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Global Aquaculture: New developments and main issues

Advocates' interest in aquaculture has grown considerably since 2001. The alarming rise of aquaculture in recent decades and its serious adverse effects have become evident and could no longer be ignored.

Advocates are not the only ones troubled by aquaculture's adverse effects. "The sustainability of aquaculture has been debated intensely since 2000. . ." These are the opening words of the paper *"A 20-year retrospective review of global aquaculture"*, written by a team of ten international academic experts, led by Rosamund Naylor at Stanford University. The paper, published in the journal *Nature* in March 2021, has been accessed over 50,000 times in seven months, and mentioned in numerous blogs and media outlets including the New York Times. It is an update of a seminal paper published in 2001 by Naylor and her colleagues.

This issue of ASWT highlights points in Naylor's review. It also includes brief notes of some recent studies on various broad topics in global aquaculture that advocates may find interesting (e.g. new trends in China; antibiotics use and resistance).

1. Global aquaculture: What happened in the last 20 years? How to respond to changes?

The three major new developments are in: 1. Freshwater aquaculture. 2. Feed. 3. Molluscs and algae.

Freshwater aquaculture experienced firm, steady growth

- Main drivers: Fewer wild fish in the sea, global trade, competitive product pricing, higher income and urbanization in developing countries.
- Rapid expansion in South and Southeast Asia is a key new feature. Growth also accelerates in South America (Chile), and Africa (Egypt). But China remains the champion.
- Private investment – not government support – enables expansion in Asia and Sub-Saharan Africa.
- Small- and medium-sized farms are the norm.

• Although the global aquaculture value chain is significant, a lot of products are consumed locally. 90% of aquaculture output is not intended for export markets.

• Of the species that are traded globally, four dominate: Salmon, shrimp, catfish, tilapia.

• Notable developments in freshwater aquaculture: 1. Over-intensification. This causes serious aquatic pollution. 2. Increased use of compound feed (a mix of mainly terrestrial and some marine ingredients) as well as supplementary feed, driven by certification initiatives. This has made intensive farming possible. 3. Proliferation of farming non-fed fish in low input-output systems in aquatic commons such as reservoirs. These systems do not disturb biodiversity and nutrient balances.

Less dependency on fishmeal and fish oil from wild fish, although captured marine fish still provide important ingredients for aquafeed in some countries.

• Reasons: High price of fishmeal and fish oil; more omnivorous species are farmed; better feed conversion ratios; better processing technologies that extract more oil and fishmeal from captured wild fish; greater use of plant ingredients.

• Replacing marine proteins with land-based ones means tighter ties between aquaculture and terrestrial global food systems. This can lead to problems and unintended consequences such as clearing Brazilian forests to grow soy for aquafeed.

Significant expansion in the cultivation of molluscs and algae:

• The volume of extractive filter-feeding bivalves and algae produced has doubled in the past two decades. Both production and consumption is led by China.

• About 65 species of molluscs, chiefly clams, oysters, mussels, are farmed. They generally do not need to be fed. And they provide eco-system service (e.g. filter excess nutrients caused by human activities).

• 99% of cultivated algae and aquatic plants come from Asia. The majority of products are used by the food industry (e.g. as additives) and for non-food sectors (e.g. in cosmetics, fertilizers, bioplastics).

• Algae farming faces a range of issues, including: 1. Lots of disease outbreaks. 2. Lack of progress in and incentives for R&D. 3. Not cost-competitive as aquafeed or for cattle. 4. Limited consumer demand.

Key challenges:

• Pathogens, pests, parasites (PPP): Chronic risks of PPP remain even with using antibiotics and adopting best management practices to avoid, detect and treat PPP.

• Harmful algal blooms: Increasing worldwide and becoming more severe.

• Climate change: Poses a number of challanges (especially with suboptimal growing temperatures), exacerbates PPP and algal blooms, and can lead to big losses unless adaptation responses are taken.

• Producers not meeting environmental sustainability goals: Some progress made, but producers are not motivated to do more because they are not rewarded with better prices or access to markets.

Responses to challenges:

• Recirculating aquaculture systems: Better efficiency; can reduce PPP risks; costly; can fail catastrophically; competitiveness with other systems uncertain.

• Offshore aquaculture: High costs and risks; public resistance; large-scale only in China and Norway.

• Governance, regulations, and certifications: Many public and private regulations, ratings, certifications, and consumer guides have emerged, including dozens from NGOs. All these schemes and certifications have serious limitations and are unevenly applied (e.g. skewed towards major export species). Consumers in Asia are getting a little more interested in certifications due to food safety concerns.

A new hybrid governance and management approach that goes beyond a particular farm to include buyers, local authorities, large and small producers, and more transparency is promising.

Seven recommendations:

1. Urge producers to adopt sustainable practices and have their products receive global certifications.

2. Continue to innovate on the feed front.

3. Ensure prudent planning, siting, regulating, and scaling of aquaculture operations.

4. Develop multiple clearly articulated, transparent, flexible governance so all stakeholders can innovate.

5. Provide improved financial and environmental management to recirculating and offshore systems.

6. Invest in a broad range of PPP prevention strategies and not wait till PPP have emerged.

7. Adopt a food systems approach that include "nutrition, equity, justice, and environmental outcomes and trade-offs across land and sea" when formulating programs and policies.

IF YOU HAVE TIME, PLEASE READ A LONGER VERSION IN THE APPENDIX

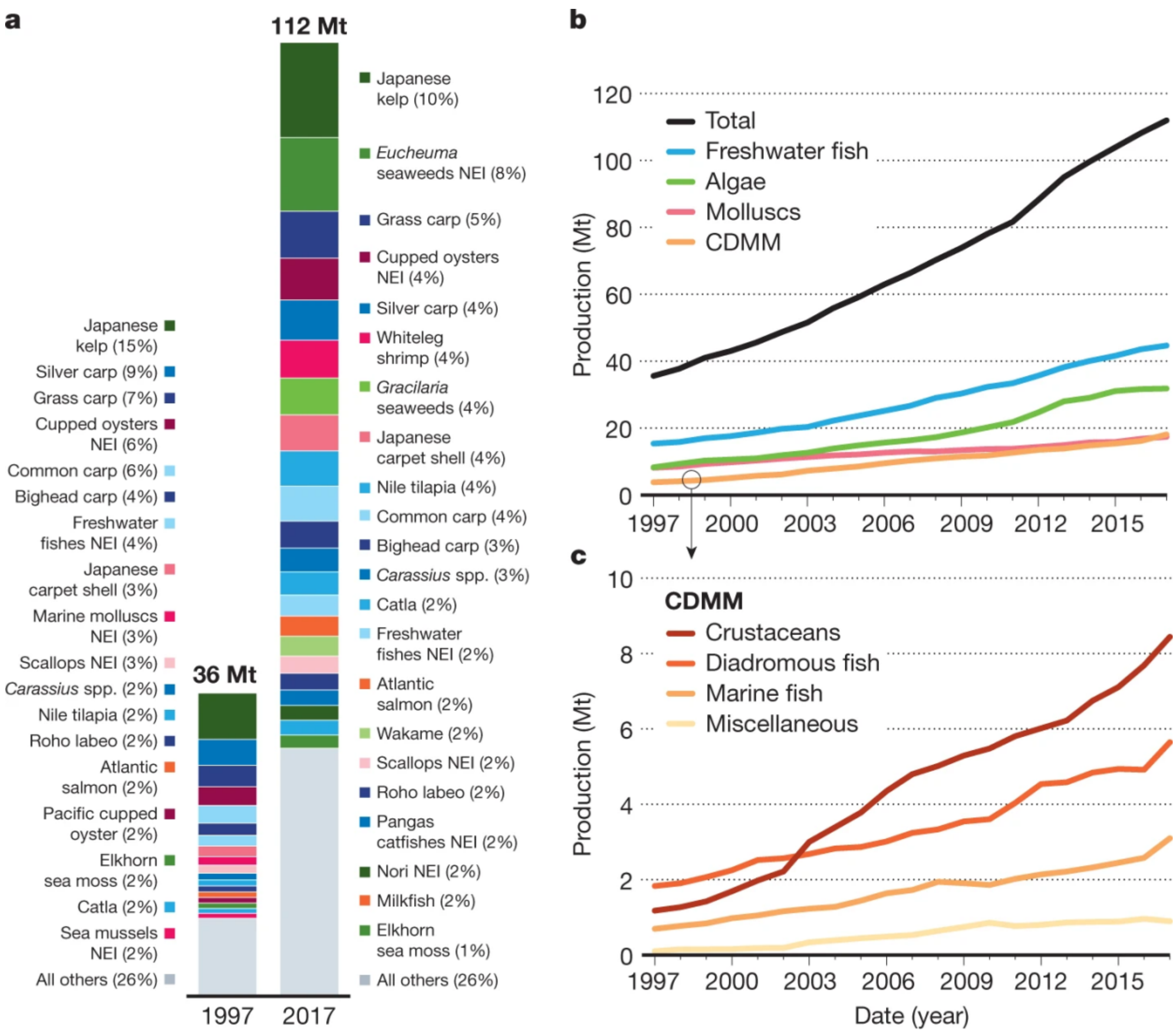

Fig. 1 | Composition and growth of global live-weight aquaculture production. a, The species composition is shown for 1997 and 2017. Green, plants and algae; blue, freshwater fish; pink, shellfish; orange, diadromous fish. b, c, Growth is shown from 1997 to 2017 for the following production categories (b): total, freshwater fish, algae, molluscs and CDMM, which comprises crustaceans, diadromous fish, marine fish, and miscellaneous species and is expanded in c. Algae comprised more than 99% of the production weight of 'algae and aquatic plants' production in 2017.

Naylor, Rosamond L., Ronald W. Hardy, Alejandro H. Buschmann, Simon R. Bush, Ling Cao, Dane H. Klinger, David C. Little, Jane Lubchenco, Sandra E. Shumway, and Max Troell. "A 20-Year Retrospective Review of Global Aquaculture." *Nature* 591, no. 7851 (March 2021): 551–563. doi: 10.1038/s41586-021-03308-6.

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2. A few production trends in the country that tops the world's aquaculture league table

China is not only the winner in aquaculture, it is #1 in marine capture fisheries as well.

Traditional farmed fish species (e.g. grass and silver carp) have become less profitable due to the rise in input costs and local consumer demand for a broader selection of seafood. This has resulted in a greater diversification in species that are farmed.

There is better knowledge of fish digestion and nutrition, processing of raw feed materials, use of compound feed, plus a trend towards systems that are low input-high output. So even though many more fish are farmed, the use of imported and domestic fishmeal derived from wild fish has remained relatively stable and not expanded. The decreased reliance on fishmeal is actually "impressive".

To lower the high cost of commercial aquafeed, some farmers go back to using "traditional methods of dyke-crop culture". This approach has led to some de-intensification.

Government policies put in place a while back are showing considerable impact on aquaculture. The emphasis on marine fisheries management and conservation has made much less wild fish available to feed farmed fish. And environmental protection legislation has reduced signficantly the areas for cultivating carps, and is driving "wholesale changes" in the country's aquculture production.

Newton, Richard, Wenbo Zhang, Zhaoxing Xian, Bruce McAdam, and David C. Little. "Intensification, Regulation and Diversification: The Changing Face of Inland Aquaculture in China." *Ambio* 50, no. 9 (September 1, 2021): 1739–1756. doi: 10.1007/s13280-021-01503-3.
Zhao, Kangshun, Min Zhang, Kang Wang, Konghao Zhu, Congjun Xu, Jiayi Xie, and Jun Xu. "Aquaculture Impacts on China's Marine Wild Fisheries Over the Past 30 Years." *Frontiers in Marine Science* 8 (July 26, 2021): 710124. doi: 10.3389/fmars.2021.710124.

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3. Aquaculture growth will be unevenly distributed globally

Taken as whole, the aquaculture sector will likely see rapid growth globally. For a number of countries, local demand is a key driver of this expansion. These demands and seafood consumption patterns are in turn shaped by each country's own level and pace of economic development.

It is interesting to see that three of the four most populous countries in the world (i.e. China, U.S., India, Indonesia) are also top aquaculture producers (U.S. is the exception). This may be explained by the strength of domestic markets and the importance of seafood in people's diets in these countries.

But growth currently is and will be unevenly distributed. "Production of the ten largest countries made up 89% of the total aquaculture production in 2016." And the rate of growth in some countries in Africa and South America is now more than that of major Asian producers.

Growth is also by no means universal. Most developed countries that led production up to the 1970s no longer play a role in the current aquaculture "revolution". EU and US are now net importers of seafood. Aquaculture is also "limited in most small island communities and some large coastal nations with important fisheries sectors".

1970	2016
1. China	1. China
2. Japan[a]	2. India
3. United States[a]	3. Indonesia
4. Spain[a]	4. Vietnam
5. India	5. Bangladesh
6. Indonesia	6. Egypt
7. France[a]	7. Norway[a]
8. Philippines	8. Chile
9. Netherlands[a]	9. Myanmar
10. Thailand	10. Thailand
11. South Korea	11. Philippines
12. Soviet Union[a]	12. Japan[a]
13. Taiwan	13. Brazil
14. Vietnam	14. South Korea
15. Bangladesh	15. Ecuador
16. Malaysia	16. United States[a]
17. Italy[a]	17. Iran
18. Germany[a]	18. Nigeria
19. Hungary[a]	19. Spain[a]
20. Romania[a]	20. Taiwan
Share in developed countries:	
41.2%	5.6%

[a] Indicates an economically developed country

Garlock, Taryn, Frank Asche, James Anderson, Trond Bjørndal, Ganesh Kumar, Kai Lorenzen, Andrew Ropicki, Martin D. Smith, and Ragnar Tveterås. "A Global Blue Revolution: Aquaculture Growth Across Regions, Species, and Countries." *Reviews in Fisheries Science & Aquaculture* 28, no. 1 (January 2, 2020): 107–116. doi: 10.1080/23308249.2019.1678111.

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4. The complexity and heterogeneity of global fish consumption patterns

If one wants to address concerns with seafood demand and consumption in the world, it is not enough to realize that the overall global demand will probably double by 2050 if real prices for fish stay constant. (Consumption has doubled once already from 2000 to 2020).

One needs to understand thoroughly what kinds of seafood (also known as "blue food") people in which places are eating/will eat, and where exactly these food are/will be produced. Figuring all this out is very complicated. But understanding the different "economic, demographic, and geographic factors and preferences" of consumers is essential for planning any form of action.

Firstly, a huge diversity of fish is produced and traded around the world. "Fish" covers thousands of species that are farmed or captured. Secondly, it is not a straightforward matter of rising income leading to more fish consumption. Different income groups, countries, regions have distinct consumption patterns, and much depends on what is "widely available, affordable, and traditionally eaten". Moreover, one needs to understand "substitution among fish groups and other animal source foods in national diets". Currently, 8% of animal protein in human diet comes from global aquaculture.

For example: Asia (e.g. China) consume large shares of freshwater fish (e.g. carp). Africa (e.g. Ghana) and South America (e.g. Peru) prefer both freshwater fish and pelagic species (e.g. sardines). Europe, North America, and Oceania favor demersal species (e.g. Atlantic cod). Some countries in Africa (e.g. Nigeria) now import frozen fillets and small fish, and the real price of fish has risen in the past decade even though traditionally fish was the cheapest source of animal protein.

Naylor, Rosamond L., Avinash Kishore, U. Rashid Sumaila, Ibrahim Issifu, Blaire P. Hunter, Ben Belton, Simon R. Bush, et al. "Blue Food Demand across Geographic and Temporal Scales." *Nature Communications* 12, no. 1 (September 15, 2021): 5413. doi: 10.1038/s41467-021-25516-4.

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5. Limitations in aquaculture certification schemes

Eight widely used global aquaculture certification schemes have been examined for the range of issues they cover (e.g. Aquaculture Stewardship Council /ASC; Global G.A.P., BRC Global Standards, Royal Society for the Prevention of Cruelty to Animals /RSPCA).

Researchers find that the schemes emphasize issues in two domains: 1. Environmental conditions and concerns (e.g. how human aquaculture activities impact the surrounding environment; how the environment in which the fish are placed affect the fish's health and welfare). 2. Governance and practices of companies and the industry (e.g. "transparency and traceability, food safety, accountability and enforcement, and social assurance").

These certifications do not do a good job at addressing other dimensions that are often regarded as essential for true sustainability. They gloss over two important categories: 1. Economic issues related to labor, employment, investment in technology and innovation. 2. Cultural issues related to respect for native culture, to employee interest and well-being.

Although often known as sustainability certifications, by taking a narrow and lopsided perspective, they "promote a skewed understanding of sustainability". Furthermore, the criteria they use are confusing, do not complement each other, and do not take into consideration how they can be implemented in the long run especially since these criteria can be contradicted by economic and social realities and structures which the certification schemes fail to cover.

Osmundsen, Tonje C., Vilde S. Amundsen, Karen A. Alexander, Frank Asche, Jennifer Bailey, Bengt Finstad, Marit Schei Olsen, Klaudia Hernández, and Hugo Salgado. "The Operationalisation of Sustainability: Sustainable Aquaculture Production as Defined by Certification Schemes." *Global Environmental Change* 60 (January 2020): 102025. doi: 10.1016/j.gloenvcha.2019.102025.

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6. GHG emissions of global aquaculture similar to that of producing sheep meat

Excluding the cultivation of aquatic plants, and focusing on key aquaculture regions in the world and the main aquatic animal species farmed "using modern, commercial feed formulations" (letting some fish grow in a backyard pond and harvesting them does not count), *on average* global aquaculture takes up about 0.49% of anthropogenic greenhouse gas emissions in 2017. This figure is similar to global GHG emissions of producing sheep meat.

Aquatic animal species have relatively high fertility, low feed intake per unit output (i.e. feed conversion ratios), and no enteric methane emission. These factors limit their GHG emissions intensity.

MacLeod, Michael J., Mohammad R. Hasan, David H. F. Robb, and Mohammad Mamun-Ur-Rashid. “Quantifying Greenhouse Gas Emissions from Global Aquaculture.” *Scientific Reports* 10, no. 1 (2020): 11679. doi: 10.1038/s41598-020-68231-8.

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7. Antimicrobial use and resistance in global aquaculture is a serious concern

In 2017, the Asia-Pacific region is responsible for 93.8% of all antimicrobials used in aquaculture, with China taking 57.9% of global consumption. It is estimated that these 2017 figures will increase 33% by 2030 to 13,600 tons. But compared with antimicrobial use for humans and for raising food animals on land, aquaculture's share will still be under 6% in a decade's time.

However, aquaculture "carries the highest use intensity per kilogram of biomass", and the consumption intensity for some farmed aquatic species groups surpasses levels used for humans and terrestrial animals. Moreover, the kinds of antibiotics used in aquaculture are not of little consequence; they are "classified as medically important" for humans. The top five aquatic species according to consumption intensity (in descending order) are: catfish, trout, tilapia, shrimp, salmon.

Antimicrobial resistance in farmed shrimp raised chiefly in low- and middle-income countries is especially concerning: 1. The quality and usage of antimicrobials in these farms is "widely unregulated". And it is very challenging to get reliable data on antibiotics usage in these places. 2. Waste is untreated and "often directly eliminated into local water sources". 3. Shrimp farmers live close to their farms, providing more opportunities for bacteria to spread. 4. Farmers cannot access alternatives to antibiotics to prevent losses to their shrimps. 5. The trend towards intensification will increase disease burden.

Levels of antimicrobial resistance in aquaculture correlate with levels of resistance in humans. Countries with high levels are mostly low- and middle-income, particularly in Southeast Asia and Africa. Poor sanitation systems and antibiotic misuse are main factors for the high levels in these countries, which are also vulnerable to climate and temperature change, adding to antimicrobial resistance risks.

Drewnowski, Adam, Schar, Daniel, Eili Y. Klein, Ramanan Laxminarayan, Marius Gilbert, and Thomas P. Van Boeckel. “Global Trends in Antimicrobial Use in Aquaculture.” *Scientific Reports* 10, no. 1 (2020): 21878. doi: 10.1038/s41598-020-78849-3.

Thornber, Kelly, David Verner-Jeffreys, Steve Hinchliffe, Muhammad Meezanur Rahman, David Bass, and Charles R. Tyler. “Evaluating Antimicrobial Resistance in the Global Shrimp Industry.” *Reviews in Aquaculture* 12, no. 2 (2020): 966–986. doi: 10.1111/raq.12367.

Reverter, Miriam, Samira Sarter, Domenico Caruso, Jean-Christophe Avarre, Marine Combe, Elodie Pepey, Laurent Pouyaud, Sarahi Vega-Heredía, Hugues de Verdal, and Rodolphe E. Gozlan. “Aquaculture at the Crossroads of Global Warming and Antimicrobial Resistance.” *Nature Communications* 11, no. 1 (2020): 1870. doi: 10.1038/s41467-020-15735-6.

EXPLANATORY NOTE:

- Academic studies are notoriously hard to find, read, and put into practical use by non-academics.
- Super-busy advocates cannot afford to spend a lot of time and effort to dig up, digest, and deploy academic research even though they recognize the value of academic studies in informing and improving their advocacy work.
- *Academic Studies Without Tears* aims to help advocates faced with this dilemma.
- Its target audience are leaders and funders of non-profit advocacy organizations addressing the many negative impacts of industrial animal agriculture in low- and middle-income countries.
- It uses a communication style – reminiscent of quiz or news items – that makes everything a breeze to read.
- Each issue focuses on a particular topic and includes 8 – 10 academic studies.
- It goes without saying that the academic studies featured are *not* the final word. They have flaws and limitations. They are just a tiny selection of perspectives and findings for advocates to consider, to whet their appetite. But every relevant data point and nugget of cogent information adds to one's store of knowledge and has the potential to spark new ideas.

APPENDIX

Long version of 1. Global aquaculture: What happened in the last 20 years? How to respond to changes?

The 1990s: The production of farmed fish and shellfish was "flourishing" in the 1990s. But it did not play a major role in global food systems. Two of the biggest concerns at that time were: The use of wild fish as feed, and aquaculture's environmental impact.

Live-weight of farmed fish and shellfish: *1987:* 10 million tonnes (Mt). *1997:* 29 Mt. *2017:* 80 Mt.

Three key developments in the last 20 years

By 2020, aquaculture has to be reckoned as a mainstream component of global food systems, influencing deeply the amount of food produced globally, food security, rural livelihoods, customers, value chains, and sustainability. Its most significant developments in the past two decades are:

1. "continued growth in the volume and value chains of fresh-water aquaculture"
2. "advances in fish nutrition, genetics, and alternative types of feed that reduce the use of wild fish in aquafeed formulations"
3. "expanded culture of extractive bivalves and seaweeds"

Steady global growth

- The aquaculture sector's global growth is driven by "the expansion in global trade, declines in the availability of wild fish, competitive product pricing, rising incomes, and urbanization".
- However, in spite of the undeniable role of the spread of global trade in powering aquaculture's firm upward trajectory, "89% of aquaculture output does not enter into international markets". The bulk of aquatic

products are consumed within the countries they are produced, and domestic markets in Asia are especially important.

- Of the seafood that *is* traded internationally, one-third of the total value of this trade is taken by four species: Salmon, shrimp, catfish, tilapia. Zooming out to the big picture of *all* seafood *produced* worldwide, these four species make up 8% of global seafood production.

Species and production systems

- Compared to 20 years ago, there is now a larger diversity of species farmed. 40% more fish, shellfish, aquatic plant, and algal *species* are cultivated in a broad range of marine, brackish, and freshwater systems globally.
- The diversity is largest in Asia, especially in China. For example, China had 86 species in 2017 in different systems, while Norway had 13 species mostly in marine caged system.
- However, 5% of the species farmed account for over 75% of global production.
- The share of freshwater fish in the aquaculture universe has increased over the past two decades, and the tradition of inland aquaculture continues to march forward.
- Developments in the Western Hemisphere are mostly in single-species, dual-species, or single-production systems (e.g. Nile tilapia and channel catfish in ponds, Atlantic salmon in cages).

Countries

- China is the clear winner. But there is rapid expansion in South and Southeast Asia. And the growth rates in South America and Africa surpass those in Asia "(albeit from a much smaller production base)".
- The largest producers outside Asia are: Norway, Chile (both focusing on Atlantic salmon), and Egypt (known for its Nile tilapia production). Each of these large non-Asian producers accounts for 1-2% of global production.

Freshwater aquaculture features and characteristics

- Freshwater fish make up "75% of global edible aquaculture volume".
- Freshwater aquaculture is not a single model of production. It refers to a "wide diversity of systems across physical and economic scales, infrastructure configurations, species, ownership, and value chains".
- Most freshwater fish are raised by small- to medium-scale businesses and ponds managed by households.
- Species produced are usually different varieties of carps, tilapia, and striped catfish in polyculture systems and earthen ponds. These freshwater fish are consumed locally and nationally as well as exported.
- Freshwater aquaculture also includes "the cultivation of freshwater and brackish-water crustaceans, produced intensively in monoculture" (e.g. whiteleg shrimp) or polyculture systems (e.g. black tiger shrimp).
- "A key characteristic of freshwater aquaculture growth during the past 20 years has been the proliferation of value chains in and across countries located in South and Southeast Asia, for example, in Andra Pradesh, India, Bangladesh, Myanmar, Thailand, and Vietnam."
- China still reigns supreme with 56% of the global output of freshwater fish in 2017, supplying domestic consumers as well as exporters.
- Government support is *not* the key reason for the emergence of freshwater aquaculture in Asian countries. More significant is "economic development, rural transformation, and urbanization" which led to an increased demand for freshwater fish, and in turn attracted *private sector investment* in freshwater aquaculture. A similar trend is now happening in parts of Sub-Saharan Africa "albeit shaped by different social and economic constraints to production, structures of the value chains, and consumer demand".
- A major problem with freshwater aquaculture is *over-intensification*. It causes nutrient pollution. For example in China, 20% of "the total input of nutrient into freshwater environments in some provinces" comes from aquaculture, and public water bodies needed for important services such as drinking water cannot be used. Intensification also triggers pathogen-related decline in production (e.g. in Lake Taal in the Philippines).
- Related to over-intensification is the *increased use of compound feed and supplementary feed*, "driven by local and international companies and certification initiatives". The use of such feed, together with fertilization, "remains a key approach to producing low-cost tilapia, catfish, and carp in semi-intensive systems, and has underpinned the growth of commercial production in Asia."
- Another new phenomenon is the mushrooming of *low input-output systems*. They are located in "aquatic commons (for example, floodplains, reservoirs, and seasonal water bodies)". The fish (e.g. exotic carp) cultivated are non-fed (i.e. not based on feed). Nutrient balances and biodiversity of indigenous species are not disturbed in these systems.

Issues with aquafeed

- 11 commonly farmed fish and shellfish that are fed wild fish (ranked according to weight of total production of the farmed fish): Fed carps, talipia, shrimp, catfishes, marine fish, salmon, freshwater crustaceans, ODF (other diadromous and freshwater) fish, milkfish, trout, eel.
- Fishmeal and fish oil remain important ingredients in feed for farmed fish, especially for China, Vietnam, and Thailand. "Roughly one-third of the Chinese domestic fish catch comprises low-valued fish (89% juveniles) that are used mainly in aquaculture feeds".
- But overall, less fishmeal and fish oil from captured wild fish are used nowadays. Main reasons: 1. They are more costly than plant-based feed, with prices doubling in the 2000s. 2. Sharp rise in farming omnivorous instead of carnivorous species. 3. Improvement in feed conversion ratios. 4. Greater use of alternative, plant protein and oil. 5. Greater fishmeal and oil recovery, and use of wastes and bycatch, in wild fish processing.
- "The aquafeed industry has become increasingly dependent on conventional animal feed ingredients from terrestrial systems that are widely traded in international markets."
- This closer tie with global land-based food systems raises feed prices, triggers environmental sustainability concerns such as putting pressure on biodiversity, and can lead to unintended consequences. For example, while replacing a good portion of marine ingredients used in feeding farmed salmon in Norway with plant protein sounds like an improvement, the fact that the replacement comes from soy grown in forest clearings in Brazil is bad news.
- For now, "the share of global animal feed used as aquafeed is small—estimated at 4% (compared with roughly 40% for poultry, 30% for swine, and 25% for ruminants)". But the share will likely expand in coming years with the farming of more finfishes and crustaceans in freshwater and marine systems.
- New feed ingredients such as single-cell proteins, insect meal, microalgae have burgeoned.

Farming molluscs and algae

- **MOLLUSCS:** Farming extractive filter-feeding bivalves and algae is a major new development because the volume of production for these species have doubled in the past two decades. They now represent 6% (molluscs) and 7.6% (algae) of total aquaculture output by edible-weight, not counting the non-food products they contribute to (e.g. fertilizers, poultry grit, construction materials, pharmaceuticals), and the broad range of eco-system services they provide.
- Expansion of molluscs farming in China – the world's largest producer and consumer of molluscs – was driven by consumer demand, and was striking. In the decade between 2005 and 2014, the volume of cultivated scallops increased by 80.4% and clams by 40.8%.
- Pros and benefits of cultivating the approximately 65 species of molluscs, chiefly clams, oysters, mussels, scallops (e.g. Japanese littleneck, Pacific cupped oysters) currently farmed: 1. They do not need to be fed, except for high-valued ones like abalone and conchs (these "account for only 2.4% of cultivated molluscan output"). 2. They provide water clarification by filtering excess nutrient such as nitrogen and phosphorous produced by human activities (e.g. agriculture, sewage discharge) from the ambient environment. 3. They provide shoreline stabilization and coastal habitat structure.
- Although uncommon and site- and species-specific, there are concerns with bivalve production systems that are overstocked, not managed sustainably, and not appropriately sited (as occur in some locations in China). The cultivated bivalves can "absorb viruses, bacteria, toxic algae, and polluted organic particles". They can cause undesirable changes "in the water quality and benthic eco-systems". Furthermore, the scale of production needs to be quite large to really purify polluted water and help with eutrophication.
- **ALGAE:** "The global production of aquatic plants and algae has tripled from 10 Mt of wet biomass in 2000 to more than 32 Mt in 2017 . . . 99% of which is produced in Asia."
- Rather than sold directly to the public as food items, most of the products are used by the food industry as additives and ingredients, and for non-food purposes (e.g. in cosmetics, nutraceuticals, fertilizers, biofuels, bioplastics).
- Algae and aquatic plant cultivation faces a number of issues: 1. High incidence of viral and bacterial outbreaks in intensive farms. 2. Lack of progress in R&D (e.g. breeding, pathogen manangement), with not much incentives for innovation because of competitive pricing. 3. Producers' inability to make use of the plants' eco-system service to gain financial returns. 4. The industry outside China and Indonesia is fragmented. 5. Using algae to replace fishmeal aquafeed and to feed cattle to reduce methane emissions is not cost-competitive. 6. Current "critical social, economic, and regulatory constraints, including unethical supply chain activities, food safety considerations, and limited consumer demand".

Key challenges

1. Pathogens, parasites, pests (PPP)

- PPP is "a chronic risk for the aquaculture sector, and the intensification of production and increased trade and supply chain integration since 2000 have amplified these risks".
- Solutions include: 1. Adopting best management practices to avoid, detect and treat PPP (e.g. site selection, stocking densities, feed quality, breeding disease resistant species). But efforts such as replacing black tiger shrimp with whiteleg shrimp in Thailand still did not prevent diseases causing huge losses to the shrimp industry. 2. Use of therapeutants including antibiotics (which can be a good or a bad thing) 3. Vaccines for high-value species. 4. Feed supplementation (e.g. with plant extracts, probiotics) to boost immunity.
- But threats keep emerging, and "incidence and management of PPP throughout the global aquaculture industry is and will remain highly unpredictable."

2. Toxic algal blooms

- Algal blooms are increasing worldwide and becoming more severe.
- They are caused by "anthropogenic processes" such as intensive systems and badly managed cultivation of finfishes and crustaceans.

3. Climate change

- A whole range of threats related to climate change can lead to losses in the aquaculture sector; especially suboptimal growing temperatures, intrusion of saltwater into freshwater areas caused by sea-level rise, freshwater shortages, droughts. Climate change can also exacerbate PPP and algal blooms.
- It is important to note that losses are not inevitable and "outcomes are contingent on adaptation responses".

4. Producers' lack of motivation to meet environmental sustainability goals

- Although producers have made progress on the environmental sustainability front "either independently or in response to government regulation, private and public sector standards, and market incentives", by and large they are not motivated to do more because they are not rewarded with better prices or access to markets.

Current responses to challenges

1. Recirculating aquaculture systems

- Pros: Less direct land and water requirements (allowing for higher stocking densities). Better operational efficiency. PPP risks reduction.
- Cons: Costly. Need lots of energy. Waste disposal problems. Possible catastrophic disease failures.
- These systems tend to be used for species with high market value or "high disease and water-quality risks", and in places that can benefit from economy of scale so that it is cost-effective (e.g. salmon; "channelled pond systems for shrimp aquaculture).
- "The competitiveness of recirculating aquaculture systems for full grow-out relative to other production systems remains uncertain, however, and there have been several failures in North America and Europe and few large-scale, commercial successes over multiple years."

2. Offshore aquaculture

- Pros: Less nutrient pollution and lice infestation.
- Cons: High capital costs and risk-to-return ratios. Need to dilute wastes effectively. Operational challenges such as strong waves and storms. Conflicts with other marine uses. Constraints from government authorities which face public resistance to large-scale developments.
- China and Norway have massive offshore cages. But other countries only have "small-scale pilot operations cultivating high-valued, carnivorous species".

3. Governance, regulations, and certification issues

- All sorts of public and private regulations, codes, standards have emerged (e.g. "sustainable", "organic") to try to address concerns and issues with aquaculture. There are 30-50 kinds of voluntary private certification, rating, and labeling from NGOs. The two largest certification schemes – Aquaculture Stewardship Council (ASC), and Global Aquaculture Alliance Best Aquaculture Practice (GAA-BAP) – cover 3% of global aquaculture production. Another 53% have been rated by consumer guides (e.g. U.S. Seafood Watch).

- But governance instruments are unevenly applied, have serious limitations, and have "struggled to match the expanded geographies, volumes, and diversity of aquaculture systems". For example:
    - Chile, Norway, and governments in Asian countries have greatly facilitated aquaculture expansion while governments elsewhere have placed restrictions.
    - Robust environmental regulations rarely accompany planned growth (with the notable exception of Norway).
    - "Uneven regulation has led to disparities in investment and trade, with only a few export nations selling into major net seafood importing markets such as the USA and European Union."
    - Although producer compliance is increasing, the level remains low. Reasons range from producers' poor literacy and lack of reporting skills, to environmental factors beyond the producers' control, and lack of demand for certified products.
    - "Certified and rated production is skewed to major export species. 57% of salmon and trout, 17% of shrimp and prawns, 17% of pangasius and 11% of tilapia are certified."
- Driven by concerns for food safety, consumers in Asia seem to show increasing interest in certified seafood products. But Asian domestic demand for certification needs to grow much more significantly before certification and rating standards can become effective globally.
- A recent development is governance and management that goes beyond a single farm, involves collaborations with buyers and governments, and tries to "foster greater inclusion of large and small-holder producers in a given jurisdiction to minimize PPP, climate, and other ecological risks". This hybrid approach helps to promote "greater transparency and trust of aquaculture products exported from developing countries" as well as improve "the 90% aquaculture output that is not directed towards export markets".

Looking ahead: Seven recommendations

1. Find ways to urge producers to adopt sustainable practices and have their products receive global certifications even though there are currently few incentives for them do so (as plenty of farmed freshwater fish go to local instead of global markets and local consumers are not that interested in certifications).
2. Continue to innovate on the feed front (as costs of fishmeal and fish oil from wild fish will only increase further, and it will be challenging to come up with significant improvements to the already efficient use of these marine resources for carnivorous species).
3. Ensure prudent planning, siting, regulating, and scaling of aquaculture operations, especially when production intensifies (so as to maximize "ecosystem services provided by farmed extractive species" and reduce critical risks associated with PPP, pollution, and climate change).
4. Develop multiple strategies and governance systems (not one-size-fits-all because of the huge diversity "across species, geographies, producers, and consumers") that are science-informed, and have clear and transparent goals, but flexible and "without overly proscriptive standards and regulations" so that all stakeholders – from industries to NGOs – can innovate.
5. Provide improved financial and environmental management to recirculating and offshore systems if they are to be encouraged, or they will not "have any chance of widespread success".
6. Invest in a broad range of PPP "prevention strategies across different aquaculture sub-sectors", with the acknowledgment that treating PPP problems after they have emerged are "largely futile".
7. Adopt a food systems approach that include "nutrition, equity, justice, and environmental outcomes and trade-offs across land and sea" when formulating programs and policies.

BONUS

Screenshot from webinar "Understanding & Advancing International Crustacean Fisheries Management Part 2", held on September 22, 2021, organized by the Lenfest Ocean Program of the Pew Charitable Trusts