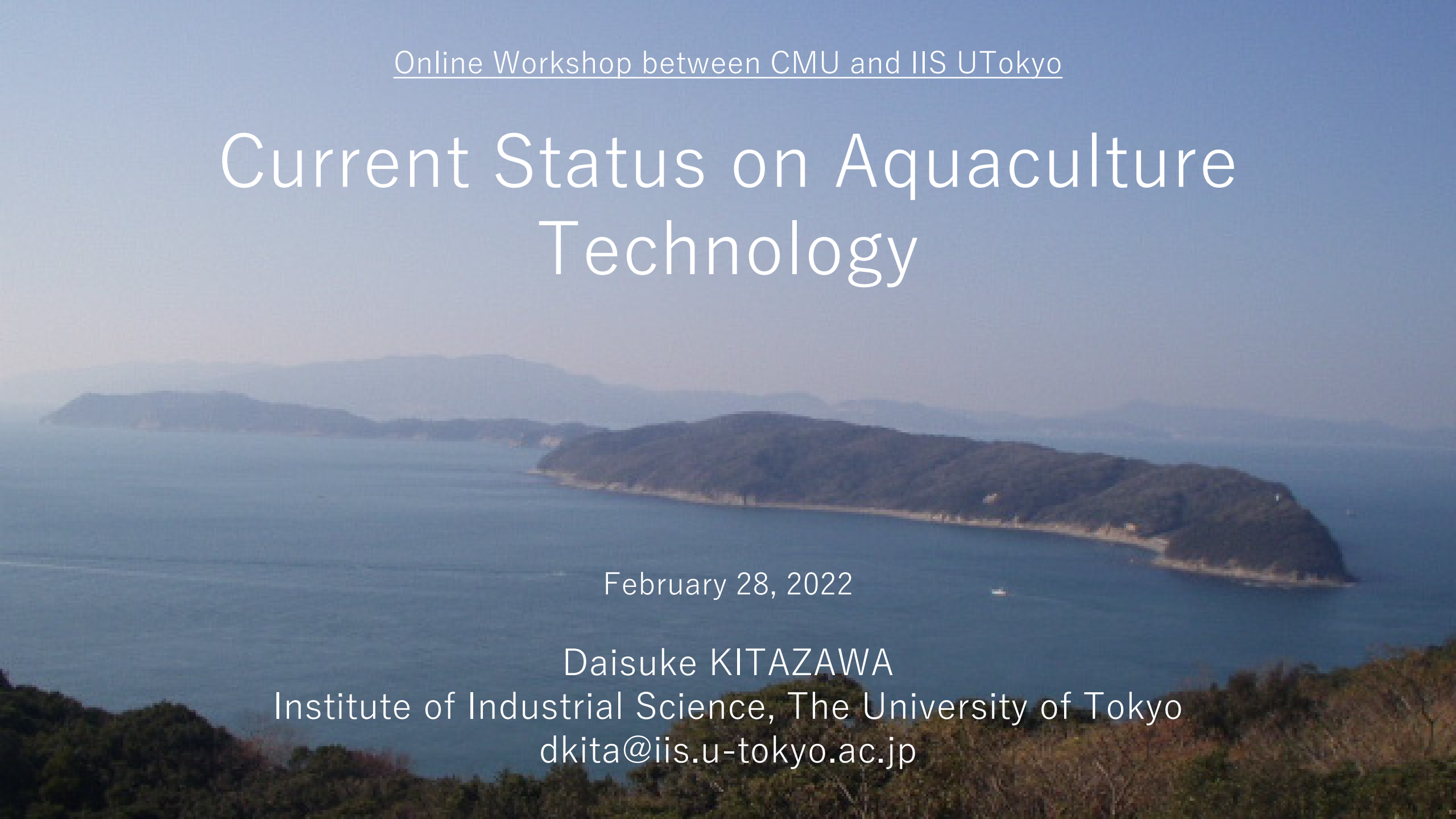
Online Workshop between CMU and IIS UTokyo

Current Status on Aquaculture Technology

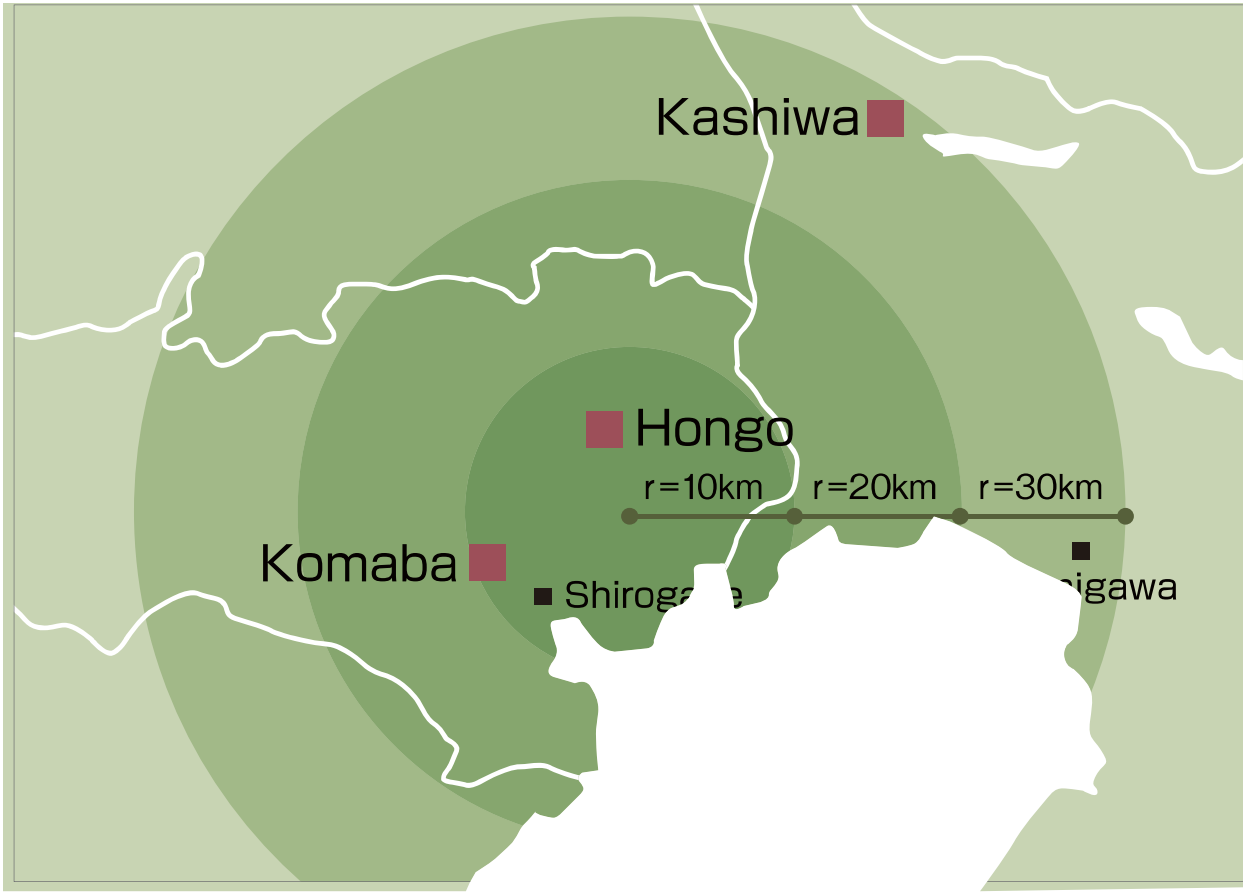


February 28, 2022

Daisuke KITAZAWA
Institute of Industrial Science, The University of Tokyo
dkita@iis.u-tokyo.ac.jp

Introduction of Our Univ.

Founded in 1877, the University of Tokyo is the oldest and largest of Japan's national universities. Exemplifying the ideals of excellence and diversity, the University serves as a forum for educational and research activities carried out at a wide array of locations, including the three core campuses of Hongo, Komaba and Kashiwa.



Introduction of Our Univ.

- Students: 28,806
- Academic and administrative staff: 11,266
- Exchange of researchers: 1,525
- Cited papers: 468,113
- Books and other materials: 9,854,341
- Start-up companies: about 430
- Overseas facilities and office: 29
- International students: 4,283
- International exchange agreement: 545
- Total number of graduates: 443,815
- Nobel prize winners: 13
- Japanese prime minister: 15
- Astronauts: 5

Introduction of Our Institute

- Founded in 1949

  Purpose:

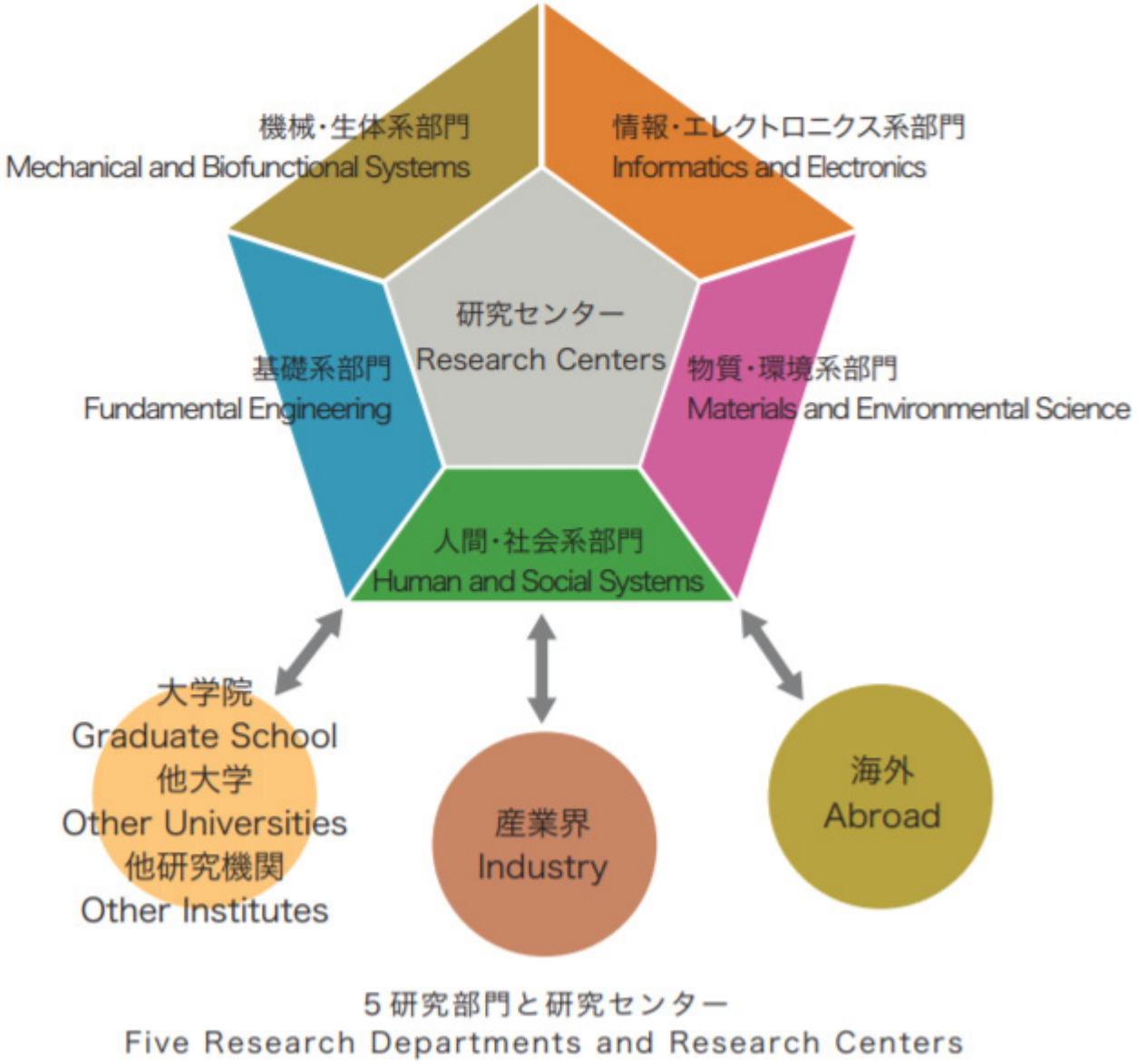
  Institute of Industrial Science (IIS), the University of Tokyo aims to “approach various engineering-related issues and value creation in a broad perspective, to carry out research and education with a focus on pioneering academic and comprehensive studies on social and industrial challenges, and to contribute the results of its activities back to society and industry”.

- Statistical Data
  - The number of faculties: 163 (Project faculties: 47)
  - The number of students:

    Doctor: 261 (146 from foreign countries)

    Master: 517 (170 from foreign countries) on January 1, 2021

Introduction of Our Institute



- Fundamental Engineering
- Mechanical and Biofunctional Systems
- Informatics and Electronics
- Materials and Environmental Science
- Human and Social Systems
- Research Centers
- ➢ Center for Integrated Underwater Observation Technology

Introduction of Our Center

Center for Integrated Underwater Observation Technology (-2020)

- We play a key role in studying integrated underwater observation technology to understand the ocean function (energy, seafloor, and biological resources, a buffer of environmental change, etc.)
- We create an academic field to co-exist with natural disaster and to utilize ocean resources in a sustainable manner.

Know the ocean function and utilize the resources

Center for Integrated Underwater Observation Technology (UT)

Staff

Director

Chang-Kyu RHEEM Prof.
Ocean Environmental Engineering

Yusuke YOKOTA Lecturer
Underwater Information System

Sensing

Simulation

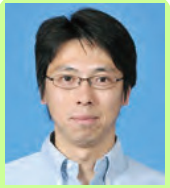
Platform

Daisuke KITAZAWA Prof.
Marine Ecosystem Engineering

Blair THORNTON Assoc. Prof.
Ocean Perception Systems

Toshihiro MAKI Assoc. Prof.
Underwater Platform Systems

Katsuyoshi KAWAGUCHI Visiting Prof.
Multidisciplinary Seafloor Observatory Engineering



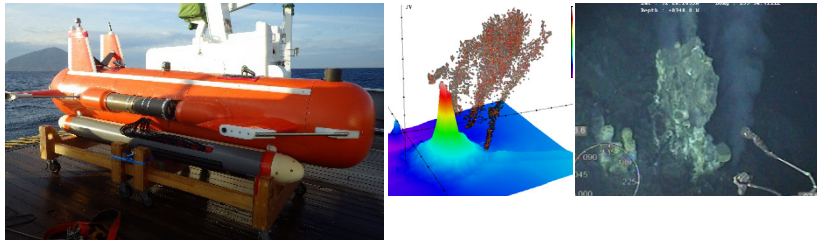
Yosuke HASEGAWA Assoc. Prof.
(Supporting Member)
Interfacial Transport Engineering

Research and Development

Sensing	Novel, integrated, and high-resolution sensing
Deep integration between sensing and platforms ⇕ Area-expanded and highly-developed sensing, deep understanding	
Platform	Highly-developed platforms and collaboration between platforms
Modeling in collaboration with sensing and platforms ⇕ Comprehensive evaluation of the ocean potential and risk	
Simulation	Modeling in the severe deficit of observation data

Introduction of Our Center

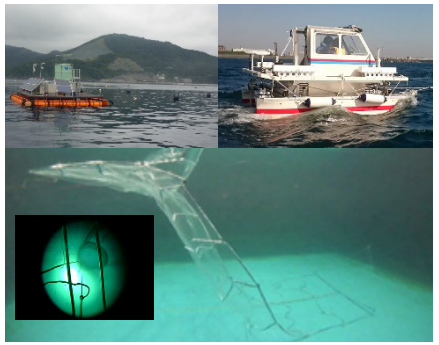
Prof. Akira Asada
Underwater Acoustic Systems Engineering



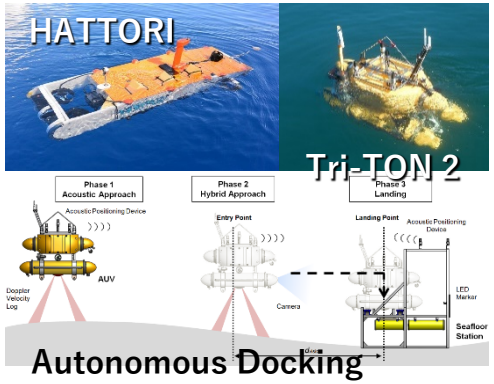
Prof. Chang-Kyu Rheem
Ocean Environmental Engineering

Prof. Katsuyoshi Kawaguchi
Multidisciplinary Seafloor Observatory Engineering

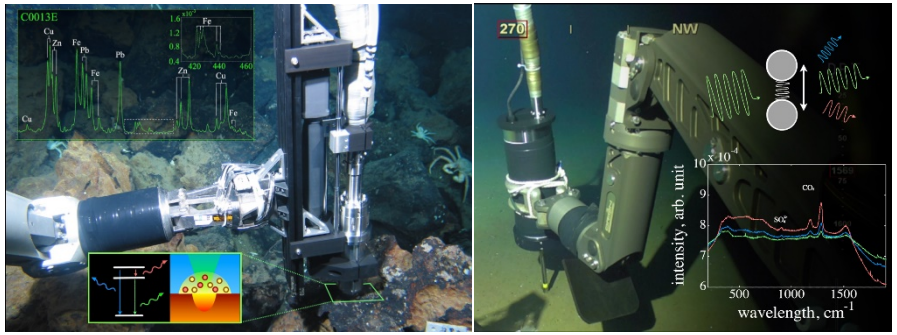
Prof. Daisuke Kitazawa
Marine Ecosystem Engineering



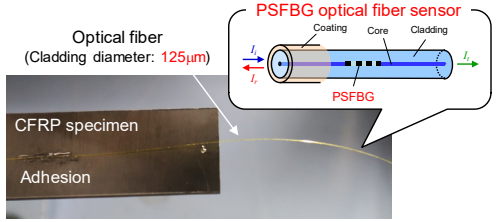
Prof. Toshihiro Maki
Underwater Platform Systems

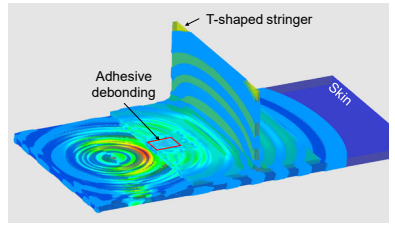


Prof. Blair Thornton
Underwater Photonics



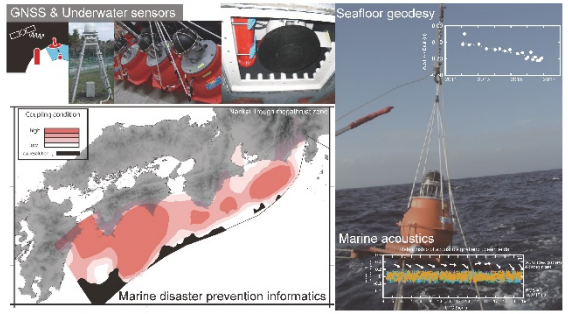
Prof. Yoji Okabe
Structural Health Diagnostics



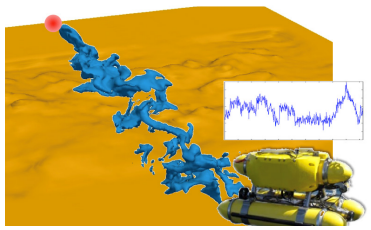


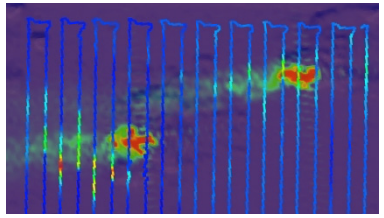
Prof. Tatsuhiro Fukuba
Multi-modal Ocean Sensing Systems

Prof. Yusuke Yokota
Underwater Information System



Prof. Yosuke Hasegawa
Interfacial Transport Engineering





Prof. Teruo Fijii etc.
Design-Led X Platform

Introduction of Myself

•1999-2001: Ph D. (Eng.), Department of Environmental and Ocean Engineering, Graduate School of Engineering, The University of Tokyo
"Study on the effects of a very large floating structure on marine ecosystem by numerical simulation"

Prof. M. Fujino Prof. T Kinoshita

•2002-2003: Department of Human and Society, Institute of Industrial Science, The University of Tokyo

•2002-: Environmental Impact Assessment (Hydrodynamic and ecosystem coupled model)

•2004: Department of Mechanical and Biofunctional Systems

•2007-: Fishery and aquacultural engineering

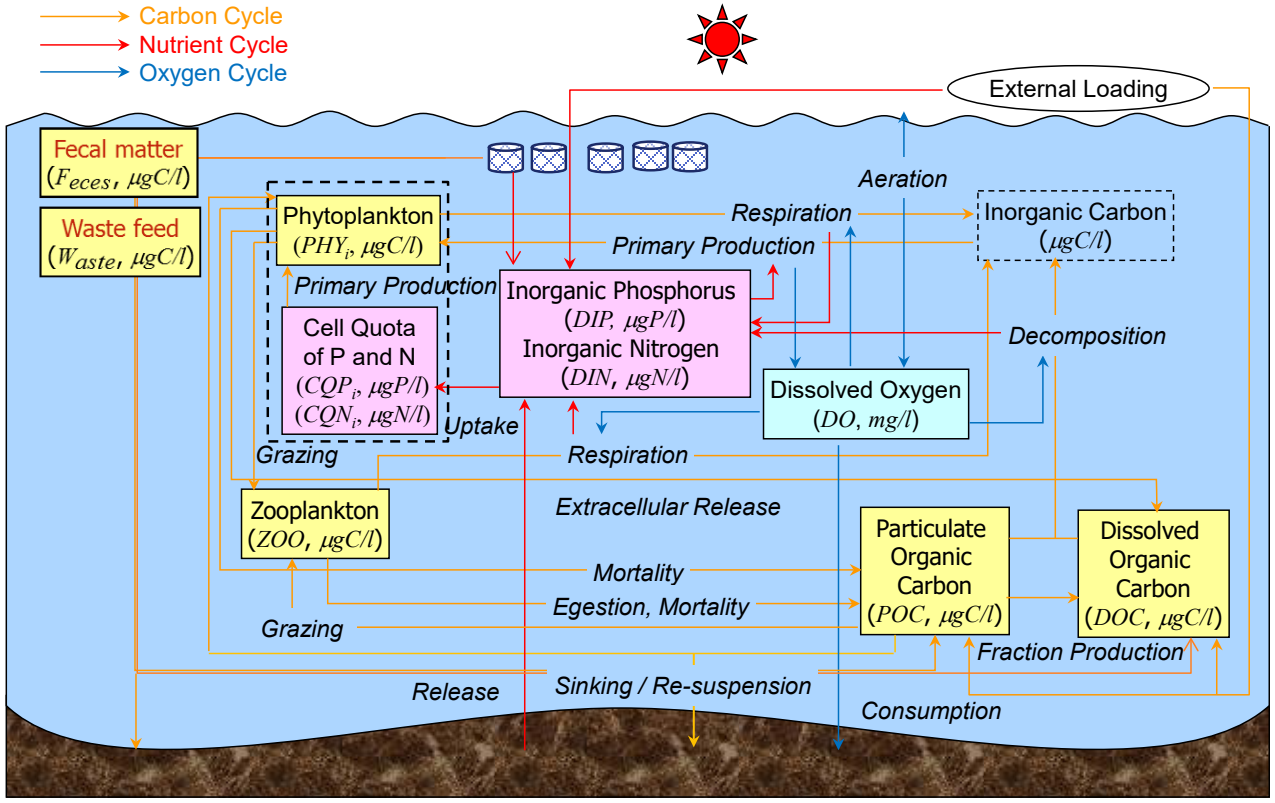
•2013-: Marine renewable energy development

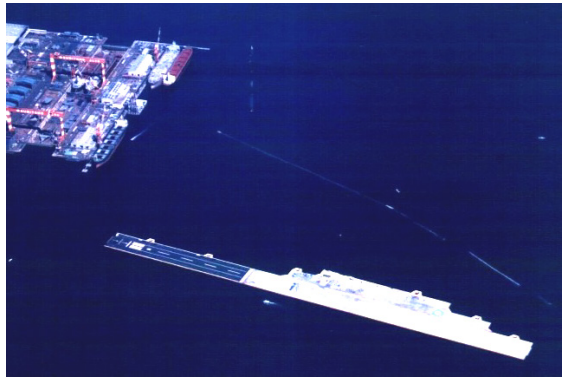
•2016: Center for Integrated Underwater Observation Technology

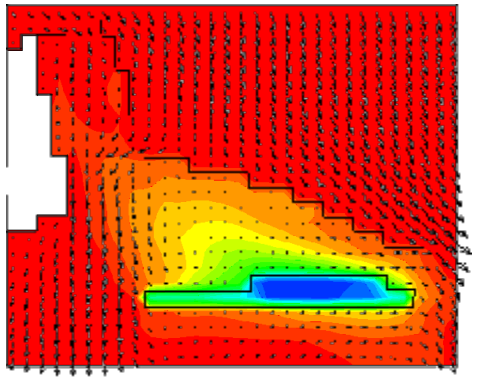
•2020: Large-Scale Experiment and Advanced-Analysis Platform

Marine Ecosystem Model

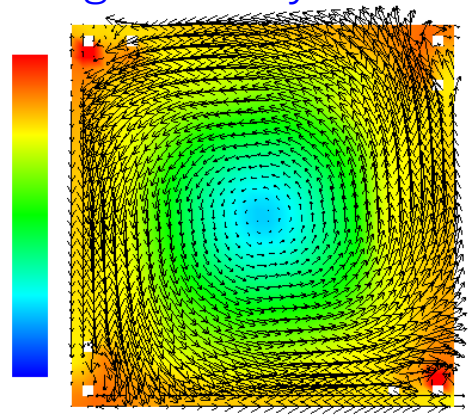
Environmental impact assessment of ocean space utilization (offshore structure), aquaculture, etc., using a hydrodynamic and lower-trophic ecosystem coupled model



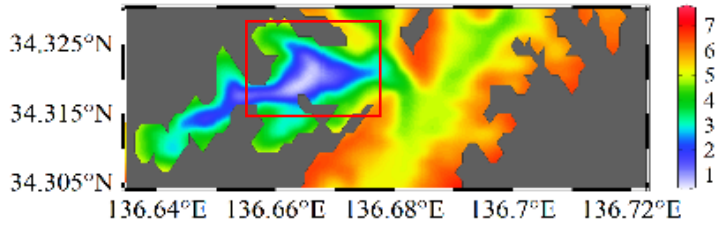




Construction of a floating runaway

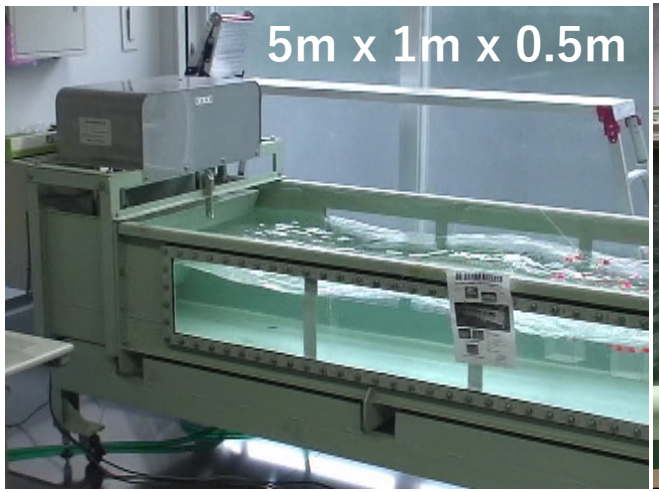


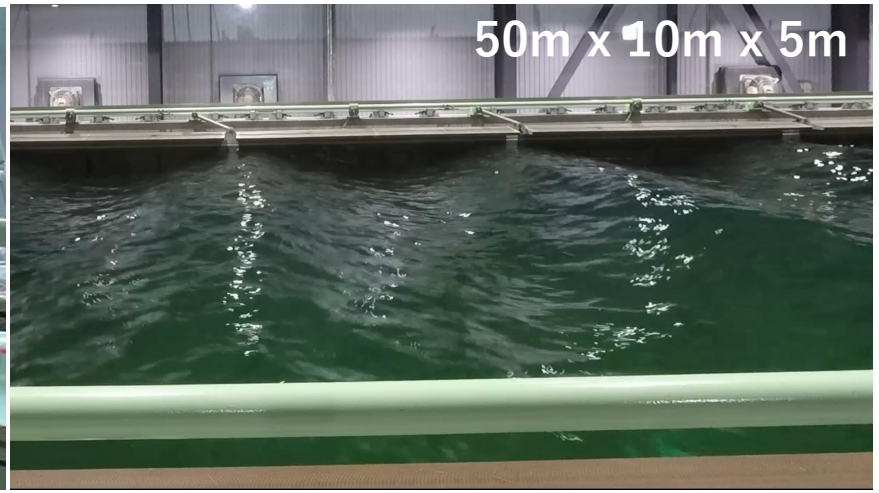
Shrimp and fish cage aquaculture

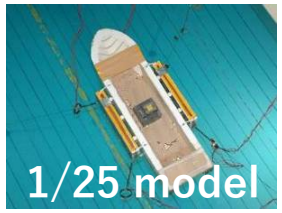


Fish cage aquaculture

Marine Food and Energy

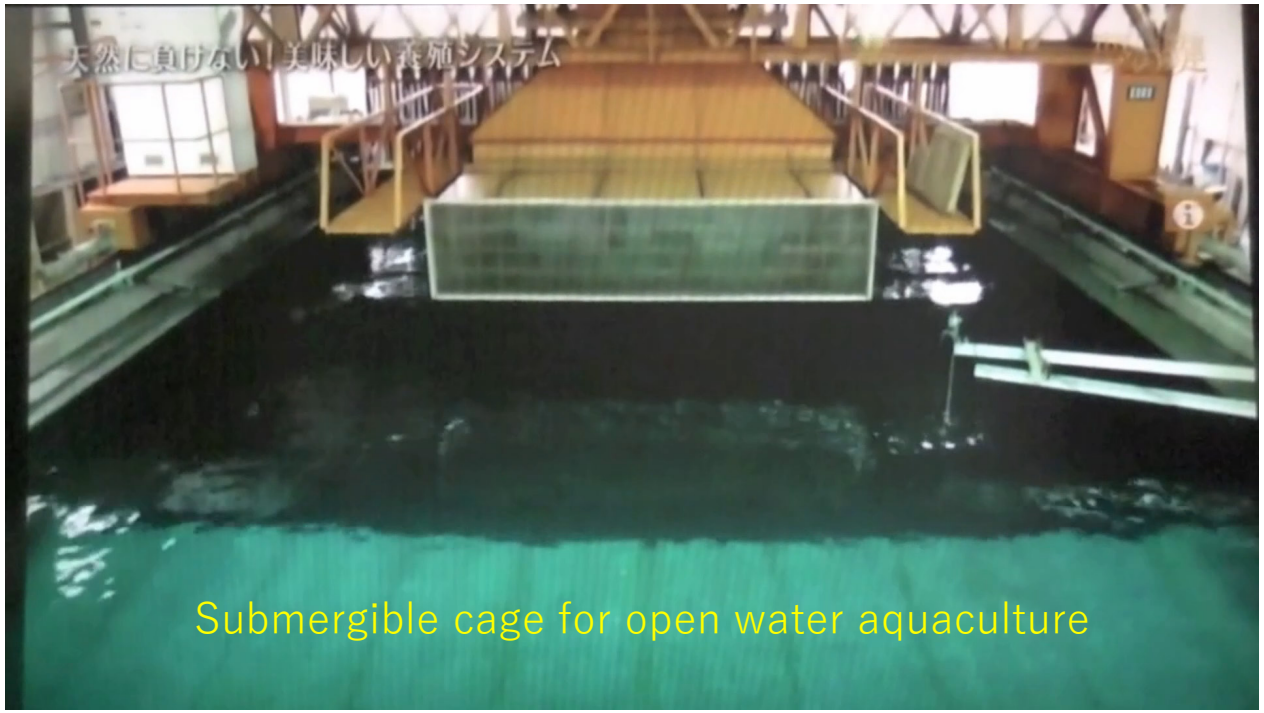






Feeding Barge

Controllable Depth Cage



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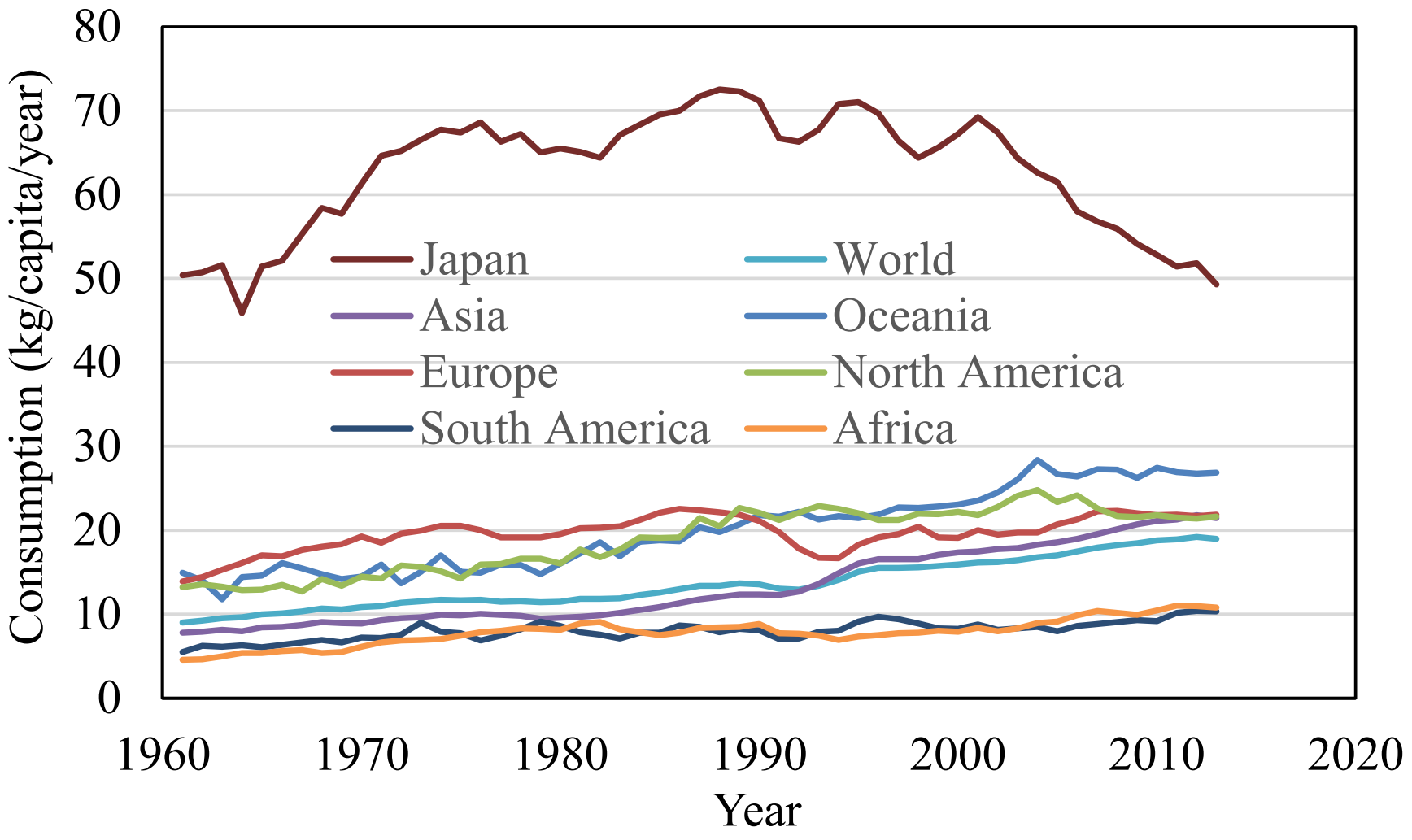
Seafood Supply



Source: Food and Agriculture Organization of the United Nations

50kg/capita/year
in Japan

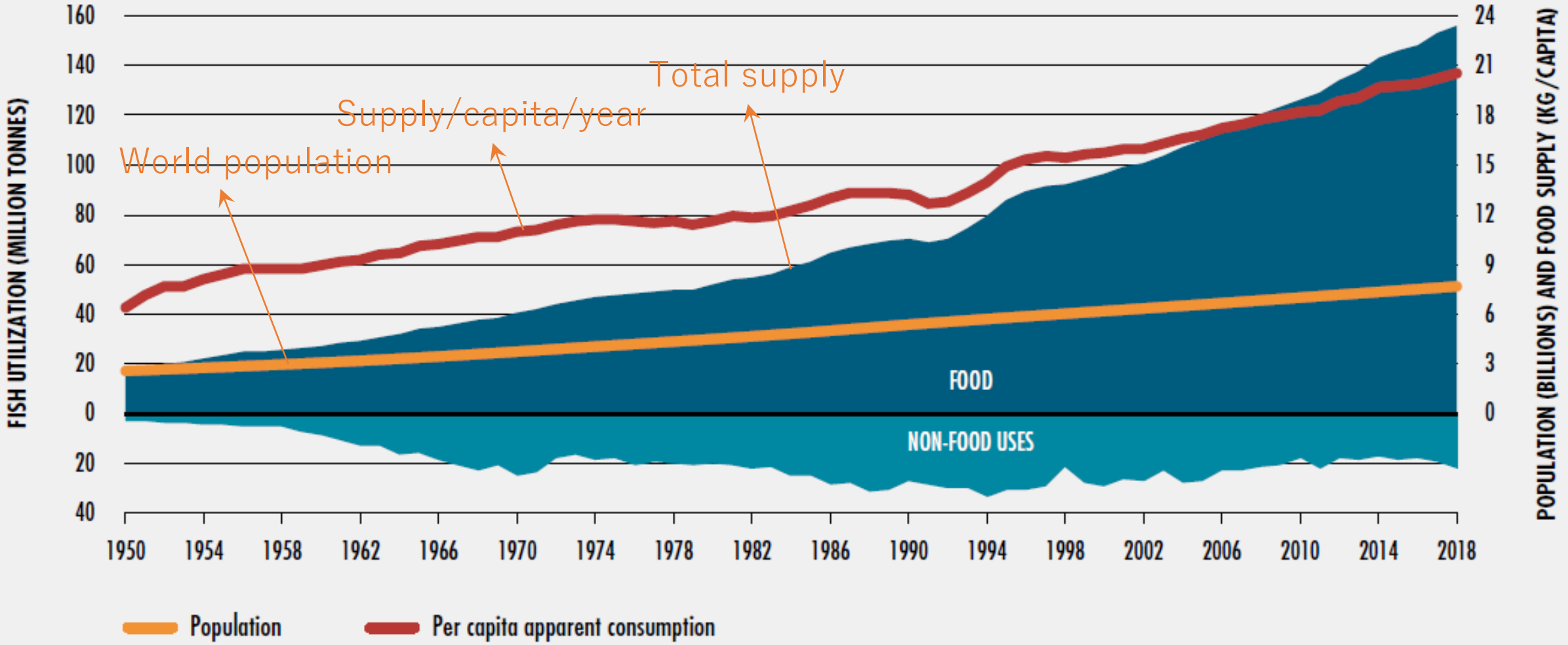
↓

1kg/capita/week

20kg/capita/year
in the world

Assuming the world population is 8 billion, **160 million tons** of seafood should be produced.

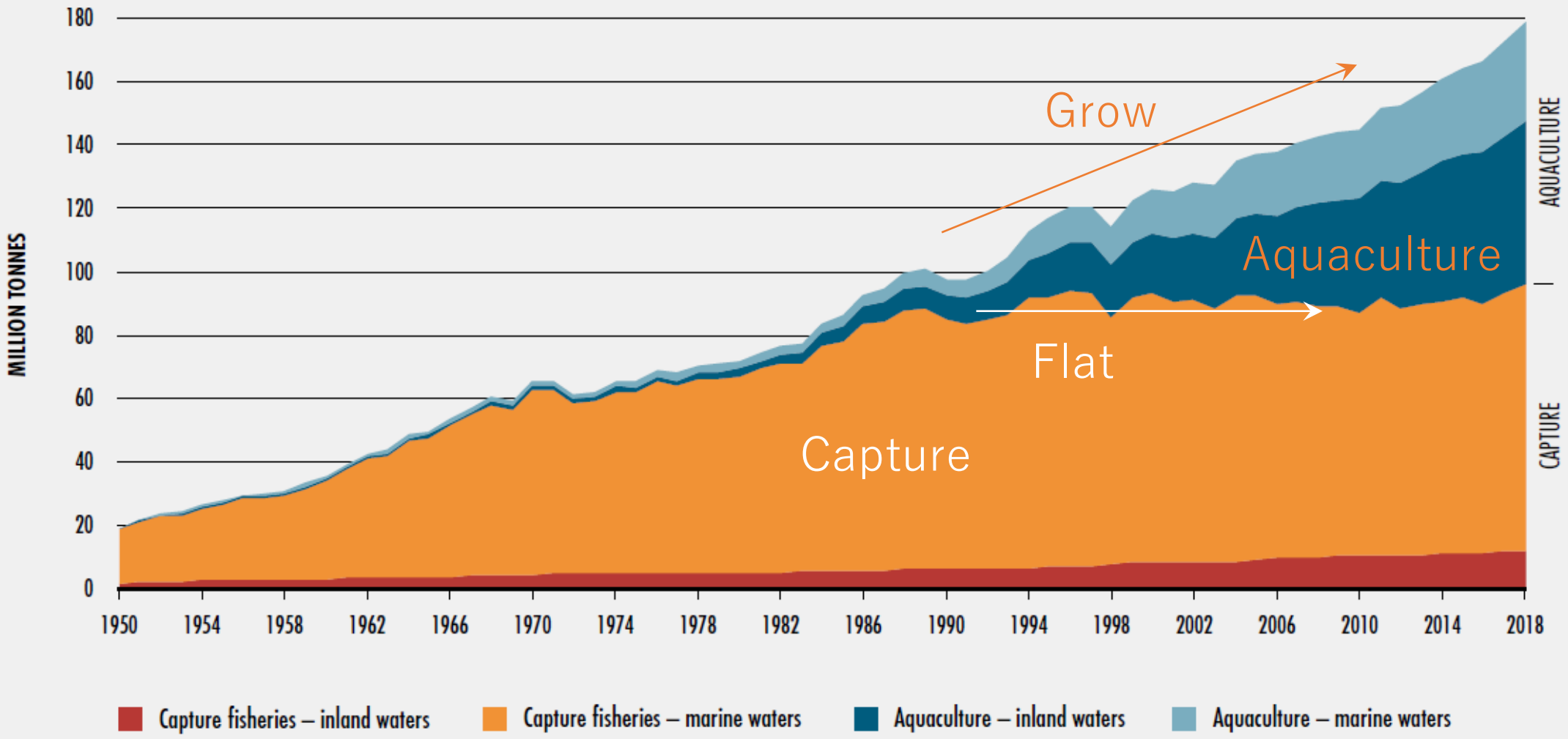
World Supply of Seafood



Source: FAO(2020) The State of World Fisheries and Aquaculture

NOTE: Excludes aquatic mammals, crocodiles, alligators and caimans, seaweeds and other aquatic plants.

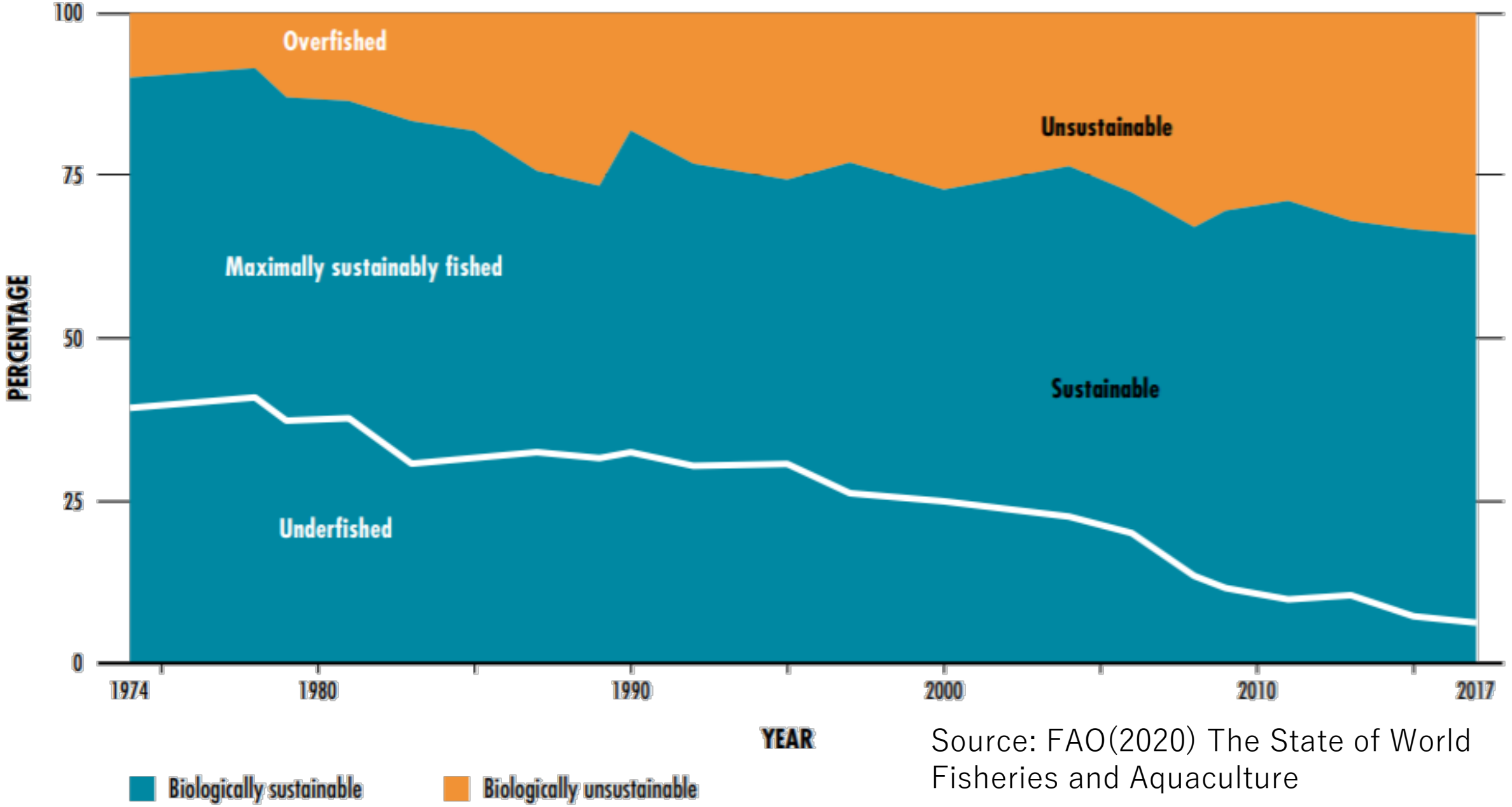
Seafood Production



Source: FAO(2020) The State of World Fisheries and Aquaculture

NOTE: Excludes aquatic mammals, crocodiles, alligators and caimans, seaweeds and other aquatic plants.

Fisheries Resources

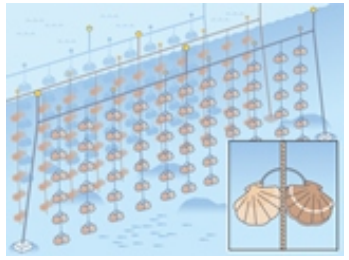


Source: FAO(2020) The State of World Fisheries and Aquaculture

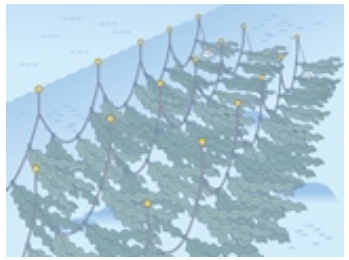
What is Aquaculture?

Non-feeding aquaculture

Bivalves



Seaweed



Feeding aquaculture

Plant, insect, …

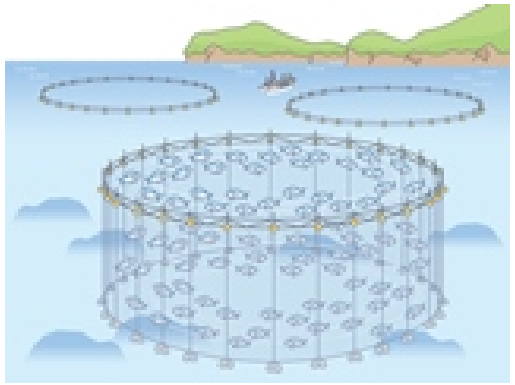
Feed

Feed

Feed

Seed

Cage aquaculture



Seedling

System

Light

Nutrients

Source: Introduction to Marine Science

Source: Ministry of Agriculture, Forestry and Fisheries

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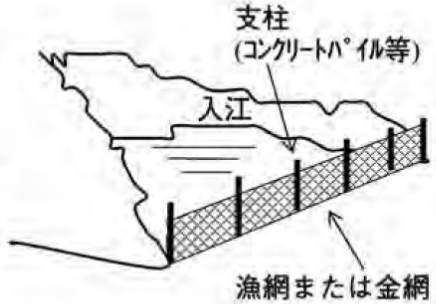
History of Aquaculture

1928 Wasaburo NOAMI
Introduction of embankment farm

Source: http://www.kahiketagyokyo.jf-net.ne.jp/yousyoku/yousyokurekisi/index.html

1954 Teruo HARADA
Introduction of cage aquaculture

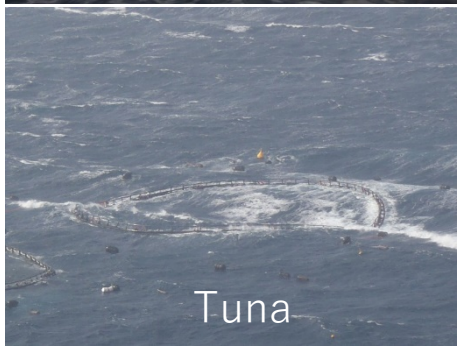
Embankment farm
築堤式



網仕切式

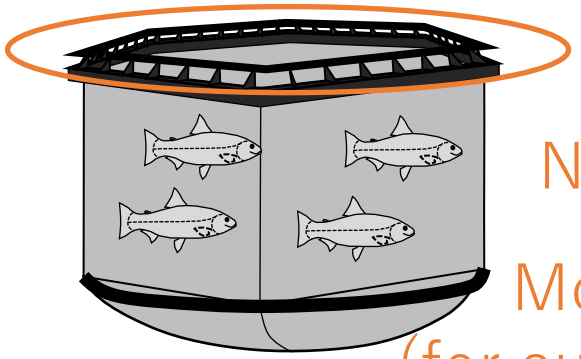
Netting farm

Cage aquaculture



Source: Miyashita (2008)

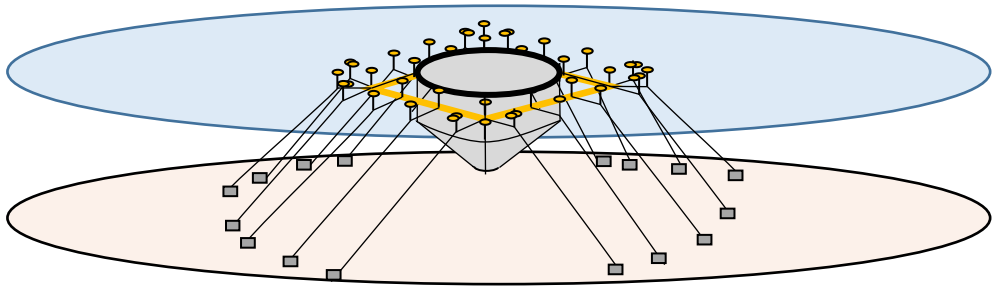
Materials of Cages



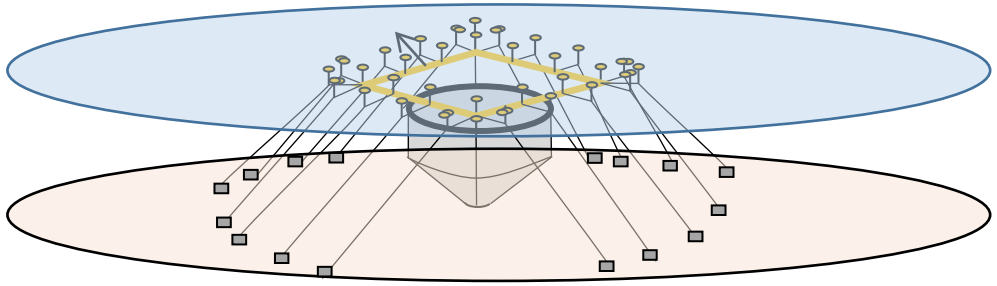
Frame & float

Netting

Mooring system
(for submergible cages)



Flotation

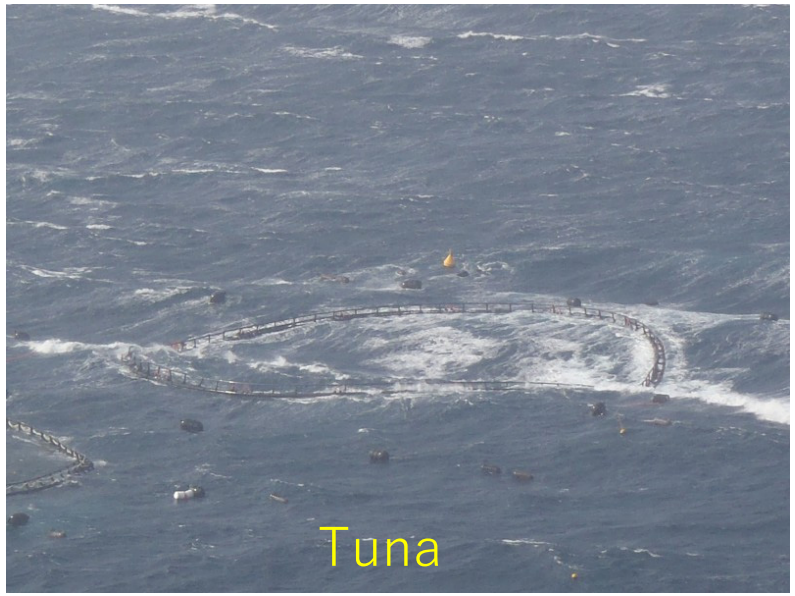


Submersion

- Frame
  - Natural lumber (bamboo, etc.)
  - Steel
    - Steel pipe, die steel, galvanization
    - Steel rod, H steel
  - High density polyethylene pipes
  - Floats and ropes
  - Rubber hoses
- Float: Styrofoam, resin pressure resistant float
- Netting
  - Synthetic fiber
    - Multifilament (Polyethylene, Polyester)
    - Monofilament (Polyester)
  - Wire mesh
    - Galvanization
    - Galvanized aluminum
    - Resin coating
    - Alloy (Copper & Nickel, etc.)
- Mooring system
  - Connected type (ropes and anchors)
  - Single point (ropes and concrete weight)
  - Framework (ropes and concrete weight)

Source: Miyashita (2008)

Wide Variety of Cages



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Design of Cages

Water tank testing

Similarity law: it is difficult to apply Froude similarity law to netting

The formation of netting is similar if the ratios of tension, hydrodynamic force, and weight are the same (Tauti, 1934).

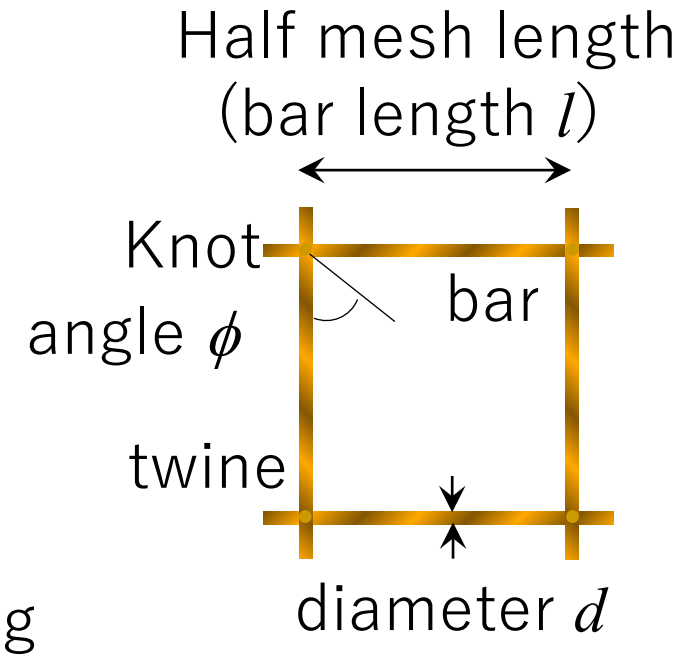
Hydrodynamic force (per area)

$$r = \frac{1}{2}\rho C_D \frac{d}{l}\left\{a_1(\varphi,\theta) + a_2(\varphi,\theta)\frac{d}{l}\right\}v^2$$

bar　　Knotting

Weight in water (per area)

$$w = b_1(\varphi)\frac{d}{l}\left(1 + b_2\frac{d}{l}\right)d(\rho_s - \rho)g$$



ρ (kg/m^3): water density　C_D (-): drag coefficient

a_1, a_2, b_1, b_2 (-): parameters related to the formation of netting

v (m/s): current speed　ρ_s (kg/m^3): density of materials　g (m/s^2): acceleration due to gravity

Similarity law

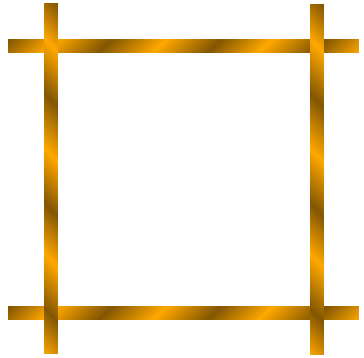
$$\frac{L_m^2 \rho_m C_{Dm} \frac{d_m}{l_m}\left\{a_1(\varphi_m,\theta_m)+a_2(\varphi_m,\theta_m)\frac{d_m}{l_m}\right\} v_m^2}{L_f^2 \rho_f C_{Df} \frac{d_f}{l_f}\left\{a_1(\varphi_f,\theta_f)+a_2(\varphi_f,\theta_f)\frac{d_f}{l_f}\right\} v_f^2} = \frac{L_m^2 b_1(\varphi_m)\frac{d_m}{l_m}\left(1+b_2\frac{d_m}{l_m}\right) d_m(\rho_{sm}-\rho_m) g_m}{L_f^2 b_1(\varphi_f)\frac{d_f}{l_f}\left(1+b_2\frac{d_f}{l_f}\right) d_f(\rho_{sf}-\rho_f) g_f}$$

L (m): length scale
m: model
f: full-scale

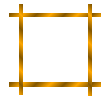
If the drag coefficient, the ratio of twine diameter to mesh length, and acceleration due to gravity are the same,

$$\frac{L_m^2 \rho_m v_m^2}{L_f^2 \rho_f v_f^2} = \frac{L_m^2 d_m(\rho_{sm}-\rho_m)}{L_f^2 d_f(\rho_{sf}-\rho_f)}$$

full-scale



model



the ratio of twine diameter to mesh length is the same =the ratio of projected area is the same

Similarity law

Force ratio

$$\frac{F_m}{F_f} = \frac{L_m^2 b_1(\varphi_m)\frac{d_m}{l_m}\left(1 + b_2\frac{d_m}{l_m}\right)d_m(\rho_{sm} - \rho_m)g_m}{L_f^2 b_1(\varphi_f)\frac{d_f}{l_f}\left(1 + b_2\frac{d_f}{l_f}\right)d_f(\rho_{sf} - \rho_f)g_f} = \frac{L_m^2 d_m(\rho_{sm} - \rho_m)}{L_f^2 d_f(\rho_{sf} - \rho_f)}$$

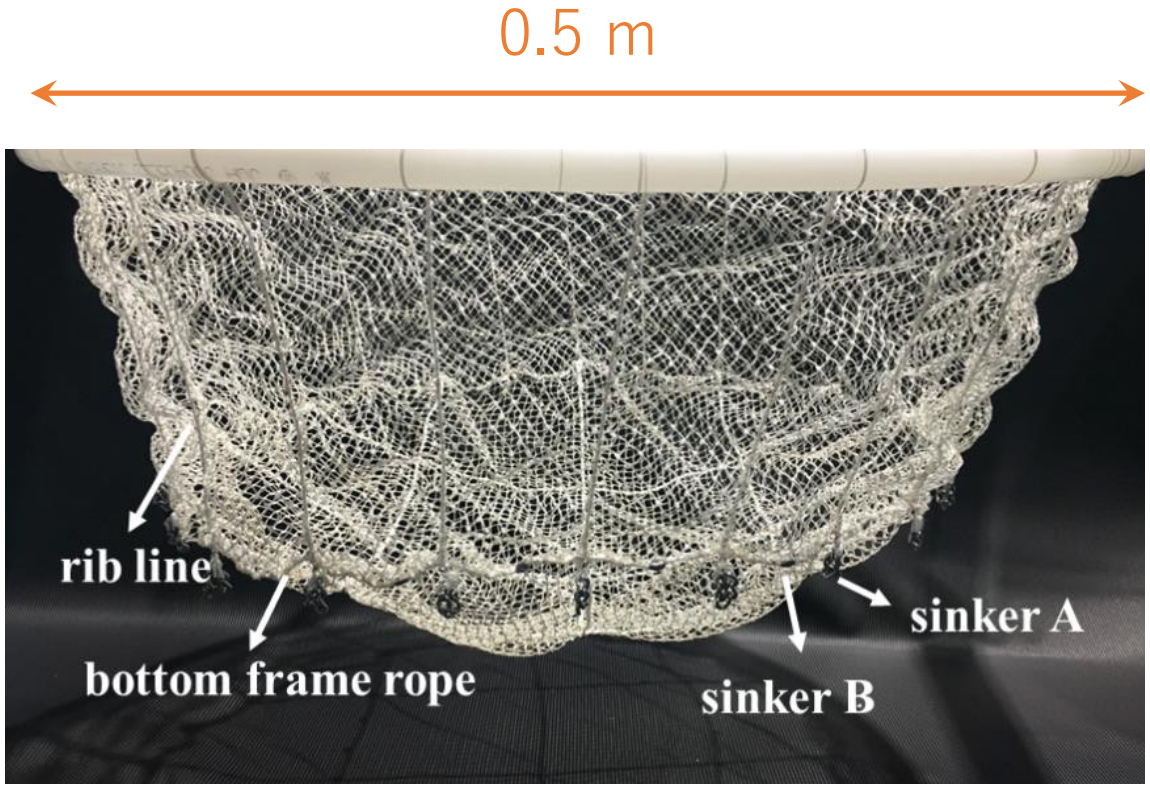
Velocity ratio

$$\frac{L_m^2\rho_m C_{Dm}\frac{d_m}{l_m}\left\{a_1(\varphi_m,\theta_m) + a_2(\varphi_m,\theta_m)\frac{d_m}{l_m}\right\}v_m^2}{L_f^2\rho_f C_{Df}\frac{d_f}{l_f}\left\{a_1(\varphi_f,\theta_f) + a_2(\varphi_f,\theta_f)\frac{d_f}{l_f}\right\}v_f^2} = \frac{L_m^2\rho_m v_m^2}{L_f^2\rho_f v_f^2} = \frac{L_m^2 d_m(\rho_{sm} - \rho_m)}{L_f^2 d_f(\rho_{sf} - \rho_f)}$$

$$\frac{v_m}{v_f} = \sqrt{\frac{d_m(\rho_{sm} - \rho_m)\rho_f}{d_f(\rho_{sf} - \rho_f)\rho_m}}$$

Example

1/50



Source: Dong et al. (2021)

Comparison

Component	Parameter	Prototype value	Model value	
Floating pipe	Material	High Density Polyethylene	Polyethylene	
	General diameter	25.0 m	0.5 m	1/50
	Pipe diameter	35.5 cm	1.74 cm	1/20
Side netting	Material	Polyethylene knotless netting	Nylon knotted netting	
	Net Height	9.0 m	0.18 m	1/50
	Twine diameter	2.7 mm	0.6 mm	1/4.5
	Mesh size	50.3 mm	11.3 mm	1/4.5
	Mesh type	Diamond mesh	Diamond mesh	
Bottom netting	Material	Polyethylene knotless netting	Nylon knotted netting	
	Twine diameter	2.7 mm	0.6 mm	
	Mesh size	50.3 mm	11.3 mm	
	Mesh type	Square mesh	Square mesh	

Source: Dong et al. (2021)

Similarity

Length scale ratio

$$\frac{L_f}{L_m} = 50$$

Twine diameter scale ratio

$$\frac{d_f}{d_m} = \frac{l_f}{l_m} = 4.5$$

Velocity ratio

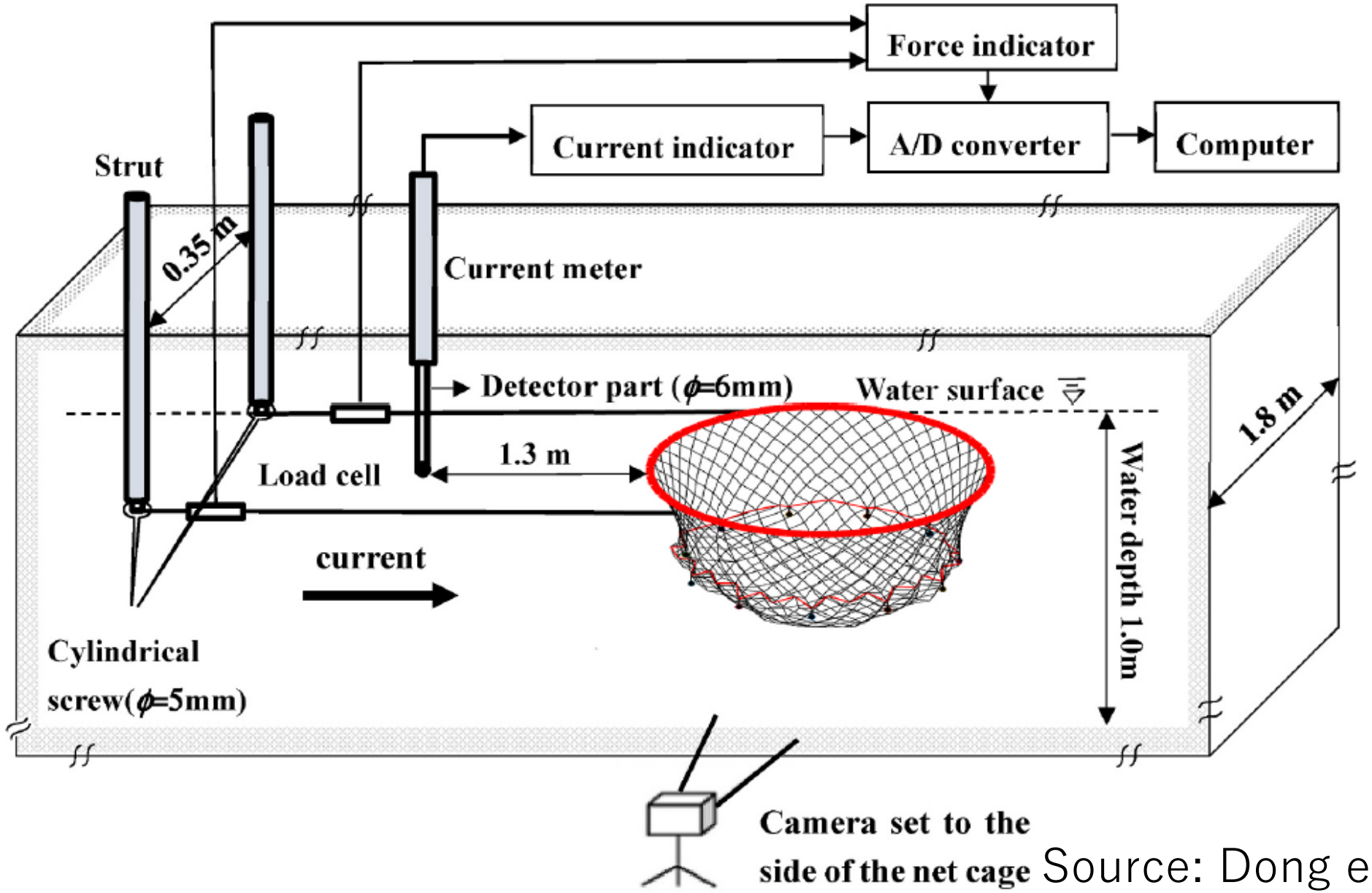
$$\frac{v_f}{v_m} = \sqrt{\frac{d_f(\rho_{sf} - \rho_f)\rho_m}{d_m(\rho_{sm} - \rho_m)\rho_f}} = 2.12$$

Force ratio

$$\frac{F_f}{F_m} = \frac{L_f^2 d_f(\rho_{sf} - \rho_f)}{L_m^2 d_m(\rho_{sm} - \rho_m)} = 11250$$

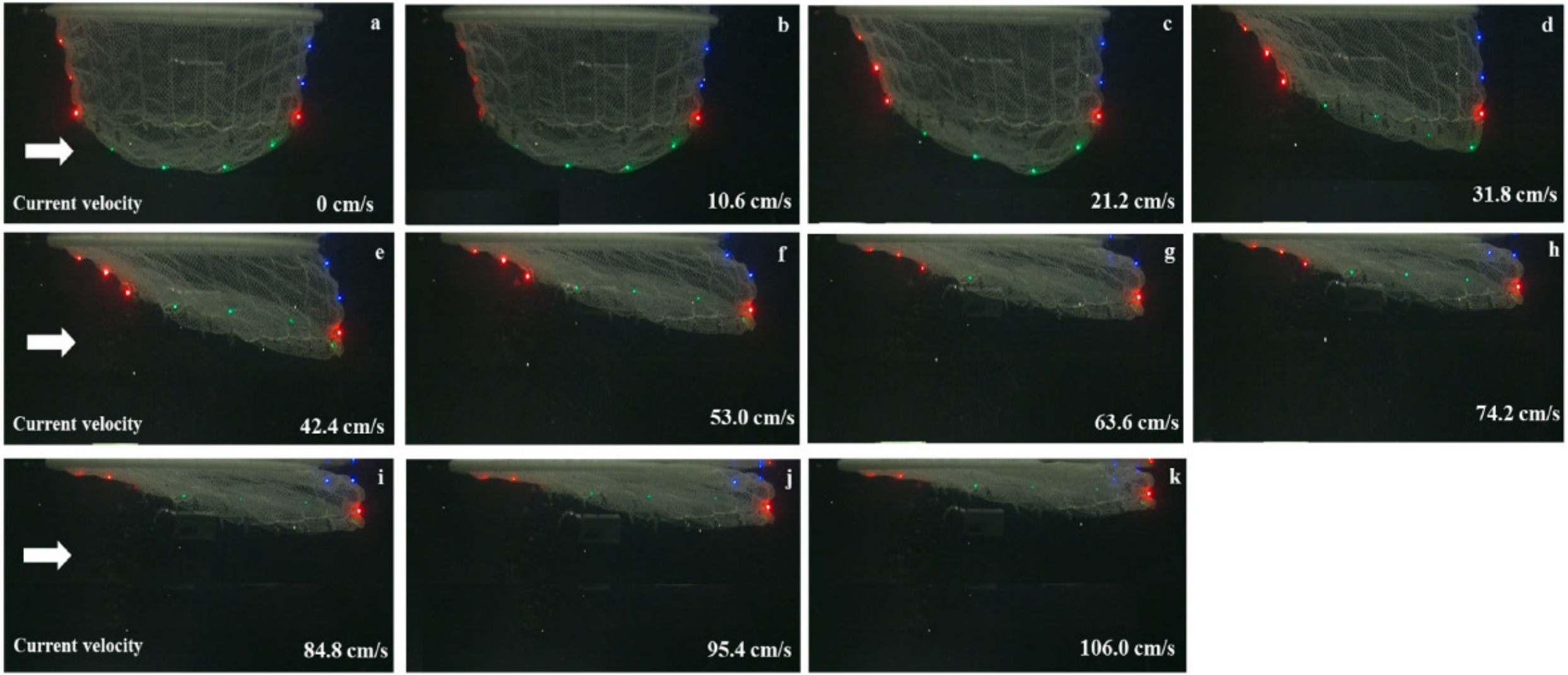
Source: Dong et al. (2021)

Experimental Set-up



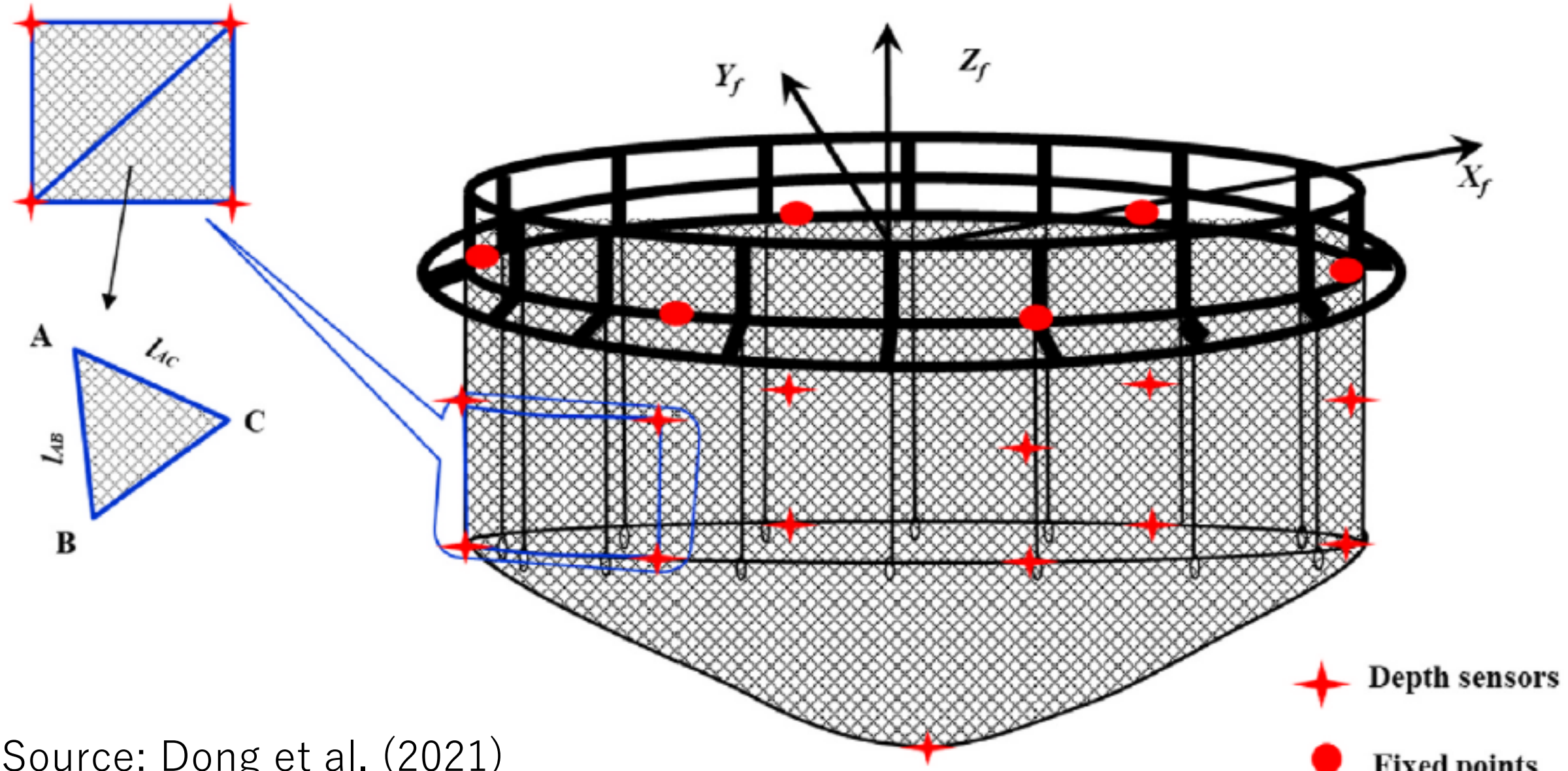
Source: Dong et al. (2021)

Deformation of Netting



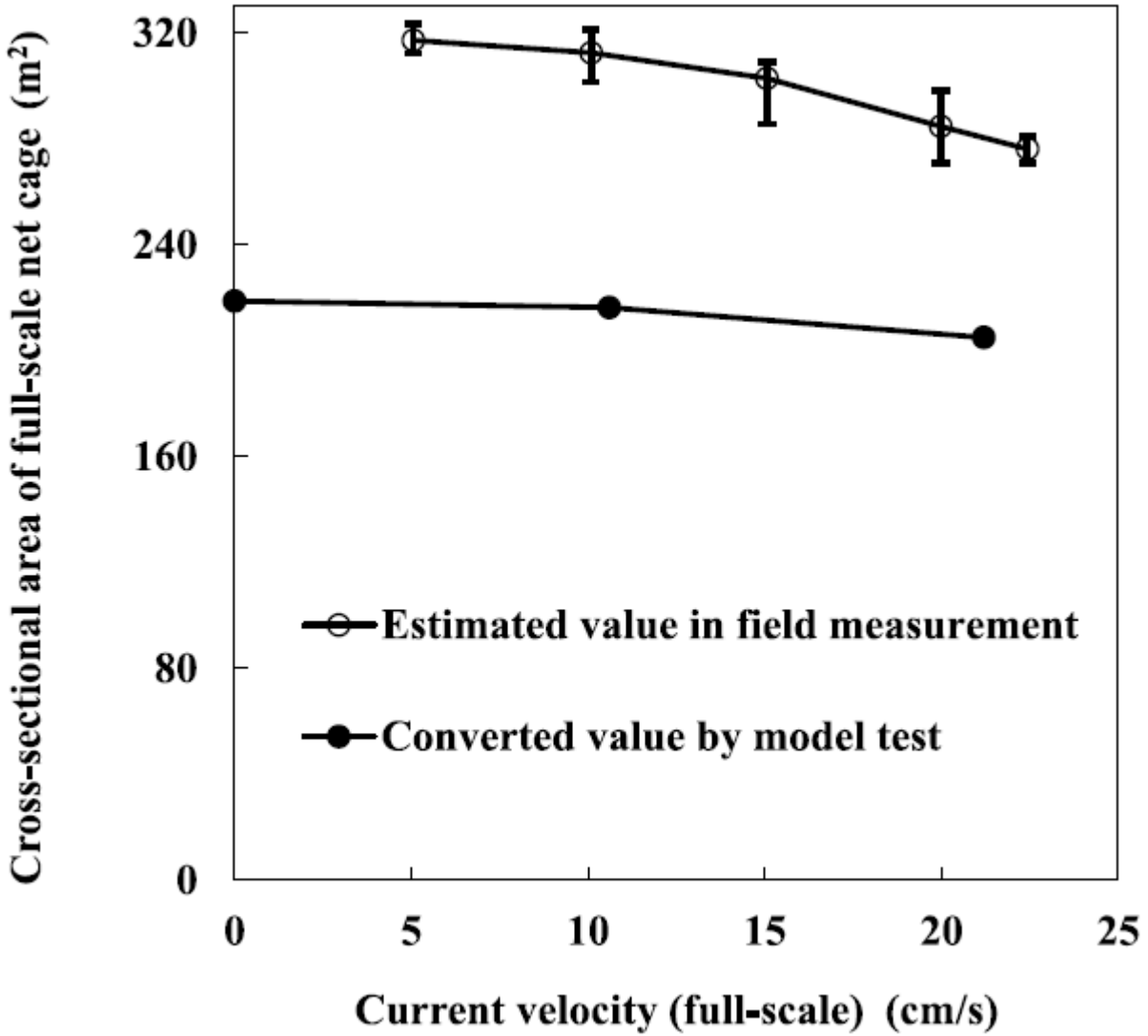
Source: Dong et al. (2021)

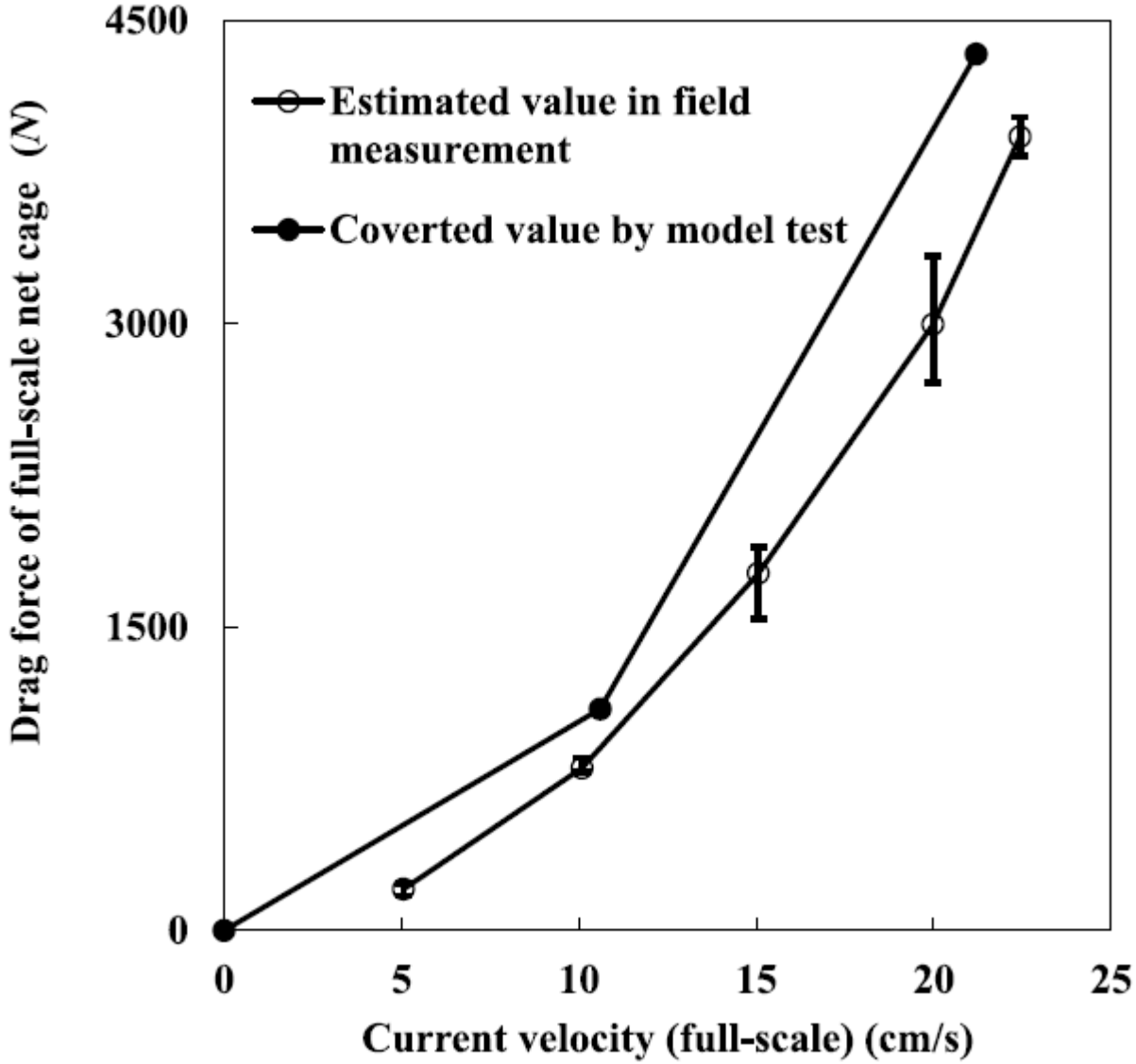
Field Measurement



Source: Dong et al. (2021)

Comparison of the Results





Source: Dong et al. (2021)

Numerical Models

FhSim: a software platform and framework for mathematical modelling and numerical simulation, with a focus on marine applications.

Aqua-FE: a software to simulate and analyze the dynamic and structural behavior of the gravity fish cages in waves and current

Moordyn: an open-source dynamic mooring line model

OrcaFlex: a software for the dynamic analysis of offshore marine systems

DUTFlexSim: a software to simulate the motion responses of the fish farm

AquaSim: an analysis and simulation tool developed by Aquastructures

SimuTrawl: a planning and analyzing tool for the engineering properties and performance of the trawl gear

etc.

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Aquaculture Technology

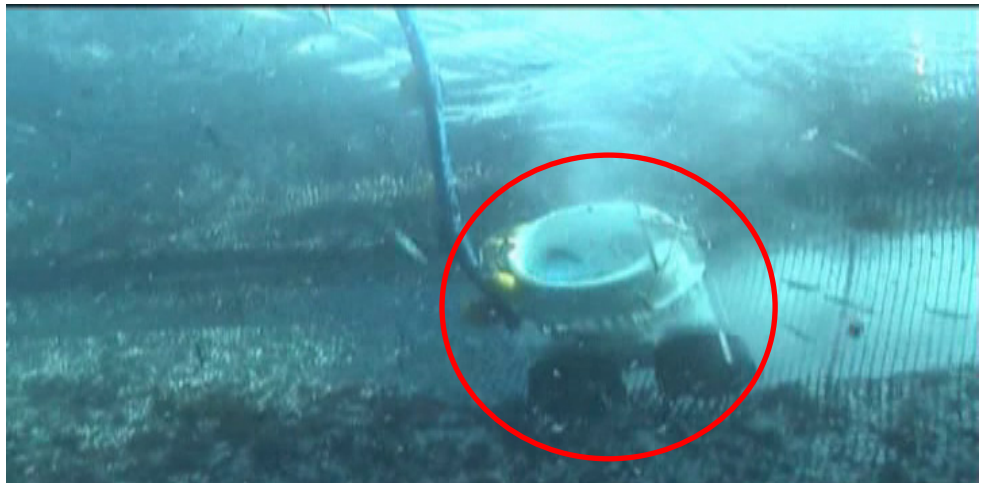
Feeding ship

Automated feeder

Feeding by hand

Collecting dead fish

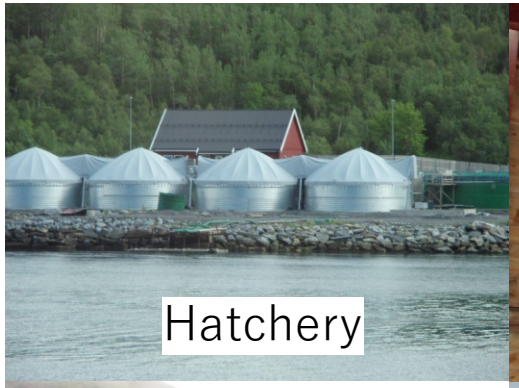
Maintenance of netting



Removal of sessile organisms


配合飼料自動定量供給装置

Aquaculture Technology


Hatchery


Dead fish removal


Control


Barge


Barge


Cod farming


Feeder


Feeding hose

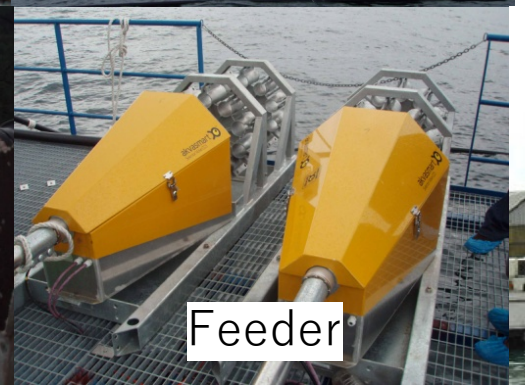

Cages


Automated feeder


Halibut


Silo


Feeding method


Feeder


Feed tank

System utilizing the advantage of Fjord topography

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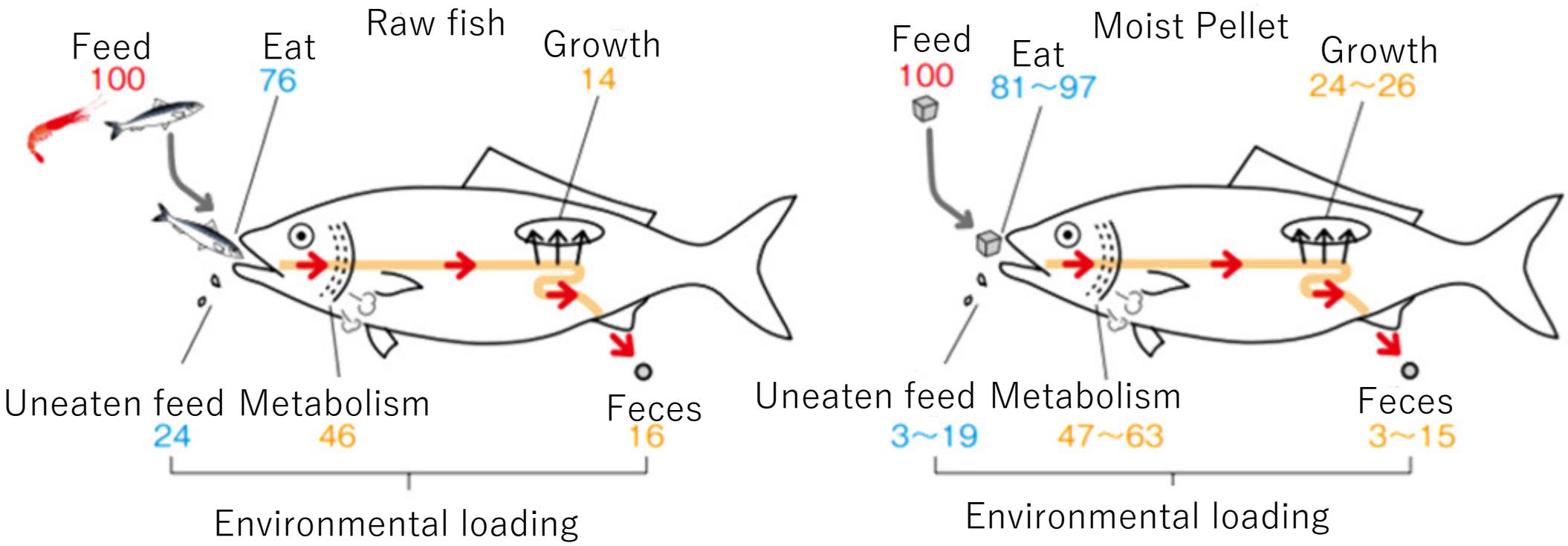
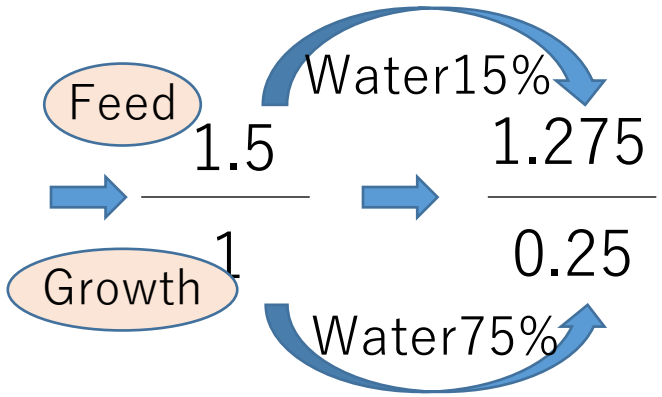
Environmental Loading



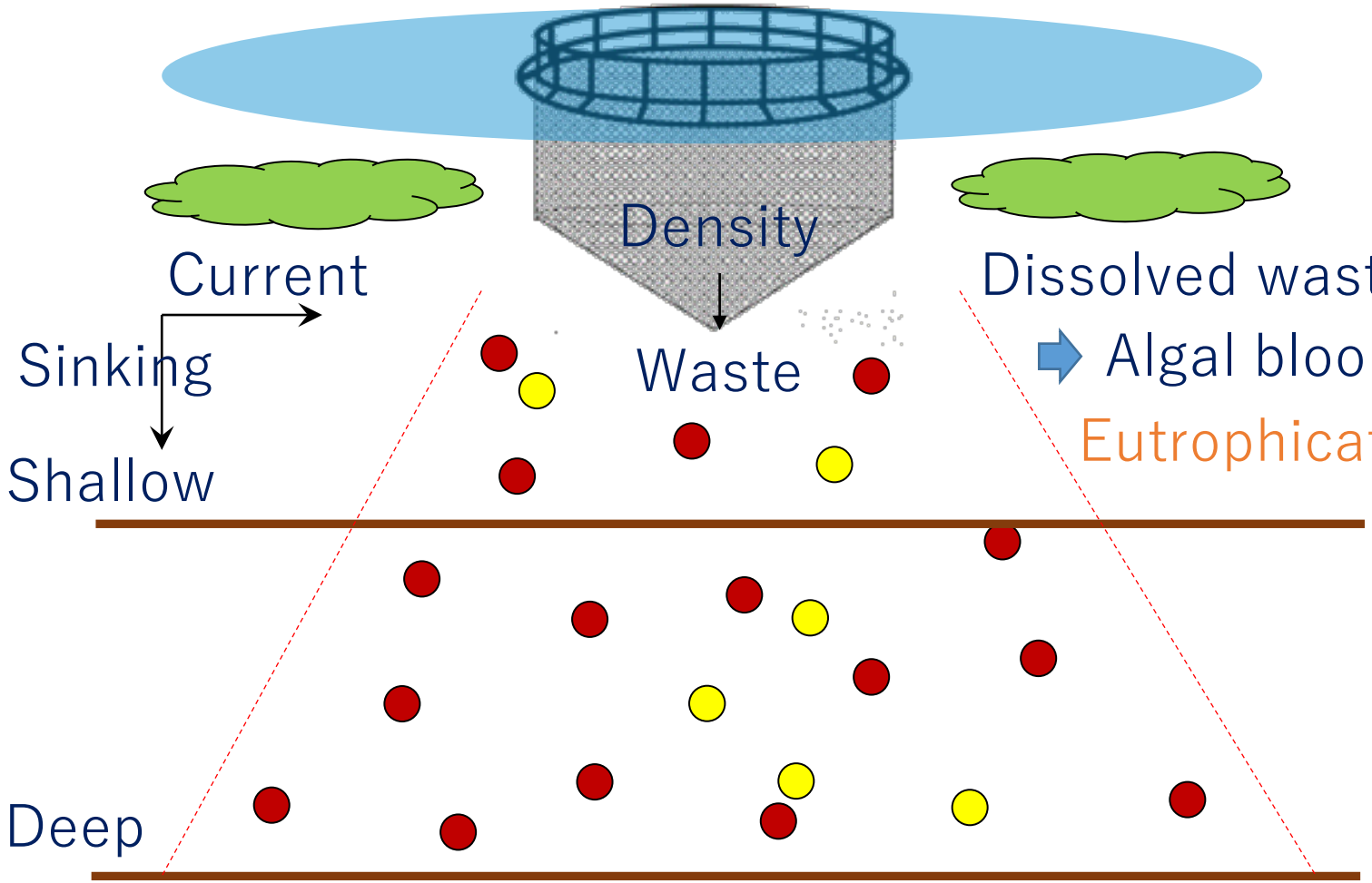
Source: White paper of Fisheries Agency (2013)

Feed Conversion Ratio (FCR)=1.5



≈ 5 ➡ 20% is used for growth

Environmental Loading



Dissolved waste

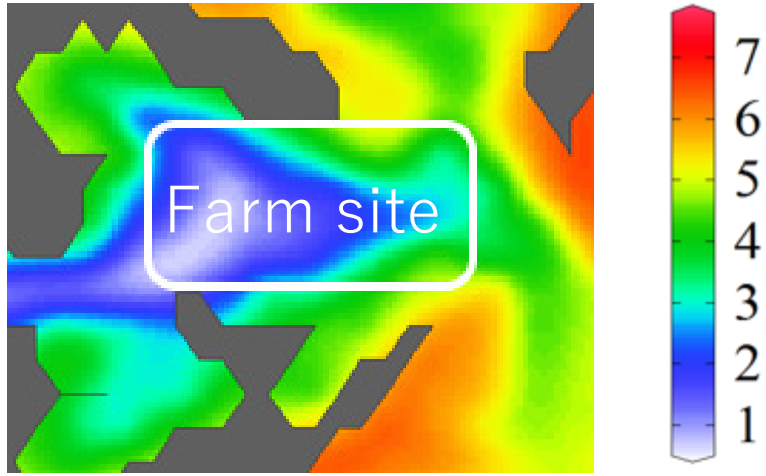
➡ Algal blooming

Eutrophication

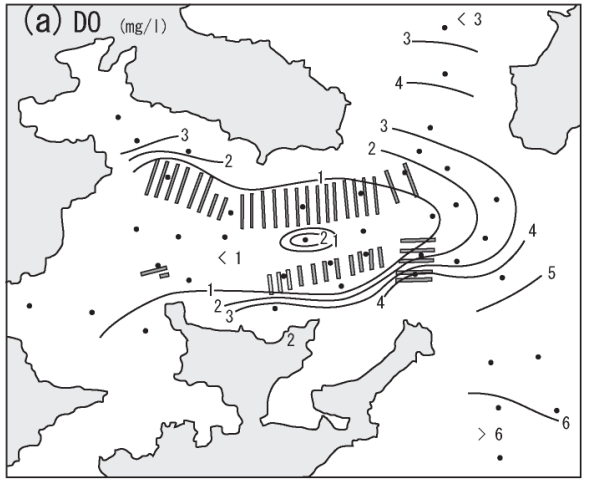
➡ Sulfide, Hypoxic water

Fjord: Water is deep though water current is weak

Dissolved oxygen in bottom water



Source: Zhang and Kitazawa (2016)



Source: Yokoyama et al. (2006)

Damage

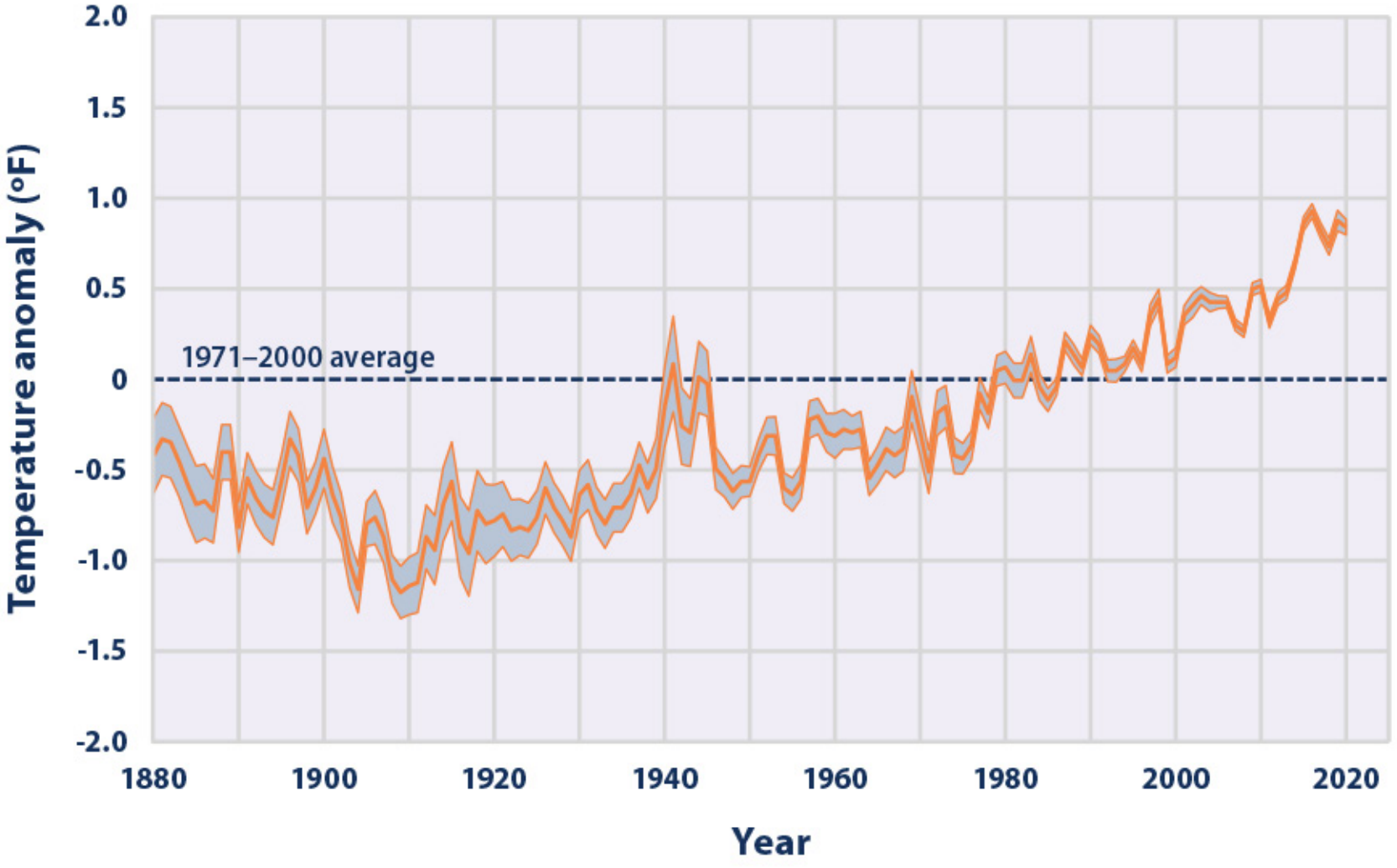
Severe damage caused by algal blooming has been reported.
2016; Chile, 2018; Japan, 2019; Norway
The other factors as well as eutrophication may be related to the algal blooming.

Source: Fisheries Agency (1985)

Source: http://www.serc.si.edu/labs/protistan_ecology/hab_parasites.aspx

Source: Nagasaki Prefecture (2009)

Other Environmental Issues



- Increase in water temperature
- Sea lice
- Escape
- Predator

…

Source: https://www.epa.gov/climate-indicators/climate-change-indicators-sea-surface-temperature

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Land-based Aquaculture

- Pond aquaculture
  River water
- Free-flow aquaculture
  Seawater

Wastewater is excreted through channels

- Recirculating aquaculture
  Recirculating water

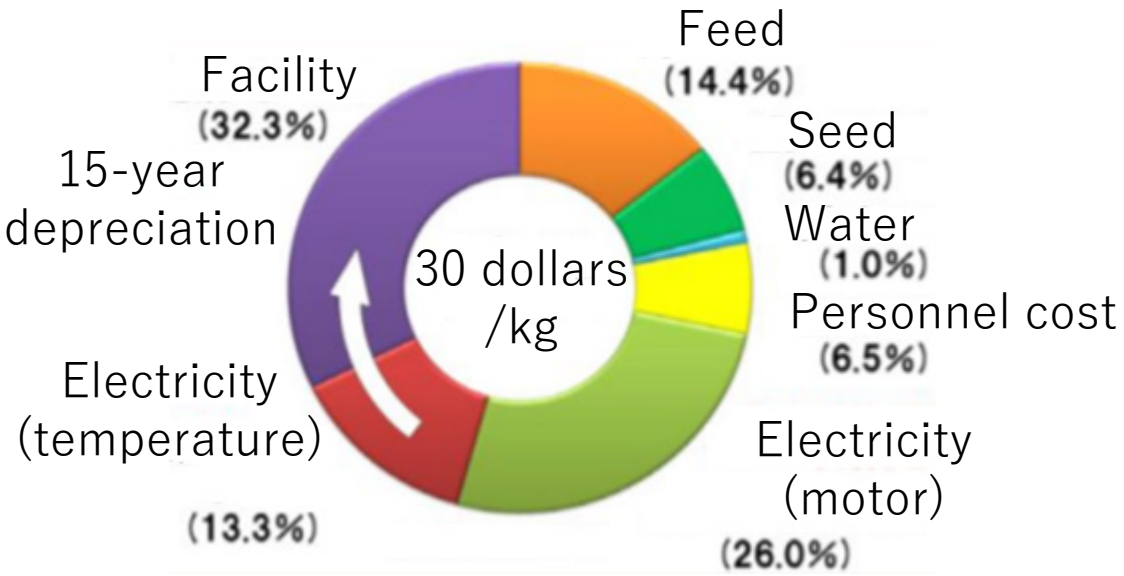
➡ Wastewater can be controlled.

Advantage of Recirculating Aquaculture System (RAS)

- Aquaponics (the combination of aquaculture and hydroponics), zero-emission
- Environment (water temperature, water quality, light intensity, etc.) can be controlled.

Facilities and energy for wastewater treatment and temperature control are required.

Land-based Aquaculture



Cost for recirculating aquaculture of pufferfish

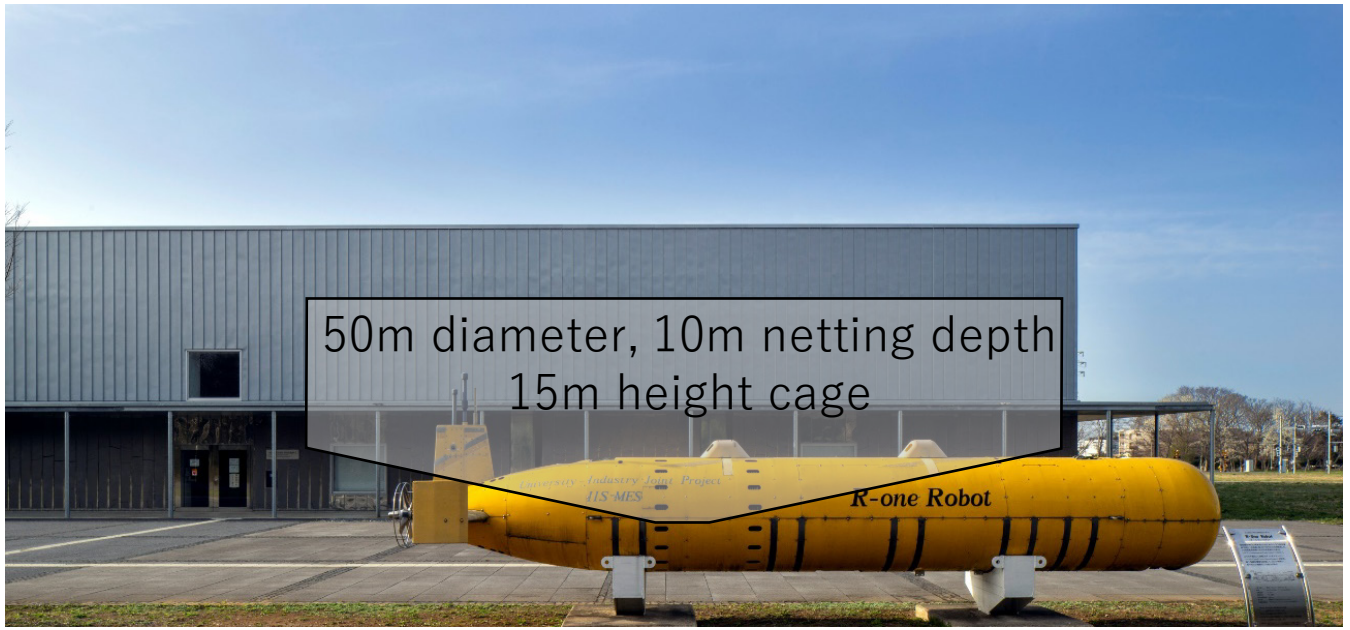
Source: Fisheries Agency (2013)

To reduce the cost for wastewater treatment, certain level of wastewater can be excreted or waste is absorbed by the other organisms (aquaponics)

Electricity cost is more than 10 dollars / kg

Utilization of groundwater, hot spring, deep-sea water will be effective.

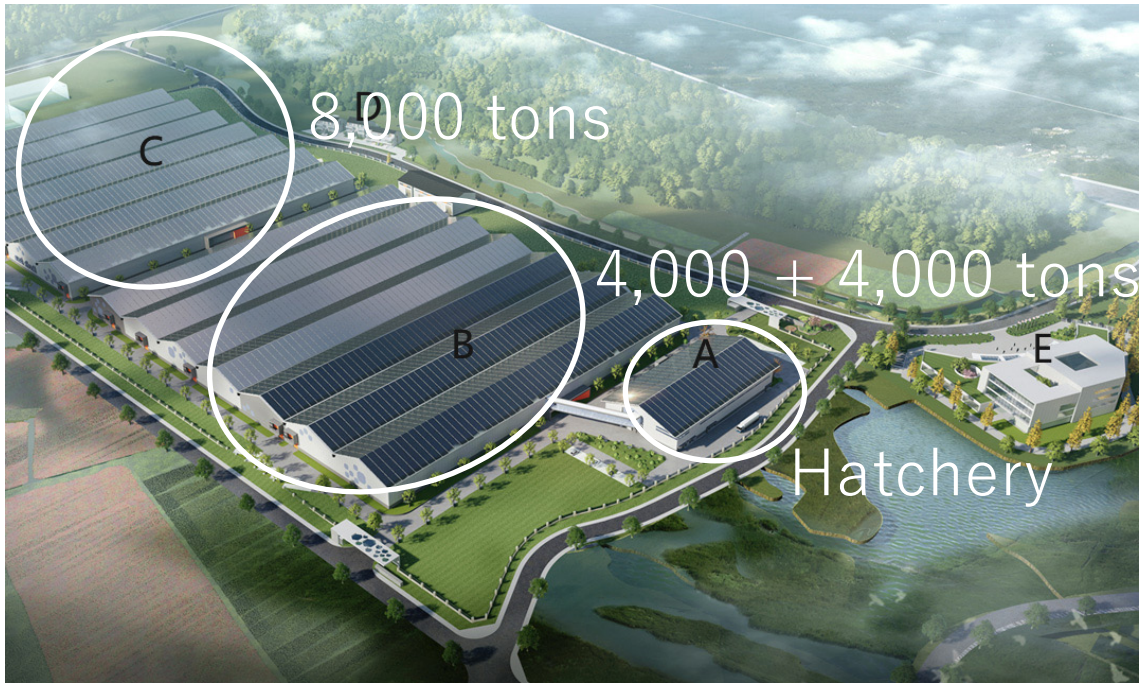
Scale-up problem



RAS in China

Source: https://www.intrafish.com/salmon/norways-norsal-signs-engineering-firm-for-china-land-based-salmon-farm-project/2-1-970637

Norsal: Shandong Province, Yantai
10,000 tons (Phase I)
30,000 tons (Phase II)



Source: http://www.nordicaquapartners.com/en-columnA/mid-16

Nordic Aqua Partners:
Zhejiang Province, Ningbo
4,000 tons (2023), 8,000 tons (2026)
16,000 tons (2027), 40,000 tons (Future)

RAS in the Other Countries

Source: https://www.billundaquaculture.com/proyectos/atlantic-sapphire-usa/

Atlantic Sapphire: Miami, USA
Intensive RAS, groundwater
Salmon 10,000 tons, Feed 35.3 tons/day

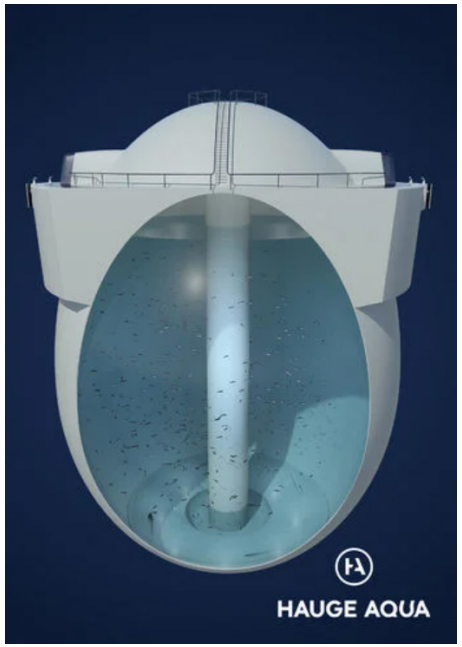
Source: https://www.the-kingfish-company.com/about

Kingfish Zeeland: The Netherlands
Intensive RAS, seawater
Amberjack 2,000 tons/3ha

100,000 tons/75ha in Sweden, etc.

RAS in the Ocean

Sandwich composite



- Personnel safety
- Low risk of sea lice
- Environmental control
- Feeding
- Recycle of uneaten feed and feces
- Escape
- Predator

Light intensity and water quality are controlled through days
Although uneaten food and feces are decomposed in the cage,
dissolved waste will be excreted in the environment.

Source: HAUGE AQUA HP (https://haugeaqua.com/technology)

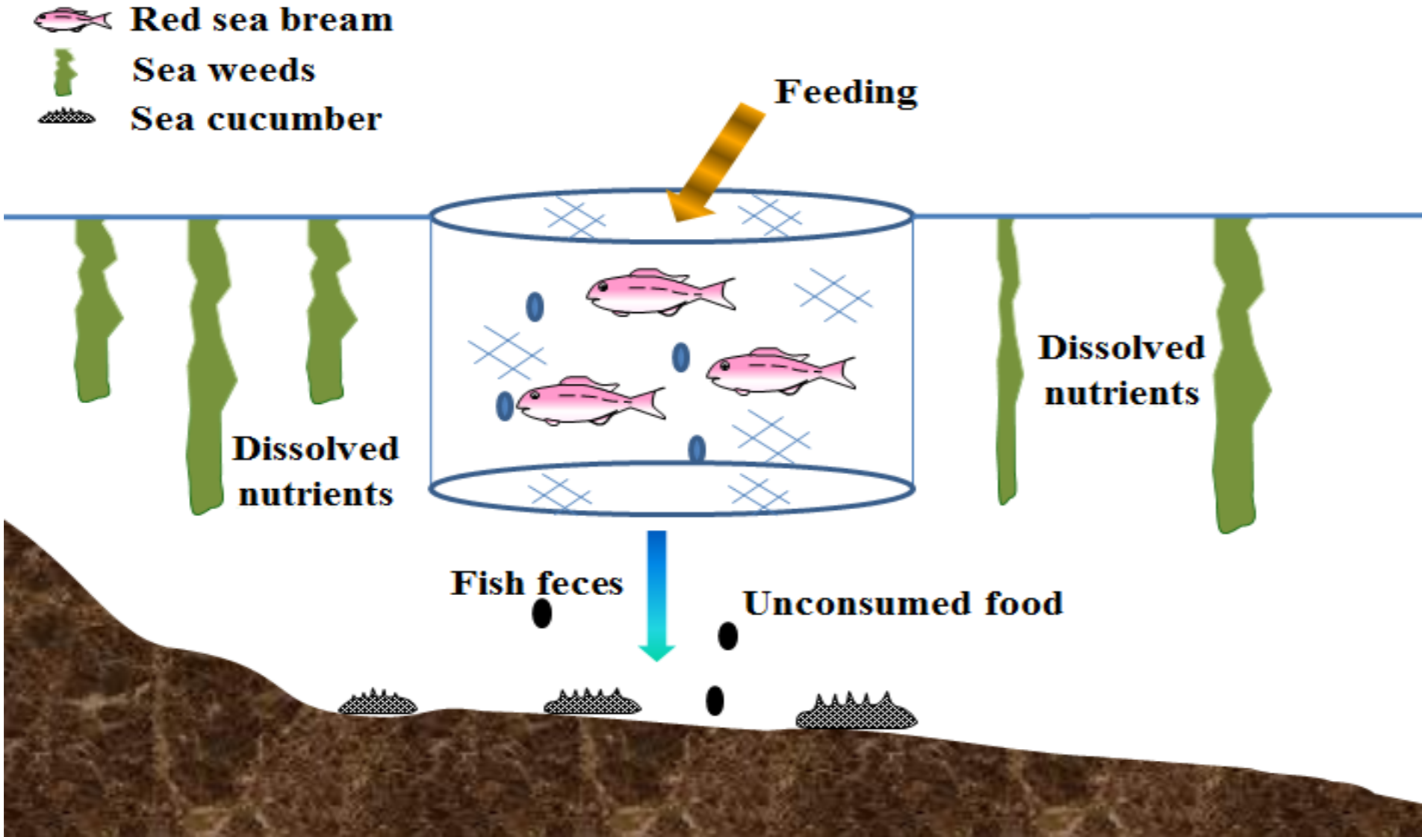
RAS in the Ocean

Prototype
48m x 28m; 5km offshore
Annual production goal: 166 tons
(Barramundi, Sea bream)
4 tanks, 475,000L/tank
2 workers

Seawater is purified for use as breeding water.
Wastewater is excreted after purification.

Possibility of IMTA

Integrated Multi-Trophic Aquaculture (IMTA)



Advantage

- Recycle and high productivity
- Environmental preservation

Disadvantage

- Additional works
- Reduced velocity

Source: Zhang et al. (2016)

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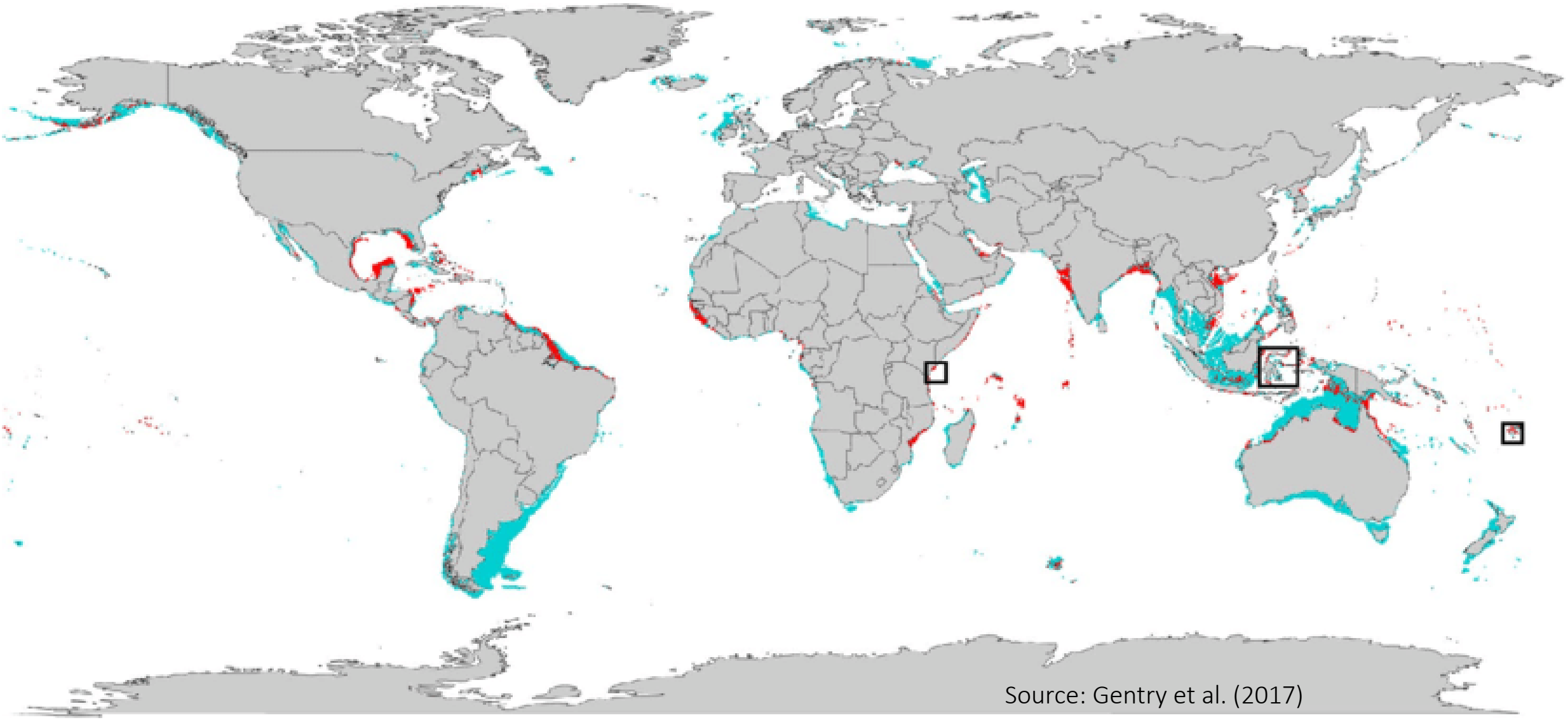
Offshore Aquaculture



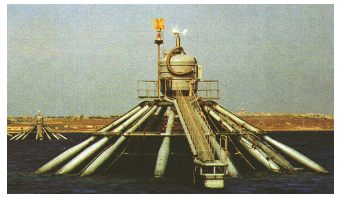
Source: Gentry et al. (2017)

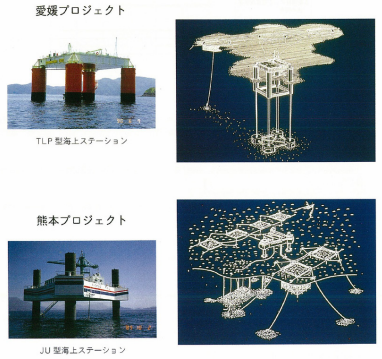
Offshore Aquaculture

1980 1990 2000 2010 2020

Japan

- Offshore aquaculture
- Large cages

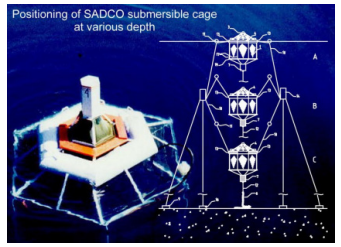




- Offshore submerged aquaculture
- Tuna farming

- Open water aquaculture

Sweden



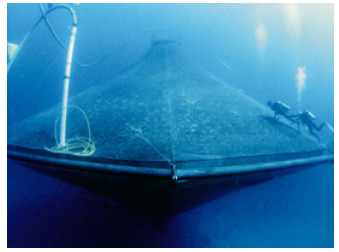
Russia

- Large submergible cages

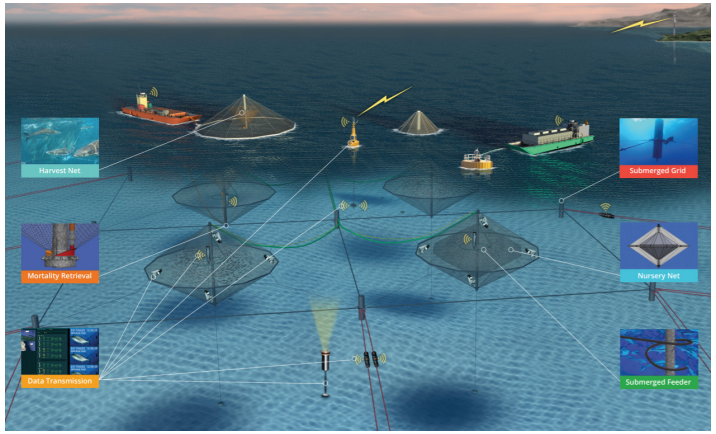
USA

- Offshore aquaculture

Panama



South Korea



- Offshore cobia aquaculture
- Offshore aquaculture

Norway

- EXPOSED

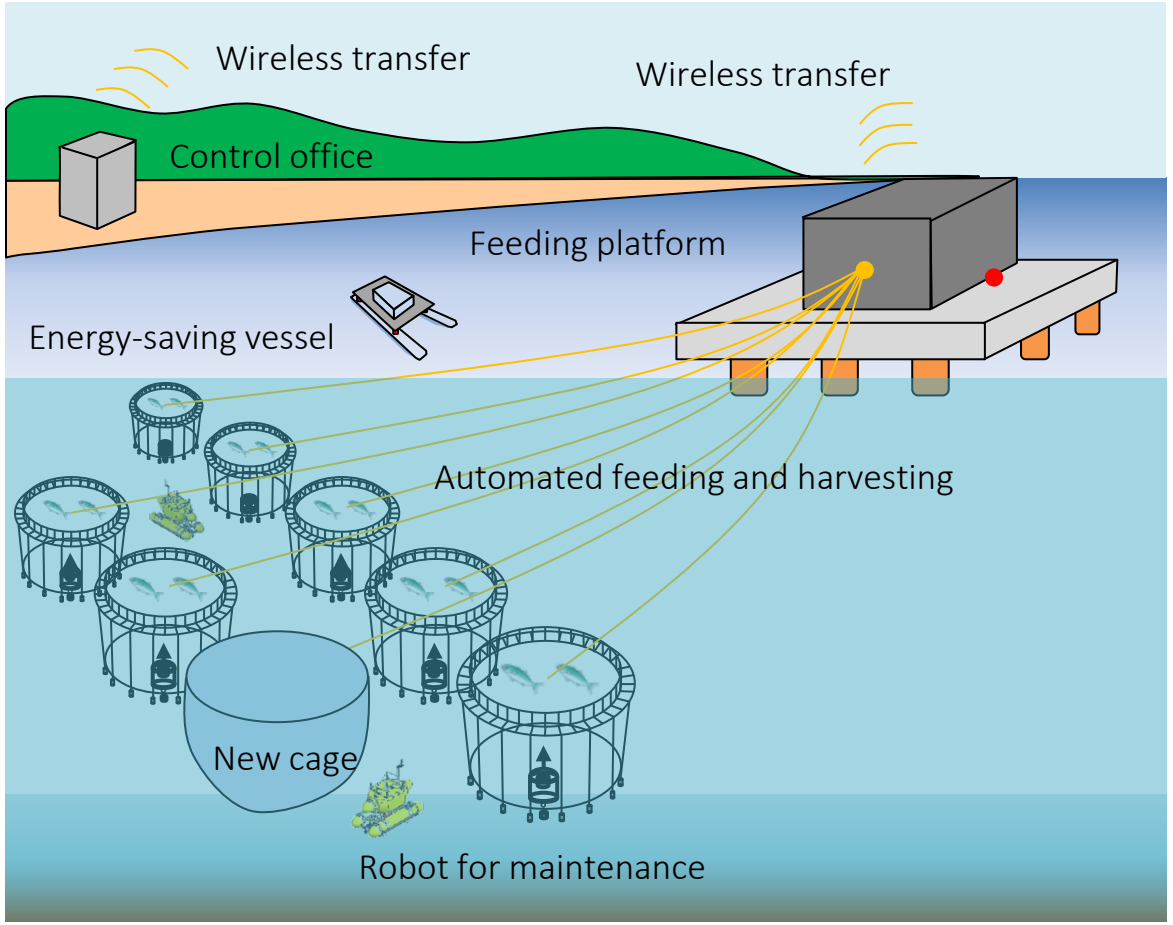
China

- China

Offshore Aquaculture

Feeding
- Platform
- Vessel
- Underwater feeding system
- Energy supply
- Feed production

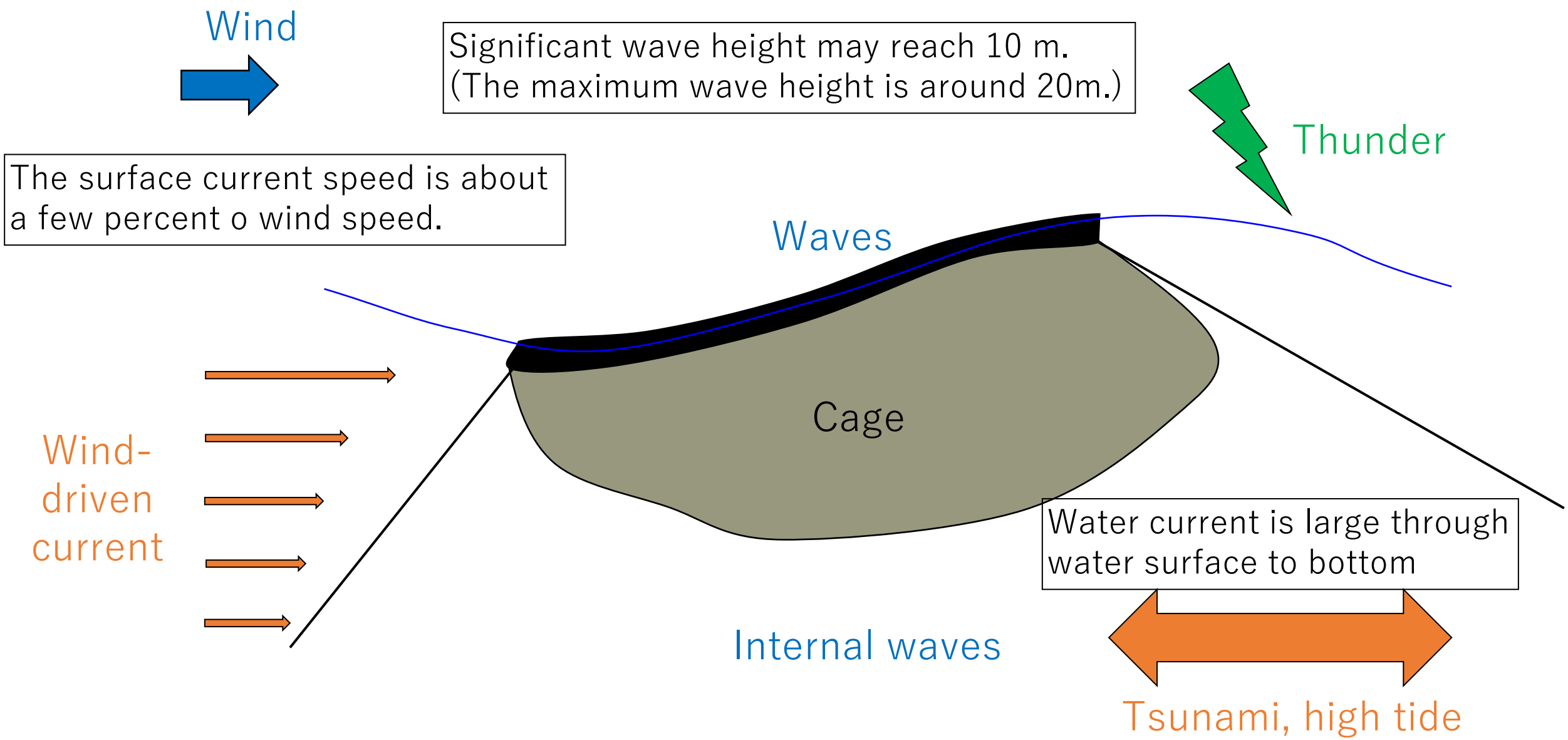
Cage
- Submergible
- Net cleaning
- Dead fish treatment
- Monitoring of fish and environment



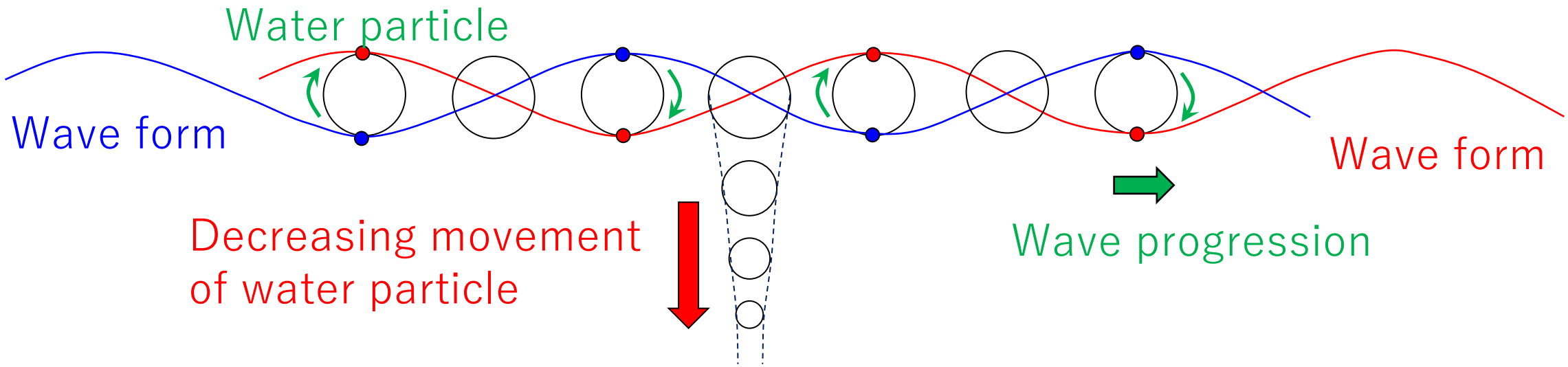
Monitoring
- Remote management
- Wireless image transfer
- Anti-theft system

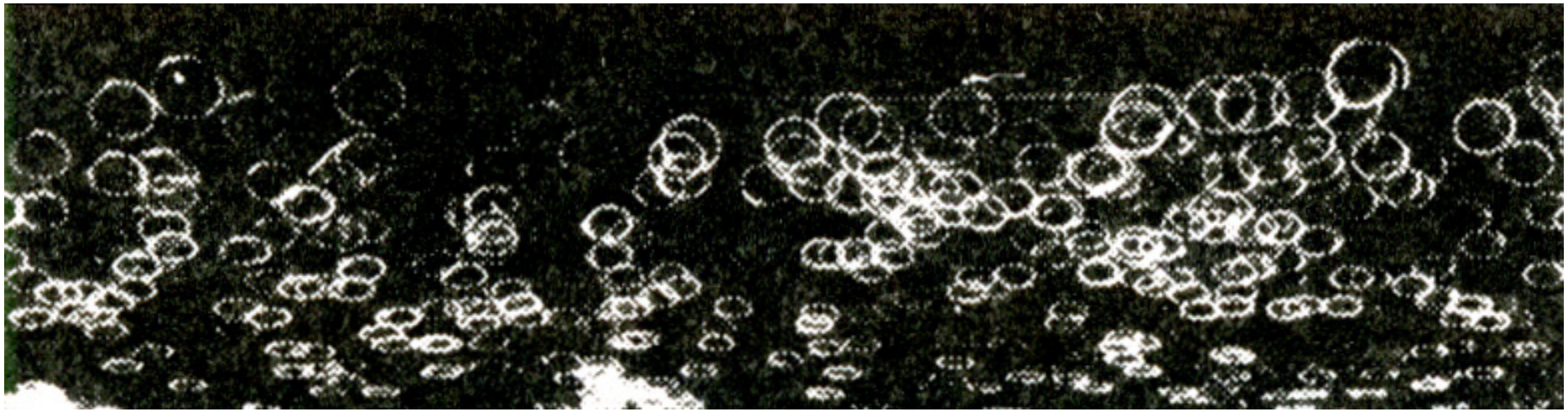
Growth of fish, Ecosystem preservation (escape problem), Sea lice, Environmental protection, …

Hydrodynamic Forces



Submergible Cages

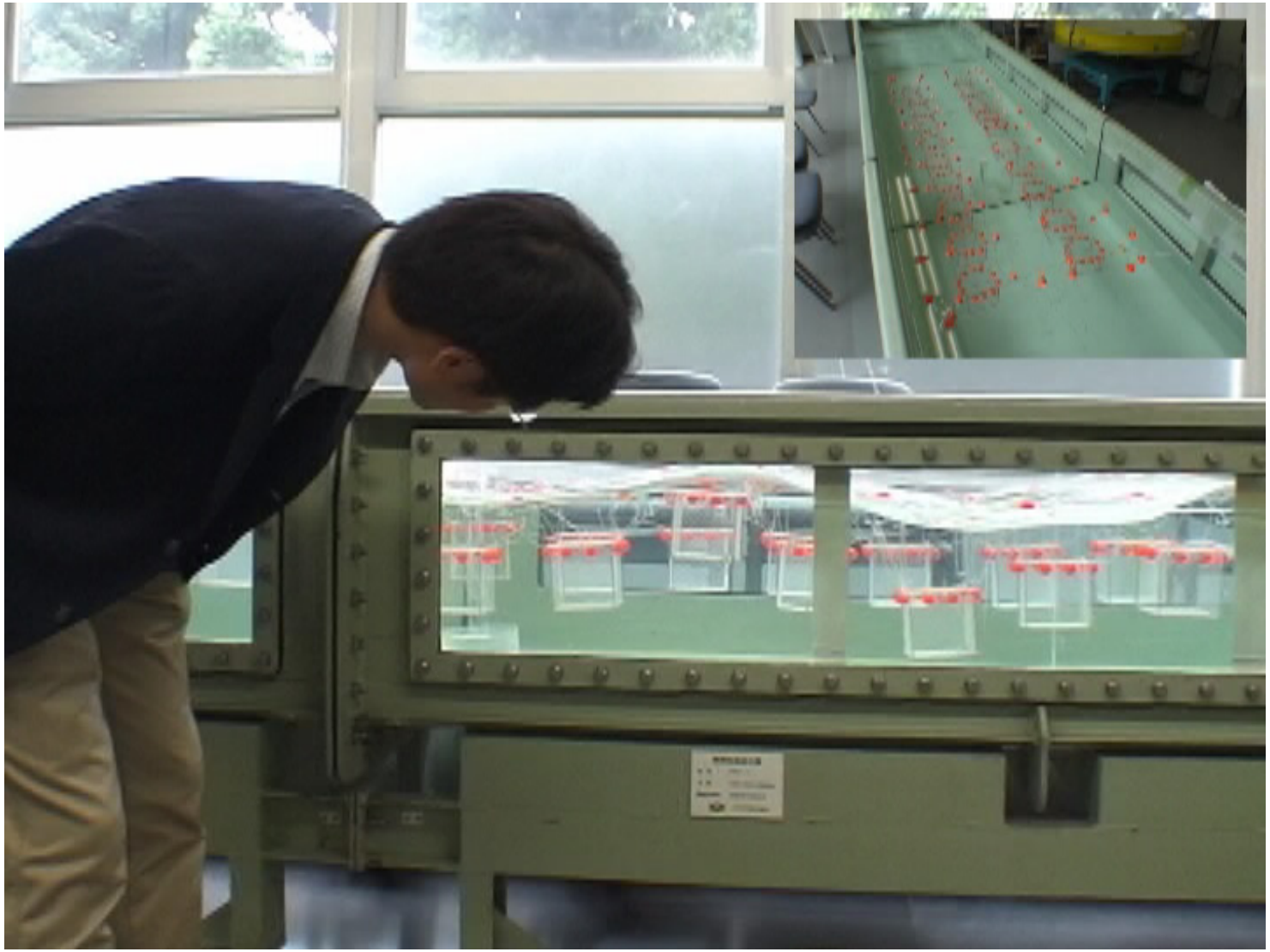




Hydrodynamic forces will be reduced if a cage is submerged.

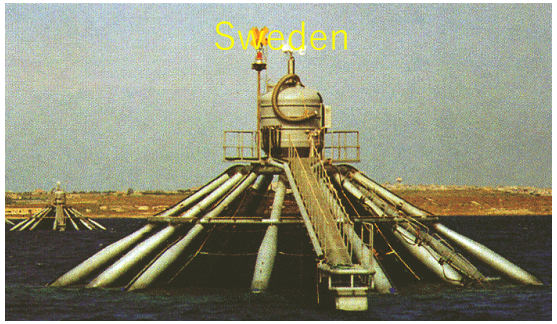
Ruellan & Wallet (1950)

Submergible Cages

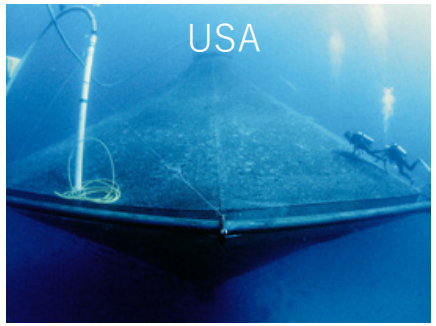


Cages can escape from high waves, high temperature, algal blooming, etc.

Submergible Cages

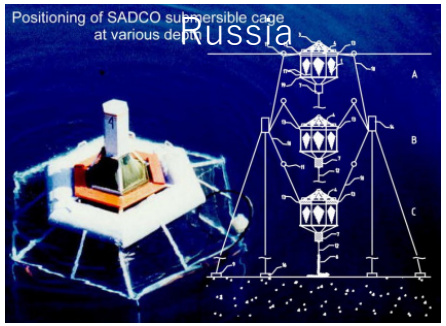


Svealv (1988)



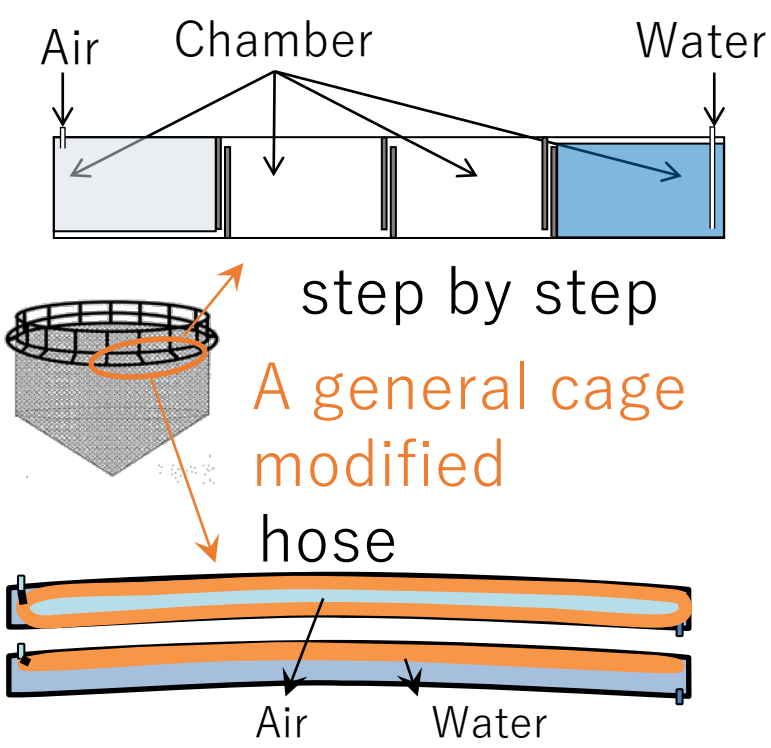
OceanSpar, priv. comm.

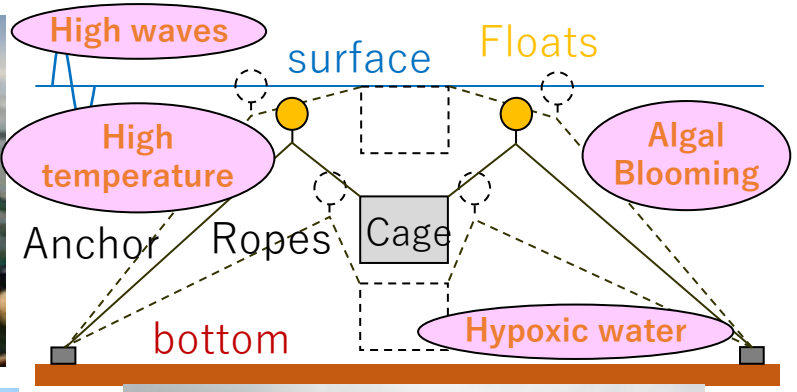
Vielma and Kankainen (2013)



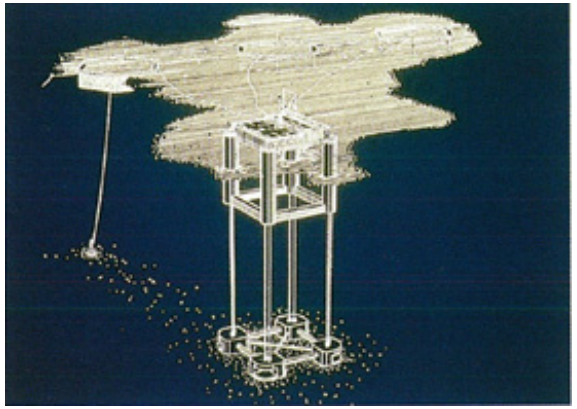
SADCO・HP

Kim et al. (2014)



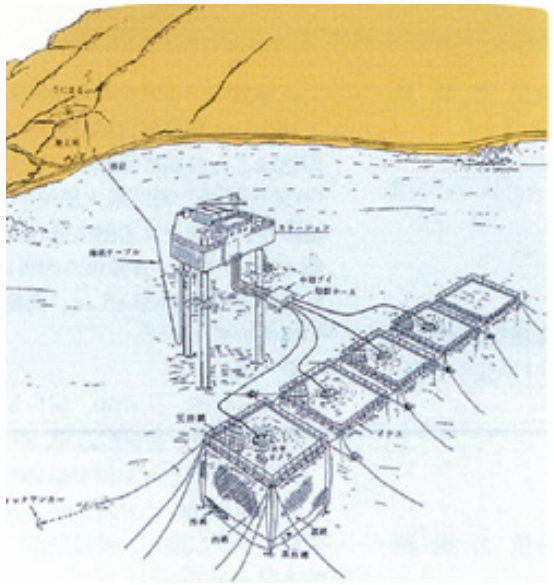


Offshore Aquaculture-Japan



TLP type platform
(Ehime)

Jack-up type platform
(Kumamoto, Hokkaido)



Bridgestone rubber hose cages

Source: Marino Forum 21

Aqua-system

Source: SOBUNSHA Co., Ltd.

Offshore Aquaculture-USA

National Oceanic and Atmospheric Administration (NOAA)
The consumption of seafood: once to twice a week

Visit NOAA in 2007

Significance of offshore aquaculture

- Self-pollution problems in coastal area
- Landscape problems in coastal area
- Licensing problems in coastal area

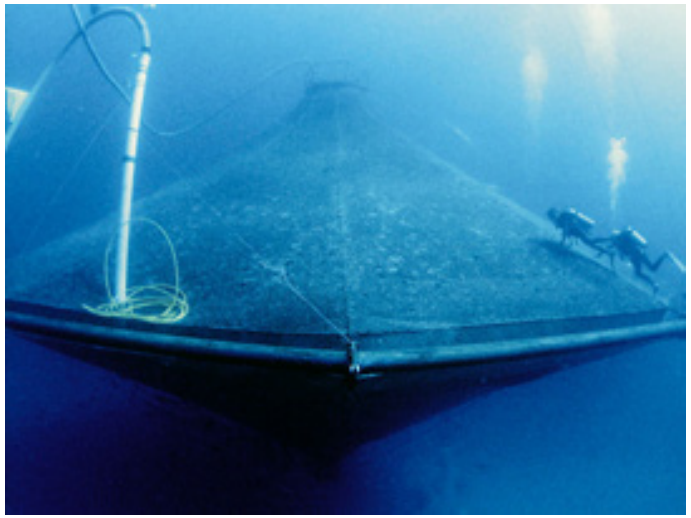
The National Offshore Aquaculture Act of 2007

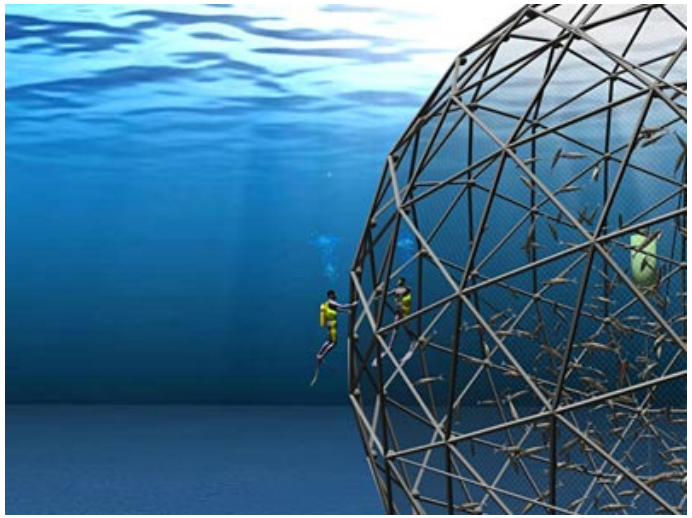
Permission of offshore aquaculture in 3 – 200 miles from the coast

Congress needs to move forward with my administration's plan to build a well managed system of offshore aquaculture… And when we get this right, these farmed fish can provide a healthy source of food and reduce pressure on the ocean ecosystems. (President Bush)

Large submergible cage

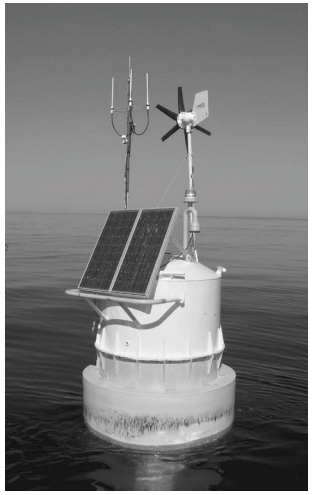
Source: Private communication

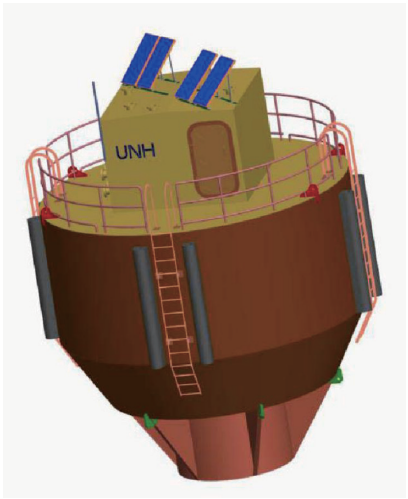


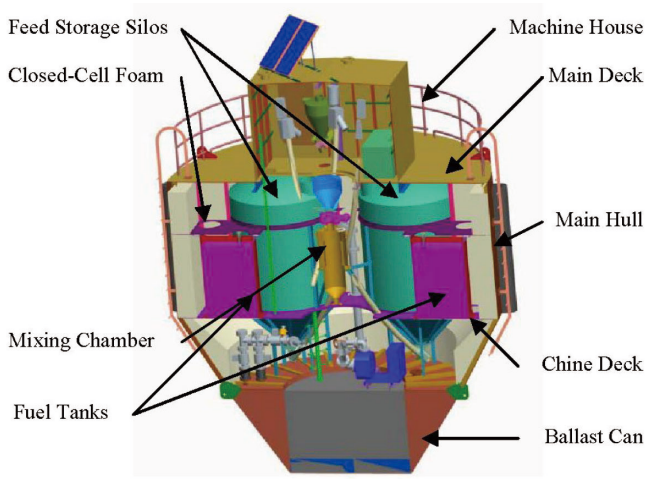


Feeding buoy

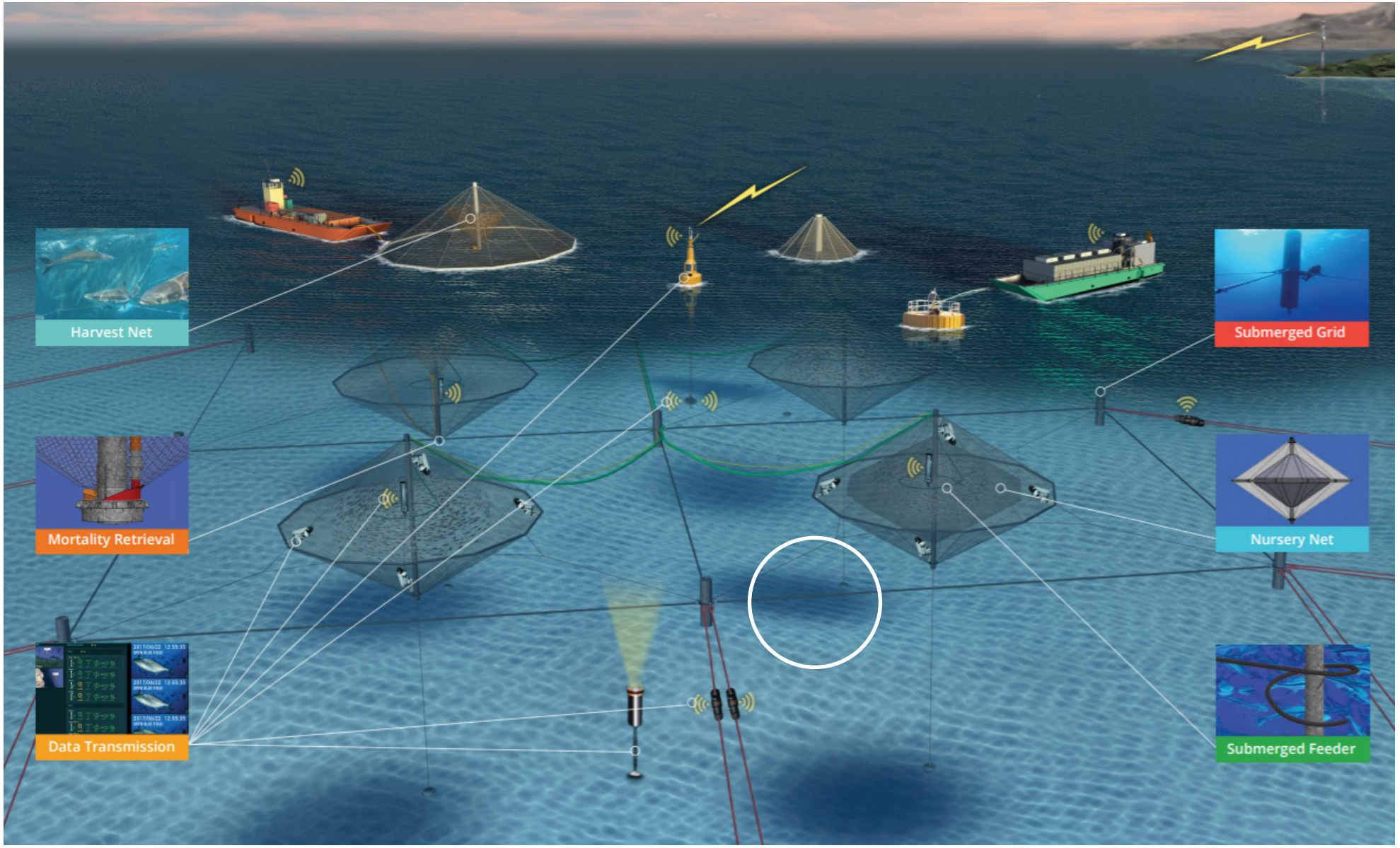
Source: Fullerton et al. (2004), Turmelle et al. (2006)







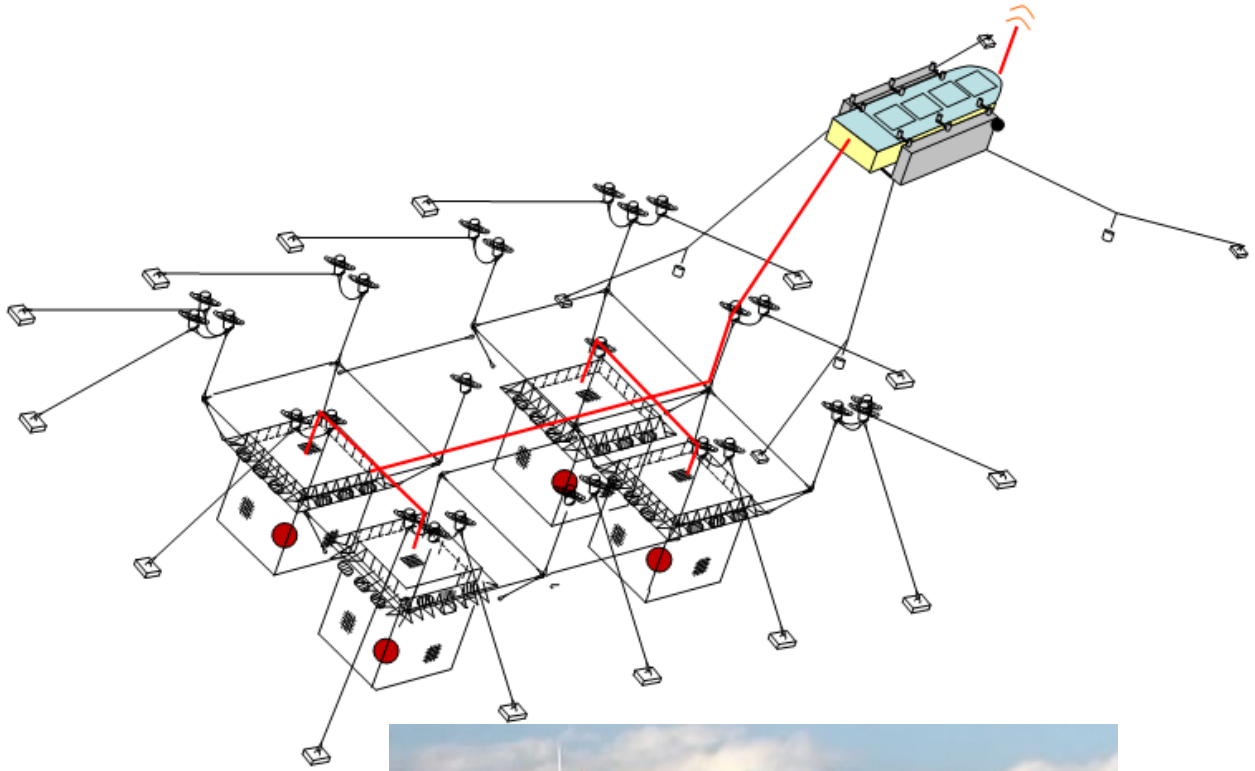
Offshore Aquaculture-USA



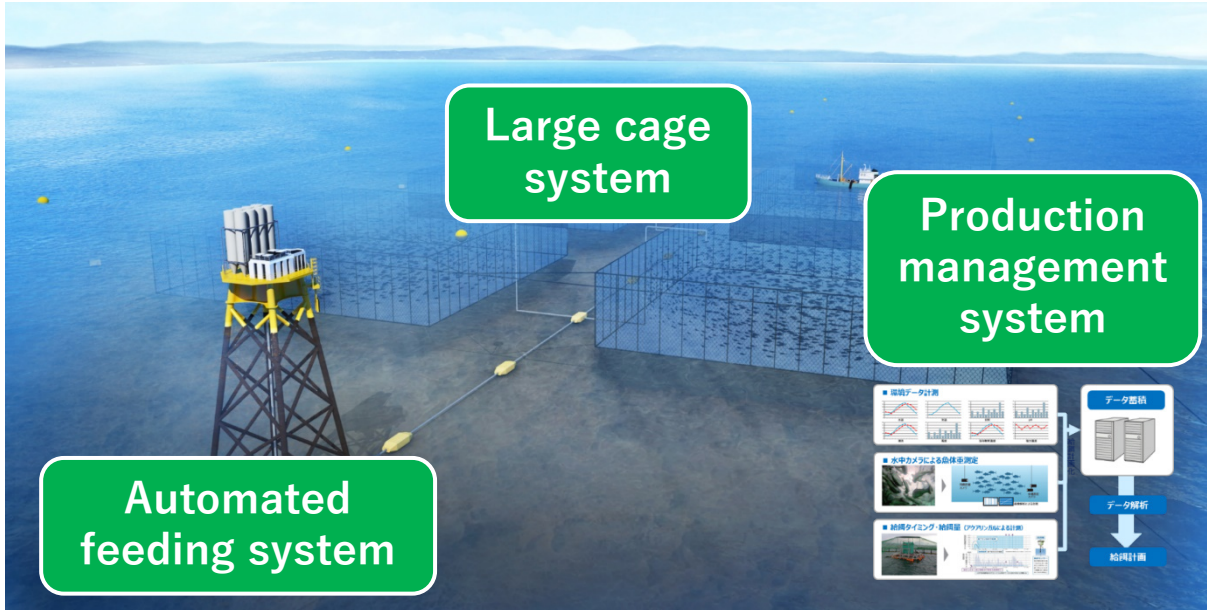
Feeding platform and multiple cages

Source: InnovaSea

Offshore Platform-Japan



Feeding barge that can withstand the significant wave heights of less than 4m



Source: NIPPON STEEL ENGINEERING CO., LTD., Yumigahama Suisan Kaisha Ltd.

Norway's EXPOSED

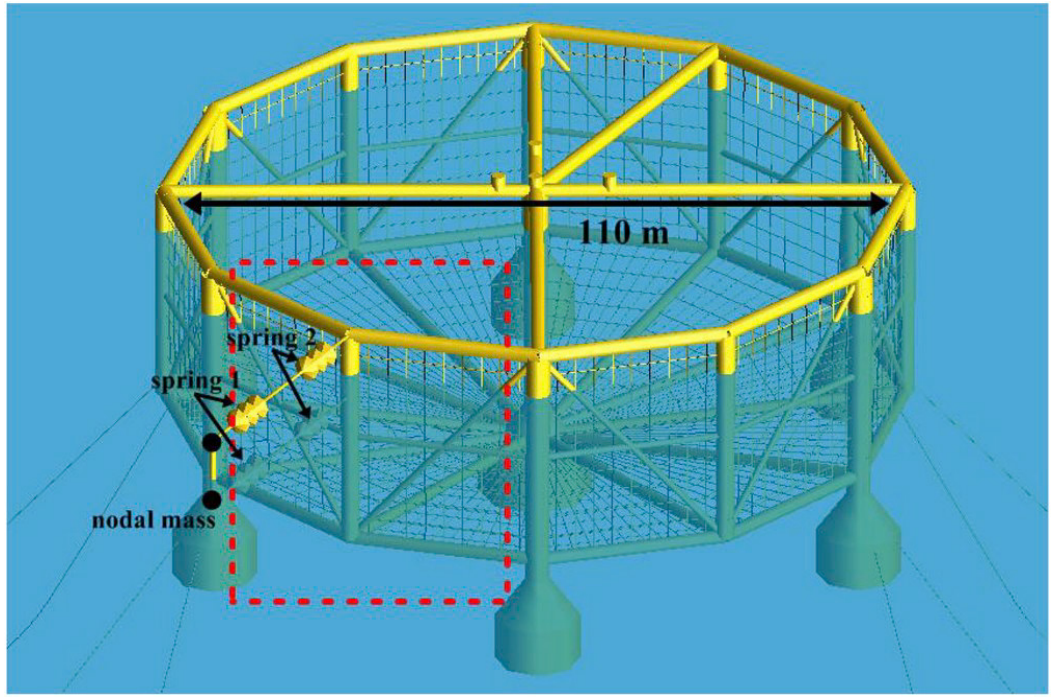
Significant parts of the Norwegian coast is today unavailable to industrial fish farming due to remoteness and exposure to harsh wind, wave, current and ice conditions. Regular as well as infrequent operations are challenging.

The Exposed Aquaculture Operations Centre (EXPOSED) will draw upon Norway's strong position in the aquaculture, maritime and offshore sectors to enable safe and sustainable seafood production in exposed coastal and ocean areas.

Norway's Aquaculture

Ocean Farm 1 (2018-)

- Height: 68m, Diameter: 110m
- Volume: 250,000 m^3
- Expected Production: 10,000 tons



Ocean Farm 2 (2024?)

Diameter: 160m

Volume: 760,000 m^3

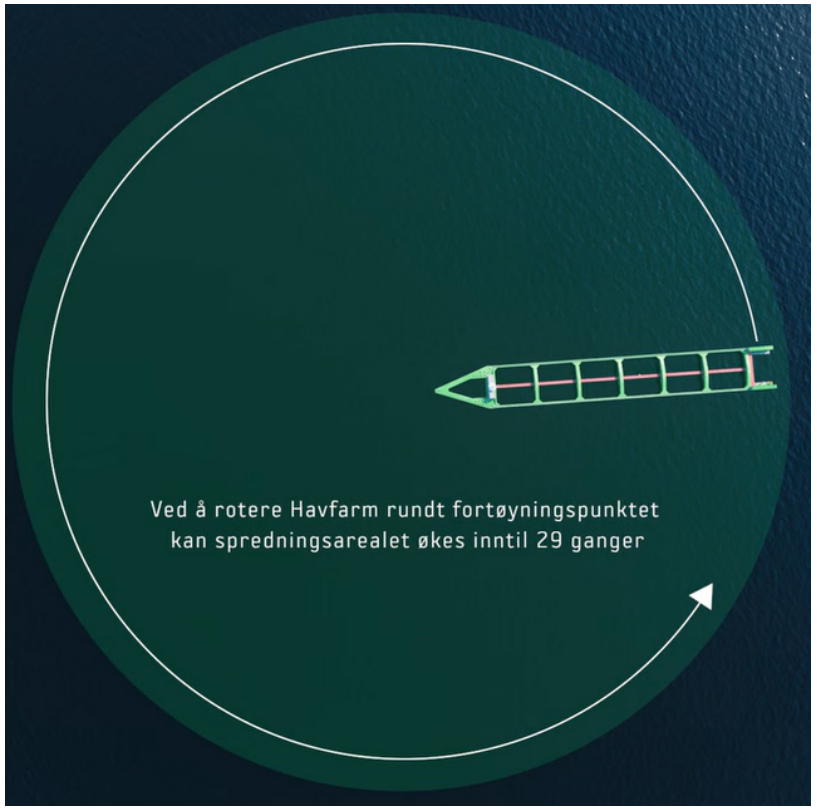
Expected Production: 23,000 tons

Source: Yu et al. (2019)

Norway's Aquaculture

Havfarm 1

- Length: 385m, Width: 60m
- Structure: 6 area (2 million ind.)
- Production: 10,000 tons



Turret mooring

Source: https://www.youtube.com/watch?v=6Tvpny5WxyM

Source: https://www.projectcargojournal.com/shipping/2020/05/11/boka-vanguard-is-shipping-a-massive-fish-farm-to-norway/

China's Aquaculture

- Yellow sea, 240km offshore
- Diameter: 60m, Depth: 38m, 300,000 ind., 1,500 tons/year
- Deep blue 2 may have three times of capacity?

Source: http://j.people.com.cn/n3/2018/0507/c95952-9457166.html

- Zuhai, 30km offshore
- Length: 91.3m, Depth: 10.3m
- Volume: 30,000 m^3
- From September 2018 (yellow croaker)

Source: Huang et al. (2020)

- Diameter: 139m, Height: 48m
- Volume: 150,000 m^3
- From April 2020

Source: https://www.undercurrentnews.com/2020/06/22/de-maas-anticipates-at-least-two-deals-for-offshore-pens-in-2020-installs-first-in-china/

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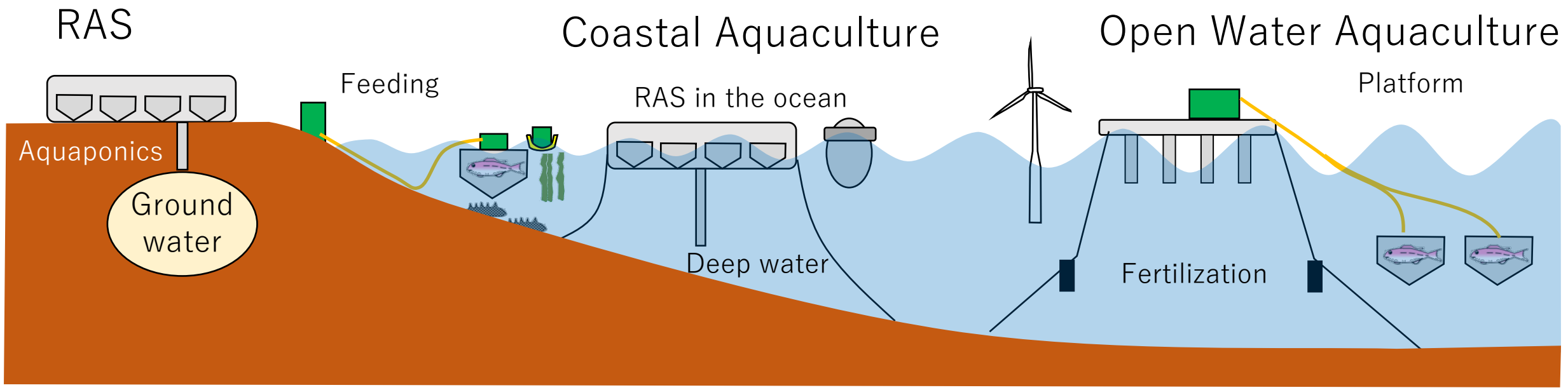
Future Scope



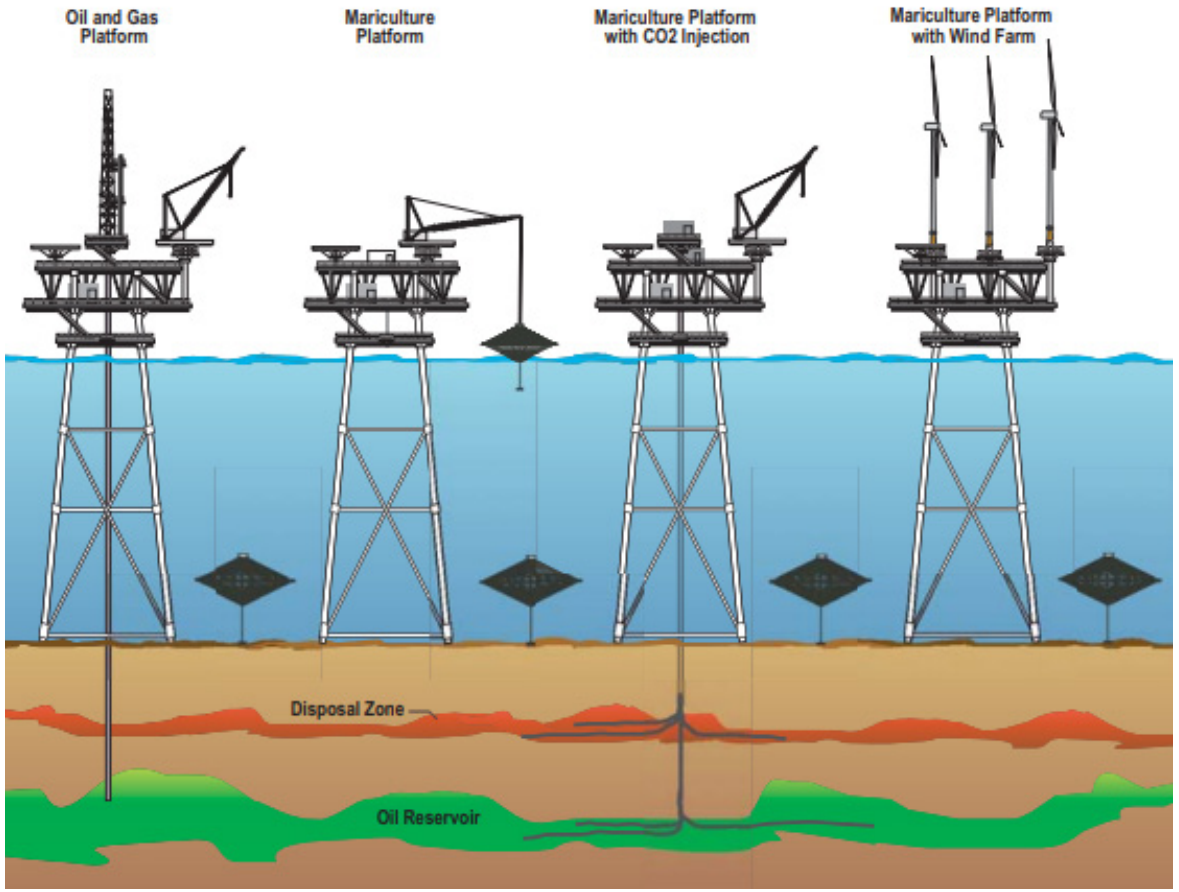
- A wide variety of aquaculture systems has been proposed.
- Coastal aquaculture system has been sophisticated, but environmental issues have become serious.
- Recirculating aquaculture system can control the environment, but additional facilities for wastewater management and temperature control are required.
- Aquaponics and Integrated Multi-Trophic Aquaculture may have the environment reserved.
- Open water aquaculture system is proposed recently. A huge aquaculture system and a combined system of a feeder and multiple cages have been proposed. A robust structure against severe natural condition is required.

Wind Farm and Cages

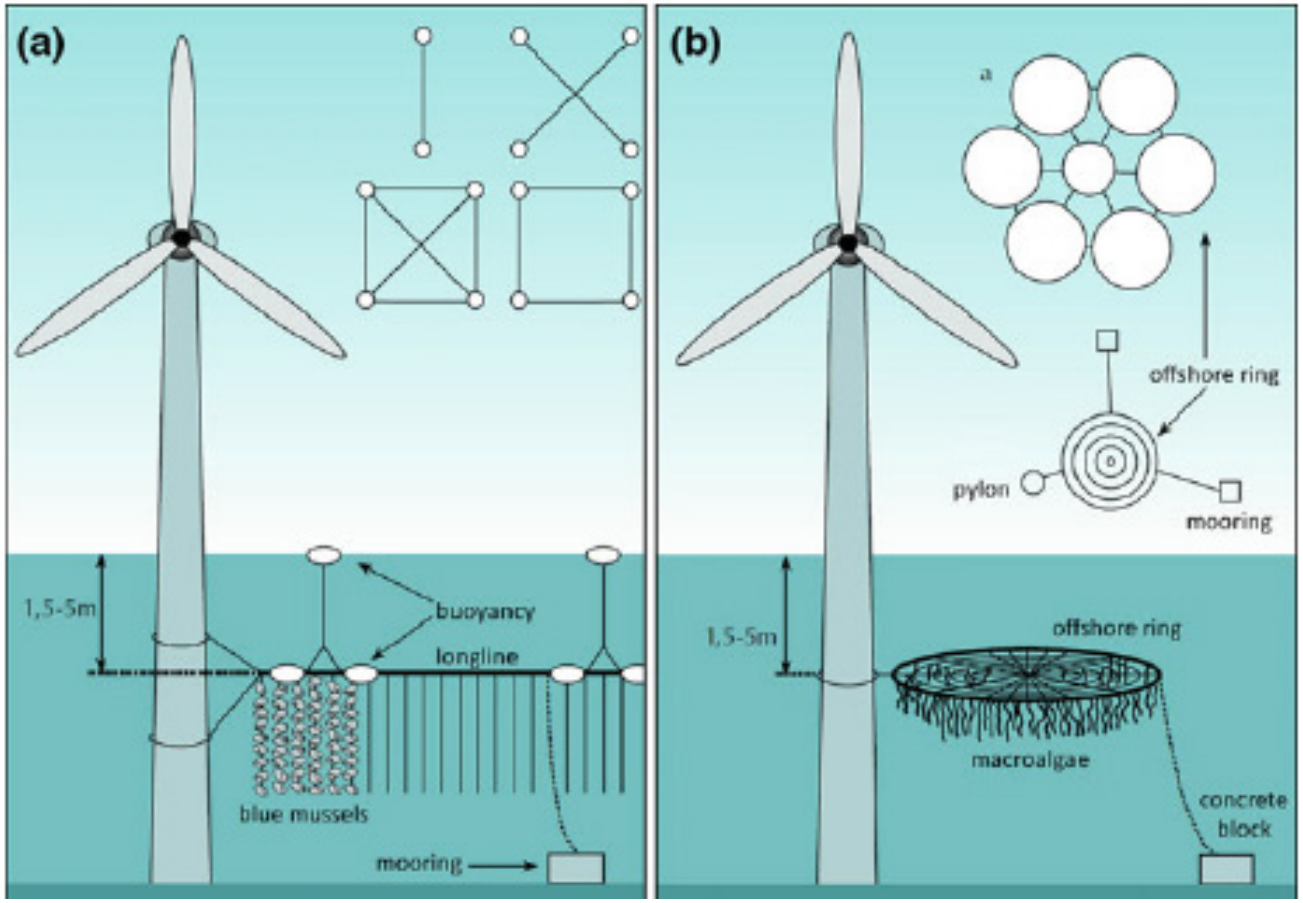
Wind turbine (5MW)		Salmon cage (25m) x 2	
Rated capacity	5MW	Volume	15,000 m^3
Capacity factor	30%	Max. stock rate	3%
Power generation	13140 MWh	Production	450 tones
Unit price	$0.2/kWh	Unit price	$6/kg
Sales	$2.6M	Sales	$2.7M

- Wind turbine provides feeding platforms for cages.
- Share operation and maintenance.
- Operation and maintenance of aquaculture in the harsh condition will be difficult.

Multi-Use Concepts



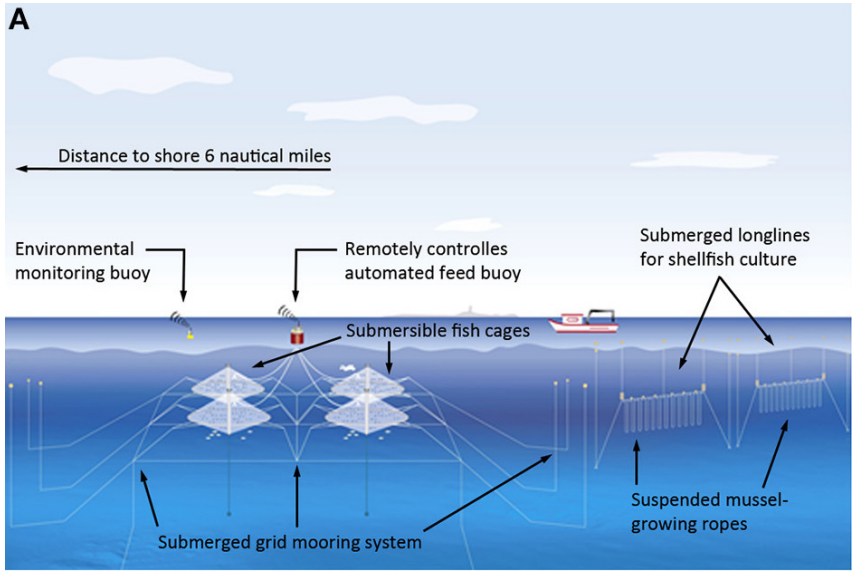
(Mariculture and other uses for offshore oil and gas platforms)



(Aquaculture perspective of multi-use sites in the open ocean)

Mermaid Project (2011-2015):
Innovative Multi-purpose offshore platforms: planning, design & operation

Offshore IMTA



Cage + Longline

Seaweed + Mussel + Wind farm

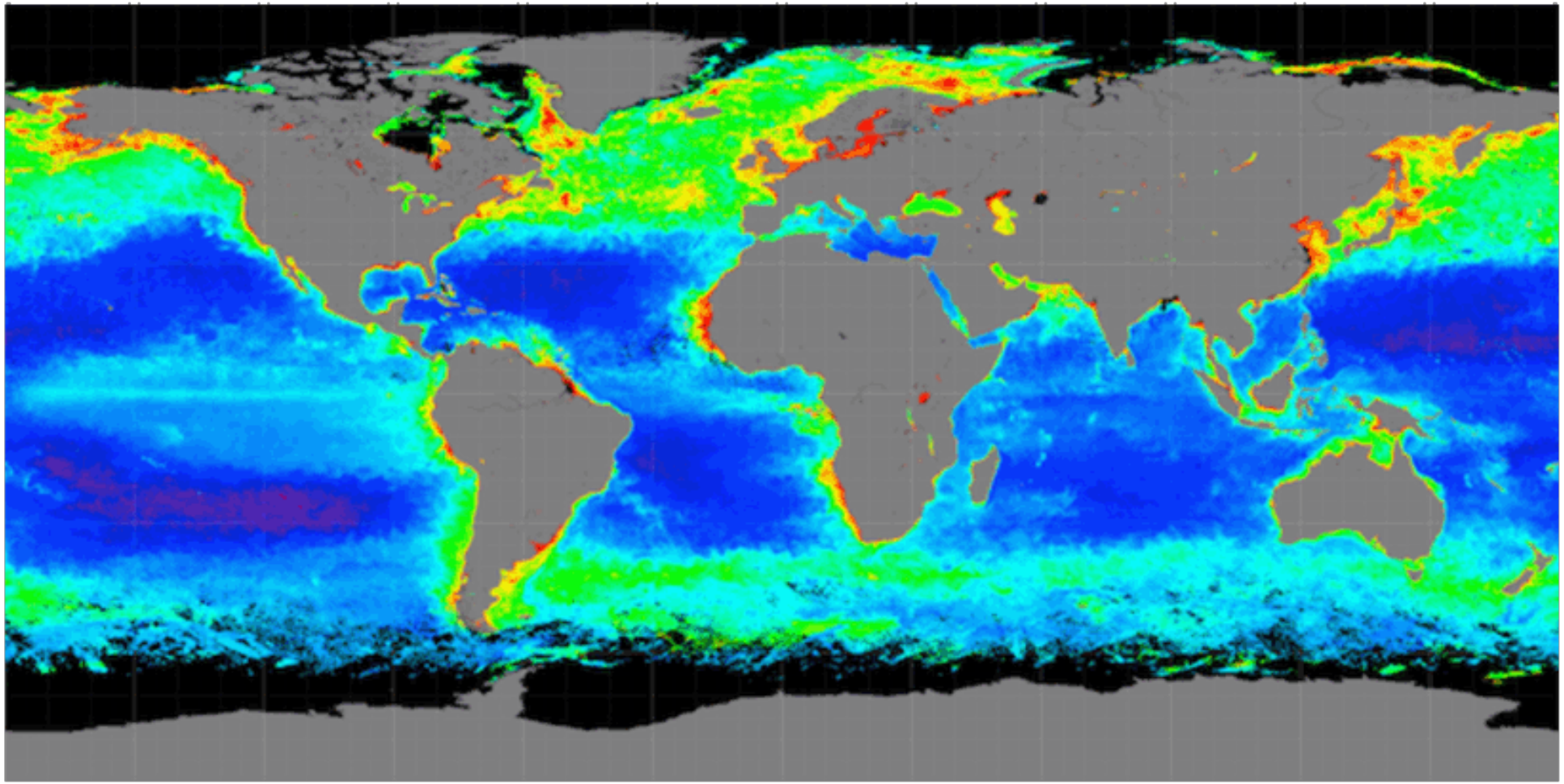
Trout + Mussel + Kelp

In the offshore site, waste spreads quickly and has small local impacts on the environment. On the other hand, the waste may eventually contribute to the increase in primary production. The waste can be recycled by IMTA.

Buck et al. (2018):
State of the Art and Challenges for Offshore Integrated Multi-Trophic Aquaculture (IMTA)

Feed Production

Feed production is based on primary production



Light
Temperature
Nutrients
(P, N, etc.)

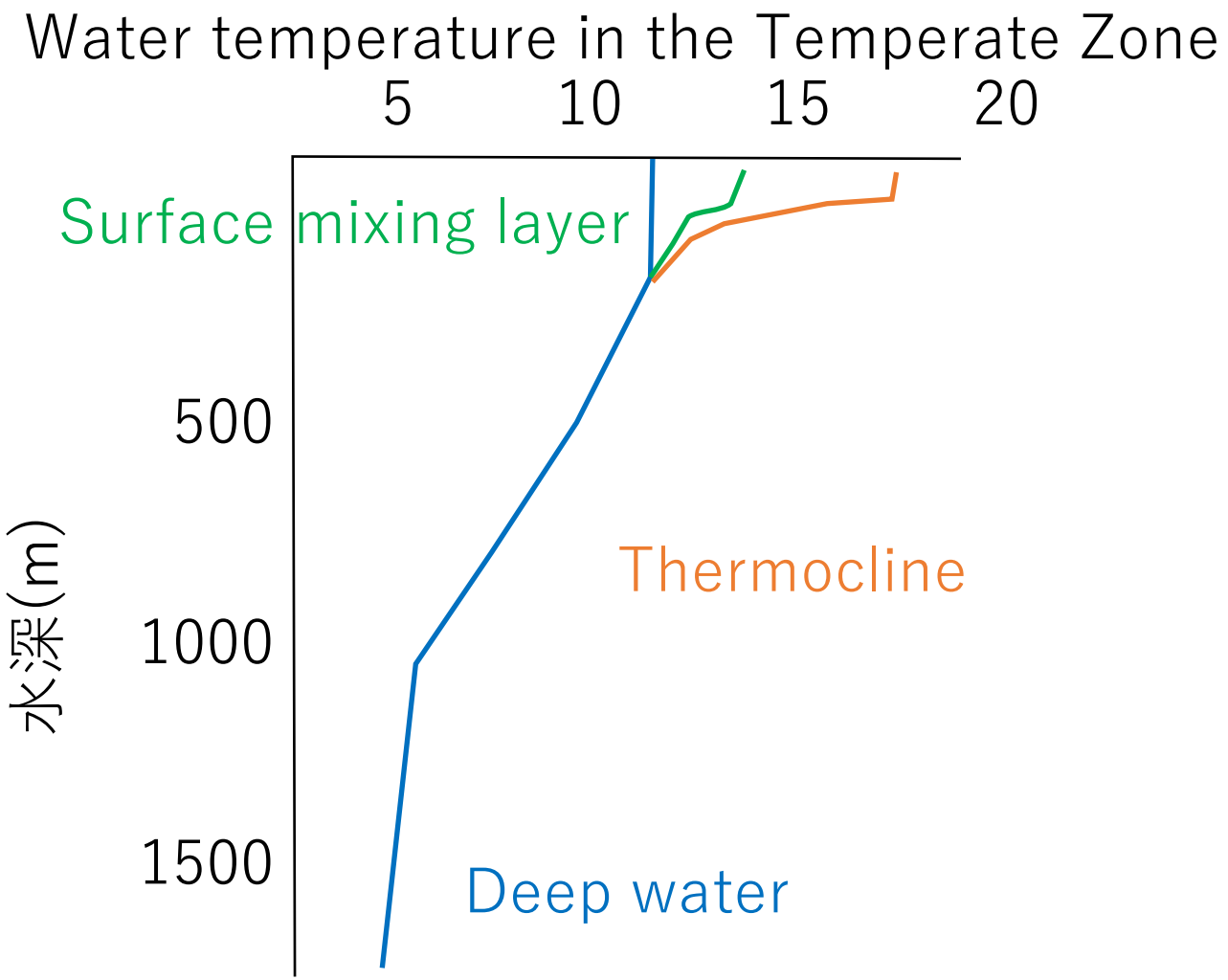
⇩

Primary Production

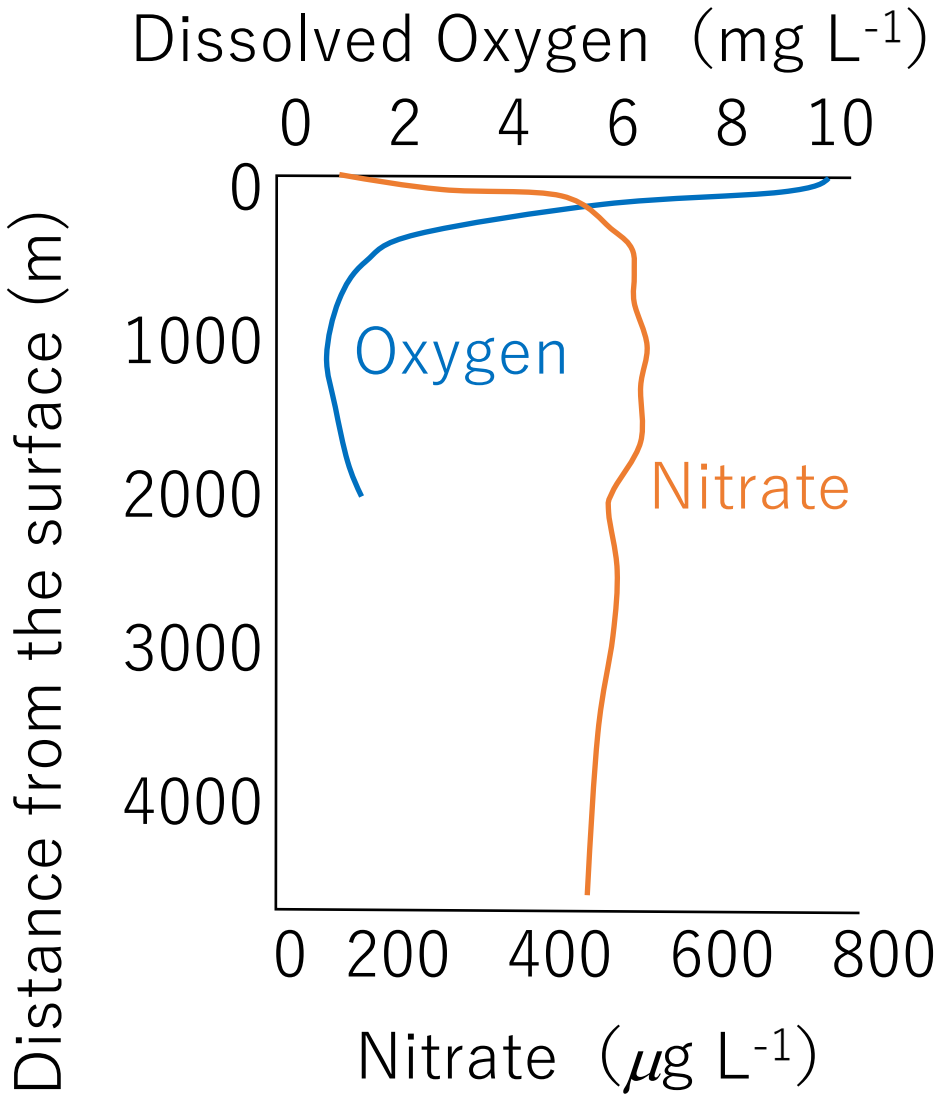
Nutrients are supplied from land and deep water.

Source: Nasa Ocean Color Chlorophyll *a*

Feed Production



Source: Biological oceanography (Lalli & Parsons) revised

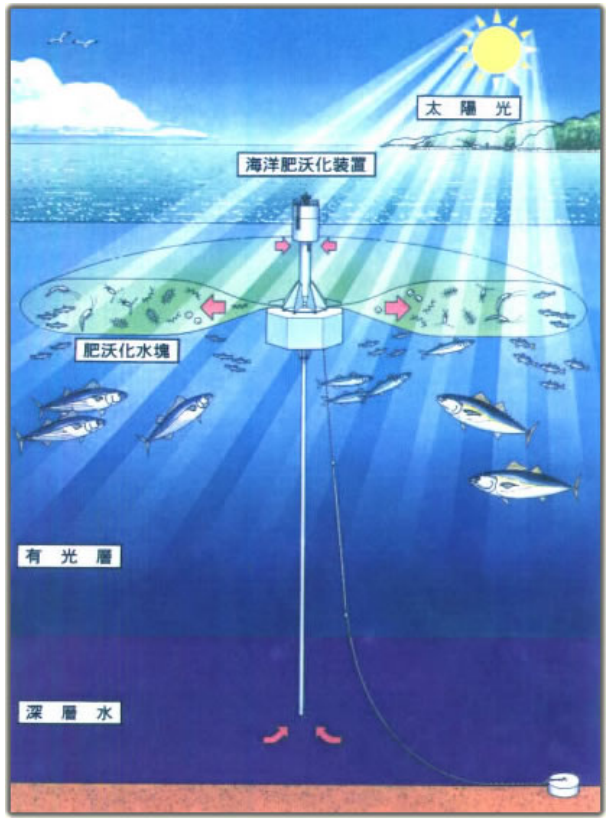


Source: Martin et al. (1989) revised

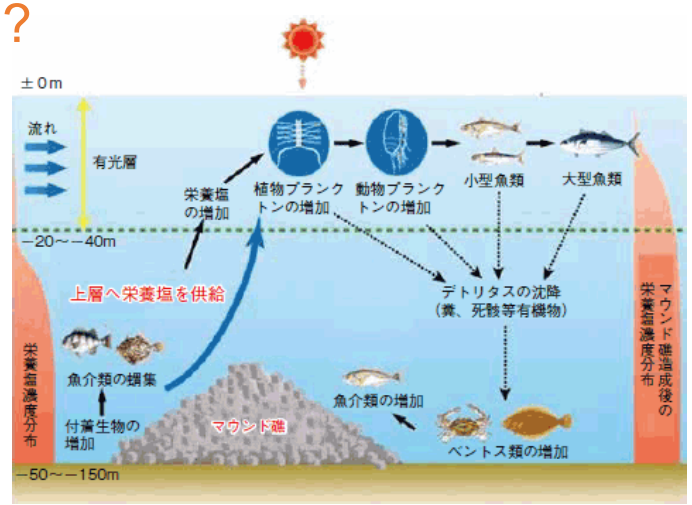
Feed Production

How can we provide enough feed for aquaculture?
1. Vegetable protein, 2. Insect, 3. Enhancing primary production, …

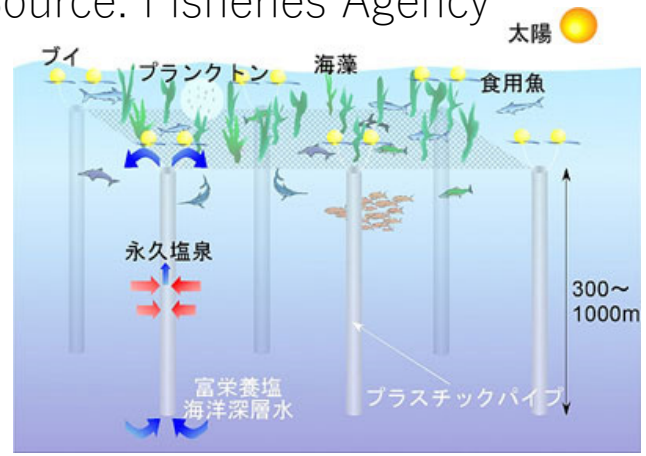
ω-3?

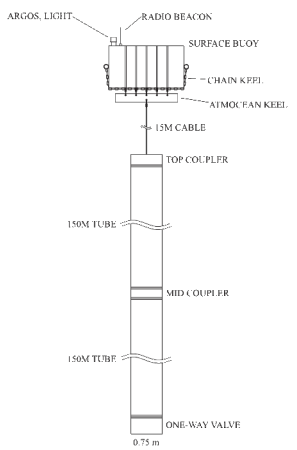


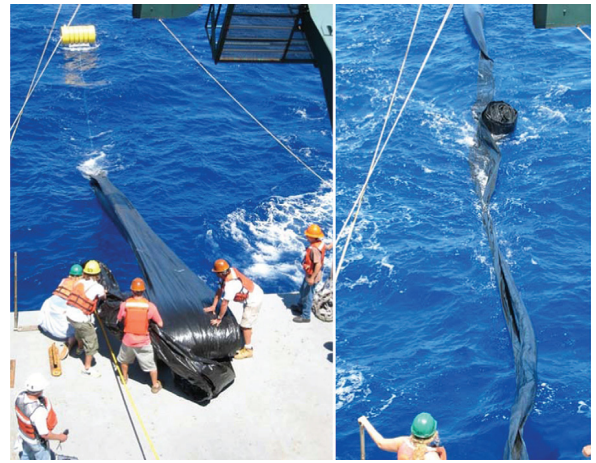
Source: Ouchi Ocean Consultant



Source: Fisheries Agency

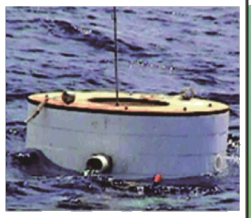




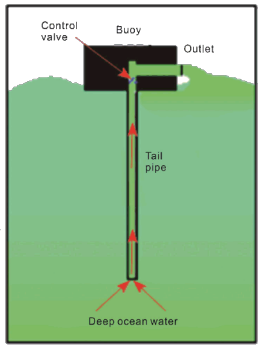


Source: White et al. (2010)

Wave pump



Source: Maruyama et al. (2004)



Source: Pan et al. (2016)

Thank you for your attention!

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