Global Conference on Aquaculture 2010

Farming the waters for People and Food

22-25 September 2010, Phuket, Thailand

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Global Conference on Aquaculture 2010

Expert Panel Presentation 1.2:

Novel and emerging technologies: can they contribute to improving aquaculture sustainability?

By
Dr. Craig L. Browdy

22–25 September 2010, Phuket, Thailand

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Sustainable aquaculture's challenges

- Feeding people
- Socioeconomic development
- Environmental responsibility
- Profitability

Can we have our cake and eat it too?

Are there opportunities for "win/win" solutions?

Necessity is the mother of invention.

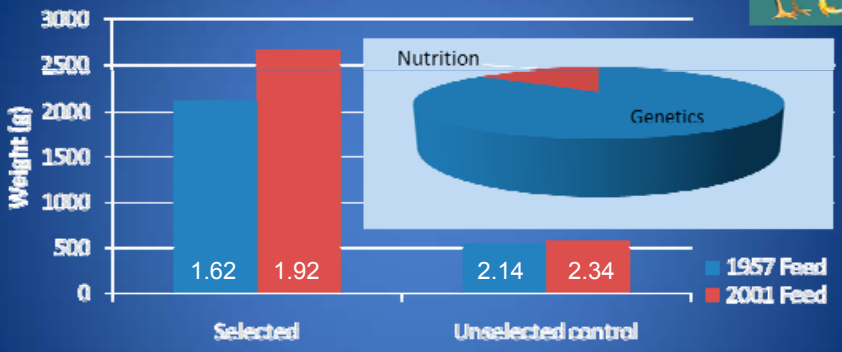
Plato

Innovation distinguishes between a leader and a follower.

Steve Jobs

http://itcilo.files.wordpress.com/2010/05/innovation2.jpg

Broiler Breeding vs. Nutrition



- breeding accounts for 85 to 90% of change in broiler growth rate 1957-2001
- Issues: skeletal, stress tolerance, reproduction

Havenstein et al. 2003

Genetic Improvement

- Less than 20% of aquaculture production
- Selective breeding programs
  - Species selection
  - Closing the life cycle in captivity
  - ICES guidelines for founder stocks (SPF stocks)
  - Biosecure nucleus breeding centers
  - Selection strategies
    - Avoiding inbreeding
    - Mating designs, statistical methods, pedigree tracking
    - Individual and family selection, walk-back selection

Selective breeding programs

- Atlantic cod (*Gadus morhua*)
- Atlantic salmon (*Salmo salar*)
- Common carp (*Cyprinus carpio*)
- Gilthead seabream (*Sparus aurata*)
- Hybrid striped bass (*Morone chrysops* × *M. saxatilis*)
- Lake Malawi tilapia (*Oreochromis*
- *shiranus*)
- Mediterranean sea bass (*Dicentrarchus labrax* L.)
- Nile tilapia (*O. niloticus*)
- Red sea bream (*Pagrus major*)
- Rohu carp (*Labeo rohita*)
- White shrimp (*Litopenaeus vannamei*)
- Tiger shrimp (*Penaeus monodon*)
- Pacific oyster (*Crassostrea gigas*)
- Sydney rock oyster *Saccostrea glomerata*
- Green-lipped mussel *Perna canaliculus*

Hulata 2009 New Technologies

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- Production-related traits
  - Growth
  - Age at maturity; Rainbow trout
  - Eliminating vertebral deformity; Atlantic salmon, Atlantic cod
  - Feed efficiency; Atlantic salmon
  - Reproductive traits; Coho salmon
  - Stress, disease and parasite resistance; Rainbow trout, Atlantic salmon, White shrimp, Sydney rock oyster
- Consumer-related traits
  - Appearance; Rainbow trout
  - Body composition; Rainbow trout
  - Carcass quality, yield; Coho salmon, pacific oyster

Hulata 2009 New Technologies

Transgenics

- Gene transfer technologies
  - Microinjection, electroporation, retroviral vectors, particle gun bombardment, sperm and testis-mediated methods, embryonic stem cells
  - Control over integration and expression
- Traits
  - Growth (salmonids, mud loach)
  - Disease resistance (catfish, grass carp)
  - Cold tolerance (salmon)

coho salmon siblings 14 months

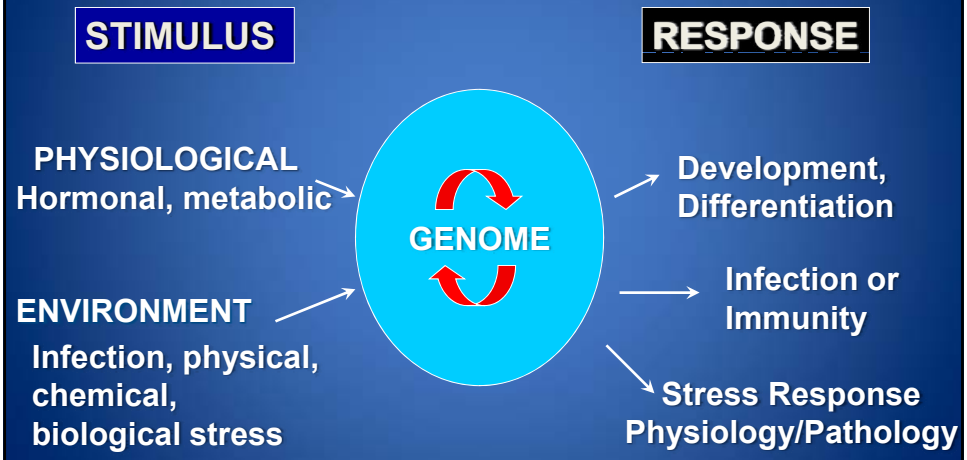
Genetically modified organisms

- Issues and risks
  - Environmental
    - Biodiversity and natural ecosystems
  - Food safety
  - Regulatory
  - Animal welfare

Risks must be honestly and accurately analyzed and understood by society for potential benefits to be realized

Kapuscinski, A.R., K.R. Hayes, S. Li, G. Dana, E.M. Hallerman and P. Schei 2007. Environmental Risk Assessment of Genetically Modified Organisms. Volume 3 Methodologies for Transgenic Fish, Oxford CABI.

Genomic enablement

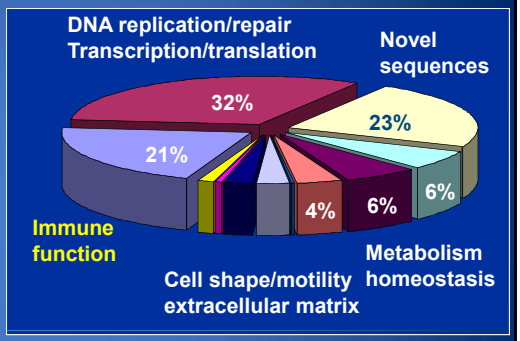


Genomic enablement

- Gene Discovery
- Expression analysis
- Marker assisted selection

Gene discovery and identification

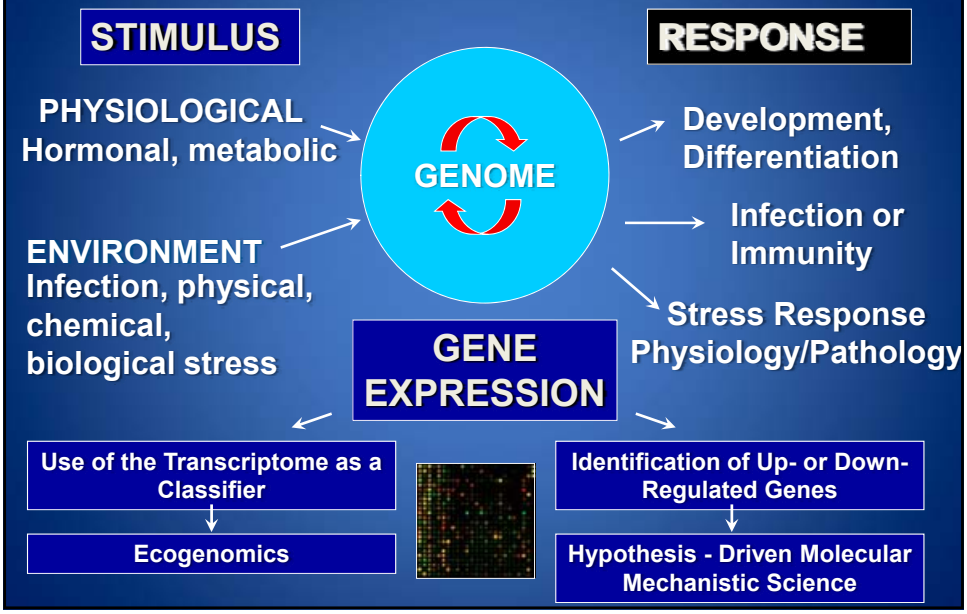
- Expressed sequences
  - Target tissue RNA
  - Message sequencing
  - Increasing availability
    - Atlantic Salmon
    - Rainbow trout
    - Catfish
    - Oysters
    - Shrimp



- High throughput transcriptome sequencing
  - Generation of large numbers of ESTs from RNA
  - Expression profiling
  - Whole genome sequencing for aquaculture species

Gross *et al.* 2001 - Dev. Comp. Immunol.

Gene expression analysis

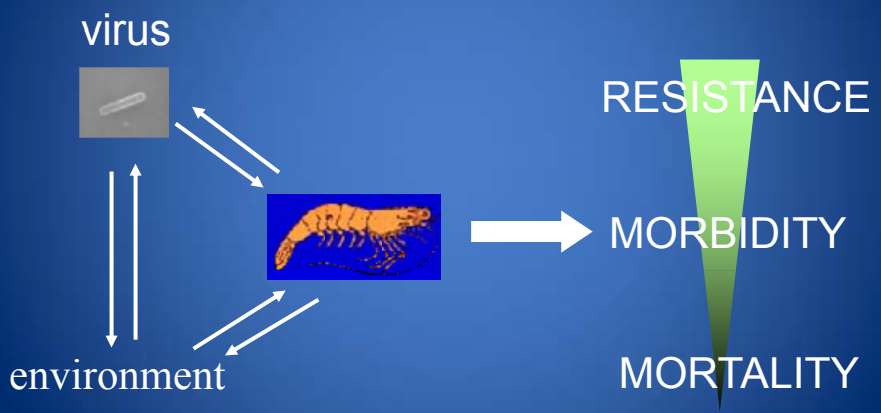


Microarray development

- Salmonids
  - 3500; Rise *et al.*, 2004a
  - 16000; von Schalburg *et al.*, 2005
  - 9000; Bonnet *et al.*, 2007
  - 32000; Koop, in progress
  - 22000; Koop, in progress
  - 950; Taggart *et al.*, 2008
- Catfish
  - 660; Ju *et al.*, 2002
  - 19000; Li *et al.*, 2006
  - 28000; Peatman *et al.*, 2007,
  - 2008; Liu *et al.*, 2008
- Oysters
  - 5000; Jenny *et al.*, 2007
- Carp
  - 13400; Gracey *et al.*, 2004
  - 13000–26000; Williams *et al.*, 2008
- Atlantic halibut
  - 9277; Douglas *et al.*, 2008
- European flounder
  - 3336; Diab *et al.*, 2008
- Rainbow trout
  - 37000; Salem *et al.*, 2008
  - 21500; Olohan *et al.*, 2008
- Three-spined stickleback
  - 9692; Geoghegan *et al.*, 2008
- Fathead minnow
  - 15 000; Klaper *et al.*, 2008
  - 4105; Kane *et al.*, 2008
  - 2000; Villeneuve *et al.*, 2008
- Goby
  - 12661; Gracey, 2008
- Largemouth bass
  - 15950; Garcia-Reyero *et al.*, 2008
- Sea bream
  - 10000; Sarropoulou *et al.*, 2005
- Shrimp
  - 3853; de la Vega *et al.*, 2008;
  - 2469; Robalino *et al.*, 2007
  - 3136; Wang *et al.*, 2006

Liu 2009 New Technologies

Hypotheses regarding antiviral immune responses in shrimp



Robalino et al 2007 Physiological Genomics, Robalino et al 2009 Veterinary Immunology and Immunopathology

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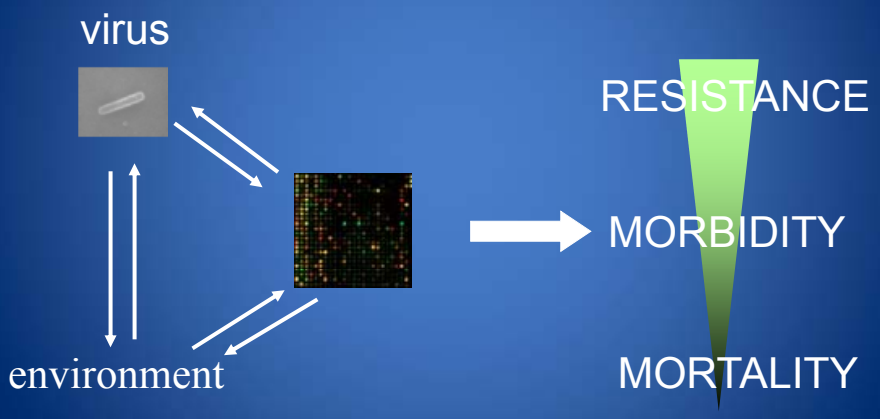

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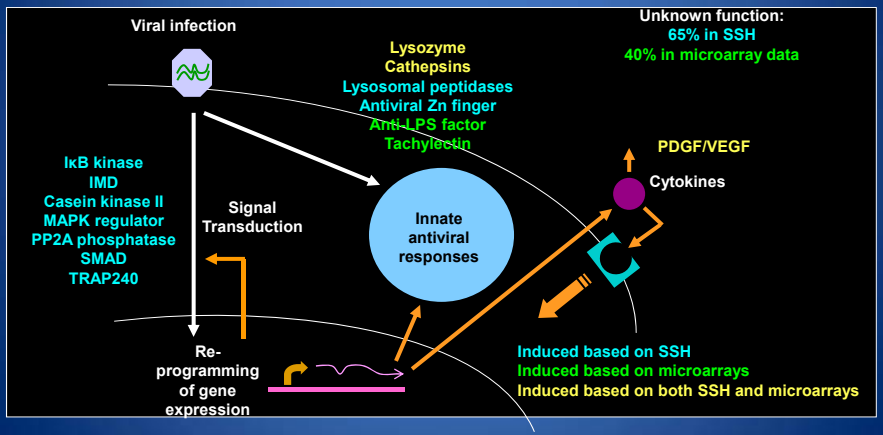


Robalino et al 2007 Physiological Genomics, Robalino et al 2009 Veterinary Immunology and Immunopathology

Genomic enablement

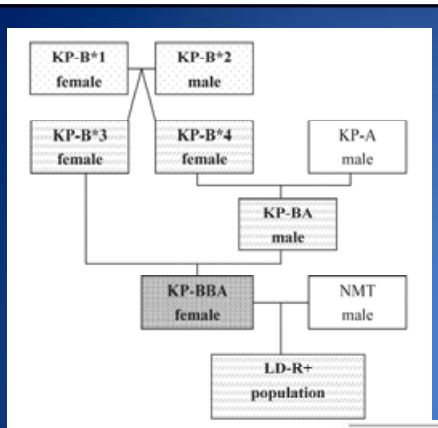
- Marker technologies
  - Allozyme markers, mitochondrial markers
  - Restriction Fragment Length Polymorphism (RFLP)
  - Amplified Fragment Length Polymorphism (AFLP)
  - Microsatellites
  - Single Nucleotide Polymorphisms (SNP)
- Uses in aquaculture
  - Analysis of population structure, diversity
  - Stock, strain, hybrid parentage identification
  - Genetic linkage analysis

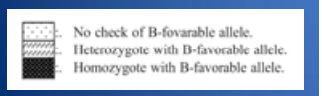
Genome mapping

- Gene Linkage Mapping
  - Rainbow trout: 1359, 1439
  - Brown trout: 302
  - Atlantic salmon: 527, 64
  - Arctic charr: 327
  - Common carp: 272
  - Tilapia: 174, 292, 552
  - Channel catfish: 293, 506
  - Walking catfish: 146
  - Yellow croaker: 375
  - Gilthead sea bream: 204
  - Atlantic halibut: 350
  - Tiger shrimp: 673
  - Kuruma prawn: 246, 401
  - White shrimp: 394
  - Chinese shrimp: 231-241
  - Eastern oyster: 13-158
  - Pacific oyster: 102, 349
  - Zhikong scallop: 545, 503
  - Pacific abalone 384
  - Sea urchin: 324-339

Liu 2009 New Technologies

- Physical mapping (BAC)
  - Atlantic salmon, tilapia, channel catfish, rainbow trout
- Enabling full genome sequencing





- Microsatellite identified with single locus dominant effect for resistance to lymphocystis disease
- Homozygous female bred with commercial strain male
- Heterozygous progeny with no incidence of disease

Population	Genetic information of B-favorable allele (*Poli.9-8TUF* on *LG15*)			Farm	No. fish tested[a]	No. fish with LD (incidence)
	Parents		Progeny			
	Male	Female				
LD-R+	−	++	+−	A	26,250	0* (0%)
				B	2620	0** (0%)
LD-R−	−	−	−	A	22,000	1000* (4.5%)
				B	3561	225** (6.3%)

Fuji et al 2007 Aquaculture

Challenges

- Diversity of species
- Costs and logistics
- Biosecurity
- Bioinformatics
- Policy and regulatory issues

Aquatic animal health

- Diagnostic technologies
  - Molecular and serological diagnostics
  - Cost, speed, sensitivity and specificity
  - Loop-mediated isothermal amplification (LAMP)
    - edwardsiellosis, enteric septicemia of catfish, nocardiosis, PKD, IHNV, WSSV, IMNV
  - Multiplex tests: Luminex bead based, microarray
  - Nanotechnology
    - antibody coated magnetic particles

Pathogen host interactions

- Pathogen biology
- Host defenses
  - Shrimp and bivalve immunology
  - Immunomodulatory interrelationships
- Epidemiology and spread

Disease control

- Regulatory issues, translocation of stocks, quarantine
- Site selection and permitting
- Systems design and management
- Fallowing, single year class stocking

- Nutrition, pre and probiotics, immunostimulants, oxidative balance

- SPR stocks
  - Selected
  - Transgenic
- Biopesticides, biological control
- New Vaccines and theraputants

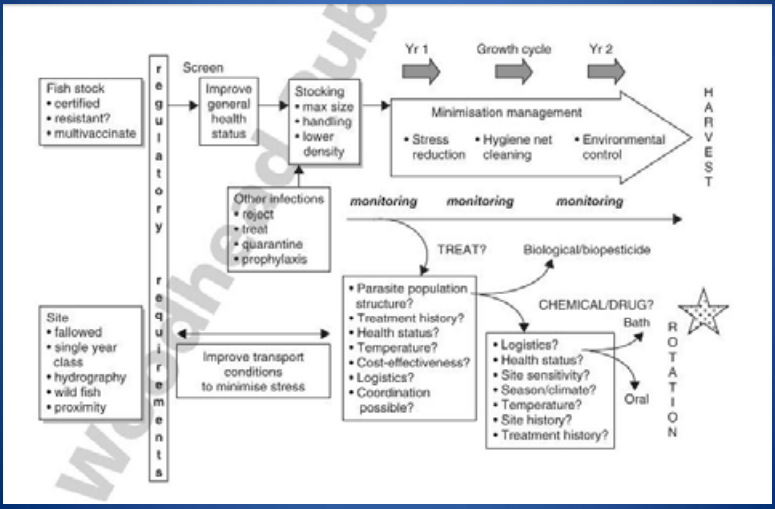
Vaccines

- **Salmonid heptavalent vaccines**
  - ***Listonella (Vibrio) anguillarum*** **serotypes O1 and O2, *V. salmonicida*, *Moritella viscosa*, *Aeromonas salmonicida*, the causative agents of vibriosis, Hitra disease, winter ulcer disease, furunculosis and infectious pancreatic necrosis virus (IPNV)**
- **Live attenuated bacterial vaccines**
  - ***Edwardsiella ictaluri*** **and *Flavobacterium columnarae*, Channel catfish and one viral vaccine (KHV for Carp in Israel)**
- **Commercial vaccines from inactivated bacterial pathogens, fewer viral vaccines, none against parasites.**
- **New vaccine development**
  - **recombinant expressed viral protein - IPNV vaccine**
  - **DNA vaccine - sequences encoding for rhabdovirus glycoproteins**
    - **Bactriophage delivery systems**
  - **Protected oral vaccines - delivery systems**

Disease control

- Chemotheraputants
  - Prophylactic and improper antibiotic use being reduced, increasing regulation
  - Regulatory and safety issues
    - Efficacy in treating the disease
    - Animal safety – tolerance, welfare
    - Food safety issues for the consumer
      - Maximum residual levels, withdrawal period
    - Quality
    - Environmental issues – ecotoxicology
      - Bath treatments; oral; slow release implants
  - Development and registration cost vs. market size
  - Pathogen resistance – need multiple treatment options
  - New technologies, gene silencing

Integrated pest management



Sommerville 2009 New Technologies

Feeds and feeding

- Improved feed formulation strategies based on nutrient availabilities and specific requirements
  - Ingredient digestibility, palatability, nutrient utilization
  - Species specific requirements
  - Near infrared spectroscopy, in vitro analyses, nutritional modeling, amino acid utilization
- Improving feed production technologies
  - Energy efficiency
  - Extrusion
    - Floating feeds
    - Leaching pellet stability, physical qualities
    - Fine grinding, microextrusion
    - Preconditioning
    - Drying
- Functional feeds
  - Stress, finishing, probiotics/prebiotics, lifecycle/seasonal

Feed production - fish meal and fish oil use

- Aquaculture will need to produce an additional 29 million tons of food fish per year to maintain current consumption rates by the year 2030
- Aquaculture 4% of global animal feed
  - 20.2 to 22.7 million tones
- Uses 68.2% total reported fish meal production

Simple Facts:
1) Supply is limited
2) Use is increasing
3) Prices are going up
4) Toxin levels a concern

Feeds and feeding

- Alternative Plant based protein sources
  - Soybean products
  - Corn products
  - Wheat and barley
  - Canola/rapeseed products
  - Distillers products
  - Peas and lupins
- Problems
  - Antinutrients
    - Trypsin inhibitor
    - Phytic acid
    - Saponins
    - lectins
  - Non-digestible compounds
    - Non soluble carbohydrates
    - Resistant starch
    - Fiber
  - Palatability
  - Essential AA, HUFA

Improving use of alternative ingredients

- Nutrient availabilities and specific requirements
- Plant breeding to reduce non digestible carbohydrates
- Use of protein concentrates
- Use of microbial enzymes such as phytase
- Use of supplementary amino acids
- Protein recovery prior to fermentation to improve DDGS
- Pallatants and attractants

Improving use of alternative ingredients

- Microbial proteins
  - Algal meals
  - Yeast
  - Bacteria
- Rendered products
  - Bovine, ovine and porcine meals
  - Blood meals
  - Poultry meals
- Seafood processing waste
- Sustainable use of plankton and krill

Improving use of alternative ingredients

- Oils
  - Blending fish and plant oils to meet energy requirements
  - EPA and DHA
    - Use of high quality fish oils
    - GM oil seeds
    - Microbial fermentation sources
    - Plankton
  - Finishing feeds

Focusing production systems technology development

- Build consensus on goals
  - Productivity, financial sustainability
  - Environmental responsibility, climate change effects, resource utilization efficiencies
  - Community socioeconomics, food security
- Develop quantitative criteria and metrics
  - Heritability and genetic gain
  - Fish in:Fish out, nutrient conversion efficiencies
  - Energy and carbon efficiencies
  - Income and food generation per unit area/input
- Evaluate progress, outcomes and impacts

Production systems

- Cage Production of Marine Finfish
  Dr. Richard Langan
- Land-based Marine Fish Production
  Dr. Yonathan Zohar
- Coastal Shellfish Production
  Dr. Daniel Cheney
- Land-based Shrimp Production
  Dr. Craig L. Browdy

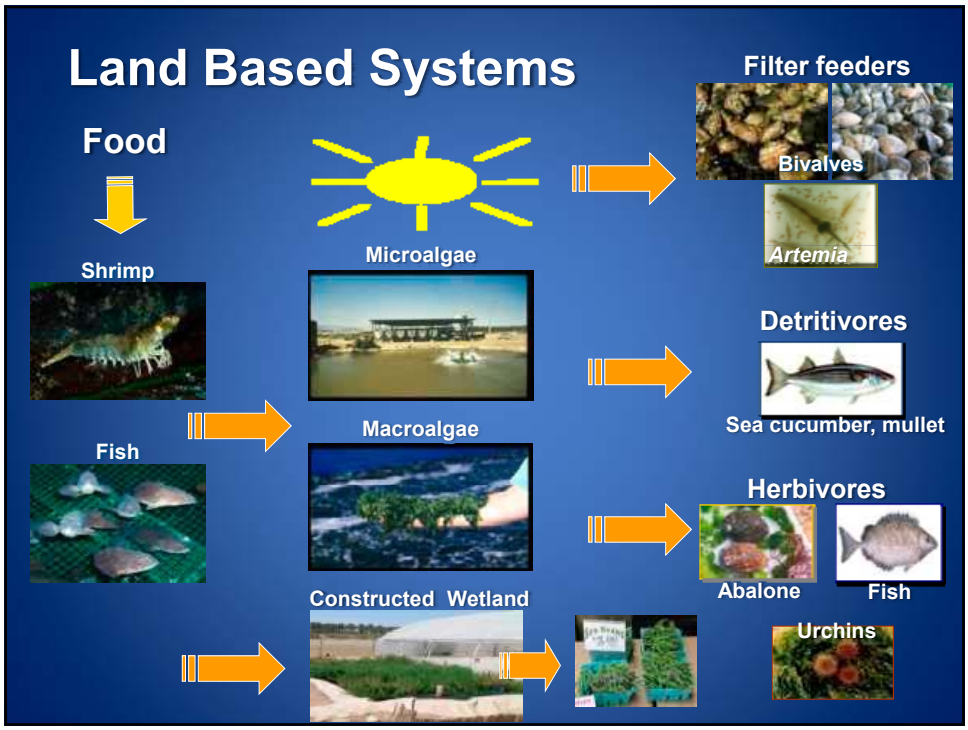
http://aquaculture.noaa.gov/pdf/noaanistwpfinal.pdf

Traditional Aquaculture Systems

- Traditional small scale Asian aquaculture systems
  - Local seed production potentially improved stocks
  - Regional and local health screening and management
  - Improved fertilization, water quality management
  - Formulated feeds
    - Improved local ingredients, use of natural inputs
    - Improved productivity using waste cycling principles
  - Sector organization to facilitate technology application
    - Cooperatives
    - Medium scale entrepreneurs
    - Technology application throughout value chain

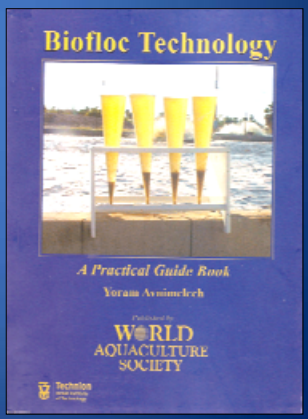
Integrated Multi-trophic Aquaculture

- Ecologically based from traditional approaches
- Nutrient waste from fed species for grazers, filter feeding species and primary producers
- Engineering use of additional trophic levels
  - Land based systems or cage culture systems
  - Efficiency and sustainability
  - Crop diversification, added value
  - Improved nutrient uptake
  - Improved social perceptions, marketing
- System profitability rather than single species

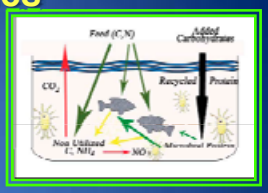


Biofloc technology

- Pond based production of shrimp, tilapia
- No water exchange
- Oxygenation, mixing
- In situ biofiltration
- Waste mineralization
- Microbial protein
- Exclusion of pathogens
- Reduced cost
- Improved sustainability



Experiments are underway to explore the role of natural productivity in improved ecologically based holistic approaches



Organic feeds

Wastes

Bacteria

Cyanobacteria

Green Algae

Diatoms

Dinoflagellates

Biofloc

Chemoautotrophs

Photoautotrophs

Heterotrophs

Supplemental nutrition

Fatty acids

Water quality

Waste cycling

Information and Communications Technology

- Monitoring, control and automation
  - Risk management – catastrophic loss prevention
  - Water quality control
  - Feeding efficiency
  - Improved efficiencies
  - Improved sensors
  - Networking
  - Remote access
- Business, enterprise planning and management
- Quality and traceability
- Internet
  - Marketing, sales
  - Public relations
  - Remote management
  - Research collaborations
  - Access to information
  - Education and extension

Conclusions

- Pace of technology development is increasing
- Advances in genetics, health, nutrition, production systems engineering and information technology have had profound effects on aquaculture production
- Innovation in sustainability and productivity have, in many cases, been implemented for and by large scale industrial aquaculture production systems
- Many examples of win/win improvements in sustainability and profitability

Conclusions

- Build consensus on goals and measurement indices to focus and measure progress and outputs of investments in technology development
- Increase development of technologies applicable to small and medium scale systems
- Extend availability of existing know-how and technologies
- Disseminate through cooperatives and investment in medium scale entrepreneurs and the value chain to support them

If you open up the mind, the opportunity to address both profits and social conditions are limitless. It's a process of innovation.

Jerry Greenfield