2018 PICES International Symposium
"Understanding Changes in Transitional Areas of the Pacific"

Potential impacts of coastal mariculture on marine ecosystems and sustainable approaches

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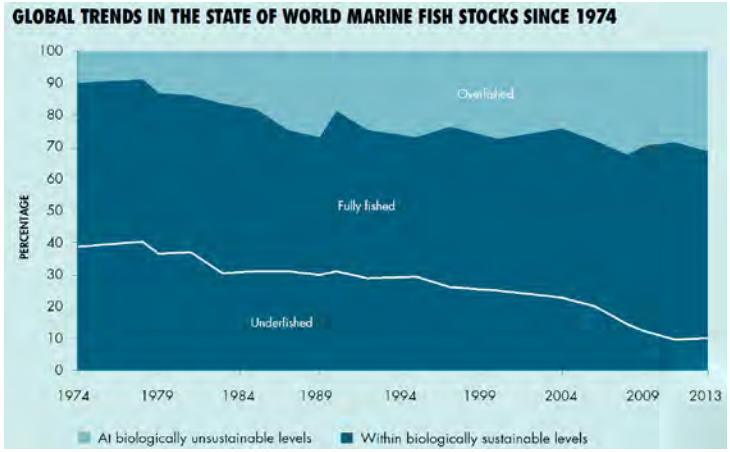
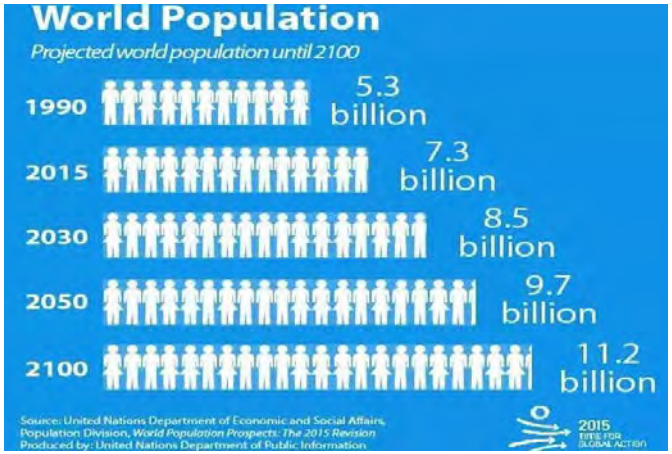
Outline

1. Global development of Mariculture
2. Potential impact of Mariculture on ecosystem
3. Towards sustainability

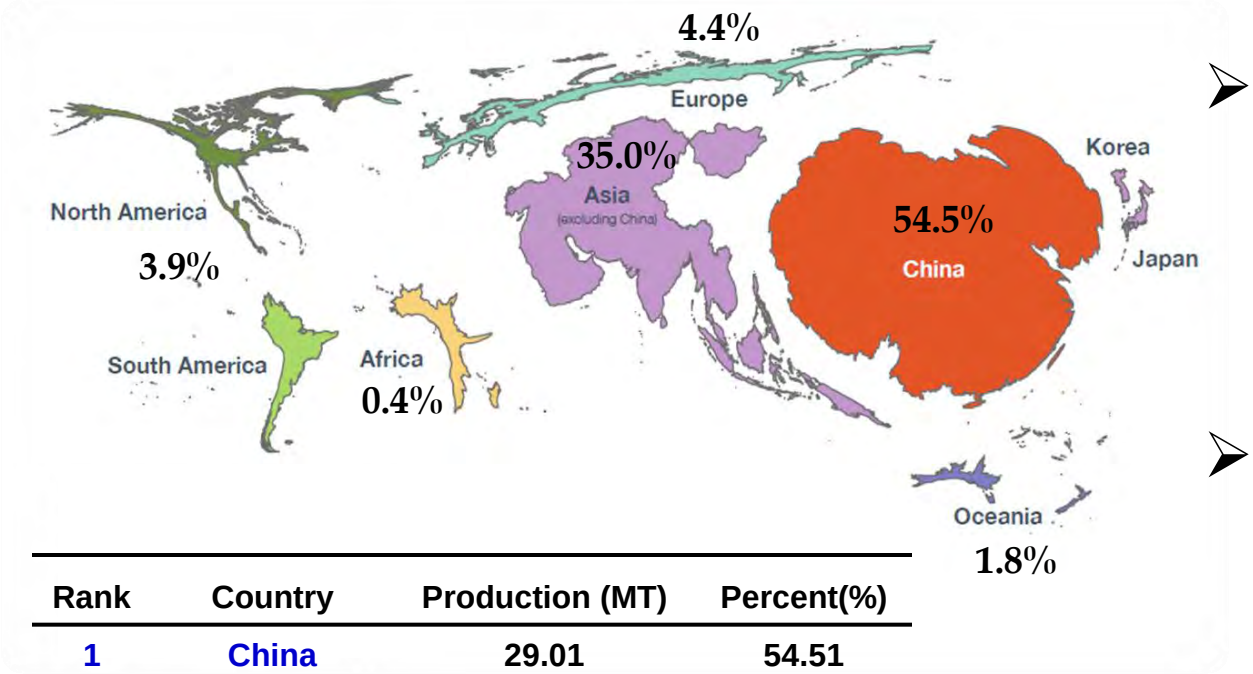
Why develop Mariculture?

- Global capture fisheries production continues to be in the trend of declination: ~90% of fish stocks were overfished and fully fished (FAO 2016);
- However, demand for seafood is constantly increasing due to the growth of world population;
- **Mariculture** becomes the possible solution to meet the growing seafood demand.





Development of mariculture around the world



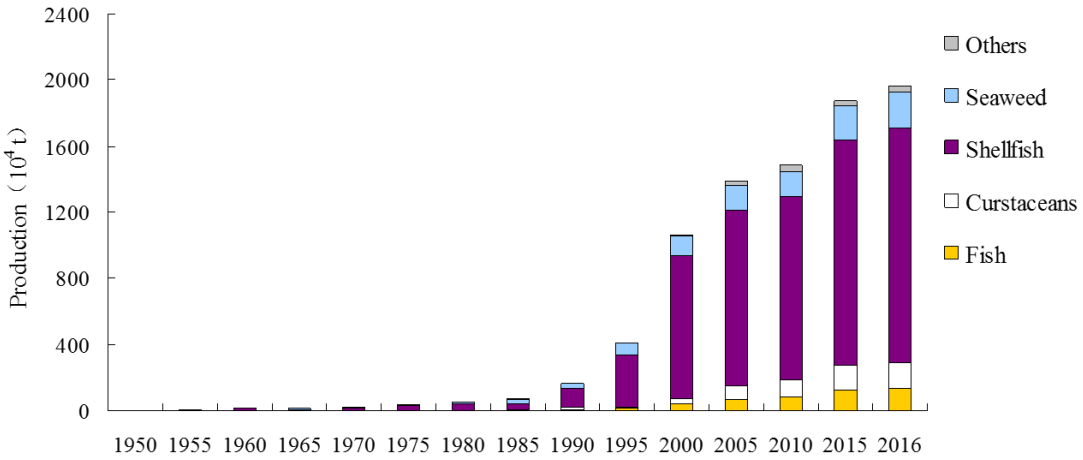
Rank	Country	Production (MT)	Percent(%)
1	China	29.01	54.51
2	Indonesia	10.68	20.07
3	Philippines	2.05	3.86
4	South Korea	1.52	2.85
5	Norway	1.25	2.34
6	Chile	1.00	1.88
7	Japan	0.99	1.87
8	Vietnam	0.91	1.70
9	Egypt	0.79	1.49
10	Thailand	0.57	1.07

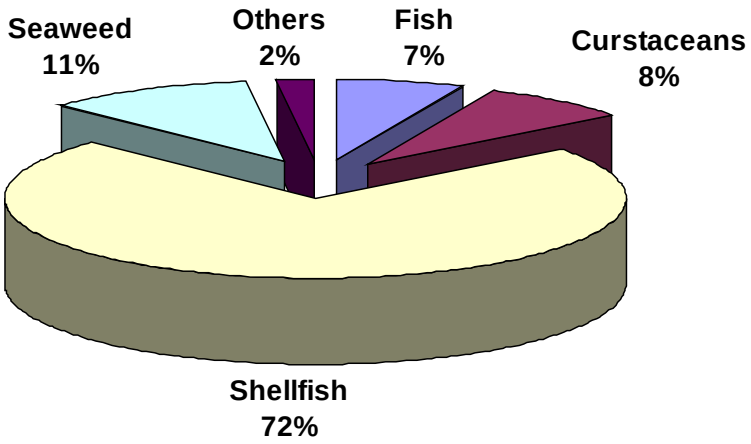
- World mariculture is heavily dominated by Asia which accounts for 89.5%;
- China is the largest mariculture country in the world.

China > (Europe + Americans) ×6!

Source：FAO(2013)

Mariculture development in China





Source：China Fisheries Statistic Yearbook (2017)

- Mariculture production in 2016: 19.63 MT.
- Shellfish and seaweed are the two most important species and occupy 83% of the total production.

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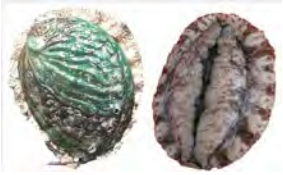
Types of Coastal Mariculture

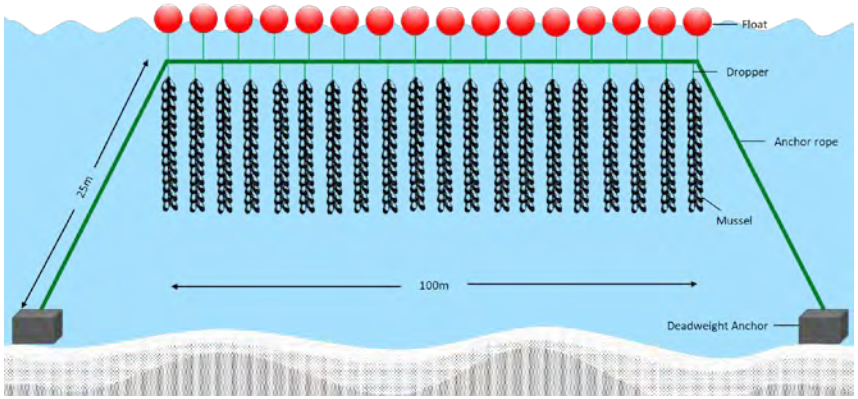
Feeding

Fish cage aquaculture



Abalone aquaculture

Non-feeding

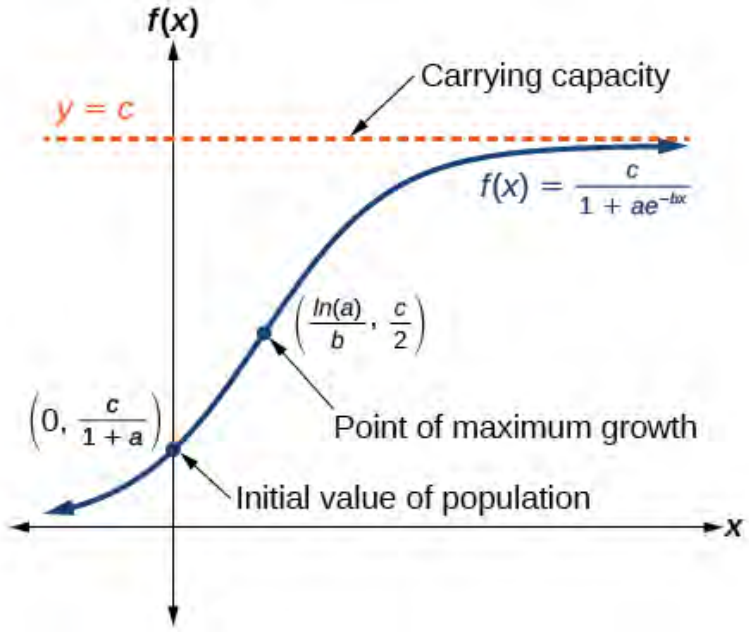


Typical longline system

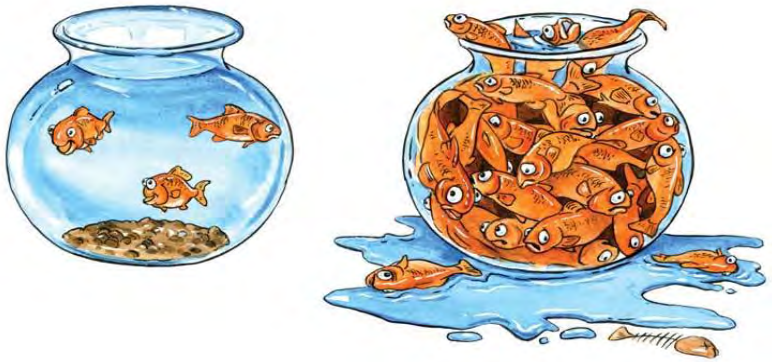
Bivalves

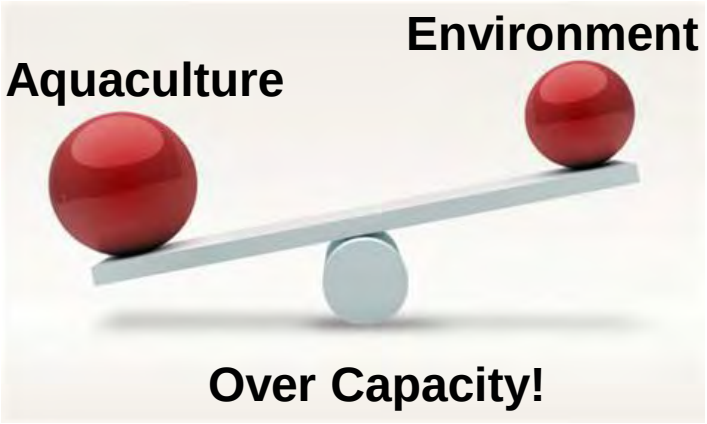
Seaweed

The Concept of Carrying Capacity

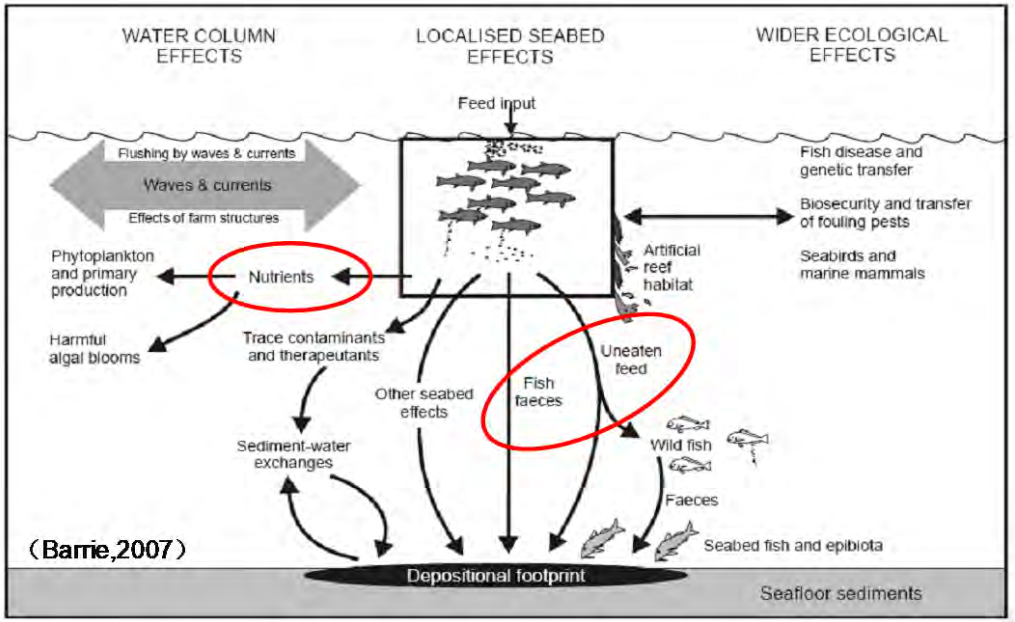


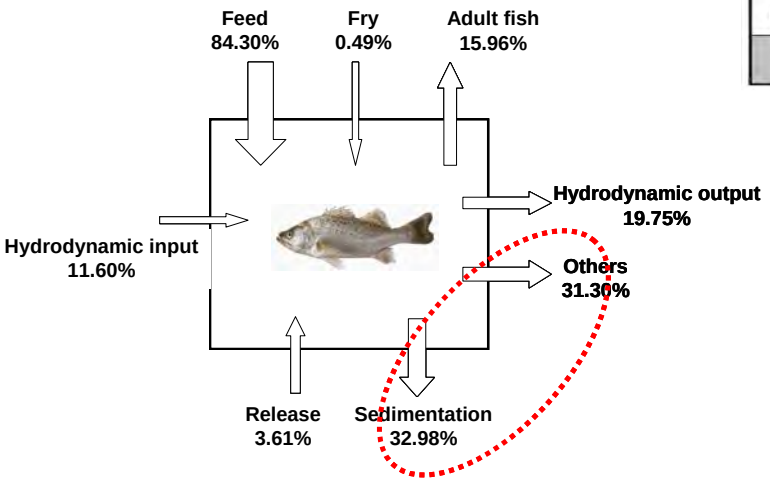
Maximum potential production of a species or population in a defined area in relation to available food resources (ICES Study Group, EIM 1987).



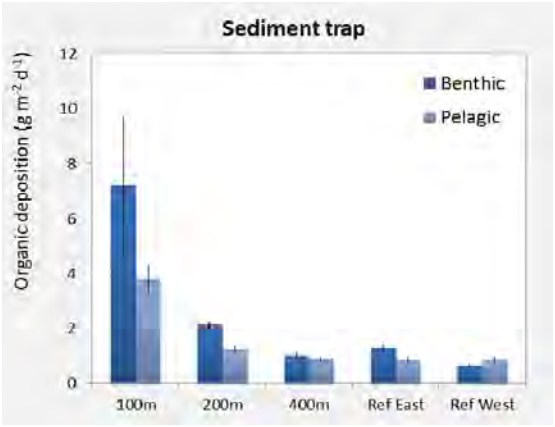


Impact of marine fish aquaculture on the environment

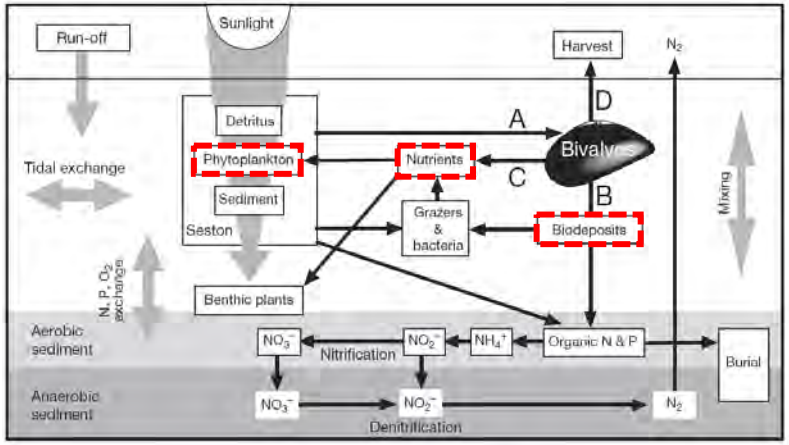


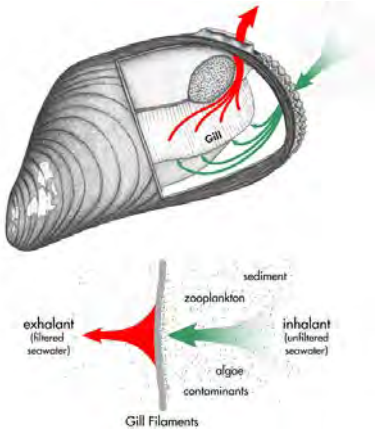


Nitrogen budget

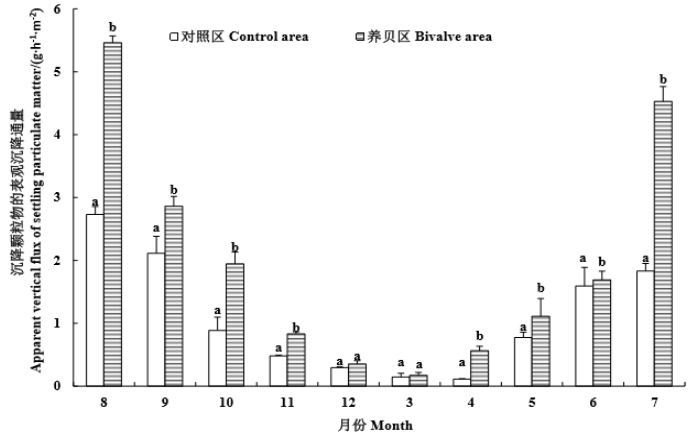


Impact of large scale bivalves aquaculture on ecosystem





Source: Cranford et al. 2006



Lv et al. 2017

- Strong capacity to filter the seawater;
- Over-stocking will cause the "**top-down**" control for phytoplankton population and reduce the food availability for food webs;
- **Organic enrichment** of the underlying sediment caused by bio-deposition of bivalves.

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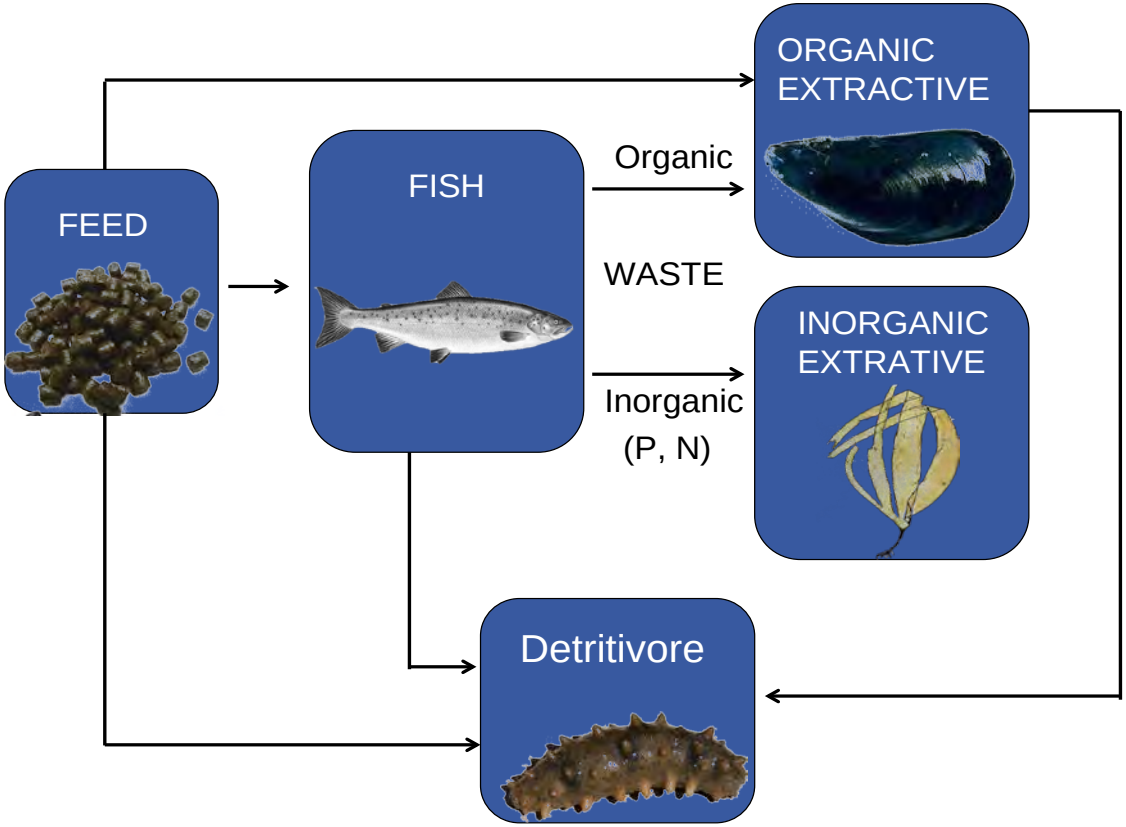
ONE OF THE BEST SOLUTION:

Integrated Multi-Trophic Aquaculture (IMTA)



IMTA is a system in which waste materials from one species serve as food or fertilizer for the next, creating a loop of healthy and sustainable aquaculture.

Current IMTA systems development -Global review

- **At or near commercial scale:**
  - China, Canada, Israel, Chile, Ireland, South Africa, UK and USA;

- **Ongoing research projects related to the development of IMTA:**
  - Norway, France, Portugal, Spain;

- **Individual groundwork towards the development of IMTA:**
  - Sweden, Finland, Australian.

Key Species Cultured in Integrated Systems

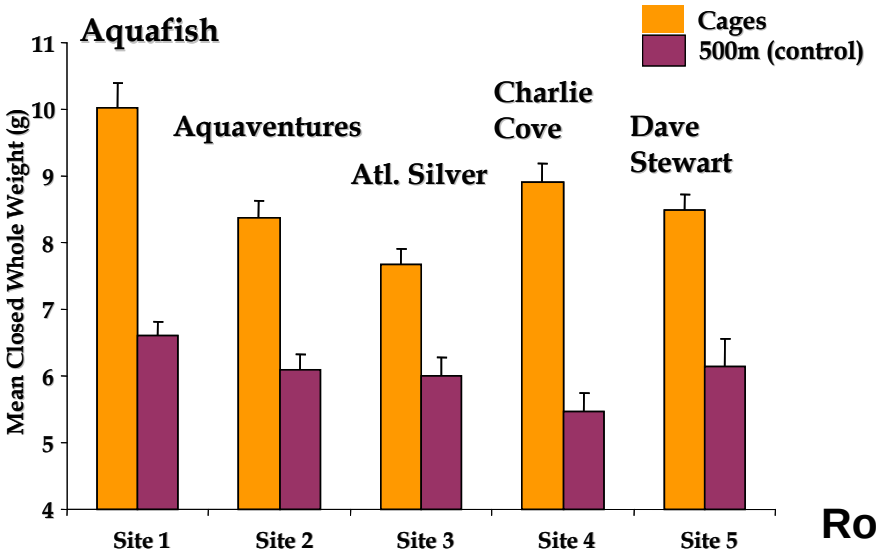
(*Integrated mariculture, FAO-529, 2009*)

Cold Seawater	Temperate Seawater	Warm Seawater
Salmo	*Pagrus major*	*Sparus aurata*
Oncorhynchus sp.	*Sparus aurata*	*Lates calcarifer*
Gadus	*Dicentrarchus labrax*	*Mugil cephalus*
	Lates calcarifer	*Chanos*
		Epinephelus sp.
Crassostrea sp.	*Mercenaria*	*Crassostrea gigas*
Mytilus sp.	*Crassostrea* sp.	*Tapes japonica*
Haliotis rufescens	*Ostrea edulis*	*Haliotis diversicolor*
Homarus	*Mytilus*	*Penaeus spp.*
Strongylocentrotus	*Ruditapes semidecussatus*	
Paracentrotus	*Penaeus* spp.	
Laminaria sp.	*Gracilaria* sp.	*Gracilaria changii*
Macrocystis sp.	*Ulva* sp.	*Ulva lactuca*
Porphyra sp.		*Kappaphycus*
Saccharina		
Undaria		
Nereis, Arenicola	*Nereis, Arenicola*	*Nereis, Arenicola*

Over 200 species are involved in R&D projects and in commercial farms around the world, in various climate conditions.

Coastal IMTA practice in Canada

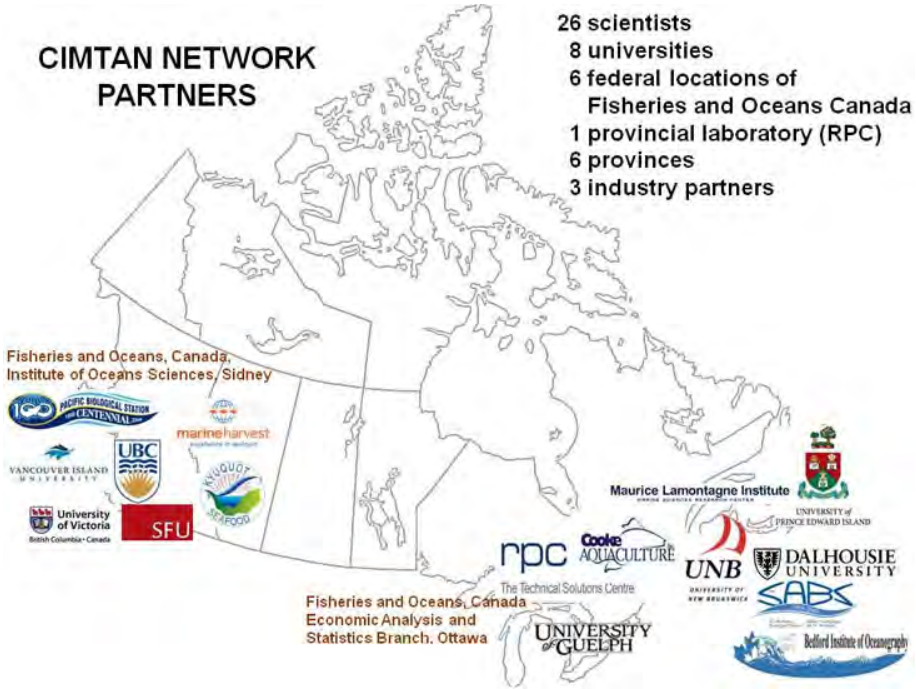
Chopin *et al*. 2008



- Salmon (*Salmo salar*);
- Blue mussels (*Mytilus edulis*) ;
- Kelps (*Saccharina latissima,Alaria esculenta*).

Robinson *et al*. 2003

CIMTAN NETWORK and PARTNERS



Canadian Integrated Multi-Trophic Aquaculture Network

Coastal IMTA practice in Norway

The INTEGRATE Project (2006-2011)

"Integrated open seawater aquaculture, possibilities of sustainable culture of high productive areas“

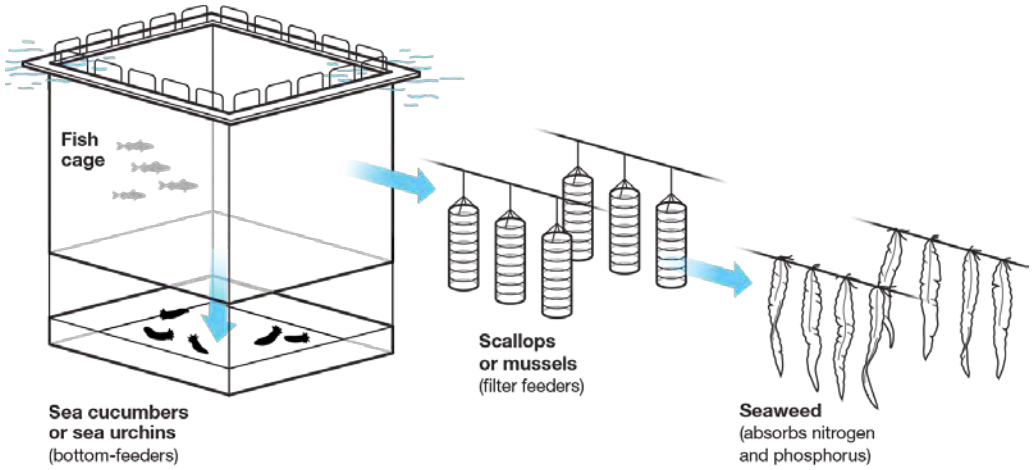
Funded by The Research Council of Norway (173527)

The EXPLOIT Project (2012-2015)

"Exploitation of nutrients from salmon aquaculture“

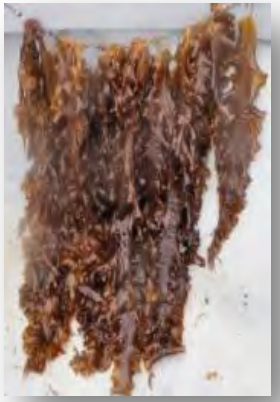
Funded by The Research Council of Norway (216201/E40)

Growth of Scallops and seaweed in IMTA system

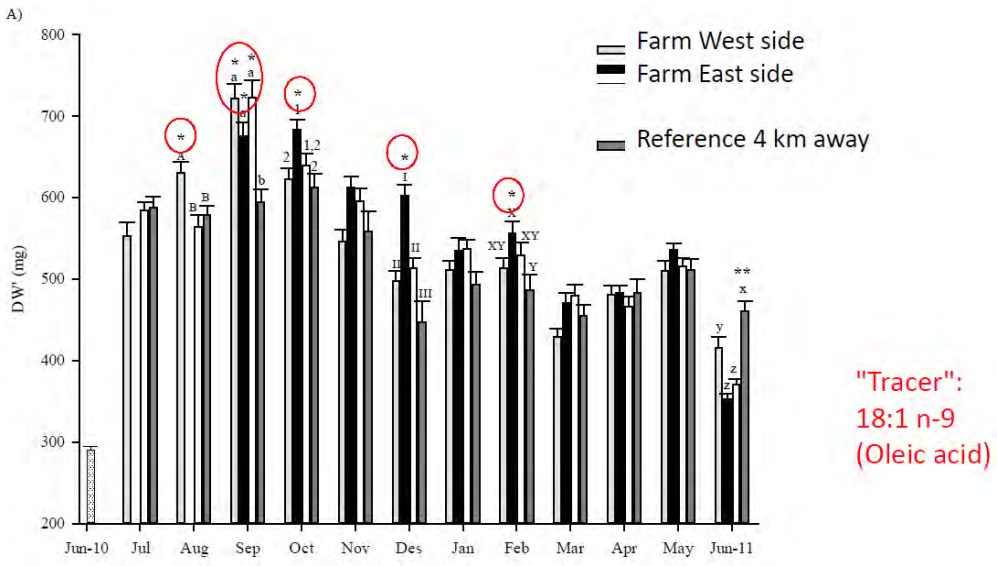


https://www.nationalgeographic.com/foodfeatures/aquaculture/

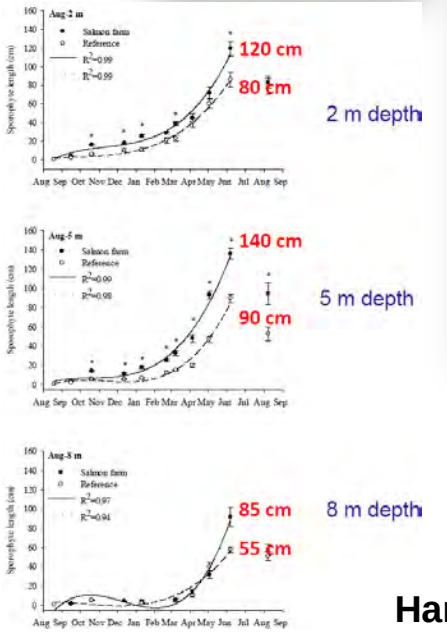
Reference



Salmon



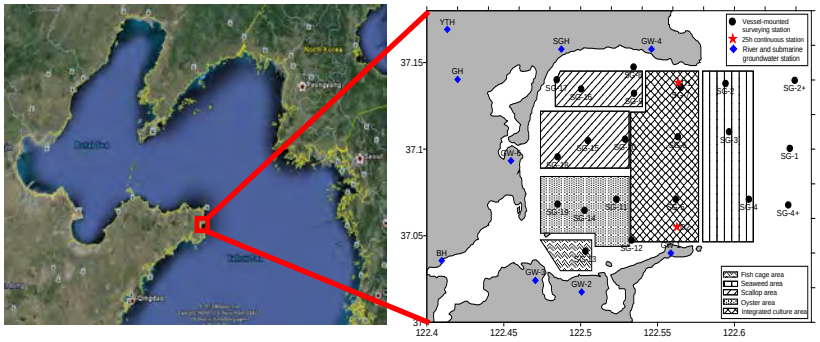
"Tracer":
18:1 n-9
(Oleic acid)



Handa *et al*. 2013

Coastal IMTA practice in China

- **Fish-driven IMTA**
- **Shellfish-driven IMTA**



Commercial scale IMTA practice in Sanggou Bay

Total Area: ~140 km^2

<u>Annual production:</u>

Kelp: 80,000 tones in dry weight

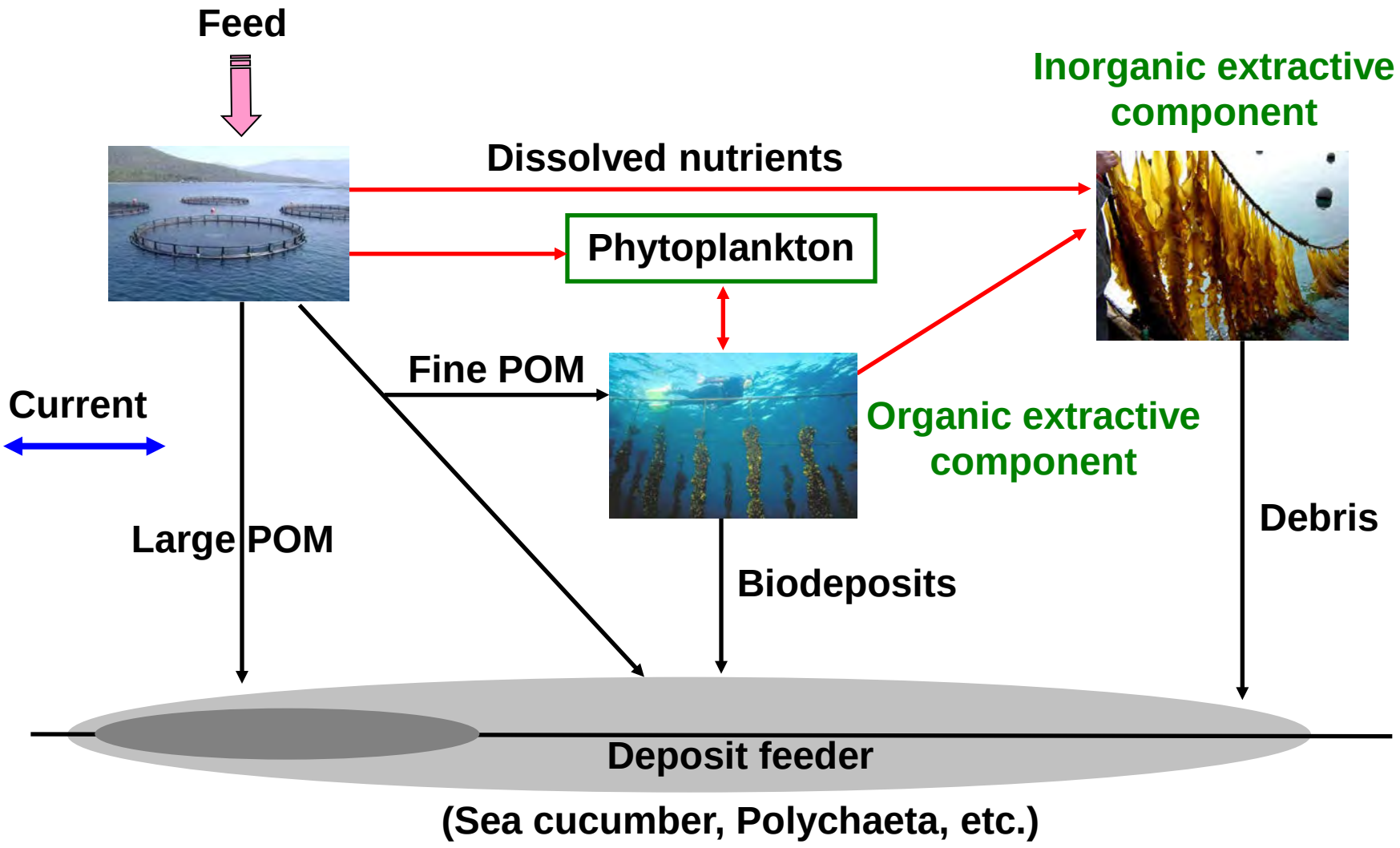
Abalone: 2,000 tones

Oyster: 120,000 tones

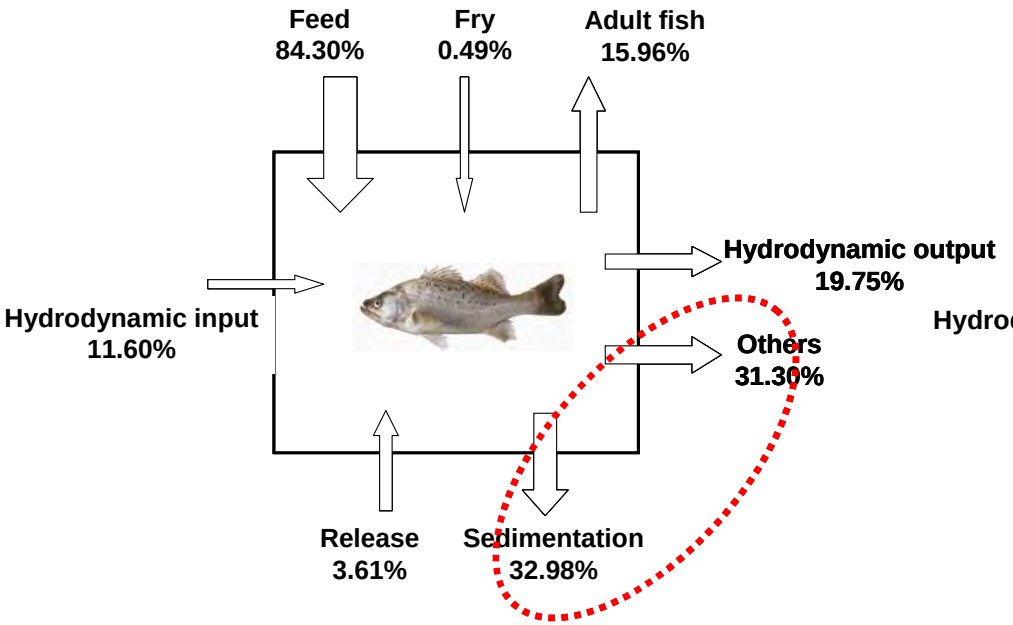
Scallop: 10,000 tones

Fish: 100 tones

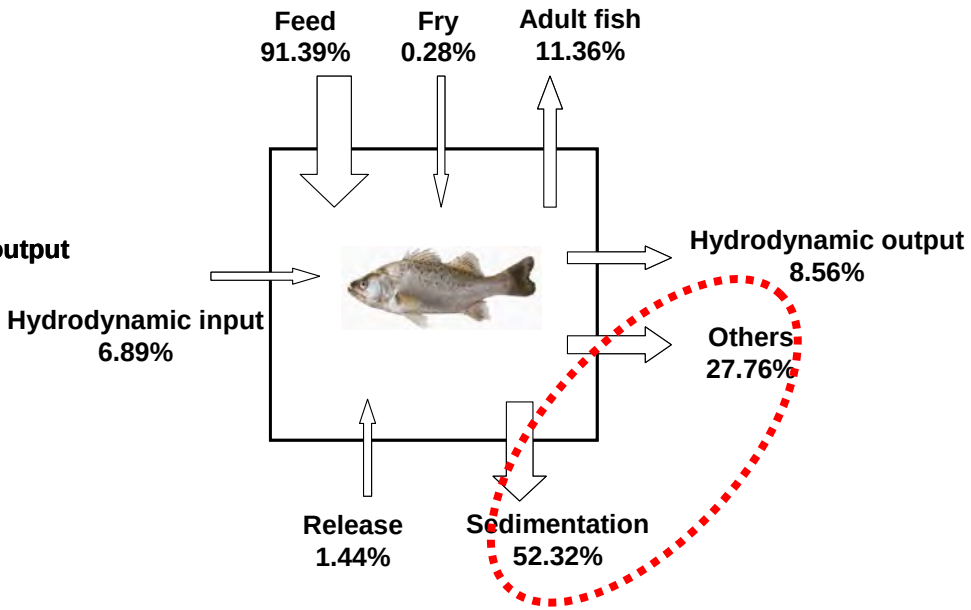
Type 1: Fish-driven IMTA



Ecosystem-level Nitrogen and Phosphorus budget



Nitrogen



Phosphorus

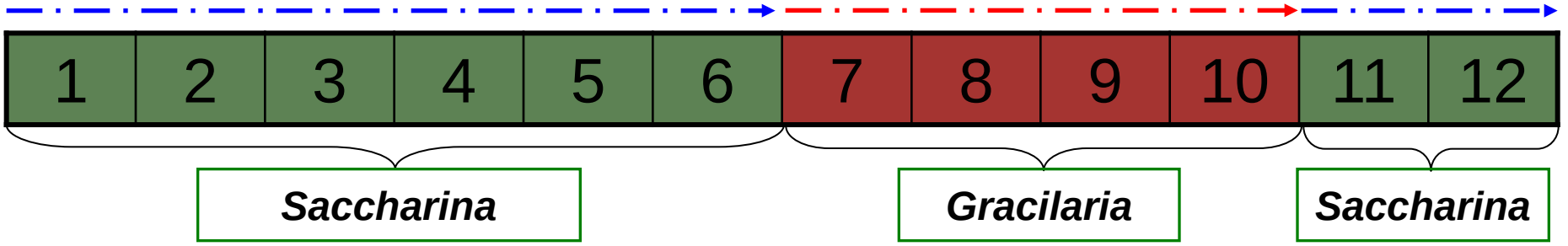
64.28% of Nitrogen and 80.08% of Phosphorus were released to the ecosystem.

Jiang *etal*.,2010

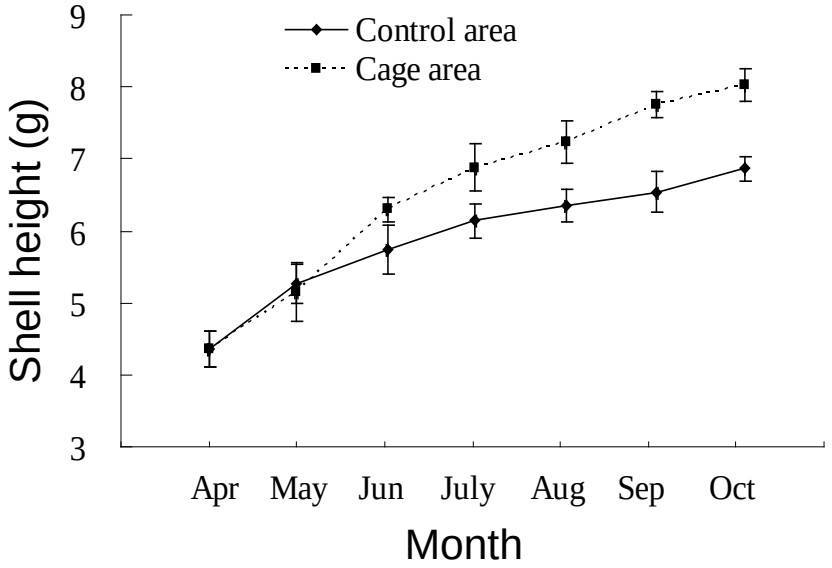
Year-round inorganic extractive component

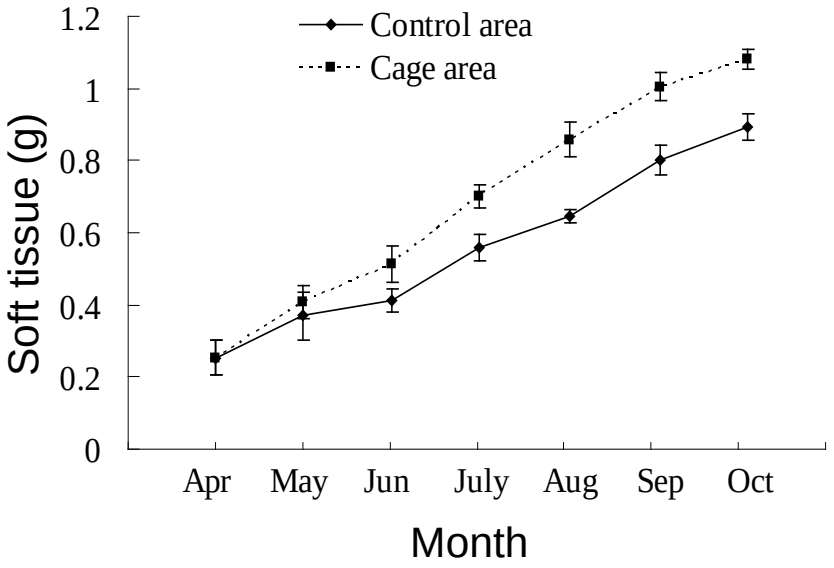
Season	Excretion kg/d	Waste feed kg/d	Feces kg/d	Total/kg	Seaweed(dw)/ Fish(ww)
Winter	31.22	46.83	3.122	7305.48	**0.94** ***(Saccharina japonica)***
Spring	51.3	76.95	5.13	12004.2	
Summer	173.24	259.86	17.324	40538.16	**1.53** ***(Gracilaria lemaneiformis)***
Autumn	99.61	149.415	9.961	23308.74	

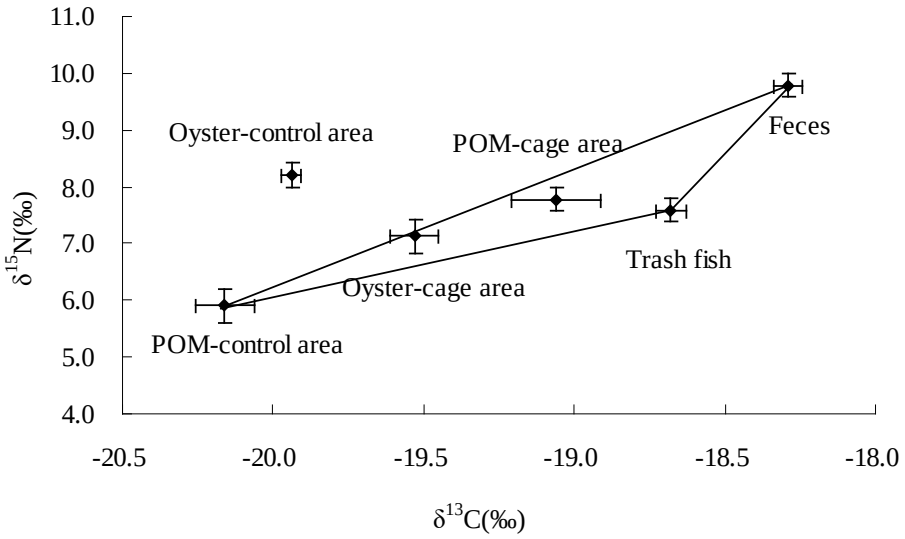
Jiang *et al.*,2010



Nutrient recovery efficiency of the bivalves





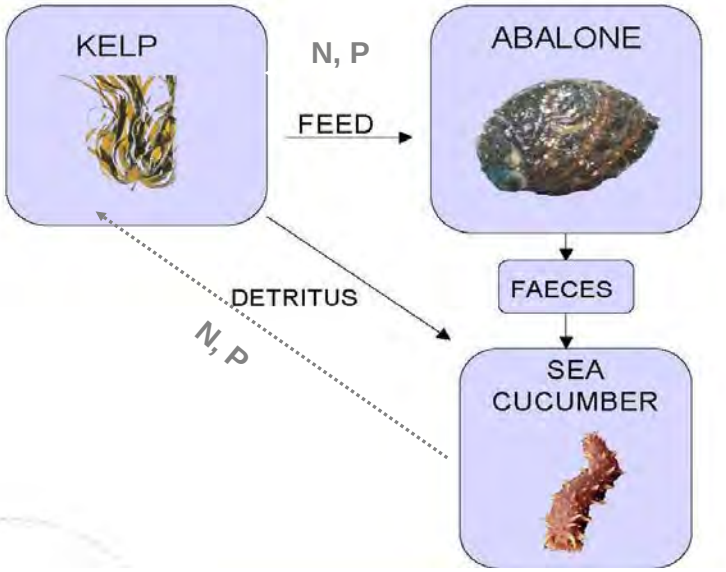


- **Shell length and tissue of oysters at the cage area increase higher than control area;**
- **The contribution of fish feces and waste feed was 29.3% and 5.6%, respectively.**

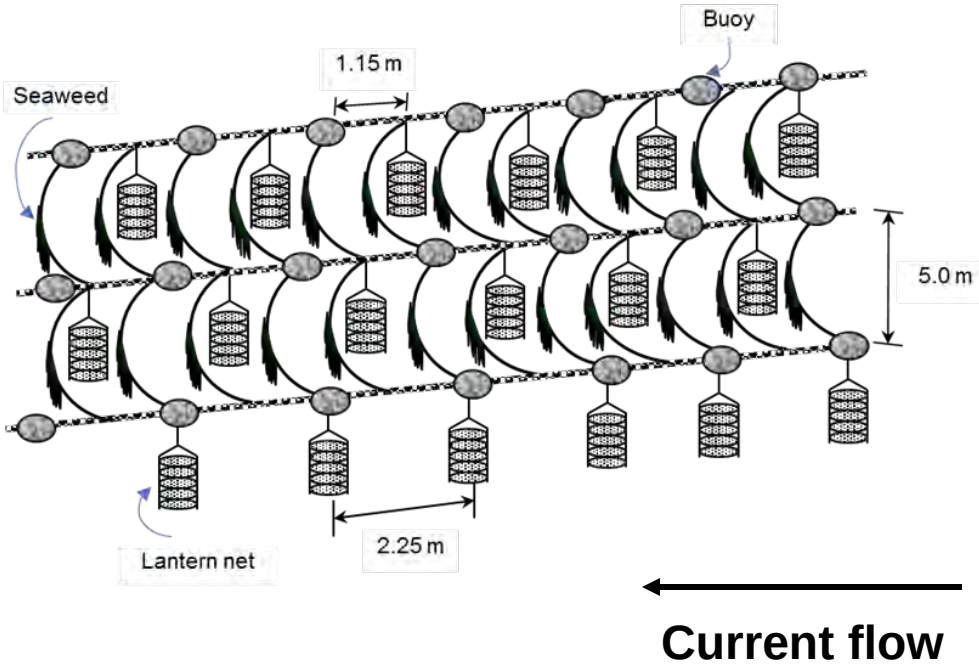
Jiang *etal.*,2011

Integrated culture of *Crassostrea gigas* and *Lateolabrax japonicus*

Type 2: Shellfish-driven IMTA



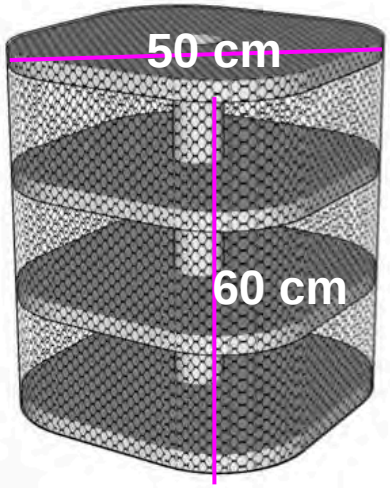
Abalone-Seaweed-Sea cucumber

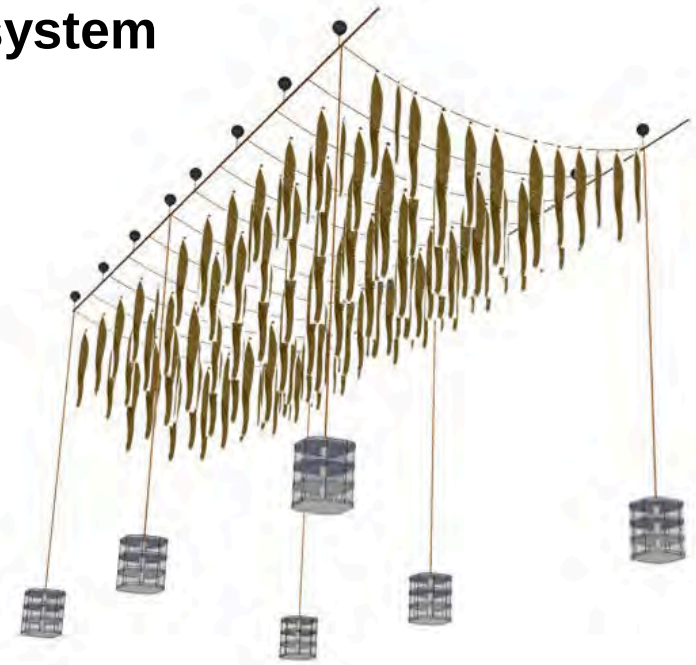


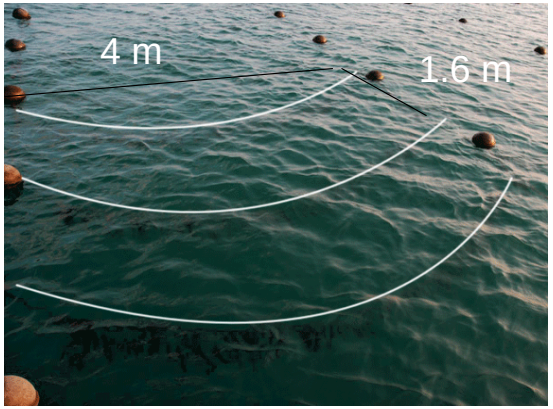
Bivalve-Seaweeds

Abalone + Kelp + Sea cucumber IMTA system

Long-line culture system

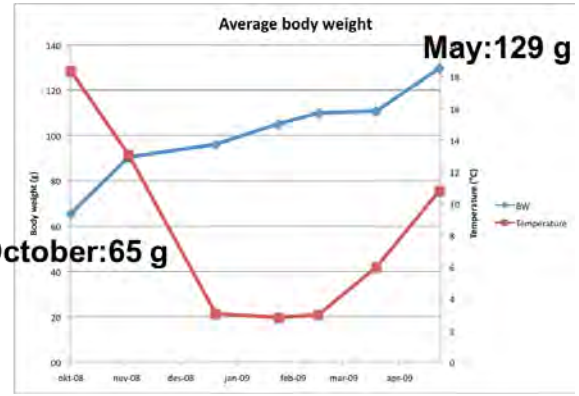


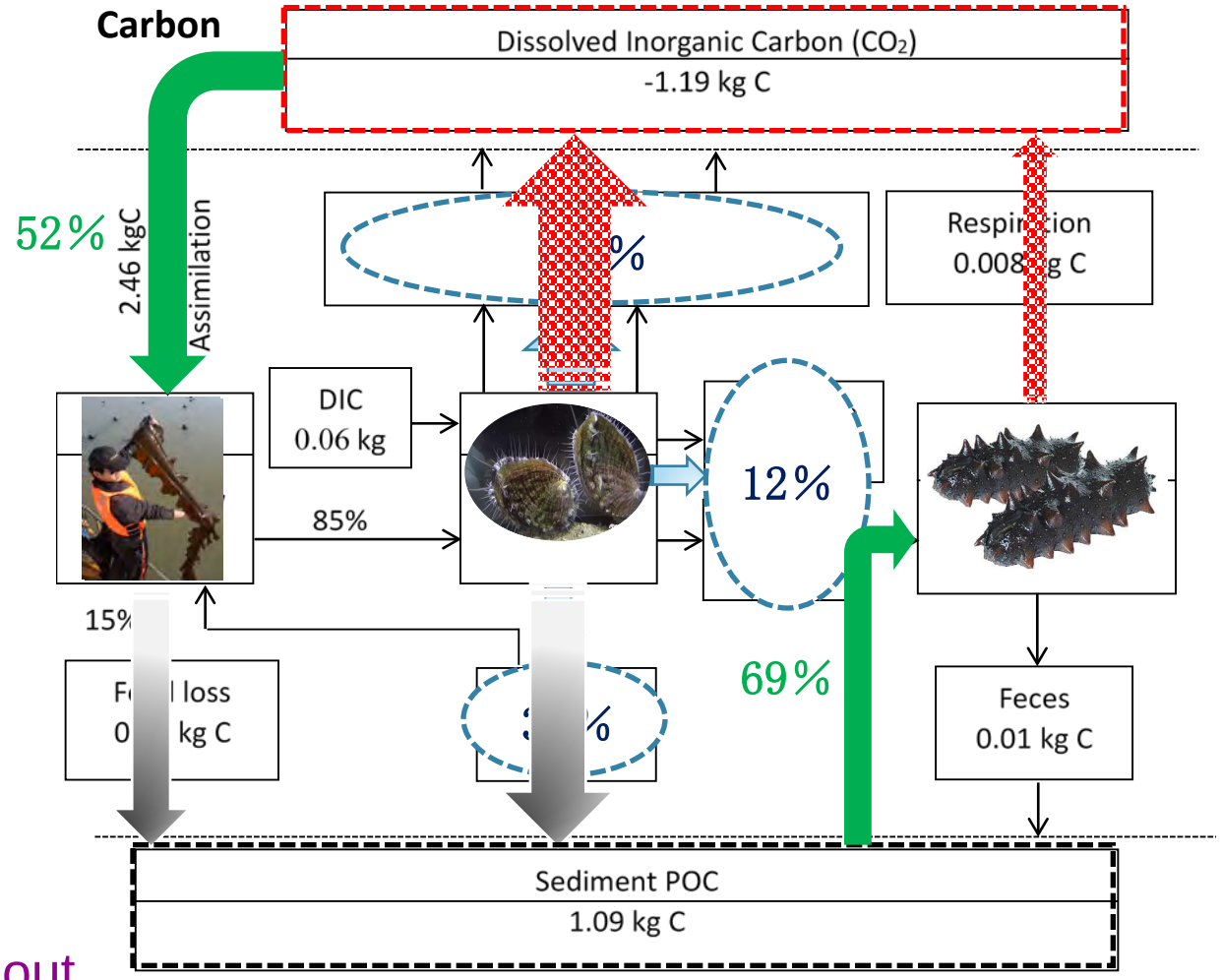




- **Kelp** longline culture
- **Abalone** net cages hanging vertically from longlines
- **Sea cucumber** *Apostichopus japonicus* added directly to the abalone cages

Abalone + Kelp + Sea cucumber IMTA system





- Reduce the negative environmental effects;
- The extra income is about 2000 RMB/longline.

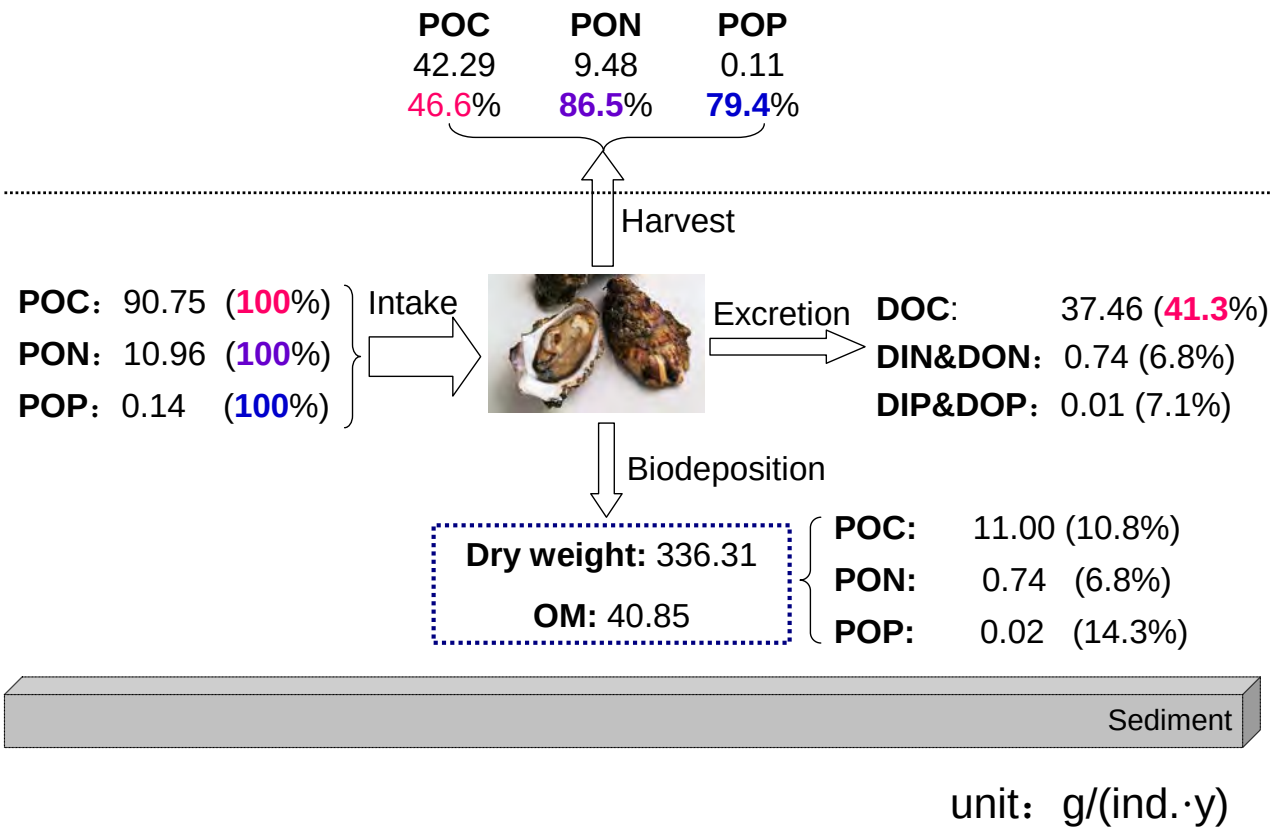
Tang et al. (2013)

Individual-level eco-physiological research on bivalves

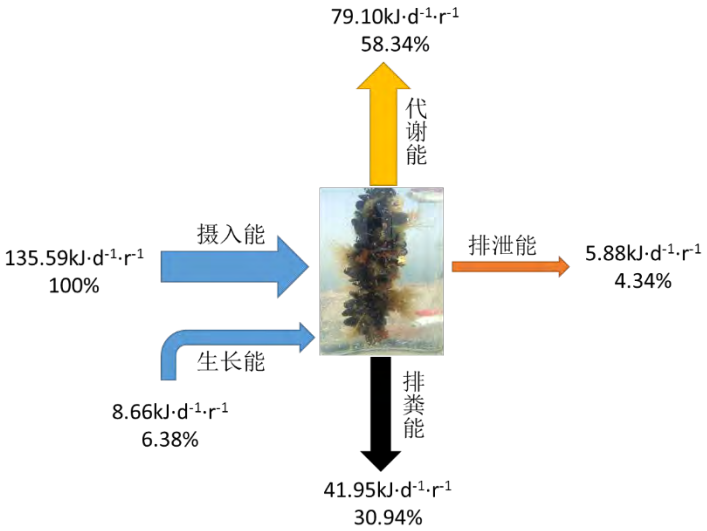
Flow-through system

Clearance rate

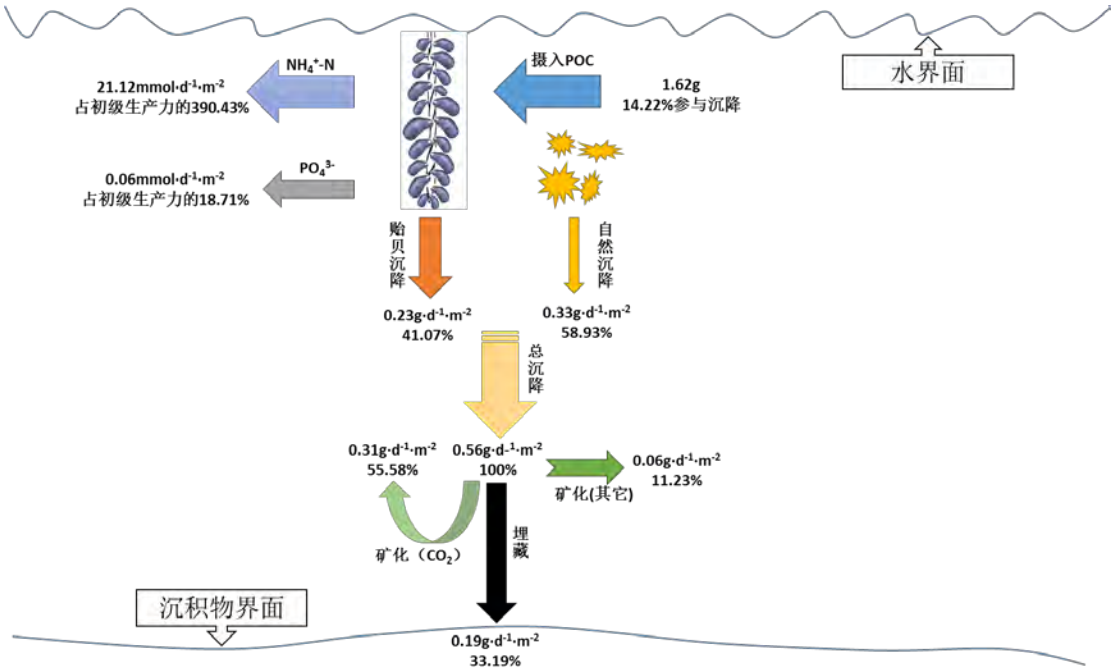
Respiration & Excretion rate



Community-level eco-physiological research on bivalves



Energy budget

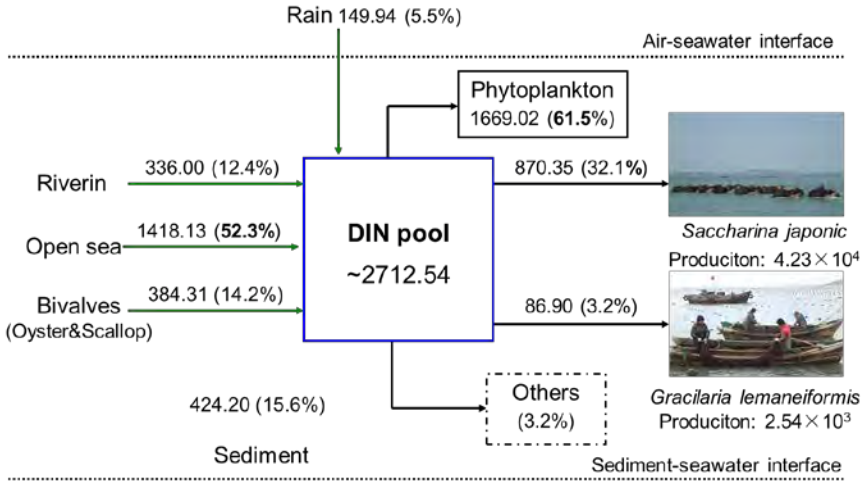


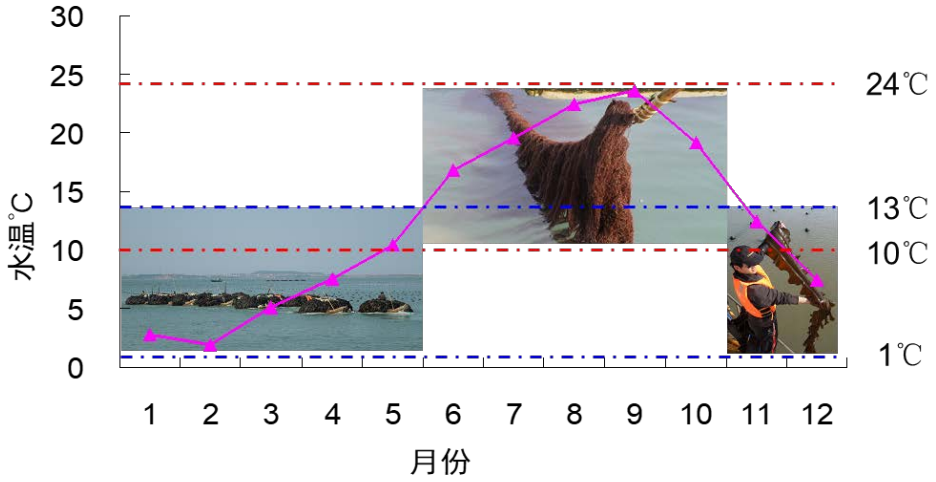
Mass balance

1+1=2?

Bivalve-Seaweed IMTA system

	DIN Excretion (t)	N content(%)	Seaweed/ Oyster (ww)
Winter&Spring	65.33	2.06 *(Saccharina japonica)*	**0.54**
Summer&Autumn	75.36	3.42 (*Gracilaria lemaneiformis*)	**0.73**





Value of ecosystem services value of IMTA

- The value of food provision service and climate regulating service provided by the IMTA system is much higher than monoculture.

Table 1 Service function in different mariculture modes in Sungo Bay
(adapted from Liu et al., 2013)

Mariculture mode	Value of food provision service (CNY/ha/yr)	Value of climate regulating service (CNY/ha/yr)
Kelp monoculture	49, 219	4, 859
Abalone monoculture	235, 409	8, 215
Abalone and kelp IMTA	325, 553	13, 591
Abalone, sea cucumber and kelp IMTA	483, 918	13, 833

Comments on IMTA developed in China

Dr. Kenny. Sherman , NOAA.

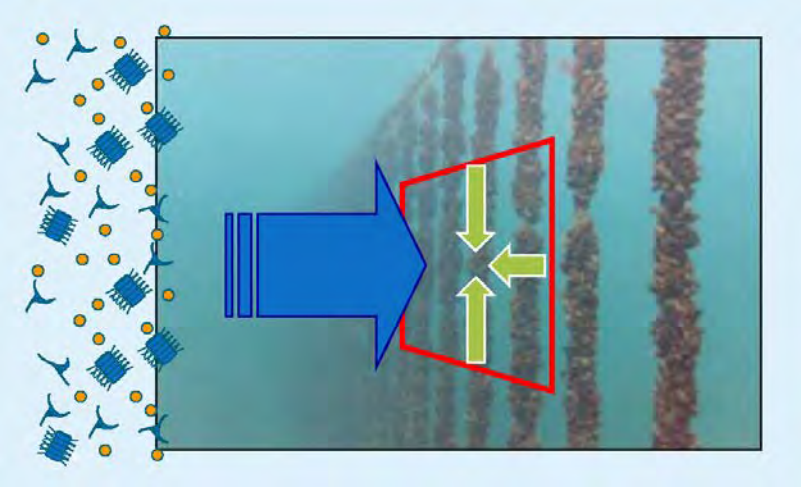
He was known as "the father of Large Marine Ecosystem"

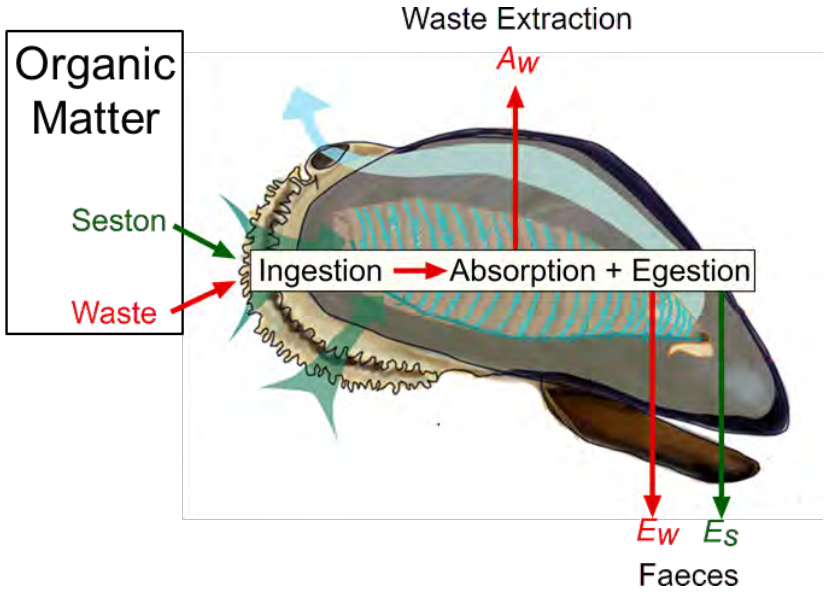
"In the penultimate chapter on the Yellow Sea LME, Professor Qisheng Tang and Dr. Jianguang Fang review the variable states of productivity and biomass yields under the influence of climate change and anthropogenic forcing. ……The IMTA technology includes the production of algae (kelp), mollusks (abalone) bivalves (bay scallop), and echinoderms (sea cucumber) to help close the fisheries protein gap, while capture fisheries recover to sustainable levels. Preliminary results suggest that the IMTA pilot should be expanded throughout the YSLME and into other Asian LMEs, where applications could provide job opportunities and food security. **The pilot IMTA project proved to be highly energy efficient and optimized the carrying capacity of coastal embayments while improving water quality, increasing protein yields, and, through carbon capture, contributing to mitigation of the effects of climate change.**"

"Frontline Observations on Climate Change and Sustainability of Large Marine Ecosystems", 2012. Large marine Ecosystem, Vol. 17

Challenges for IMTA—Bivalves issue

- "**Double-edged sword**": Biodeposition or Biomitigation?
- **Nutrient recovery efficiency:** The bivalves diet need to be at least 20~30% fish waste, otherwise they produce more faecal organic matter than they extract from fish waste.





Mitigation Requirement:
Waste absorption > Seston egestion

Cranford *et al.*,2013

Challenges for IMTA--Deposit-feeder issue

Fine POM, 22.65%

Dissolved Nutrients, ~20%

Large POM 57.35%

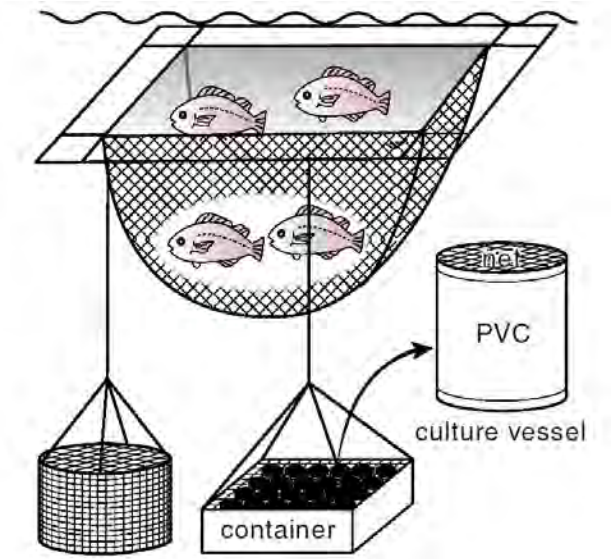
Filter-feeding bivalves

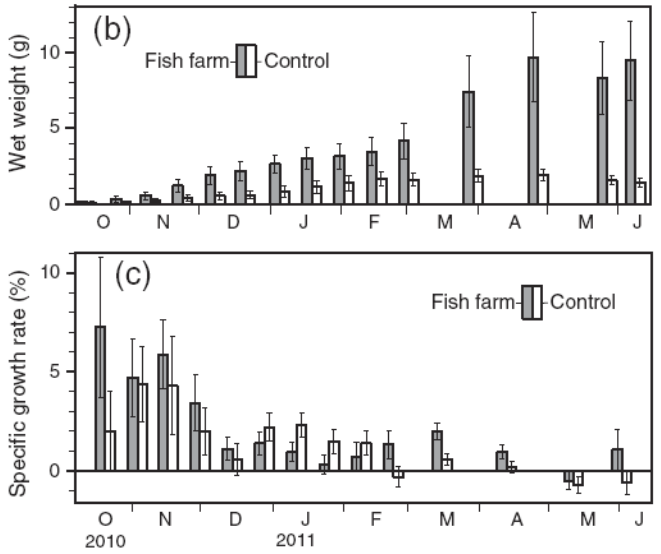
Seaweed

Deposit feeder !

Ongoing Work …

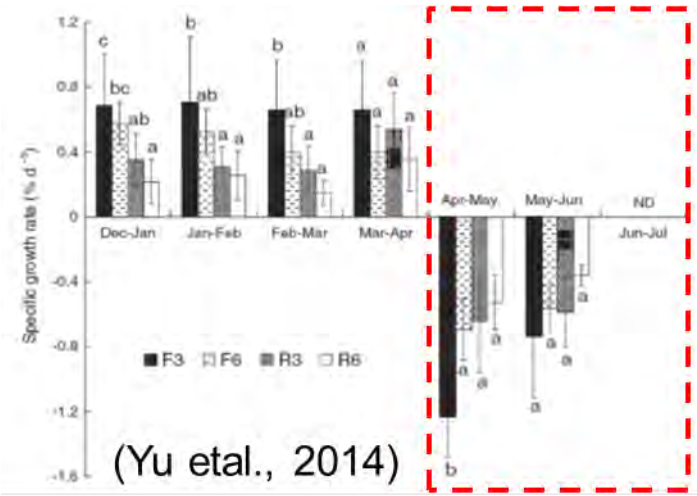
Integrated sea cucumber into IMTA system



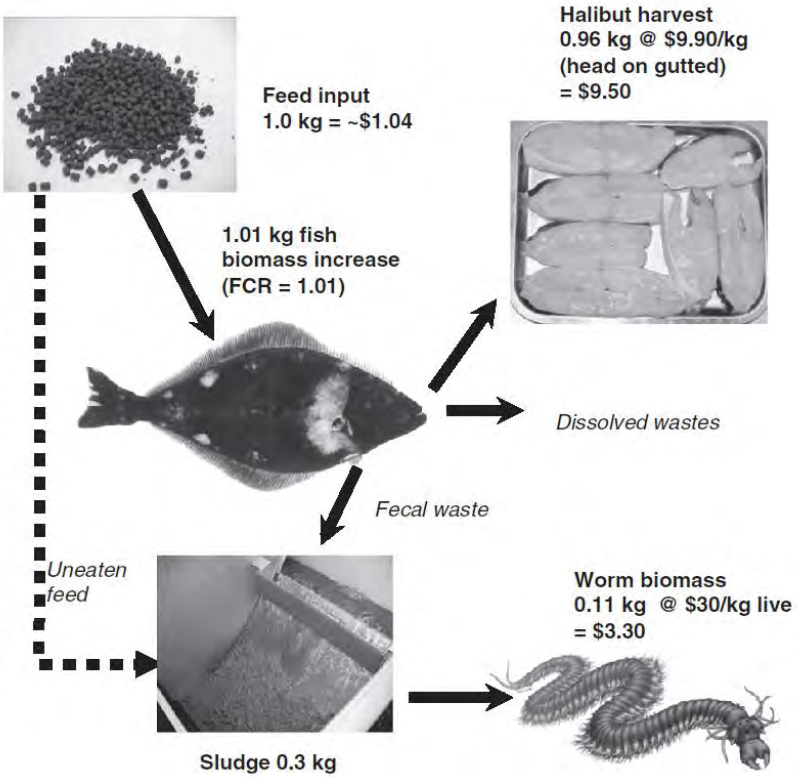


Hisashi,2013

- The survival and growth of the sea cucumbers *Apostichopus japonicus* were enhanced by the fish;
- **Aestivation** (Summer sleep).



Integrated polychaete into IMTA system



Nereis virens

Recirculation fish culture system

(Nicholas *etal*., 2011)

Items	Body Weight (g)		Feeding Rate (%)	
	De	Se	De	Se
L	3.58 ± 0.09^{c}	3.45 ± 0.11^{c}	16.94 ± 2.53^{a}	20.34 ± 1.81^{a}
M	2.20 ± 0.07^{b}	2.05 ± 0.07^{b}	29.76 ± 3.05^{b}	27.18 ± 0.45^{a}
S	0.95 ± 0.05^{a}	0.9 ± 0.06^{a}	$64.40 \pm 1.89^{c*}$	$50.26 \pm 3.65^{b*}$

Perinereis aibuhitensis

Coastal system

(Fang *etal*., 2017)

- Naughty animals like polychates, it's difficult to control them in the field;
- We are still keep seeking the potential benthic candidates ……

Towards IMTA future……

IMTA Workshop, Norway

Sino-US Marine Ranching Workshop

2015-04 | **2016-05** | **2016-06** | **2017-03**

APEC Ecological Mariculture Seminar

25thPACON International Conference

IMTA concept being paid more and more attention in recent years and will continue to be more powerful in the future.

Thanks for your attention!

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