Open ocean aquaculture:

Economics (and policy)

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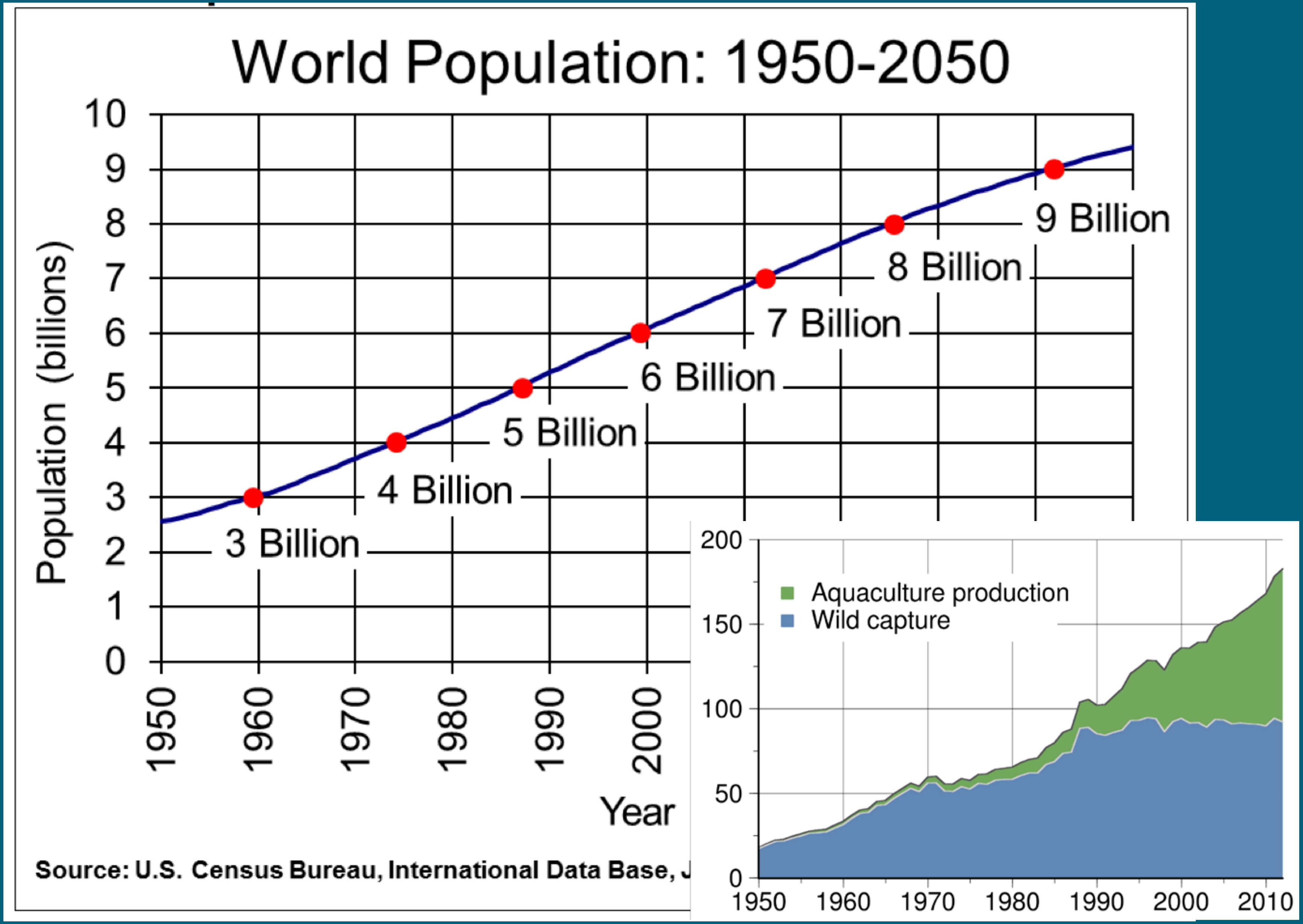
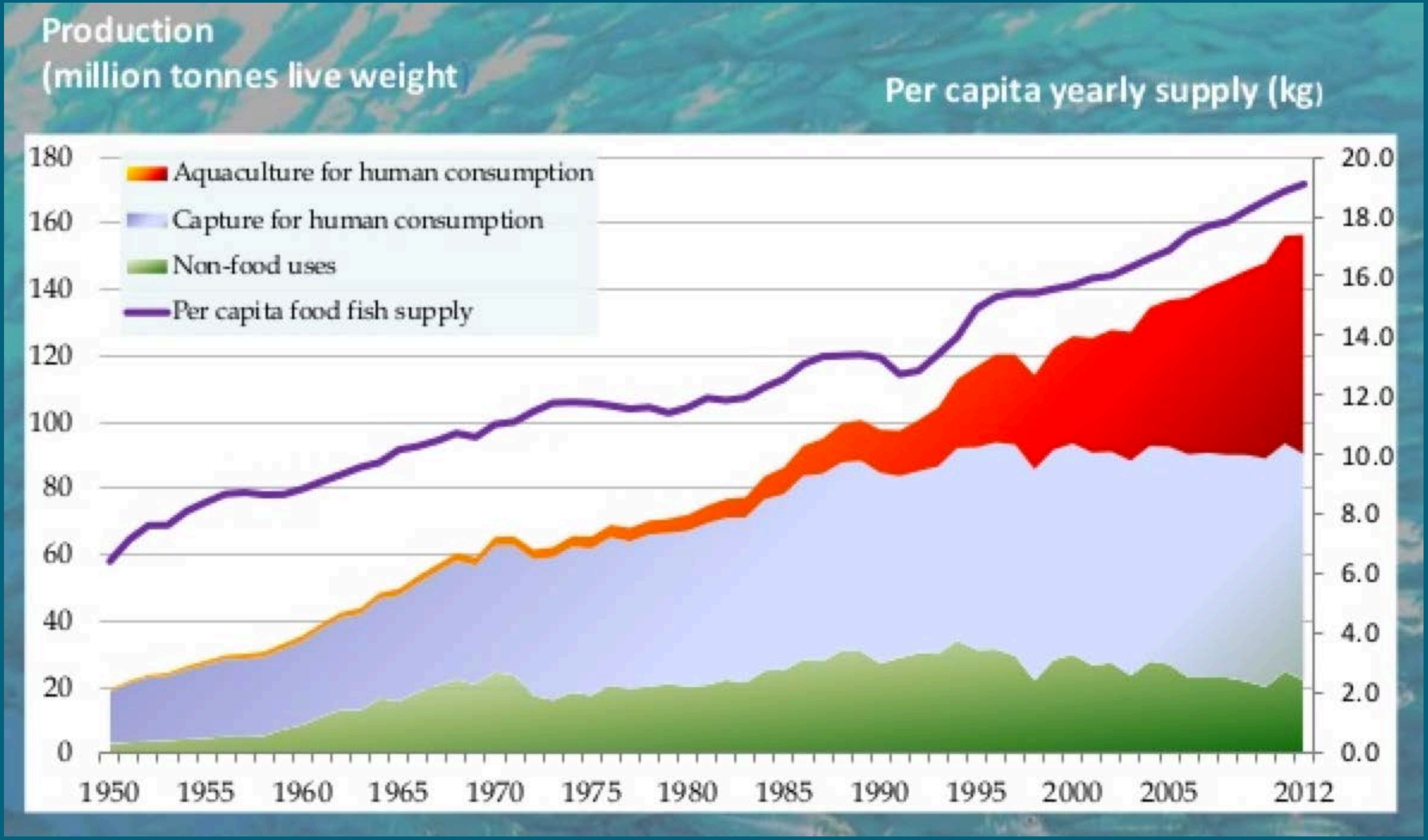
Outline

- Global trends in aquaculture
- Economic drivers of profitability
- Potential for robotics

Context


World Population: 1950-2050
Population (billions)
10
9
8
7
6
5
4
3
2
1
0
3 Billion
4 Billion
5 Billion
6 Billion
7 Billion
8 Billion
9 Billion
1950
1960
1970
1980
1990
2000
Year
Source: U.S. Census Bureau, International Data Base, J
Aquaculture production
Wild capture
200
150
100
50
0
1950
1960
1970
1980
1990
2000
2010

World Demand is Growing Rapidly

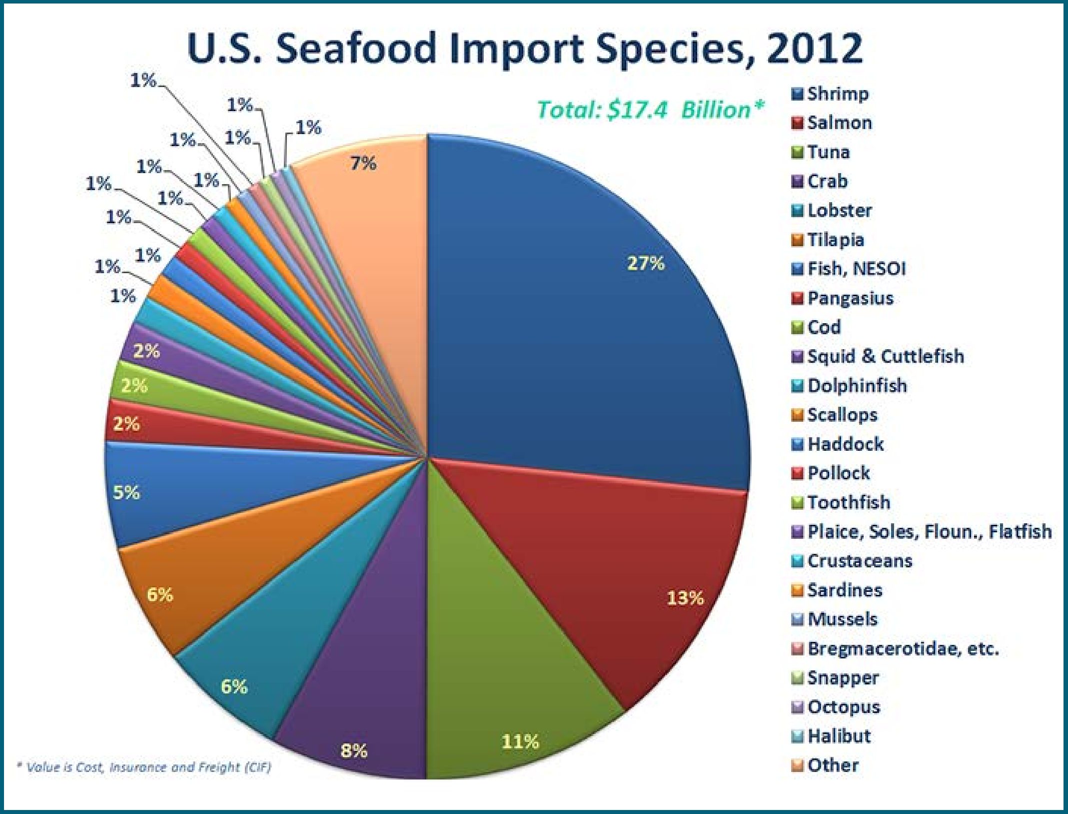


Source: FAO

US Seafood Supply, 2012

80% + of US consumption is imported

50% + of that is farmed



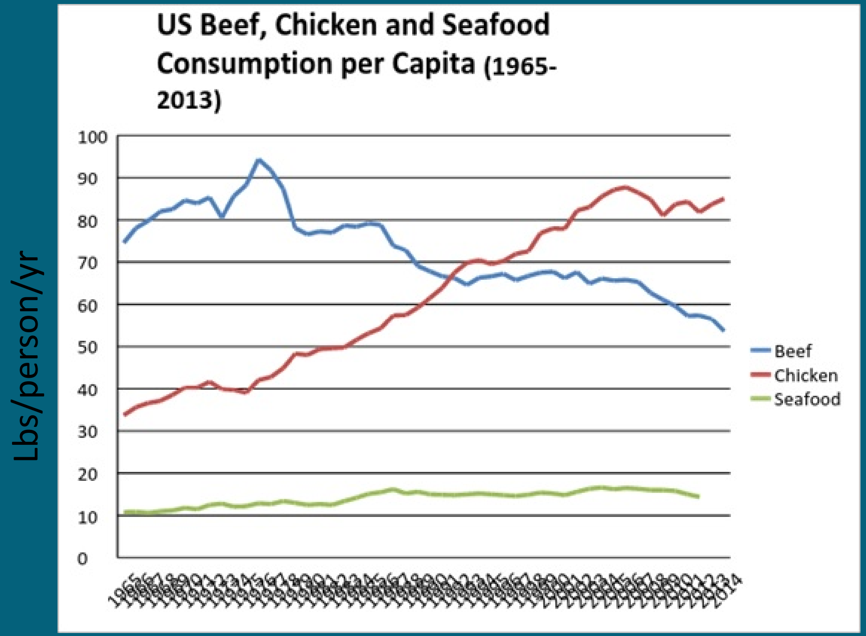
Future Seafood Demand

US population:
- 2015: 322 million
- 2050: 440 million

  seafood consumption:
  - 12 kg/year live weight; trend?
  - (US gov't recommends 25% more)

World population:
- 2015: 7.3 billion
- 2050: 9.4 billion

  seafood consumption:
  - 19.5 kg/year live weight & rising



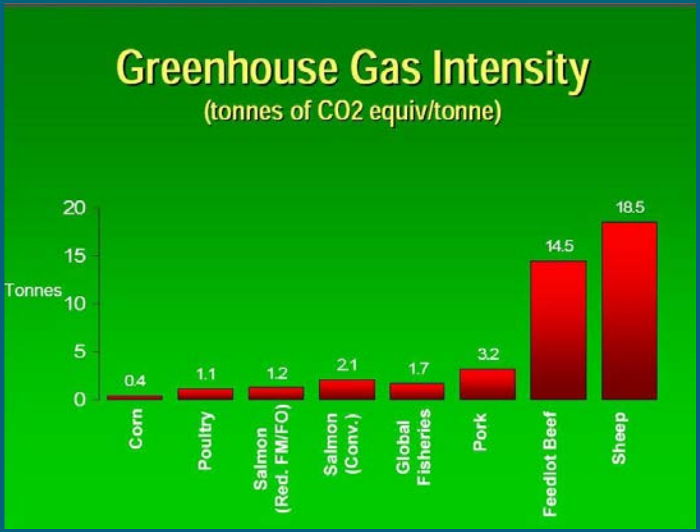
Source: WWF

We'll need another 1-2 million tons/year by 2050 in the USA, and 40 million tons/year by 2050 globally…at least.

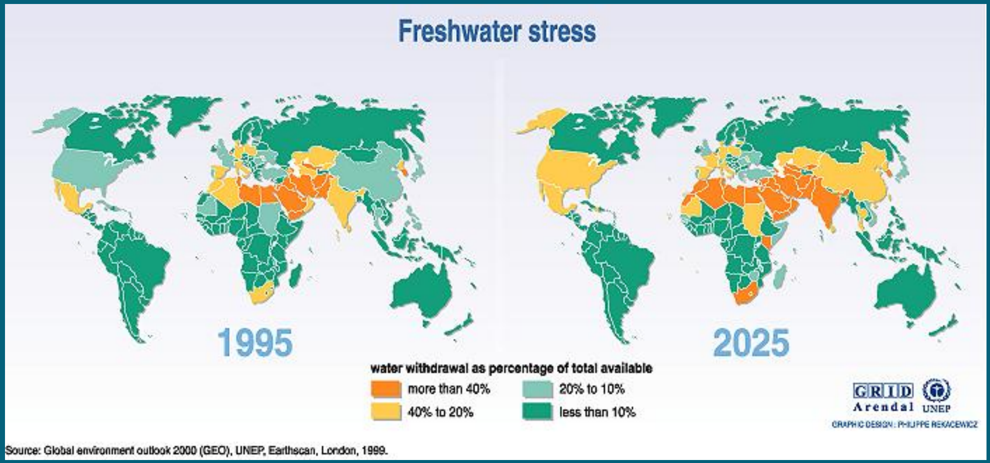
Aquaculture…but what kind?

Global trends that will shape food production:

- Concern over C emissions, ecological efficiency of food production
- Constraints on fresh water and arable land
- Trend toward locally produced food, shorter and simpler supply chains

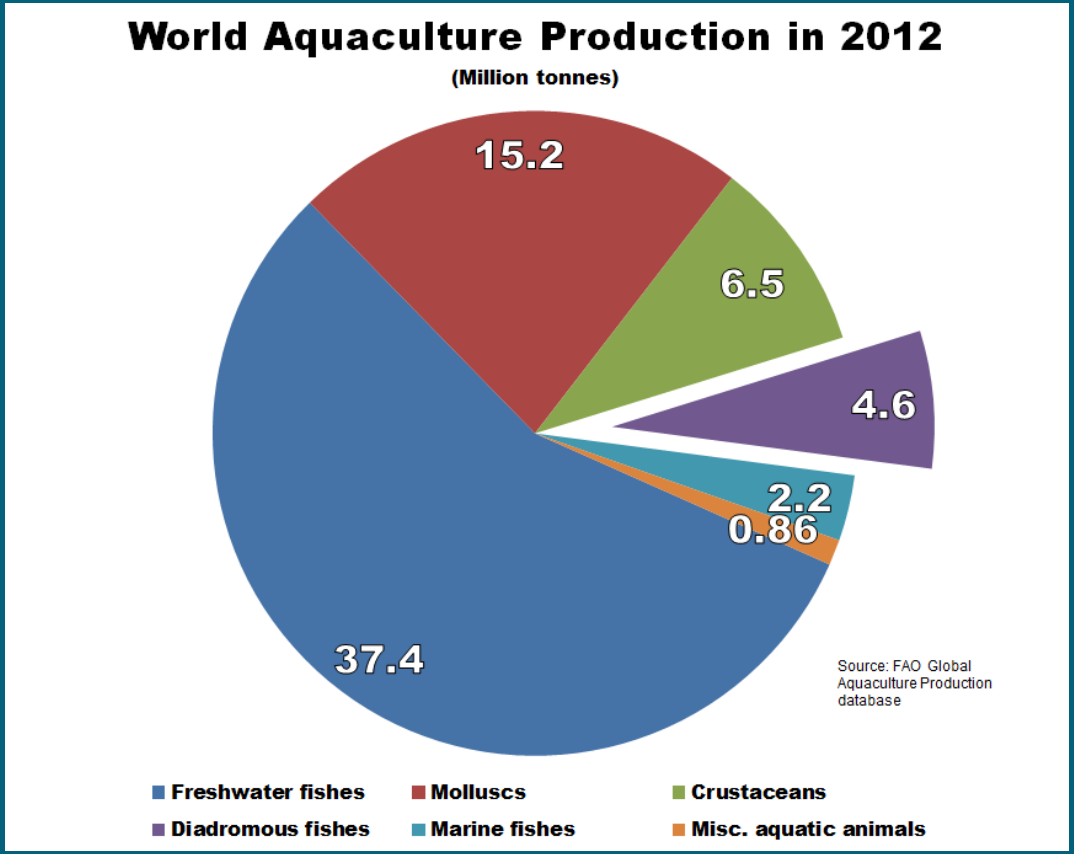


Source: Pelletier and Tyedmers (2007)



Aquaculture…but what kind?

- Historically dominated by freshwater finfish
- Recent growth: shellfish
- Future:
  - Marine
  - Open ocean
  - Recirculating



Near-Shore vs. Open-Ocean

Near-Shore	Open-Ocean
Make full use of permitted site	Large area, very low-density
Multiple pens in array	Independent cages
Fixed location, multiple anchors	Location less critical
Site rotation for fallowing	Little or no bottom impact
Rely on human intervention	Mechanization where possible

- Conventional technologies are suitable only a narrow band of sheltered waters.

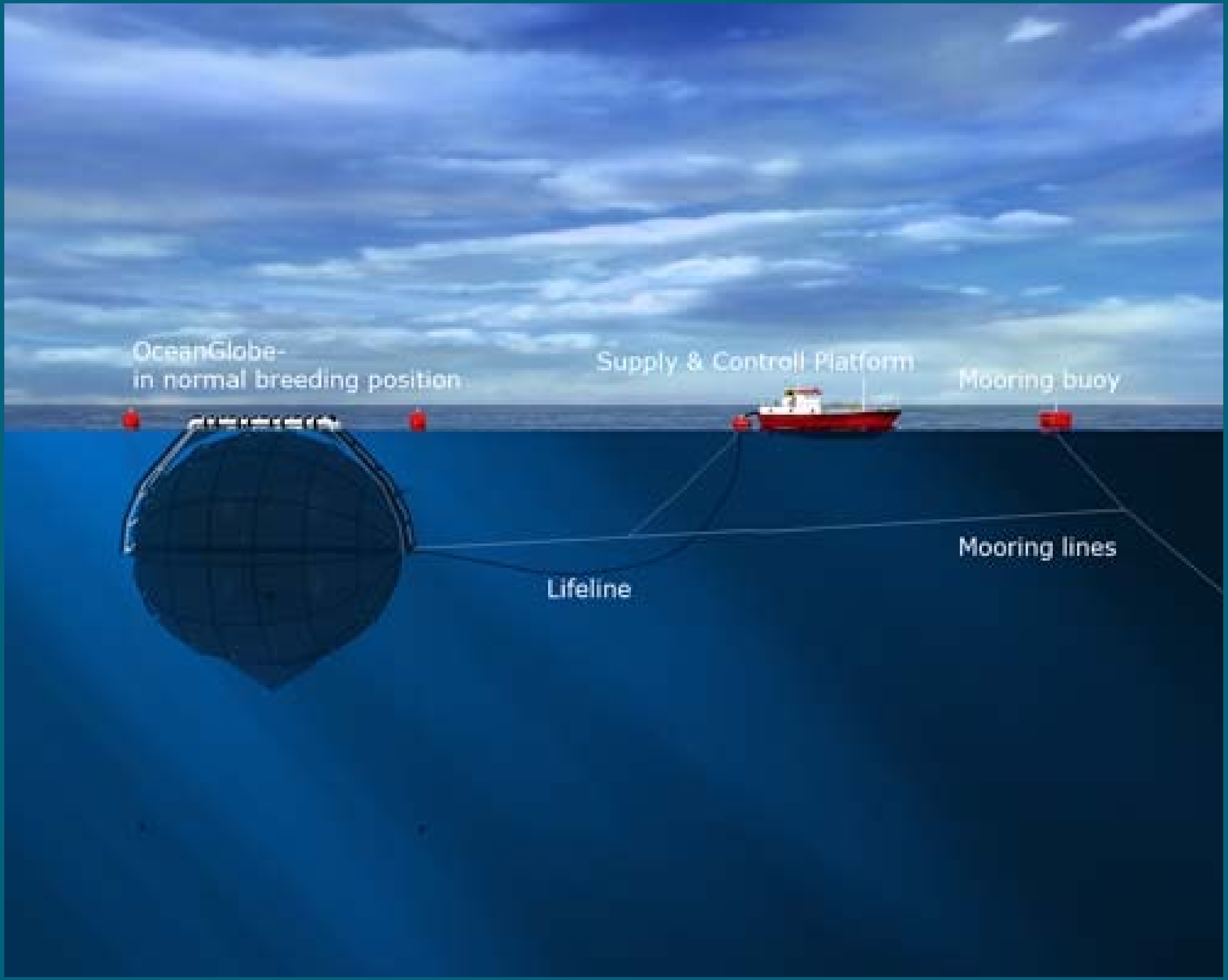
Source: Cliff Goudey

Near-shore Technology

Salmon pens, Maine and Washington

OceanGlobe
Byks AS, Norway

- 40,000 m^3 design

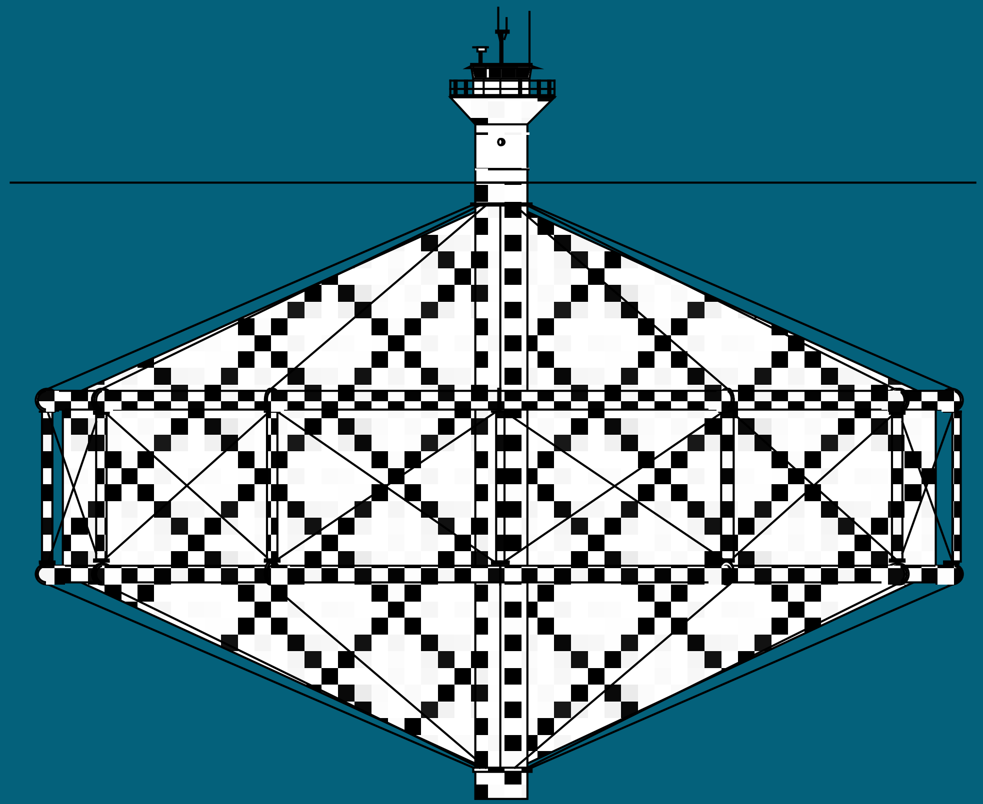


Source: Byks AS, Norway

Ocean Drifter
Conceptual design by Cliff Goudey

- 64,000 m³ design
- Manned or autonomous
- Low-speed self-propulsion (gyres/reciprocating currents)

64,000 Cubic Meter Ocean Drifter



Source: Cliff Goudey

Pros and cons of open ocean

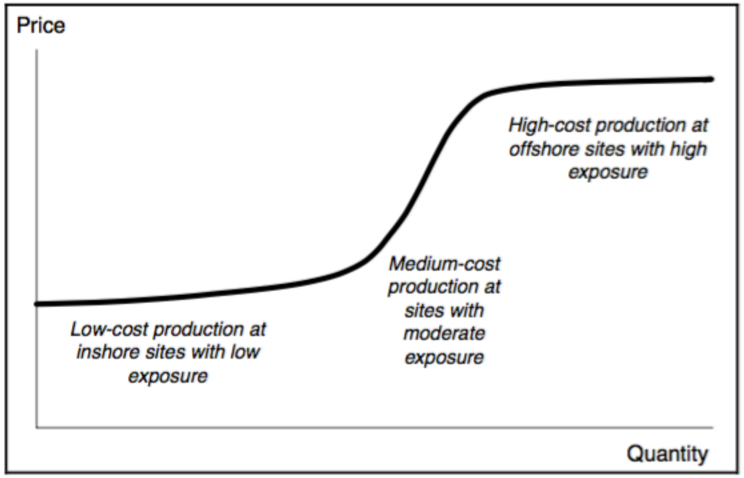
- Cons:
  - Exposure (structures, vessels)
  - Logistics (transport costs)
  - Water depth (mooring system)
  - Working conditions
  - Industry economies of scale
  - Operating and regulatory experience
- Pros:
  - Water quality
  - Availability of sites
  - Use conflicts
  - Farm economies of scale
  - Distance from markets

Knapp (2008)

Some basic economics of aquaculture, courtesy of Gunnar Knapp

Higher production costs at open water sites limit competitiveness with low-cost near-shore sites

Figure 2.2. Hypothetical U.S. marine aquaculture supply curve.



Knapp (2008)

What could make open water aquaculture more competitive?

Demand growth

Supply constraints on near-shore sites

Stricter regulation on near-shore sites

Technological change

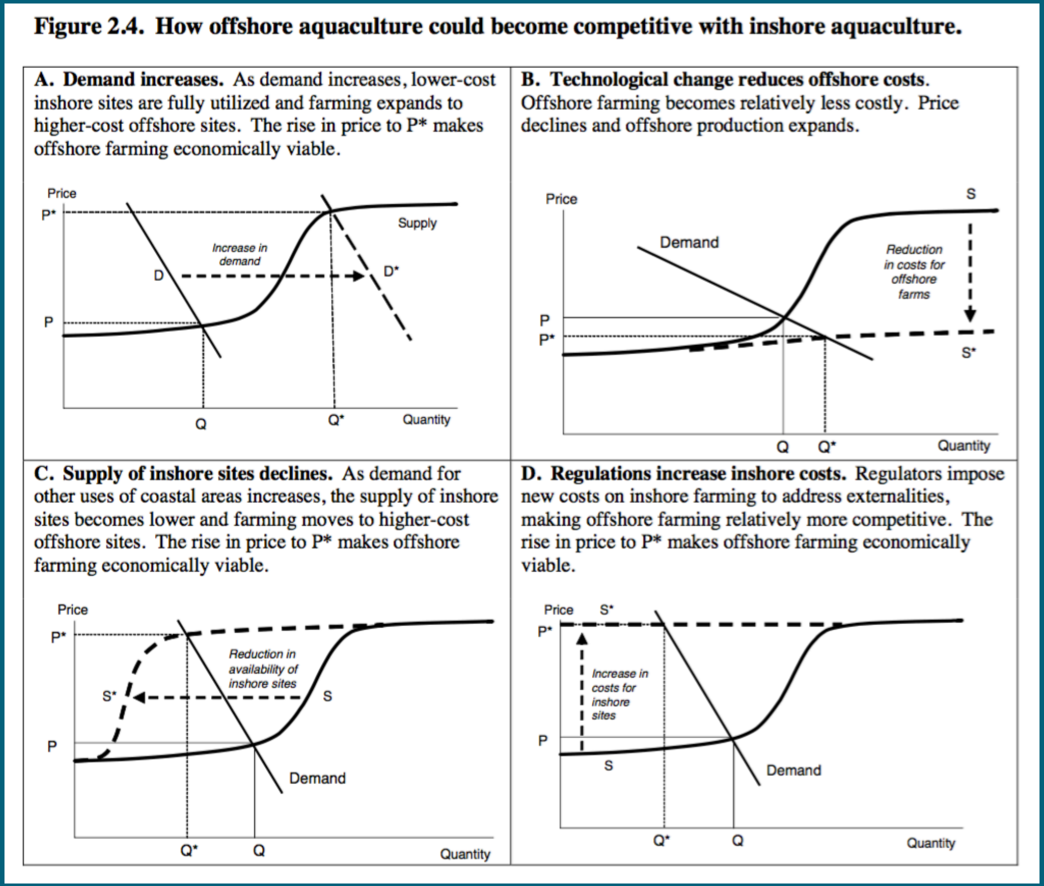


Figure 2.4. How offshore aquaculture could become competitive with inshore aquaculture.

Knapp (2008)

The role of local production

Open-ocean technology could enable greater US production, even if near shore sites are limited

US-produced open ocean seafood might command a price premium

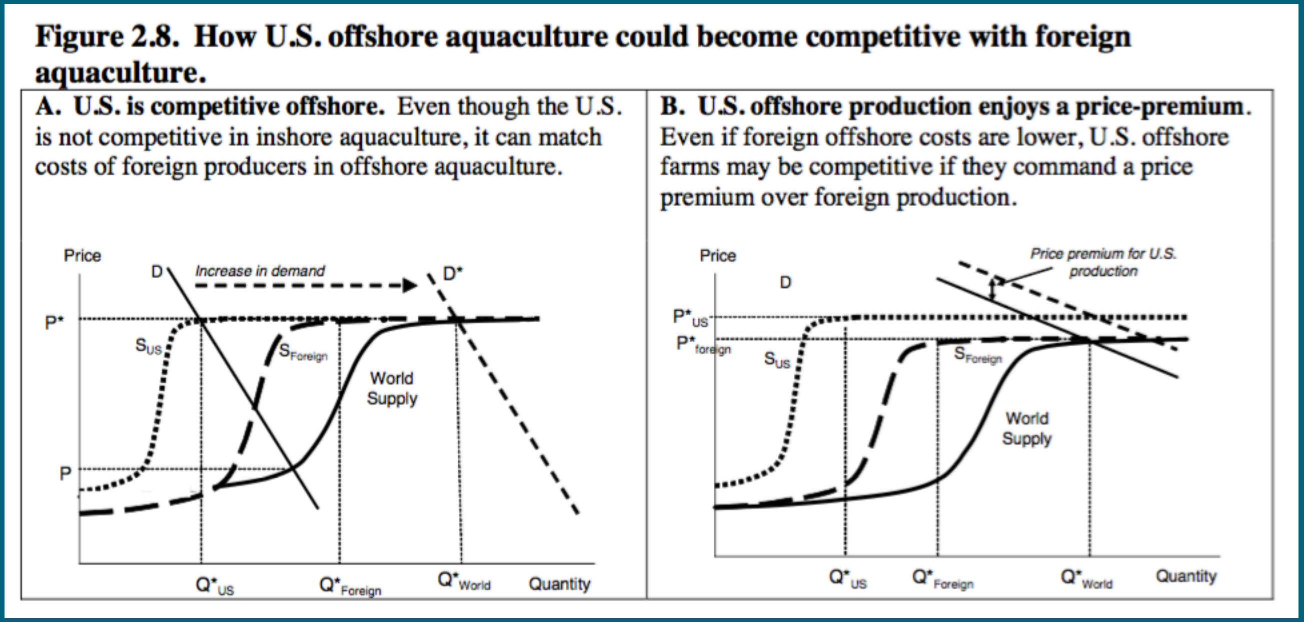


Figure 2.8. How U.S. offshore aquaculture could become competitive with foreign aquaculture.

A. U.S. is competitive offshore. Even though the U.S. is not competitive in inshore aquaculture, it can match costs of foreign producers in offshore aquaculture.

B. U.S. offshore production enjoys a price-premium. Even if foreign offshore costs are lower, U.S. offshore farms may be competitive if they command a price premium over foreign production.

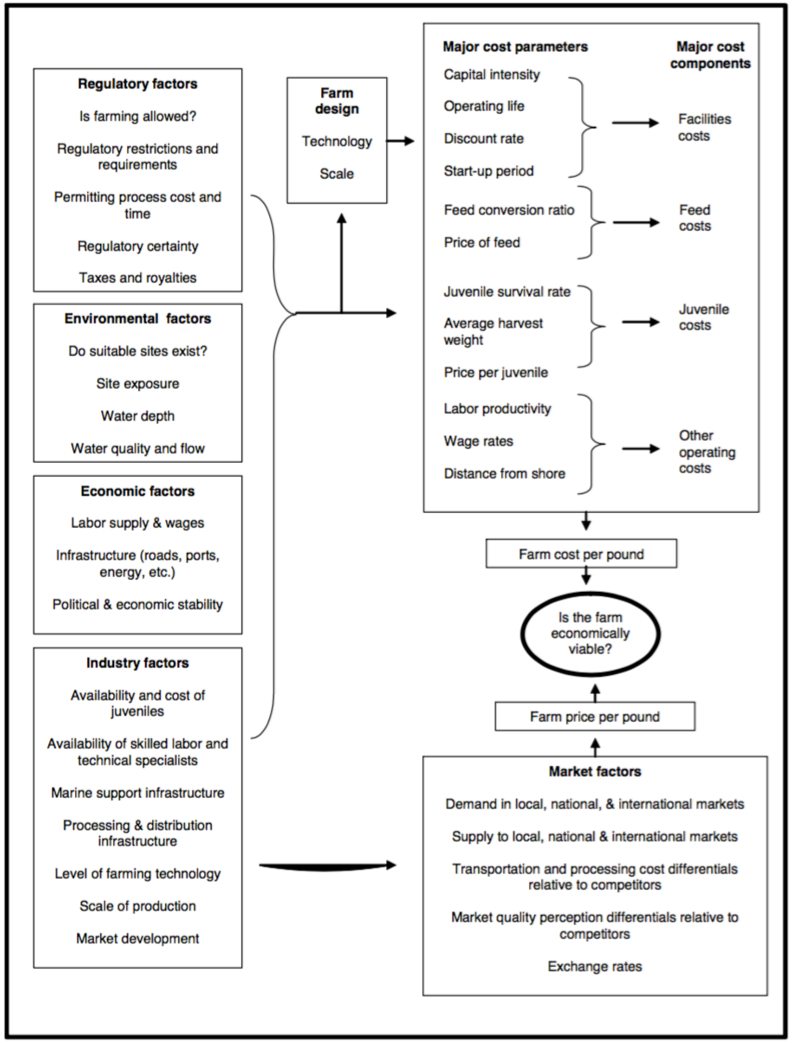
Knapp (2008)

What affects economic viability?

- Capital investment
- Operating cost
- Production density
- Juvenile survival rate
- Feed conversion ratio
- Market price
- Cost of capital

Knapp (2008)

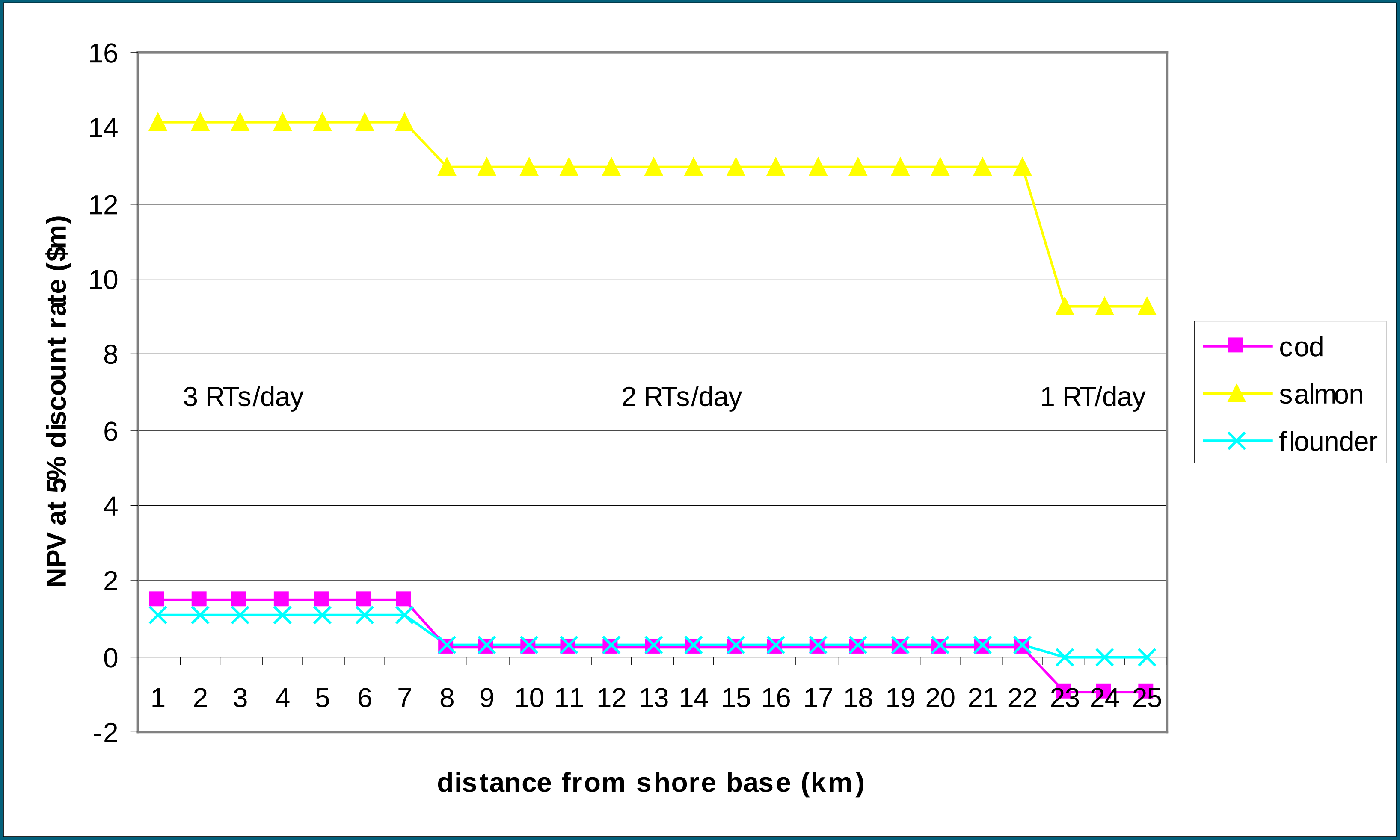
Figure 2.9. Major factors affecting the economic viability of a fish farm.



Production cost: Near-shore vs. Open Ocean

- Increased capital and operating cost of cages, feed system, mooring: 2-3 X near-shore costs
- Increased cost of logistics due to greater distance from port

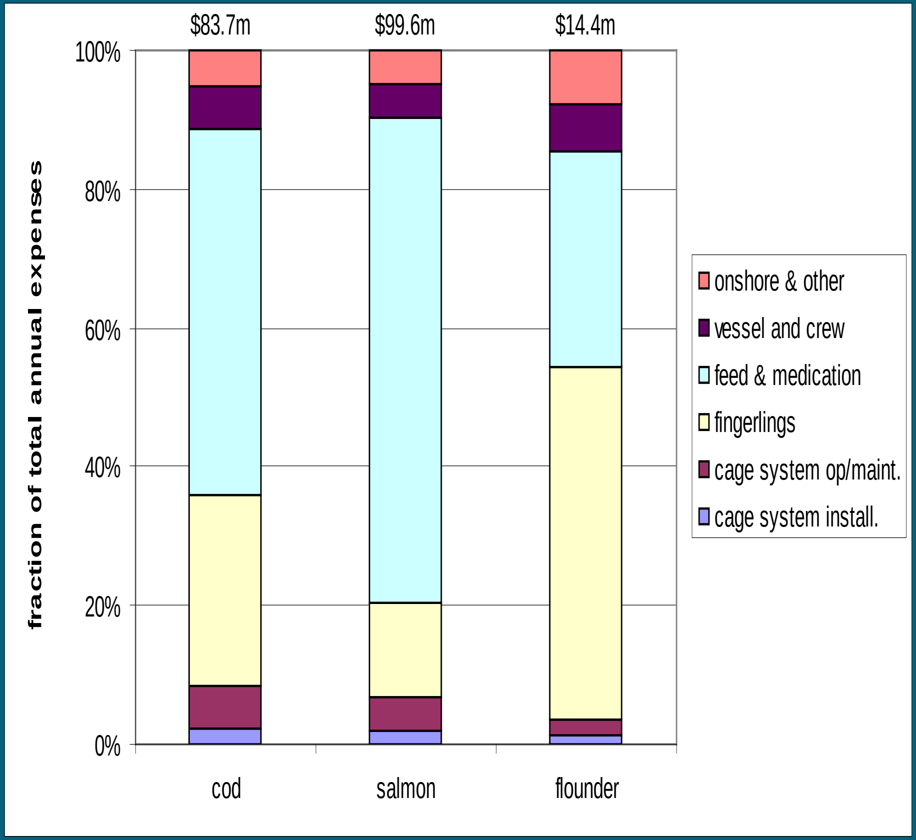
Cost Effect of Distance from Shore



Major Cost Components

Feed	40%
Facilities	20%
Stocking	10-15%
Operations	15%
labor	7-10%

Knapp (2008)



Kite-Powell et al. (2003)

Summary

- Global aquaculture output will have to grow significantly
- Marine, open water production will be needed
- Key challenges in open water aquaculture: efficient facilities, and operations/logistics
- Robotics/automation can directly address about 15% of cost of current operational model
- Robotics/automation that enables very large autonomous systems can open new possibilities in scale economies