Can aquaculture become the new blue biotechnology of the future ?

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Ghent University Belgium



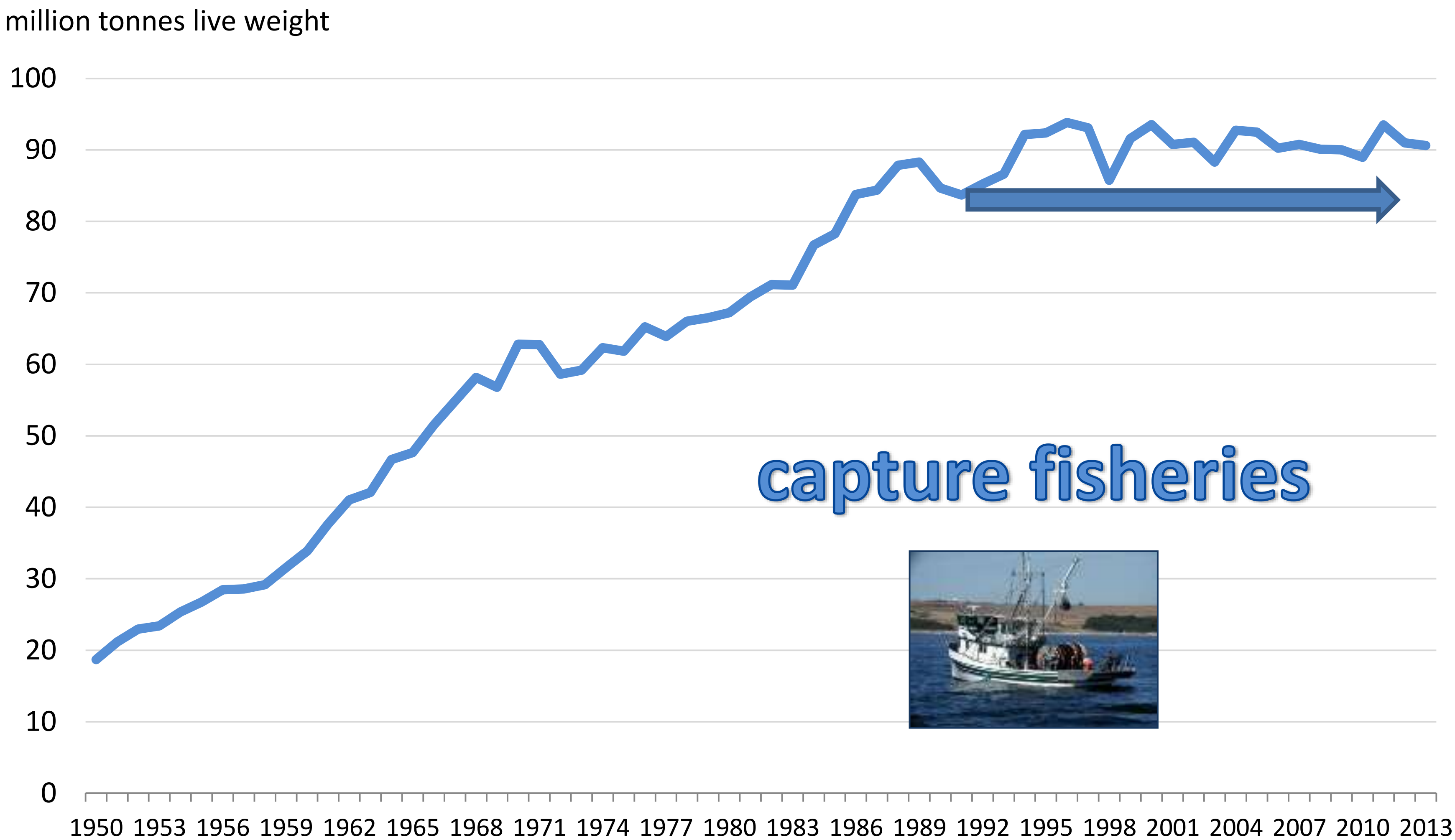
Aquatic Products - Seafood

Eating seafood is beneficial to consumer's health

- Improve intelligence
- Cut the risk of heart diseases
- Stress, depression, Schizophrenia
- Decreased risk of developing Alzheimer's
- Prevention of obesity

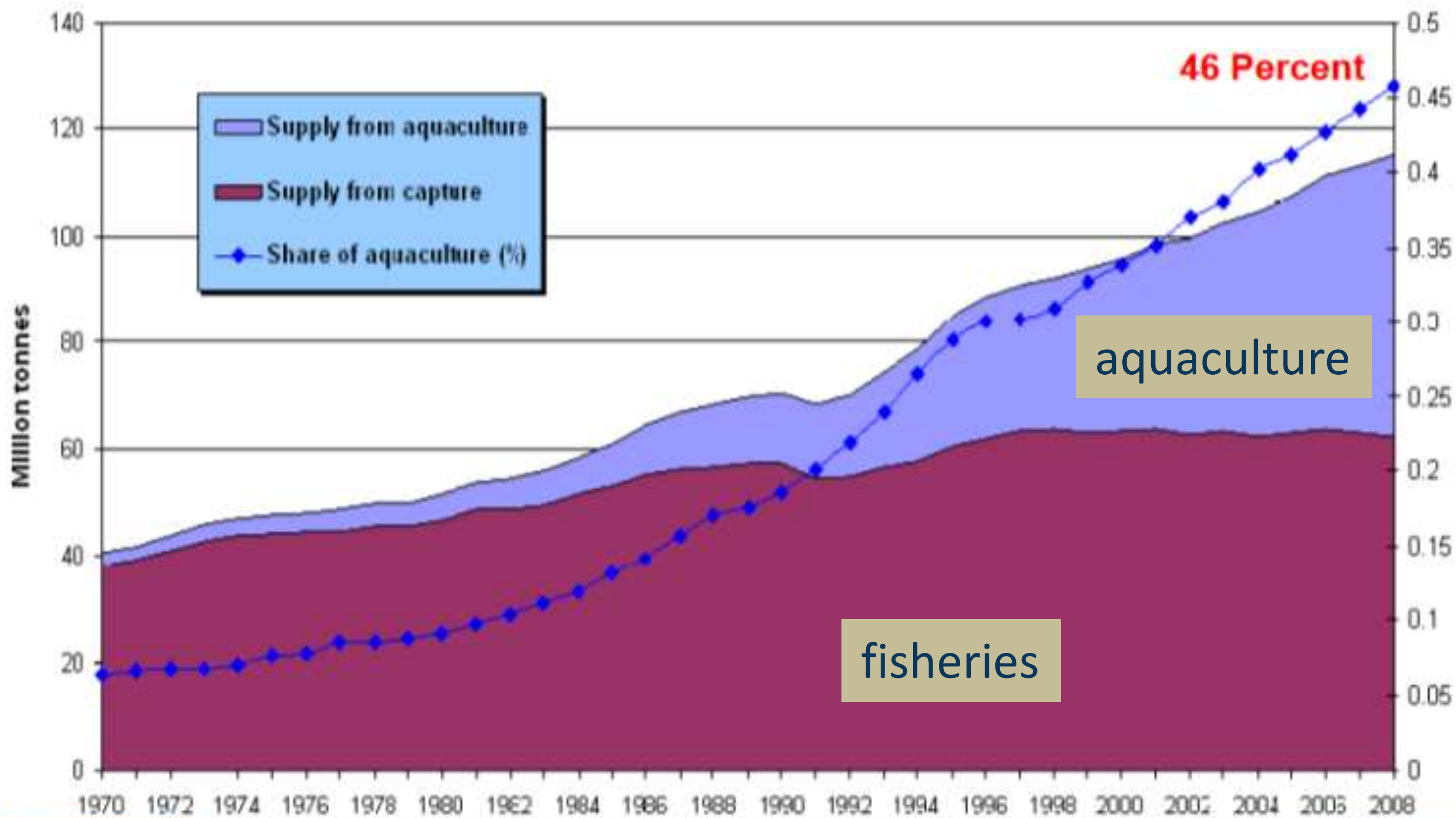
- Decrease risk of asthma
- Decrease risk of cancer
- Important for brain development
- Improve skin conditions
- Cut the risk of diabetes
- Positive influence on dyslexic and hyperactive children
- Improvement of migraine

Seafood sources



Variety in fishing techniques

Contribution of aquaculture to world fish consumption

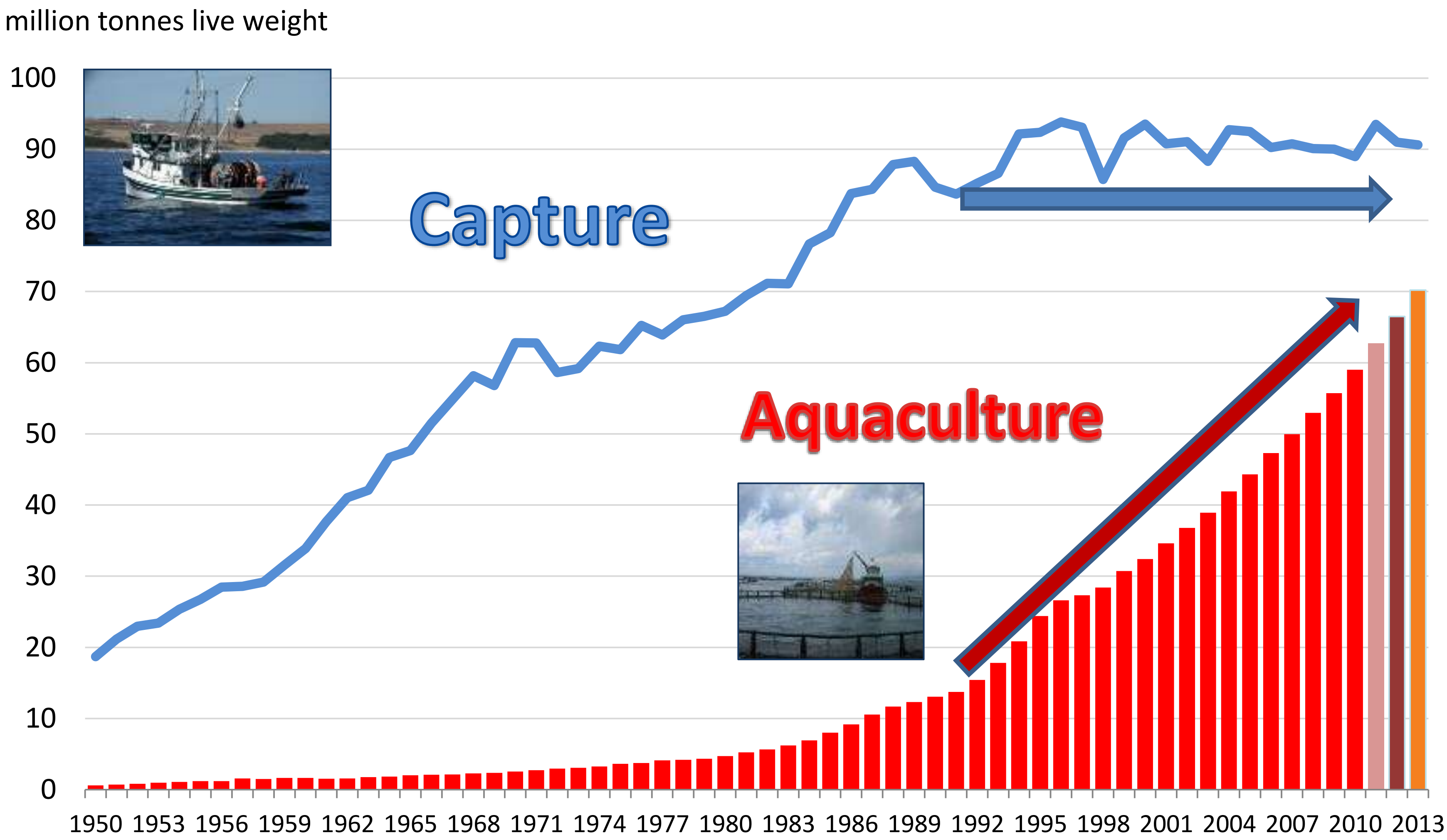


Fan Li, 200 BC

Aquaculture =

intervention of man
in the production process
of aquatic organisms

Seafood sources




fish 42 mT (63% in value)
Courtesy John Bostock

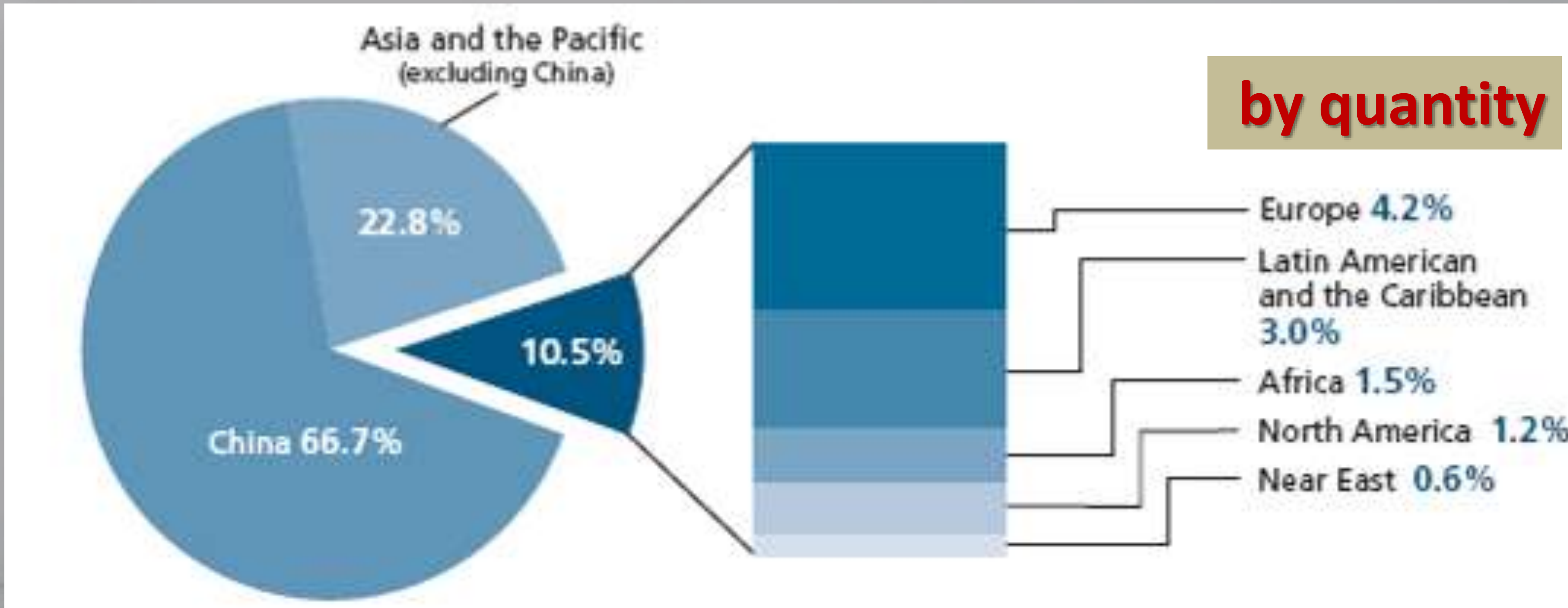

molluscs 14 mT (12 % in value)

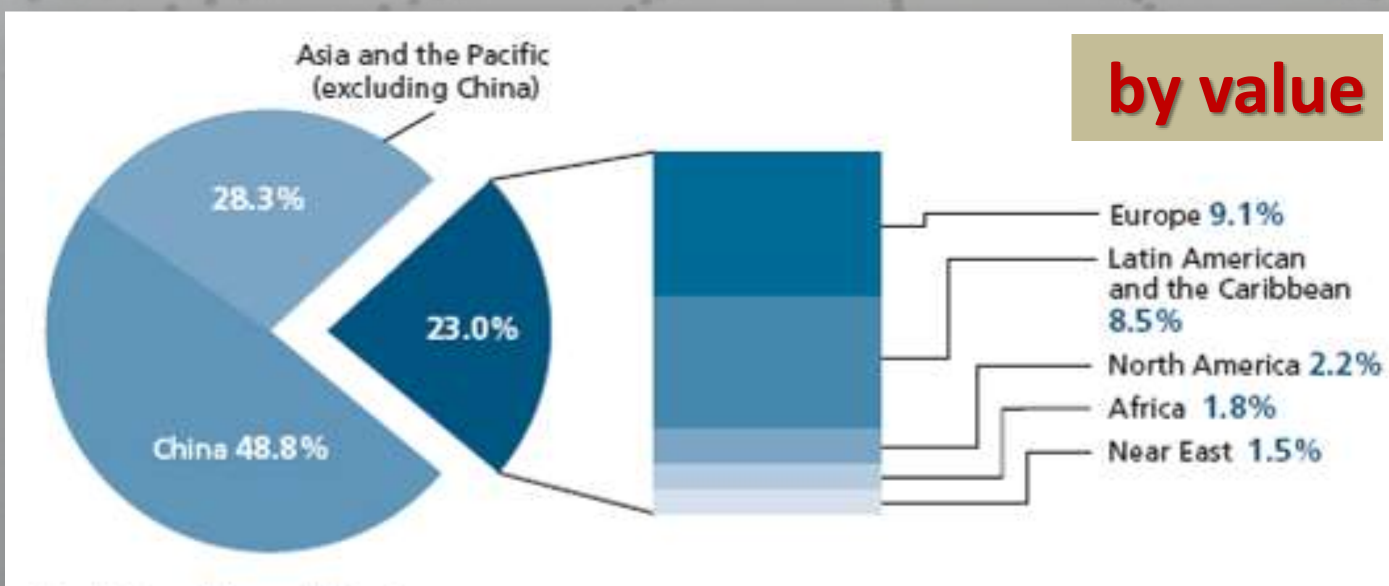
FAO, 2013


crustaceans 6 mT (21% in value)


seaweeds 21 mT (4% in value)
Courtesy Ferenc Lévai

Aquaculture production per region





Note: Data exclude aquatic plants.

FAO, 2009

FOOD versus BUSINESS aquaculture

FOOD aquaculture

Asia, esp. China
- long history
- large production
- integrated farming

BUSINESS aquaculture

Recent developments (since 1960s)
- Japan, later Europe, America's, etc
- successful new industry
- monoculture

Integration livestock - fish

Small scale goat rearing integrated with fish in Subang

Small scale broiler chickens integrated with fish in Sukabumi

Integration crop – fish/prawn/crab

FOOD versus BUSINESS aquaculture

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BUSINESS aquaculture

Recent developments (since 1960s)
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- **successful new industry**
- **monoculture**

BUSINESS aquaculture

biology
technology
profitability

monoculture approach

Predictable availability of fry, fingerlings, postlarvae, seed, spores, ...

Cage systems

12,000 ton/yr salmon farm in Norway

operated by <10 people

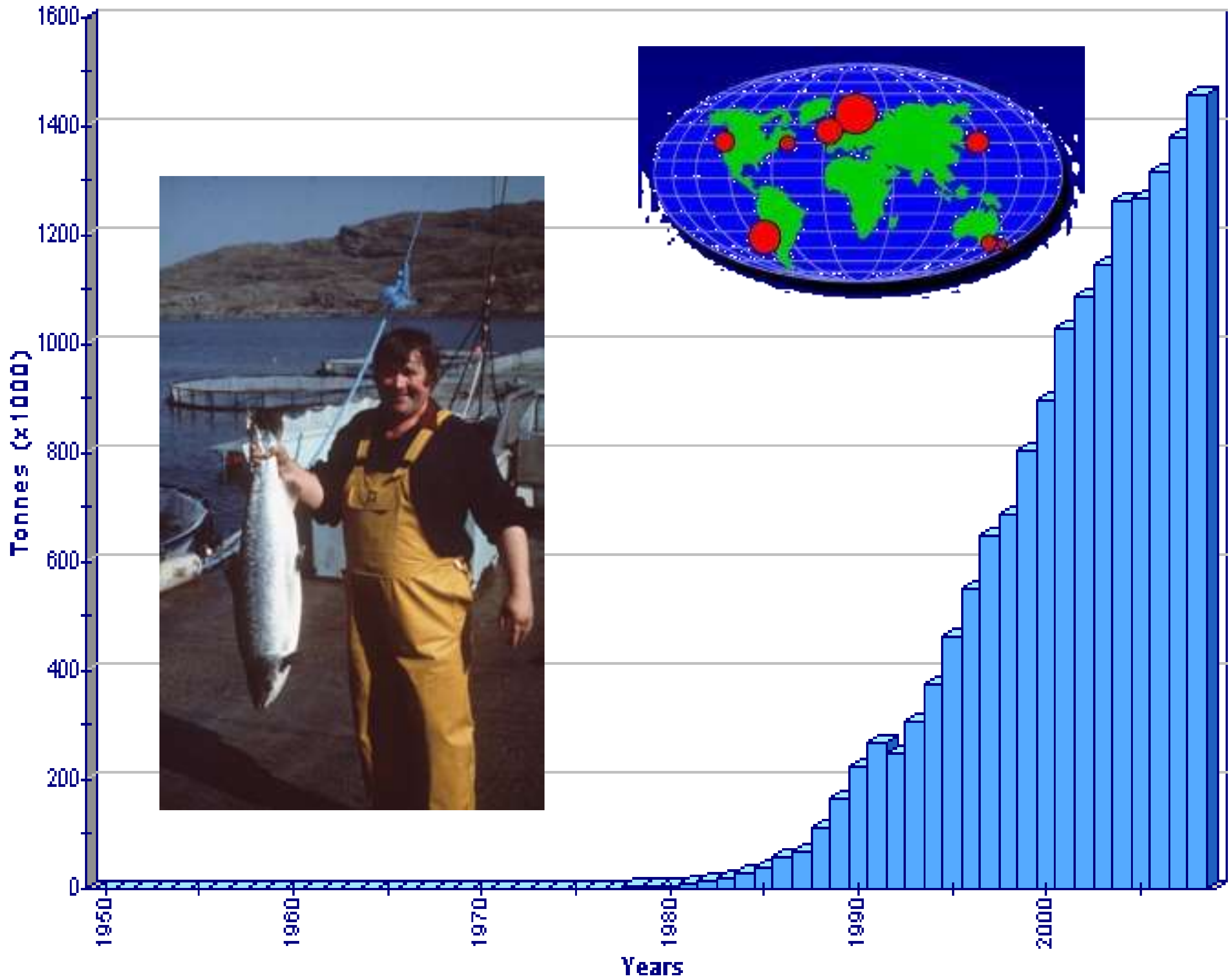
Pond systems

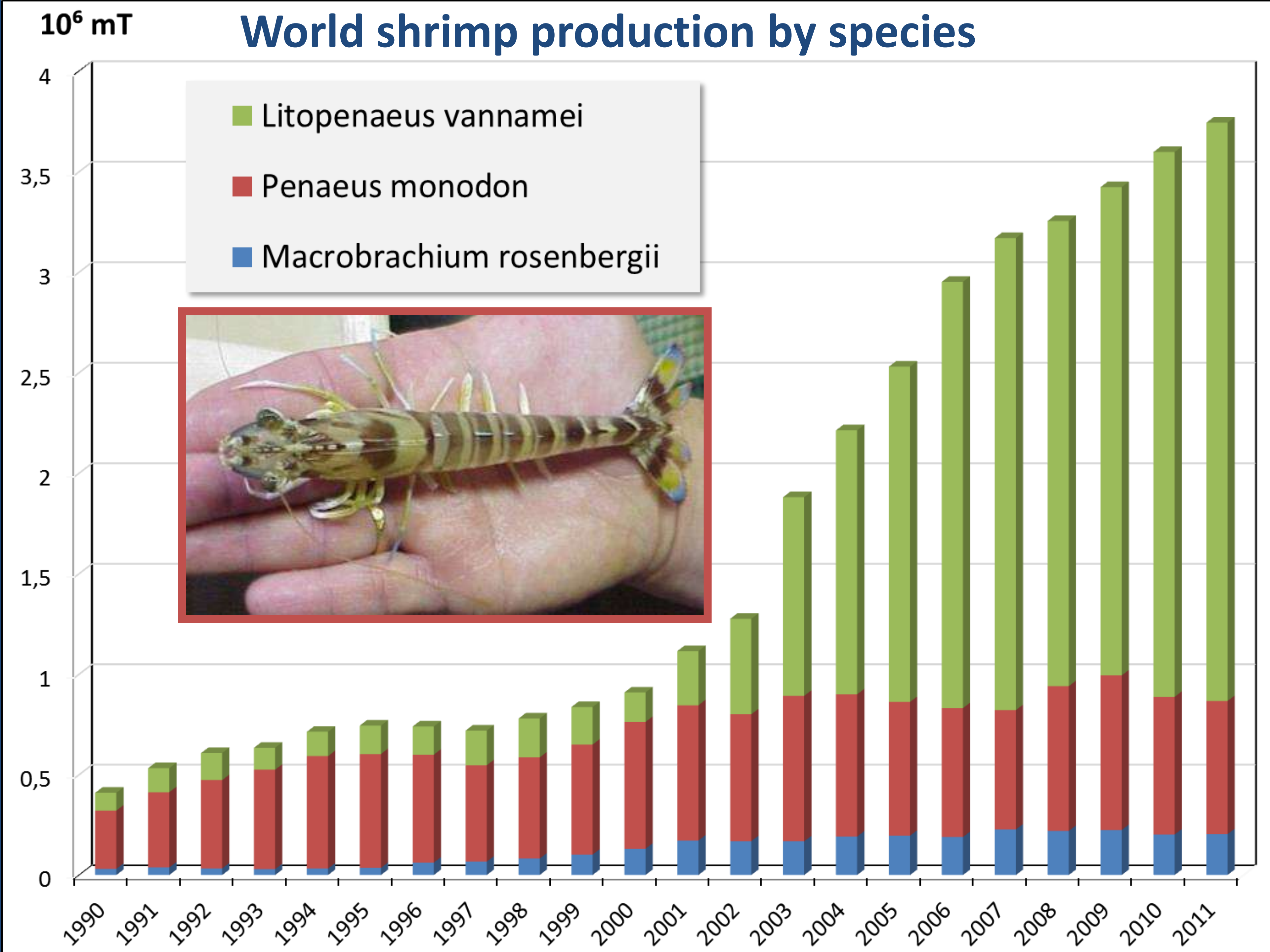
Courtesy Harache

Tank systems

Recirculation systems

WORLD SALMON PRODUCTION

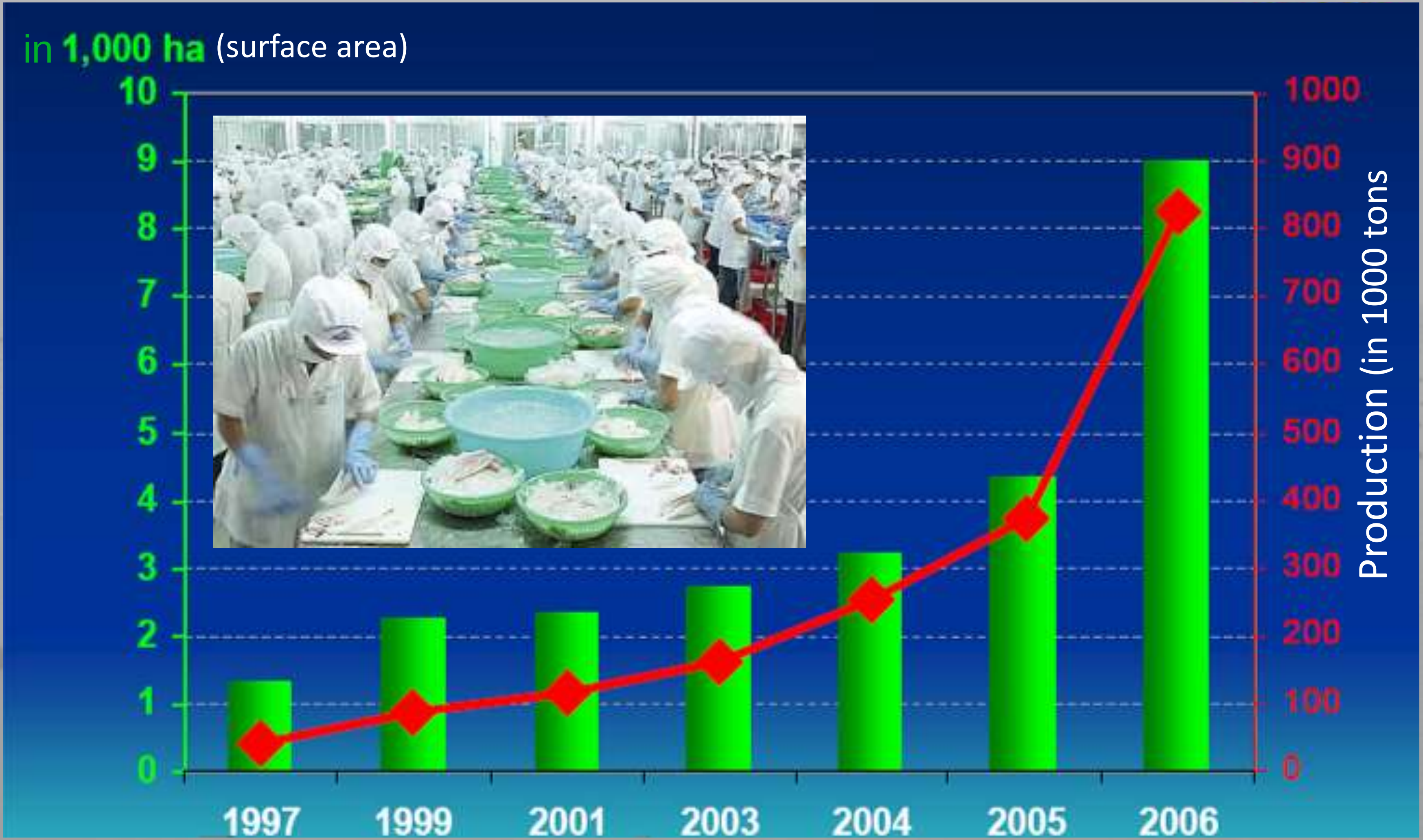



10⁶ mT
World shrimp production by species
Litopenaeus vannamei
Penaeus monodon
Macrobrachium rosenbergii
4
3,5
3
2,5
2
1,5
1
0,5
0
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011

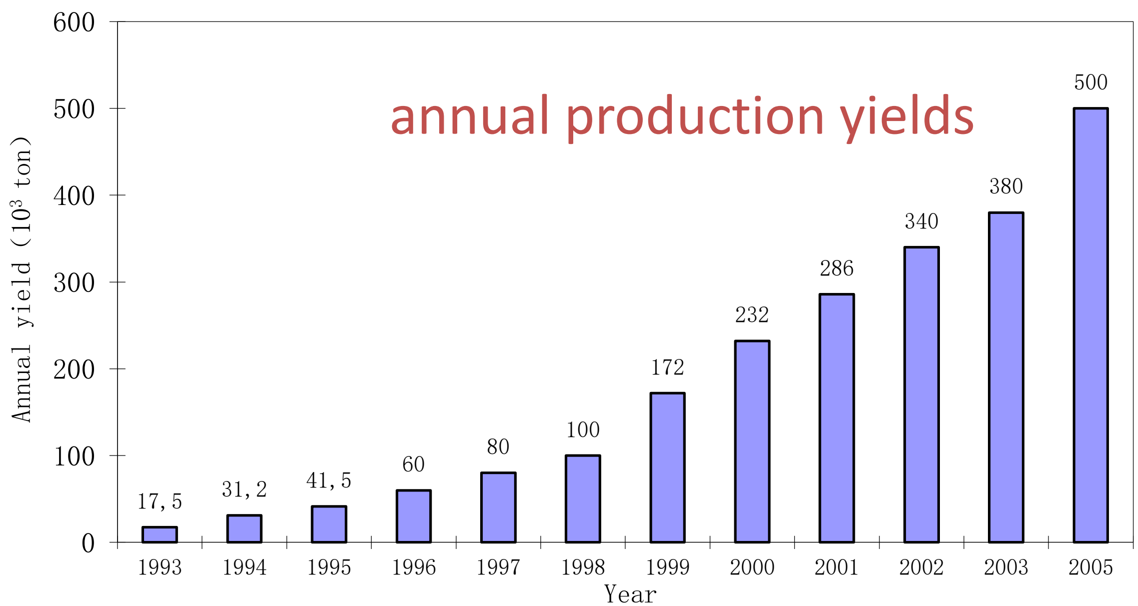
PANGASIUS CATFISH FARMING IN VIETNAM

> 1,000,000 TONS/YEAR

PANGASIUS CATFISH FARMING IN VIETNAM



Slide 9


annual production yields
Annual yield（10³ ton）
Year
600
500
400
300
200
100
0
17, 5
31, 2
41, 5
60
80
100
172
232
286
340
380
500
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2005

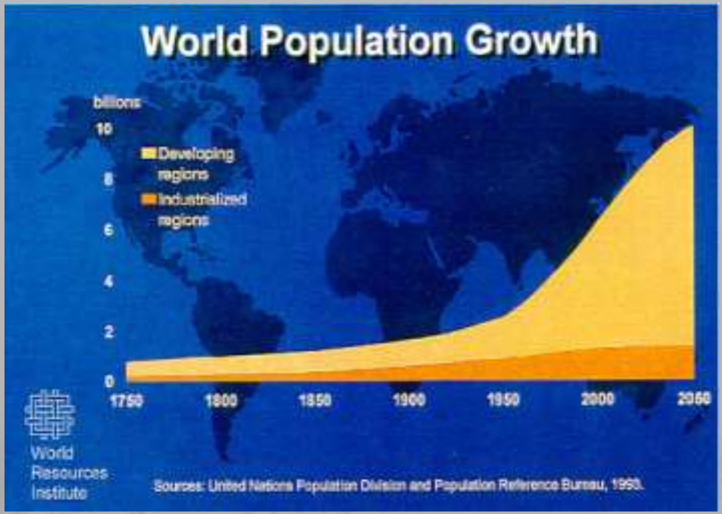
scallop farming

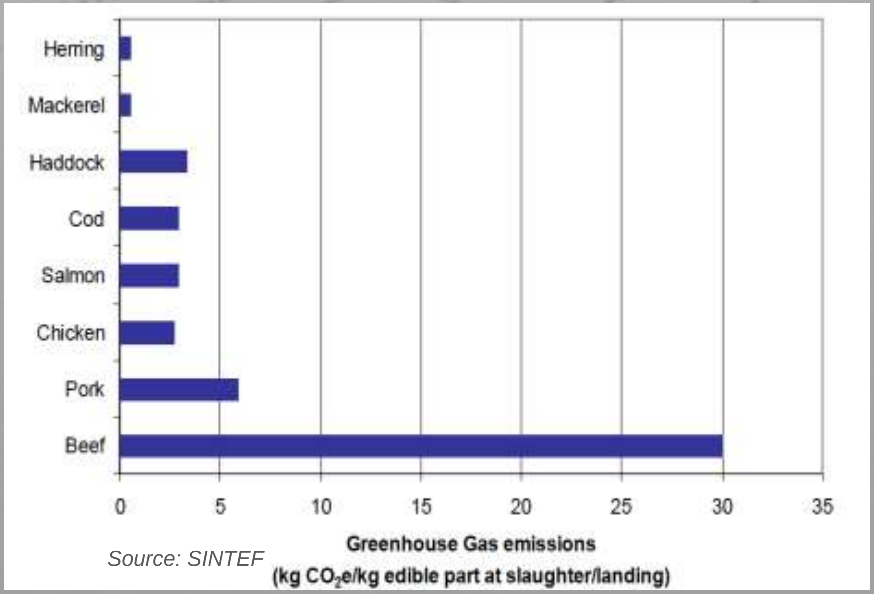
mollusc farming: 14 million ton / year

red and brown
algae farming in China

seaweed farming: 21 million ton / year

Population growth puts pressure on food resources



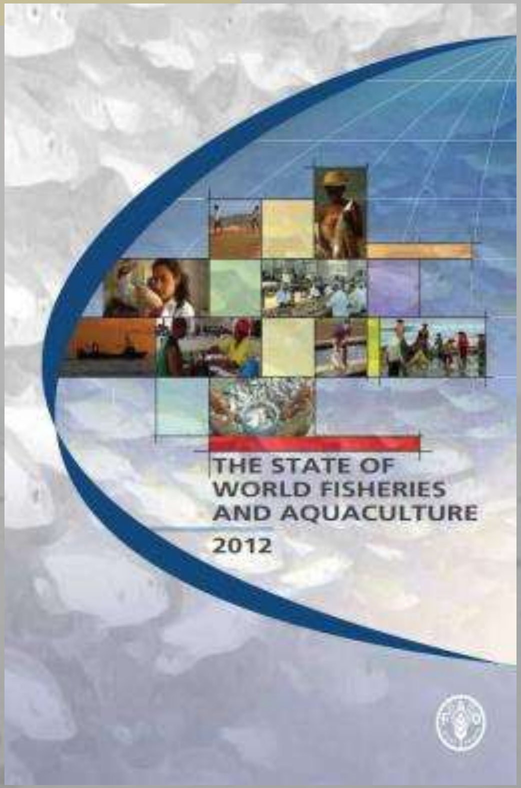


- Global population growth is leading to increased demand for food **(+70% by 2050)** and pressure on natural food resources.
- Animal livestock alone will not be capable to meet the need of 70% more proteins, due to its highly negative ecoprint.
- Terrestrial farming will need 30% more land to meet increased demand. By 2030, a lack of fresh water for agriculture is likely.

(source: FAO)

Challenges, threats & opportunities for future aquaculture

Ten years from now, aquaculture will need to produce **50 %** more per year than current annual production



ISSUES AT STAKE

- **Food security**
- **Food safety**
- **Western versus Asian industry approach**
- **Industry consolidation versus small farmers subsistence**
- **Level-playing field**
- **Fair business for small farmers in Asia**
- **Sustainability : economical, ecological, energy, resources**

Global Conference on Aquaculture 2010

Priorities for future aquaculture

from an **empiricial** approach
towards
a **knowledge-based** bio-industry

AQUACULTURE :
BLUE BIOTECHNOLOGY OF THE FUTURE ?

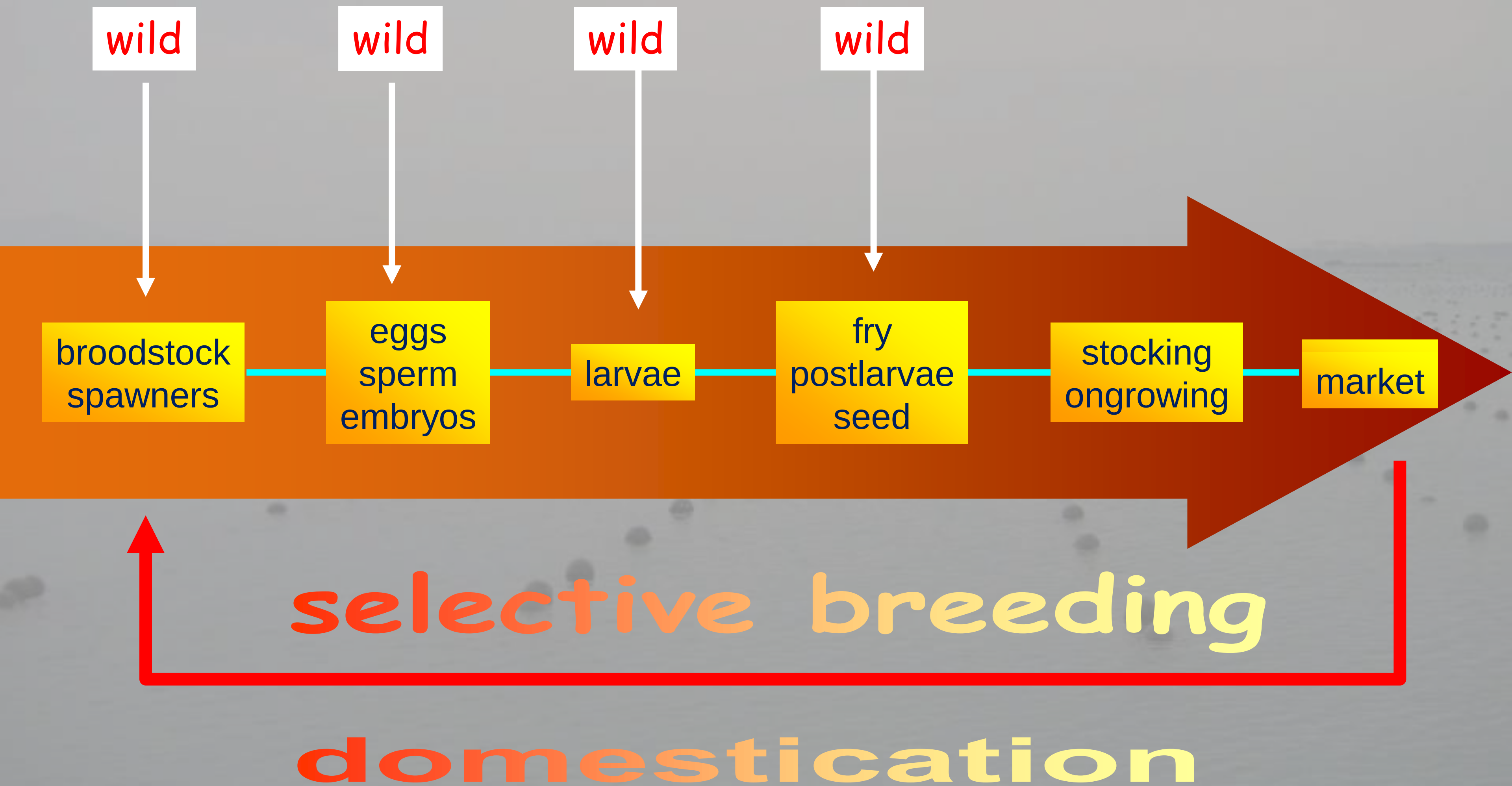
resulting in **new concepts & products**
for a sustainable aquaculture

Priorities for future aquaculture

- Complete independence from natural stocks through **DOMESTICATION**
- Improved / more cost-effective **SEED PRODUCTION**
- Better targeted **SPECIES SELECTION**
- Development of more efficient stocks through **SELECTIVE BREEDING**
- More **MICROBIAL MANAGEMENT** for more sustainable production
- Better understanding of **IMMUNE SYSTEMS** in vertebrates and invertebrates
- More **INTEGRATED PRODUCTION SYSTEMS** for plant and animal farming
- **COASTAL AND OFF-SHORE FARMS** of food and energy
- Full independence from fisheries stocks for **LIPID AND PROTEIN INGREDIENTS** in aquatic feeds
- More attention for **INTEGRATION** of restocking activities with **FISHERIES** management
- **SOCIETAL LEVERAGE:**
    - multi-stakeholder interaction
    - international cooperation on a win-win basis

Priorities for future aquaculture

Complete independence from natural stocks through **domestication,** opening the way for **selective breeding** programs



Priorities for future aquaculture

Improved / more cost-effective **SEED PRODUCTION**

Predictable **&** ***cost-effective*** **availability of *high-quality* fry, fingerlings, postlarvae, seed, spores, ...**

THE key to successfull aquaculture !

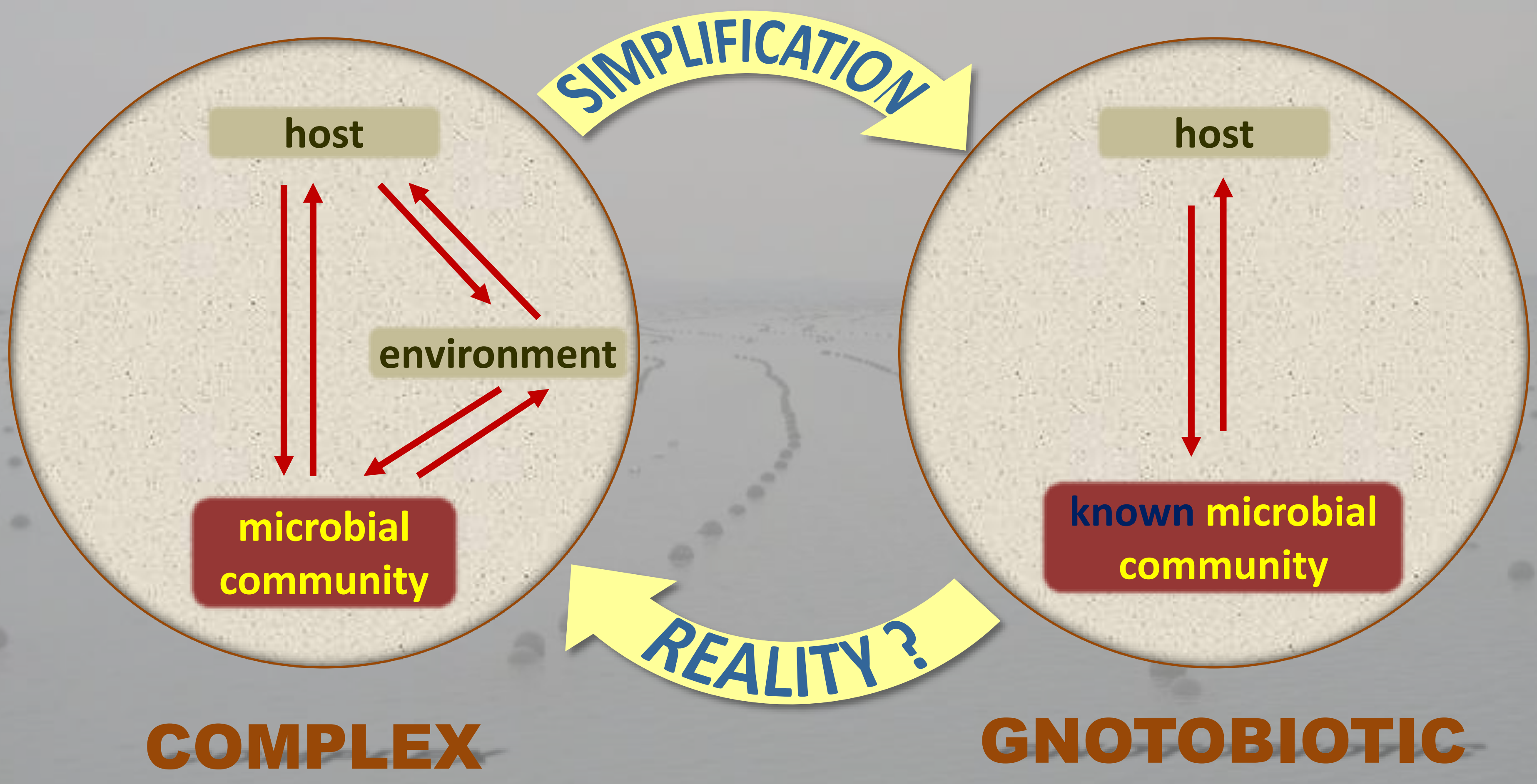
Priorities for future aquaculture

Improved / more cost-effective **SEED PRODUCTION**

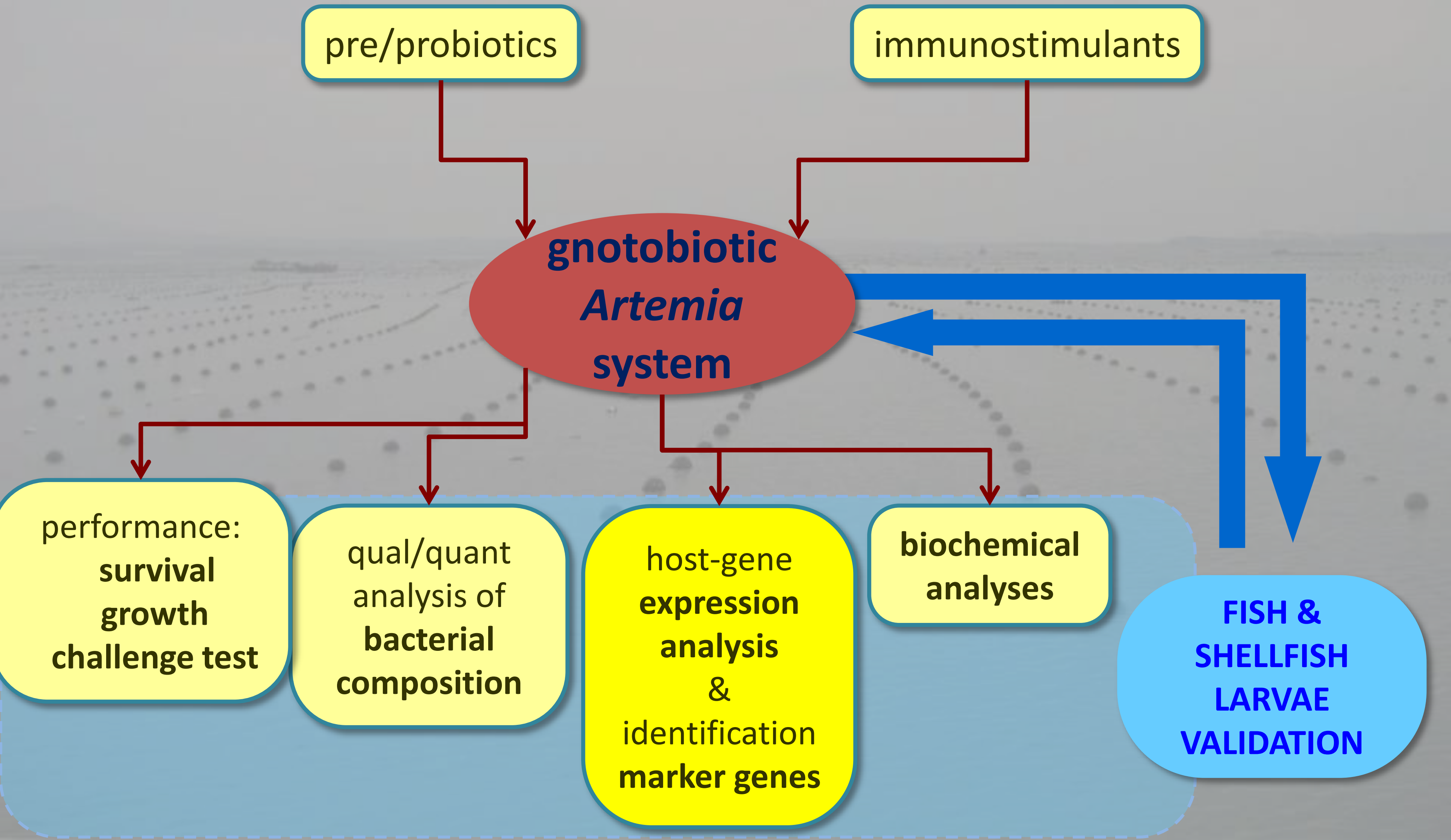
example:
Sea bass/bream larviculture in the Mediterranean

- annual production of 1 billion fry
- market value of 15 Euro cents a piece
- average survival 20 % by day 60
- low survival = critical bottleneck for future cost efficiency and sustainability of the industry
- microbial interference considered to be the main culprit
- no selected breeds available yet

NEW APPROACH IN THE STUDY OF HOST-MICROBE INTERACTIONS



Development of innovative microbial management systems



ARTEMIA AS MODEL SYSTEM IN LARVICULTURE RESEARCH

- **host-microbe interactions**

→ ***Influencing microbial numbers or activity***

  - ❑ quorum sensing / quorum quenching
  - ❑ Poly-β-hydroxybutyrate

→ ***Stimulating the host's immune response***

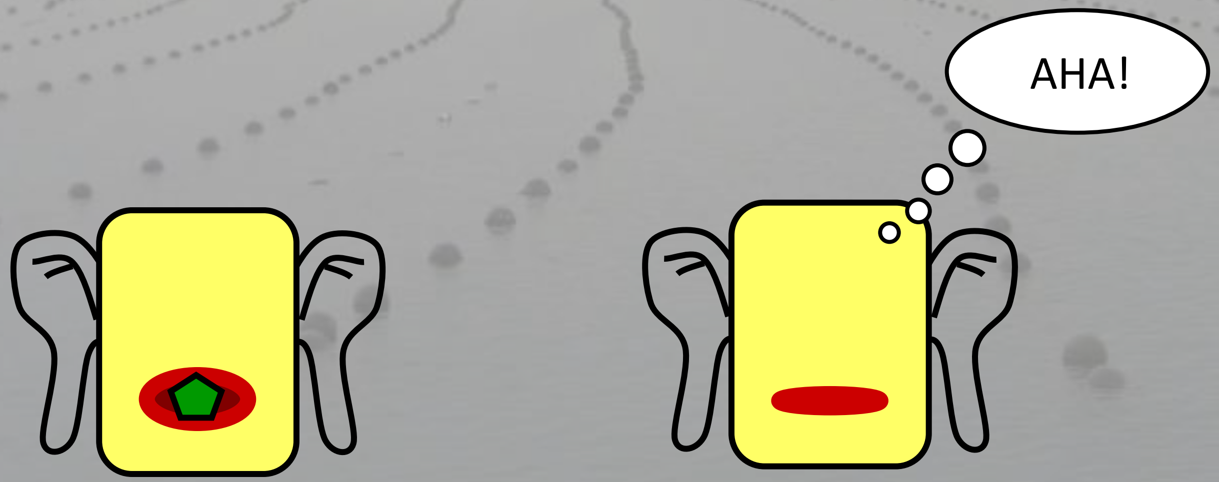
  - ❑ heat shock proteins
  - ❑ yeast cell wall-bound glucan

Quorum Sensing (QS)

bacteria **sense and respond** to environmental changes

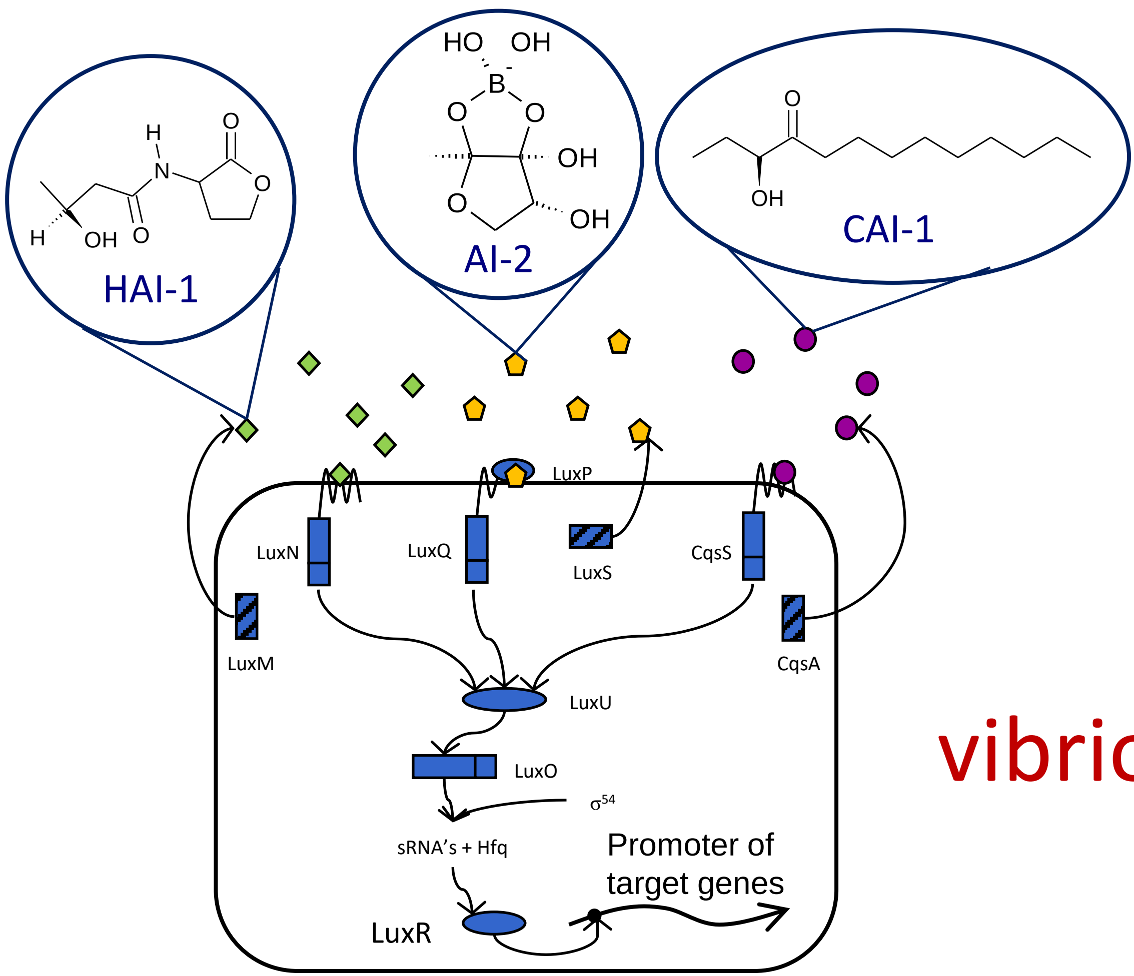
and to each other through **extracellular**

signal molecules ≈ hormones in higher organisms



Presence of QS signal molecules affects gene expression

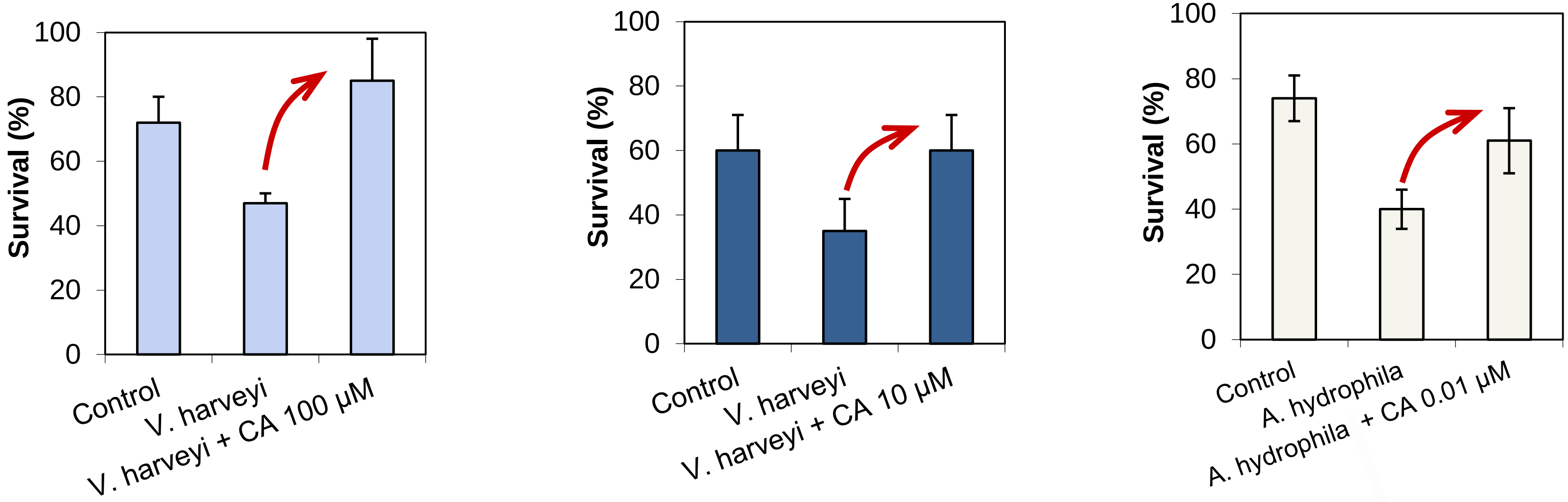
f.ex. virulence factors (biofilm formation, toxin secretion, etc.)



vibrios

QS-disruption to control bacterial infections

- ❑ **use of QS inhibitors** (e.g. plant extracts)
- ❑ degradation of QS signals by other bacteria



Artemia
Vibrio harveyi

Macrobrachium
Vibrio harveyi

Burbot
Aeromonas hydrophila

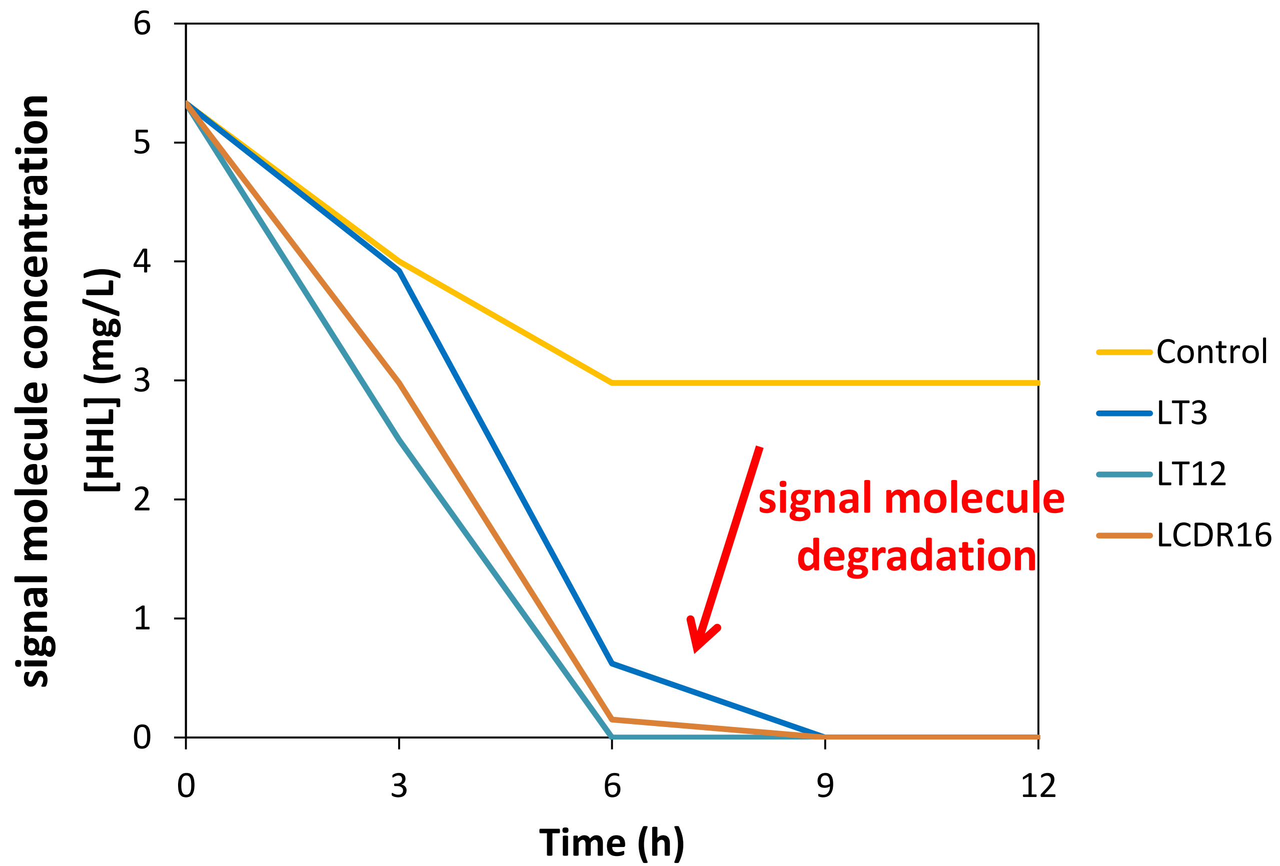
Crustaceans: 10-100 µM

Fish: 0.01 µM

QS-disruption to control bacterial infections

☑ use of QS inhibitors (e.g. plant extracts)

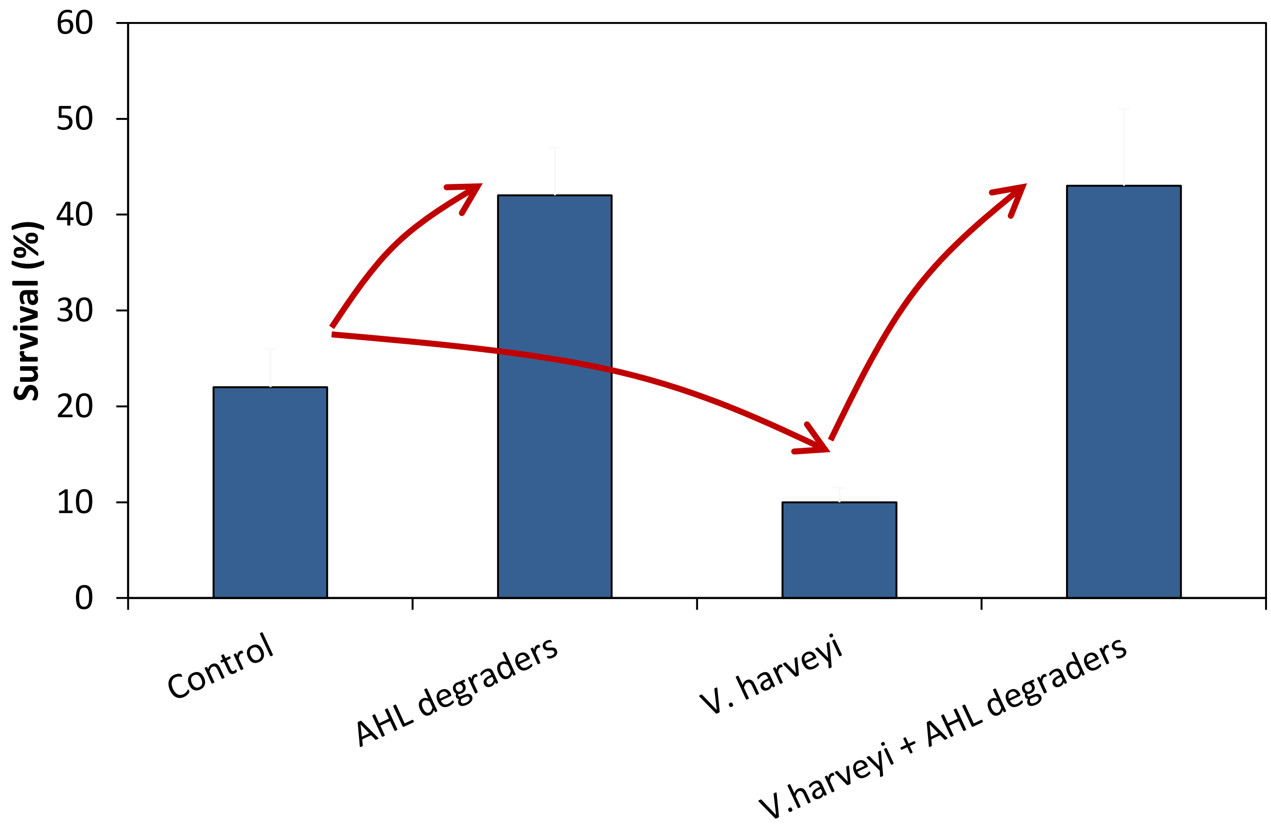
❑ **degradation of QS signals by other bacteria**
f.ex. *Bacillus* strains isolated from aquatic organisms



QS-disruption to control bacterial infections

☑ use of QS inhibitors (e.g. plant extracts)

❑ **degradation of QS signals by other bacteria**
use of signal-degrading probionts in *Macrobrachium* larviculture

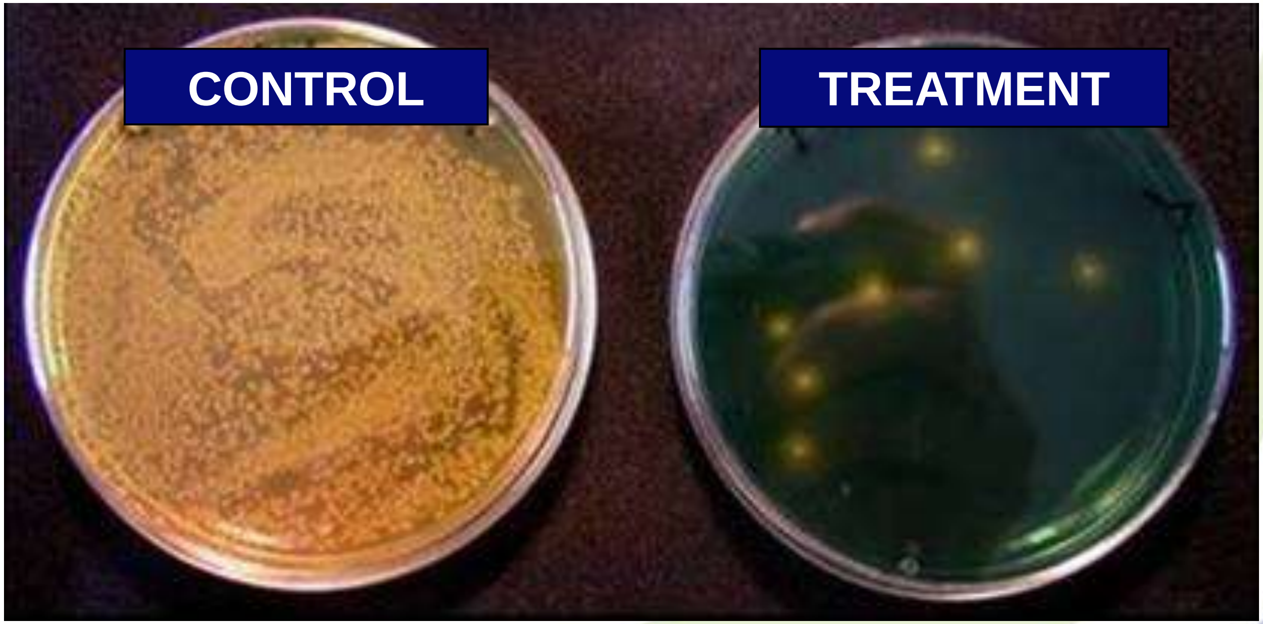


NOVEL MICROBIAL CONTROL STRATEGY FOR ROTIFERS IN FINFISH HATCHERIES

Sanocare® SURE POWDER

Tests - rotifers

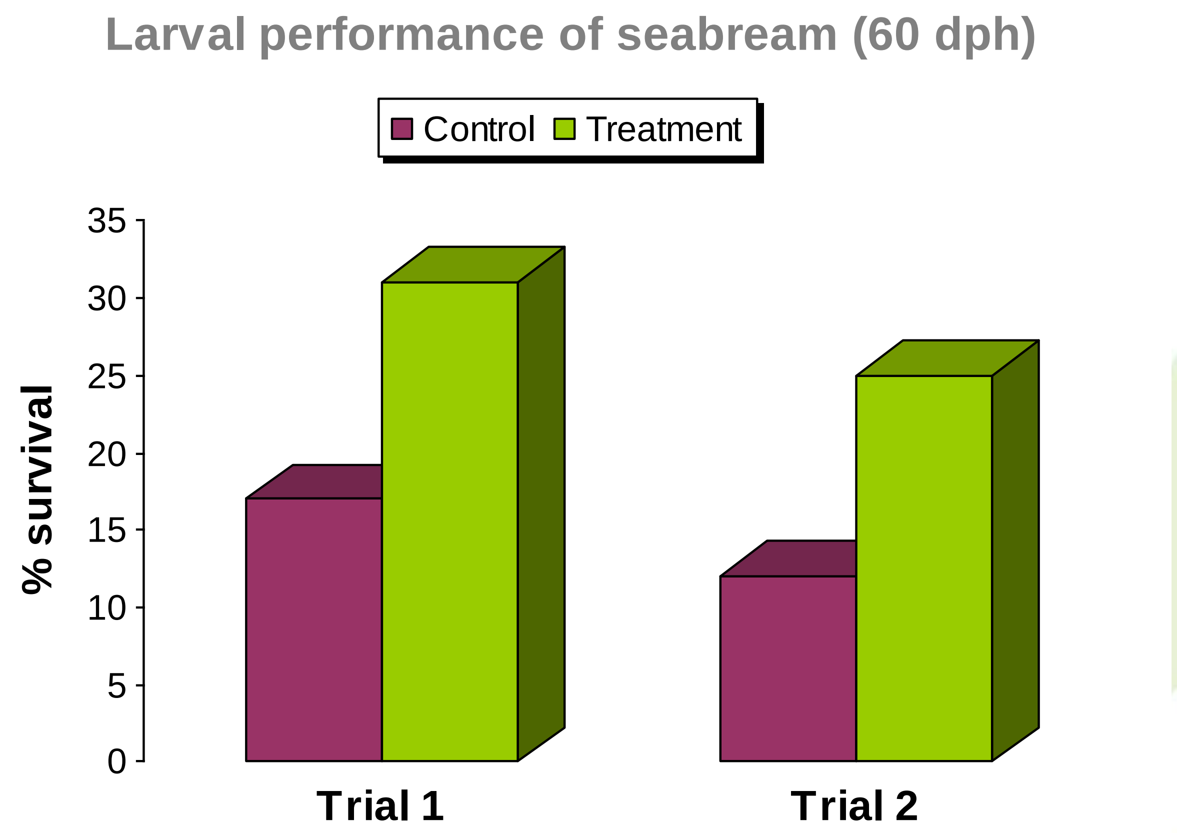
- **Bacterial load**
  - Total of heterotrophic bacteria was determined by platings on Marine Agar medium
  - Total of *Vibrio* was determined by platings on TCBS medium



Test results - seabream

- **Increased survival rate**

Effect on performance of seabream larvae was determined in 2 consecutive trials (no replicates).



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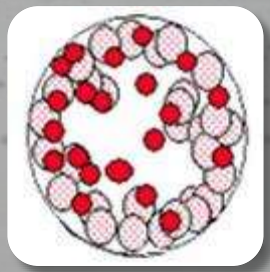
→ ***Stimulating the host's immune response***

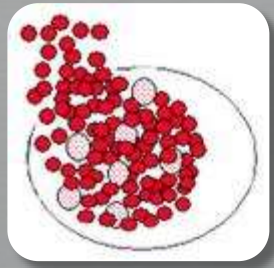
- ❑ heat shock proteins
- ❑ yeast cell wall-bound glucan

Heat shock proteins (Hsps)

- ✓ highly conserved proteins, available in all living cells
- ✓ Induced after exposure to stressors (heat, cold, O_2 deprivation, radicals, disease etc)

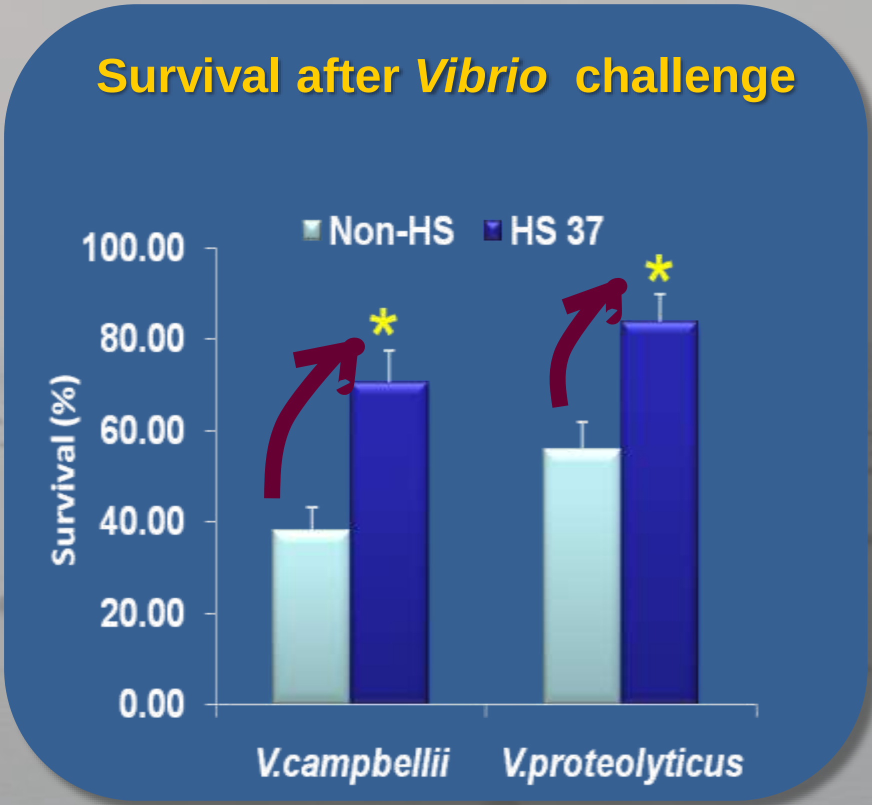


- ✓ Inside the cell, act as molecular chaperones – assist in protein biogenesis and degradation



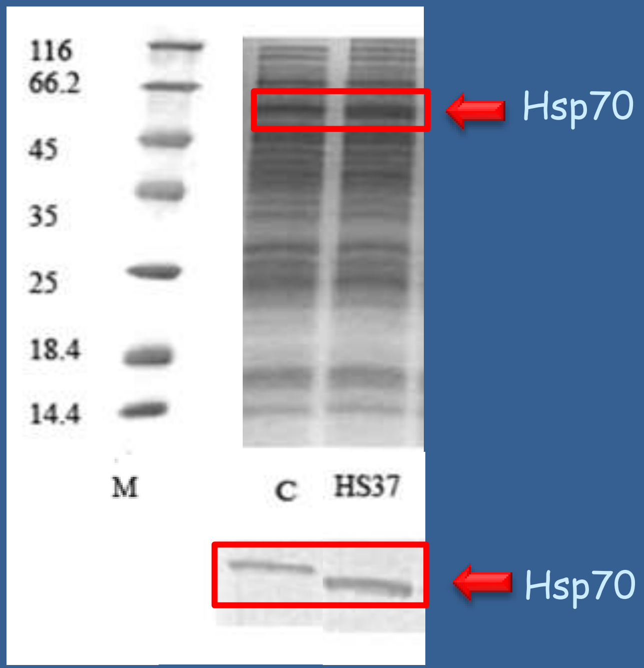
- ✓ Extracellular Hsps serve as danger signals and modulate both innate and adaptive immune responses

Hsps effects in *Artemia - Vibrio* challenge test

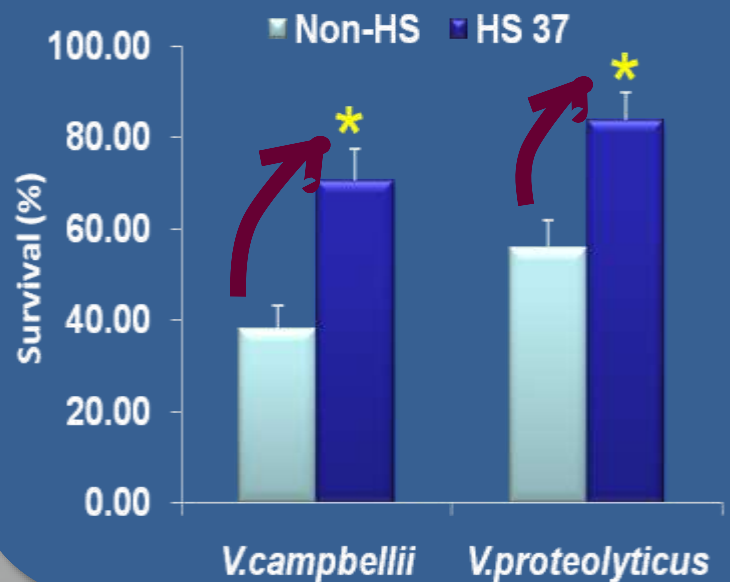


Hsps effects in *Artemia* - *Vibrio* challenge test

Endogenous Hsp accumulation



Survival after *Vibrio* challenge

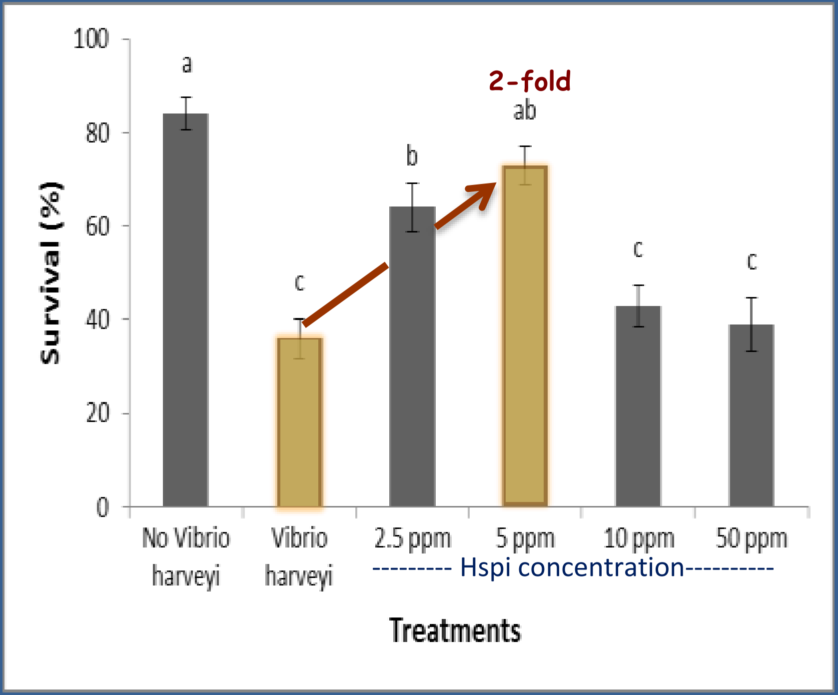


Correlation exists between enhanced protection and Hsp70 accumulation new concept: **use of Hsp-inducing compounds**

- ✓ heat shock is not an ideal way to enhance Hsps in aquaculture
- ✓ less traumatic approaches are needed to manipulate Hsps expression
- ✓ can compound(s) extracted from plants induce Hsp70 in aquaculture animals?
- ✓ can they confer protection against stress and disease ?

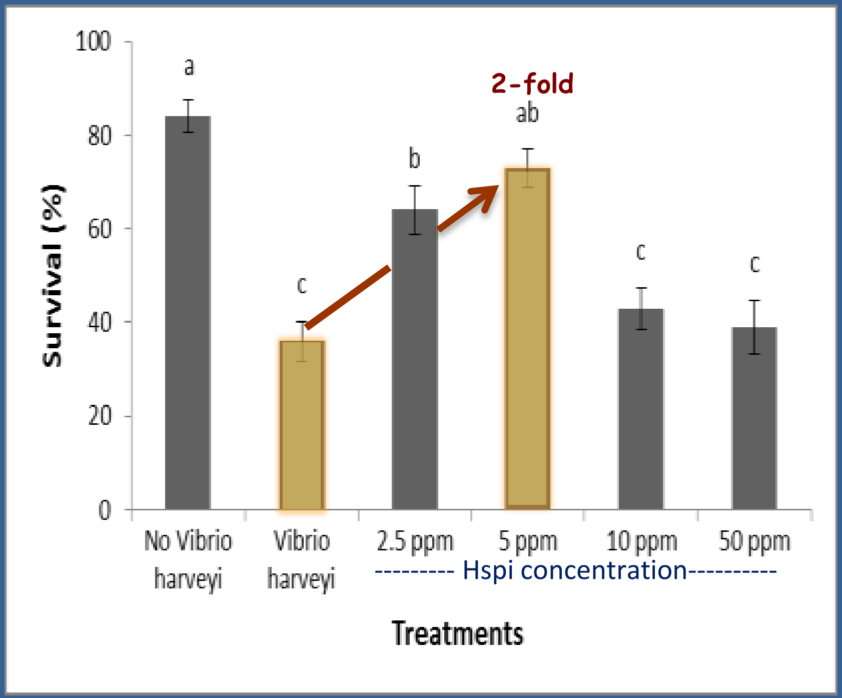
Protective effect of Hsp-inducing compounds against *Vibrio harveyi*

Survival after *Vibrio* challenge

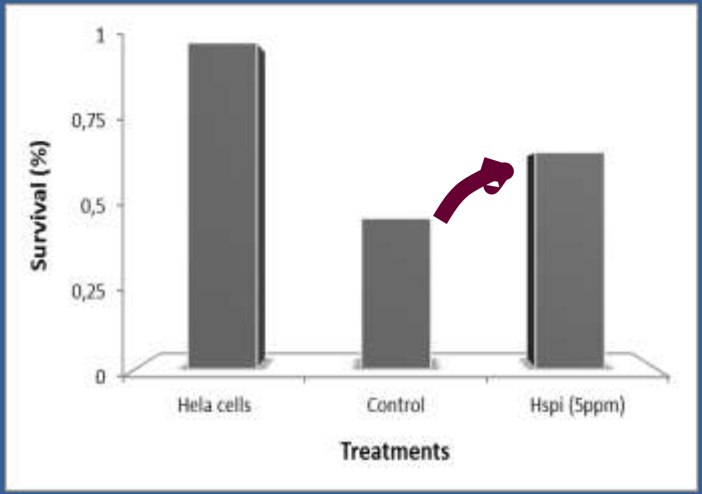


Protective effect of Hsp-inducing compounds against *Vibrio harveyi*

Survival after *Vibrio* challenge

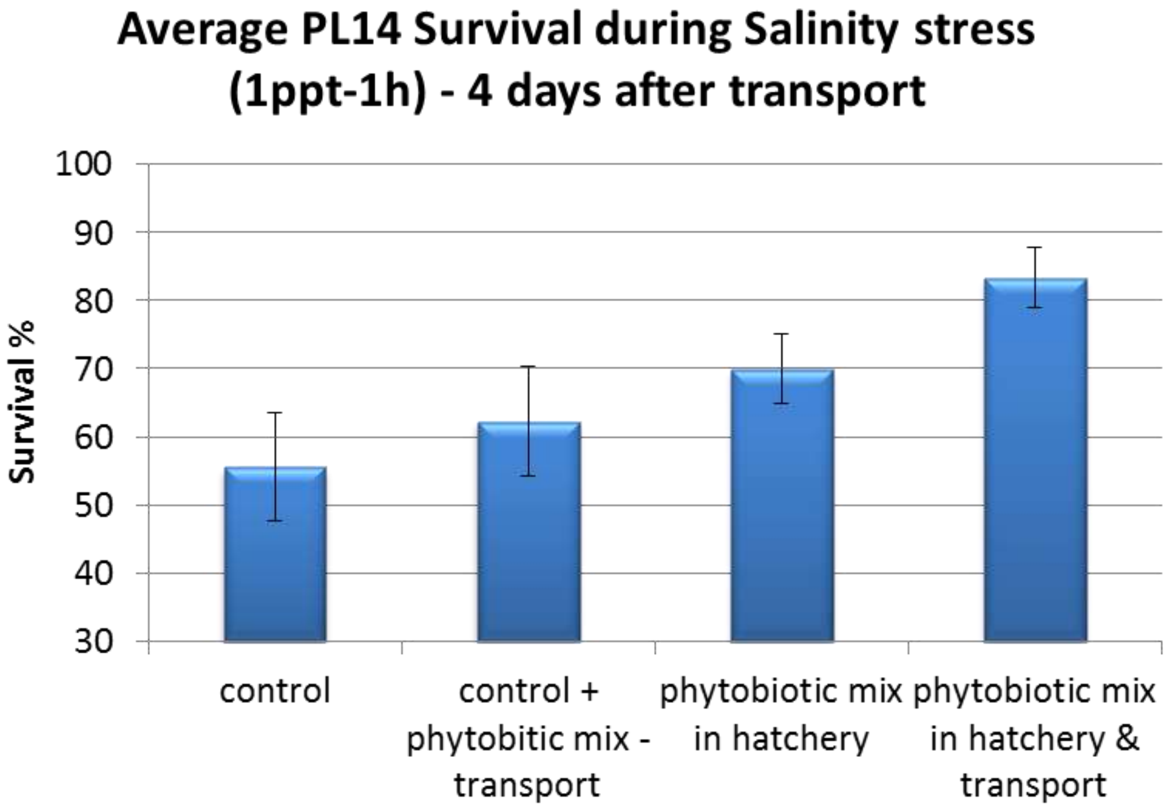


Induction of Hsp70



Hatchery health protocols:
New HSP technology increases stress resistance

Application phytochemical mix prior/during transport



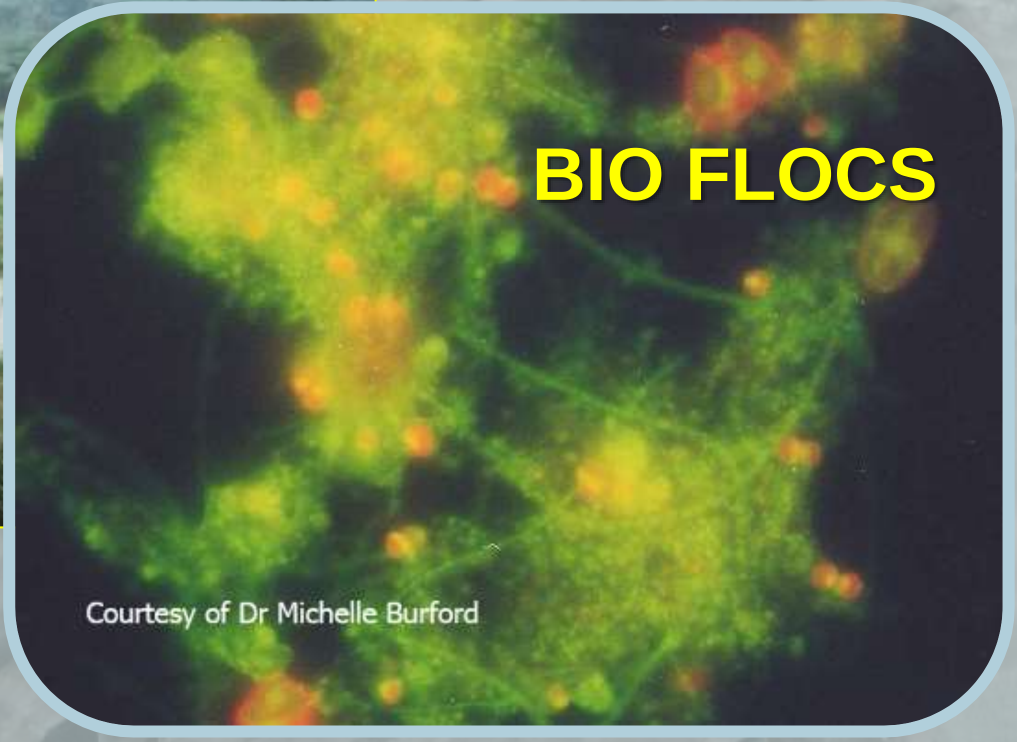
PL transport trial

Global Conference on Aquaculture 2010

Priorities for future aquaculture

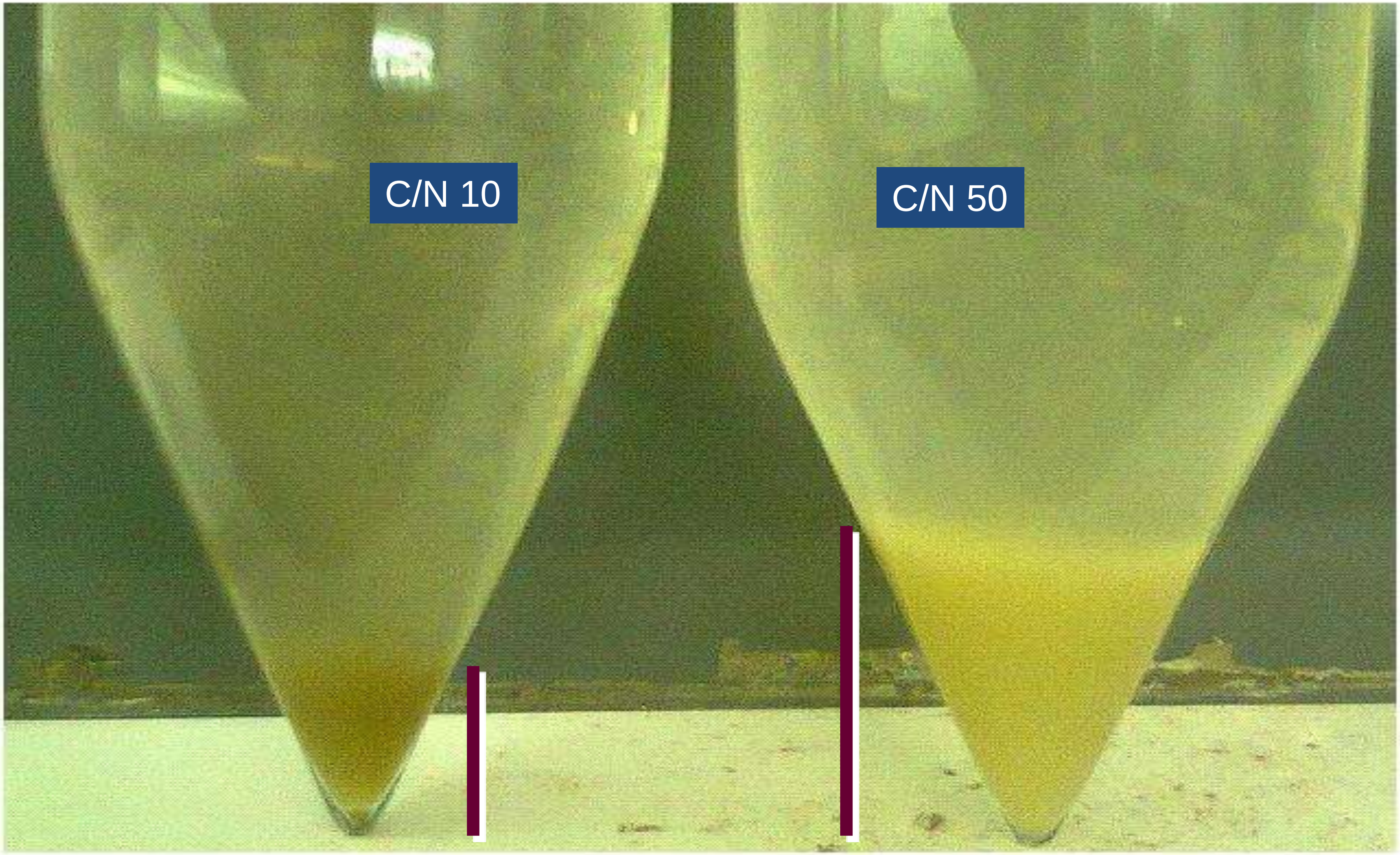
more **MICROBIAL MANAGEMENT** for more sustainable production

> 40 mT of fish & shrimp are produced in ponds



What is the role of the microflora ?

Recent documentation:
30 % N contribution from bio flocs !



Volume of bioflocs formed per day in different C/N regimes


Production

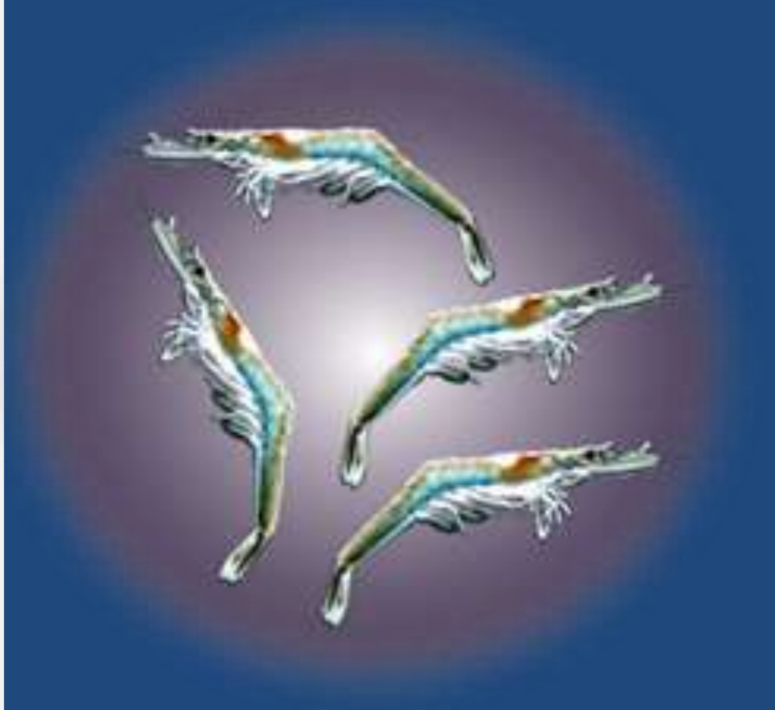
Do current pond culture practices sustain Early Mortality Syndrome in shrimp farming?

Redrafted after: De Schryver et al. (2014) Early Mortality Syndrome Outbreaks: a Microbial Management Issue in Shrimp Farming? PLOS Pathogens, doi: 10.1371/journal.ppat.1003919

Summary:
The early mortality syndrome (EMS) is without any doubt the most frequently discussed topic in the shrimp culture industry these days. Initiatives such a FAO/MARD Workshop on EM bring together stakeholders in ar formulate suggest to deal with this problem. But coul the currently strategies a appropriate?

Peter De Schryver
Tom Defoirdt
Patrick Sorgeloos

Laboratory of Aquaculture & *Artemia* Reference Center



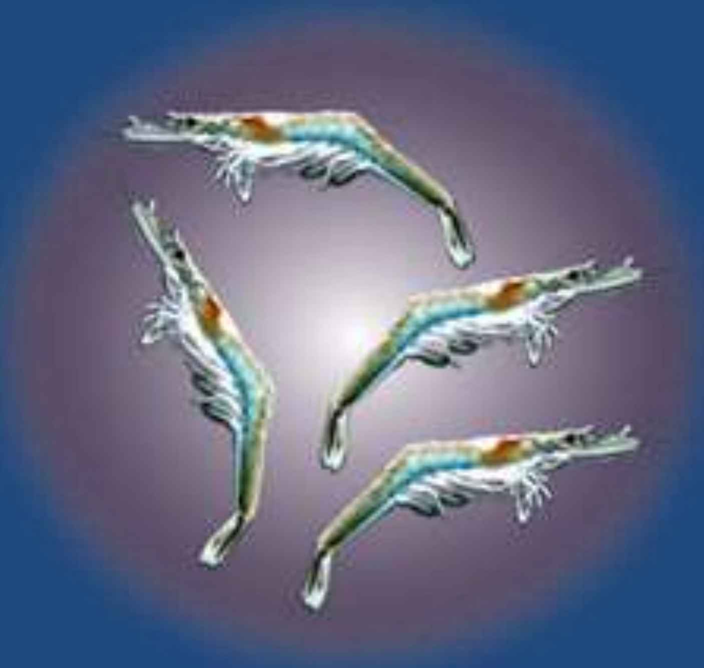
Various Critical - Multifactorial Causes?

microbial diversity & stability compromised?

mature/aged water versus facilitating opportunitistic bacteria (*Vibrio spp.*)

fry/postlarval competence compromised?

production cost savings (dietary treatments, stocking stage, ...)



Various Critical - Multifactorial Causes?

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Microbial control:
Specific pathogens and opportunists

↓ ↓

- Specific pathogens may be stopped by **strong hygienic barriers** into the system: **BIOSECURITY!**

- A lot of the problems in aquaculture caused by naturally occurring opportunistic bacteria that become pathogenic when the host is weakened by environmental stress

- It is possible to set up selection to **outcompete the opportunists!**

Generally one out of two different strategies favoured:

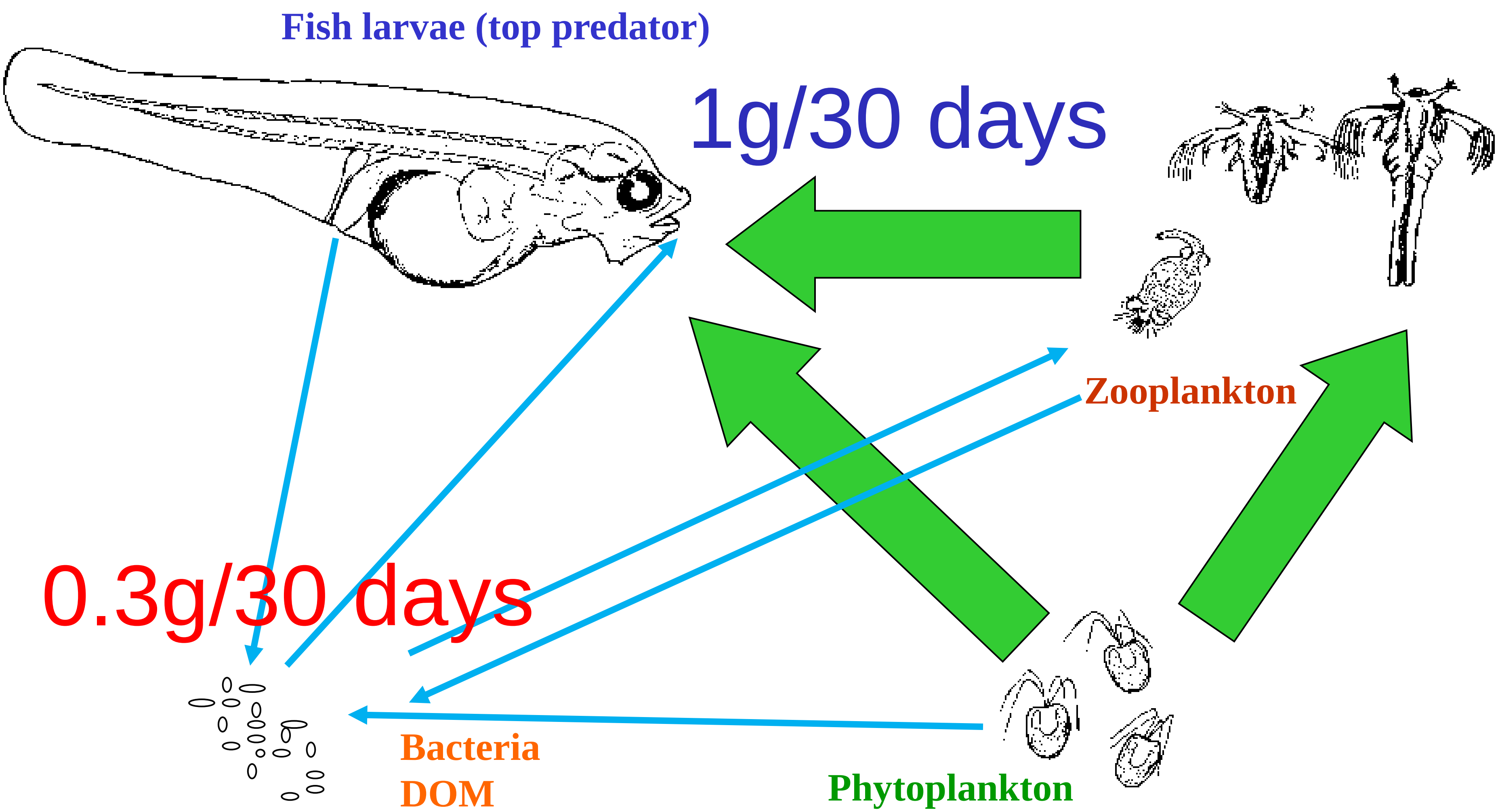
Ecological r/K-theory

Carrying capacity (CC)
= Max biomass/number of bacteria that can be maintained in the system over time

Depends on:
Supply of available organic matter

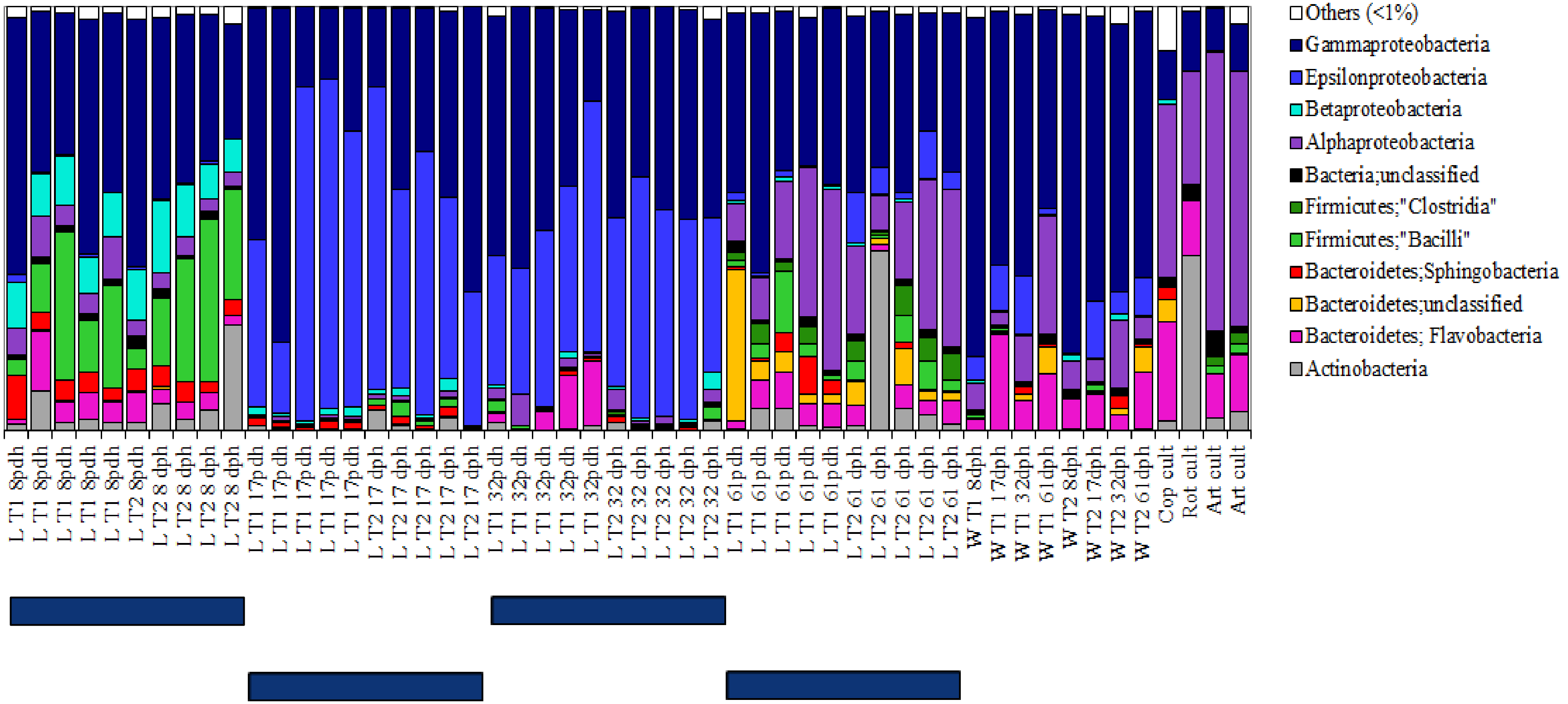
Selection	Environment	Substrate supply / bacteria	Favoured ability	
r-selection	Unpredictable/unstable, Empty niches	High	Rapid reproduction, Fast growth	→ Opportunists
K-selection	Stable or predictable, crowded	Low, Close to CC	Competing on limited resources	→ Specialists

The first-feeding ecosystem: marine fish hatchery



Larval microbial community

Large temporal variation



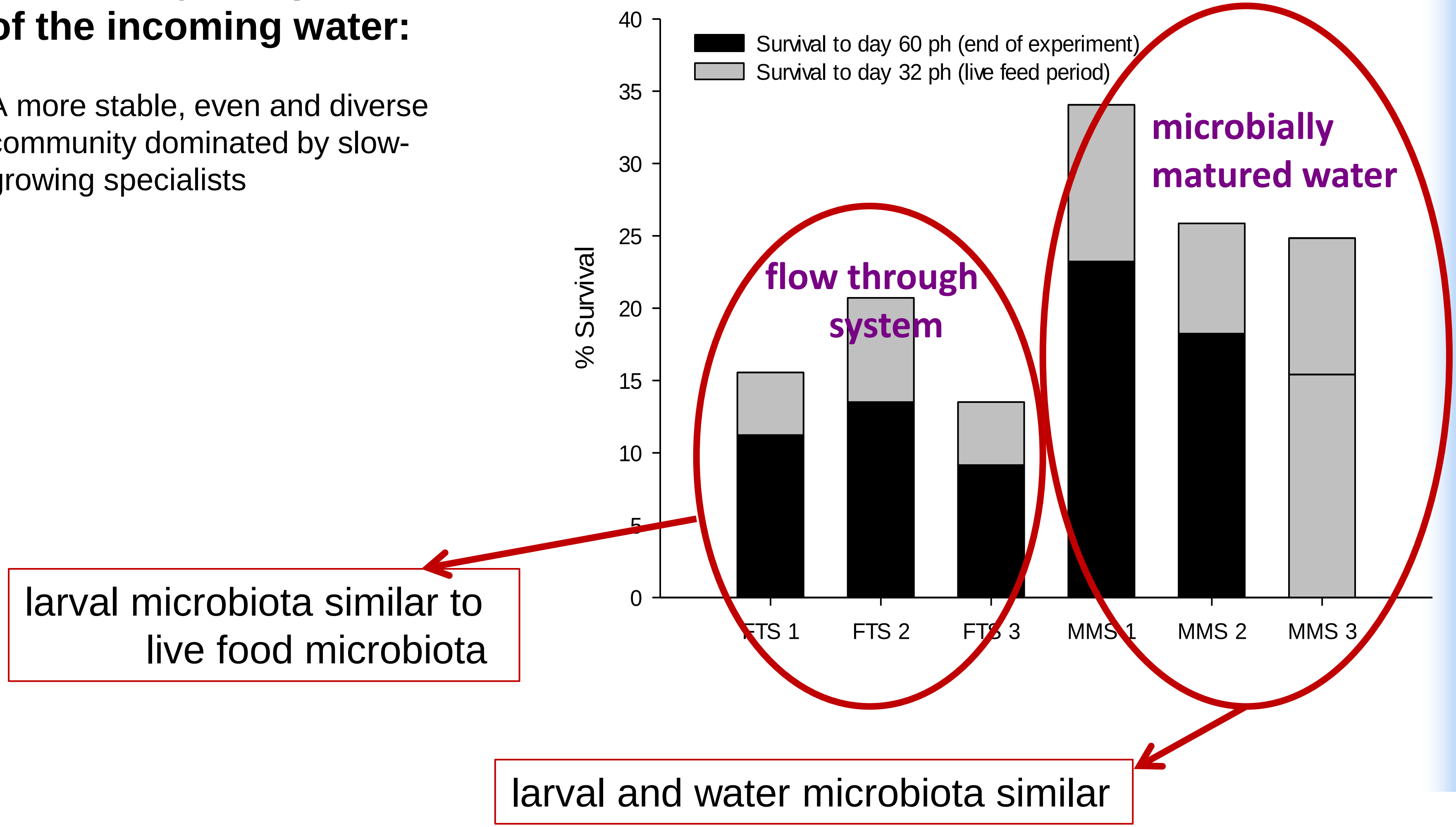
DAH 8 DAH17 DAH32 DAH61

K-selection: Microbial maturation

Effects on the microbial community composition of the incoming water:

A more stable, even and diverse community dominated by slow-growing specialists

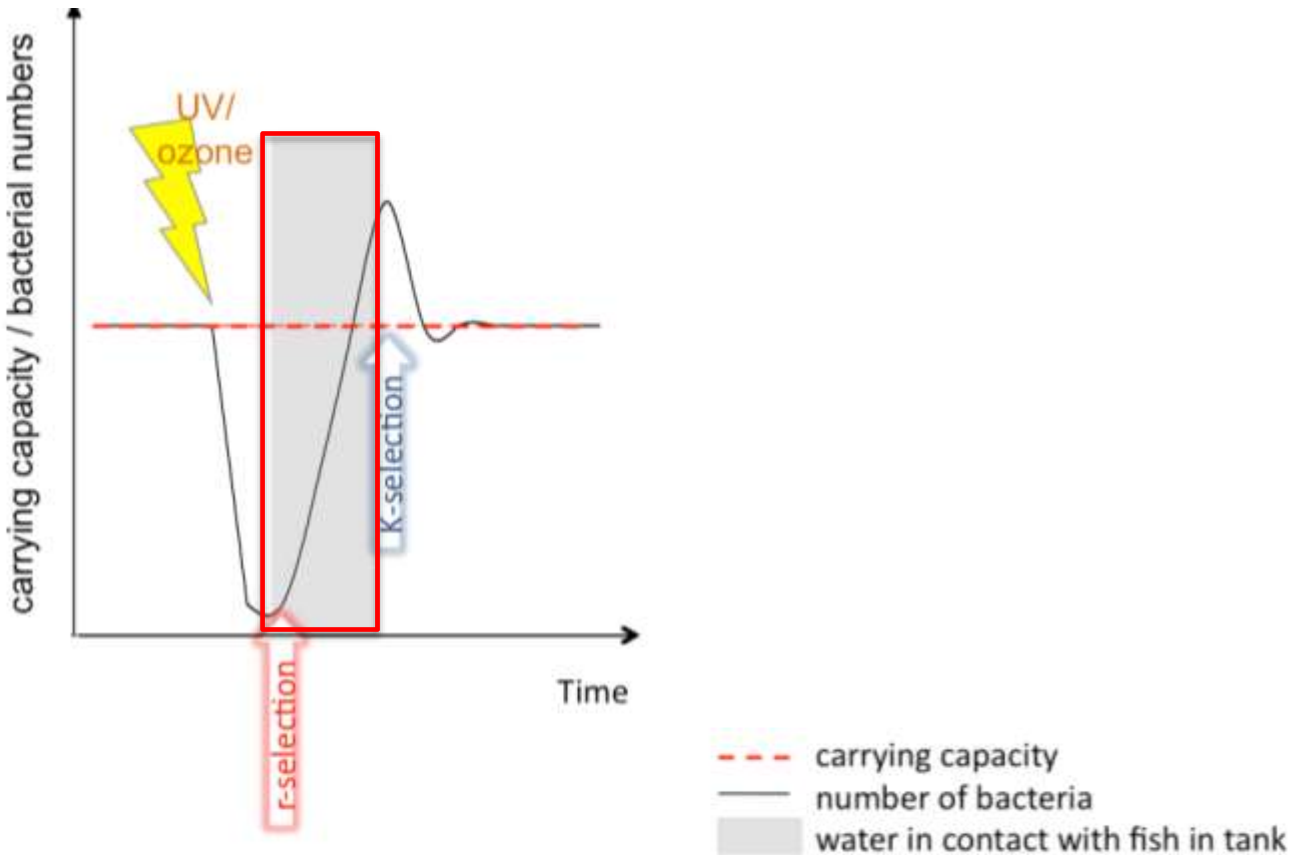
Effect on the fish: Significantly higher survival



Ecological context of opportunistic pathogens in aquaculture

mainly opportunistic pathogens cause disease in aquatic young animals, especially under stress conditions

Disinfection: decreased bacterial numbers



Source: De Schryver et al. (2014). ISME Journal, 1 - 9

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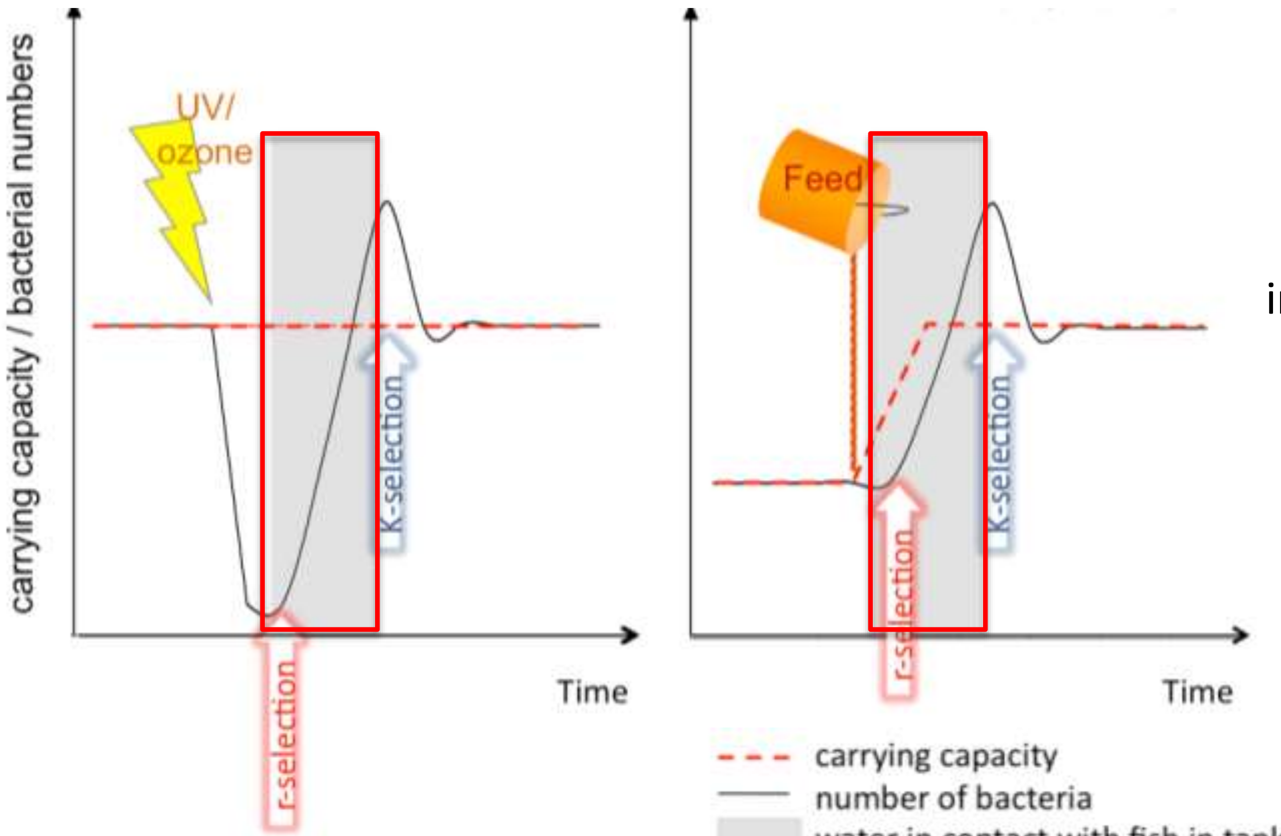


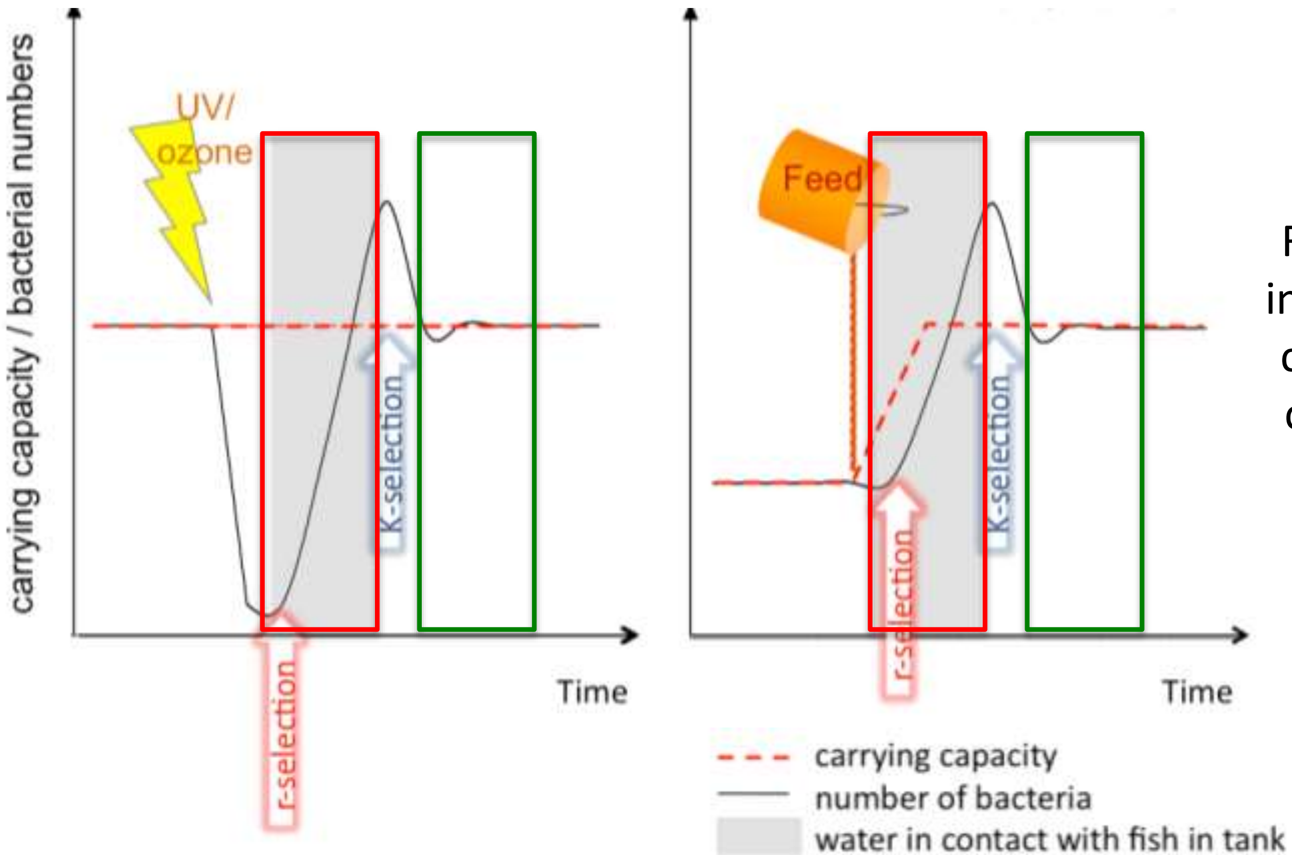
Feeding: increased carrying capacity

Source: De Schryver et al. (2014). ISME Journal, 1 - 9

Application of microbially matured water systems

after the r-strategist pioneer community comes the K-strategist mature community

Disinfection: decreased bacterial numbers

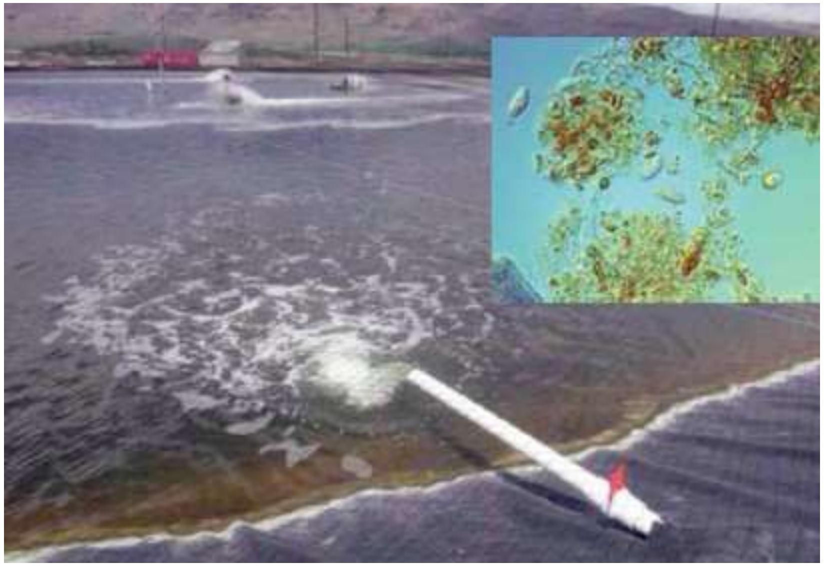


Feeding: increased carrying capacity

Source: De Schryver et al. (2014). ISME Journal, 1 - 9

Empirical observations of the strategy of microbial-matured water

- Algae-rich greenwater systems
- Probiotics
- Tilapia co-culture
- Biofloc systems
- Recirculation systems

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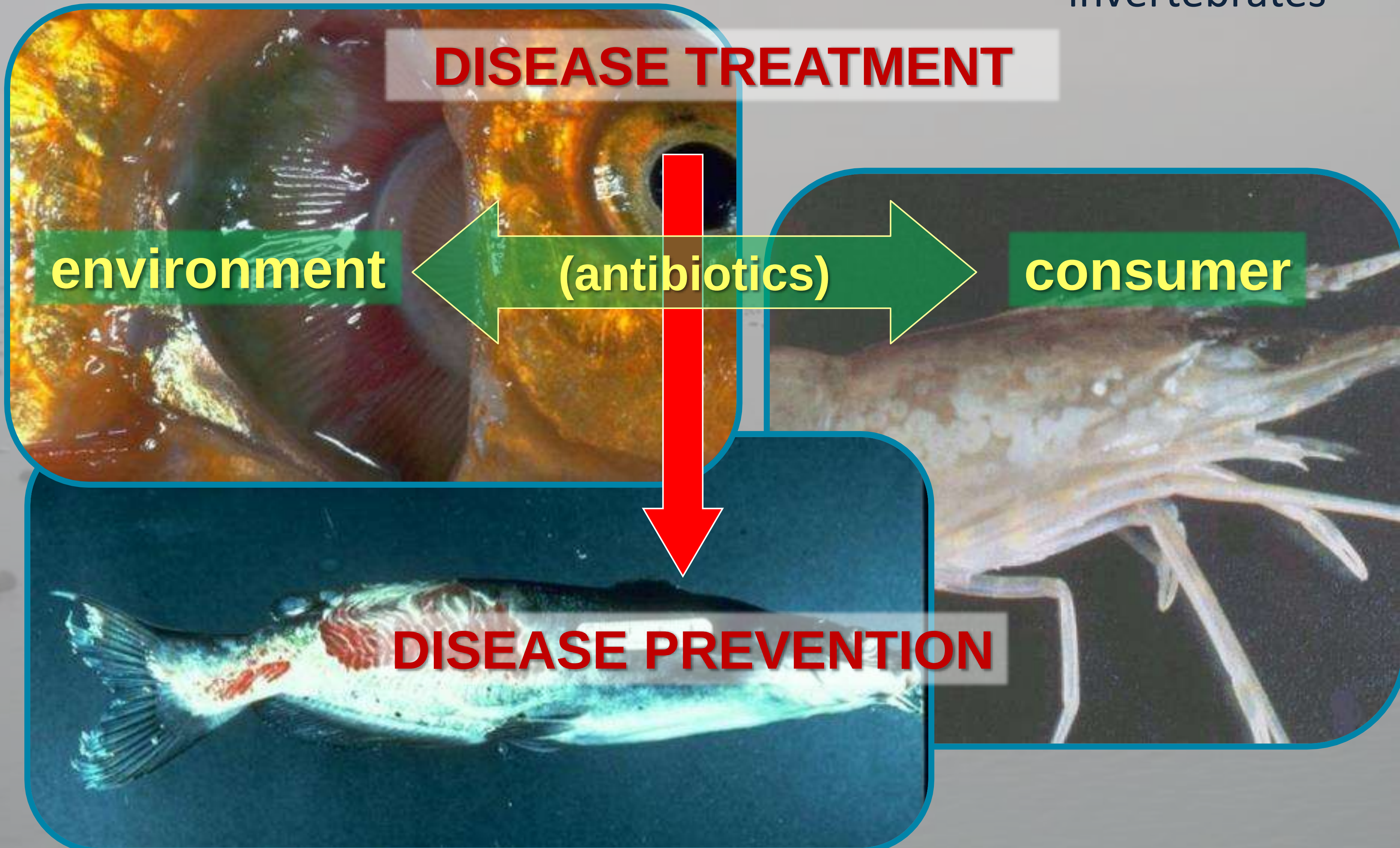
Priorities for future aquaculture

Better understanding of **IMMUNE SYSTEMS** in vertebrates and invertebrates



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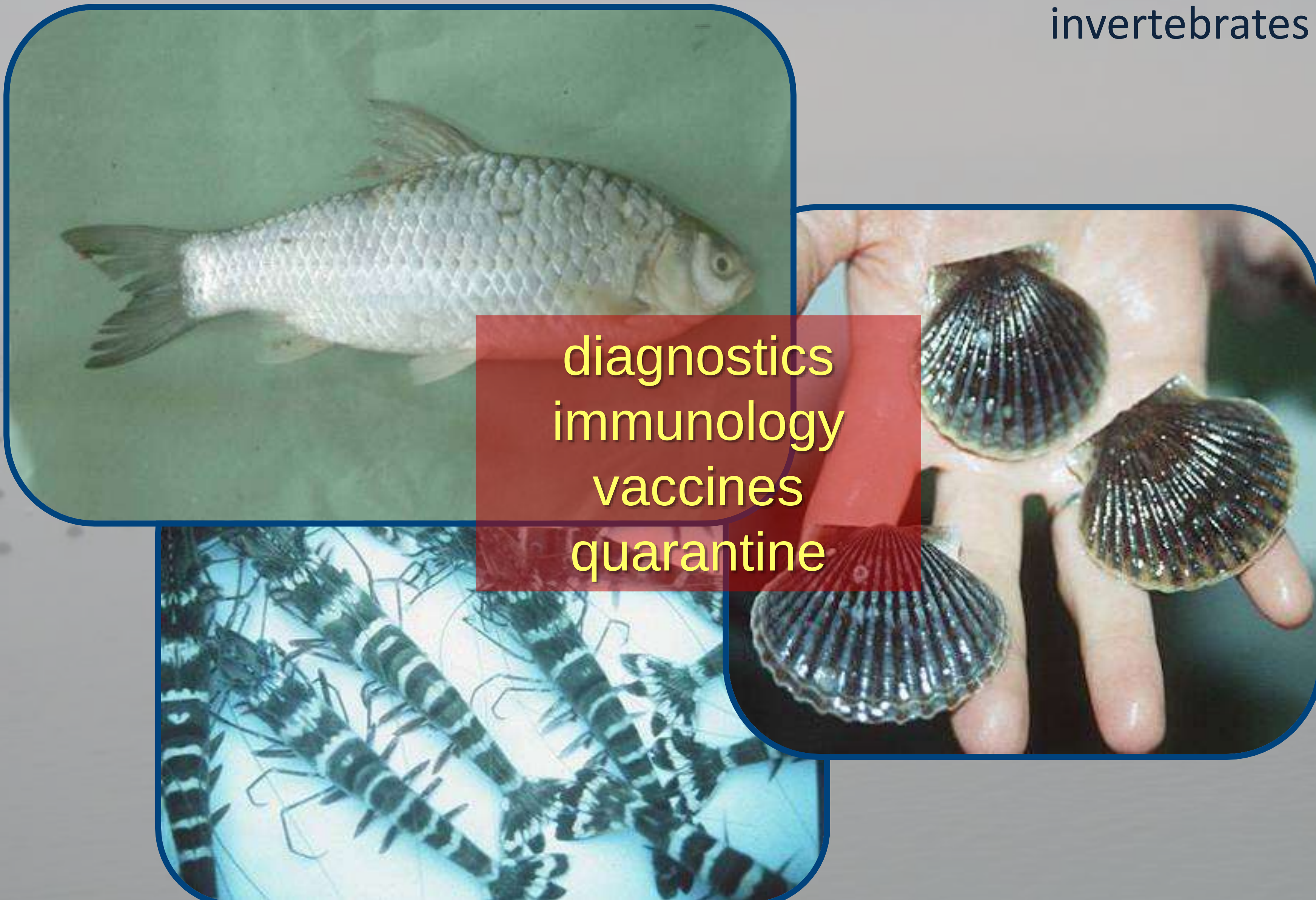

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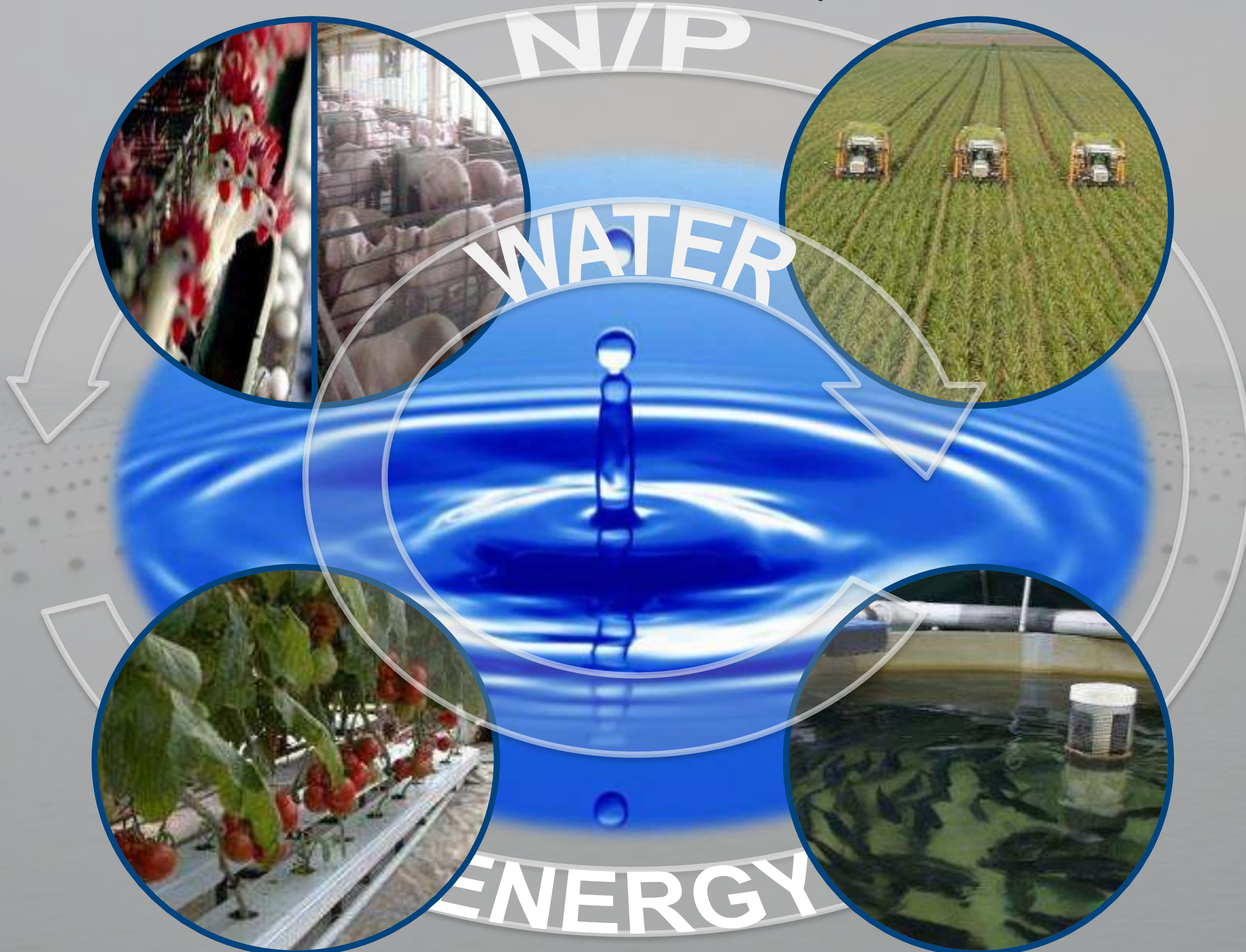
Priorities for future technology innovation

1. Complete independence from natural stocks through **DOMESTICATION**
2. Improved / more cost-effective **SEED PRODUCTION**
3. Better targeted **SPECIES SELECTION**
4. Development of more efficient stocks through **SELECTIVE BREEDING**
5. More **MICROBIAL MANAGEMENT** for more sustainable production
6. Better understanding of **IMMUNE SYSTEMS** in vertebrates and invertebrates
7. More **INTEGRATED PRODUCTION SYSTEMS** for plant and animal farming
8. **COASTAL AND OFF-SHORE FARMS** of food and energy
9. Full independence from fisheries stocks for **LIPID AND PROTEIN INGREDIENTS** in aquatic feeds
10. More attention for **INTEGRATION** of restocking activities with **FISHERIES** management

Priorities for future aquaculture

More **INTEGRATED PRODUCTION SYSTEMS** for plant and animal farming



Priorities for future aquaculture

EXTRACTIVE aquaculture

nutrient recycling

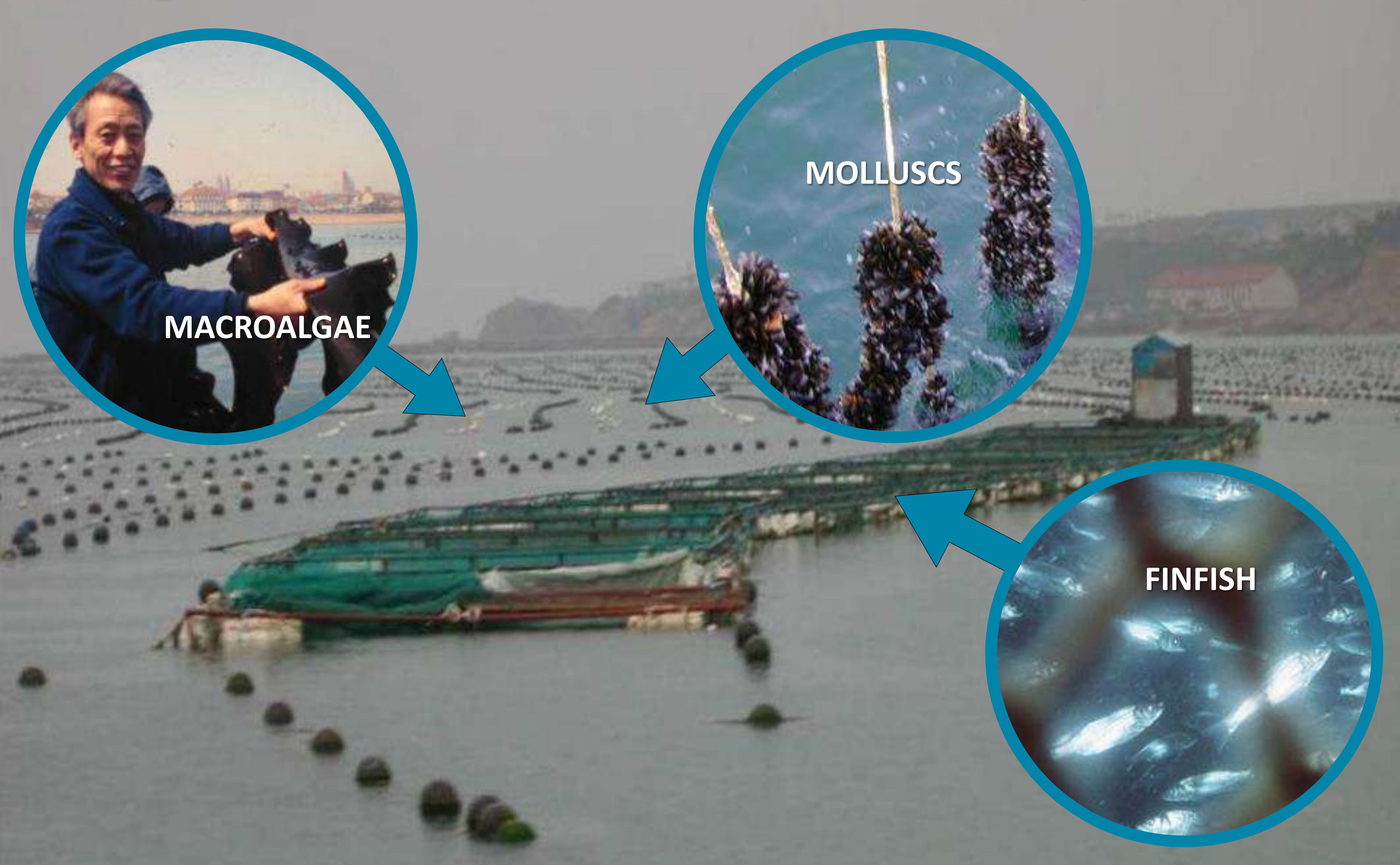
FED aquaculture

COASTAL AND OFF-SHORE FARMS for food

seaweed and molluscs

Priorities for future aquaculture

integration of culture of different trophic levels




Integrated culture of fish, molluscs and seaweeds

COASTAL AND OFF-SHORE FARMS for food

Priorities for future aquaculture

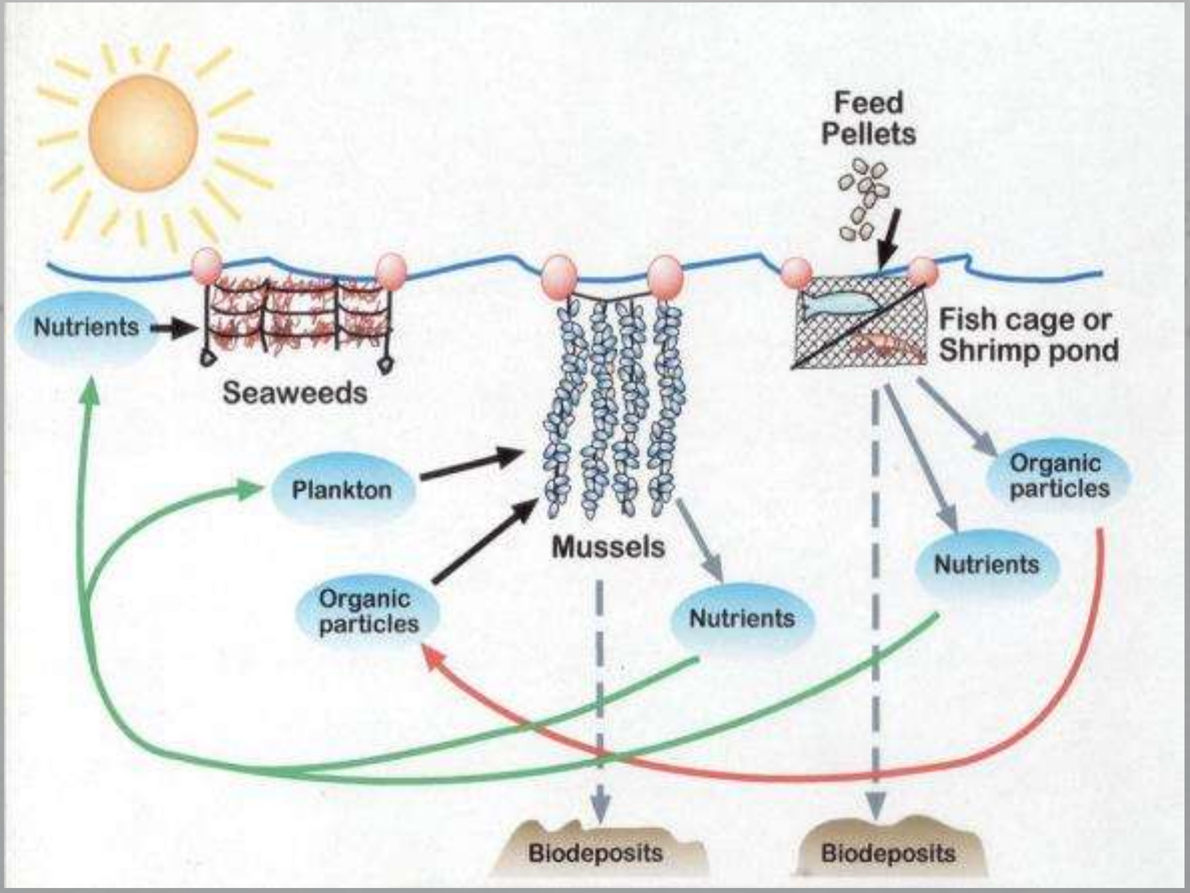
COASTAL AND OFF-SHORE FARMS for food and energy

Multi-trophic aquaculture - for food production

integrating - for bioremediation

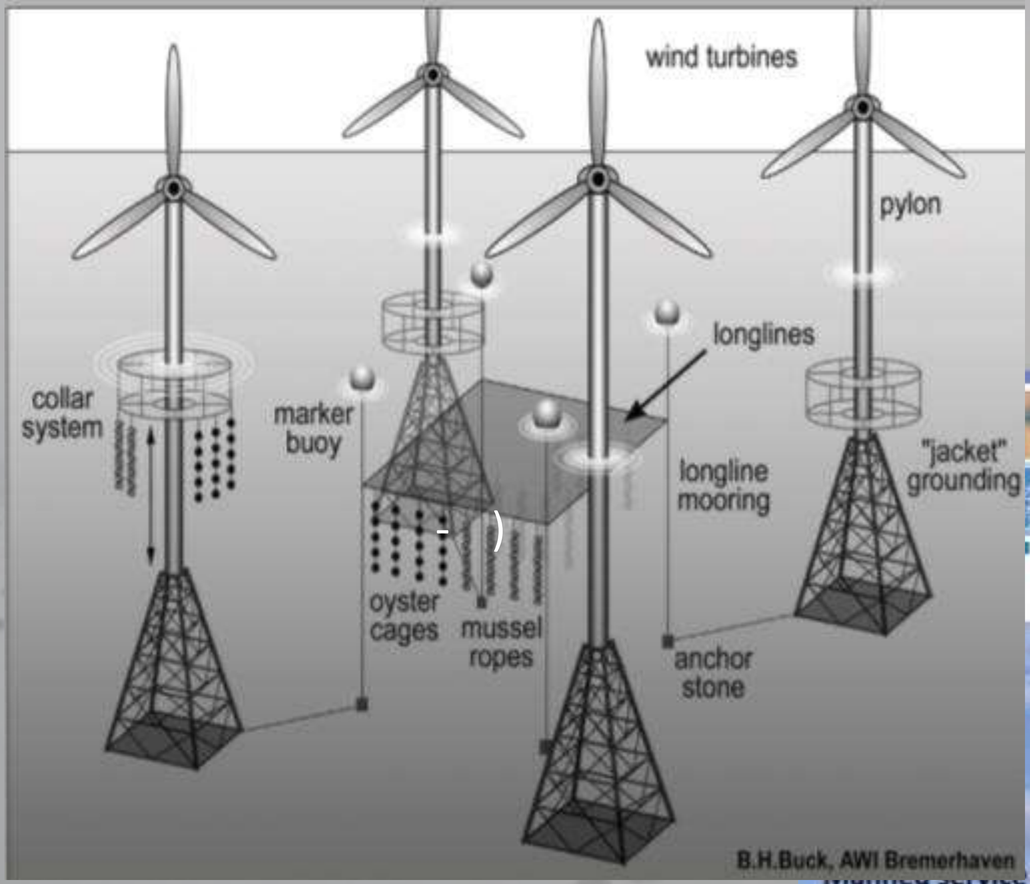
different niches of the ecosystem: fish, shellfish & seaweeds

and maximizing nutrient recycling



Priorities for future aquaculture

COASTAL AND OFF-SHORE FARMS for food and energy



Energy generation

(wind, wave, thermal)

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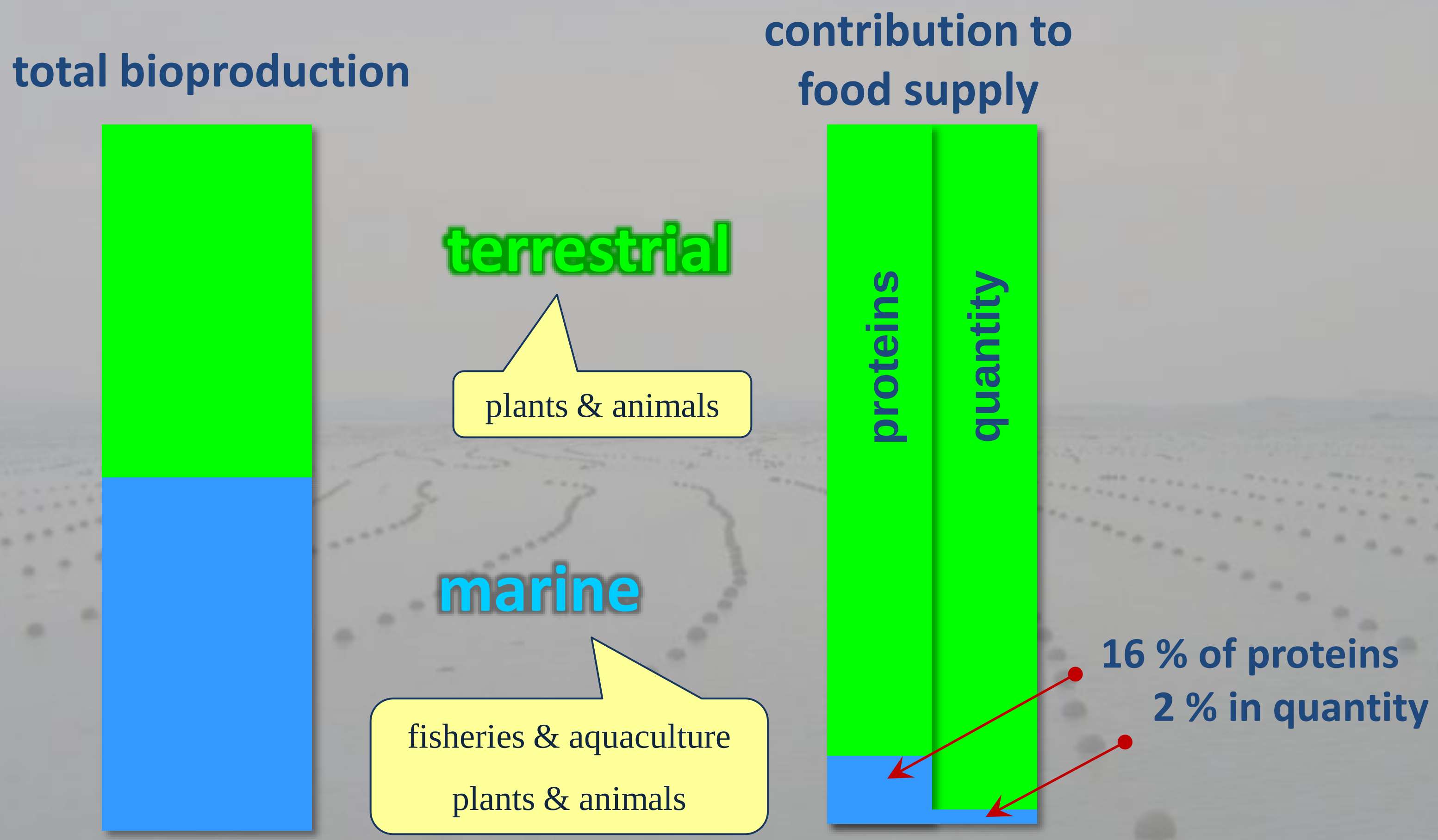
Global primary production and food supply



from Field et al. (1998) and Duarte et al. (2009)

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