Shrimp Supply Chain at a Crossroads?: Quality, Disease Externalities, and Market Structure

Aya Suzuki (U Tokyo)

Asian Economic Development Conference 2023

July 15, 2023 @ Fukutake Hall, U Tokyo

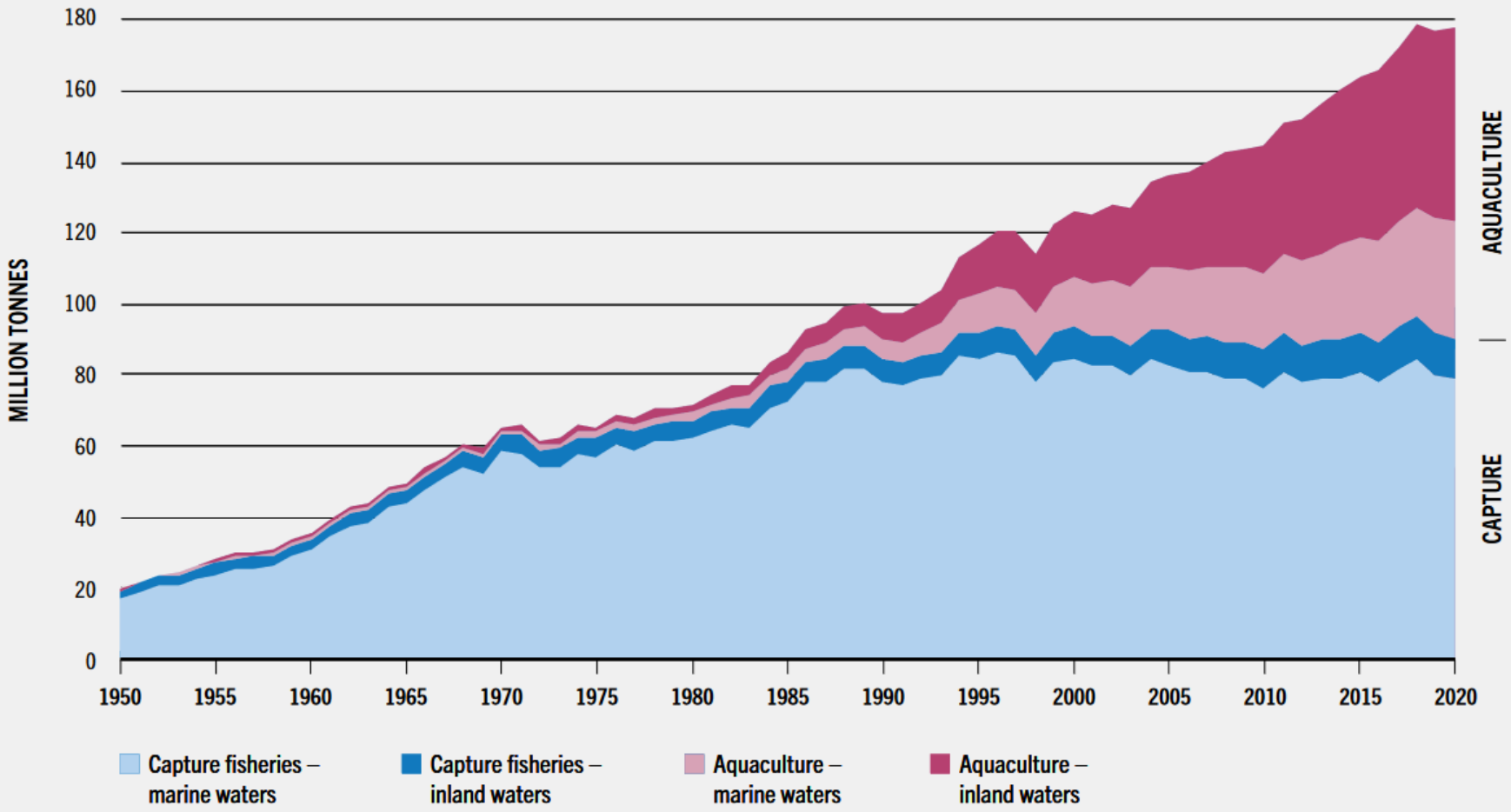
Key Message

- Rising aquaculture sector, largely Asian phenomenon
- Shrimp production dominated by smallholder producers in developing countries.
- Beneficial for developing countries:
  - Income generating source
  - Lower prices as supply enlarges
  - Higher nutrition (protein)
- My argument today: this window of opportunity for large global demand may close quickly for developing country producers unless quality is guaranteed with clear traceability.
- I want to focus on quality, disease and externality issues in aquaculture.

Aquaculture Trend & Shrimp Sector

Rise in Aquaculture largely Asian phenomenon

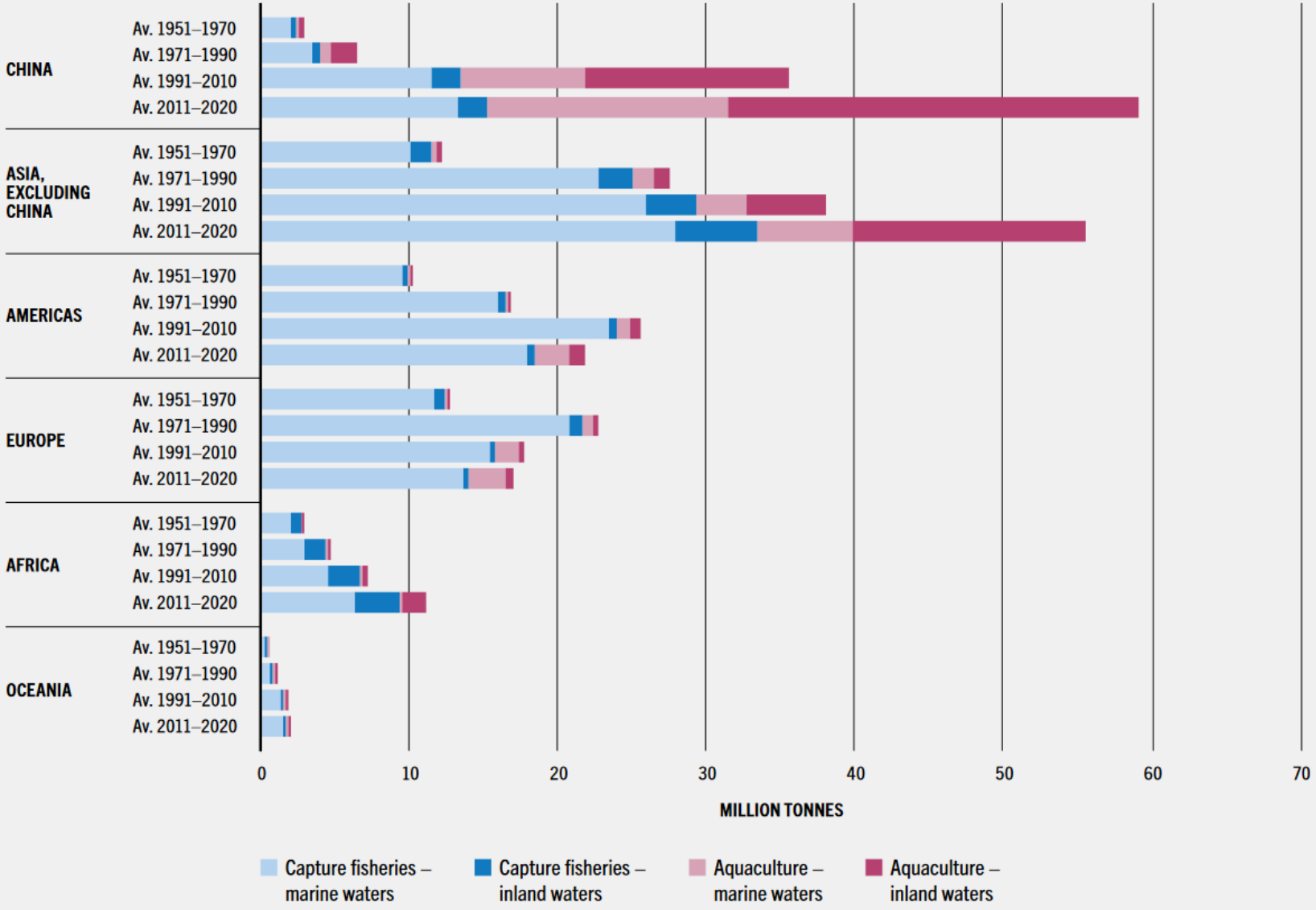
FIGURE 1 WORLD CAPTURE FISHERIES AND AQUACULTURE PRODUCTION



NOTES: Excluding aquatic mammals, crocodiles, alligators, caimans and algae. Data expressed in live weight equivalent.
SOURCE: FAO.

FAO2022

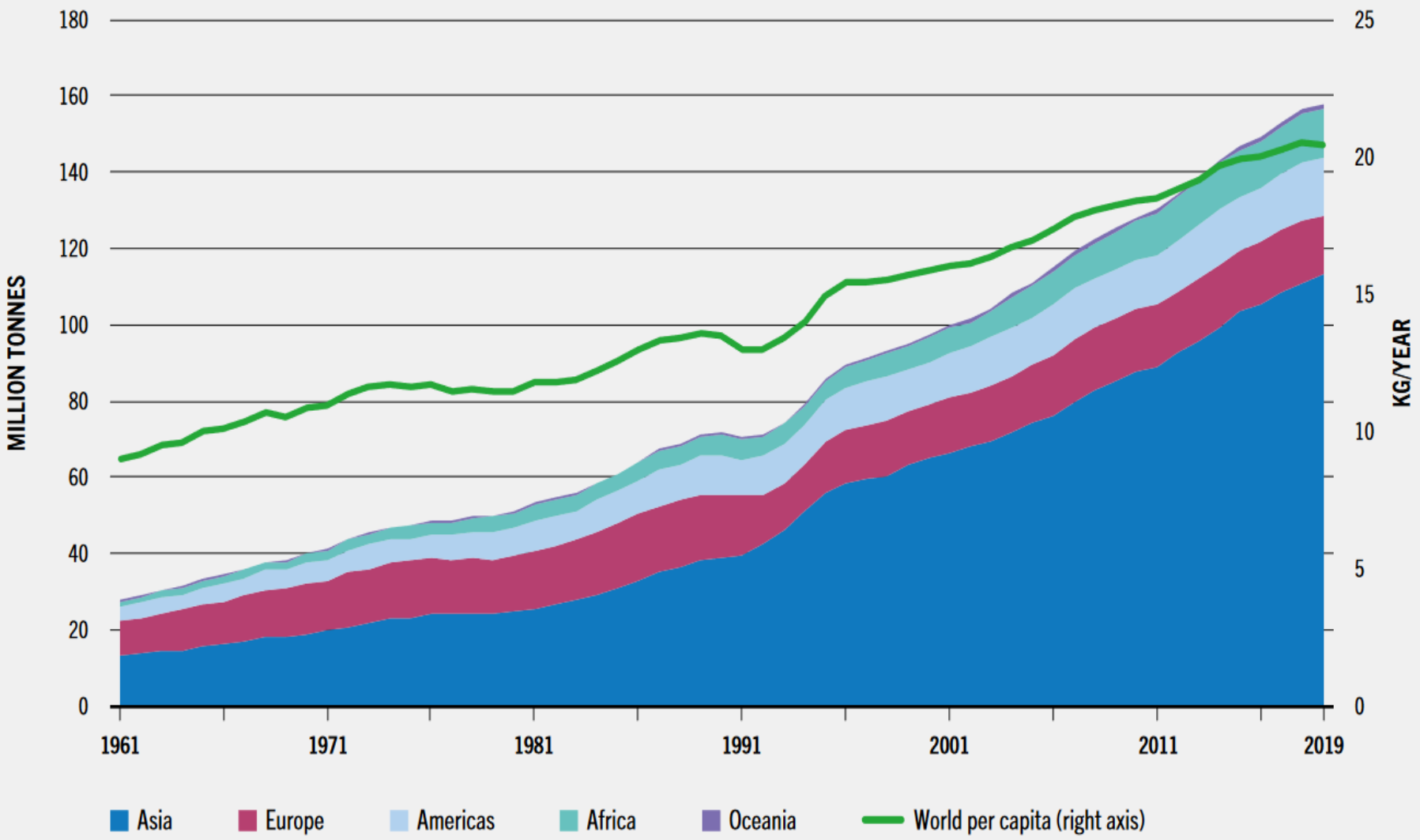
FIGURE 5 REGIONAL CONTRIBUTION TO WORLD CAPTURE FISHERIES AND AQUACULTURE PRODUCTION



NOTES: Excluding aquatic mammals, crocodiles, alligators and caimans and algae. Data expressed in live weight equivalent.
SOURCE: FAO.

FAO2022

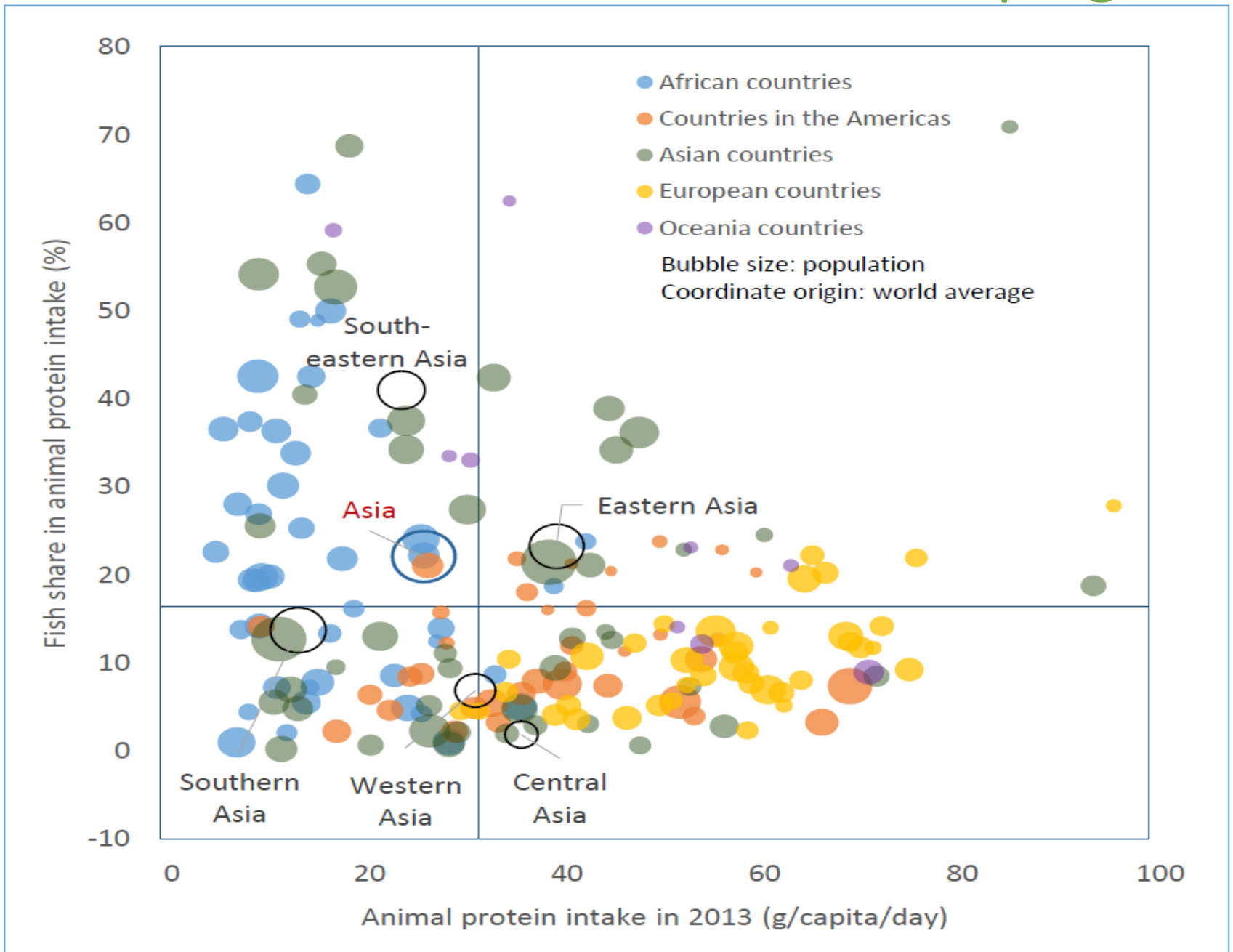
FIGURE 39 AQUATIC FOOD CONSUMPTION BY CONTINENT, 1961–2019



NOTE: Data in million tonnes expressed in live weight equivalent.
SOURCE: FAO.

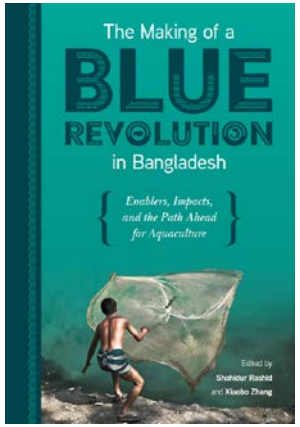
FAO2022

Important source of nutrition for developing countries



FAO (2018)

Benefits for the smallholders



- **Lower fish prices**: 9.5% growth of inland aquaculture reduced price of fish from aquaculture by 12% (Murshed-e-Jahan et al. 2010, Rashid & Zhang 2019)
- **Pro-poor**: Change in fish consumption due to growth of inland aquaculture: 152.1% by the extreme poor, 114% by moderate poor, 88.2% by non-poor (Toufigue & Belton 2014)
- **Improvement in protein intake**: Annual fish consumption p.c. grew from 7.7kg (1980) > 13kg (2000) > 18kg (2010) (Rashid & Zhang 2019)
- **Achieved by intensification** of fish farming: Pond area growth 31% while prod volume grew by 117.4%
- Aquaculture growth contributed to **2.11% of income increase** & **poverty reduction of 1.7%** (10% of the reduction in the period) (Rashid & Zhang 2019)
- Thus, aquaculture in general pro-poor (income generating source & nutrition) and global demand keep increasing.

Shrimp Sector:

- Catch dominant in the 1970s, Trawling fishing banned in 1980s
- Extensive farming traditionally practiced in many parts of Asia
- 1983: Artificial spawning method innovation in Taiwan supported by Japanese researchers (Murai 1988)
- ADB, private sectors (CP, Mitsubishi, etc.) played important roles. Intensive farming spread first to SE Asia, then to the rest of the world.
- Shrimp from capture & farming mostly substitutes (Asche et al. 2012), except maybe for organic extensive shrimp

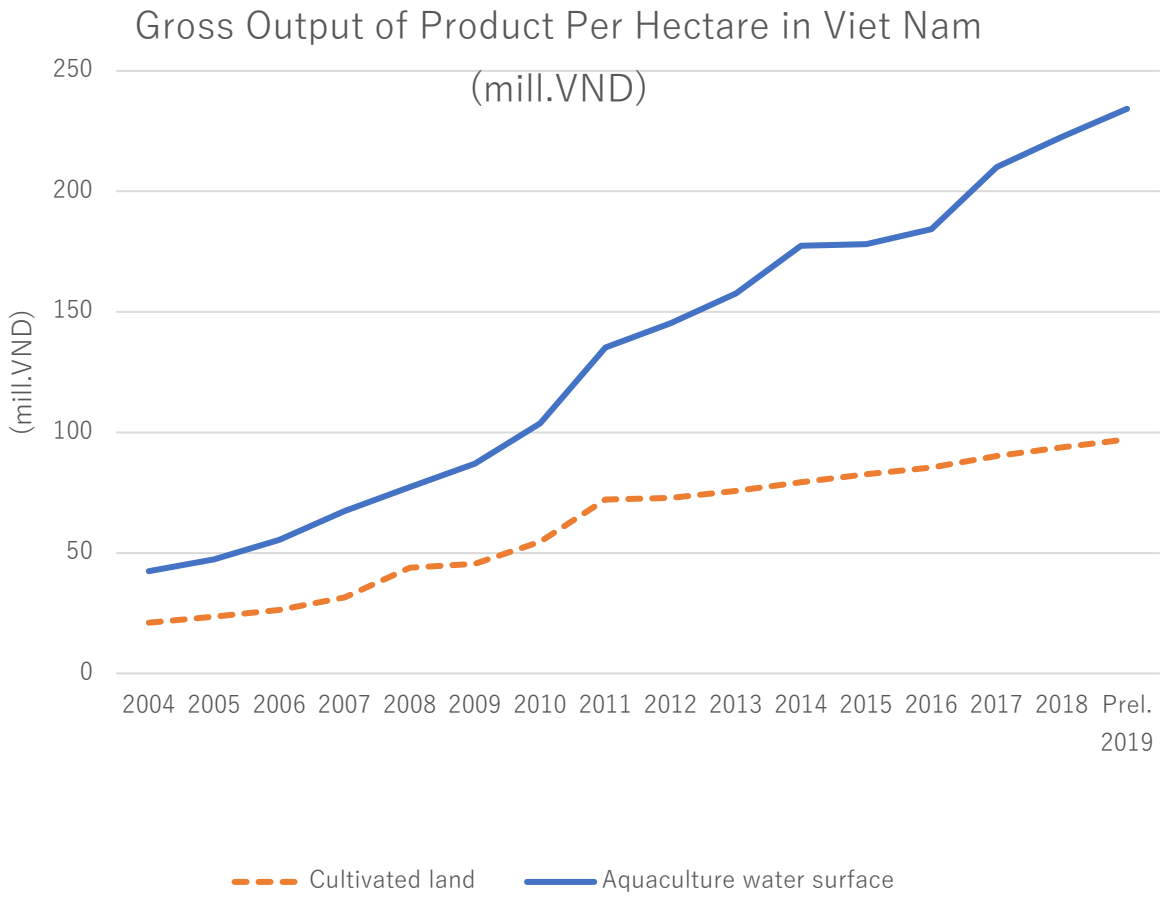
Extensive

Intensive

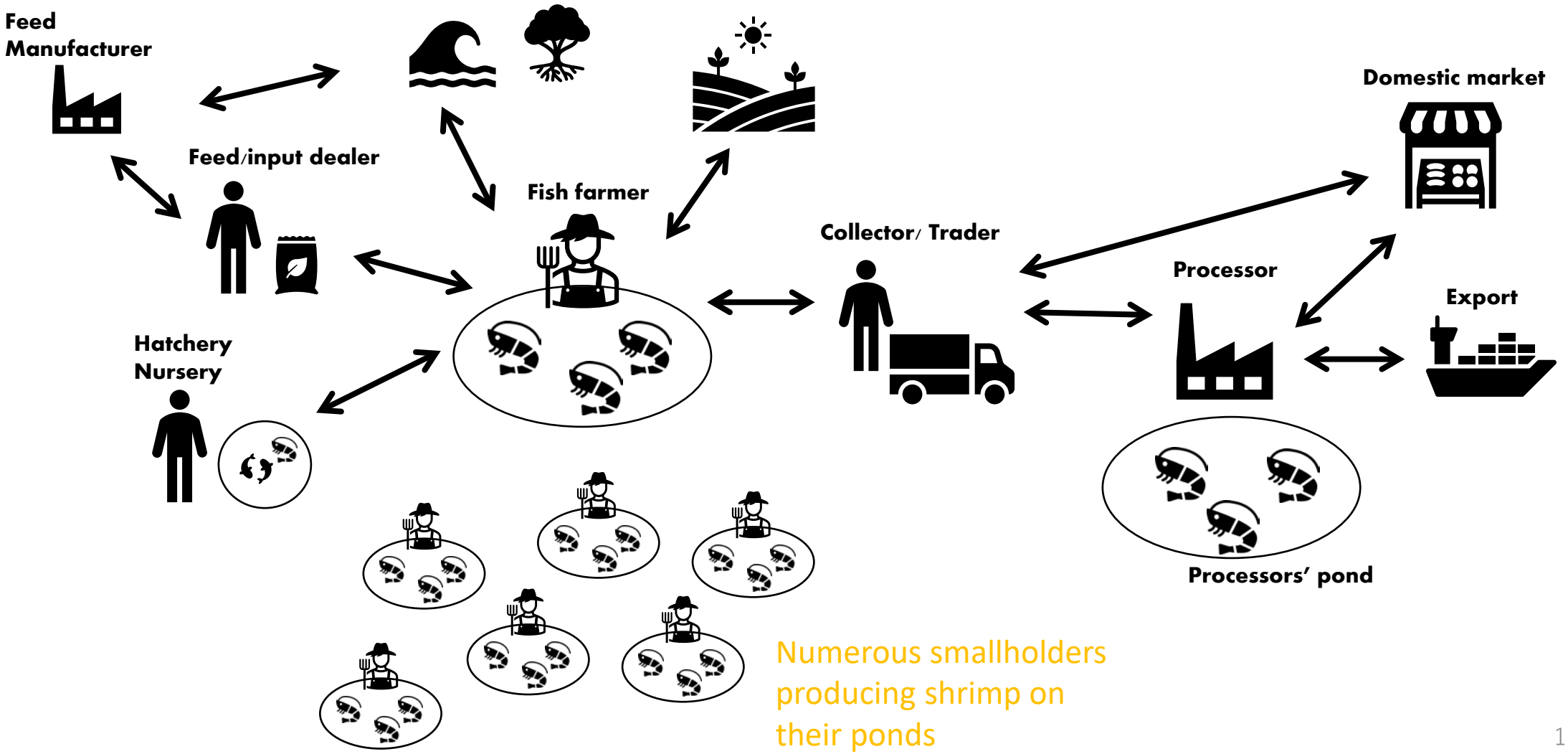
Super intensive

Smallholder as dominant producers

- Shrimp production dominated by numerous smallholders in Asia (Hall 2004, Hernandez et al. 2018)
  - Less than 1ha on average (Hall 2004)
  - Rapid conversion to aquacultural pond in Vietnam
  - “Shrimp 10 times more profitable than rice.”
- Less vertically controlled vs. pangasius sector, where contract farming is offered, in Vietnam (Trifkovic 2014)



Typical Shrimp Supply Chain



Numerous smallholders producing shrimp on their ponds

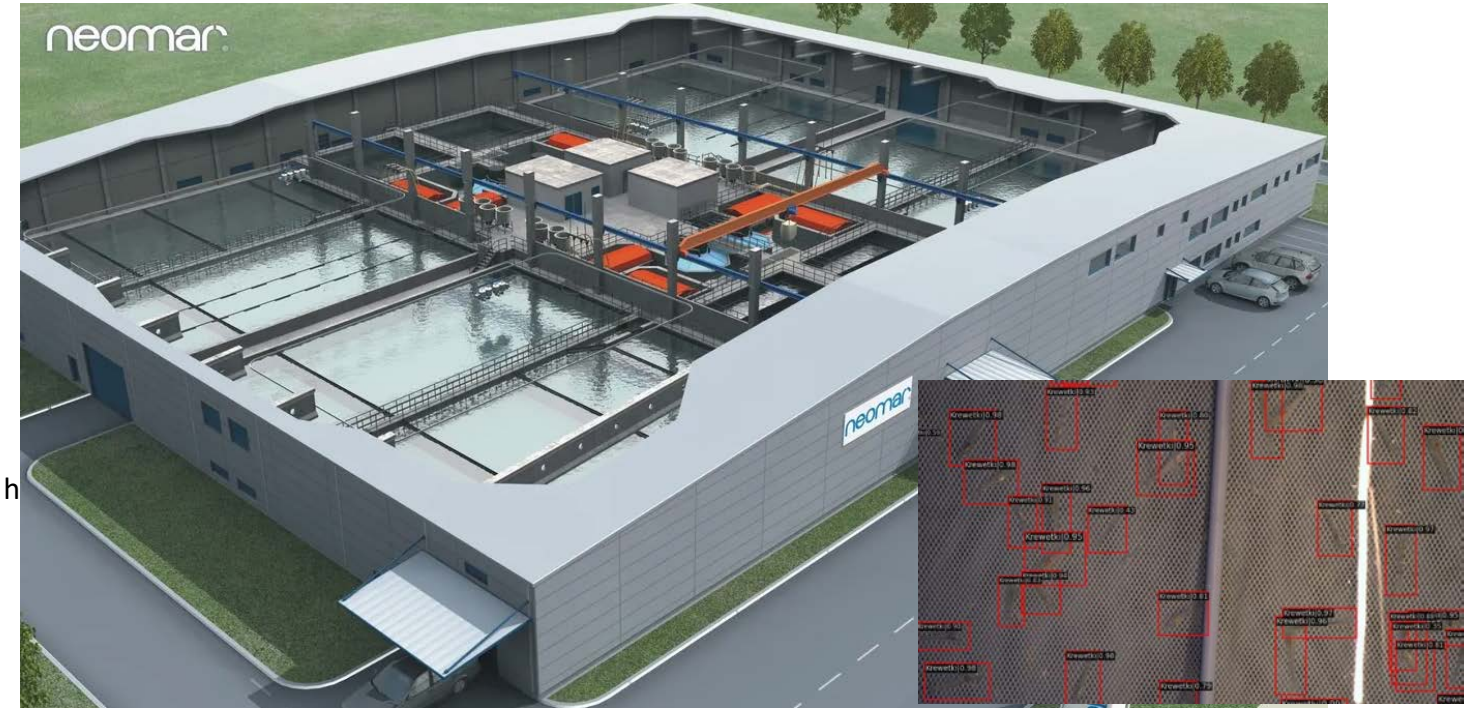
...but can they continue?

- In contrast to highly concentrated & vertically integrated salmon industry in Norway (Fischer et al. 2017)
  - As farming & processing technologies became more capital intensive, AC curve became steeper, which led more vertical integration of these stages (Kvaloy and Tveteras 2008).
- Many high-value agriculture sector tend to be vertically controlled as the industry matures and the quality standard required by market rises.
  - Food and agricultural commodity market (Swinnen & Maertens 2007), Pineapple market (Fold and Gough 2008), Fishmeal market (Hansman et al. 2020)

“Next Generation” Indoor Shrimp

https://ecoshrimp-sys.com/

https://thefishsite.com/articles/germanys-clearwater-shrimp-ras-champion-oceanloop



h

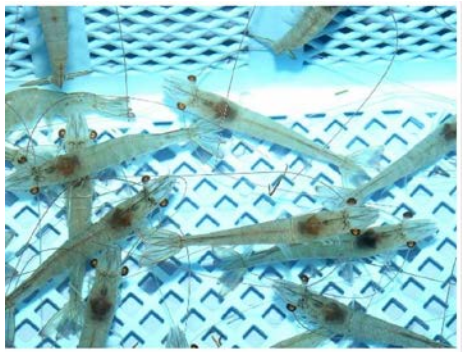
After more than 11 years of trial & error and R&D, we have succeeded to create an ideal and natural environment for our shrimp in an **innovative, stable and sustainable aquaculture system, one of the first of its kind in the World.**

The application of our cutting-edge Microbial Technology with artificial saltwater, enables production of clean and **fresh shrimp indoors and at any location, additives free.** https://norayseafood.es/en/technology/

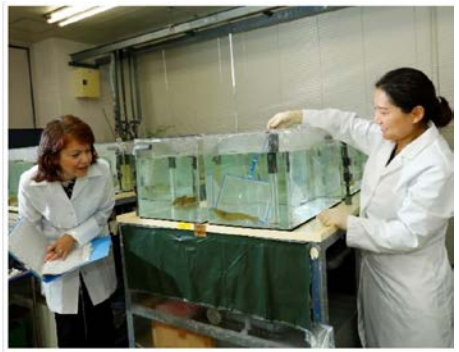
Kansai Electric Power Co.

https://www.nikkei.com/article/DGXZQOUF041GR0U2A700C2000000/

JIRCAS



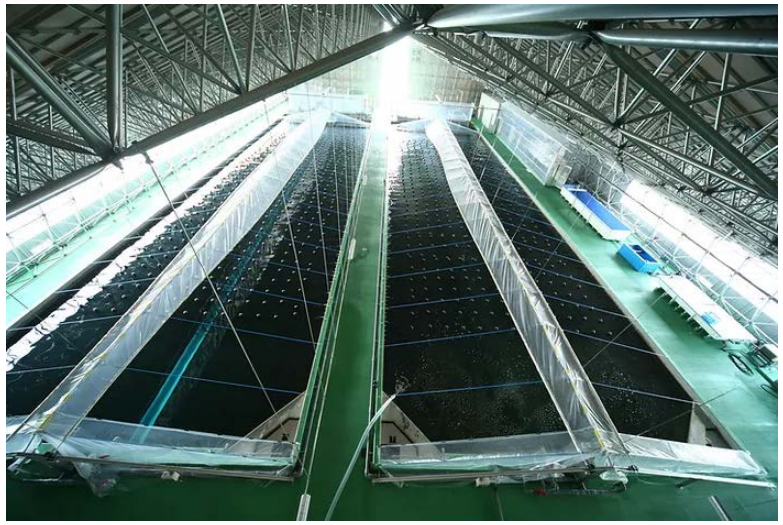
閉鎖循環式屋内型エビ生産システム（ISPS）で生産しているバナメイエビ（新潟県妙高市）



ShrimpTech JIRCAS

https://www.jircas.go.jp/ja/release/2021/press202124

IMT



https://www.imteng.co.jp/

JR East

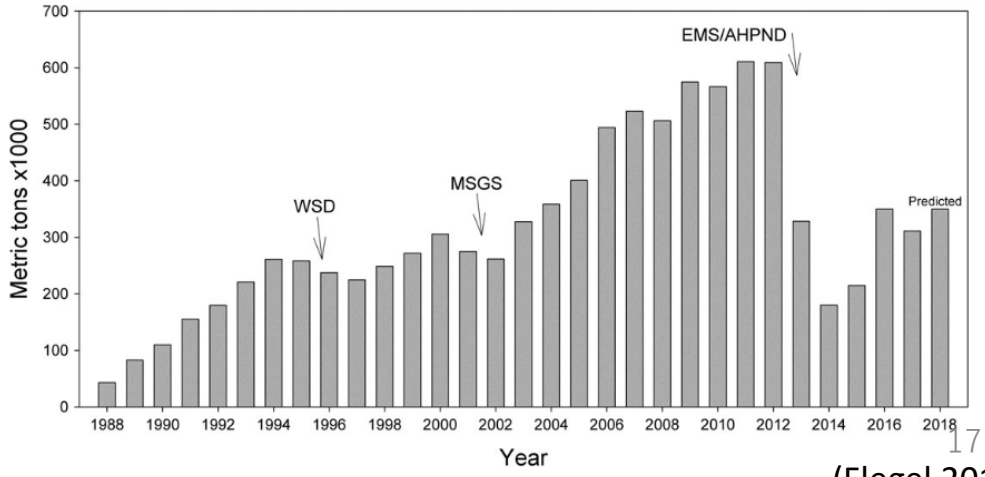
https://www.nikkei.com/article/DGXZQOCC074560X00C22A4000000/

- Emergence of shrimp produced under full control system
  - Safe, additives-free, environmentally-friendly (no soil pollution, no mangrove destruction, no land subsidence, less CO2, etc.), fresh as the production sites are closer to consumers, perfect traceability, Aquaculture Stewardship Council Certification
- While the share in the global market is still small, with the fast development of the sector, investors' keen interests on aqua-tech companies, and increasing global demand, this indoor shrimp market may grow rapidly in near future.
- Can the smallholder shrimp farmers in developing countries continue to participate in the market?
  - Need to understand the role that smallholders play in the current market (Why processors purchase from smallholders while they can also produce?)
  - Consider major issues in the sector: disease & externality

Issues: Disease & Externality

Diseases, Antibiotics, & Externality

- "Aquaculture's history is one of victories over diseases followed by new challenges (Lafferty et al. 2015, p476)"
  - 80% of all ponds face disease (Khiem et al. 2020 based on ADB-NACA report)
  - 40% of shrimp lost annually due to viral pathogens (Stentiford et al. 2012)
  - Magnified with intensification of farming methods (Leung & Tran 00, Lafferty et al. 2015, Suzuki & Nam 2018)
    - Higher density increasing stress for fish/shrimp (King & Naylor 2012)
    - More inputs used and more uneaten feed >> pollutes water
  - Causes of disease often difficult to trace, water quality critically important
  - Impacts could be fatal for farmers

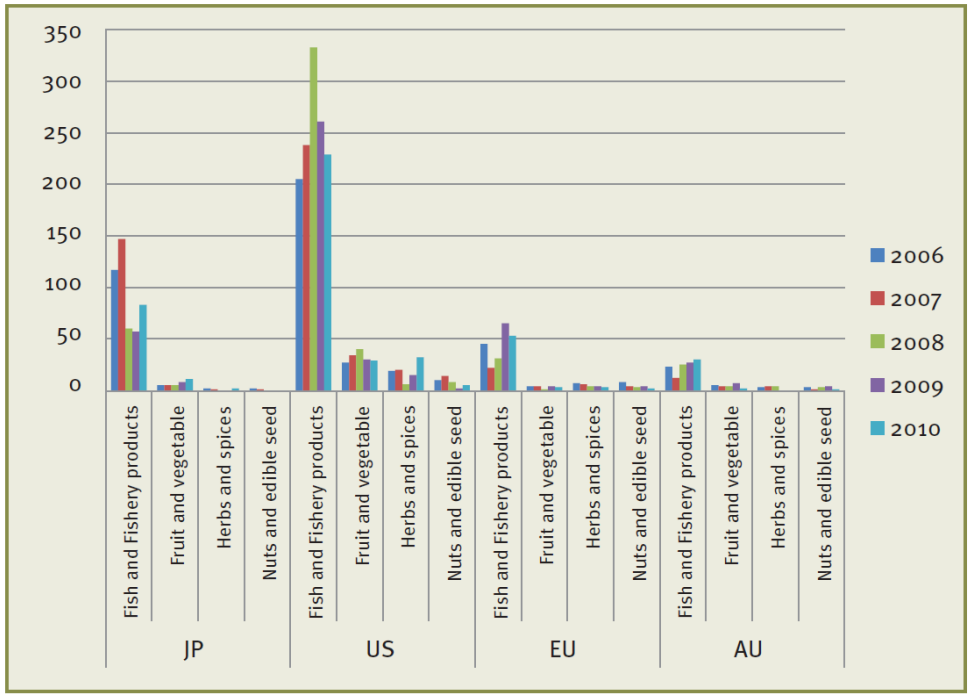


(Flegel 2019)

- Use of antibiotics to prevent & treat the disease
  - Aquaculture developed in a similar manner with livestock rearing, but fish vaccines not widely available (Asche et al. 2022)
  - Various standards at international markets
  - Unobserved unless tested formally in labs
  - Many shipments rejected at the ports of developed countries (UNIDO-IDE 2013)

- Negative externality via waterways
  - More later

Figure 5.1: Number of rejections by major agriculture commodity group for Vietnamese products exported to four markets, 2006–2010

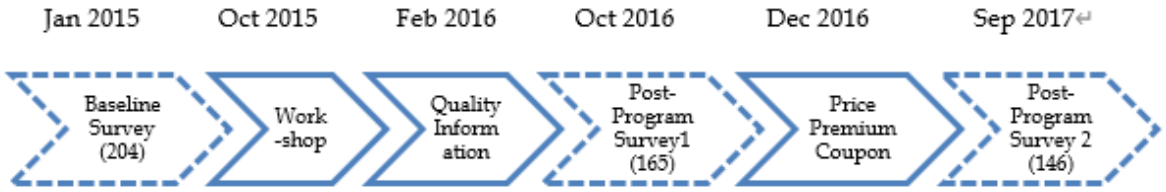


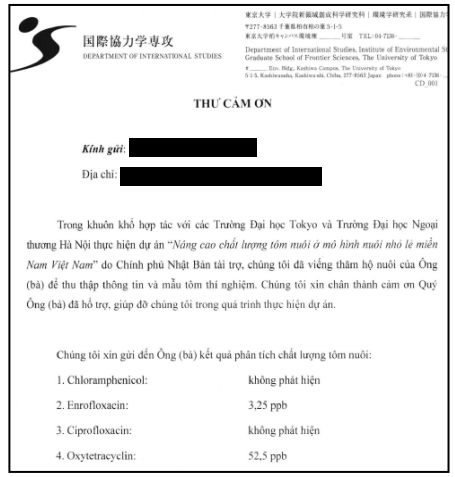
Source: UNIDO dataset and analysis, based on EU RASFF, US OASIS, AQIS, and Japanese MHLW data

(UNIDO-IDE 2013)

Suzuki, Nam, Lee (2023)

- Problem: Use of antibiotics among farmers (Chi et al. 2017, Braun et al. 2019, Lee et al. 2019)
- Our Study: How can we induce behavioral change for farmers? RCT
  - Technical Knowledge? (workshop)
  - Quality Information? (lab test result)
  - Price? (offered price premium)
- Data
  - 3-year panel data
  - HH survey data + Shrimp lab tests
- Methods
  - Intention-to-Treat
  - Treatment-Effect-on-Treated





THƯ CẢM ƠN

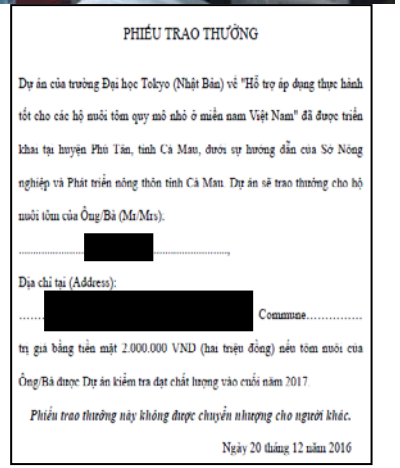
Kính gửi: [redacted]

Địa chỉ: [redacted]

Trong khuôn khổ hợp tác với các Trường Đại học Tokyo và Trường Đại học Ngoại thương Hà Nội thực hiện dự án "*Nâng cao chất lượng tôm nuôi ở mô hình nuôi nhỏ lẻ miền Nam Việt Nam*" do Chính phủ Nhật Bản tài trợ, chúng tôi đã viếng thăm hộ nuôi của Ông (bà) để thu thập thông tin và mẫu tôm thí nghiệm. Chúng tôi xin chân thành cảm ơn Quý Ông (bà) đã hỗ trợ, giúp đỡ chúng tôi trong quá trình thực hiện dự án.

Chúng tôi xin gửi đến Ông (bà) kết quả phân tích chất lượng tôm nuôi:

1. Chloramphenicol:	không phát hiện
2. Enrofloxacin:	3,25 ppb
3. Ciprofloxacin:	không phát hiện
4. Oxytetracyclin:	52,5 ppb



PHIẾU TRAO THƯỞNG

Dự án của trường Đại học Tokyo (Nhật Bản) về "Hỗ trợ áp dụng thực hành tốt cho các hộ nuôi tôm quy mô nhỏ ở miền nam Việt Nam" đã được triển khai tại huyện Phú Tân, tỉnh Cà Mau, dưới sự hướng dẫn của Sở Nông nghiệp và Phát triển nông thôn tỉnh Cà Mau. Dự án sẽ trao thưởng cho hộ nuôi tôm của Ông/Bà (Mr/Mrs).

[redacted]

Địa chỉ tại (Address): [redacted] Commune.....

trị giá bằng tiền mặt 2.000.000 VND (hai triệu đồng) nếu tôm nuôi của Ông/Bà được Dự án kiểm tra đạt chất lượng vào cuối năm 2017.

Phiếu trao thưởng này không được chuyển nhượng cho người khác.

Ngày 20 tháng 12 năm 2016

ITT Effects on Knowledge & Practices (FE)

	Knowledge		Practice			
	prohibited chemical	water quality (10 max)	Test water daily	Keep records	ln (shrimp density)	Chemical Detection
Workshop x 16	0.006	0.062	-0.001	-0.029	-0.457	
Workshop x 17	-0.019	-0.676	-0.01	**-0.200***	-0.594	-0.03
Quality info x 16	**0.170***	-0.074	-0.182	0.079	0.182	
Quality info x 17	0.000	0.161	0.041	**0.216***	0.27	**-0.282****
Premium x 17	-0.089	0.815	0.22	-0.045	0.873	-0.057
2016	0.260***	1				
2017	0.637***	3				
Constant	0.171***	2				
Observation	515	512	515	510	504	302
R2	0.368	0.468	0.091	0.065	0.032	0.098
Wald χ^2	30.59***	42.71***	4.68***	2.92***	1.43	2.16*

Quality information experiment (quantifying residues for farmers) had positive impacts in changing farmers' use of antibiotics.

ITT Effects on Knowledge & Practices (FE); Sub-sample

	Knowledge		Practice			
	prohibited chemical	water quality (10 max)	Test water daily	Keep records	ln (shrimp density)	Chemical Detection
A: Positive Detection at Baseline						
Workshop x 16	0.07	-0.833	-0.278	-0.141	-0.446	
Workshop x 17	-0.238	-1.371	-0.412	-0.237	-0.485	0.119
Quality info x 16	**0.321***	0.805	-0.274	0.205	-0.745	
Quality info x 17	0.097	0.793	0.195	**0.406***	-0.452	**-0.548****
Premium x 17	0.217	1.475	**0.662*****	0.183	2.224	**-0.458***
B. Negative Detection at Baseline						
Workshop x 16	-0.025					
Workshop x 17	0.054					
Quality info x 16	0.111	-0.425	-0.145	0.031	0.542	
Quality info x 17	-0.016	-0.069	0.019	0.144	0.729	**0.000*****
Premium x 17	-0.222	0.521	0.054	-0.156	0.337	**0.200***

These positive changes occurred among farmers who were detected positive at the baseline survey.

Internalize Externalities - Textbook Solutions

Pigouvian Tax	• **Difficult to visualize and collect fees**
Standards or Quota	• **Difficult to visualize, monitor, and punish when not followed**
Property Rights	• **Difficult to assign property rights on river water**
Central or Vertical Control	• **Some processor own ponds, but limited supply** • **Difficult to control the river/ sea water**
Collective Action (Horizontal Control)	• **Some communities regulate water intake (Indonesia, Sri Lanka), Free rider problem exist**

A simple model of processors' decision to offer vertical control

Consider two types of risks in shrimp production (Q_i): quality risk (q_i) and disease risk (d_i).

- q_i is measurable quality standard, which is affected by the practices taken by producers (i.e., antibiotics, BMPs).
- d_i is the probability of disease outbreak and has a stochastic nature (σ_i) due to externalities from i's neighbors.

$$Q_i = f(q_i, d_i(\sigma_i))$$

Processors can choose to exercise vertical control (e.g. "contract-farming" or producing shrimp on their own ponds) or purchase from surrounding farmers.

Processors' profit can be defined as: $\pi_j = f\left(Q_j\left(q_j, d_j(\sigma_j)\right)\right)$

where j = vertical control (v) or farmer purchase (f)

Processors decide to exercise vertical control when:

$$E(\pi_v) > E(\pi_f)$$

Average quality of shrimp higher under vertical control:

$$E(q_v) > E(q_f) > q^*$$

where q* indicates the minimum quality standard required by downstream buyers

Variance of production also higher under vertical control:

$$V(Q_v(d_v(\sigma_v))) > V(Q_f(d_f(\sigma_f)))$$

because $\sigma_i > \prod_i^n \sigma_i$.

Processors decide to purchase from surrounding farmers when disease risk dominates the quality risk, i.e.,

$$E(\pi_v(q_v, d_v(\sigma_v))) < E(\pi_f(q_f, d_f(\sigma_f)))$$

Implication from the model & field observations:

- Vertical control not exercised in this sector due to this lower variance of disease risk that enables smallholders to participate in the shrimp export supply chain.

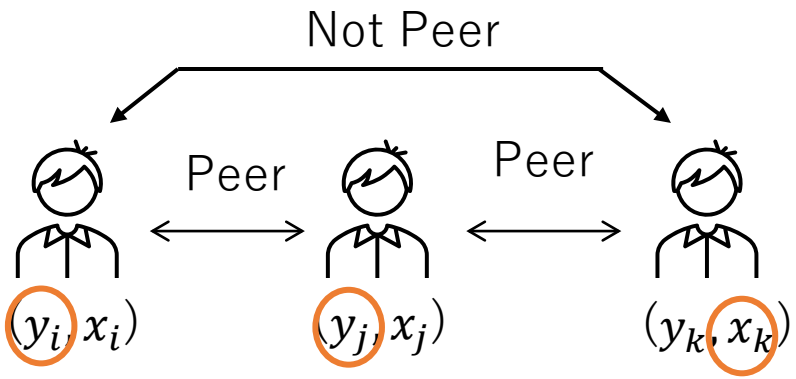
$$V(Q_v) > V(Q_f)$$

  - i.e., Better purchasing shrimp from a large pool of various ponds than sticking to the same ponds all the time
  - "Quality" is measured at the purchase by processors in their lab
  - Only the relatively wealthier smallholders tend to participate in shrimp sector.
- Fischer et al. (2017) based on salmon industry's case theoretically showed:
  - Intensification increase disease risk
  - Extensification also reduces incentives to internalize disease risk (free-rider)

- Examine the spread of disease risk in our data in Vietnam:

Externalities in Vietnam shrimp sector

- Suzuki, Olivia, Nam, and Lee (2022)
  - Examined the spillovers of physical pathogens or polluted water and the spillover of knowledge on farming methods ("peer effects")
  - Methods
    - OLS (linear-in-means models)
    - Spatial autoregressive models (SAM) and Spatial Durbin Models (SDM)
    - IV method relying on Bramoulle et al. (2009)
      - Under $\mathrm{E}(e_i|X, W) = 0$ (chara and network exogenous to outcome y, i.e., correlated effects are solved), simultaneity of endogenous effects & exogenous contextual effects can be identified using the higher order spatial lag as an instrument for the endogenous effects

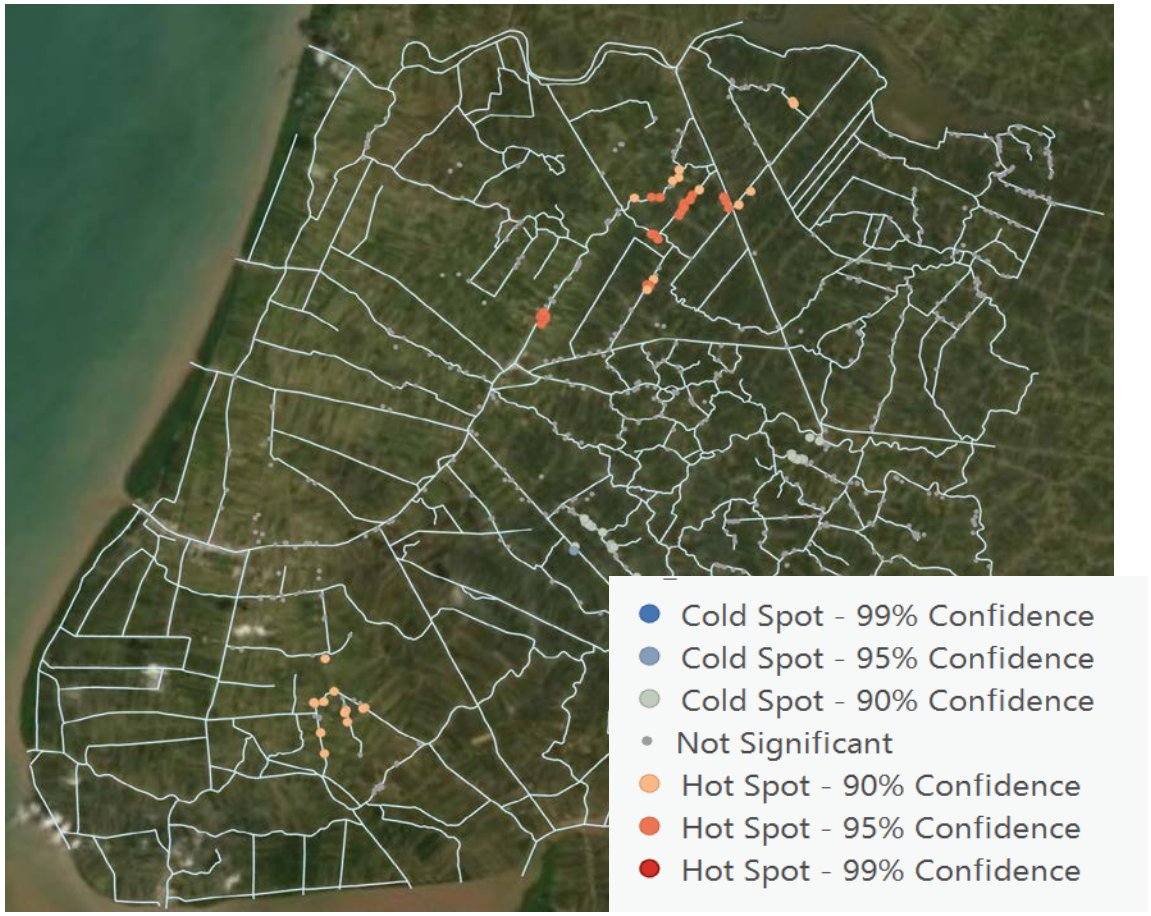


Effect of farmer k's characteristics affect farmer i's outcome only through the outcome of farmer j

Optimized Hot Spot Analysis

Gi* static (Getis and Ord 1992)

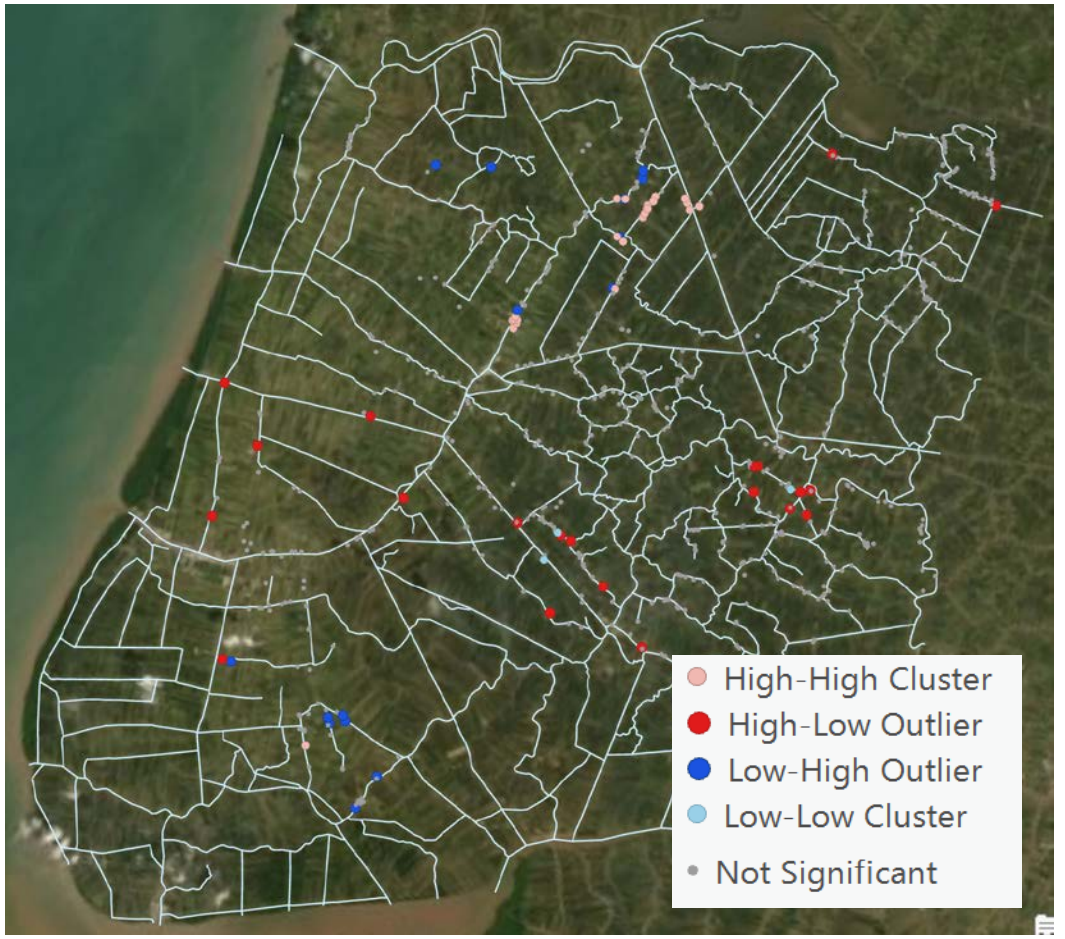
$$G_i^*(d) = \frac{\sum_{j=1}^{n} w_{ij}(d)x_j}{\sum_{j=1}^{n} x_j}, j \text{ may equal to } i$$



Optimized Outlier Analysis

Local Moran's I (Anselin 1995)

$$I_i = z_i \sum_{j=1}^{n} w_{ij} z_j$$



Spatial Regression (Y=Disease Outbreak)

		SAR	SAR	SDM	SDM
	Education	0.005	0.009	-0.001	0.003
	Shrimp farming experience	0.001	0	-0.003	-0.004
	Shrimp farming knowledge	-0.033***	-0.020**	-0.029***	-0.016*
	Total plot size	-0.027	-0.042	0.003	-0.02
	Trust in village	0.018	0.024	0.051**	0.050**
	Practice: recording		-0.281***		-0.241***
	Practice: water quality check		0.03		0.059
	Practice: equipment		-0.277**		-0.287**
Spatial Lags	% disease outbreak	0.712***	0.628***	0.479***	0.416***
	Education			0.021	0.012
	Shrimp farming experience			0.060**	0.051**
	Shrimp farming knowledge			-0.001	-0.033
	Practice: recording			-0.820***	-0.598**
	Practice: water quality check			-0.194	-0.093
	Practice: equipment			-0.4	-0.269

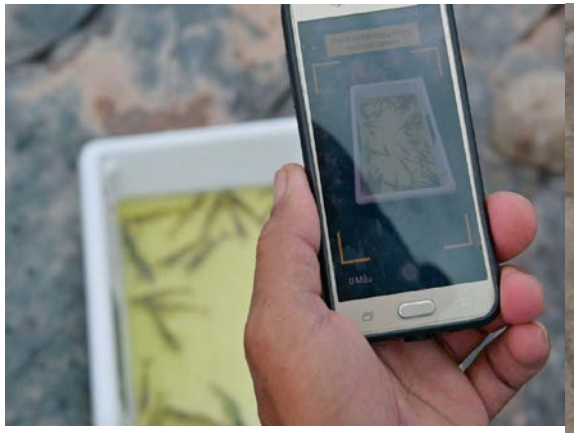
OLS, changing radius of “neighborhood” (Y=Disease Outbreak)

		500m	1km	2km
	=1 if male	-0.091	-0.112	-0.087
	Age	0.000	0.000	0.000
	Education	0.006	0.001	-0.001
	Shrimp farming experience	-0.004	-0.002	-0.002
	Shrimp farming knowledge	-0.030***	-0.019**	-0.023***
	Total plot size	-0.025	-0.005	0.006
	Trust in village	0.039**	0.036**	0.024
Neighborhood Effects	# shrimp farmers	-0.005	-0.001	-0.002
	% disease outbreak	0.240**	0.311**	0.449
	Education	0.006	0.004	0.000
	Shrimp farming experience	0.017	0.01	0.008
	Shrimp farming knowledge	0.001	-0.025	-0.015
	Practice: recording	-0.338***	-0.319*	-0.478
	Practice: water quality check	0.033	0.035	0.359
	Practice: equipment	-0.414*	-0.104	-0.329

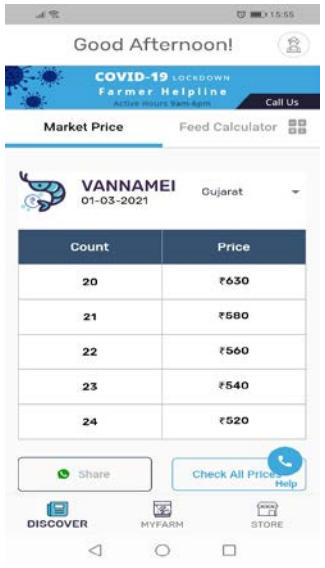
- Disease risk spatially correlated, but the effect dampens as we enlarge the “neighborhood” area.
- Pooling the disease risk among smallholders seems one of the reasons why the processors are not choosing to exercise formal vertical control while the quality is important.
- It is a trade off between expected quality and probability of disease, i.e., $E(q_i)$ and $Pr(d_i)$.
- Emerging fully controlled indoor system has substantially low $Pr(d_i)$ with high $E(q_i)$.
- Smallholders may have 2 options to continue their participation.
  - To improve on $E(q_i)$ by introducing better farming practices.
  - To reduce $Pr(d_i)$ further by horizontal coordination.
- We have digital technologies available.

Digital technologies

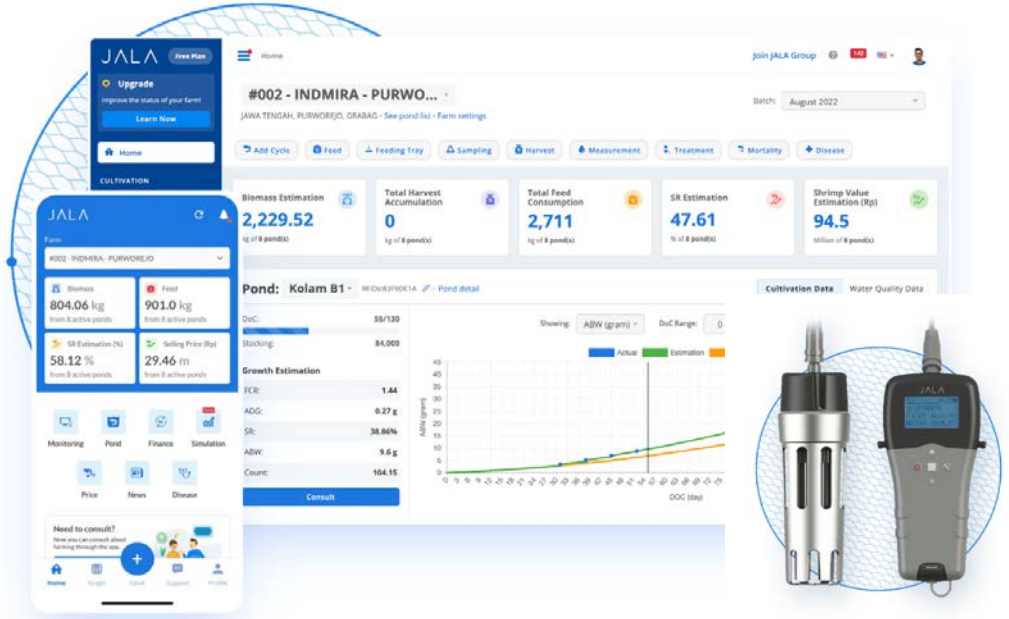
- Digital technologies can help visualize unobserved aspects in aquaculture & improve farmers' decision-making
- Farmers sharing their own farming practices & market info via SNS



https://www.xpertsea.com/



https://aquaconnect.blue/



https://jala.tech/app

Good practices on traceability

- “Movement Document” in Thailand (2016)
- Digitalized this system as “Aquatic Animal Purchasing Document” in 2021.

- Ecuador shrimp sector: use of IBM Food Trust based on blockchain technology to assure traceability

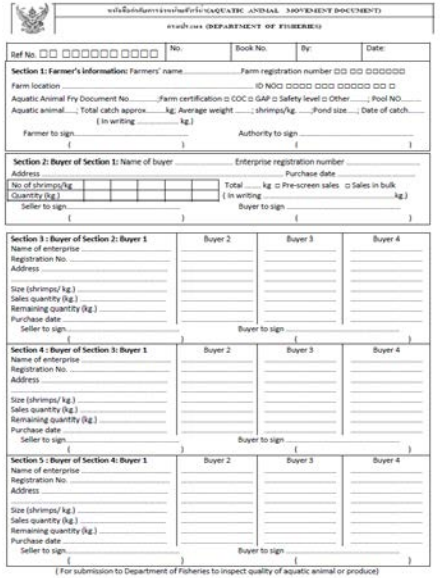
SSP shrimp’s journey from farm to fork with

Blockchain technology

SSP joined the IBM Food Trust ecosystem, a platform that uses blockchain technology to help **provide traceability of SSP shrimp and deliver greater accountability and transparency** to customers for every element of SSP’s premium Ecuadorian farmed shrimp production and journey to the consumer plate.

https://www.sustainableshrimppartnership.org/

“Movement Document”



“Shrimp Farmer Registration”

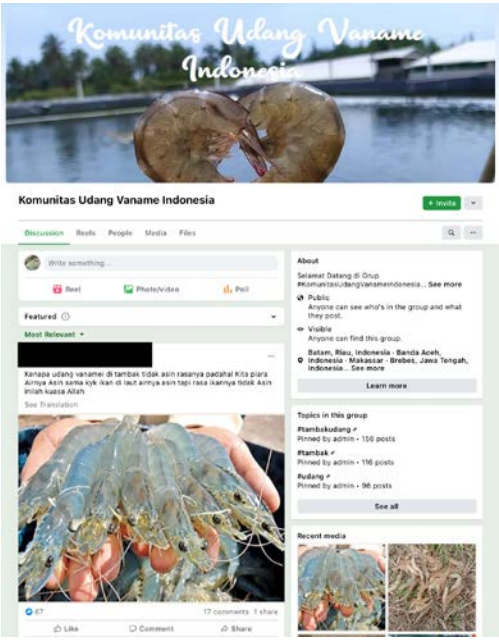
“Aquatic Animal Purchasing Document (APD)”

https://apdsouth.fisheries.go.th//shrimp/

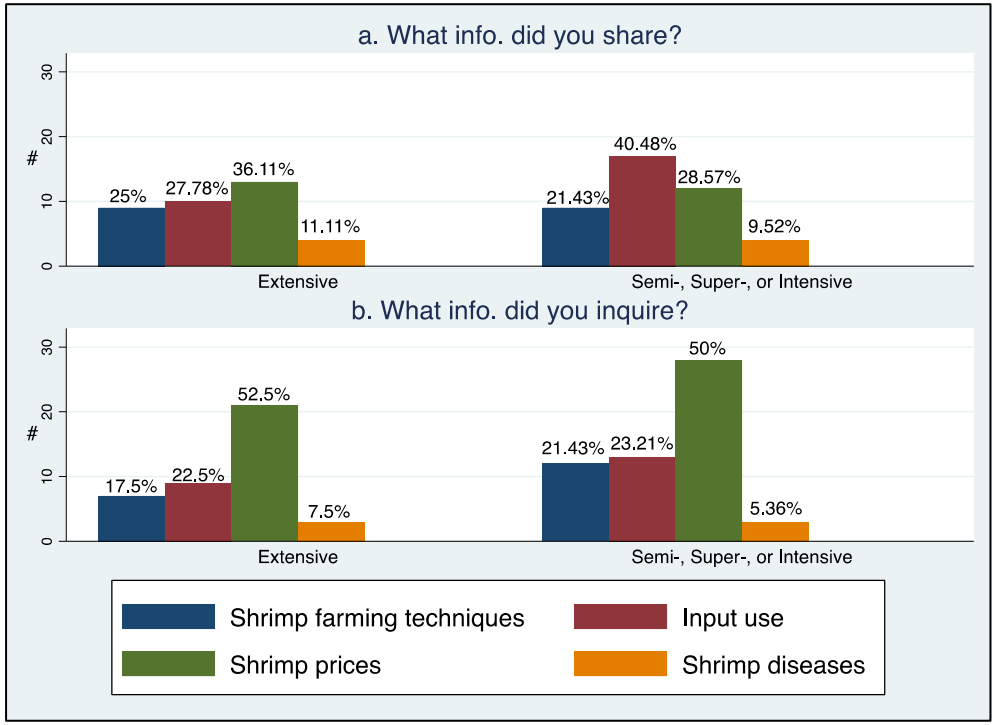
Lee, Pratiwi, Farikha, Suzuki, & Kurosaki (2023)

Indonesian Vannamei Shrimp Community “Komunitas Udang Vaname Indonesia” (KUVI)

- Established in Sept, 2018. 117,000 membership as of Jan 2023
- Information exchange regarding market prices, inputs, and technical aspects
- Top of “Most trusted info source”: Farmers in the same village. Even among KUVI members, KUVI info ranked 4th. >> Complementary role to traditional info sources



KUVI FB



Most trusted info source

	KUVI	Non-KUVI
Extension	14.4%	5.5%
KUVI	9.9%	0.7%
Farmers in same village	45.7%	79.9%
Farmers in other village	1.7%	2.8%
Family	21.4%	10.6%
Others	7.0%	0.6%

Note) Based on own survey, N=1,574

Conclusions

- For developing countries to continue benefitting from globalization of shrimp export, necessary to control for quality and negative externalities. Fully controlled indoor system is emerging in developed countries.
- Important to improve $E(q_i)$ by adopting good farming practices and reduce $Pr(d_i)$ further by horizontal coordination.
- Digital tools are available and effective to enhance knowledge, strengthen peer effects, monitor behavior, visualize the unobserved quality, and establish traceability. These seem to be the key for smallholders in developing countries to continue playing an important role in this sector.

Thank you for your attention!

ayaszk@k.u-tokyo.ac.jp