Coastal and Estuarine Processes
http://ecowin.org/aulas/mega/pce

Aquaculture

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http://ecowin.org/

Universidade Nova de Lisboa

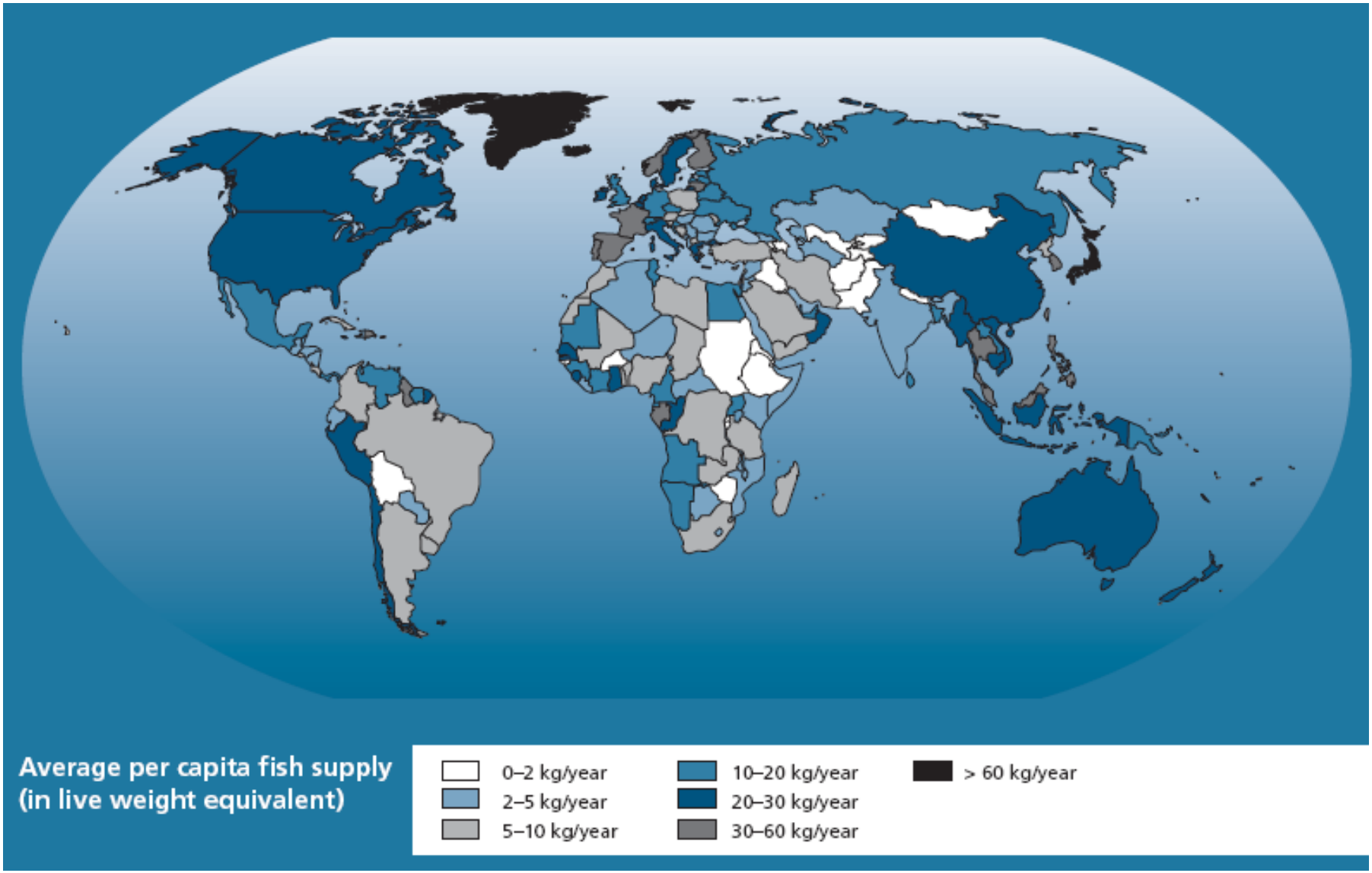
Aquaculture and fisheries

Lecture topics

- World supply and demand
- Species, nations, and trade
- Aquaculture, the blue revolution?
- Carrying capacity and site selection
- Co-use and offshore aquaculture
- Summary

Fish as a food

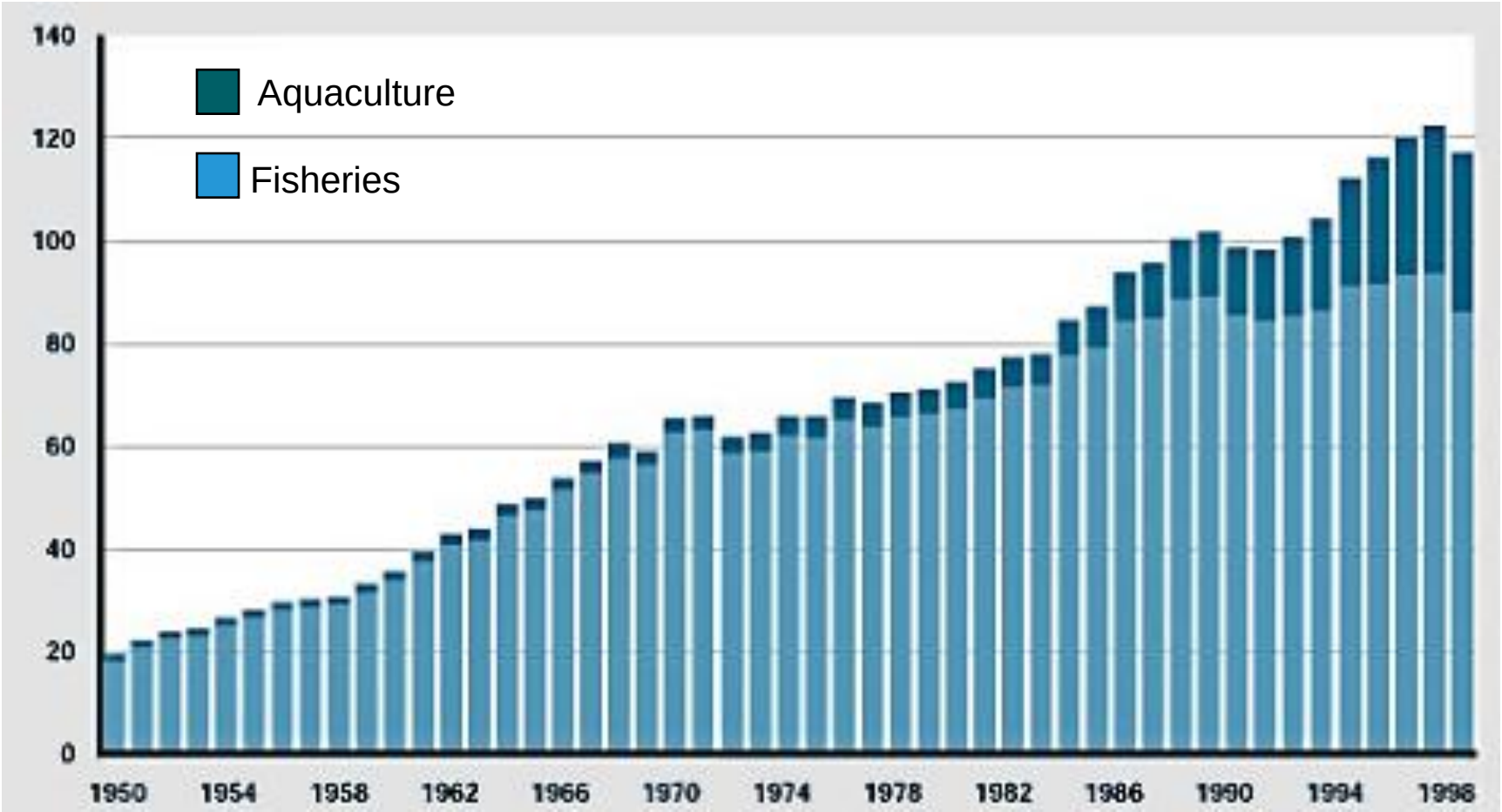
World per capita supply (average 2003-2005)



FAO, 2009. The State of World Fisheries and Aquaculture (SOFIA). Food and Agriculture Organization of the U.N.

The state of world fisheries and aquaculture SOFIA 2000 (FAO)

10^6 ton y^{-1}



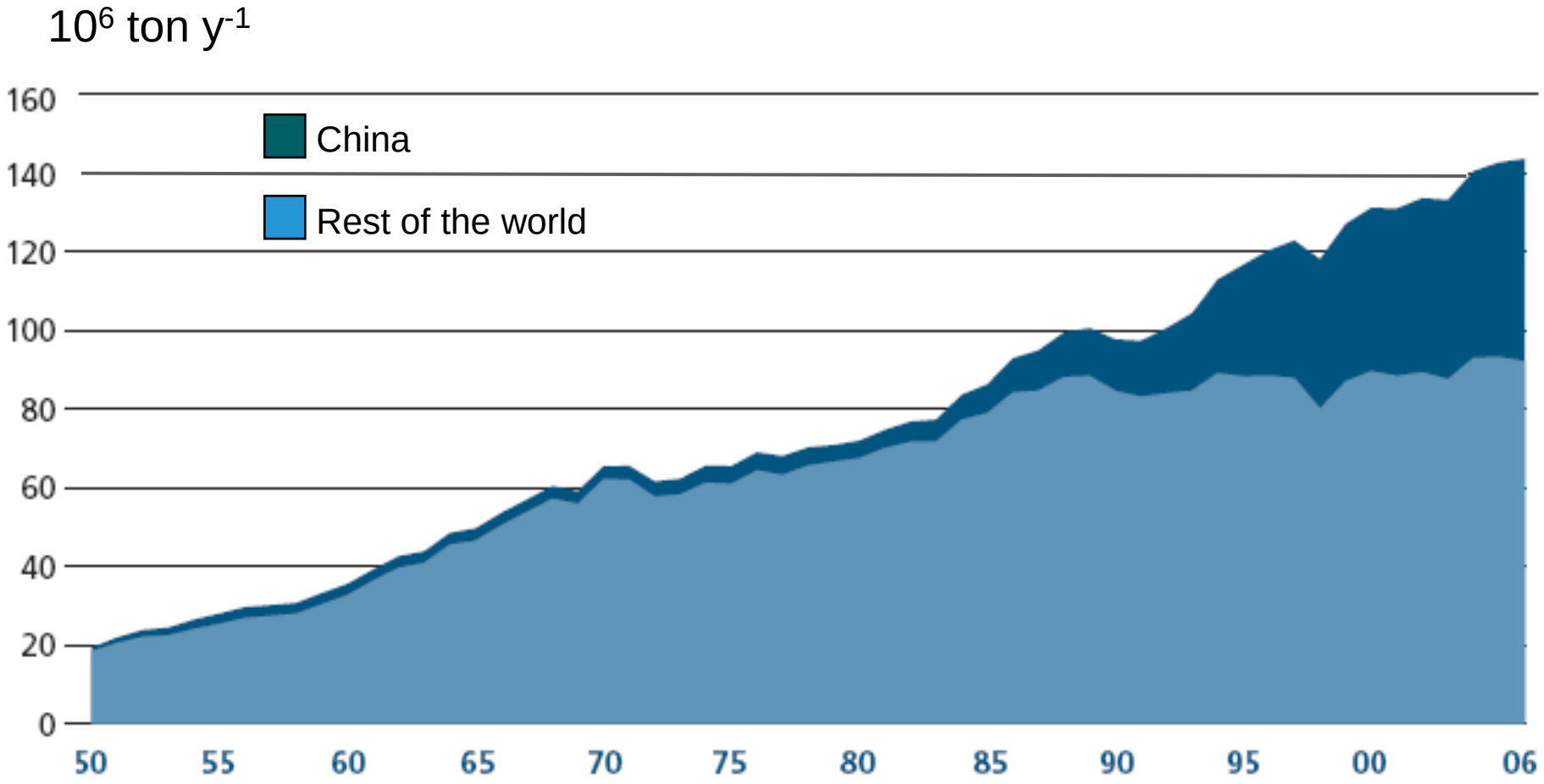
FAO, 2001. The State of World Fisheries and Aquaculture (SOFIA). Food and Agriculture Organization of the U.N.

World capture fisheries and aquaculture

WORLD PRODUCTION	2002	2003	2004	2005	2006
			(million tonnes)		
INLAND					
Capture	8.7	9.0	8.9	9.7	10.1
Aquaculture	24.0	25.5	27.8	29.6	31.6
Total inland	32.7	34.4	36.7	39.3	41.7
MARINE					
Capture	84.5	81.5	85.7	84.5	81.9
Aquaculture	16.4	17.2	18.1	18.9	20.1
Total marine	100.9	98.7	103.8	103.4	102.0
TOTAL CAPTURE	93.2	90.5	94.6	94.2	92.0
TOTAL AQUACULTURE	40.4	42.7	45.9	48.5	51.7
TOTAL WORLD FISHERIES	133.6	133.2	140.5	142.7	143.6
UTILIZATION					
Human consumption	100.7	103.4	104.5	107.1	110.4
Non-food uses	32.9	29.8	36.0	35.6	33.3
Population (billions)	6.3	6.4	6.4	6.5	6.6
Per capita food fish supply (kg)	16.0	16.3	16.2	16.4	16.7

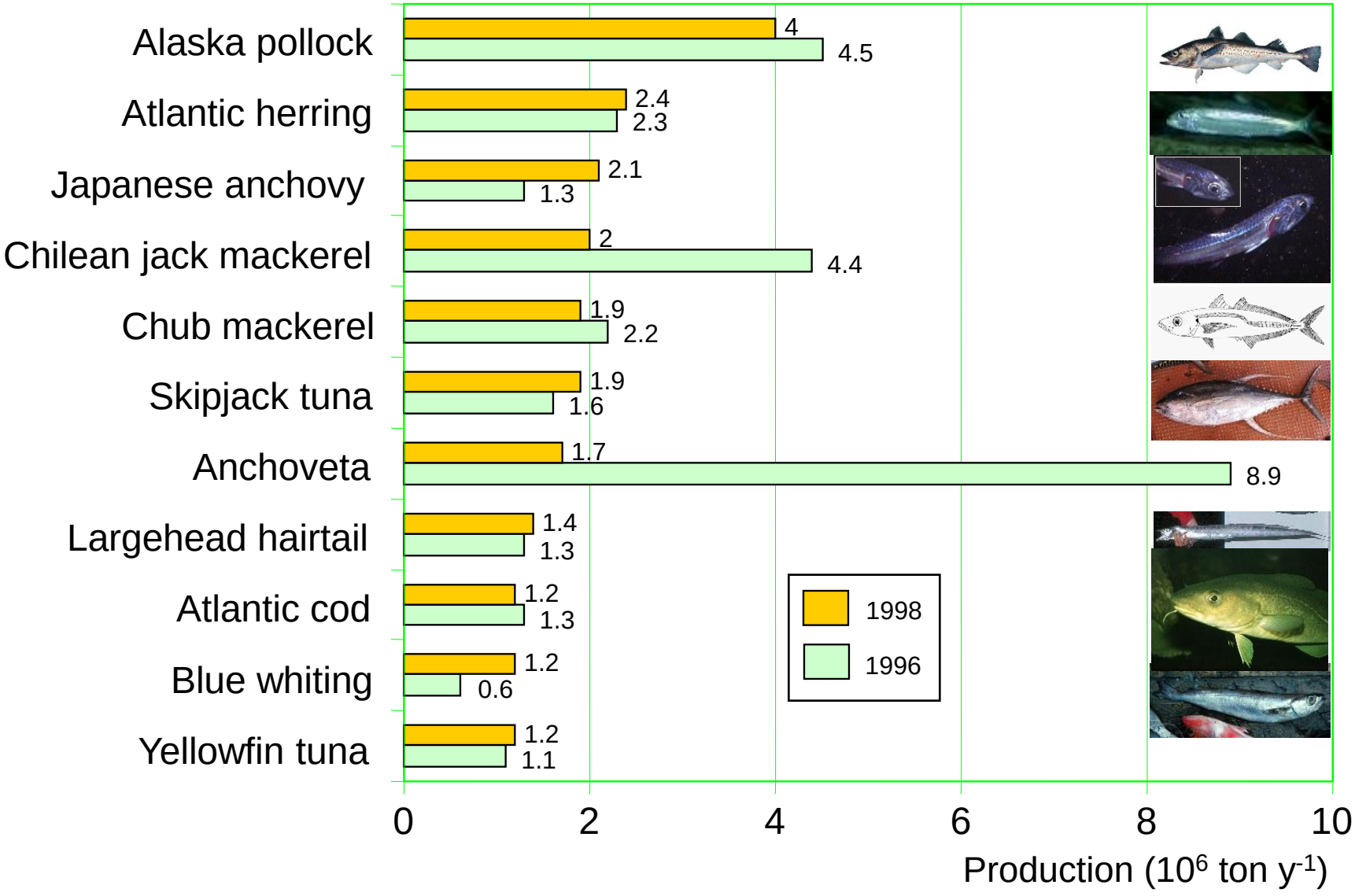
FAO, 2009. The State of World Fisheries and Aquaculture (SOFIA). Food and Agriculture Organization of the U.N.

The state of world fisheries and aquaculture SOFIA 2010 (FAO)



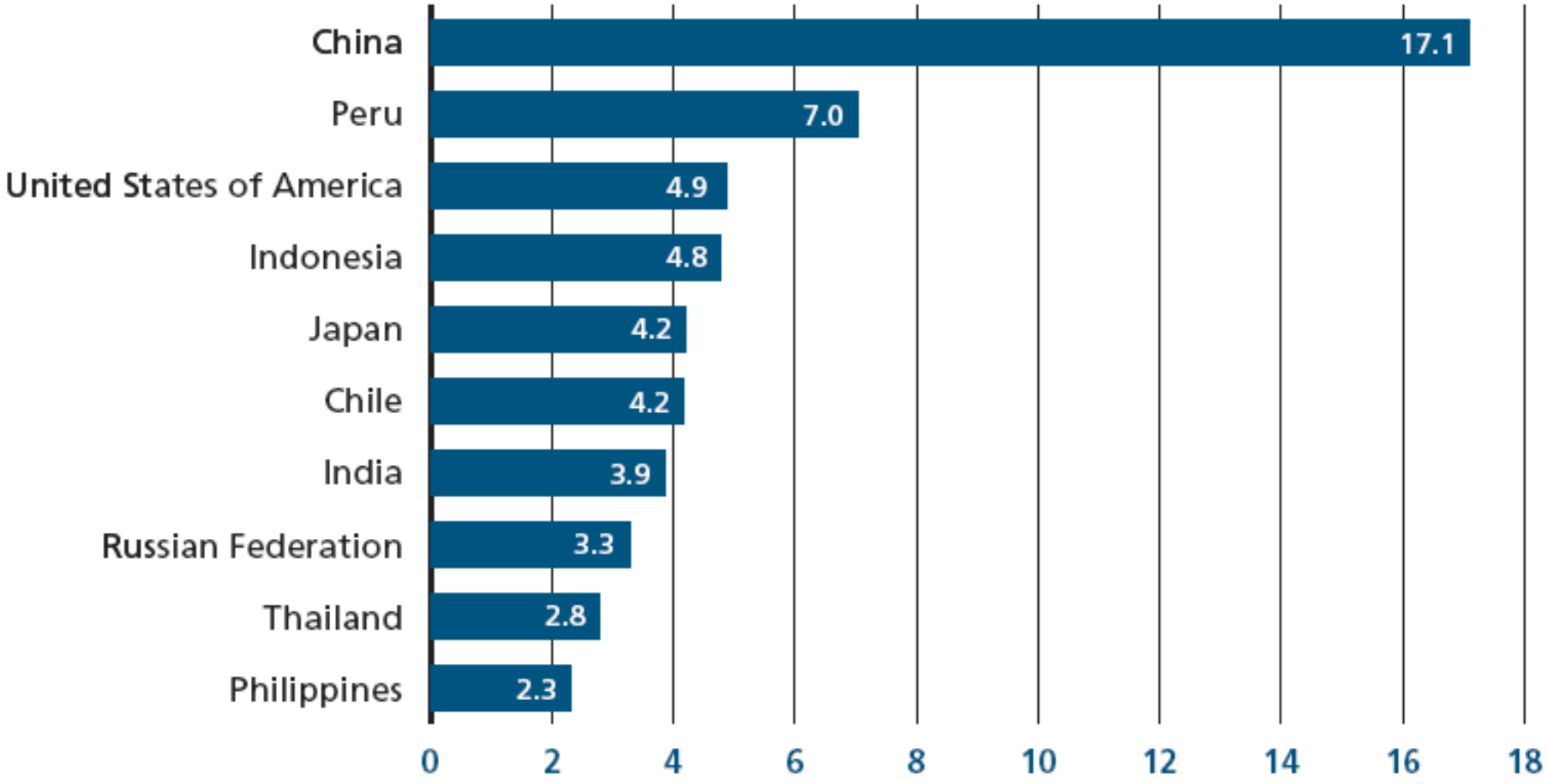
FAO, 2009. The State of World Fisheries and Aquaculture (SOFIA). Food and Agriculture Organization of the U.N.

Distribution of production among major fish species



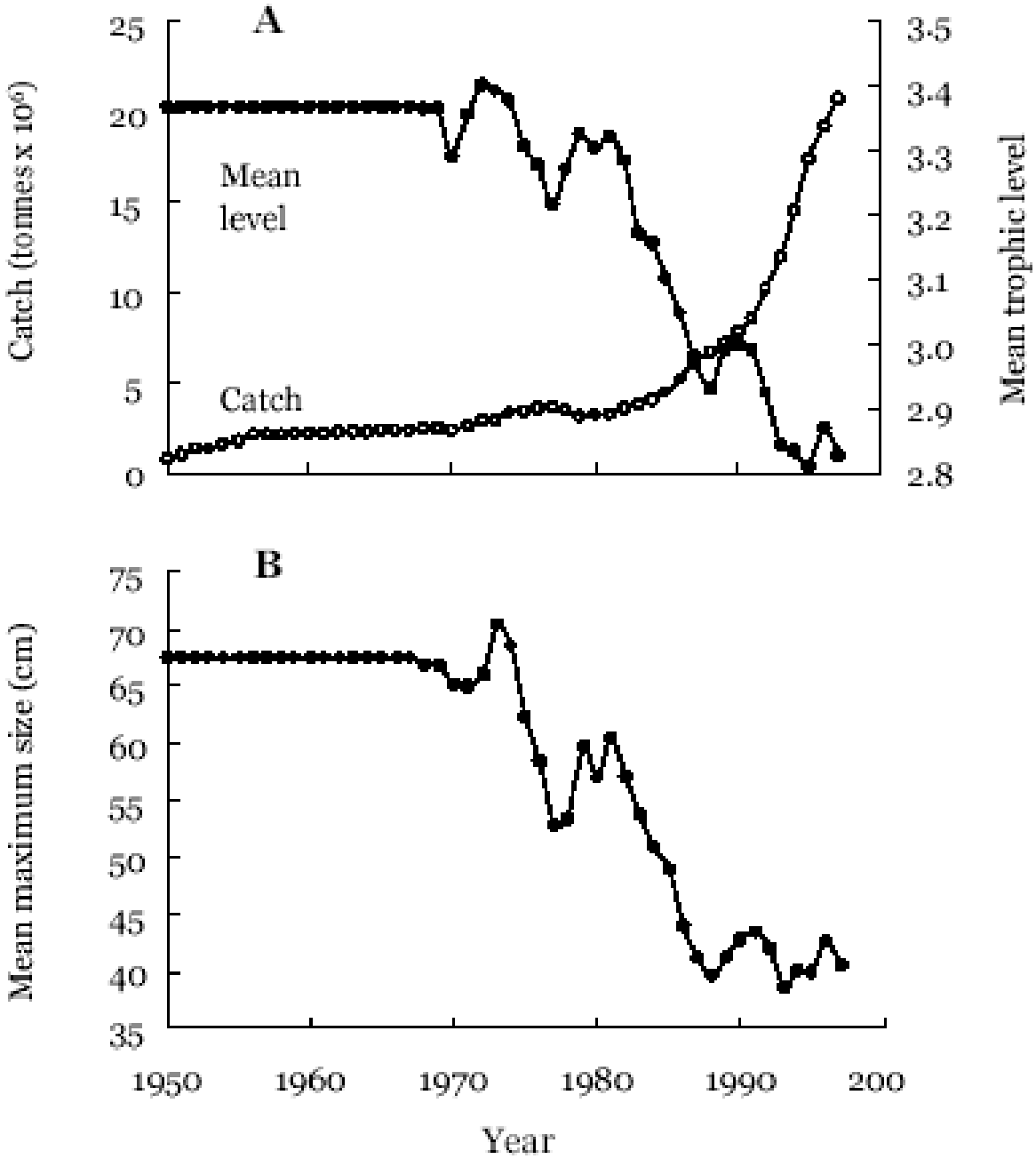
FAO, 2001. The State of World Fisheries and Aquaculture (SOFIA). Food and Agriculture Organization of the U.N.

Capture fishery production by country
SOFIA 2008 (FAO)



FAO, 2008. The State of World Fisheries and Aquaculture (SOFIA). Food and Agriculture Organization of the U.N.

Chinese fishery data



Watson, R., Pang, L., Pauly, D., 2001. The Marine Fisheries of China: Development and Reported Catches. Fisheries Centre Research Report 9(2). Univ. British Colombia, Canada.

European Union capture fisheries and aquaculture

	1986	1990	1994	1998
Aquaculture production				
Inland production *('000 tonnes)*	171	221	241	249
Percentage of world total	3.0	2.7	2.0	1.3
Marine production *('000 tonnes)*	699	717	796	1 085
Percentage of world total	20.6	14.5	9.2	8.9
Fisheries production				
Inland production *('000 tonnes)*	113	107	104	120
Percentage of world total	1.9	1.7	1.6	1.5
Marine production *('000 tonnes)*	6 774	6 067	6 737	6 419
Percentage of world total	8.6	7.7	8.0	8.2
Fisheries and aquaculture production				
Combined total *('000 tonnes)*	7 757	7 114	7 878	7 873
Percentage of world total	8.3	7.2	7.0	6.7

FAO, 2009. The State of World Fisheries and Aquaculture (SOFIA). Food and Agriculture Organization of the U.N.

Relevance of world aquaculture

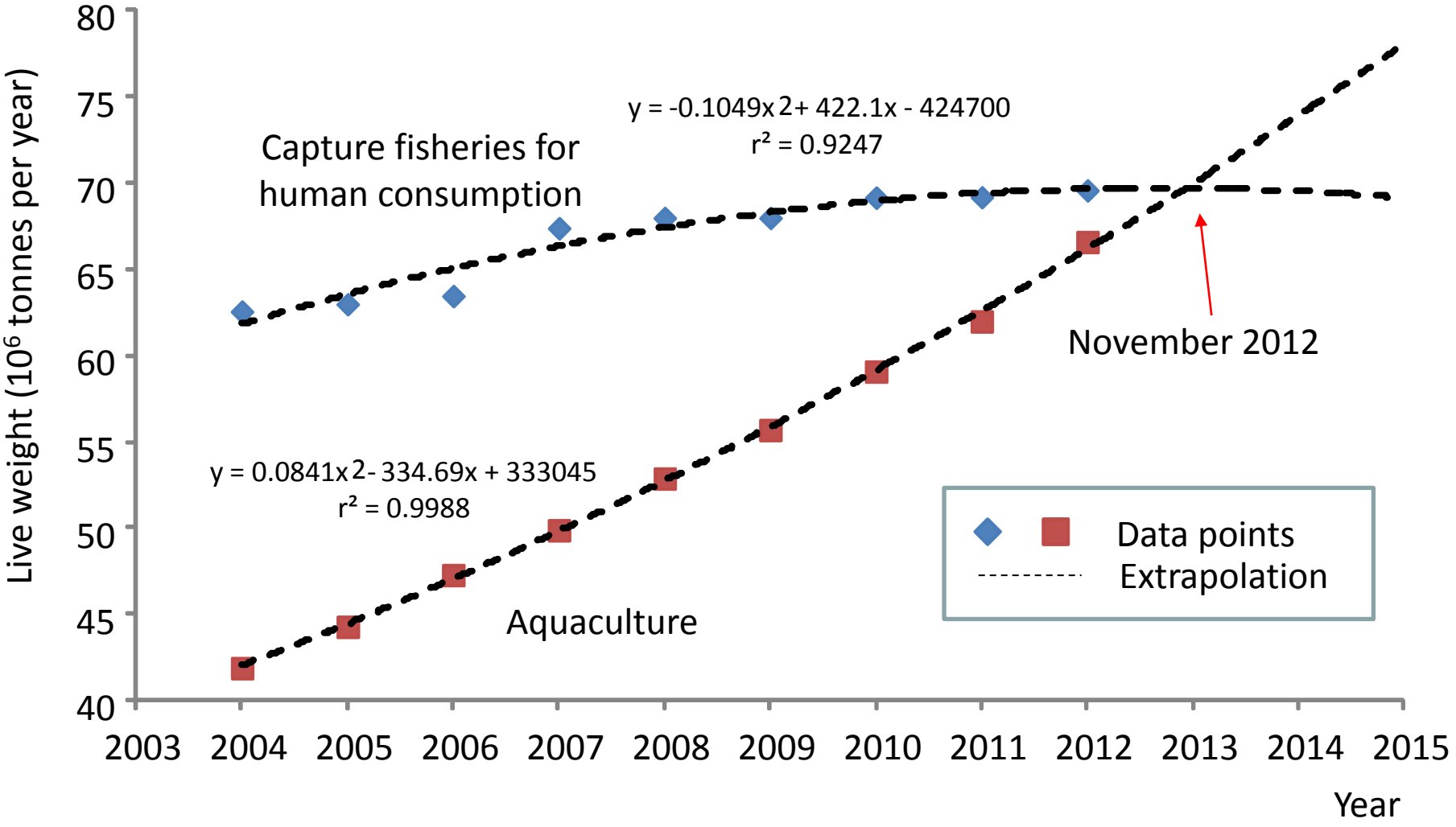
Volume and value

FAO Global Aquaculture Conference 2010

- 50% of aquatic products originate from aquaculture (SOFIA, 2010)
- 90% of the 68 million tonnes of aquaculture products (105 billion USD) originate from Asia (Sorgeloos, 2010)
- Production of striped catfish *Pangasius* in the Mekong delta is >1 Mt y^{-1}, highest yields in the world, 350-400 tonnes ha^{-1} per crop (Sena da Silva, 2010)
- 30 Mt y^{-1} of extra aquatic products required to feed the planet by 2050 (Swaminathan, 2010)
- US predicted expansion from 0.5 to 1.5 Mt y^{-1} (Olin, 2010)
- Europe: production is 4.2% by volume, 9.1% by value (Sorgeloos, 2010)

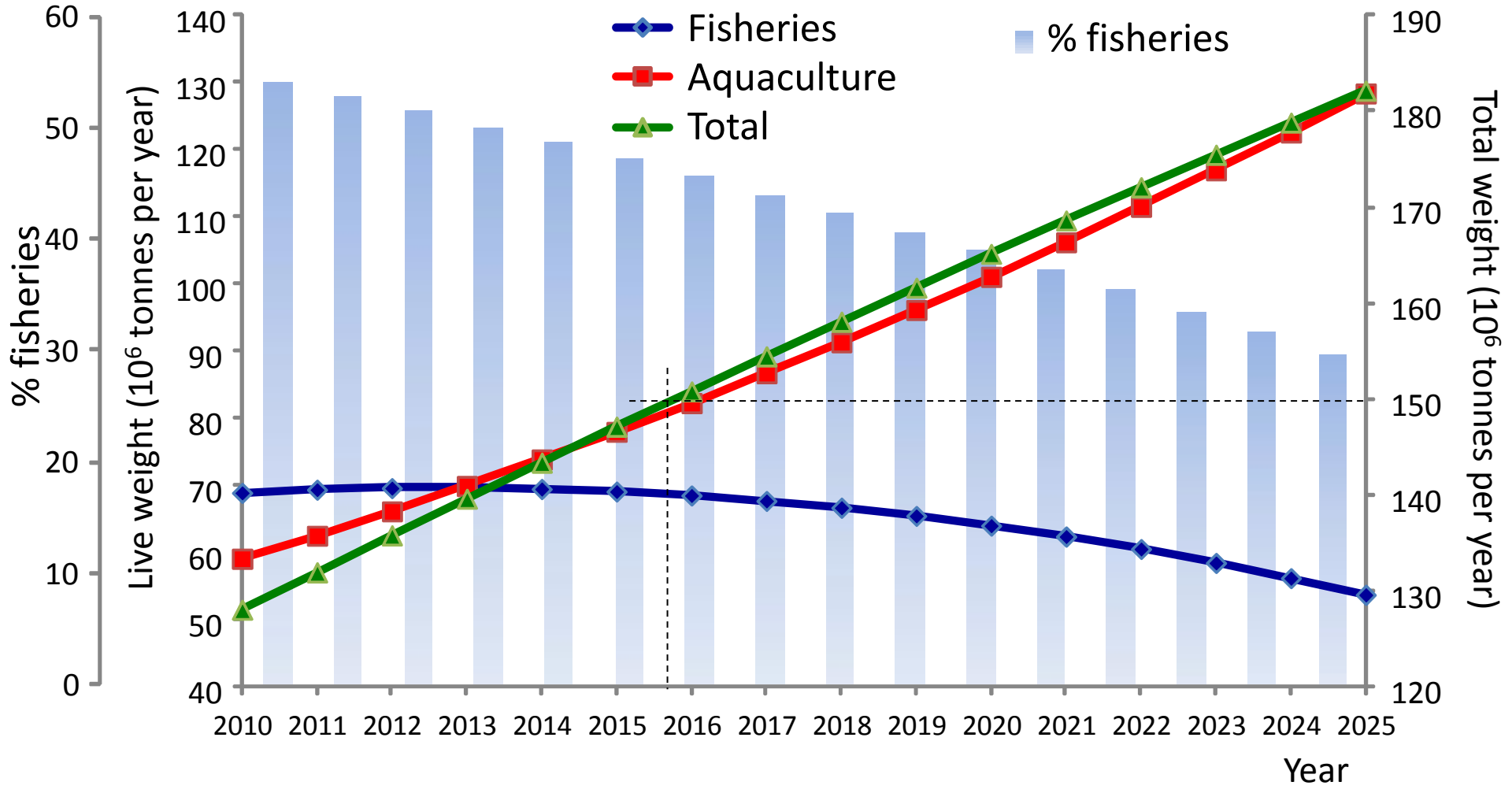
Growth of both population and aquaculture will take place in developing nations

Trends in fisheries and aquaculture



Equivalent to the emergence of agriculture 10,000 years ago in the Neolithic period.

Trends in fisheries and aquaculture : 2010-2025



For projected APR growth in aquaculture and fisheries, 150 million tonnes in Sept 2015.

Aquaculture in Europe

Sustainability and legislation

Environmental, legal, and social pressures

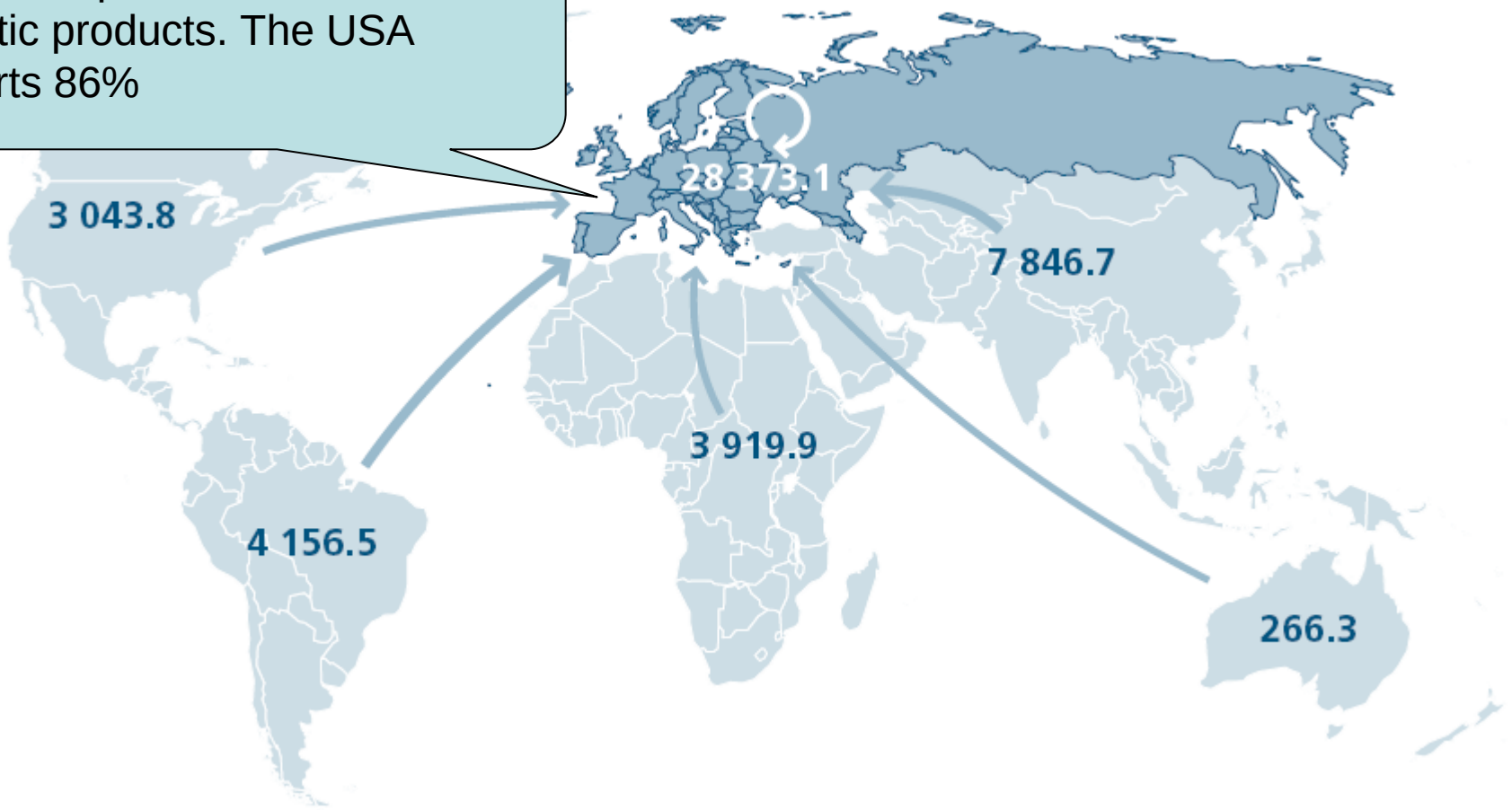
- Aquaculture is the most heavily regulated food production sector in Europe (Varadi, 2010)
- Competition for space, access to capital, availability of special services, limited authorised veterinary products (Varadi, 2010)
- Water Framework Directive (2000/60/EC) – no reference to aquaculture. Benthic biodiversity, fish (in transitional waters); Good Ecological Status in Europe by 2015
- Marine Strategy Framework Directive (2008/56/EC) – Fish and Shellfish Quality Descriptor (QD3). Aquaculture is seen only as a pressure. Good Environmental Status by 2020
- Many other parts of the world don't come close to the EU regulatory panorama

In all likelihood Europe will add value over volume.

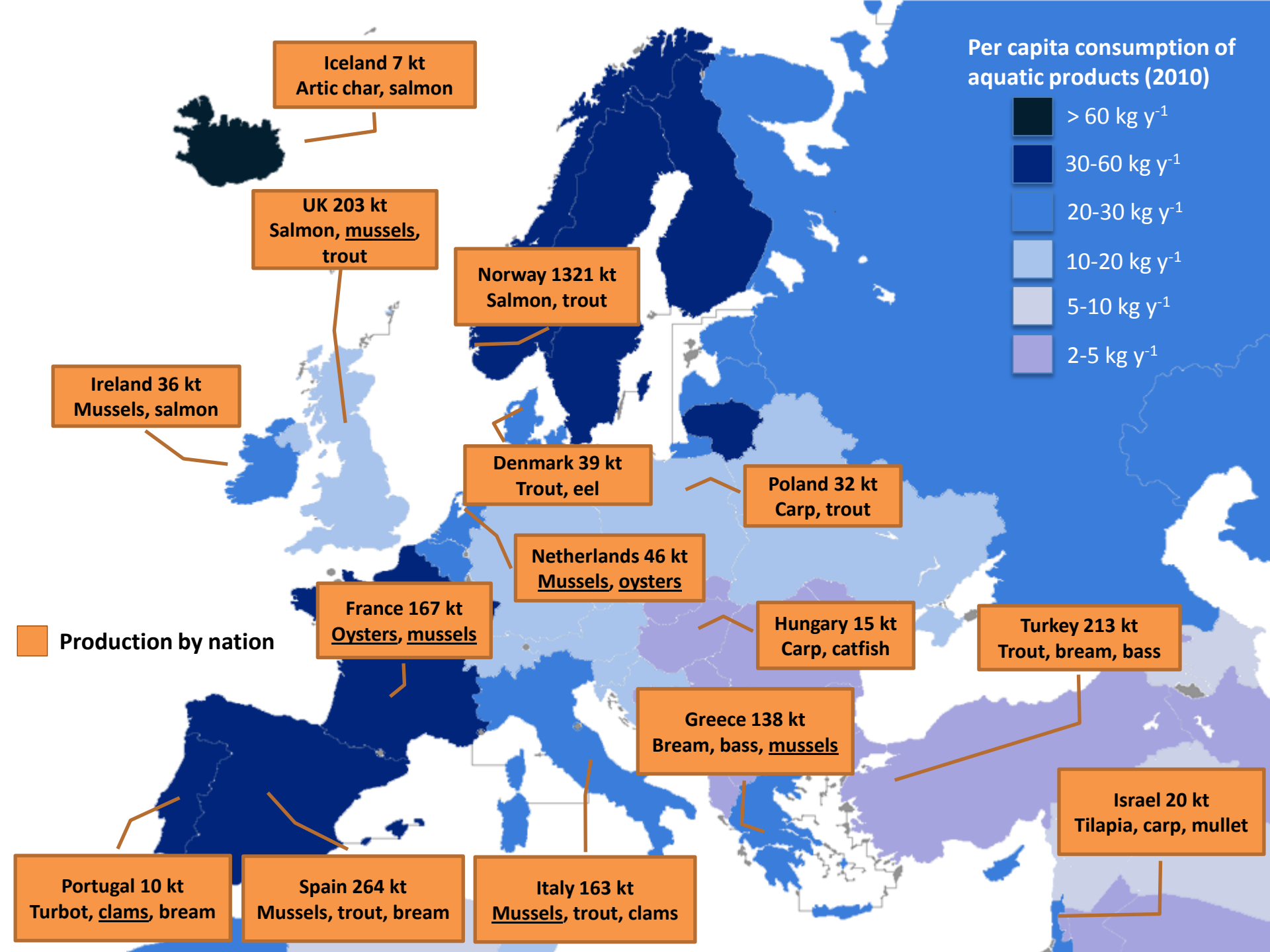
Imports to Europe

All numbers in millions of USD (SOFIA 2012)

Europe imports 74% of its aquatic products. The USA imports 86%



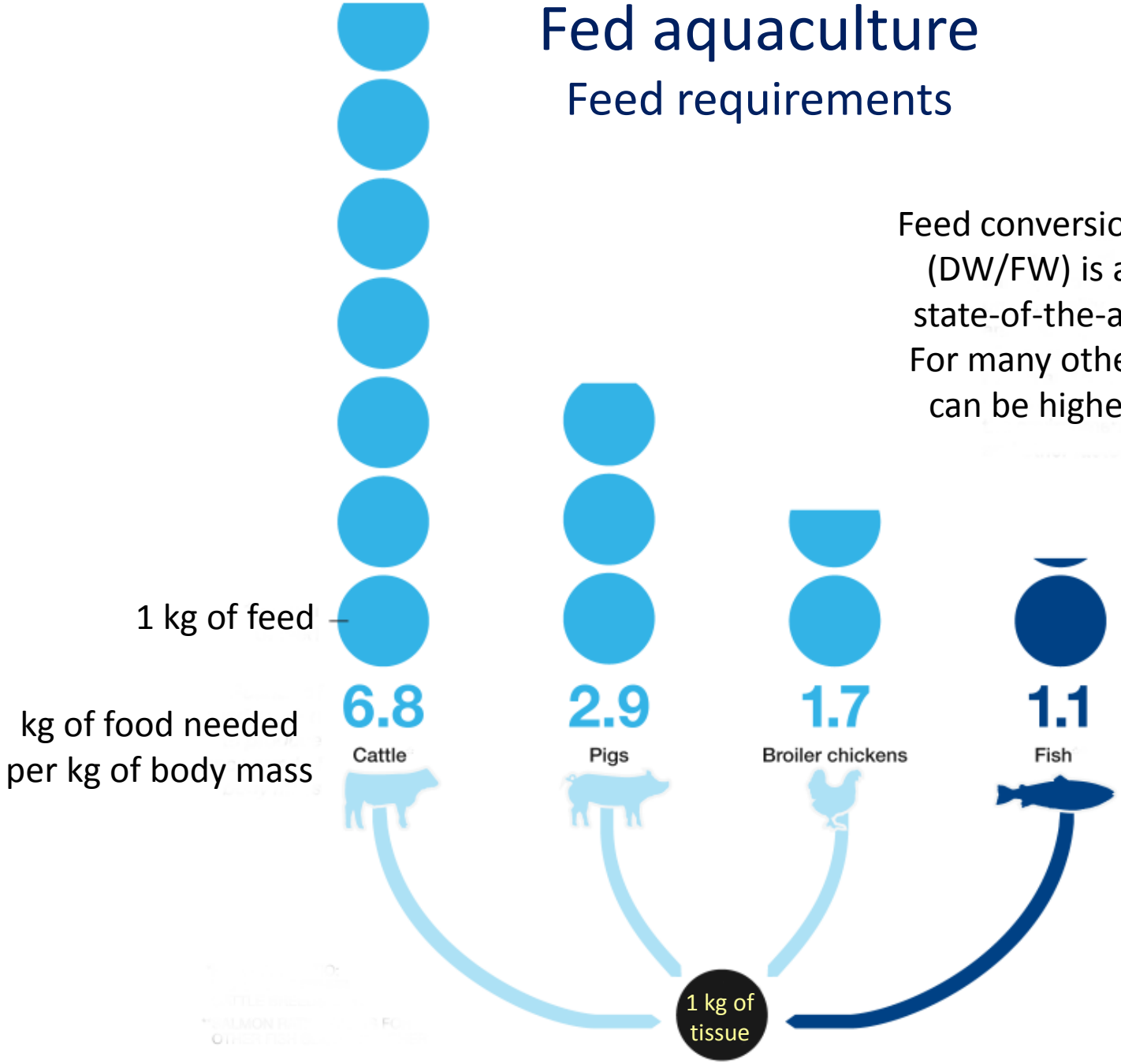
If European consumption was at the level of Portugal (57.4 kg y^{-1} per capita) an extra 27 million tonnes of fish products would be required annually.


Per capita consumption of aquatic products (2010)
> 60 kg y-1
30-60 kg y-1
20-30 kg y-1
10-20 kg y-1
5-10 kg y-1
2-5 kg y-1
Production by nation
Iceland 7 kt
Artic char, salmon
UK 203 kt
Salmon, mussels, trout
Norway 1321 kt
Salmon, trout
Ireland 36 kt
Mussels, salmon
Denmark 39 kt
Trout, eel
Poland 32 kt
Carp, trout
Netherlands 46 kt
Mussels, oysters
France 167 kt
Oysters, mussels
Hungary 15 kt
Carp, catfish
Turkey 213 kt
Trout, bream, bass
Greece 138 kt
Bream, bass, mussels
Israel 20 kt
Tilapia, carp, mullet
Portugal 10 kt
Turbot, clams, bream
Spain 264 kt
Mussels, trout, bream
Italy 163 kt
Mussels, trout, clams

Fed aquaculture

Feed requirements

Feed conversion ratio (FCR) of 1.1 (DW/FW) is a typical value for state-of-the-art salmon culture. For many other species, the FCR can be higher , up to about 2.



Finfish aquaculture has the best efficiency in the animal production industry.

Chiangrai pond culture, Thailand

Tilapia, *Oreochromis niloticus*

Nori in Fujian, China - *Porphyra yezoensis*

Worldwide production of 600,000 tonnes, feeds demand for Sushi.

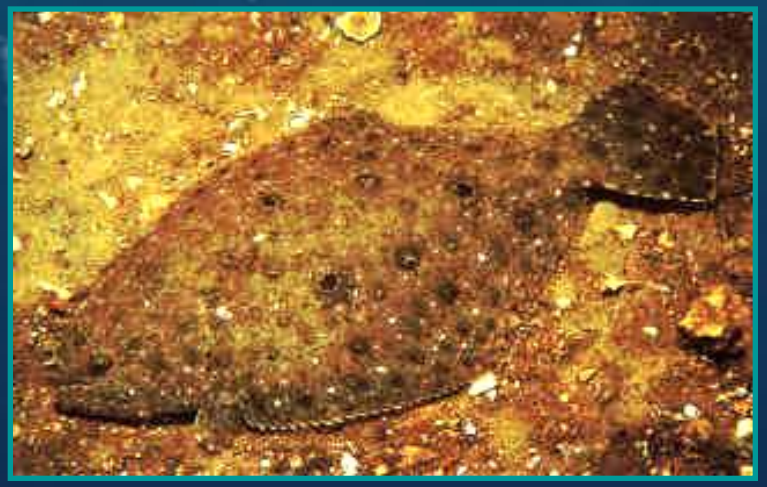
Tilapia cage culture

Laguna de Bay, Philippines

Overstocking and slow water turnover can lead to excess organic material.

Black sea bream, *Acanthopagrus schlegeli*

Black rockfish, *Sebastes schlegeli*



Olive flounder, *Paralichthys olivaceus*

Mountain trout, *Oncorhynchus masou*

Abalone, *Haliotis discus hannai*

Pacific oyster, *Crassostrea gigas*

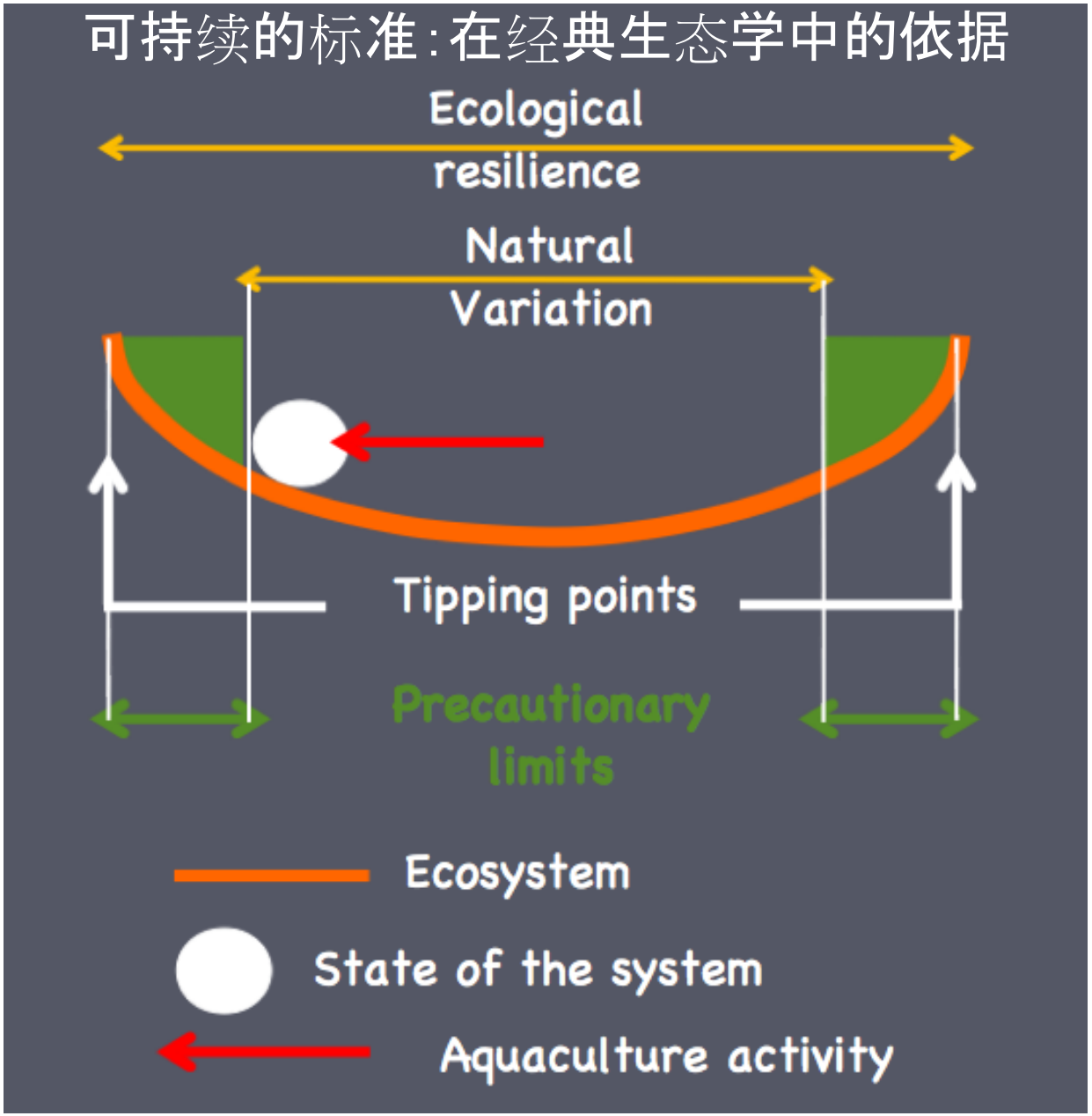
Chinese scallop,

养殖生态类型

- 网箱养殖Cage Culture： 美国红鱼、真鲷、

2005年6月8日工作人员正在进行扇贝的增殖放流行动
(scallop enhancement)

Sustainability criteria: foundation in classical ecology



Over carrying capacity farming

Zhu, 2010

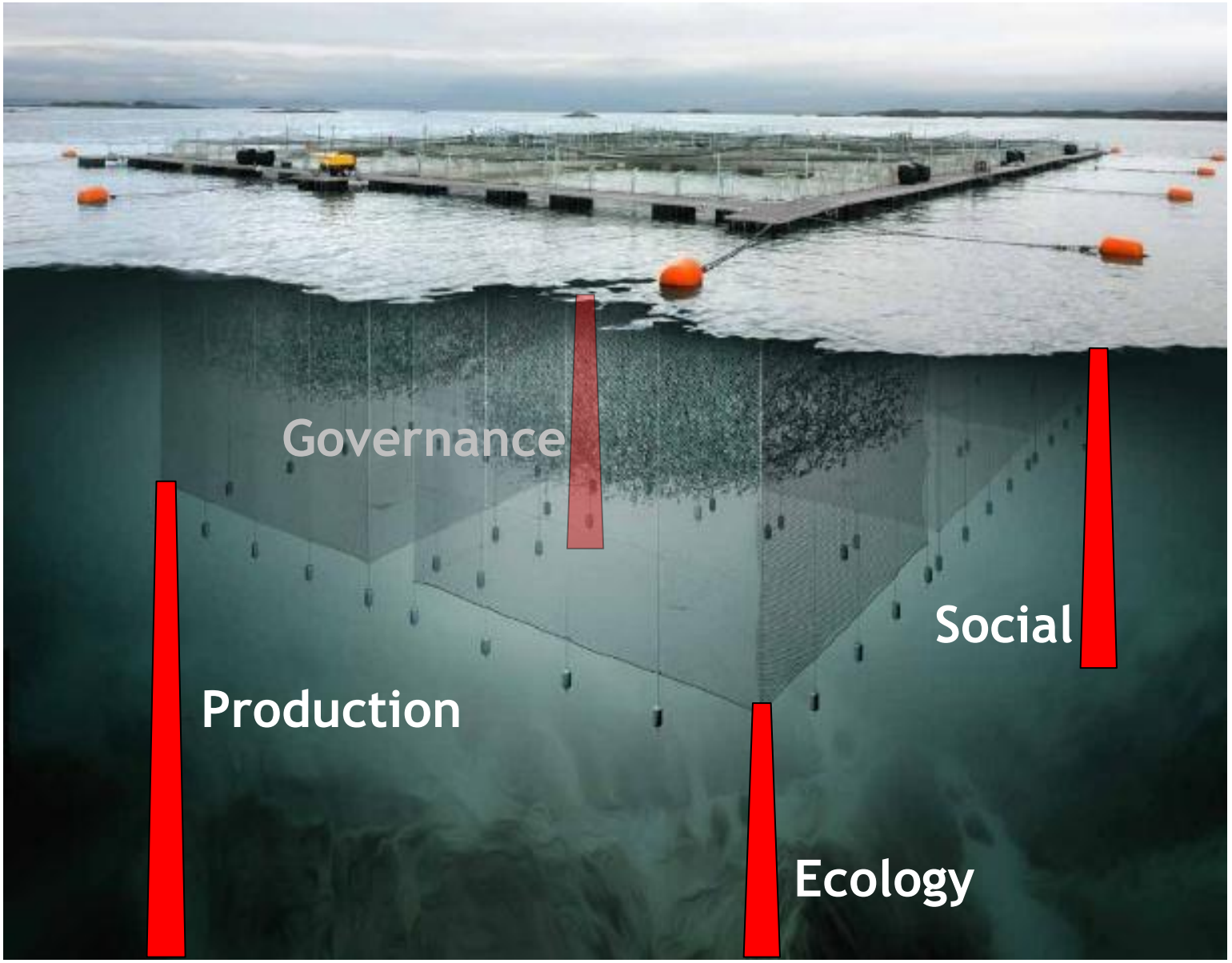
Rapid overstocking…

- Yellow croaker cage farming was started in Sandu Bay in 1995, **1000** fish cages in Qingshan, 1996.
- **50,000** fish cages in Qingshan, (**260, 000** fish cages in the whole Sandu Bay,) 2005
- Carrying capacity research indicated 40% of the cages should be removed in 2005, but things remain unchanged.

Zhu, 2010

Zhu, 2010

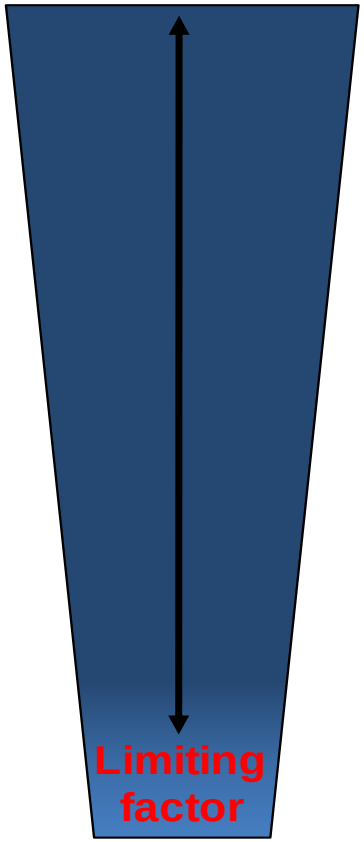
Carrying Capacity – a Multidimensional Problem



Four pillars for sustainable aquaculture. In the West, the social pillar is limiting.

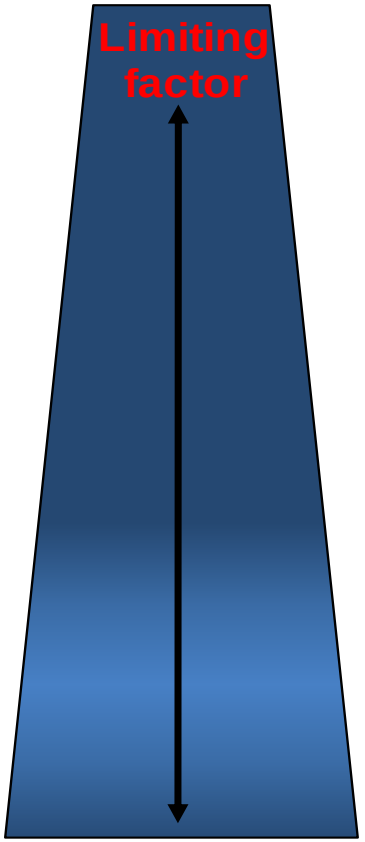
Different types of carrying capacity for aquaculture

US, Europe, Canada



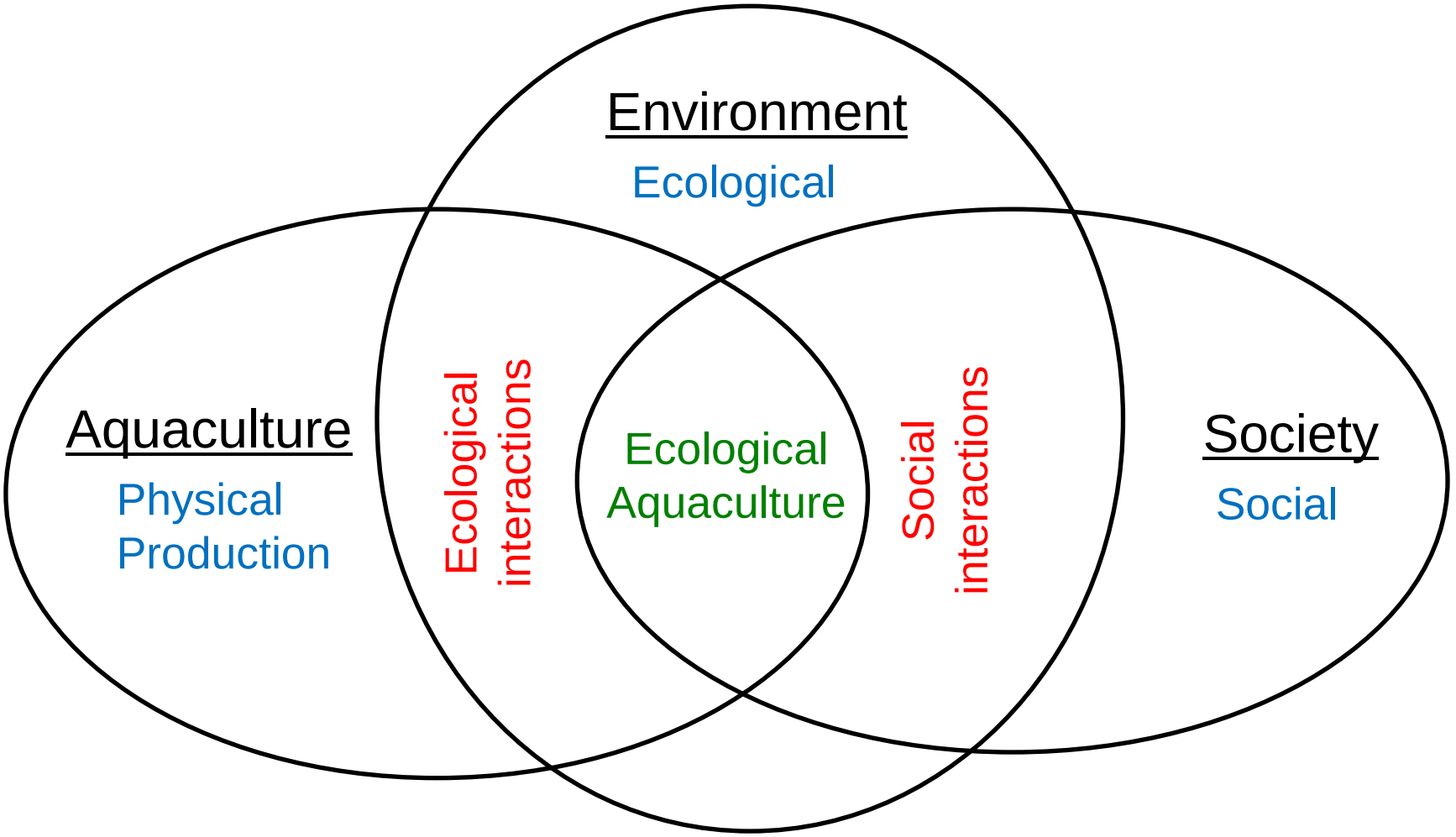
Types of carrying capacity

Southeast Asia, China



Different parts of the world see carrying capacity in very different ways.

Carrying Capacity Framework for Aquaculture



Costa-Pierce & Ferreira, FAO Ecosystem Approach to Aquaculture, Stirling, 2010.

Ecosystem Approach to Aquaculture (FAO)

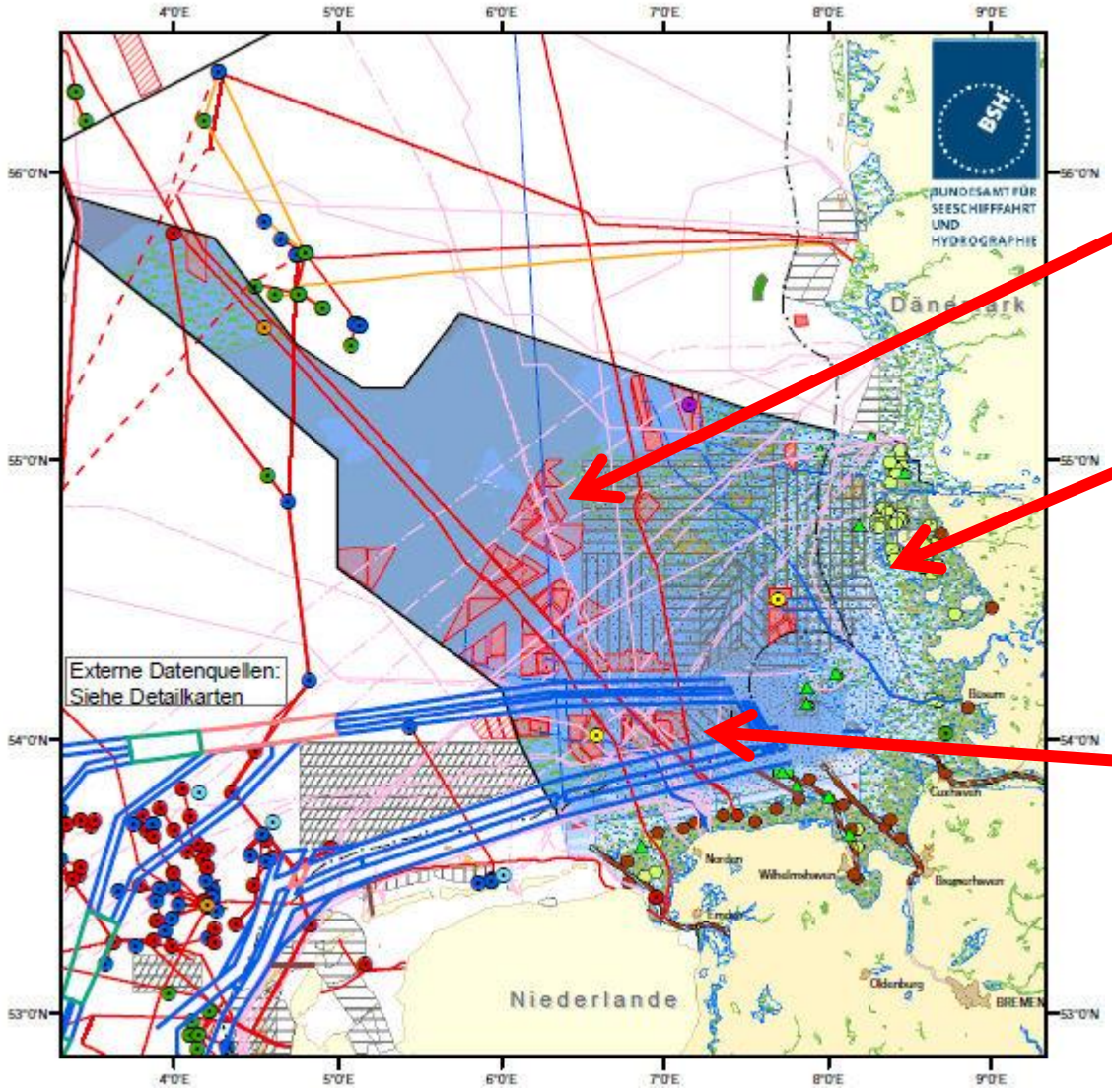
Three principles

- Aquaculture should be developed in the context of ecosystem functions and services (including biodiversity) with no degradation of these beyond their resilience;
- Aquaculture should improve human-well being and equity for all relevant stakeholders;
- Aquaculture should be developed in the context of other sectors, policies and goals.

Soto, 2010

EAA: ecosystem balance, social equity, multiple uses

North Sea marine spatial conflicts



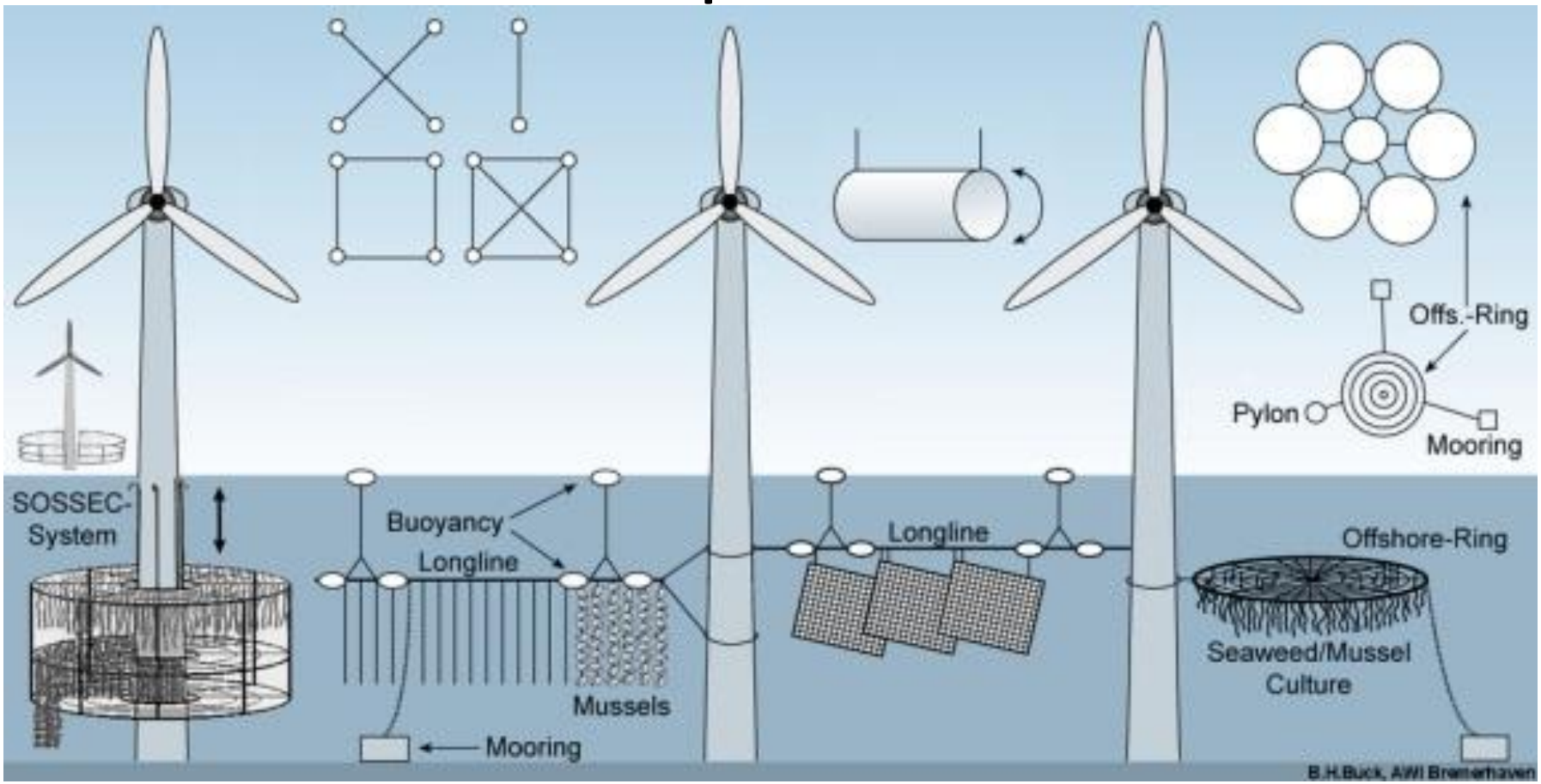
Windfarms

Fisheries

Navigation

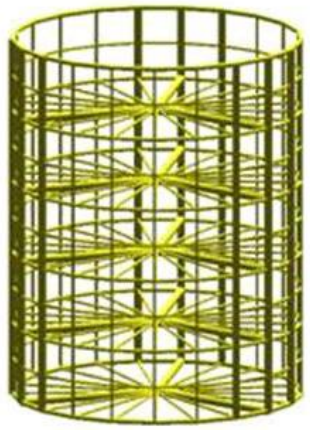
Source: BSH

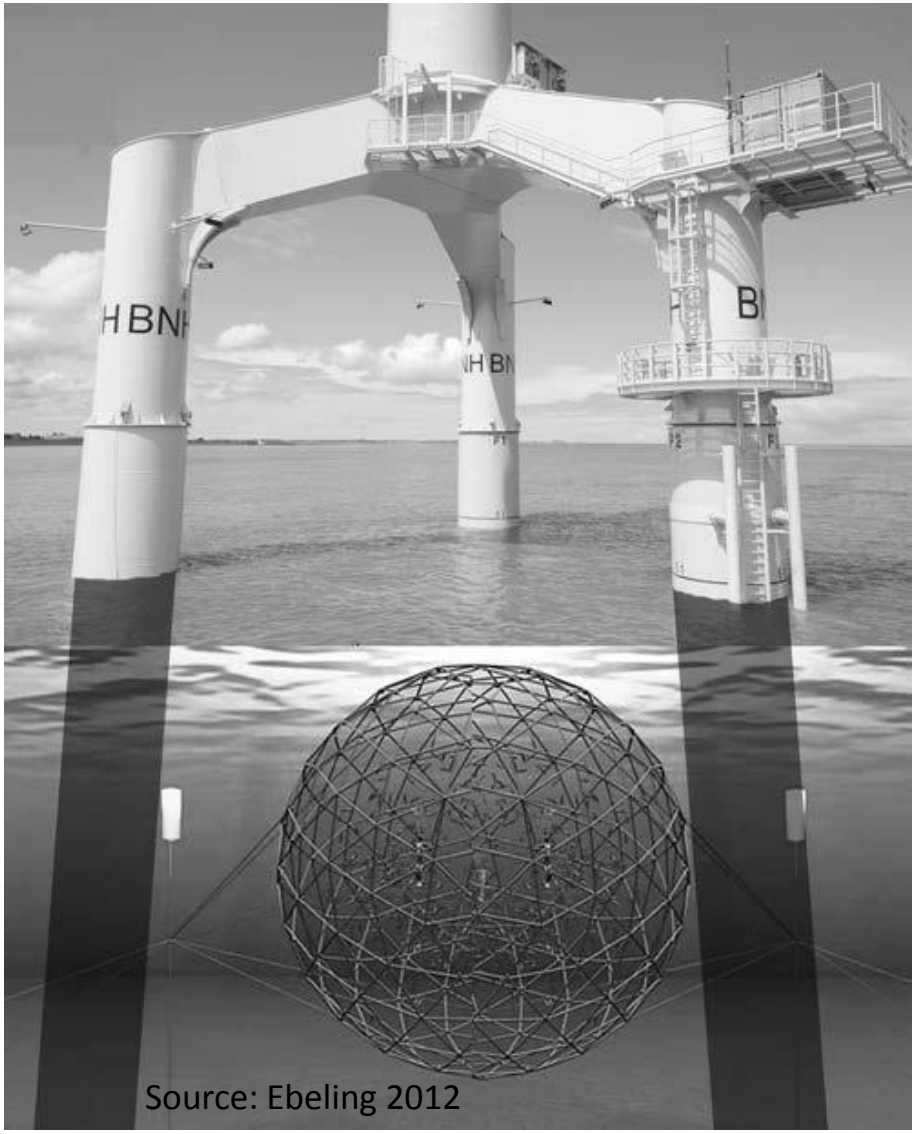
Combination of offshore windfarms and aquaculture



Potential use of wind turbines and enclosed space for cultivating finfish, shellfish, and seaweeds

Offshore windfarm – single turbine



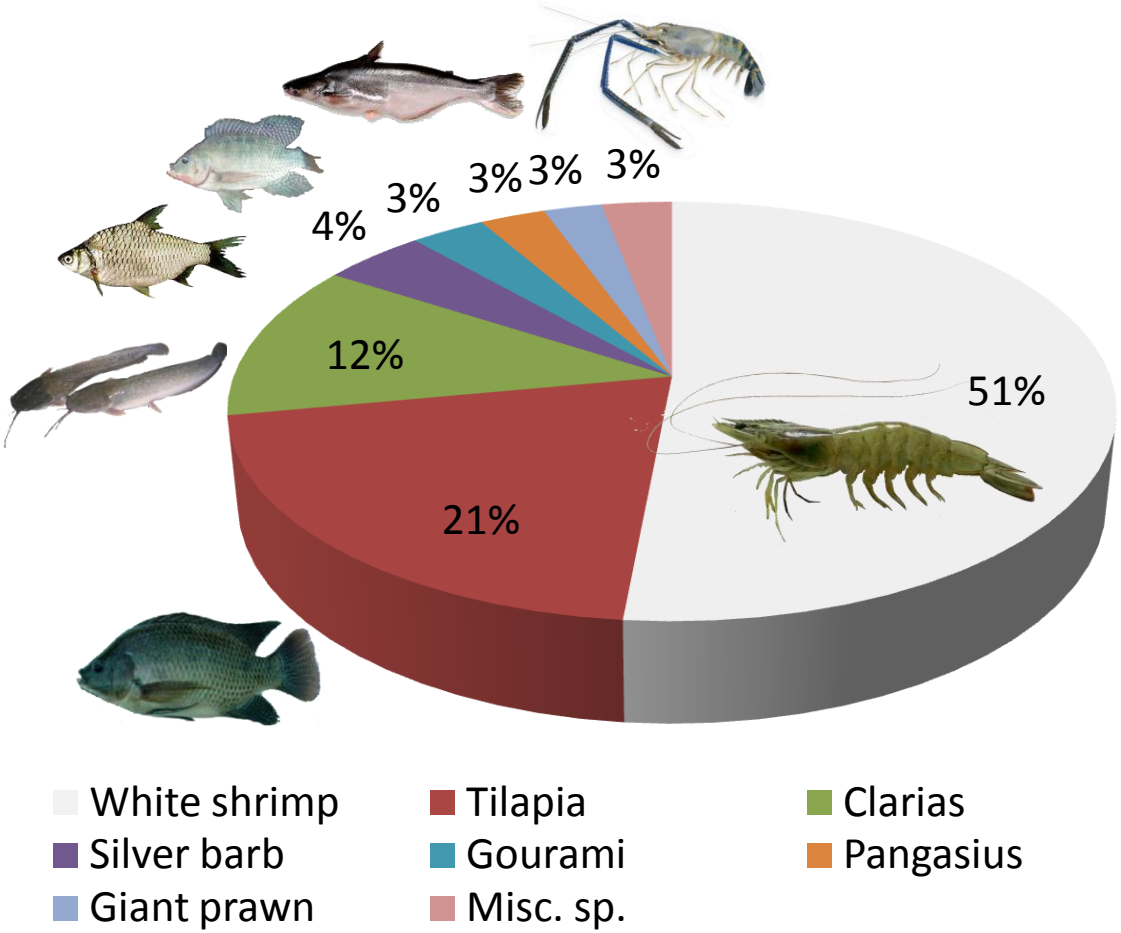


A turbine costs 15-20 million € and a height above sea level of 25 m
Operators resist co-use due to permitting, safety and insurance concerns

Integrated Multi-Trophic Aquaculture: Panacea or Hype?

- Aquaculture description and modeling framework
- Finfish and shrimp individual growth models
- Simulation of growth in ponds
- Production, environmental externalities and IMTA
- Upscaling to the Kingdom of Thailand

Species production from aquaculture
Data for Thailand, 2009



Species	Tons y^{-1}
Tilapia	221 042
Clarias	130 064
Silver barb	47 231
Gourami	34 220
Pangasius	30 200
Giant prawn	26 785
Misc. sp.	32 338
Total inland	**521 880**
White shrimp	**553 899**

White shrimp production is approximately the same as the total for inland aquaculture.

Source: Department of Fisheries Thailand

Export of aquaculture products from Thailand

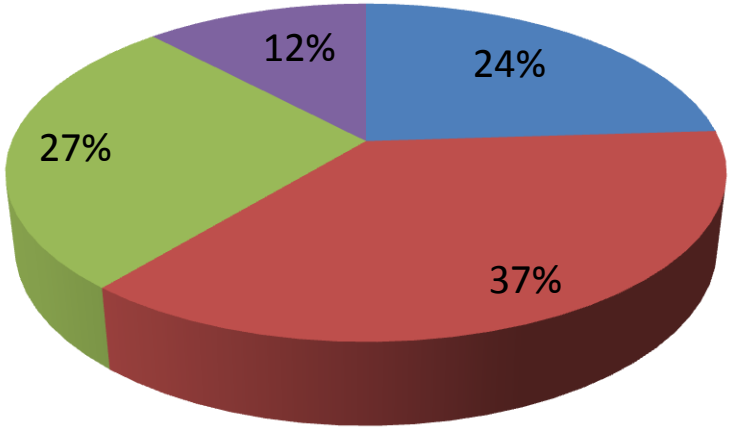
Inland total and white shrimp

Inland 

33 454 tons y^{-1}

1 421 M baht y^{-1}

33.25 M euro y^{-1}

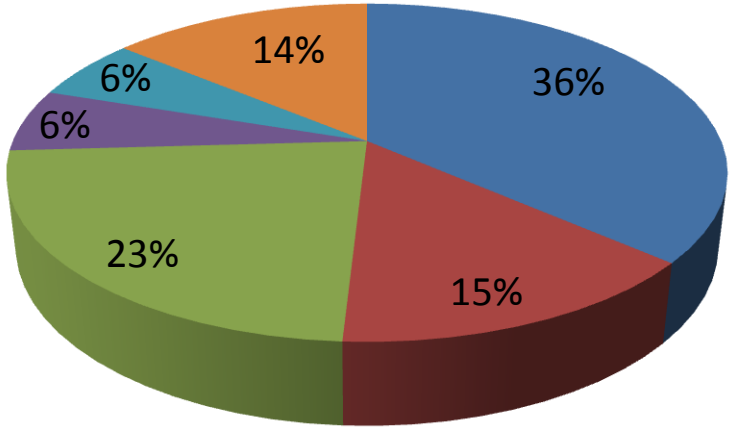


White shrimp 

311 322 tons y^{-1}

78 920 M baht y^{-1}

1 846.65 M euro y^{-1}



White shrimp (*Litopenaeus vannamei*) is a high value product. During 2003-2009, export was ten times more than inland export, and income was fifty-five times higher.

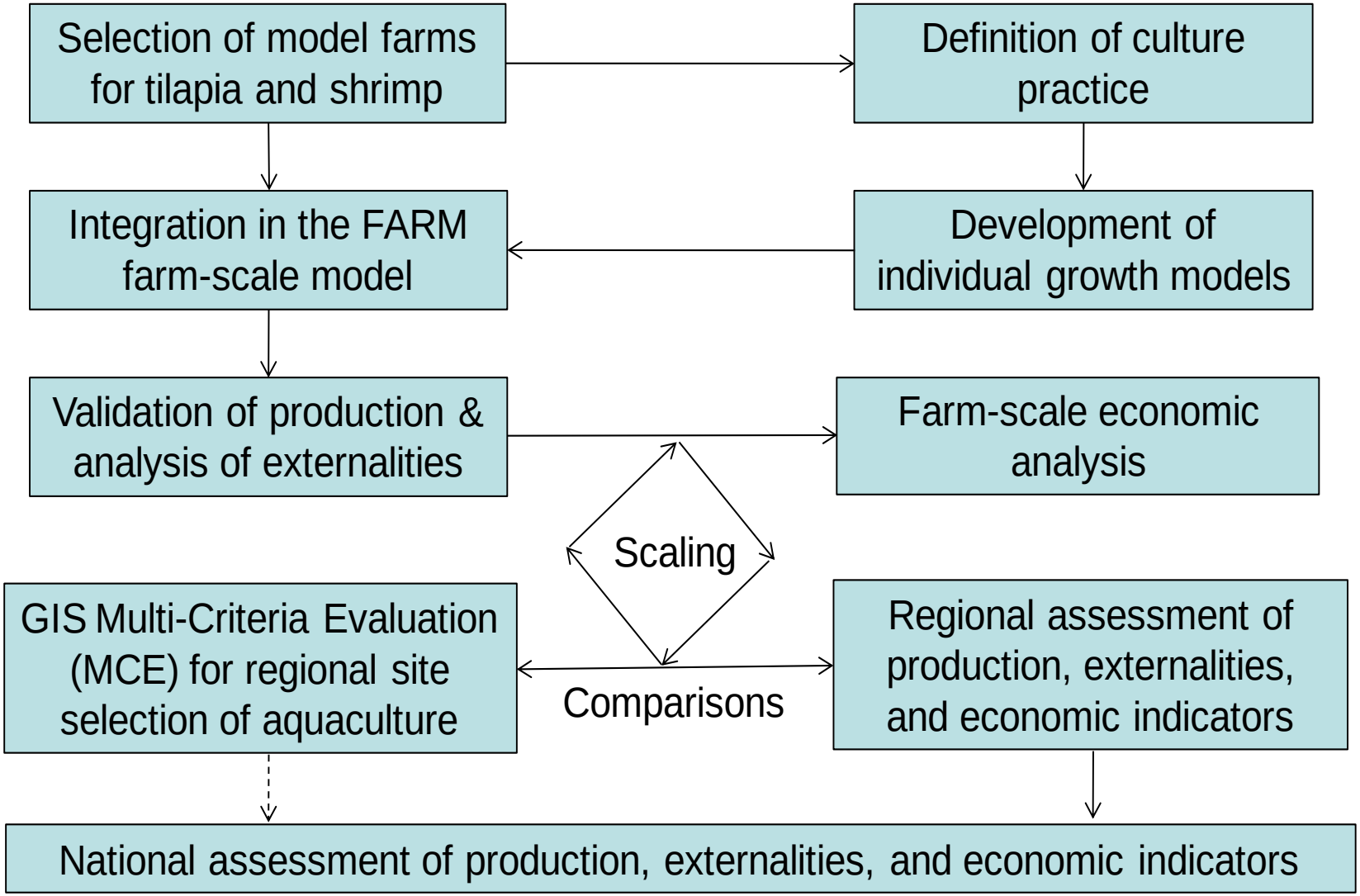
Source: Department of Fisheries Thailand


Nile tilapia
Central Thailand


Nile tilapia
Central Thailand

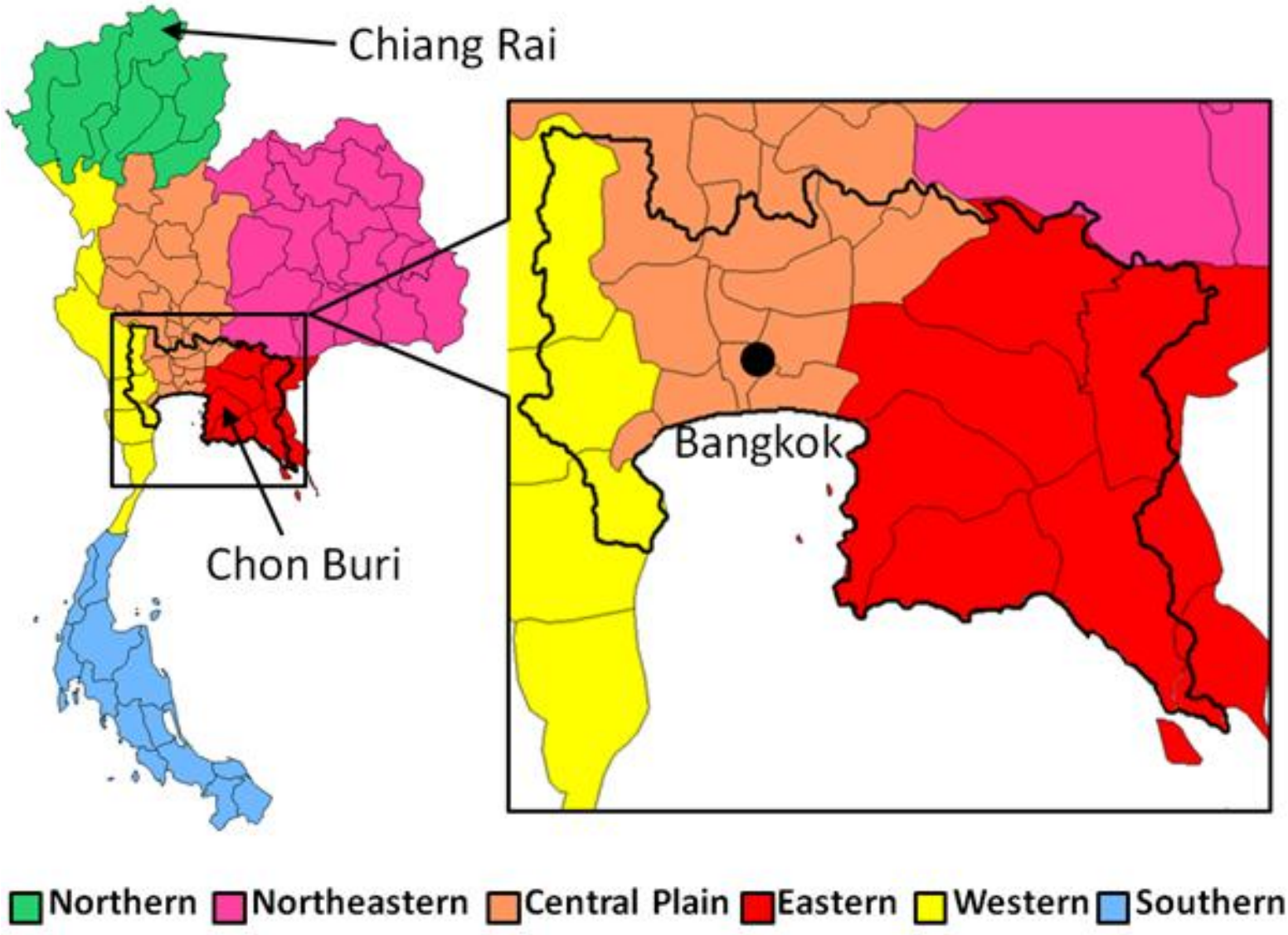
Modelling framework

Field and experimental data combined with various models



A combination of models helps address different aspects of sustainability.

Study areas in Thailand



Tilapia in NW Thailand, IMTA in Western Thailand.

FARM setup for Chiangrai pond culture

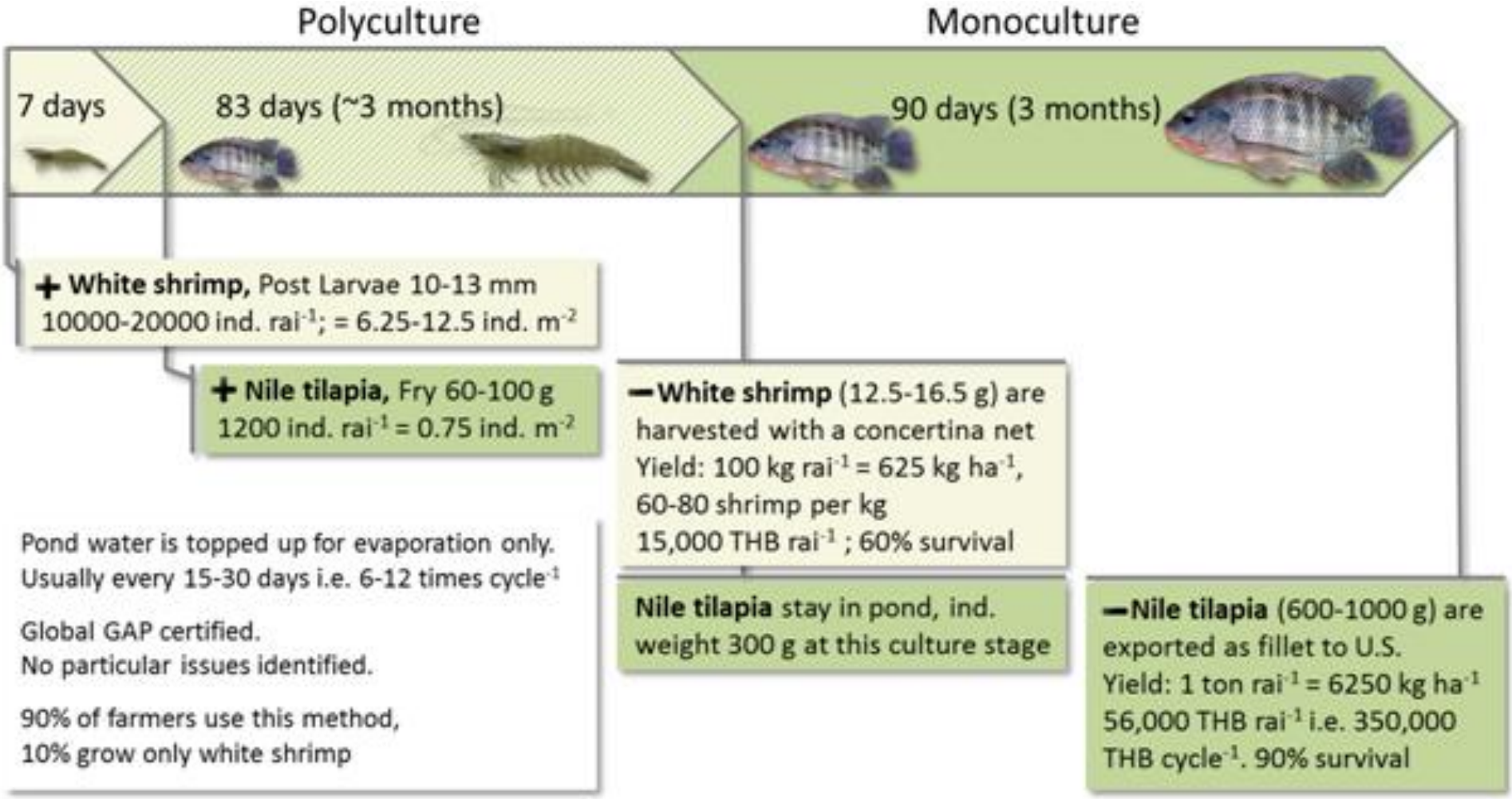
Tilapia, *Oreochromis niloticus*

Cholburee, Thailand

Integrated culture of tilapia and shrimp

Shrimp go in for one week, then the tilapia are added and eat the *Azolla*.

IMTA culture practice



Put the shrimp in first so the tilapia don't eat them.

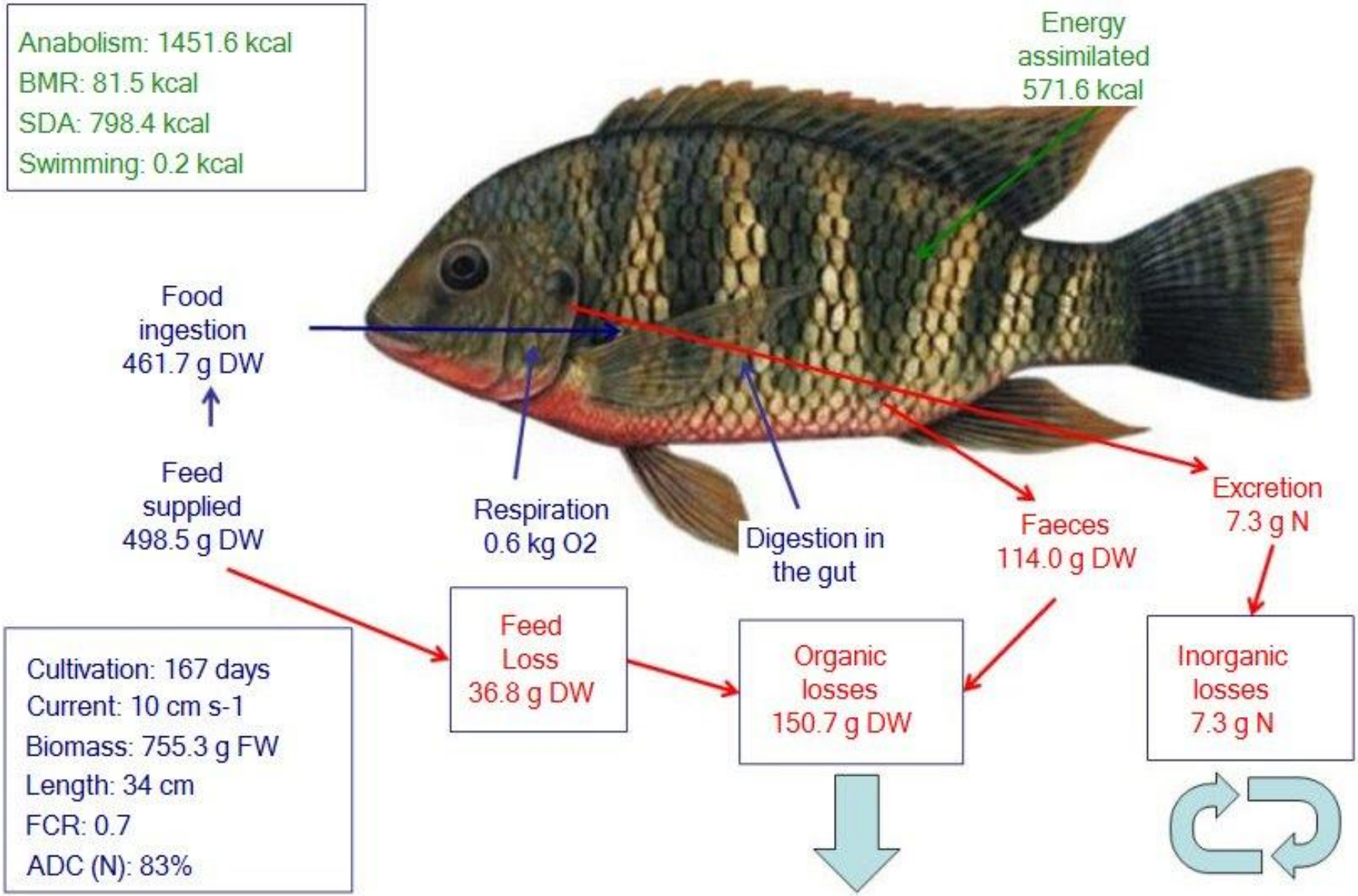
Blinded by the light

Luring the shrimp with an energy-efficient 220 V bulb

Shrimp are lured at night and captured in concertina nets.

Individual mass balance for Nile tilapia cultivation

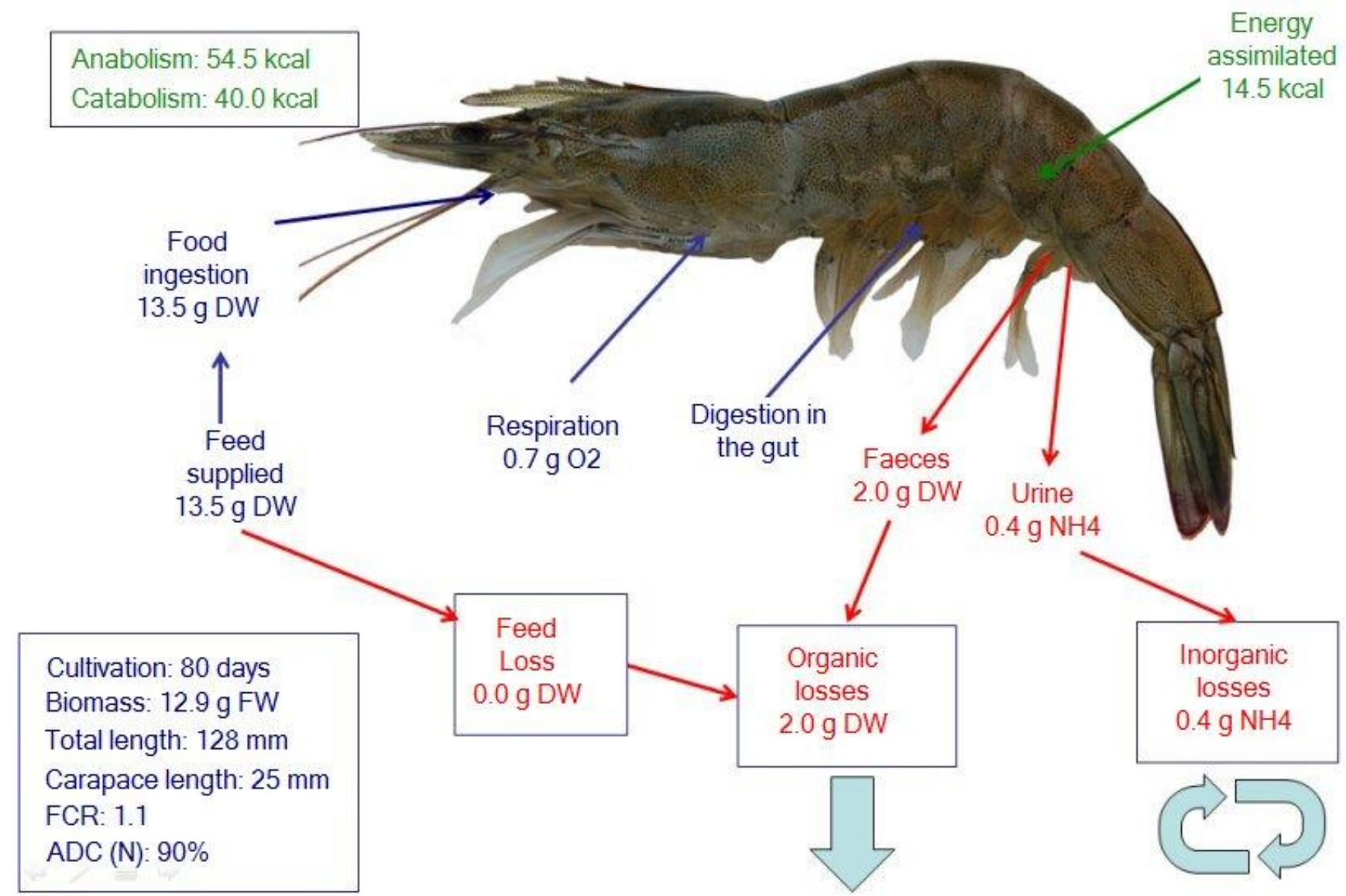
Final weight: 755 g, AquaFish model



Average individual weight for three ponds (8 rai) in Chiangrai is 713±59 g.

Individual mass balance for white shrimp cultivation

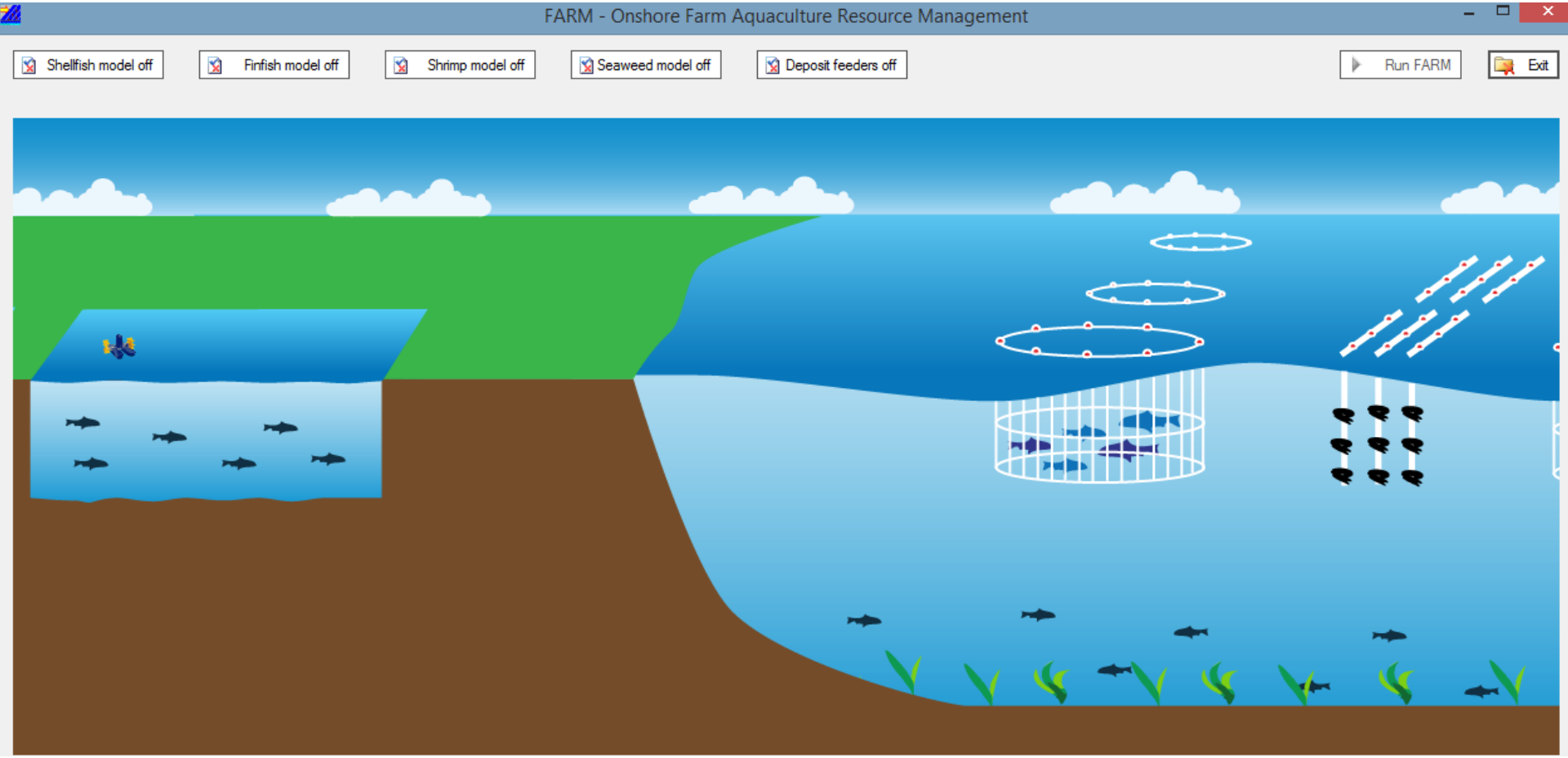
Final weight: 12.8 g, AquaShrimp model



White shrimp (*Litopenaeus vannamei*) weight in ponds varies between 10-25 g.

FARM model

Application to Integrated Multi-Trophic Aquaculture (IMTA)



FARM model for finfish, shellfish, or seaweed monoculture, and IMTA.

Ferreira et al, 2014. Analysis of production and environmental effects of Nile tilapia and white shrimp culture in Thailand. Aquaculture, http://dx.doi.org/10.1016/j.aquaculture.2014.08.042.

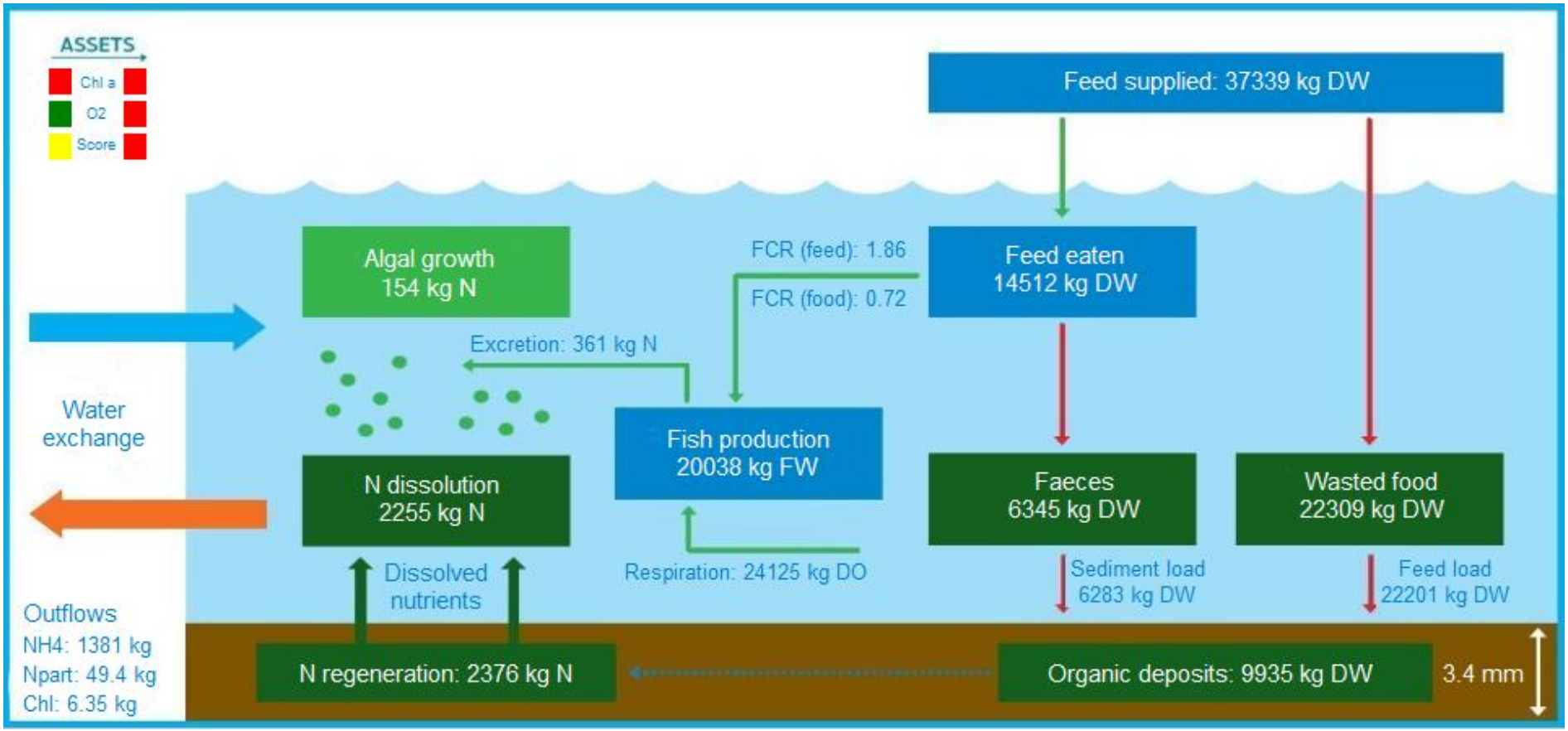
Production and environmental effects of pond culture of Nile tilapia (*O. niloticus*) in monoculture - Chiangrai

Variable	FARM - tilapia Monoculture	Data - tilapia monoculture
Model inputs		
Seeding density	3.13 fish per m^2 2 rai (3200 m^2) ponds	
Seeding density (kg FW)	801.3	800
Model outputs		
Production		
Total (TPP) (kg TFW)	5115.6	5400
Feed Conversion Ratio (FCR)	1.80	1.69
Environmental externalities		
Outflow of NH_4^+ (kg N)	224.5	-
Outflow of chlorophyll (kg chl)	1.27	-
Profit and loss		
Total income = Aquaculture products ($)	**8747.69**	**9234**
Total expenditure ($)	**7659.50**	**7388.28**
Feed cost ($)	6276.77	6324
Seed cost ($)	969.25	967.7
Energy cost ($)	413.48	96.58
Farm Profit = Income-Expenditure ($)	**1088.19**	**1845.72**

FARM model: results per pond; recorded data: average of three ponds.

FARM model for culture of finfish

Mass balance for pond culture of Nile tilapia in Chiangrai

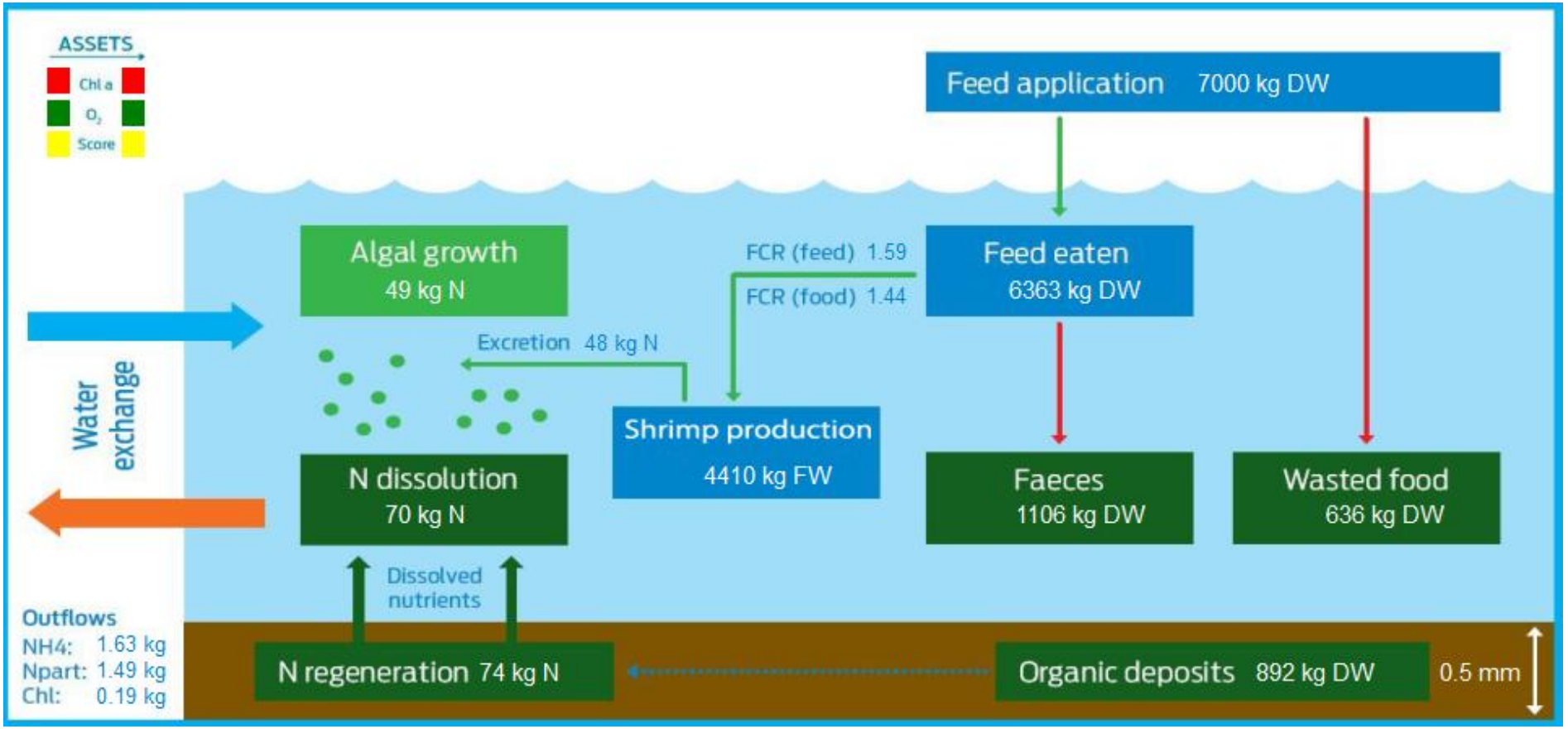


Mass balance for tilapia pond culture (4 ponds, 8 rai total area,167 day cycle, starting day 206, seed weight 80 g, harvest weight >650 g). Yield of 5009.4 kg per pond (recorded data - average: 5400 kg and FCR 1.69).

Ferreira et al, 2014. Aquaculture, http://dx.doi.org/10.1016/j.aquaculture.2014.08.042.

FARM model for shrimp monoculture

Mass balance for pond culture of white shrimp in Chanthaburi



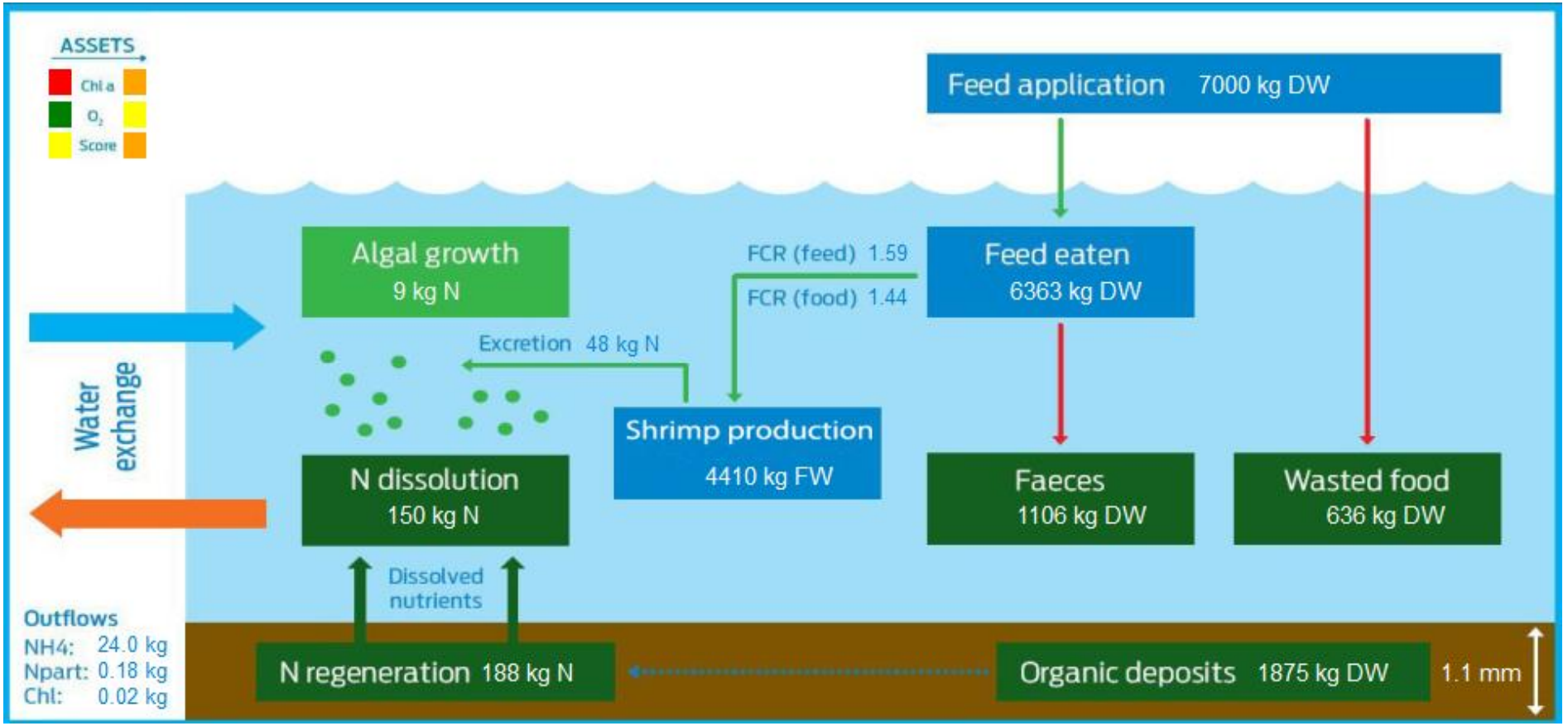
Mass balance for shrimp pond culture (1 pond, 2.5 rai area, 81 day cycle, density 80 ind. m^{-2}, starting day 1, seed weight 0.002 g, harvest weight >16 g). Yield of 4409.8 kg per pond (recorded data: 4000 kg, FCR 1.32).

Ferreira et al, 2014. Aquaculture, http://dx.doi.org/10.1016/j.aquaculture.2014.08.042.

FARM model for integrated multi-trophic aquaculture

Mass balance for co-cultivation of tilapia and white shrimp

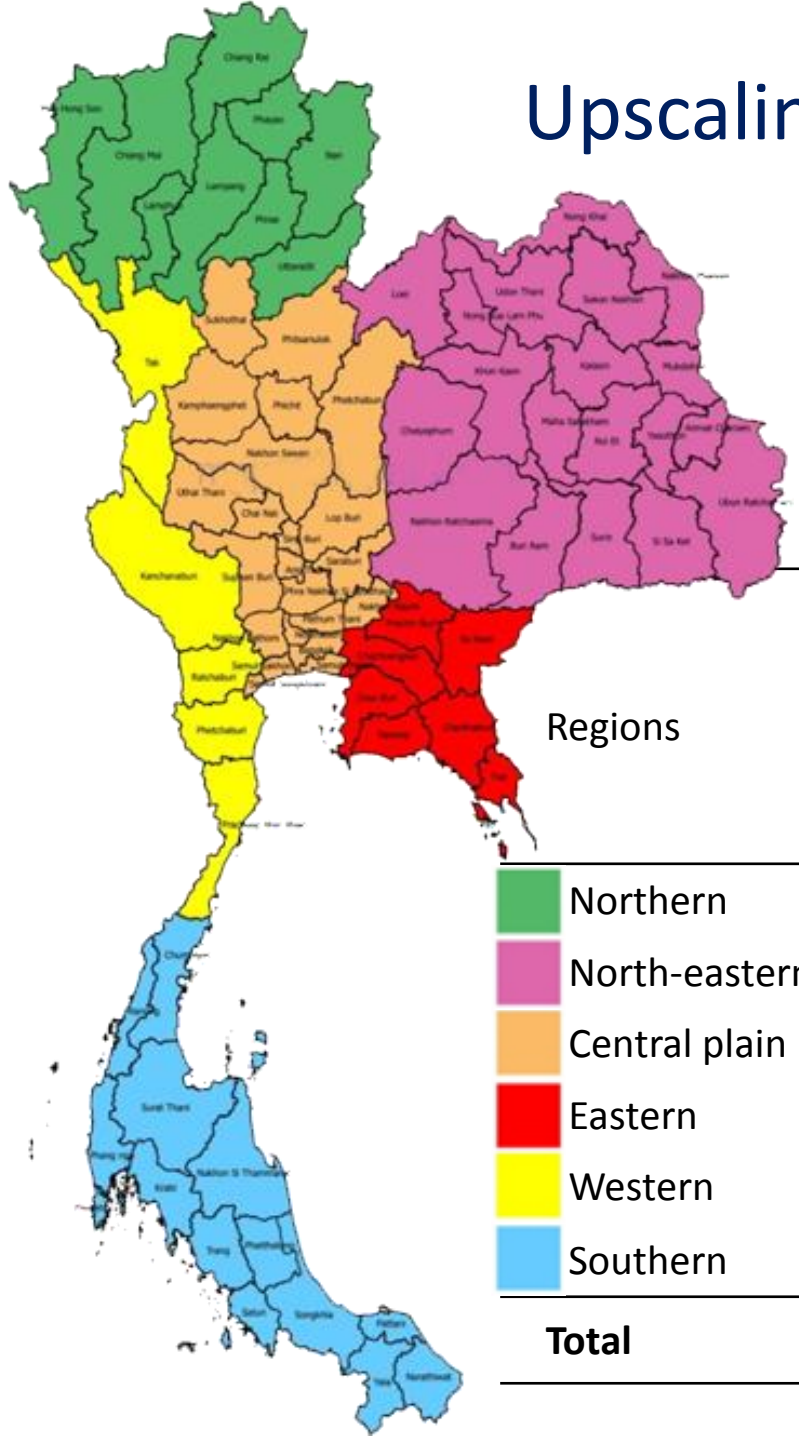
Simulation for 81 days (one shrimp cycle)



Tilapia increase sedimentation of organics and diagenesis, but significantly reduce algal growth through filtration, and therefore chlorophyll emissions. There is an additional crop of about 1 ton of tilapia (400 g weight) in this 2.5 rai farm.

Upscaling to the Kingdom of Thailand

Production and environment



Regions	Aquaculture production	Primary production	Environmental externalities due to outflows		
			Ammonia	Chlorophyll *a*	PEQ
	t y^{-1}	t N y^{-1}	t N y^{-1}	kg chl y^{-1}	
Northern	36 004	718	126	125	38 187
North-eastern	42 981	857	150	149	45 587
Central plain	16 500	329	58	57	17 501
Eastern	32 957	657	115	115	34 956
Western	21 296	425	75	74	22 587
Southern	8 556	171	30	30	9 075
Total	**158 293**	**3 156**	**554**	**550**	**167 893**

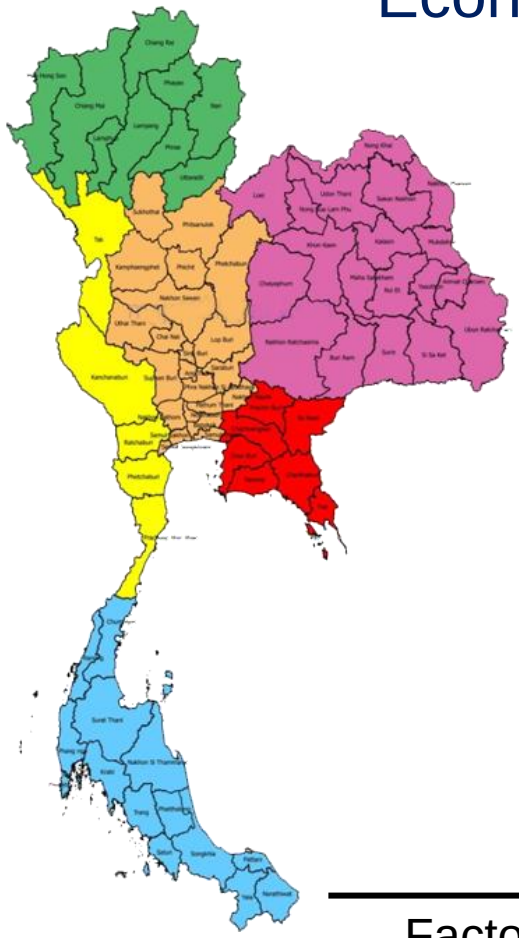
Upscaling to the Kingdom of Thailand

Production and environment

Regions	Aquaculture production	Primary production	Environmental externalities due to outflows		
			Ammonia	Chlorophyll *a*	PEQ
	t y^{-1}	t N y^{-1}	t N y^{-1}	kg chl y^{-1}	
Central	170 975	1 641	36	6 642	10 774
Eastern	41 143	395	9	1 598	2 593
Western	43 063	413	9	1 673	2 714
Southern	298 718	2 867	62	11 605	18 824
Total	**553 899**	**5 316**	**115**	**21 518**	**34 904**

Upscaling to the Kingdom of Thailand

Economic analysis for Nile tilapia



Direct economic indicators

	Millions USD
Total revenue	253.27
Total expenditure	187.98
Labour income for 500 000 people	10.40 (5.5%)
Direct job creation	400,000-650,000

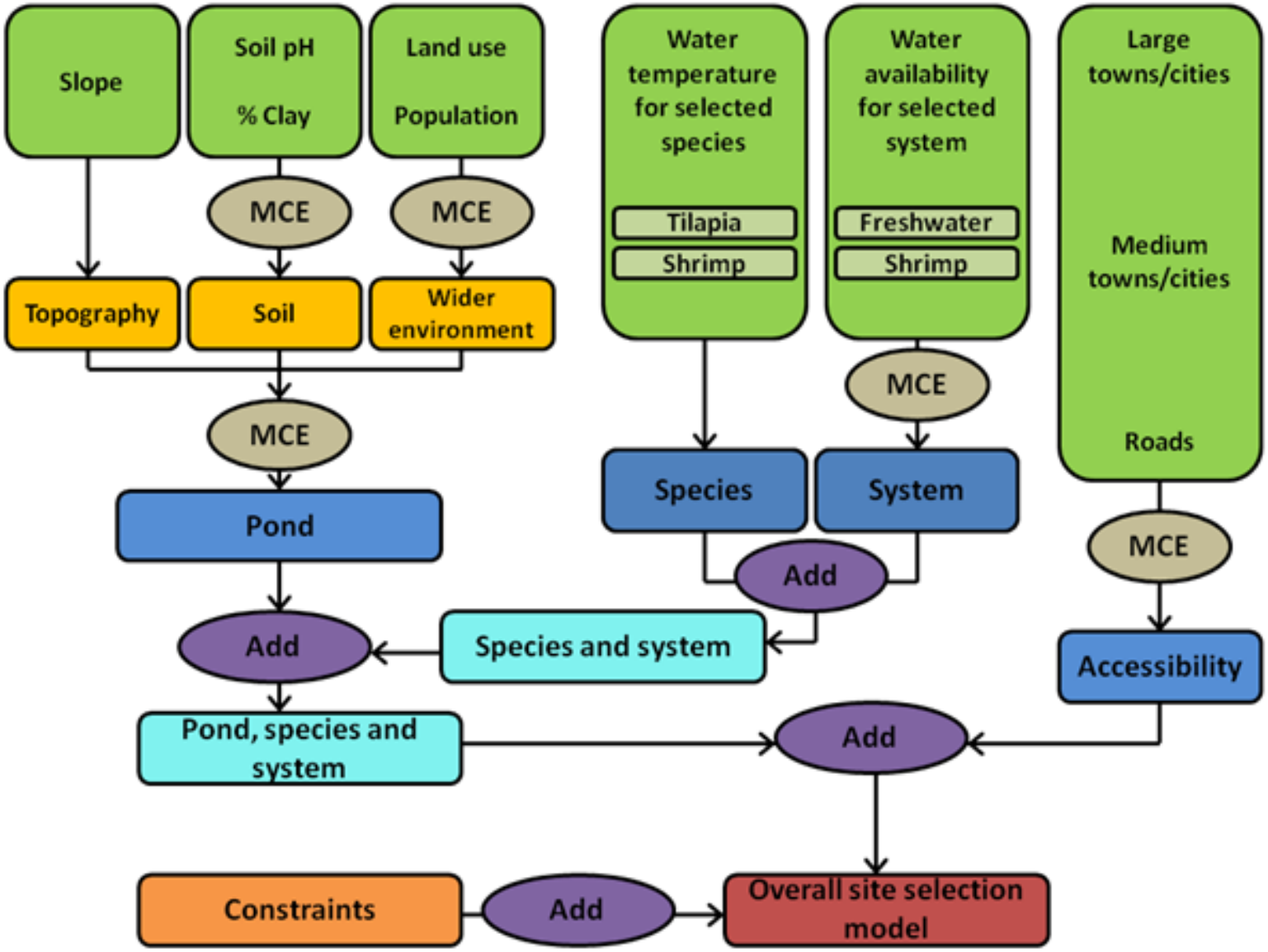
Indirect/induced economic impacts

	Value added to revenue	Jobs created from revenue	Costs of internalization
Factors	VAD ratio: 0.38	64 per million USD	10^6 USD
Value	96.24 M USD	16 209	21.1

Economic data from Thailand, based on DOF and FAO.

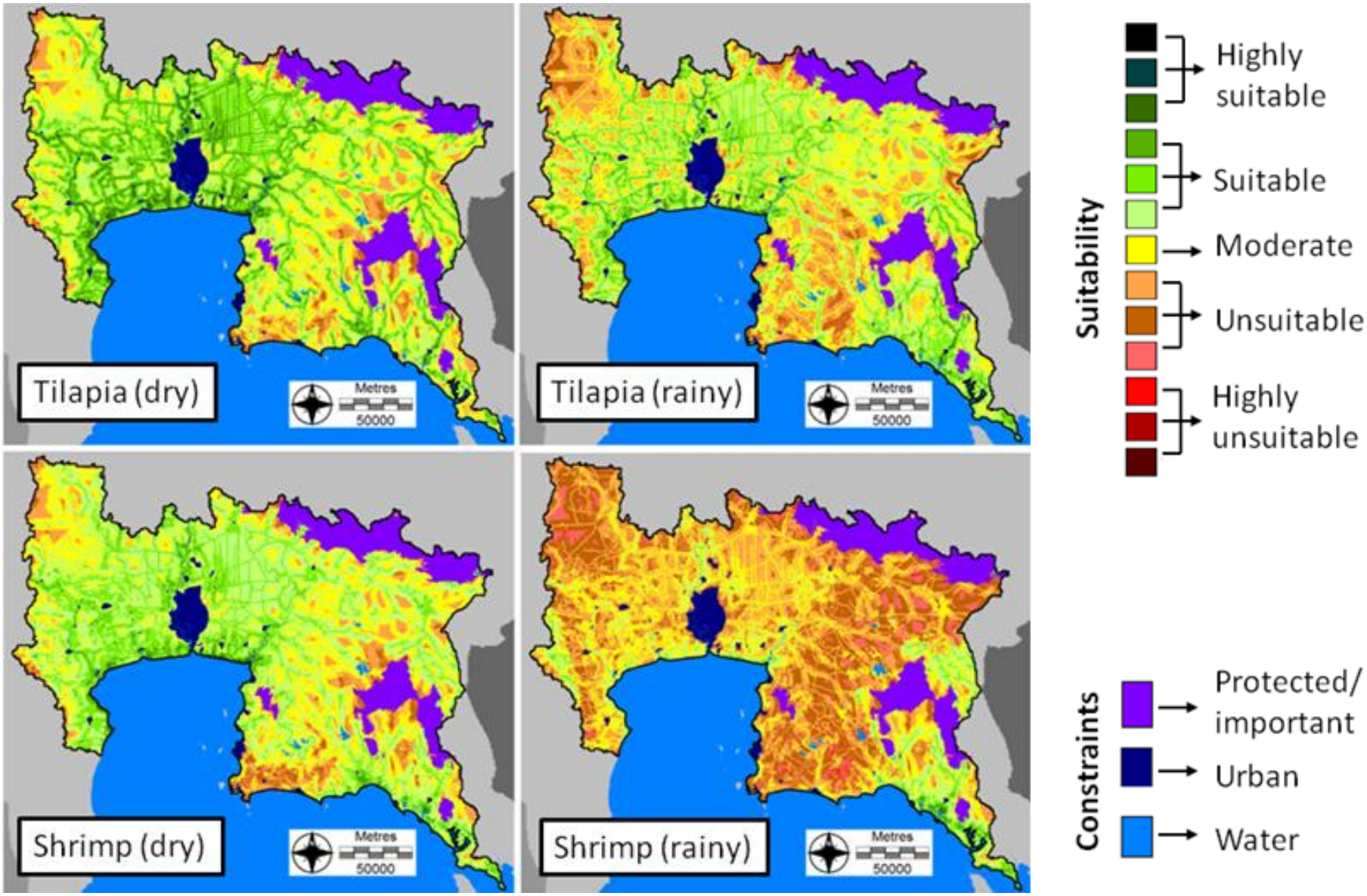
Cost of negative externalities assuming 1/3 of PEQ = 6% of production income.

Structure of site suitability model



MCE based on slope, pH, land use, water temperature, water availability, towns and roads.

Site suitability analysis for pond culture in Thailand



MCE based on slope, pH, land use, water temperature, water availability, towns and roads.

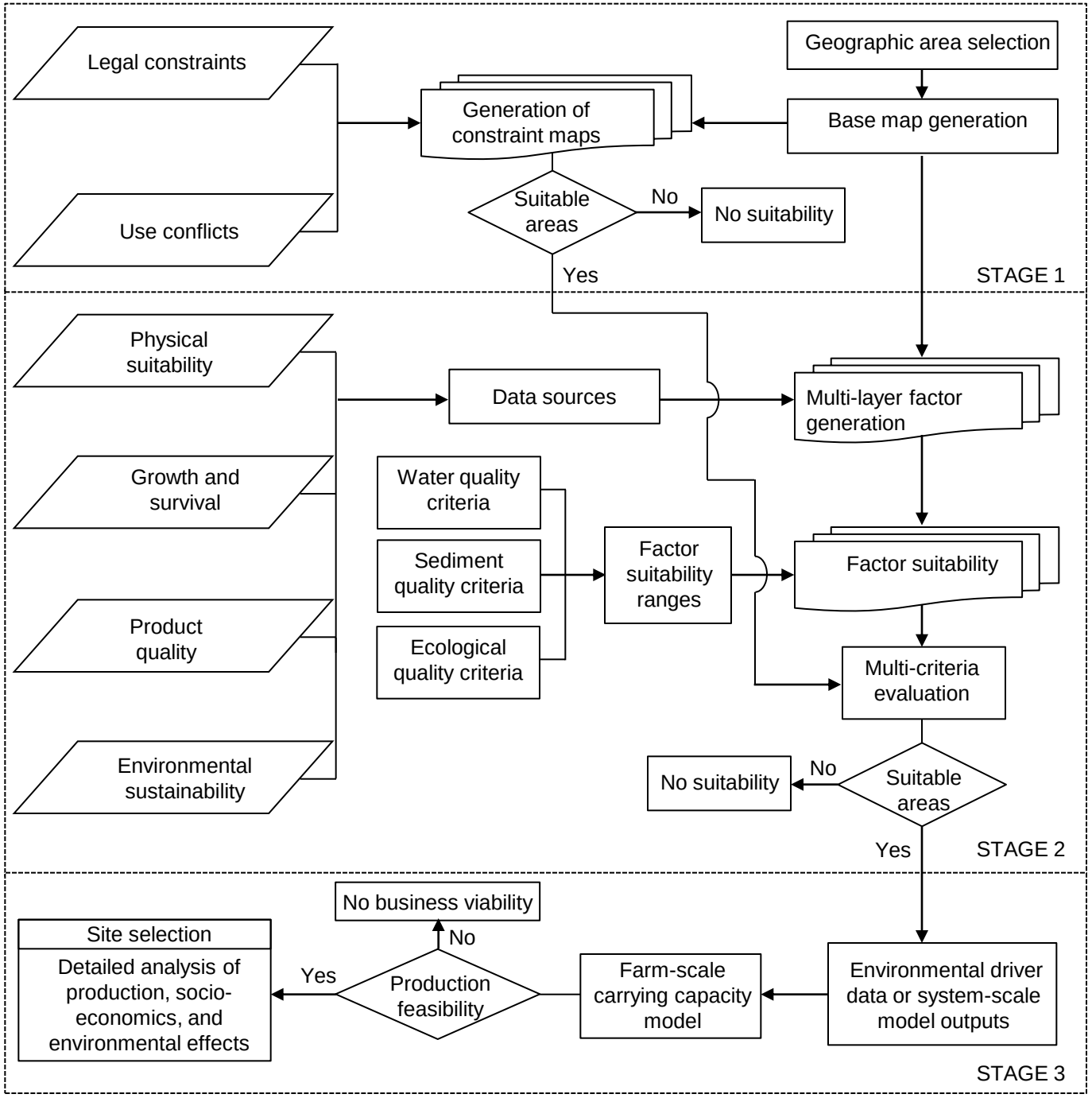
Summary – Freshwater Case Study

- Models such as FARM are valuable for analysis of environmental effects and different culture scenarios;
- IMTA of tilapia with shrimp helps reduce some negative externalities of shrimp culture, but adds to others;
- Chlorophyll outflow from shrimp farming is forty times greater than from tilapia cultivation;
- Dynamic modelling can be combined with spatial data to provide global estimates of production and environmental effects—this allows a more integrated economic valuation;
- In tilapia monoculture, nitrogen emissions equate to 170,000 PEQ, but a substantial part is recycled in agri-aqua;
- Estimated gross profit from tilapia is about 65 million USD per year;
- The potential total cost of reducing externalities (20.1×10^6 USD) would lower profit by at least one third.

http://ecowin.org/aulas/mega/pce

Systems approach for site selection

Every talk needs a horrendogram!



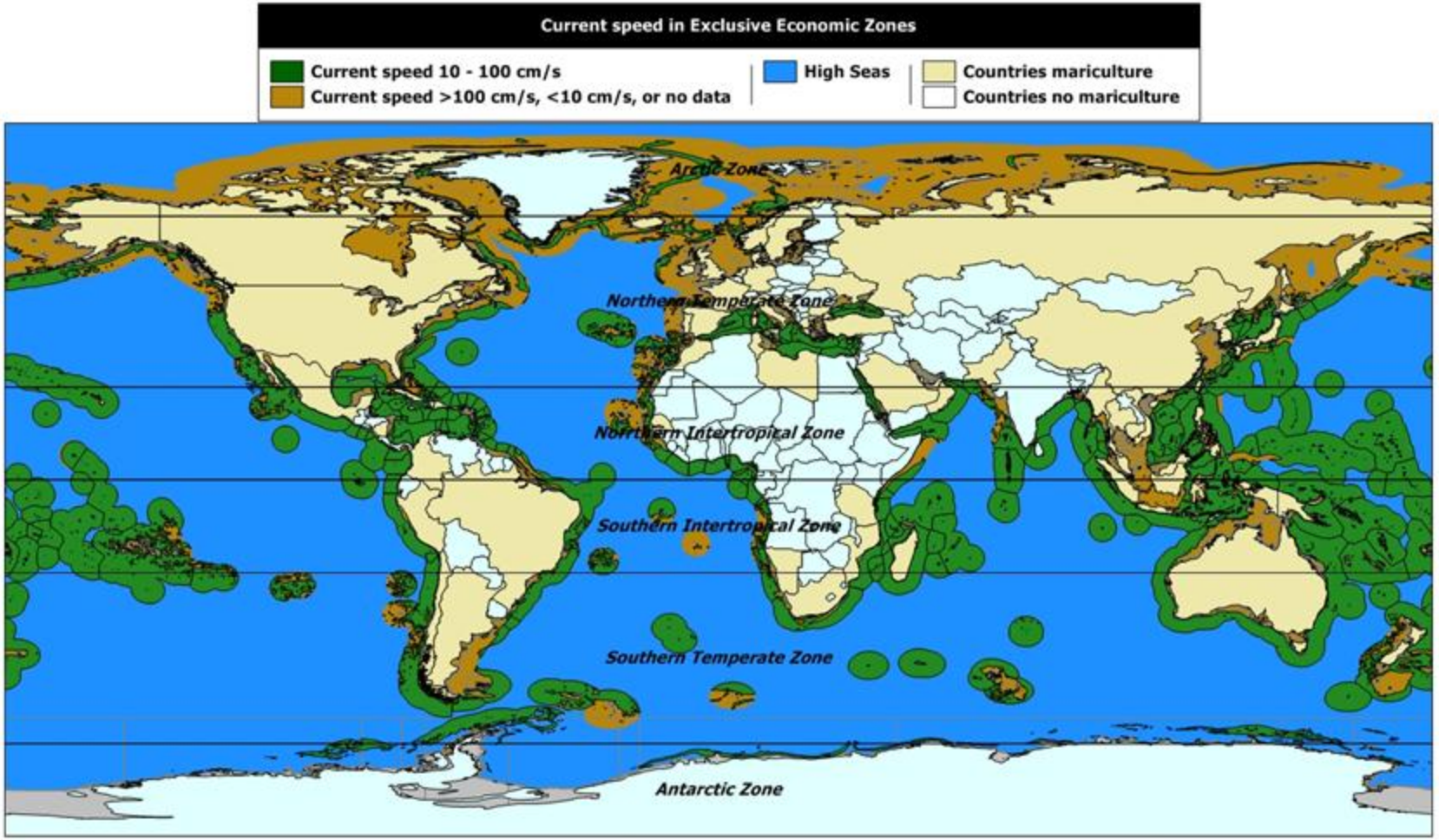
Silva et al., 2011.

Offshore aquaculture

The extra thirty million tonnes needed to feed the world in 2050 is at the top end of this range

Current speeds: 0.1-1 m s^{-1}, suitable depth range for cages [illegible]

123 countries with at least 100 km^2 that meet these criteria: 10^6 - 10^7 ton y^{-1}

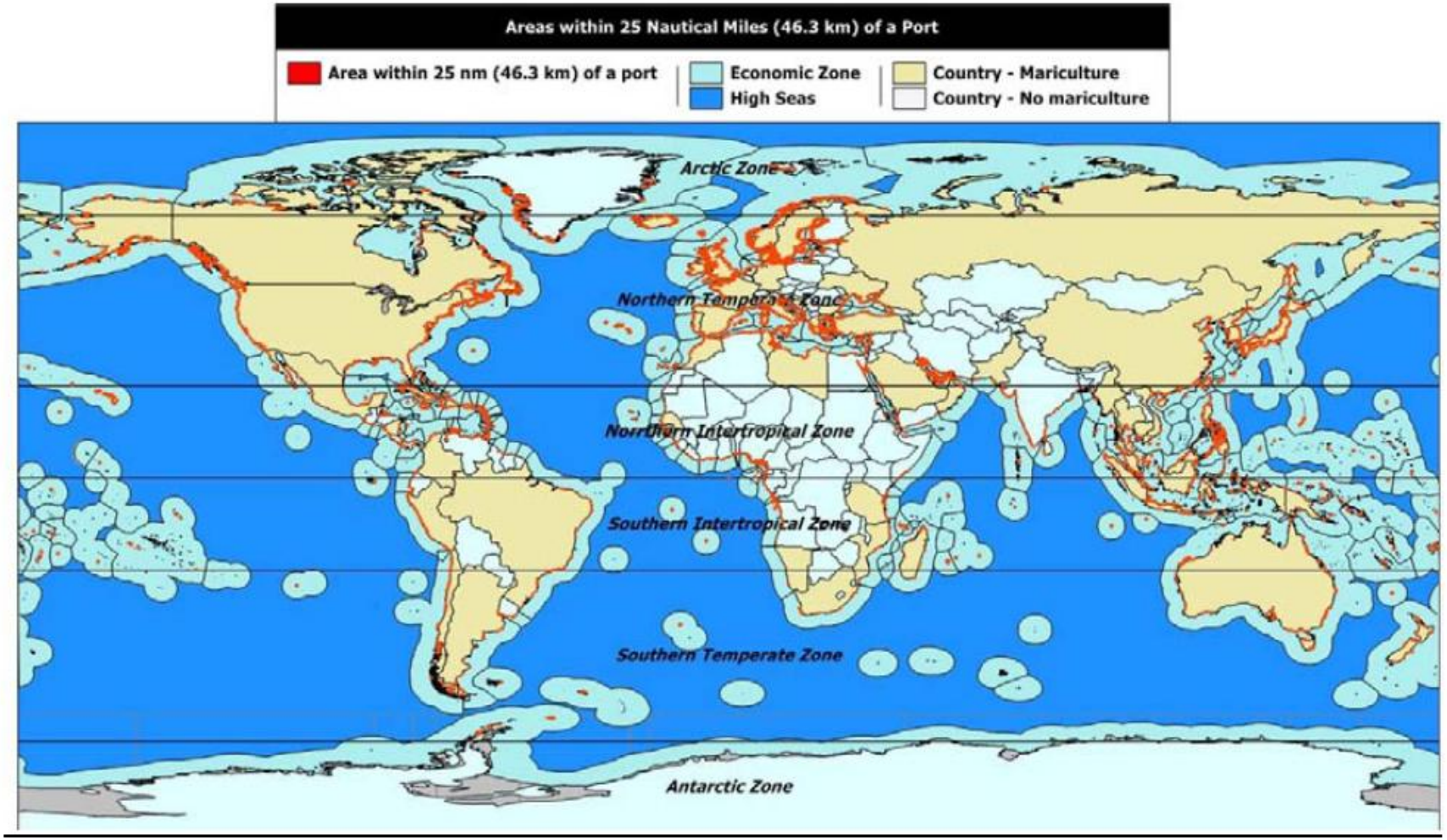


Kapetsky et al., 2010. FAO Workshop, Rome, 2010.

Offshore aquaculture

Areas within 25 nautical miles (46.3 km) of a port

UK has120,000 km^2 that meet criteria for cages, longlines,and 25nm to port



Kapetsky et al., 2010. FAO Workshop, Rome, 2010.

Offshore aquaculture - aquapods

Integrated Multi-Trophic Aquaculture

Vancouver Island, Canada

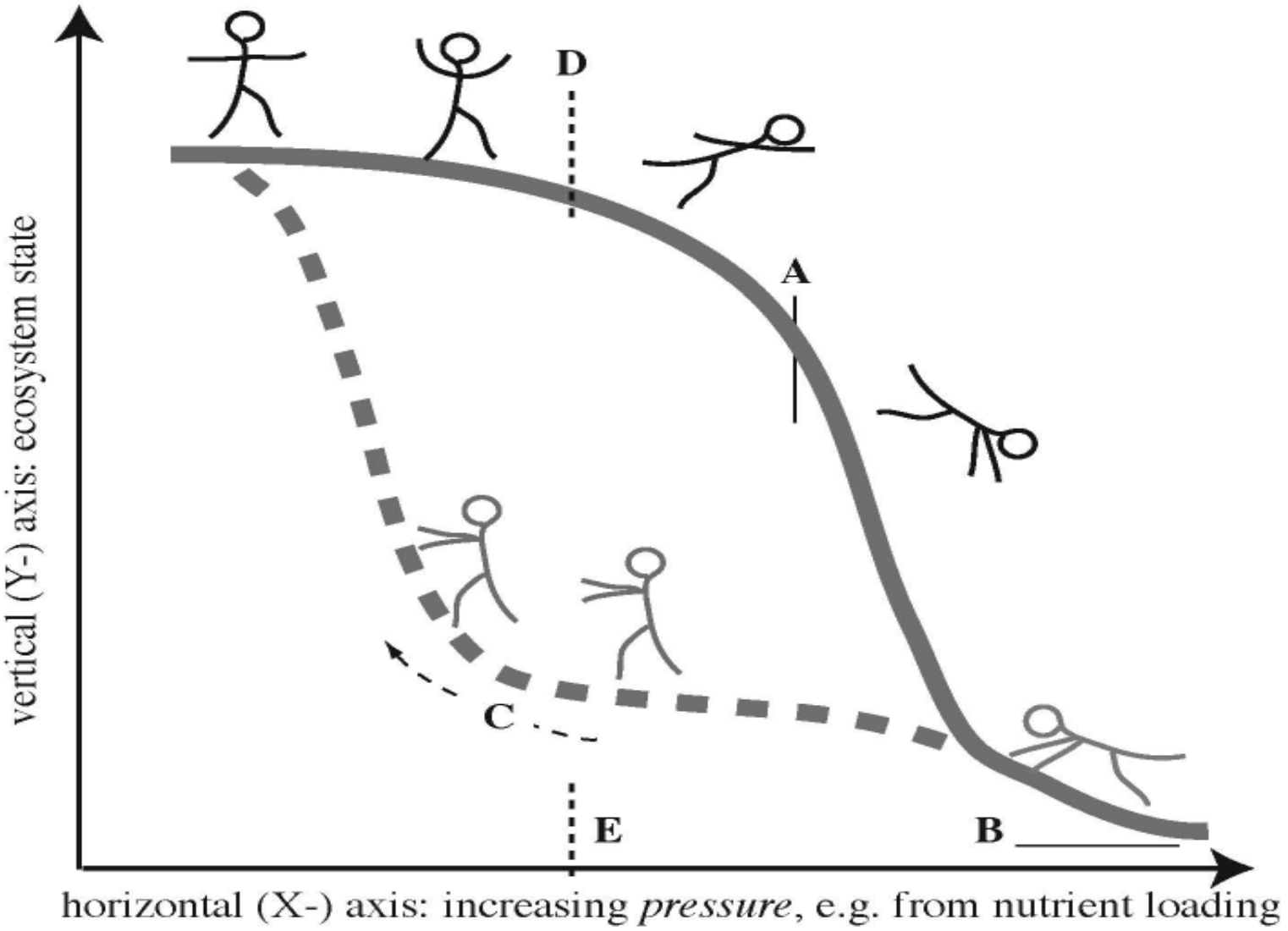
Scallop lanterns as part of an IMTA setup that includes sablefish, kelp, and sea cucumbers.

Summary

- Carrying capacity is not a level playing field
- Food security seems a remote issue in the Western World, but trade imbalance and jobs do not
- Fish will be more expensive as producer countries increase per capita GDP
- Models inform some questions, but the social component is key in Western society
- High level aquaculture policy direction in the EU, US, and Canada does not filter down to local management practice
- Collaboration needs instruments, contact, and confidence

All slides
http://ecowin.org/aulas/mega/pce/

Resilience…


D
A
C
E
B
vertical (Y-) axis: ecosystem state
horizontal (X-) axis: increasing *pressure*, e.g. from nutrient loading