THE BIOREMEDIATION POTENTIAL OF ECONOMICALLY IMPORTANT SEAWEED IN INTEGRATED AQUACULTURE SYSTEMS WITH FINFISH

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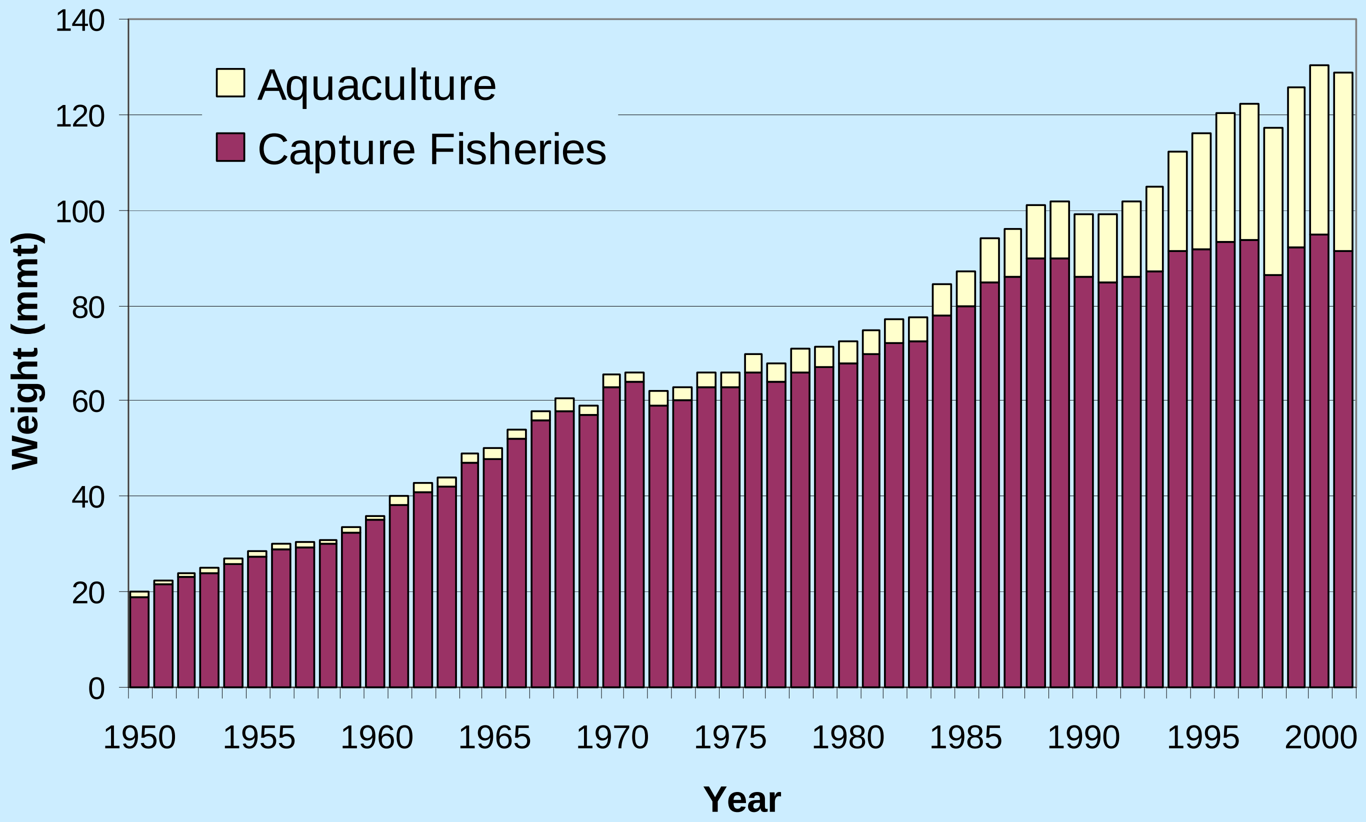
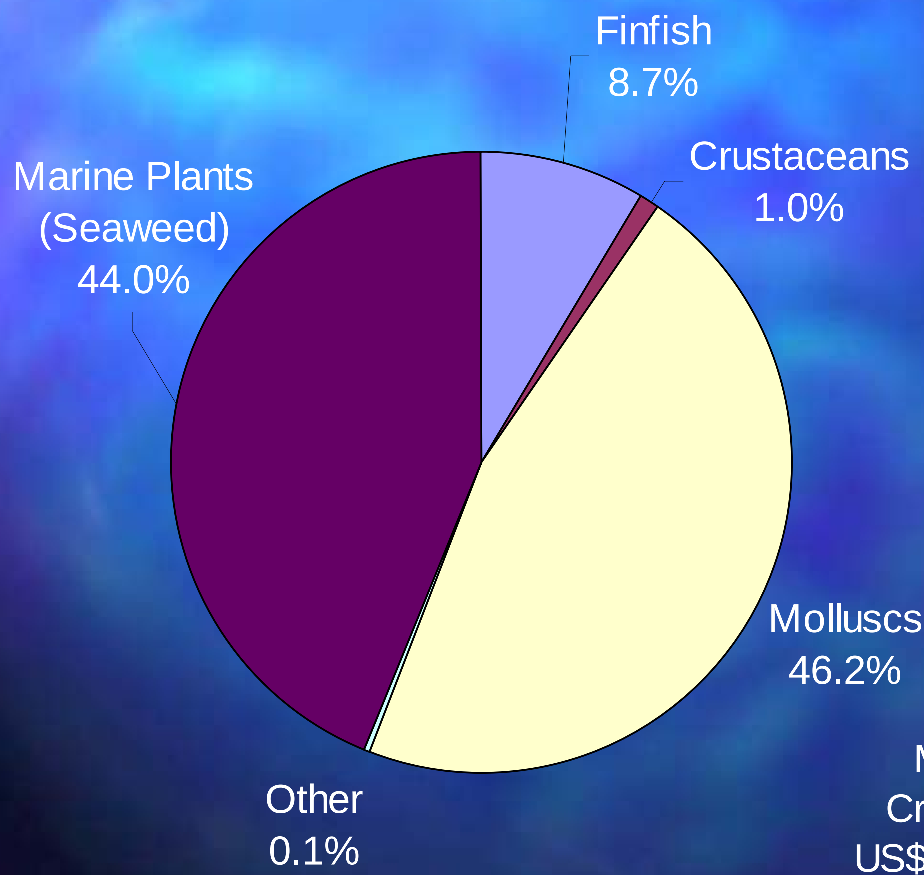
World Capture Fisheries and Aquaculture Production



Source: FAO, The State of World Fisheries and Aquaculture 2000, 2003

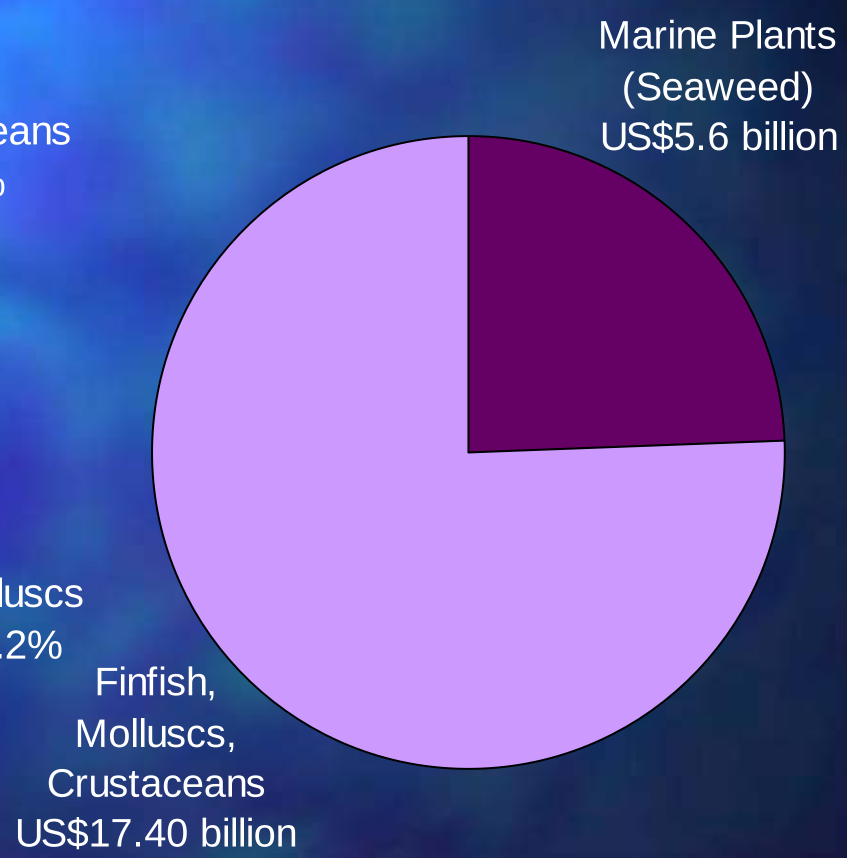
Marine Aquaculture by Species Group

Production by Weight



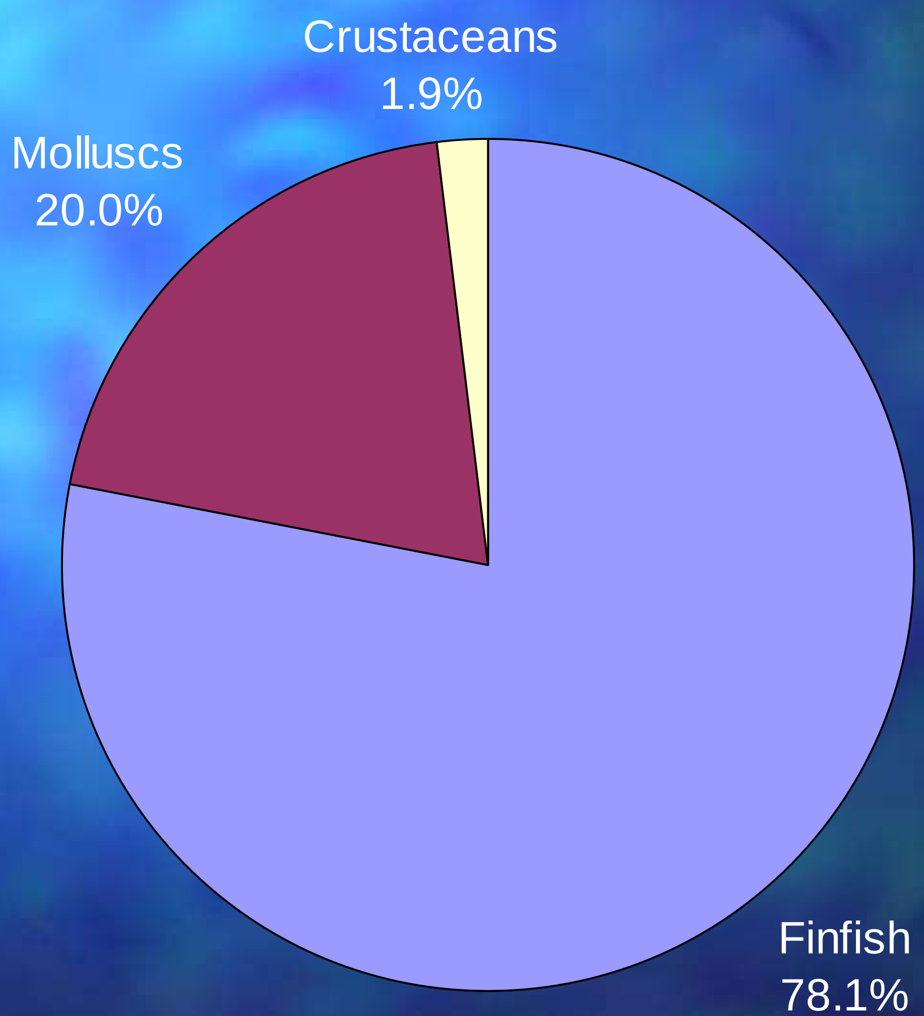
Economic Value

($US Billion)



Source: FAO, The State of World Fisheries and Aquaculture 2002

North American Aquaculture



Source: FAO, Review of the State of World Aquaculture 2003

Finfish Mariculture in the Northeast

- Coastal and Off-shore Pens
    - Salmon, Cod, Summer Flounder, Halibut
- Coastal On-shore Tanks
    - – Hatchery, Nursery
        - Cod, Summer Flounder, Halibut, Black Sea Bass, Striped Bass Hybrid
    - – Grow-out
        - Summer Flounder, Black Sea Bass, Striped Bass Hybrid

Obstacles to the Growth of Marine Aquaculture in the U.S.

- Coastal zone use conflicts
- Permit, licensing, lease application processes
- Compliance with environmental regulations
  - EPA, Clean Water Act
    - Lack cost-effective technology for management of effluent and solid wastes

Finfish Aquaculture Waste Production

- Solid wastes
  - Uneaten Food
  - Feces
- Dissolved Metabolic Wastes
  - CO_2
  - NH_4
  - PO_4

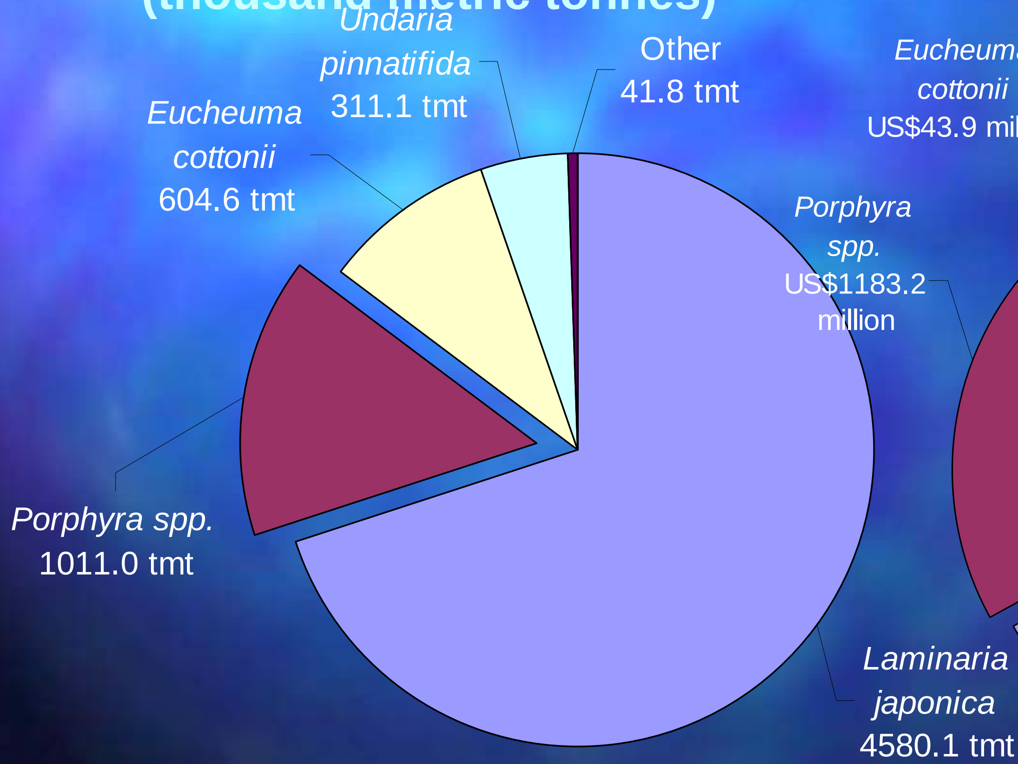
Green tides near finfish aquaculture

The green alga *Ulva lactuca* completely covering rocky intertidal

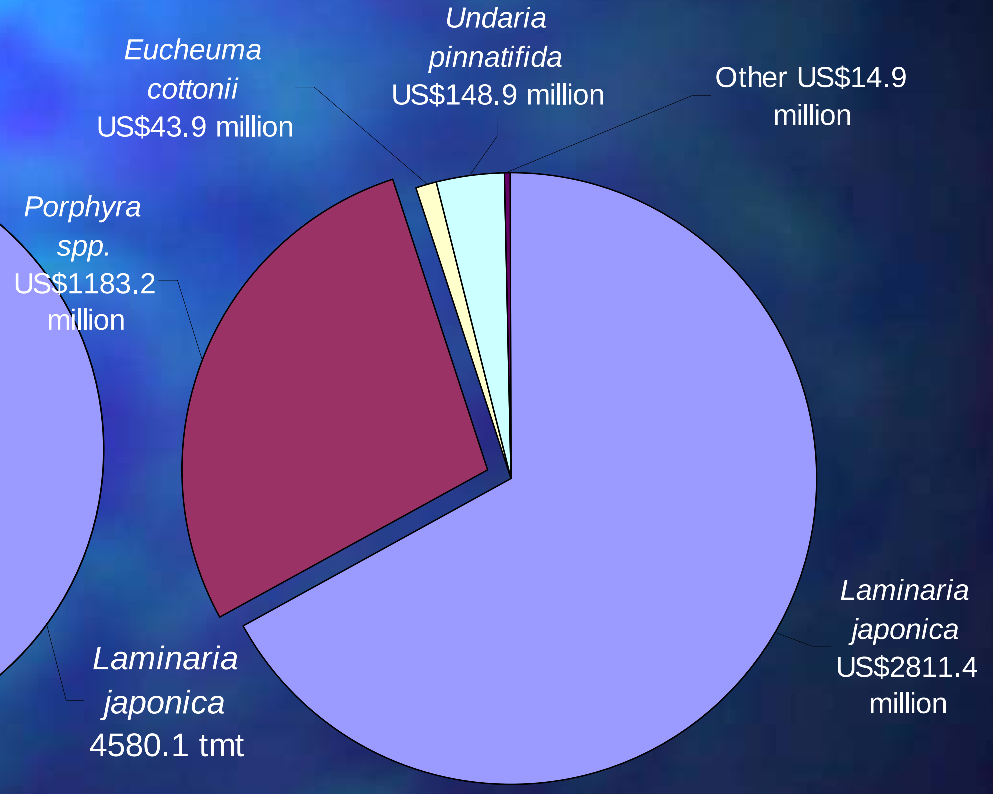
How do we increase aquaculture production without exacerbating nutrient loading of coastal waters?

Seaweed Aquaculture

Production by Weight
(thousand metric tonnes)



Economic Value
($US Million)



Source: FAO, Review of the State of World Aquaculture 2003

Table-1. World wide Economic Value of Seaweeds Used for Industrial Consumption

Product	Value (10^6 US$)	Raw material (mt)	Raw material (UA $/mt)	Product (mt)	Product (US $/mt)
Carrageenan	~270	400,000	600	~25,000	9,600
Alginate	~213	460,000	459	~23,000	9,174
Agar	~132	125,000	1056	~7,500	17,600
Soil Additives	~ 30	550,000	18	~510,000	20
Fertilizer	~ 10	10,000	500	~1,000	500
Seaweed Meal	~ 10	50,000	100	~10,000	5,000
Pharmaceuticals, nutraceuticals, botanicals, pigments, bioactive compounds	~ 3	3,000	?	600	?
Total	665	1,598,000		~577,100	

Source: Hanisak (1998); Porse (1998); Zemke & Ohn (1999); FAO 2000; Chopin et al. 2001; and McHugh (2001)

Balanced ecosystem approach

- fed aquaculture of finfish with extractive organic aquaculture of shellfish and extractive inorganic aquaculture of seaweed

Integrated Culture Examples

- Israel: Sea bream + *Ulva*; abalone + fish + *Ulva*; abalone + fish + mollusc + *Ulva*
- Chile: seaweed biofilter - *Gracilaria* + turbot; *Macrocystis* + salmon
- China: Shrimp + crab + seaweeds; mussel + scallop + *Laminaria*/ *Undaria*; fish + *Gracilaria*; fish + seagrass + *Kappaphycus*
- France: sewage treatment system- *Ulva*
- Hawaii (USA): shrimp + *Gracilaria*
- Japan: shrimp + *Ulva* + ???
- Maine (USA): salmon + *Porphyra*
- Norway: salmon + mussel + *Laminaria*
- Philippine (with Norway): sea urchin / sea cucumber + *Eucheuma*/ *Gracilaria*
- Portugal: seaweed biofilter – *Asparagopsis* + *Seabream*
- South Africa: finfish aquaculture effluent + *Gracilaria*
- Southeast Asia: shrimp + seaweeds (primarily *Gracilaria*) Australia: shrimp + oyster + *Gracilaria*

(modified, in part, from Ik Kyo Chung)

Cultivation & harvesting of *Porphyra* (courtesy of M. Notoya & C.H. Sohn)

Porphyra species

- Simple, flat sheet gametophyte
  (high SA/V)

- 1-2 cell layers: all productive

- fast growth (up to 24% d^{-1})

- high nutrient accumulation
  (possibility of 6-8% N DW)

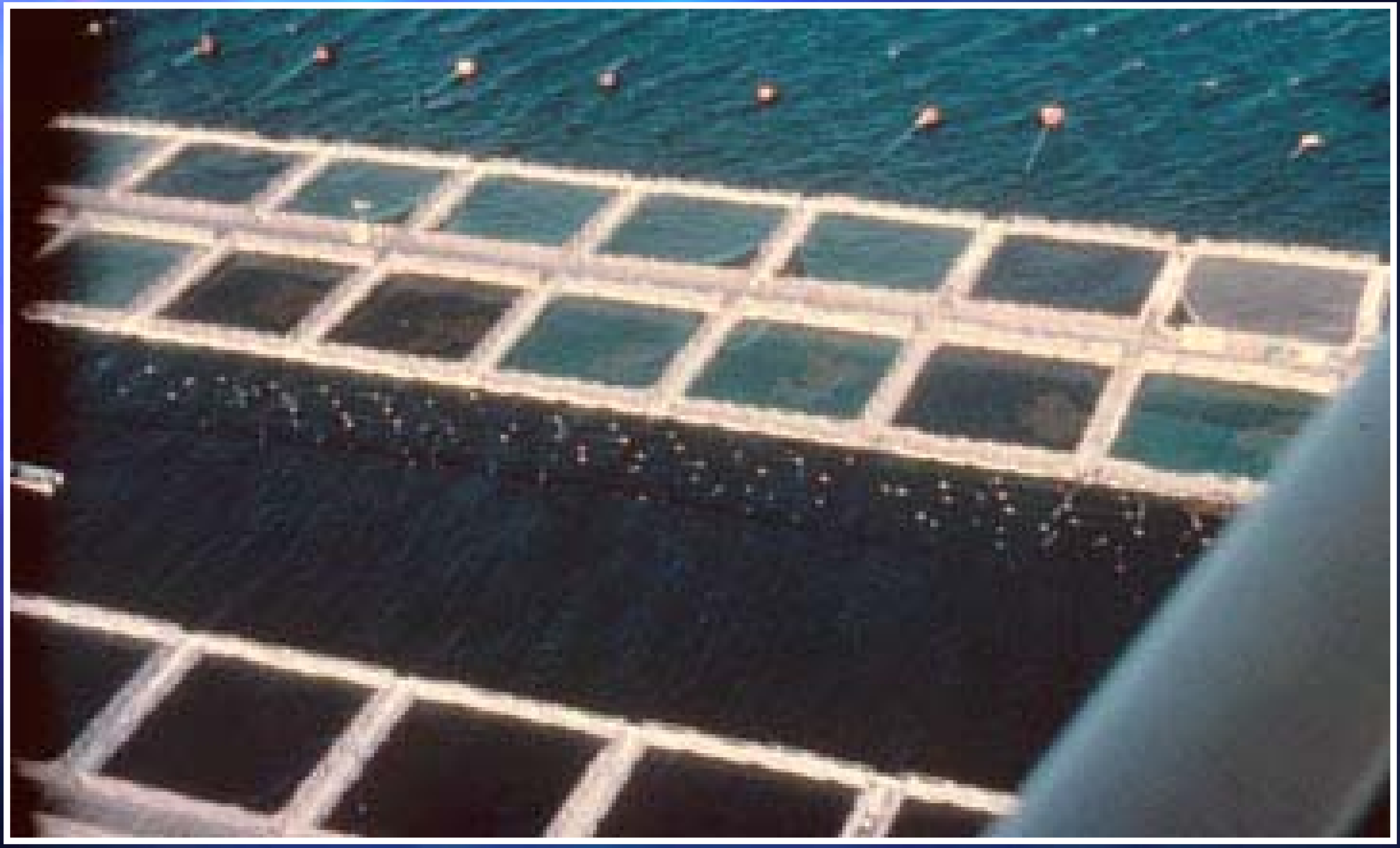
- high protein content (up to 50% DW)

- salable harvest (nori, high-value r-phycoerythrin, source of Omega-3 & 6 fatty acids, several aa, feed additives, MAAs, vitamin C and mineral salts)

(Courtesy of X.G. Fei)

High vs Low Nutrients

Porphyra – Salmon (courtesy I. Levine)



Balanced Ecosystem Approach

- *Ackefors* (1999, pers. comm.)
  - 7.0 kg of P and 49.3 kg of N released into the water column per ton of fish per year
  - How many ***Porphyra*** nets are necessary for the bioremediation of this nutrification of coastal waters?
    - **27 nets for P**
    - **22 nets for N** (McVey *et al.* 2002)
      - Reduction in biodiversity
  - Toxic to fish in tank culture
    - NH_4 -> NH_3 (toxic to fish)
      - Conversion to NH_3 is pH dependent

Biomass production and nutrient removal of *Porphyra* within 3-6 months in China
(courtesy of X.G. Fei)

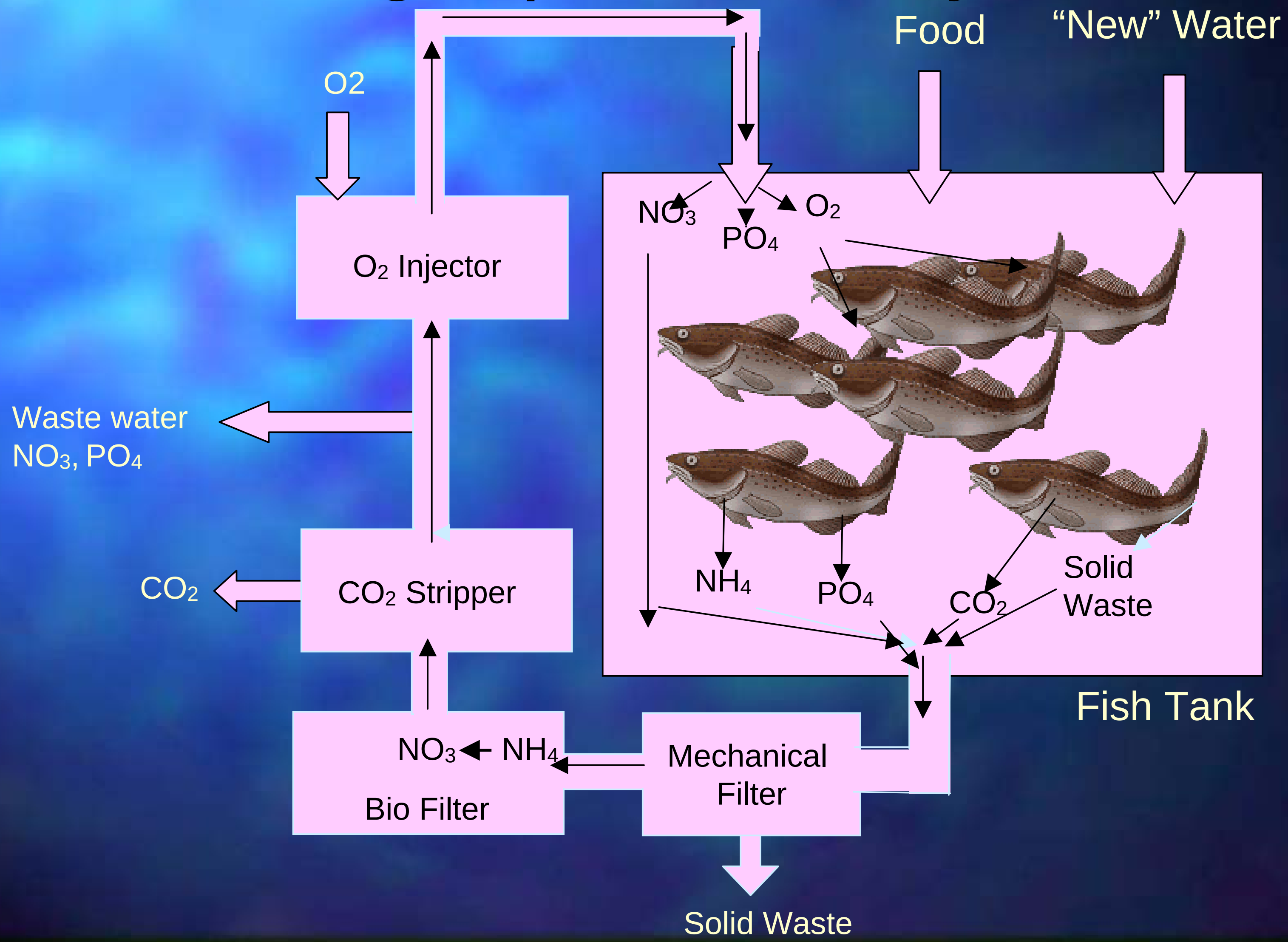
30 -- --- 60 wt /ha

N (6.20%)	1.86	3.72
P (0.58%)	0.17	0.35

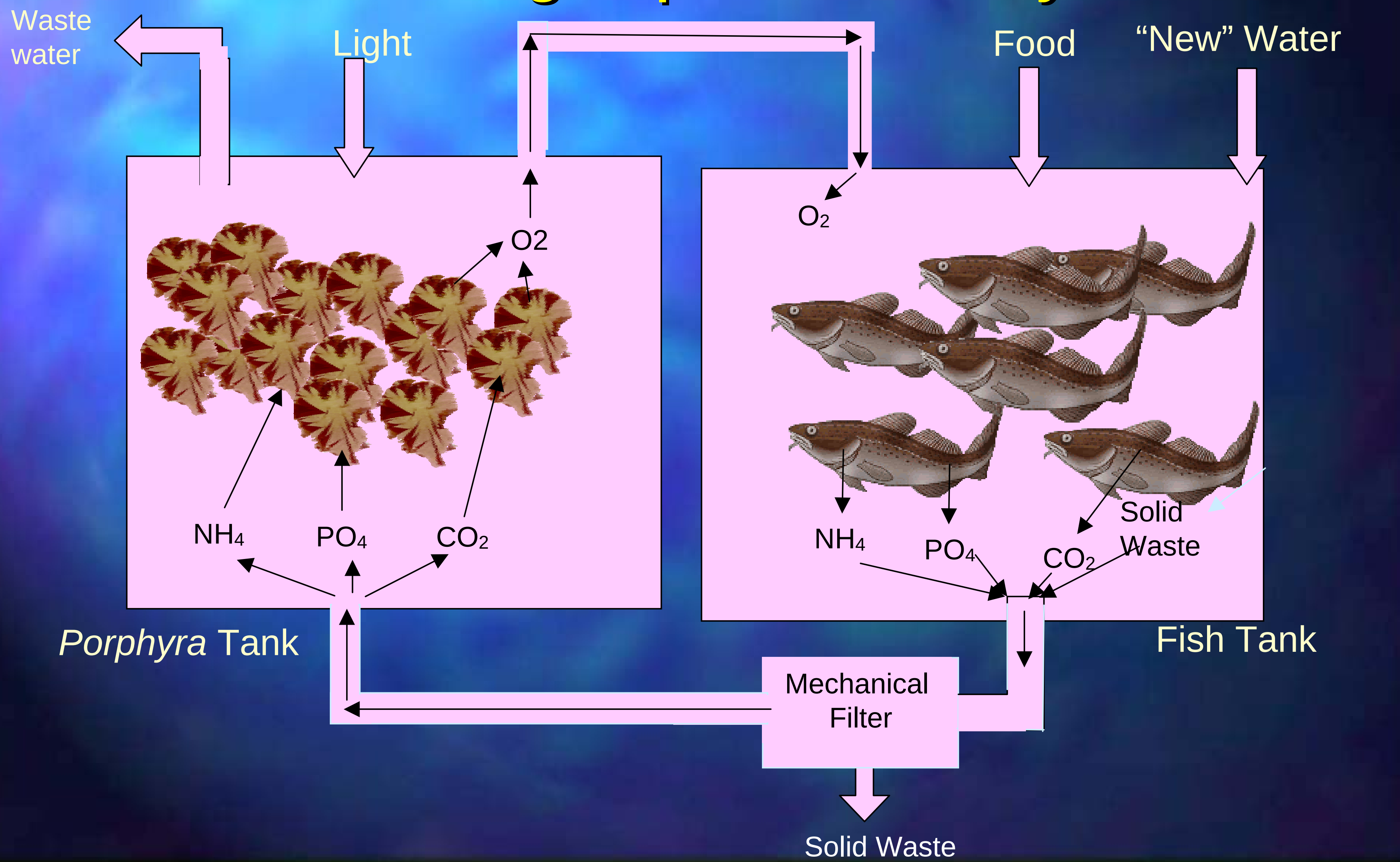
Integrated Aquaculture Project

- International, multi-institutional effort
  - UConn, UNH, SUNY, UNB, Great Bay Aquaculture, BRVAS, visiting scientists from China, Korea, Mexico
- Funding through NOAA OAR
  - Sea Grant (CT, NH, NY), NMAI, & International Programs Office
- Current Goal: Develop Modular Integrated Recirculating Aquaculture System (MIRAS)
  - Cod, Summer Flounder, Black Sea Bass
  - Native *Porphyra* species
- Application
  - Hatcheries, nurseries, tank-based grow-out operations
    - Great Bay Aquaculture
  - Urban aquaculture

Conventional Finfish Recirculating Aquaculture System



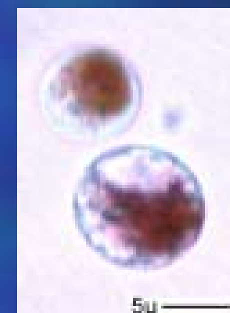
Integrated Finfish/*Porphyra* Recirculating Aquaculture System



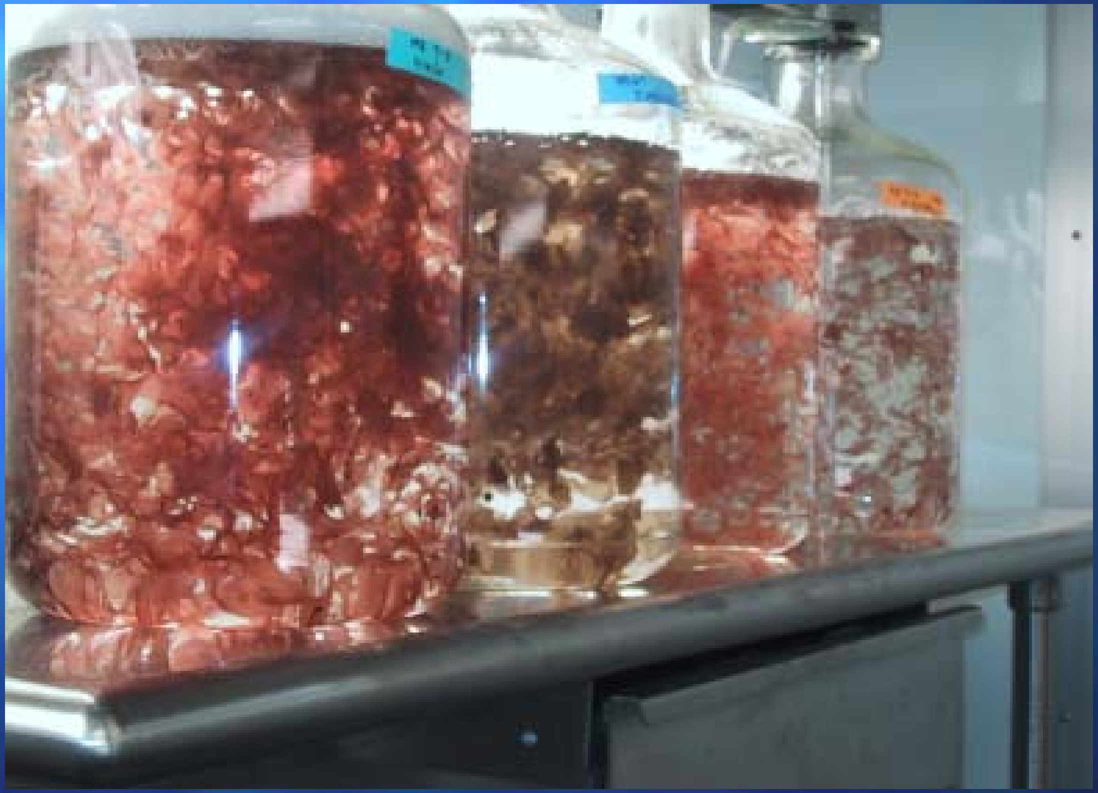
Integrated Aquaculture Project

- *Porphyra*
  - ➢ Collect, identify, and initiate cultures from native species of *Porphyra*
  - – Determine optimum conditions for growth, nutrient uptake, and pigment production
    - ■ Temperature, Light, Nutrients, Stocking Density
      - – Determine growth rates
      - – Determine nutrient uptake rates
      - – Determine pigment production rates
  - – Develop mass culture techniques
    - ■ Production of sporlings
    - ■ Grow-out of blades

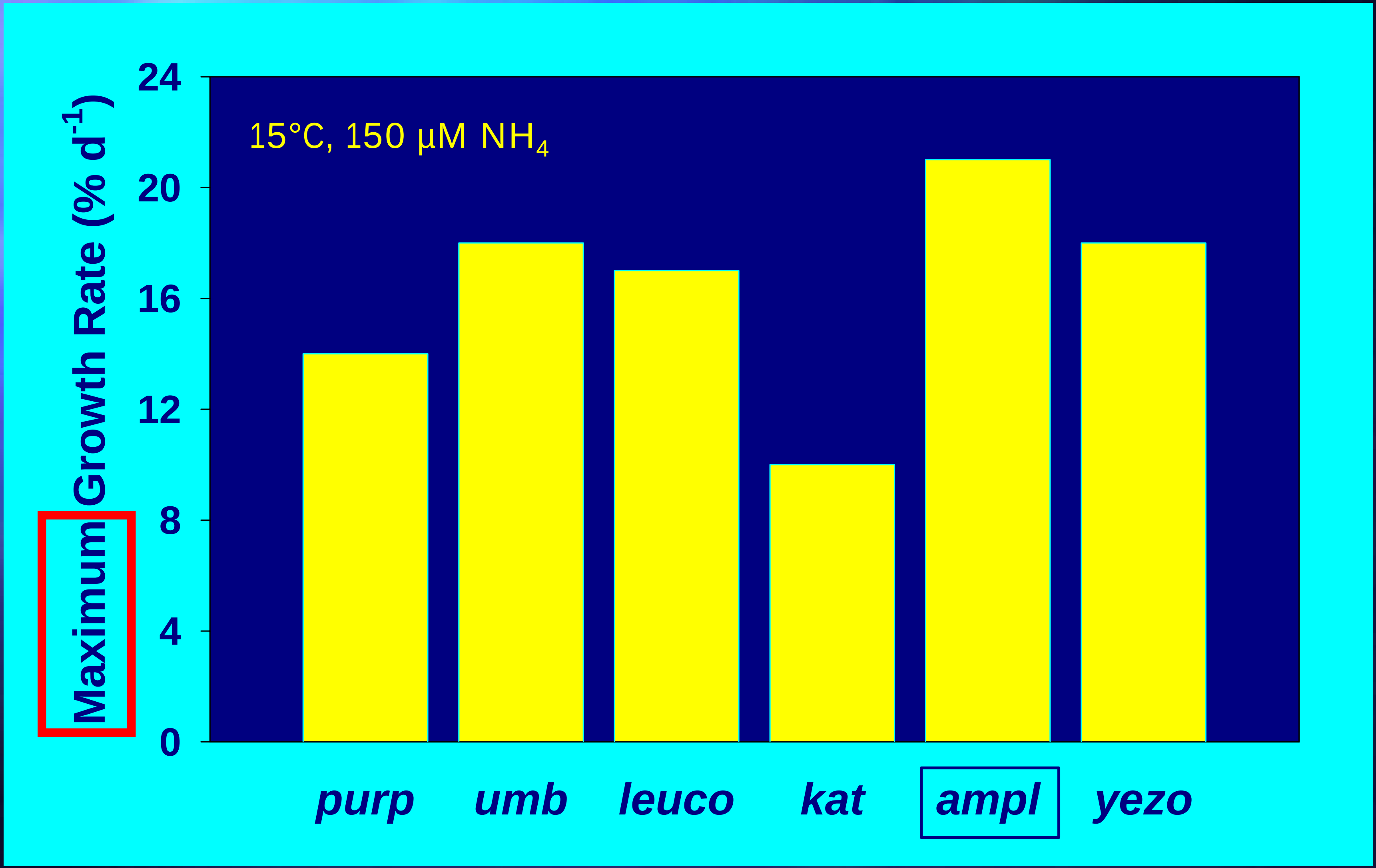
Collect, Identify and Initiate Cultures from native species of *Porphyra*



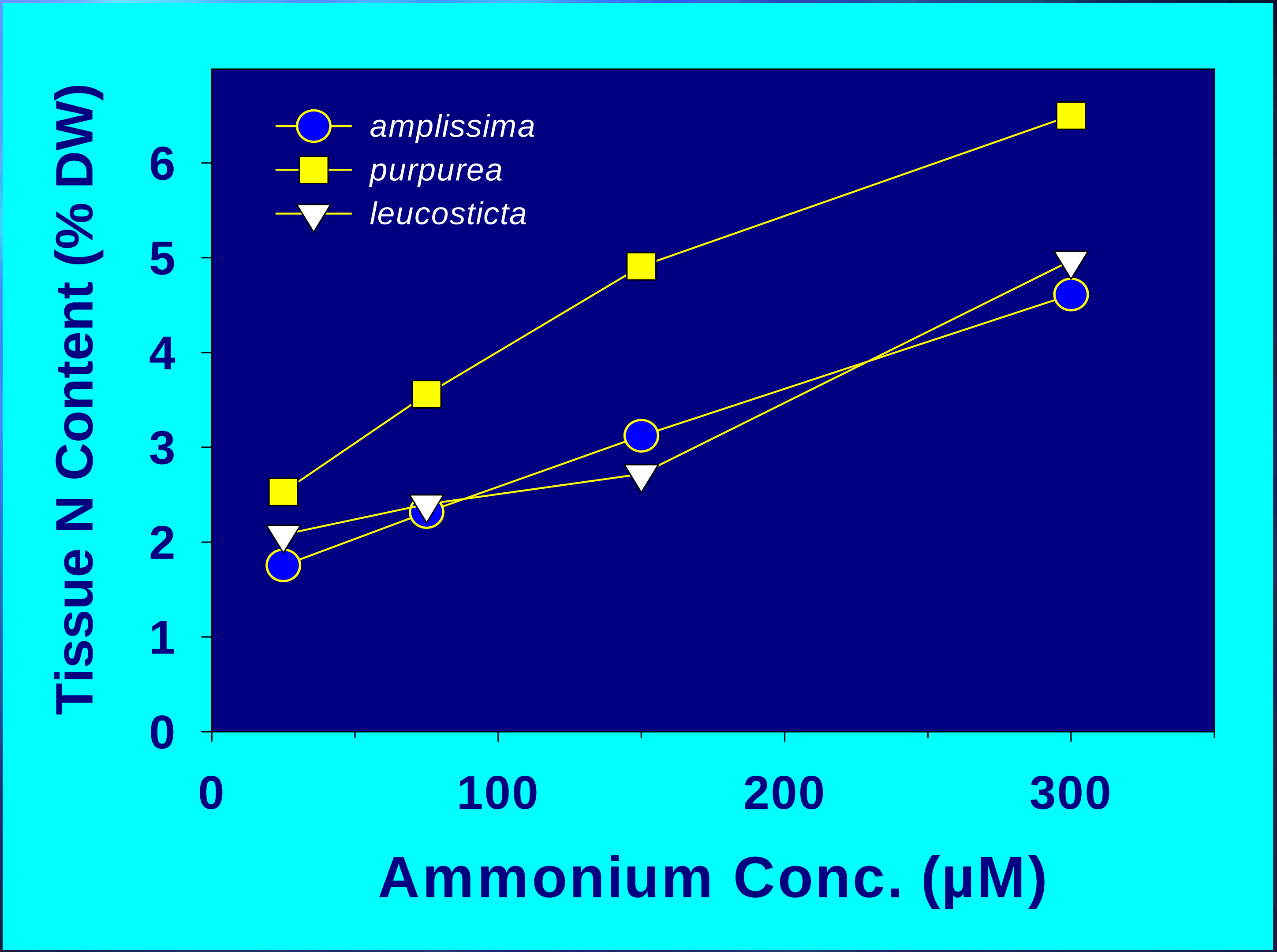
Develop mass culture techniques



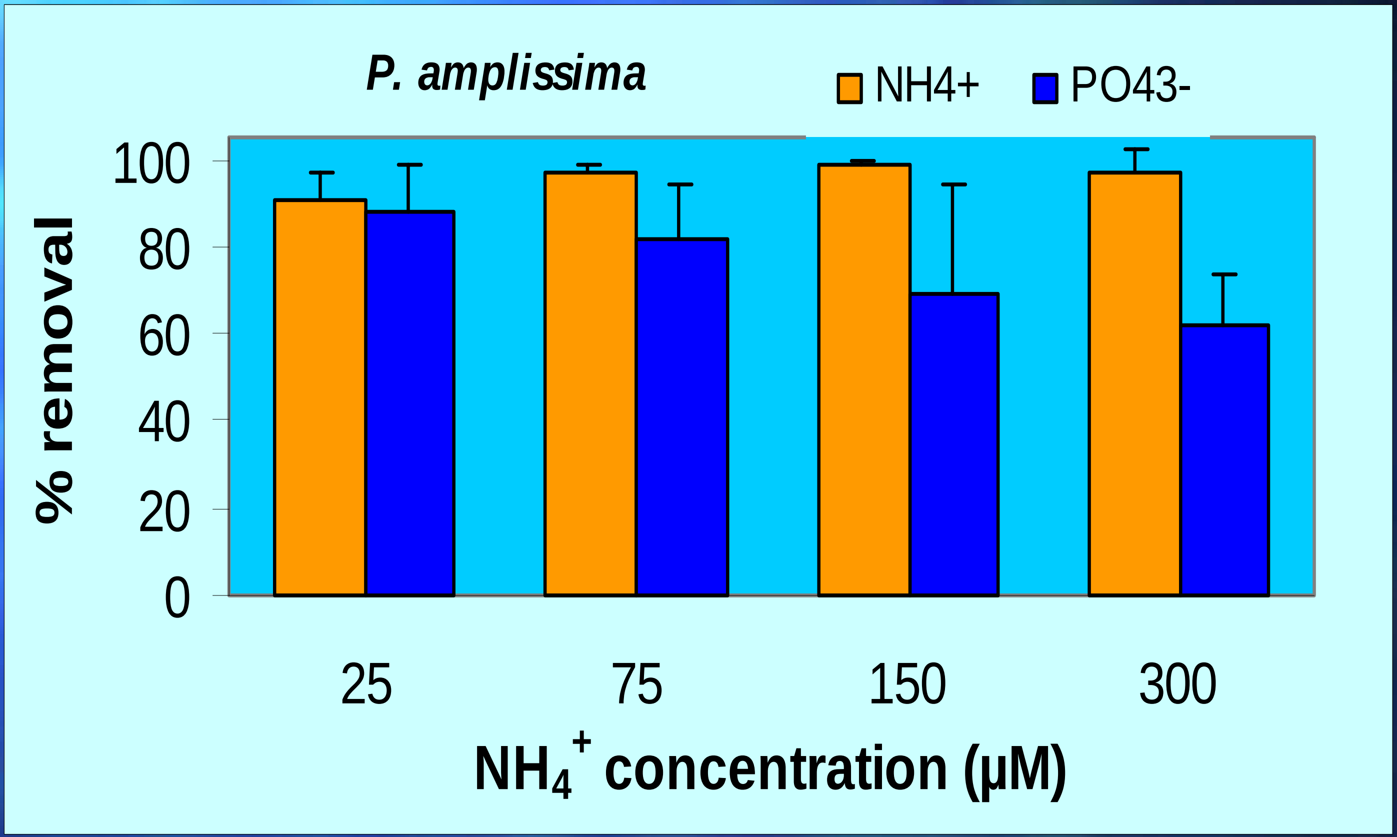
Long Term Results: Growth Rate



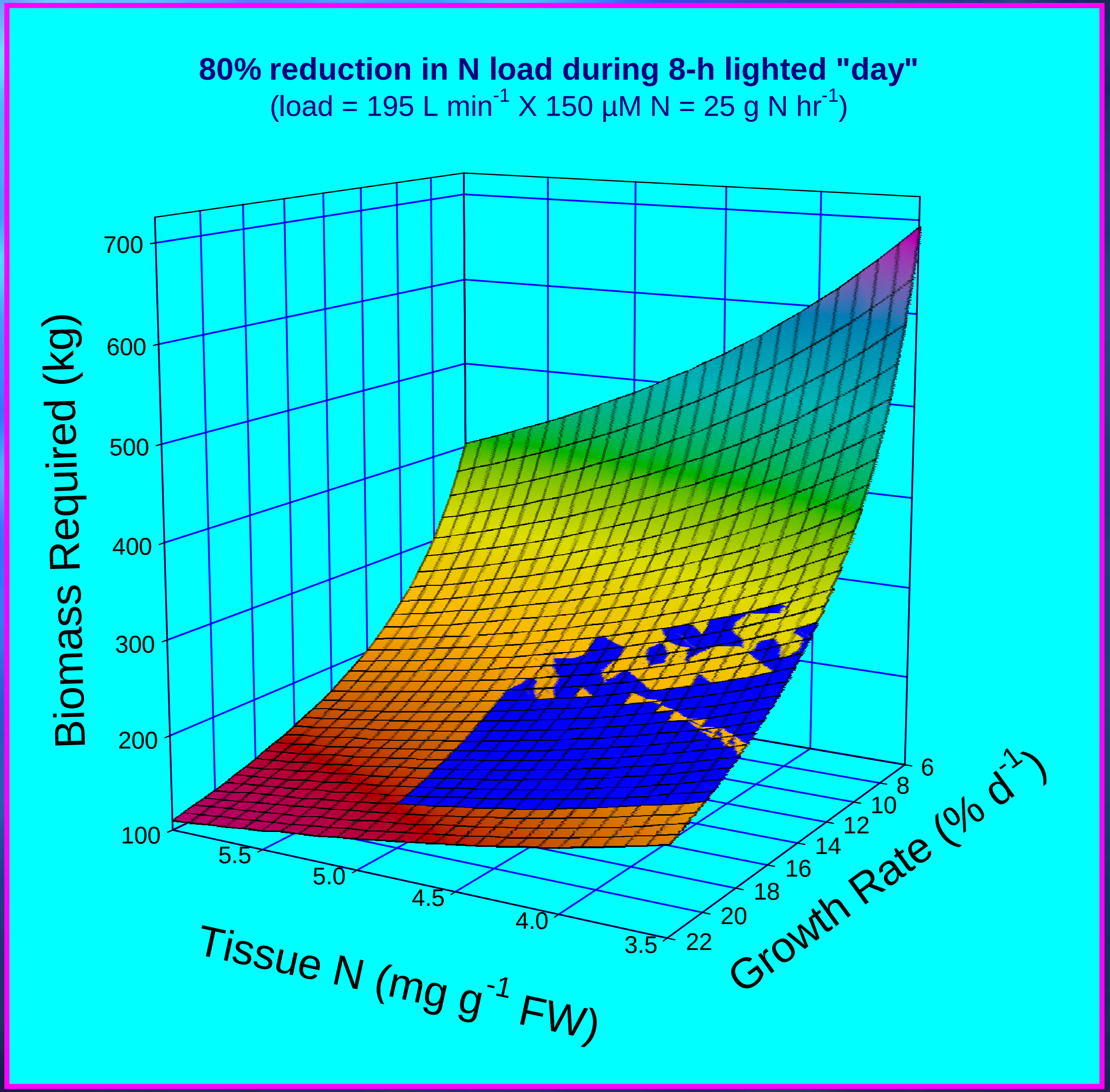
Long Term Results: Tissue N



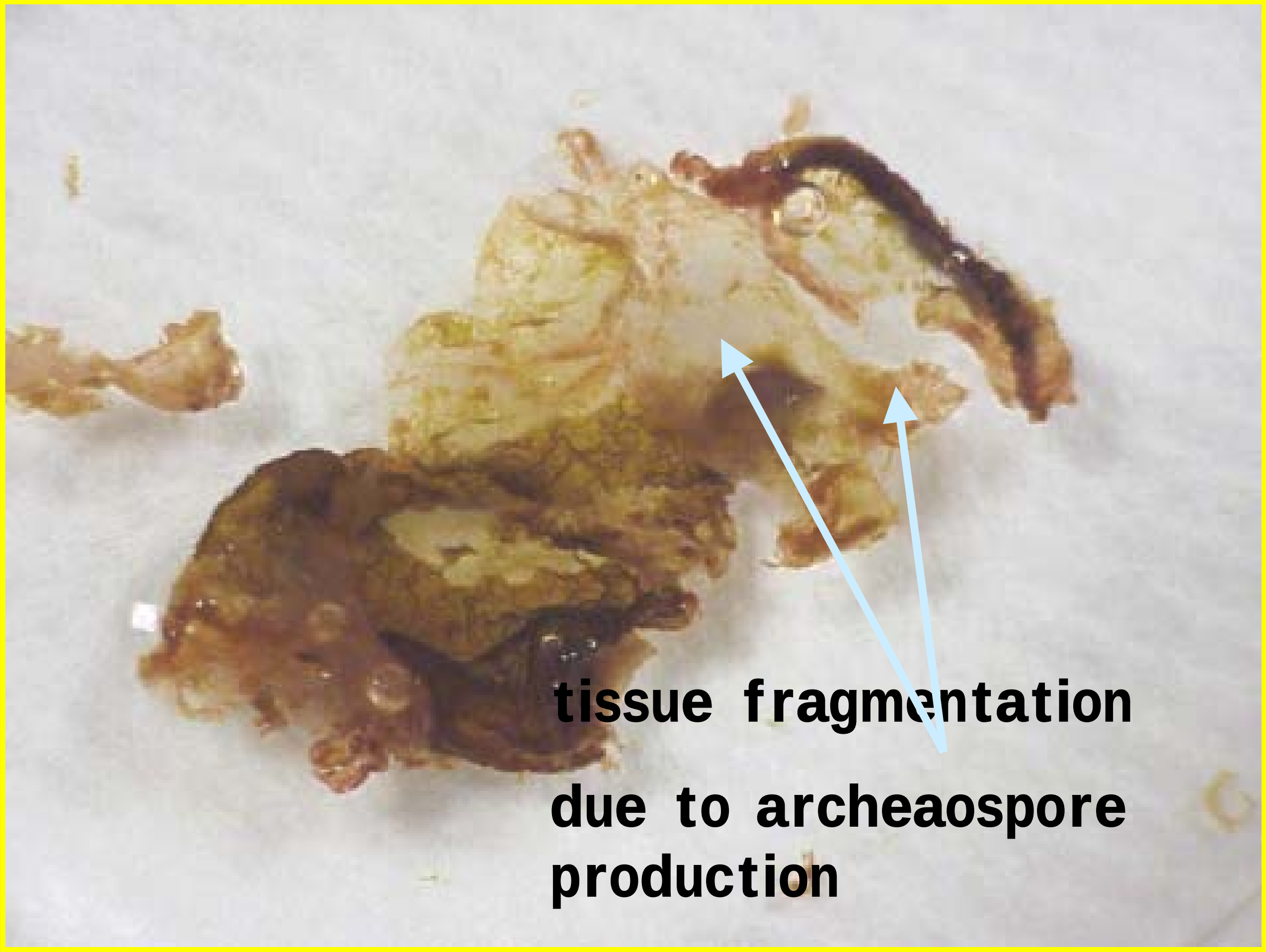
Long Term Results: Bioremediation (3.5 day batch)



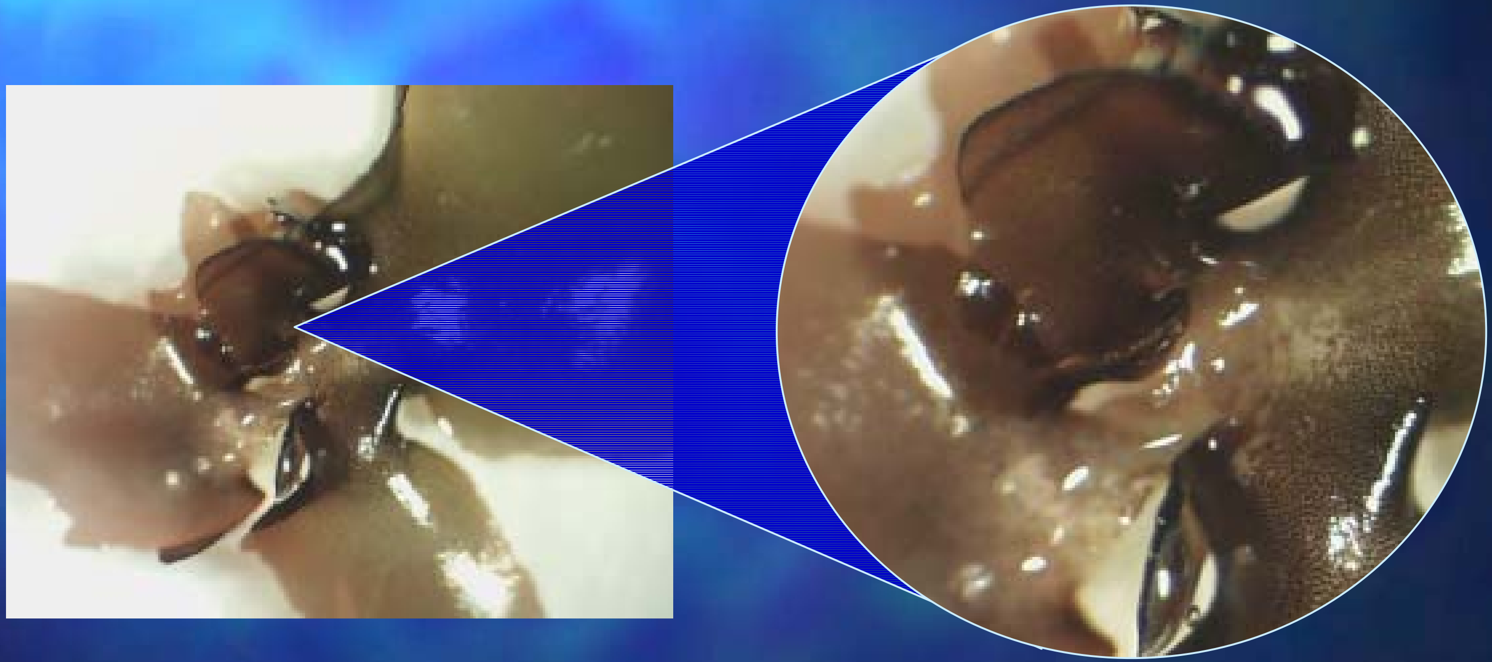
Long Term Results: Requirements for Bioremediation



Long Term Results: Reproduction



Formation of new plants in *Porphyra dioca*: note at the basal parts of old plants new plants develop vegetatively.



Integrated Aquaculture Project

- Fish *(Cod, Black Sea Bass, Summer Flounder)*
  - Determine optimum conditions for growth
    - Temperature, Feeding Rates, Nutrient tolerance, Stocking Density
  - Determine growth rates
  - Determine nutrient production rates

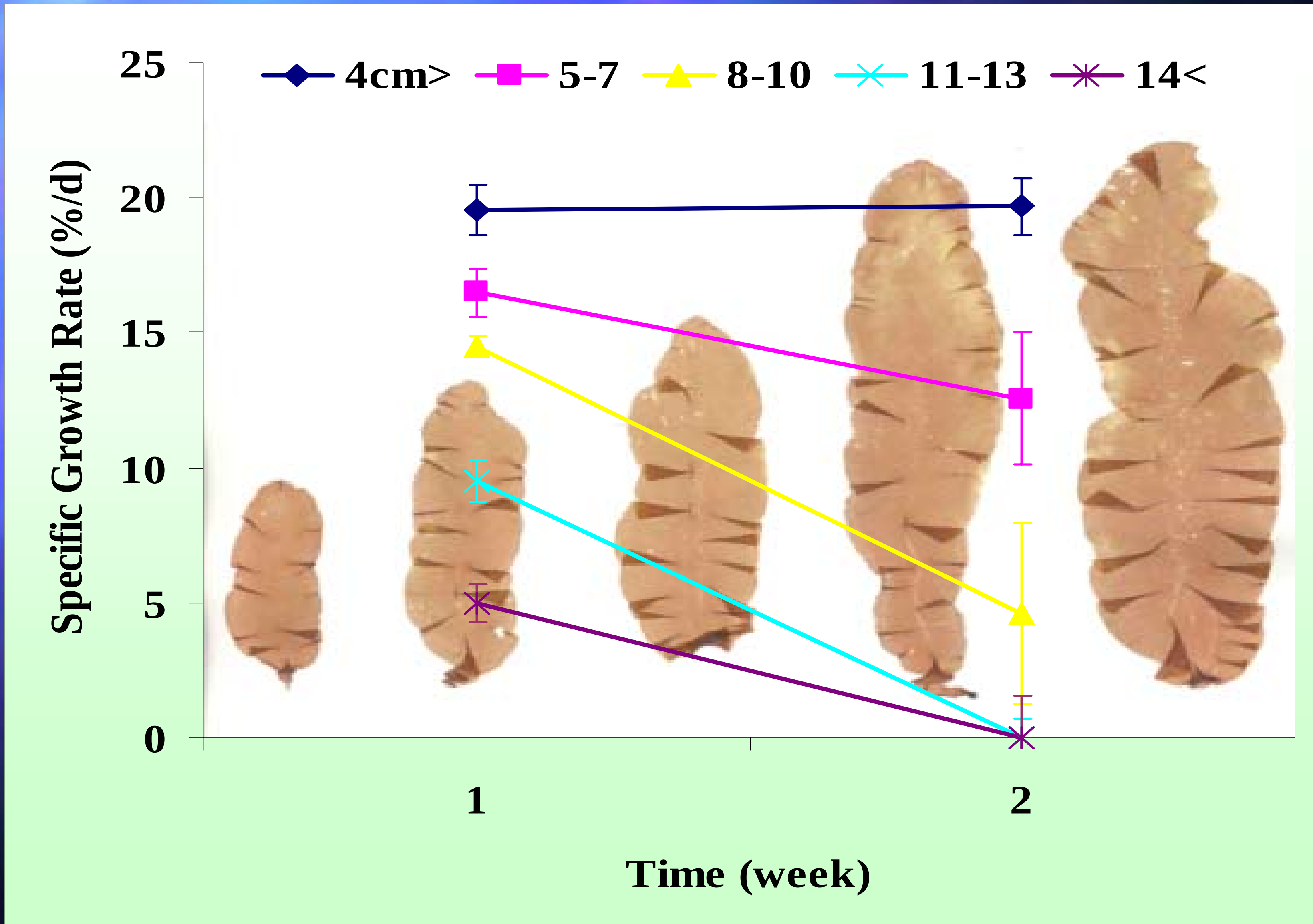
Integrated Aquaculture Project

- Integrated Finfish/*Porphyra*
  - Construct Recirculating Tank System
    - Temperature, Light, Filtration, Aeration
  - Determine optimum operating parameters
    - Fish:Seaweed biomass ratio, Recirculation rates, Nutrient levels
  - Develop Operating Models
    - Optimize production of fish, seaweed, pigment and nutrient removal
  - Develop economic models
  - Technology Transfer

Determine optimum operating parameters

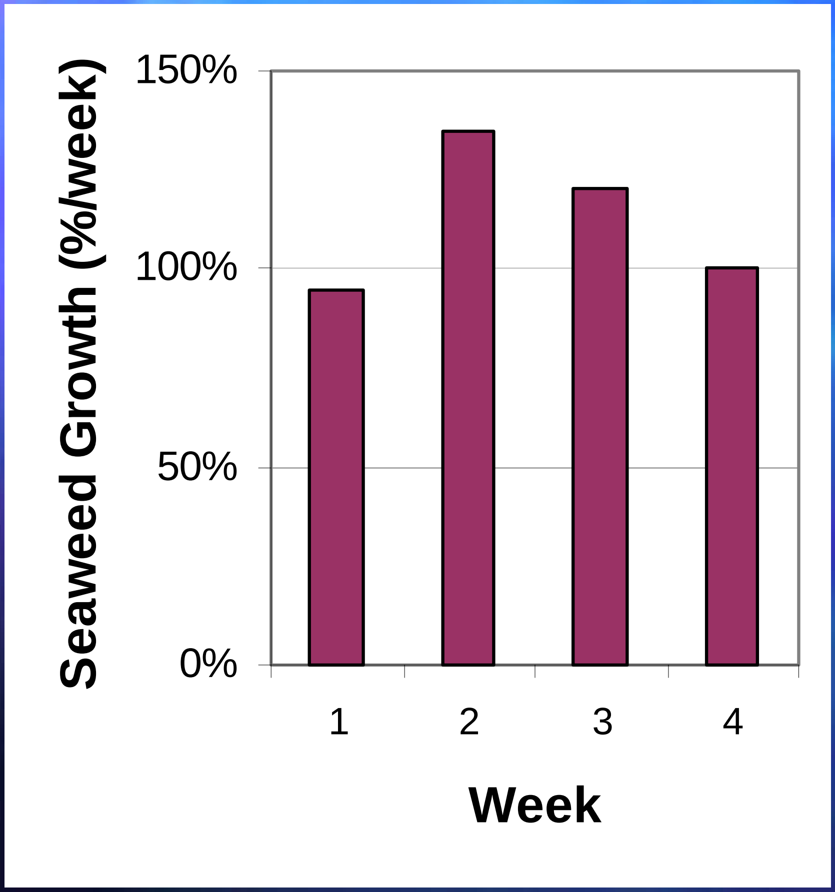
Pilot Scale Integrated Aquaculture System at GreatBay Aquaculture

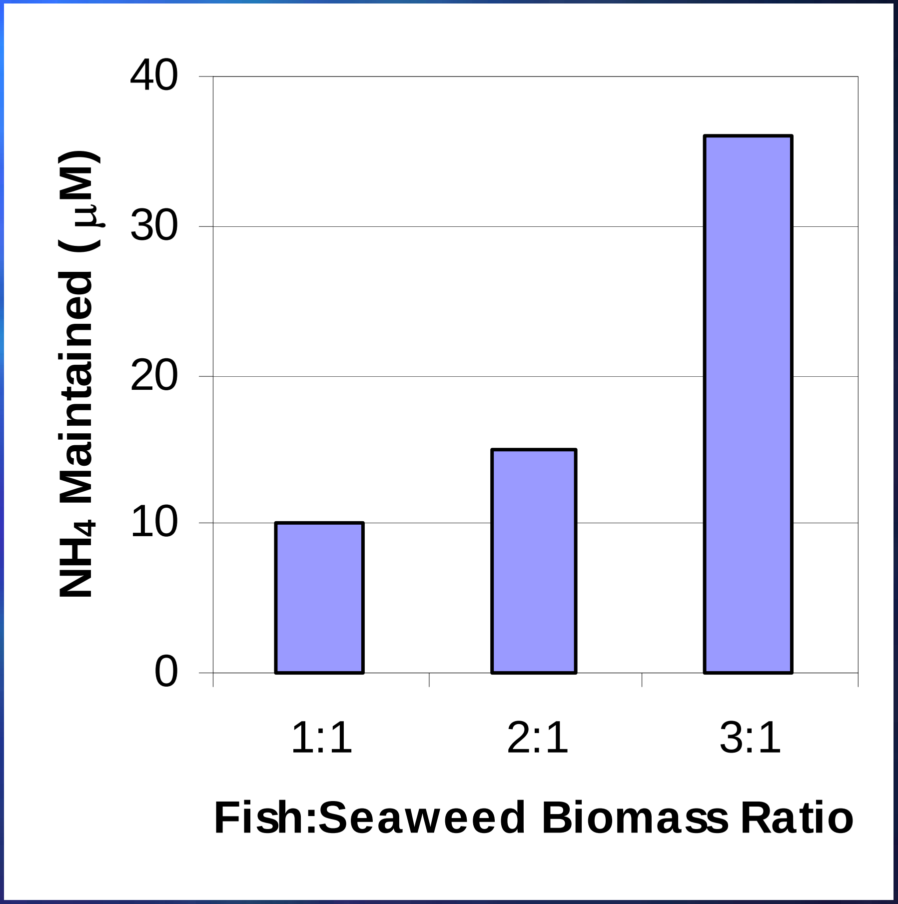
Photos C. Neefus 2004



4cm>
5-7
8-10
11-13
14<
Specific Growth Rate (%/d)
25
20
15
10
5
0
1
2
Time (week)

Initial Results from Cod/*Porphyra amplissima* Demonstration





Kappaphycus alvarezii

Courtesy Anne Hurtado

Seaweed farming low technology methods

Nutrient concentration in *Kappaphycus* in Xincun Bay

	N		C		C:N	P
May-00						
K. alvarezii st 3	2.69 (0.26)		28.64 (0.63)		12.72 (0.92)	0.112 (0.007)
Nov-00						
K. alvarezii st 1	1.69 (0.12)		30.64 (0.41)		21.16 (1.18)	0.154 (0.005)
K. alvarezii st 2	1.50 (0.28)		28.61 (1.65)		22.56 (2.79)	0.144 (0.024)
K. alvarezii st 3	1.60 (0.05)		31.69 (0.38)		23.08 (0.94)	0.187 (0.005)
K. alvarezii st 4.1	1.33 (0.12)		27.95 (2.33)		24.47 (0.28)	0.223 (0.011)
K. alvarezii st 4.2	1.09 (0.01)		26.60 (0.18)		28.56 (0.30)	0.209 (0.004)
Jan-01						
K. alvarezii st 1	1.32 (0.20)		25.58 (1.22)		22.90 (2.66)	0.17 (0.01)

Annual Production in Xincun Bay (1999)	Potential nutrient removal by algae		
		N	P
2000 mt	May	53.8 mt	2.24 mt
	November	28.8 mt	3.66 mt

Acknowledgments

Support for the Integrated Aquaculture Project has been provided by NOAA's OAR through the Connecticut, New Hampshire and New York Sea Grant College Programs, the National Marine Aquaculture Initiative, and the International Programs Office of NOAA's OAR; State of Connecticut Critical Technologies Program; Support for Hainan Is. work was provided by the Georgia and Connecticut Sea Grant College Programs; I.K. Chung (Korea), Prof. X.G. Fei (China), Dr. A. Neori (Israel), Dr. A. Buschmann (Chile), Dr. I. Levine (U.S.) and J.P. McVey (U.S.) for their invaluable discussions.

Domo arigato!