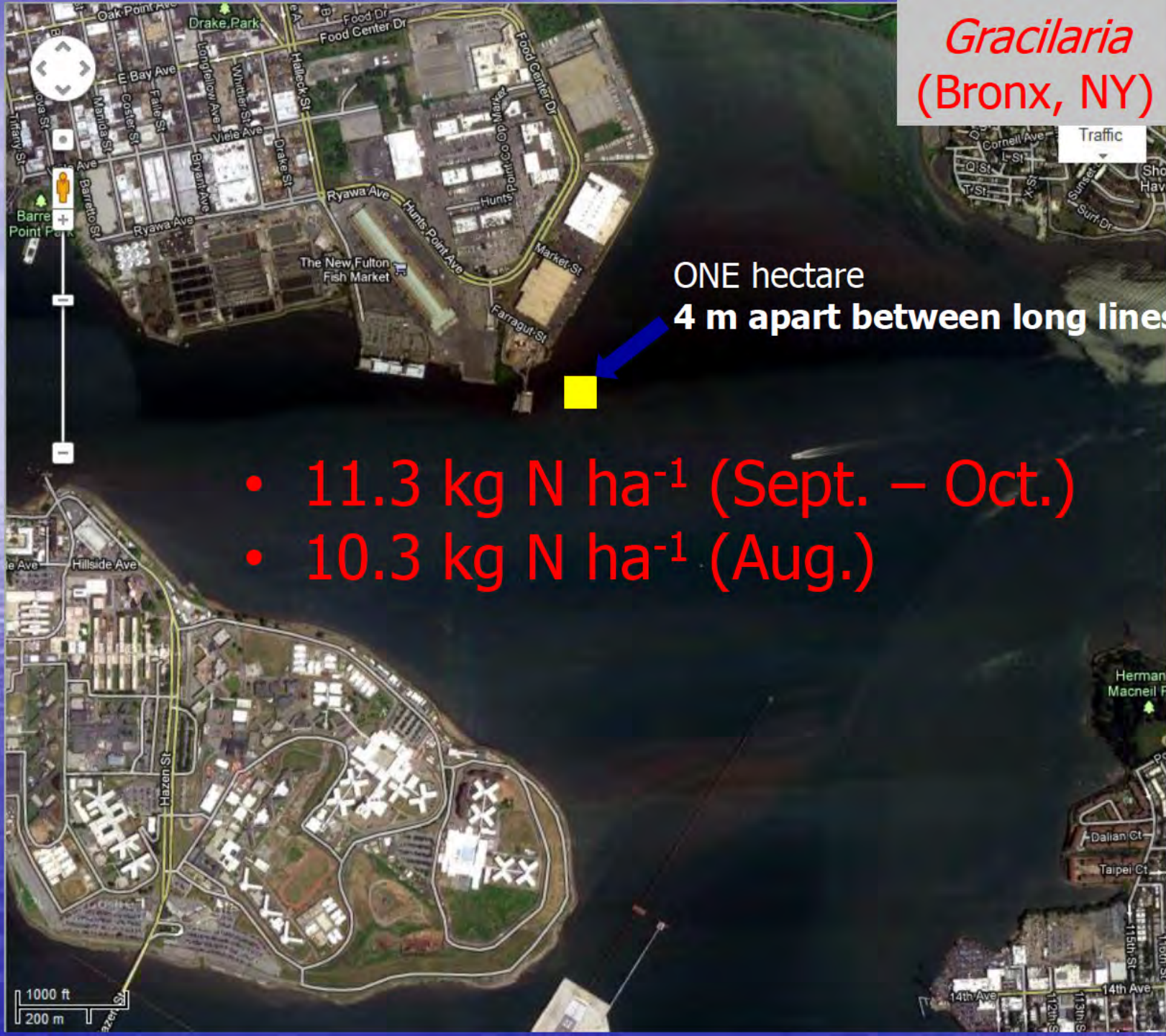
- Growing season: June – Oct. ( $> 15^{\circ}\text{C}$  or  $> 60^{\circ}\text{F}$ )
- Productivity:  $\sim 2.1\text{ kg/m/month}$  (Nutrient limited condition)  
 $\sim 12.2\text{ kg/m/month}$  (Nutrient enriched condition)



# Evaluation of the Nitrogen Removal Capacity of *Gracilaria* and kelp



# *Gracilaria* (Bronx, NY)



ONE hectare  
4 m apart between long lines

- 11.3 kg N ha<sup>-1</sup> (Sept. – Oct.)
- 10.3 kg N ha<sup>-1</sup> (Aug.)

*Gracilaria*  
(LIS, CT)



Map  
Traffic

$\sim 7.8 \text{ kg N ha}^{-1}$   
(August - October)

■ ← ONE hectare  
4 m apart between long lines



## **What's Next in Coastal Management? Bioextraction technologies that move towards a balanced ecosystem approach**

In nutrient rich coastal waters we can use extractive organic aquaculture of shellfish and extractive inorganic aquaculture of seaweed to provide invaluable ecosystem services!

# Acknowledgments

Support for many of our aquaculture projects had been provided by through the Connecticut, New Hampshire and Rhode Island Sea Grant College Programs, the National Marine Aquaculture Initiative, and the International Programs Office of NOAA's OAR; NOAA's SBIR Program; State of Connecticut Critical Technologies Program; Long Island Sound Futures Fund (EPA), National Fish & Wildlife Foundation; to M.H. Abreu (Portugal), A. Buschmann (Chile), S.H. Brawley (U.S.), I.K. Chung (Korea), B. Costa-Pierce (U.S.), J. Curtis (U.S.), M. Dring (U.K.), X.G. Fei (China), P. He (China), G. Kraemer (U.S.), J.A. Lee (Korea), I. Levine (U.S.), J.P. McVey (U.S.), A. Neori (Israel), R. Pereira (Portugal), M. Rawson (U.S.), Y.F. Yang (China), & J. Zertuche (Mexico) for their invaluable discussions.

