Harnessing the Waters

VOLUME I

A TRILLION DOLLAR INVESTMENT OPPORTUNITY IN **SUSTAINABLE AQUACULTURE**

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WWF

1818 H Street NW, Washington, DC 20433

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Acknowledgments

In 2007, the World Bank published Changing the Face of the Waters, a landmark report that outlined the opportunities and challenges of sustainable aquaculture. It helped shape global thinking on aquaculture's potential to contribute to economic growth, food security, and environmental protection.

Eighteen years on, aquaculture has expanded rapidly, becoming a vital part of global food systems as wild fisheries face increasing pressure and demand for animal protein rises. Yet access to finance remains a key constraint—particularly in developing countries where capital is limited and risks are high.

Harnessing the Waters: A Trillion Dollar Investment Opportunity in Sustainable Aquaculture revisits the aquaculture story with a new focus on finance. Through case studies of seven key industries, it examines how financial systems have supported or hindered sector development. The report distills lessons to guide smarter investment and promote inclusive, sustainable growth in aquaculture.

This report, "Harnessing the Waters: A Trillion Dollar Investment Opportunity in Sustainable Aquaculture" is part of the AquaInvest Platform, a global advisory services and analytics (ASA). It was prepared by Harrison Charo Karisa (AquaInvest Platform Co-Task Team Leader and Senior Fisheries Specialist and Serge Mayaka (Founder and Managing Principal at Akipeo) and Sergio Nates (WWF) with support from Christopher Ian Brett (Task Team Leader AquaInvest Platform Lead Agribusiness Specialist).

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EXECUTIVE SUMMARY

Aquaculture has grown rapidly, expanding at an annual rate of 6 percent since 1990. In 1980, it accounted for just 10 percent of global aquatic food production, but by 2022, this figure had risen to 59 percent. Given that over 90 percent of wild fisheries are at or beyond sustainable limits, aquaculture has become an essential source of protein and calories for a growing global population.

This report aims to inform a diverse audience including financial institutions, multilateral banks, governments, philanthropies, and private investors on investments in aquaculture. It provides insights into the opportunities and risks of investing in the sector using several case studies across the globe each of which explores the development of a specific species or species group from adoption to maturity. By reviewing the successes and challenges of aquaculture production across key production markets the report derives insights from real-world experiences to guide future investments in sustainable aquaculture. It examines the future of aquaculture in the provision of animal protein based on historical trends, debunks myths around aquaculture and explores finance and investment mechanisms in sustainable aquaculture development.

The report was developed as a collaborative effort with the World Wildlife Fund under the PROBLUE-funded Global ASA AquaInvest Platform. Additional support was provided by the Gordon and Betty Moore Foundation. It is a product of comprehensive consultative process involving a wide range of experts from various countries and technical backgrounds. By engaging both public- and private-sector players, it highlights aquaculture as a long-term investment opportunity that ensures future food security while fostering economic and environmental sustainability.

The specific questions included the following:

1. What do historical trends tell us about the future of aquaculture in providing aquatic or blue foods?
2. How have different financial mechanisms, government, private-sector involvement, research and innovation shaped the development of aquaculture industries?
3. How has the industry resolved various technical, social, and environmental challenges and harnessed successes and failures over the years?
4. What are the development pathways of selected aquaculture value chains, and what insights can be gained from the roles of public and private finance in their start-up and growth?
5. How do we create an enabling environment that tackles risks, harnesses opportunities, and guides aquaculture financiers?

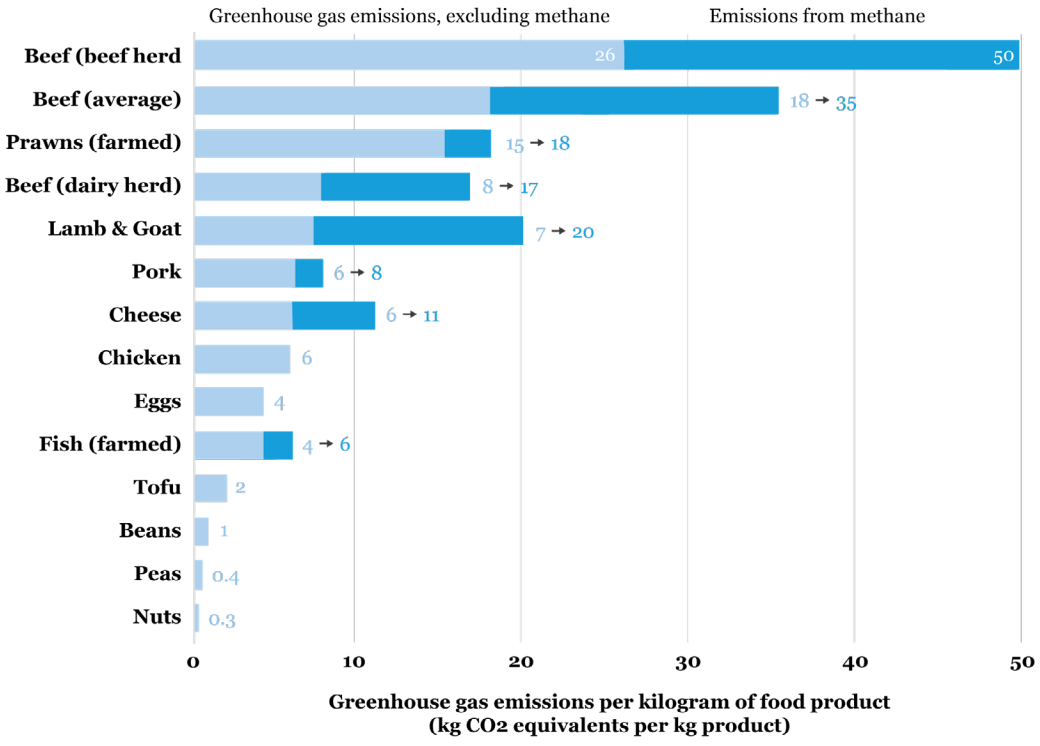
The case studies that inform the insights and key takeaways in this report are presented in detail in volume 2 of this report; and readers are encouraged to review them for further details.

KEY MESSAGES

Following are the key messages and insights gathered from this report.

1. **Aquaculture is one of the most sustainable animal protein production industries in terms of global carbon footprint, efficiency in resources use, and sustainability.** Aquaculture has the lowest carbon footprint and lowest greenhouse gas emissions (GHG) of all animal protein production sectors (Figure 1).
2. **The rapid growth of the aquaculture industry is a sum of its ability to address numerous challenges to emerge as the fastest-growing animal protein producing industry.** Aquaculture has proven to be a resilient industry able to tackle emerging challenges over the past 70 years of continuous growth.
    a. In the 1970s, aquaculture production accounted for 5.5 percent of total global seafood production. Fifty years later, it produces 59 percent of global seafood (FAO 2024b), a dramatic growth trajectory.

Figure 1. Farmed Fish Shows Lowest GHG Emissions of Animal Production

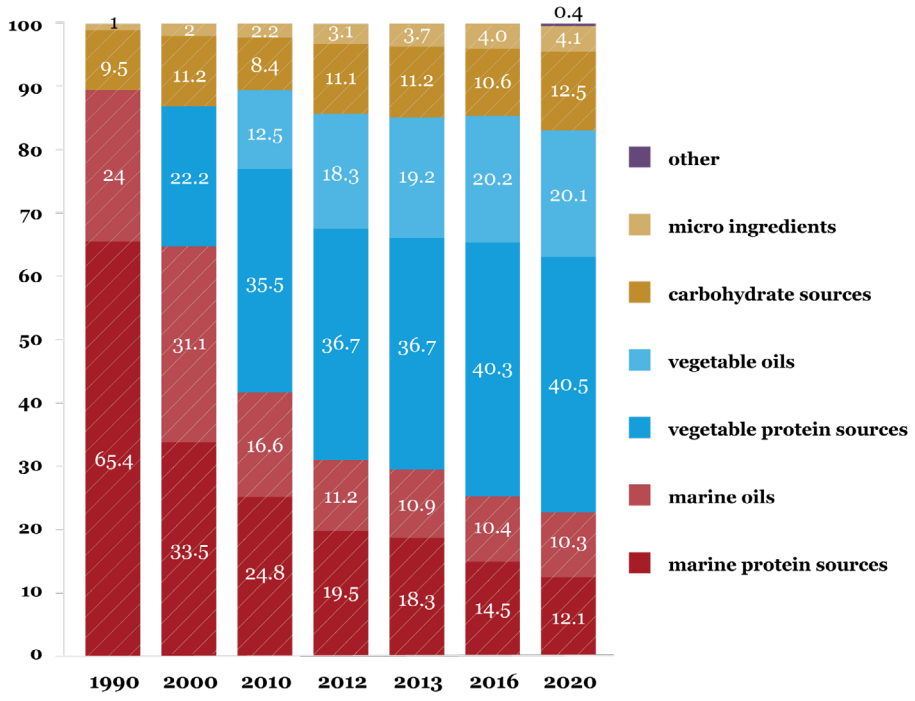


Source: Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. Science. Processed by Our World in Data. "Greenhouse gas emissions per kilogram" [dataset], https://ourworldindata.org/grapher/ghg-per-kg-poore. Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. Science. [original data].

b. The reliance on fishmeal for aquaculture feed was initially a key bottleneck in the sustainable growth of aquaculture production. Concerted industry efforts have reduced fishmeal use drastically as evidenced by the use of fish meal and oil in salmon; progressively reduced from 89.4 percent in 1990 to 22.4 percent by 2020 (Aas et al. 2022; see Figure 2). This dramatic decline was made possible by increased replacement with plant-based alternatives like soybeans, single-cell protein, and insect meals (Macusi et al. 2023).

3. **Research and innovations in resource-efficient technologies—such as the internet of things (IoT), digitalization, novel feeds, genetically improved seed, and culture systems engineering—sustain a relatively lower carbon footprint for aquaculture.** For example, environmental concerns in Viet Nam have driven improvements in sludge treatment, water monitoring, and greenhouse gas reduction initiatives. Large-scale farms increasingly use aerators to enhance water quality and reduce feed conversion ratios, and IoT-based water quality monitoring is gaining traction. In Chile, Viet Nam and elsewhere, novel feeds such as insect meals and microalgae are common.

Figure 2. Increase in Plant-Based Protein Alternatives Since 1990



Source: Aas et al., 2022.

4. **Governments play a crucial role in nascent aquaculture industry and are responsible for nurturing the transition to the private-sector to its potential.** Although each country's aquaculture industry has its own comparative advantages and development pathway, the market leaders are characterized by:

   a. country-level strategies focused on aquaculture development, and relatively effective implementation of policies and public-sector support to create a supportive enabling environment for aquaculture production;

   b. public support for private investments in research and development (R&D) to improve quality and efficiency of feed and other inputs, and overall enhancement of production yields;

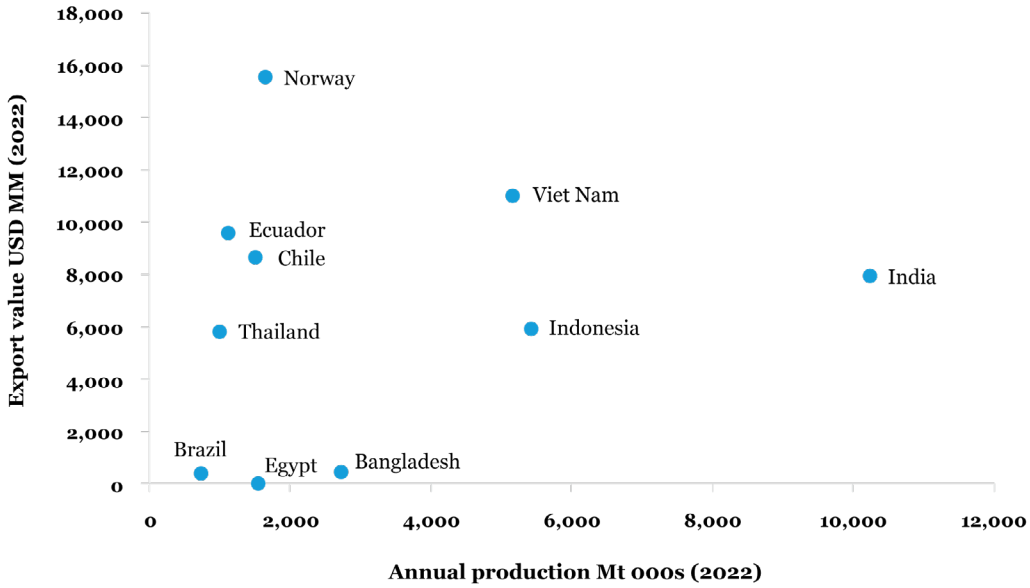
   c. public-private initiatives to improve resilience of aquaculture production, including effective responses to production shocks, such as management of disease outbreaks; and

   d. industry-level collaboration, often in conjunction with government agencies, to aid in the development of export markets for the country's aquaculture producers.

5. **One of the country-level indicators of developed, efficient aquaculture production is the relationship between total aquaculture production volume and the value of aquaculture exports.**

   ◇ Significant export volume indicates consistent production of higher-quality seafood that complies with international regulations and food safety standards. Figure 3 shows this country-level indicator for the top 10 aquaculture producer nations, excluding China, which accounts for over 60 percent of global aquaculture production.

Figure 3. Annual Production Versus Export Value for Top Producer Nations (excl. China) in 2022



Source: FAO 2024b.

6. **By 2050 global aquaculture is forecast to increase by 64 million metric tons to reach 159 million metric tons of aquatic animal protein production in a business-as-usual (BAU) setting while an Upside scenario forecasts the potential for production to reach 255 million metric tons.**

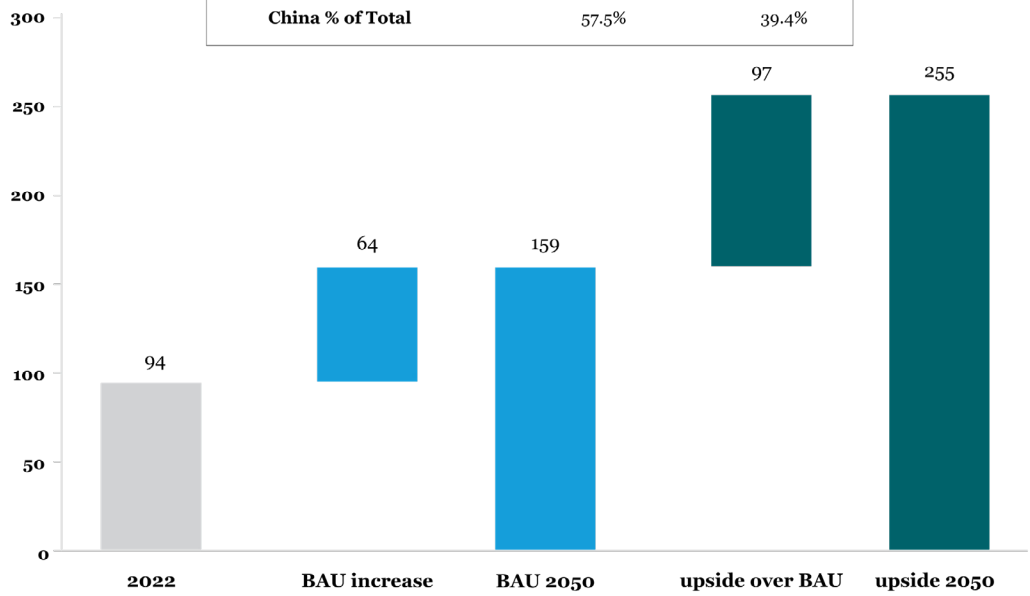
    a. Global aquaculture production reached 94 million metric tons in 2022 (FAO 2024a). This represented a 5.1 percent compound annual growth rate (CAGR) over the previous 25 years.

    b. In the BAU case, global aquaculture production is forecast to grow at a CAGR of 1.9 percent from 2025 to 2050 to 159 million metric tons by 2050. The BAU growth case maintains the same global production market structure, with the existing top 10 producer nations representing approximately 90 percent of global production as of 2050.

    c. The upside case forecasts global aquaculture production reaching 255 million metric tons by 2050, almost 100 million metric tons higher than the BAU case. This would be a 3.8 percent CAGR over the 25-year forecast period relative to the historical CAGR of 5.1 percent. China's proportion of total production is forecast to drop to just under 40 percent from its current level of close to 60 percent in large part because of aquaculture production growth outside the current top 10 producers (Figure 4).

Figure 4. 2050 Business as Usual and Upside Case Global Aquaculture Production Projections

2050 Forecast	Business as Usual	Upside
Historical 25yr CAGR	5.1%	5.1%
Forecast 25yr CAGR	1.9%	3.8%
China % of Total	57.5%	39.4%



Source: World Bank.

7. **The growth and upside potential of aquaculture is rooted in emerging markets,** particularly countries that will be among the largest economies or the most populous countries by 2050. Aquaculture today is dominated by countries in Asia (85 percent of the total); with only two markets in Latin America (Chile and Ecuador) and one African country (Egypt) producing more that 1 million metric tons as of 2022. Under the 2050 upside case projections, Asia's share of global production could drop to 70 percent due to 34 percent of the new production capacity coming from Latin America, sub-Saharan Africa, Mexico and Turkey.

8. **The projected BAU increase in aquaculture production will have a powerful social impact globally, generating 8 million to 14 million new jobs by 2050, the upside case generating an additional 13 million to 22 million.** Even at the low end of the projection, the addition of 21 million jobs in the upside scenario would represent a doubling of the number of people employed in aquaculture globally by 2050.

9. **Aquaculture is potentially the largest sustainable food investment opportunity over the next 25 years, having a projected US$0.5 trillion to US$1.5 trillion of financing required between 2025 and 2050 under the business as usual and upside cases respectively.**

    a. To realize aquaculture's sustainable growth potential, a greater proportion of current aquaculture must transition from small-scale production to more intensive production practices. This will require significant transition financing and investment capital across multiple markets to help small scale farmers increase their yields through improved practices such as pond aeration, and use of aquafeeds. Channeling capital to small-scale producers will accelerate demand for sustainable loan facilities and thematic bonds designed to incentivize sustainable aquaculture production practices.

    b. To meet the demand generated by the projected aquaculture growth, new and emerging alternative feed sources will be required. Holding fish meal and fish oil usage in aquaculture feed constant would require production volume of alternative feed sources to double by 2050 under the BAU scenario, and to triple under the upside scenario. This multiplier effect on aquaculture feed demand will spark exponential growth in investment opportunities for alternative sources such as algae, insect meal and other nonfish sources that can scale up substantially to fill the coming feed supply gap.

    c. Because most of the upside case growth is forecast to come from production markets outside the current top 10, the upside case shows a greater requirement for ancillary investments such as transportation infrastructure, cold chain logistics and distributed energy connections to build out new supply chains.

10. **A deep and diverse ecosystem of complementary investors will be needed to realize the potential for sustainable aquaculture production**

    a. Public finance investors alongside philanthropic and concessional investors need to work together to create blended financing facilities for aquaculture producers. Access to credit is a key bottleneck to aquaculture growth, due mainly to the traditional commercial bank risk aversion that continues to result in over-dependence on collateral-based lending. This has several limiting effects including gender bias and pushing producers towards predatory value chain financing.

    b. Development Financial Institutions (DFIs) and other public finance institutions that offer credit guarantee products to commercial lenders in emerging markets must explicitly include aquaculture loans as eligible for their coverage to accelerate the transition away from an over-reliance on collateral-based lending in the aquaculture sector.

    c. Philanthropic and concessional investors are crucial for the early scale-up of sustainable aquaculture operations and in developing and seeding aggregation and derisking facilities.

    d. Private investors have multiple current and future entry points to participate in the explosive growth of aquaculture. Existing large producer markets such Norway and Chile provide current investment opportunities for private investors. Beyond these investment-grade markets, private investors can look to high-growth producer markets such as India and Viet Nam, or larger investment markets poised to become future leaders in aquaculture production such as Brazil, Mexico, and Turkey. Private investors can also focus on the feed inputs market or technology applications for exposure to aquaculture's growth diversified across multiple markets.

INVESTING IN THE FUTURE

Aquaculture, the farming of aquatic organisms in both freshwater, and marine environment (mariculture) has recently become the primary source of aquatic production globally. Aquaculture has demonstrated a unique growth trajectory at an annual rate of 6 percent since 1990 and has for decades been the fastest-growing food production sector in the world. In 1980, aquaculture accounted for 10 percent of all aquatic food production (farmed fish and crustaceans, plus wild capture seafood, freshwater fish and aquatic plants). In 2011, it surpassed global beef production and by 2022 accounted for 59 percent of total aquatic food production (FAO 2024b). Given that the percentage of wild capture fishery stocks fished at unsustainable catch limits has been increasing—from 10 percent in 1974 to 37.7 percent in 2021 (FAO 2024b)—going forward, aquaculture will remain the most critical source in meeting global demand for aquatic foods. But this trend is not new or unexpected. In 2007, a World Bank report—Changing the Face of the Waters: The Promise and Challenge of Sustainable Aquaculture—recognized aquaculture as a surging industry that had continually outstripped projections. It predicted correctly that the trend, already accounting for 43 percent of aquatic production at that time, would continue far into the future.

The recent growth of aquaculture motivated the estimation of the asset value of aquaculture for all major aquaculture-producing countries in the 2024 Changing Wealth of Nations report (World Bank, 2024). Although a comprehensive estimation was not possible given data limitations, results indicated that aquaculture could generate resource rents in countries such as Norway, Egypt, Ecuador, and Indonesia. Other countries may have had positive resource rents, but lack of data records was a major impediment. Direct extrapolation of results was not possible, but the report estimated a resource rent of about US$20 billion based on conservative average resource rent values or an equivalent of an asset value of US$500 billion in nominal terms, more than double the estimated asset value for global capture fisheries of US$228 billion in 2020. Less conservative estimates of resource rents were expected to be as high as US$55 billion, equivalent to a total asset value of more than US$1,300 billion. Given that global aquaculture production is continuing to grow, driven by increased demand and improved efficiency of aquaculture practices, aquaculture's asset value has the potential for even greater impacts in the future.

The Harnessing the Waters: A Trillion-Dollar Investment Opportunity in Sustainable Aquaculture report, in its two volumes, examines the future of aquaculture in provision of aquatic or blue foods based on historical trends, debunks myths around aquaculture and explores the role of finance and investment in sustainable aquaculture development. Volume I is a synthesis of the case studies and outlook for investors; volume II offers details of each case study for those who would delve deeper into particular species and context.

The report focuses on the following specific research questions:

1. What do historical trends tell us about the future of aquaculture in providing aquatic or blue foods?
2. What role do finance and investment play in sustainable aquaculture development? How have financial mechanisms, government, the private-sector,

capacity-building, policy and regulatory frameworks, research and innovation shaped the development of aquaculture industries?

3. How have different jurisdictions and technologies resolved various technical, social, and environmental challenges over the years? How have successes and failures influenced growth in each industry, and what actions resolved them?
4. What are the development pathways of selected aquaculture value chains, and what insights can be gained from the roles of public and private finance in their start-up and growth?
5. What are the risks, opportunities, and rewards for aquaculture financiers?
6. What lessons can be learned to establish effective enabling conditions that facilitate financial investment in sustainable aquaculture endeavors? How can real-world experiences guide future investments in sustainable aquaculture?

This report analyzes seven mature aquaculture industries across countries, exploring how finance and investment, government, the private-sector, capacity-building, policy and regulatory frameworks, research and innovation and different players have shaped their development. The selected value chains include industries engaged in global and regional trade, as well as those focused on domestic consumption. Different jurisdictions and technologies have resolved various technical, social, and environmental challenges over the years. The study describes their development pathways and provides insights into the roles public and private finance played in their start-up and growth. Each case study follows a specific species or species group from inception to industrial maturity. Successes and failures that influenced growth in each industry are identified, and the root causes and solutions are discussed to help readers understand the risks, opportunities, and rewards for aquaculture financiers. Rather than relying on theoretical models, the report derives insights from real-world experiences to guide future investments in sustainable aquaculture. In doing so, it reveals an industry that has faced considerable hurdles during its decades of continuous growth, and whose robustness and resilience is a result of consistent resolution of emerging challenges and risks. On a global scale, the present growth trajectory is likely to continue far into the future. However, for this to happen, aquaculture must persist in the use of new technologies and innovations and enhance resilience in the face of environmental challenges and consumers that demand and expect quality. Adoption of these technologies will require adequate allocation of financial resources from both the public and private-sector backed by suitable investment instruments.

The intended audience for this report is a range of public and private financial institutions and multilateral banks, as well as governments, philanthropies, and individuals seeking to enable greater aquaculture investments in one or more regions. By addressing both public and private finance sector players with ambitions or interests in investing in aquaculture value chains, this report intends to advance the development of sustainable aquaculture, emphasizing its role in meeting future global food demands while fostering economic growth and environmental sustainability. It also seeks to show the future of aquaculture and gives recommendations on its sustainability.

AN OLD YET NEW INDUSTRY

The transition from wild harvest to agrarian practices has occurred over centuries, increasing the efficiency of food production; the one notable exception to this transition from wild to farmed food products is in the aquatic—or seafood—sector (the Food and Agriculture Organization of the United Nations uses the term "seafood" to represent products in its fish and fishery products database, FishstatJ). Until the late 1960s, most aquatic organisms or "seafood" products were captured through fishing at sea and gleaning on shore (FAO 2024b). The farming of seafood, or "aquaculture," has been conducted for more than 4,000 years, but did not become noticeable in global food systems until the 20th century (Stickney 2000), when aquaculture feeds, mechanical aeration, and a variety of refined breeding techniques began to be used. Consequently, aquaculture started to grow more rapidly. In the 1970s, aquaculture production accounted for 5.5 percent of total global seafood production. Fifty years later, aquaculture is the main source of aquatic foods (FAO 2024b), a dramatic growth trajectory. But this did not come except at the backlog of serious reputational challenges. Although some can be categorized as mythical (see box 1), these challenges are discussed.

Aquaculture includes the cultivation of more than 730 aquatic organisms that include 564 taxonomically recognized species of fish, crustaceans, mollusks, aquatic plants and algae. Given the rich biodiversity in aquatic ecosystems, the number of aquaculture species is still dwarfed by approximately 3000 species captured from the wild (FAO, 2024b). Nevertheless, considering aquaculture's unique growth trajectory and dominance, it is expected that more species will be brought into farming production. The growth of aquaculture has helped supplement the demand for aquatic foods and the economic and livelihood empowerment of communities and thus relieves some of the pressures on capture fisheries. However, because aquaculture does not target all wild fish species, capture fisheries still retain the same or even greater fishing effort to catch an ever-reducing volume of fish due to overcapacity in the sector. The future of domestication and diversification of aquaculture species depends on the conservation of wild stocks. Thus, fisheries management ought not slow down with the success of aquaculture but instead remain complementary.

Box 1. Ten Common Myths About Aquaculture

Myth 1: Aquaculture is harmful to the environment and causes massive deforestation.

Reality: Aquaculture no longer causes as much deforestation and shrimp farming in Ecuador thrives within forested mangroves. Sustainable aquaculture practices are designed to minimize environmental impact and help restore ecosystems.

Myth 2: Farmed fish are less nutritious than wild-caught fish.

Reality: Farmed fish can be just as nutritious as wild-caught fish (if not tastier), and their diet can be controlled to enhance their nutritional value.

Myth 3: Aquaculture uses excessive antibiotics.

Reality: Responsible aquaculture practices use antibiotics sparingly and only, when necessary, with strict regulations and certification standards in place to ensure food safety.

Myth 4: Aquaculture depletes wild fish stocks.

Reality: Many aquaculture operations use plant-based feeds or little of sustainably sourced fish meal, reducing pressure on wild fish populations.

Myth 5: Farmed fish are full of chemicals and contaminants.

Reality: Regulations and monitoring ensure that farmed fish are safe to eat, with contaminant levels well below safety thresholds.

Myth 6: Aquaculture is only about fish farming.

Reality: Aquaculture includes the farming of various aquatic organisms, such as shellfish, seaweed, and crustaceans.

Myth 7: Aquaculture is a new and unproven industry.

Reality: Aquaculture has been practiced for thousands of years and has evolved into a sophisticated and scientifically managed industry.

Myth 8: Aquaculture is not sustainable.

Reality: Sustainable aquaculture practices are being developed and implemented worldwide, focusing on environmental, economic, and social sustainability.

Myth 9: Aquaculture produces poor-quality fish in poor conditions and welfare.

Reality: High-quality standards, animal welfare principles, and best practices in aquaculture ensure that farmed fish are healthy, safe and of good quality.

Myth 10: Aquaculture is not necessary.

Reality: Given the growing global demand for seafood and declining wild fish stocks, aquaculture is essential for meeting future food needs sustainably.

These myths often stem from misunderstandings or outdated information. Sustainable aquaculture practices are continually improving, making it a vital part of the global food system.

SETTING THE RECORD STRAIGHT

The rapid development of aquaculture has raised numerous concerns including environmental ramifications, pollution, habitat destruction, spread of diseases, and the impact on wild species through demand for fish oil and fish meal (Greenpeace 2019; Talbot and Hole 1994; Spencer et al. 2024). Table 1 summarizes the negative impacts that irresponsible aquaculture has had on the environment as well as the positive impacts of responsible aquaculture. The negative impacts include loss and degradation of habitats (exemplified famously by mangrove deforestation), salinization of soils, water pollution through misuse of chemicals and antibiotics, and alteration of food webs. These directly affect the environment when good aquaculture practices at local level are not followed consistently. Other negative effects include depletion of wild species, genetic resources, and biodiversity through sourcing of seed and broodstock and interaction with farmed species, spread of disease and parasites to wild species and impacts of exotics. The action on these effects act at a wider geographical level and are risks inherent in carrying out aquaculture in the open natural environment.

Studies indicate that large-scale land-use changes were the predominant cause of loss of mangrove areas. It has been reported, for example, that mariculture ponds were either directly or indirectly responsible for between 50 percent and 80 percent of the loss of mangroves areas in parts of Asia (Primavera 1991; Wolanski et al. 2000). Although the trend appears to have dissipated somewhat, many still remember the mangrove deforestation that the boom and proliferation of onshore aquaculture for shrimp and finfish had in the mid-1970s and early 1980s (Friess et al., 2019). Although aquaculture remains one of the factors that led to decimation of mangroves, adoption of good mangrove restoration of aquaculture ponds and advancement in shrimp production technology have lessened the threat over the years. In Viet Nam, mangrove loss reduced to 17.5 percent and mangrove areas increased by 17.9 percent between 2011 and 2023 as a result of a series of government measures and enforcement of aquaculture regulations (Tran, Reef and Zhu, 2024). It has been shown, for example, that aquaculture ponds restored passively back into mangroves improving biodiversity better than (Jayakody et al. 2012) and achieving net primary productivity like natural mangroves (Sidik et al. 2019). According to Jiang et al., (2025), aquaculture areas offer opportunities for mangrove restoration, as most still maintain suitable landscape-scale biophysical conditions and can offer large blue carbon benefits. Furthermore, the Integrated Mangrove Fishery Farming System (IMFFS), which involves integrated cultivation of mangroves, halophytes and culture of fish, crabs and prawns, enhances coastal aquaculture sustainability and strengthens resilience of coastal communities (Selvam et al, 2012). The ability to employ different types of shrimp-mangrove-rice farming in degraded saline lands avoids adverse effects of aquaculture expansion and improves farmer economics (Liao, 2025).

Misinformation and misunderstanding are therefore largely responsible for the negative perception and masking of objective assessment and contextualization of the mitigation measures in place for sustainable aquaculture. The aquaculture practiced today is far from the destructive aquaculture of that time though quite often, aquaculture bears the brunt even when other factors are involved. Dewalt, Vergne, and Harding (1996) demonstrate the involvement of multiple causes in the environmental degradation of the Gulf of Fonseca among them aquaculture, increasing number of fishermen, construction of salt ponds, firewood, harmful agricultural practices, and poor policies and regulations. Nevertheless, Dewalt, Vergne, and Harding (1996) seek to set the record straight citing mixed messages on aquaculture's impact on the environment and quoting frustrations: "Despite our apportioning of the blame to many groups in the region, our original report (Vergne, Hardin and DeWalt, 1993) has been presented in some sources as a blanket indictment of the shrimp industry." A view of aquaculture that recognizes the development context and balances the challenges and negative impacts on one hand and mitigation measures and benefits on the other hand, is needed to realize the numerous opportunities aquaculture presents.

Interestingly, some of the benefits of responsible aquaculture in Table 1, such as desalinization of soils, disease, pest and weed control, nutrient and heavy metal sink, stock recovery and preservation of wetlands appear to have the opposite effect of irresponsible aquaculture on the environment. This is an indication that an emphasis on responsible aquaculture could undo the harmful effects. This emphasis is more dramatic given that Table 1 is a replica of table 2.1 from World Bank's 2007 report Changing the Face of the Waters: The Promise and Challenge of Sustainable Aquaculture. Investments can choose which kind of aquaculture to practice between responsible and irresponsible with attendant implications. Second, it indicates that the negative perceptions on aquaculture are not new. Third, that aquaculture has continued to grow despite the perception of being the most serious source of negative environmental impacts is a testament of the dominance of the positive effects of responsible aquaculture that came as a result of lessons learned.

The farming of salmon in Chile for example, faced serious criticism over environmental impacts, regulatory issues, and conflicts with local communities. Concerns included water pollution and benthic degradation from uneaten feed and waste accumulation, high antibiotic use, escapes of farmed salmon, and conflicts with Indigenous communities. The infectious salmon anemia (ISA) crisis of 2007 to 2009 which went on to reduce production by half, was a trigger for stricter application of biosecurity measures and environmental regulations. This resulted in self-regulation of companies to minimize nutrient pollution, improve feed efficiency, and develop integrated multi-trophic aquaculture approaches. Carbon neutrality has become a target with carbon footprint in salmon transport and processing being an area of focus.

Table 1. Environmental Costs and Benefits of Aquaculture

Negative Environmental Impacts of Irresponsible Aquaculture	Environmental Benefits Impacts from Responsible Aquaculture
Loss or degradation of habitats such as mangrove systems	Agricultural and human waste treatment
Salinization of soil and water	Water treatment and recycling
Coastal and freshwater pollution for example contamination of water and fauna through misuse of chemicals and antibiotics	Nutrient and heavy metal sink
Alteration of local food webs and ecology	Pest control
Depletion of wild resources and biodiversity for seed or broodstock	Weed control
Spread of parasites and diseases to wild stocks	Disease vector control
Depletion of wild genetic resources through interaction between wild populations and cultured populations	Desalinization of sodic soils
Impact of introduction of exotics (deliberate or inadvertent)	Recovery of depleted wild stocks
	Preservation of wetlands

Source: World Bank, 2007.

Thus, refocusing efforts toward sustainable aquaculture can lead to complete reversal of the negative aquaculture that has been known for in the past. Throughout the case studies, we see the aquaculture industry responding by providing solutions through research, technologies, and innovations. A casual review of literature shows that the problems of aquaculture have always been articulated by the industry with a view to resolving them (see, for example Armikolae, 2011; Beveridge and Philips 1993; Páez-Osuna 2001; Visch et al. 2020). A close reexamination of the facts based on scientific evidence is necessary to set the record straight. It is evident from the case studies in this report that although these challenges should not be downplayed, aquaculture has been able to address each of them to emerge the fastest-growing food production sector.

The capacity of aquaculture to contribute to net production of aquatic foods and to replace capture fisheries has long been a point of debate. Hannesson (2003) argued, erroneously, that aquaculture could not supersede wild fish stocks as a source of supply of fish because of environmental challenges and dependence on fishmeal and oil. Similar sentiments were raised recently claiming that because the two modes of production tend to target a different set of species, aquaculture is likely to only supplement wild fisheries (Longo and York (2024). However, statistics have debunked this notion, global aquaculture having already overtaken fisheries as primary source of aquatic animal food in 2022 (FAO, 2024a). Although aquaculture contributed up to 59 percent of global aquatic production in 2022 when including seaweed and 51 percent excluding seaweed, a closer examination

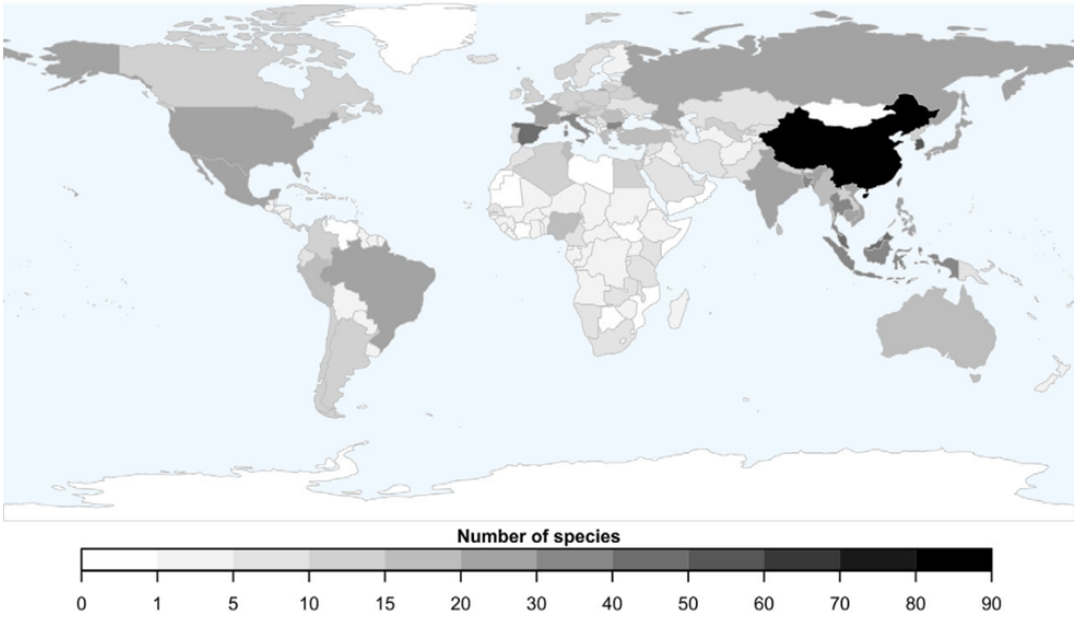
of the large producer countries reveals even higher aquaculture dominance. For example, China, India, Viet Nam and Bangladesh produced respectively 80 percent, 65.1 percent, 60 percent and 57.4 percent of total aquatic production from aquaculture in 2022. Thus, though it has been correctly argued that aquaculture cannot be the panacea to creating sustainable wild fisheries, fish farming has over the years demonstrated capacity to continue replacing wild fisheries. Considering increasing efforts at domestication of new species, application of technologies, use of novel feeds and use of byproducts, aquaculture will continue as a net contributor to global seafood supply (Sandström et al. 2022). The rapid expansion of aquaculture is a significant opportunity to promote environmentally sustainable and financially profitable seafood production.

Sourcing of seed from the wild for some difficult to breed marine species has been another area of concern. Efforts at domestication have been intensified over the last few years though the effective number of species varies across countries. It has been argued that aquaculture targets only a small proportion of the wild aquatic species so far, but the diversity and dispersion of aquaculture products is also expected to continue expanding. Currently aquaculture includes the cultivation of more than 730 aquatic organisms, including finfish (47 percent), aquatic plants and algae (29 percent), mollusks (14 percent) and crustaceans (9 percent) as shown in Table 2. The rate of diversification of aquaculture species has been on a steady rise, increasing from 73 in 1950 to 438 in 2018 and to 448 species in 2020 with fewer species dominating global production (Cai, Yan, and Leung 2022; Cai et al. 2023). Although a high rate of diversification would be ideal as an avenue for building resilience and biodiverse aquaculture, the incentives for diversification have been discouraging for private-sector players (Cai et al. 2023).

Although no clear relationship emerges between the species farmed and total production, it is instrumental that Asia, which dominates the aquaculture sector and contributes more than 90 percent of overall production boasts a much greater diversity in cultivated species than other regions. Notably, nine of the top 10 countries with the highest aquaculture species diversity are in Asia, China taking the lead by a significant margin (Figure 5). For example, in 2017 China cultivated 86 species of aquatic organisms in various production systems, whereas Norway cultivated 13, mainly in marine cage systems (Metian et al., 2020).

Although this report focuses on food and nutrition security and presents aquaculture as a source of protein and food, the growth of aquaculture benefits several other nonfood uses. The Global Seaweed New and Emerging Report (World Bank, 2023) presents at least ten applications of farmed seaweed including biostimulants, bioplastics, fabrics including textiles and biosynthetic leather, construction materials, nutraceuticals, pharmaceuticals, methane reducing additives. Nonfood products from finfish also include fish leather, burn treatment bandage, ornamentals and recreation, biopolymer, albumins, pearl essence, biochemical, biochar, antimicrobial proteins, pharmaceuticals, and wastewater treatment, among others as well as employment especially in rural areas (Sarkar et al. 2023; Sarkar et al. 2024). Being recognized as a highly efficient system for producing protein for human consumption, aquaculture has the potential to lower carbon emissions for other less efficient food systems (Napier et al., 2020).

Figure 5. Number of Farmed Species, by Economies, 2017



Source: Metian et al. (2020).

Note: The scale of the legend is not linear; it provides more resolution for lower values

Table 2. Global Aquaculture Production in 2022, Aggregated by the International Standard Statistical Classification of Aquatic Animals and Plants

ISSCAAP Division	Production (million tons)	Percent
Aquatic plants and algae	35.078	29
Crustaceans	11.237	9
Diadromous1 fish	5.847	5
Freshwater fish	48.129	39
Marine fish	3.484	3
Miscellaneous aquatic animal products	0.002	0
Miscellaneous aquatic animals	1.062	1
Mollusks	17.741	14

Source: FAO (2024a).

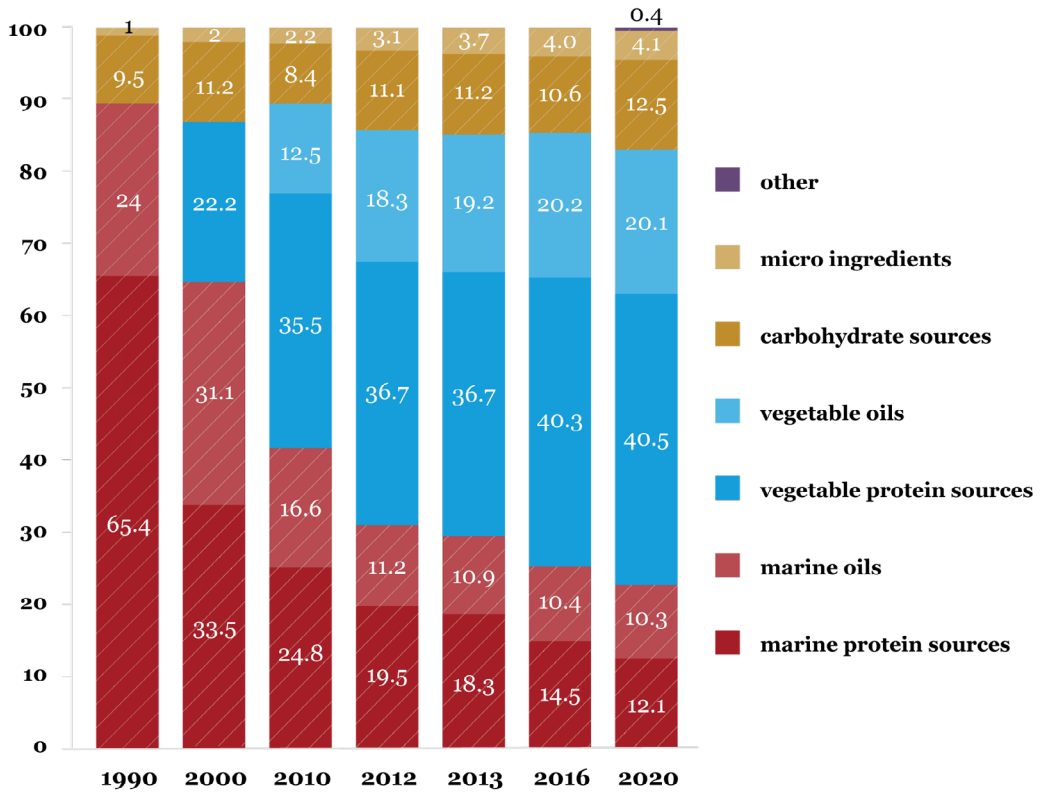
[1]Aquatic organisms that migrate between salt and fresh water during their natural life cycle.

Two types of aquaculture are recognizable by their mode of nutrition: fed and unfed aquaculture. Nonfed aquaculture (such as the extractive culture of shellfish, and seaweed) is among the world's most efficient mass producers of plant and animal proteins. The nonfed or low trophic species feed on naturally available food and are at the bottom of the trophic pyramid. Fed aquaculture currently accounts for two-thirds of aquaculture globally. Because fed aquaculture was fully dependent on fish meal and oil, it was thought that growth of aquaculture could affect fisheries negatively (Hannesson, 2003; Tacon and

Metian, 2009; Naylor et al., 2009; Boyd 2013, 2015). Although historically, large proportion of fish meal and oil were used to make up the ingredients in fish feed (Boyd, 2015), with aquaculture using up to 60 percent of fish meal production and around 80 percent of fish oil production globally at that time (Boyd, 2013), this has recently changed drastically. Thus, although authors such as Spenser and colleagues (2024) claim higher fish inputs to farmed fish outputs, such arguments consider neither the contribution of aquaculture to conservation of wild stocks nor the advancements in fish nutrition nor that aquaculture has not led to an increase in fishing for marine ingredients (Glencross et al., 2024).

Due to concerted industry efforts away from fishmeal made possible by alternative aquafeed ingredients supplied from animal wastes, insect meals, single-cell protein, and plant-based protein sources (Macusi et al., 2023), the use of fish to feed fish has decreased dramatically (Figure 6). For example, the use of fish meal and oil in salmon, a carnivorous fish, has continued to progressively reduce from 89.4 percent in 1990 to 22.4 percent by 2020 being substituted with plant-based alternatives such as soybeans (Aas et al., 2022). No such dramatic reduction in use of fishmeal and fish oils has been noted elsewhere. Aquaculture is therefore expected to continue weaning itself from dependence on fisheries. From the foregoing, it seems clear that though aquaculture will continue to depend on resources in the aquatic environment, that dependence will continue decreasing over time.

Figure 6. Feed Ingredients (percent) in Norwegian Salmon Feed, 1990–2022 (Duplicate of Figure 2)



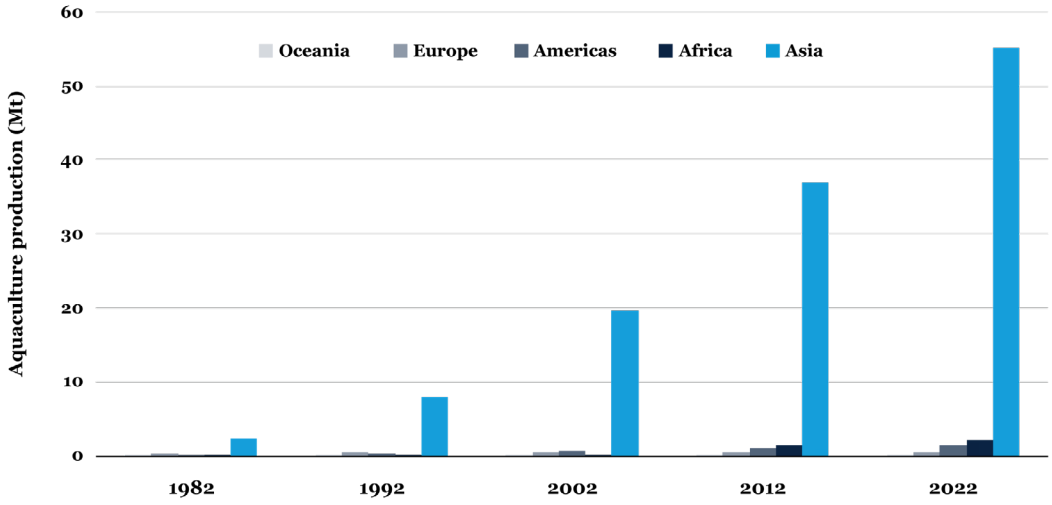
Source: Aas et al., 2022.

It has been claimed that aquaculture expansion is hampered by declining availability of suitable land and water for which inland aquaculture must compete with agriculture, municipal water supplies, industrial water use and hydroelectric dams. Despite the challenges and competition for freshwater, freshwater aquaculture in recent decades has grown rapidly, motivated by the increased demand for aquatic products in the face of declining capture fisheries (Fluet-Chouinard et al. 2018). Evidence suggests considerable growth in inland aquaculture in South Asia and Africa (see Figures 7 and 8). Africa, for example, is growing at 7 percent annually—higher than aquaculture's global average expansion rate (Ragasa et al. 2022). Freshwater systems have dominated this growth: only 1 percent has been in the marine environment.

Improvements in the development of this industry can also be attributed to new technologies. The application of efficient technologies through research and innovations in artificial intelligence, digitalization, novel feeds, genetically improved seed, and culture systems engineering has sustained a relatively lower carbon footprint for aquaculture.

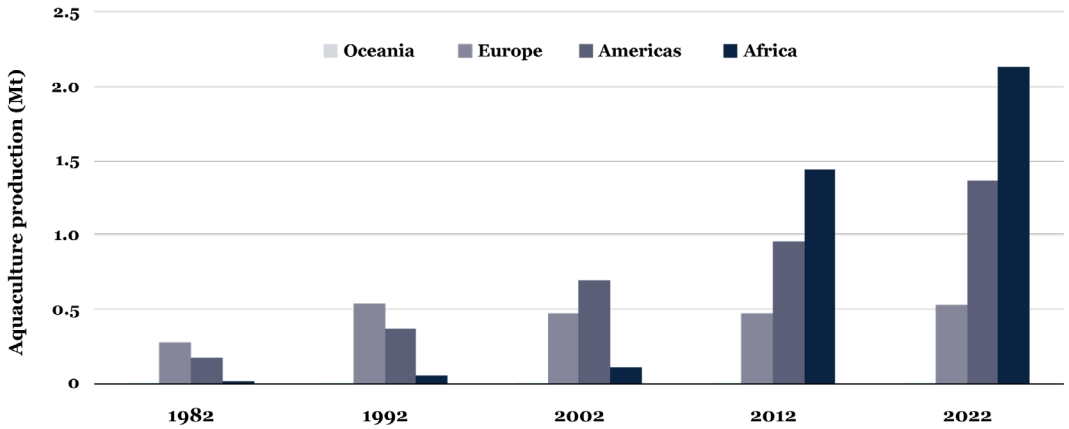
Furthermore, while it is thought that fish are raised under conditions that compromise their welfare due to overcrowding, poor water quality, inhumane handling and slaughtering, the application of fish welfare is gaining traction as a critical component of sustainable seafood production. The global shift from wild capture to aquaculture has intensified the need for ethical and sustainable practices that address stress, disease, and behavioral needs of farmed species, resulting in direct improvement of productivity, product quality, and reducing environmental impact. This is often enhanced by adherence to fish production standards, certification schemes and welfare assessments in aquaculture (Browning, 2023). A recent Learn Blue series organized by the World Bank and FAI demonstrated that fish welfare is a "win-win-win" for animals, farmers, and consumers.

Figure 7. Freshwater Aquaculture Production Across Continents



Source: World Bank.

Figure 8. Global Freshwater Aquaculture Production Excluding Asia



Source: World Bank.

NATURAL RESOURCE USE AND SCARCITY

Governments, businesses and the investment community continue to recognize aquaculture's contribution to improved livelihoods, national food and nutrition security, jobs and income generation especially in rural areas. Amid concern for land conversion, soil erosion and degradation, and competition for freshwater, the ocean is a great opportunity for a step-change in the magnitude of aquatic food production. The use of land, freshwater and energy is overall low for the global aquaculture sector, seaweed and herbivorous fish requiring no or limited input. Boyd and McNevin (2014) postulated that land may be the most important limiting factor in aquaculture production systems given the dominance of ponds systems. However, because fishponds are generally less efficient (Table 3), efforts should be concentrated on systems that can maximize returns on investment (Rutaisire et al. 2010).

Focus on the more intensive systems and use of the oceans is likely to reduce reliance on traditional pond systems. Hofherr, Natale, and Trujillo (2015) found that space limitation in absolute terms is unlikely to be a constraint in expansion of mariculture in the European Union (EU) countries. Froehlich and colleagues (2018) concluded that even if one-third of human global protein demand was met using farmed fish by 2050, the impact on land use relative to livestock would be comparatively low because of the high feed efficiency of aquatic species.

Degraded saline lands unsuitable for primary agriculture can be used for integrated agriculture aquaculture (Dong and Li 2023). As Giri and colleagues (2022) indicated, about 98 percent (average 821.9 hectares per year) of new aquaculture expansion in Sundarbans region in India have originated from the conversion of agricultural land rendered unsuitable by salinization (DasGupta et al. 2019). In the present report, transition of former agricultural lands into aquaculture due to salinity intrusion has been reported, including in Egypt, Bangladesh and Viet Nam. This type of conversion has less impact on biodiversity than conversion of natural forests.

Table 3. A Comparison of the Potential Fish Yield from Different Cultures Systems by Small-Scale Farmers, Uganda

Production system	Yield (kg m^3)
Ponds	0.2
Tanks	100
Cages	150
Raceways	200

Source: Rutaisire et al. 2010.

Feed is the single highest operating cost for aquaculture operations, representing up to 70 percent of the total operating costs given the relatively high protein required of farmed fish. Access to feed can be a major constraint in developing the aquaculture industry in a country. Land and freshwater are two natural resources needed for production of plant-based feed ingredients and certain novel animal-based feeds such as insect meals. Ideally, successful production of feed ingredients from the landscape around the fish farms could help the aquaculture system thrive if agricultural and aquacultural activities are well-planned simultaneously. Thus, planning for their production and use is complicated by the multiple usage and international trade.

Currently, more than 800 million tons of cereals (one-third of total cereal production) are used for animal feed production and projected to be more than 1.1 billion tons by 2050 (Makkar 2018). The demand for soybeans is expected to increase as aquaculture production increases and with it, more pressure on land and forested landscapes. Landscape planners and agricultural experts will need to plan for this anticipated expansion while enabling farmers to benefit from extra incomes fueled by demand for aquafeed ingredients.

FINANCING WHAT AQUACULTURE?

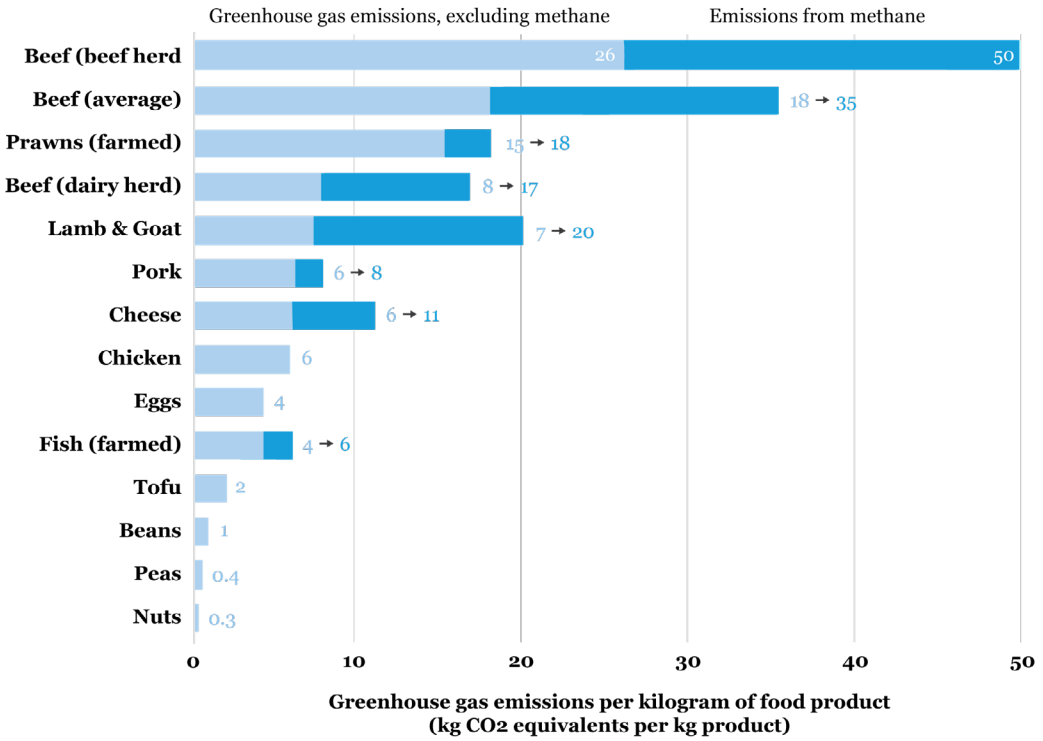
Aquaculture, although vital for global food security and income generation, has often been criticized for negative environmental impacts. Such criticism is normally leveled at the highly intensive systems without considering the totality of effect by several culture systems. Aquaculture is a nature-based solution (NBS) and ecosystem services provider (IUCN, 2020; Hughes, 2021; Le Guevello et al., 2023, Bodycomb et al., 2023). By harnessing the principles of natural ecosystems, integrated aquaculture can be an NBS that not only reduces the environmental footprint of aquaculture operations but also promotes ecological sustainability, biodiversity-friendly practices, biodiversity conservation, and potentially facilitate payment for ecosystems services (Le et al. 2024).

Investing in integrated aquaculture with other farming activities to enhance ecosystem services can be highly attractive as a social, responsible activity. Collectively, it is evident that integrated aquaculture aligns with climate change mitigation goals. In essence, integrated aquaculture project initiatives have the potential to meet the criteria for carbon offset programs, allowing them to generate revenue by selling carbon credits, thus incentivizing sustainable practices. The cultivation of aquatic plants (such as seagrasses, seaweed, and mangroves) effectively absorbs and stores carbon, and reduces CO2 emission in the air, which is crucial in mitigating climate change. By enhancing carbon sinks, promoting carbon-rich sediments and reducing land-based emissions, aquaculture holds the potential for carbon sequestration and reducing greenhouse gas (GHG) emissions.

Unknown to some, aquaculture is one of the animal production sectors with the least carbon footprint as demonstrated by low greenhouse gas emissions (Figure 9).

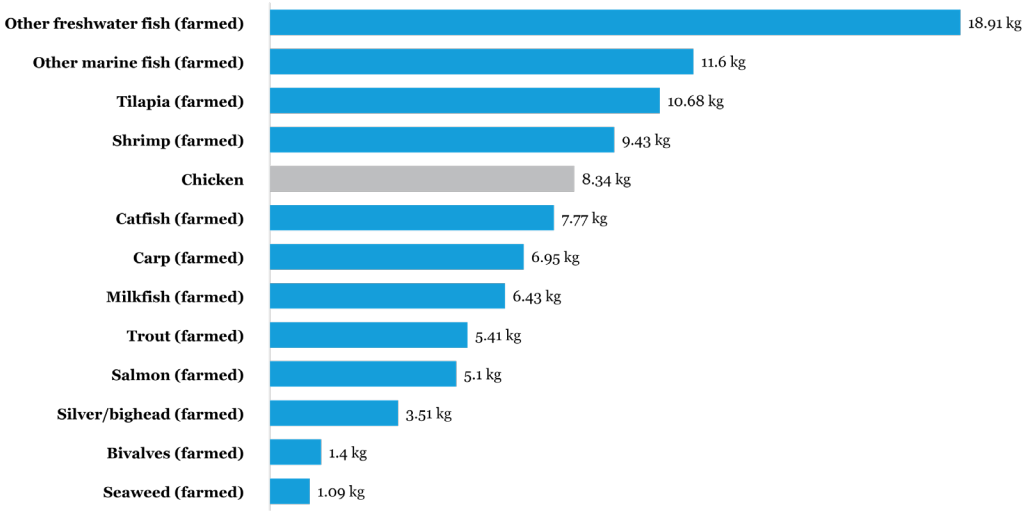
Furthermore, differences in GHG emissions across species may be interesting in deciding which species to prioritize (Figure 9 and 10). However, the level of GHG emission from different species is determined by numerous factors including resource-use efficiency, genetics and quality of feed.

Figure 9. Comparative GHG Emissions of Animal Protein Production Sectors (Duplicate of Figure 1)



Source: Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. Science. Processed by Our World in Data. "Greenhouse gas emissions per kilogram" [dataset], https://ourworldindata.org/grapher/ghg-per-kg-poore. Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. Science. [original data].

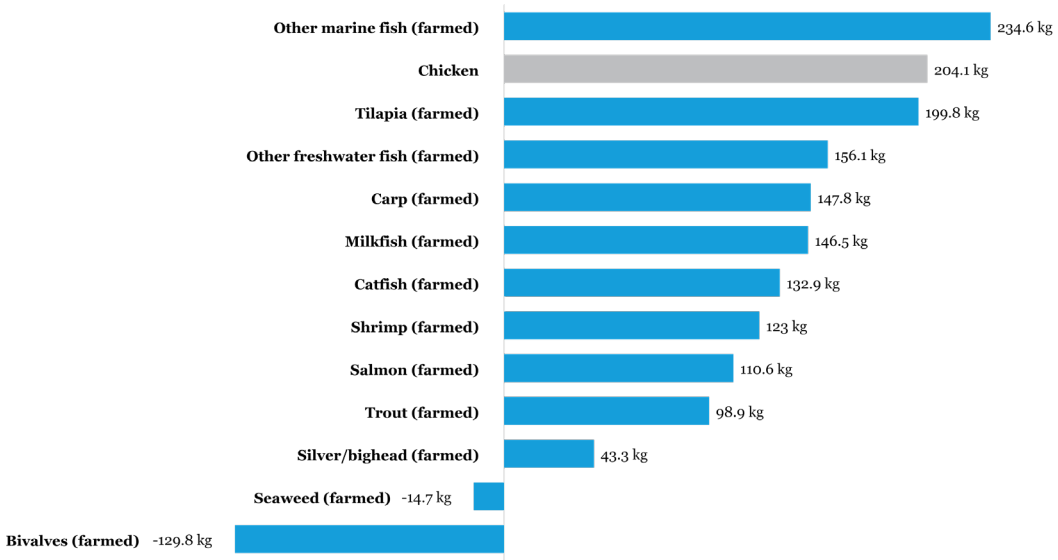
Figure 10. Greenhouse Gas (GHG) Emission Rates from Farmed Fish Production



Source: Our World in Data, https://ourworldindata.org/grapher/ghg-emissions-seafood, based on data from Gephart et al. (2021).

Note: GHG emissions are expressed in kilograms of carbon dioxide-equivalents ($CO_{2\text{-}eq}$) per kilogram of edible weight.

Figure 11. Nitrogen Emissions in Kilograms of Nitrogen per Ton of Edible Weight



Source: Our World in Data, https://ourworldindata.org/grapher/nitrogen-emissions-seafood, based on data from Gephart et al. (2021).

Note: Chicken, the lowest-carbon meat, is used for comparison.

In recent years, interest in farming the sea has been growing because of increased competition for land and freshwater resources. Yu and colleagues (2024) estimate that 9.16 ± 1.22 million square kilometers of potentially suitable seawaters are available for offshore finfish mariculture. On the other hand, an upper limit to seaweed aquaculture, has been estimated at 48 million square kilometers, equivalent to about 700,000 million tons of fresh weight per year (Froehlich, et al. 2019). This type of offshore mariculture is contemplated as the future of production that requires substantial capital investment and with great potential for production. The inclusion of integrated multitrophic aquaculture alongside fish cages reduces would-be excess nutrients in the water and sediments. As shown in Table 3, cages are among the most productive aquaculture systems.

Implementing circular economy principles into integrated aquaculture systems represents a holistic approach to the aquaculture industry that aligns with broader goals of environmental and economic sustainability. This strategy will also prevent resource-use conflicts through better planning including spatial landscape and seascape programs while creating alternative livelihoods and diversifying income-generating activities. However, successful implementation may require a supportive regulatory framework, policies, and investment in technology innovation.

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CASE STUDIES

Seven comprehensive case studies of major aquaculture species across seven diverse markets are presented to illustrate how production methods, regulatory environments, and country-specific factors significantly influence investment outcomes. By examining aquaculture sectors in Ecuador (whiteleg shrimp), China (carp), Bangladesh (black tiger shrimp), Thailand (giant freshwater prawn), Chile (Atlantic salmon), Egypt (Nile tilapia), and Viet Nam (pangasius), the analysis evaluates investment opportunities through detailed examination of species-specific risks, technological advancements, market dynamics, and financial challenges. The comparative analysis reveals how these countries have developed unique approaches to aquaculture based on their environmental conditions, historical context, market positioning, and technological capabilities—providing crucial insights for investors, policymakers, and industry stakeholders seeking to understand the complex factors driving sustainable growth and profitability in global aquaculture.

1 ECUADOR: WHITELEG SHRIMP

Ecuador today is the world's second-largest shrimp producer, farming 225,000 hectares of a native whiteleg shrimp (*Litopenaeus vannamei*); its projected 2024 production was 1.477 million tons at an export value of US$6.3 billion.

The country has maintained its competitiveness through improvements in production efficiency despite falling global shrimp prices due to oversupply. Rather than pursuing high-intensity farming, Ecuador focused on moderate yield increases through reasonable stocking densities, improved feed management, and effective water quality and disease control. This has increased production efficiency, leading producers achieving feed conversion ratios as low as 1.4 and producing up to three shrimp cycles per year.

Feed production is a crucial component of Ecuador's shrimp farming success. Shrimp farming has also shifted toward greater use of electric aeration, reducing dependency on diesel and lowering costs, though recent subsidy cuts on fuel have introduced some uncertainty. The industry's processing and export sector is well developed, with vertically integrated companies handling shrimp from hatchery to export. The top 10 exporters account for more than 60 percent of exports.

Ecuador's ability to produce high-quality shrimp with lower costs than competitors gives it an edge in global markets. However, challenges persist, including disease outbreaks, extreme weather events patterns such as El Niño, and security concerns related to criminal activity. A major environmental issue associated with shrimp farming is habitat conversion, such as the extensive mangrove deforestation that occurred in the early years of industry expansion. Government regulations now mandate mangrove restoration and impose fines for deforestation, though enforcement varies. Many farms have also moved away from mangrove areas because of the lower yields associated with acidic soils.

Market concentration is a key risk: 60 to 70 percent of exports go to China. A free trade agreement with China, ratified in 2024, is expected to further solidify Ecuador's dominance in the Chinese market. Still, the industry is looking to diversify. Other challenges include

the removal of diesel fuel subsidies, creating uncertainty for large farms, and new anti-dumping suits filed by the Southern Shrimp Alliance against Ecuador and other producers.

The sector's financing landscape has evolved. Today, the industry benefits from diverse financing sources, including commercial banks, international investors, and specialized financial products. However, access to capital remains a challenge for mid-sized operations and ventures focused on new species or value-added processing.

The industry's resilience is rooted in its ability to adapt to changing conditions through technological innovation, efficient production methods, and strategic financial decisions. Moving forward, Ecuador's shrimp industry will need to continue diversifying its markets, upgrading processing capabilities, and ensuring long-term environmental responsibility to maintain its competitive position.

2 CHINA: CARP

China's carp aquaculture sector—black carp, grass carp, silver carp, and bighead carp—began in 475 BCE, when the first known book on aquaculture was written. Today, China leads global carp production, accounting for more than 65 percent of total output, reaching 20.23 million tons in 2021 and valued at more than USUS$46 billion. China's carp production is the largest single aquaculture sector in the world, a testament to centuries of accumulated knowledge combined with modern techniques (Hua Yue et al., 2024).

The sector's development accelerated significantly after 1949 with government involvement in artificial propagation. Since the 1980s, Chinese carp aquaculture has transformed from semi-intensive farming to high-density monoculture systems, a transition facilitated by policy reforms that opened China to international trade, bringing improved technologies, equipment, and foreign investment.

Most carp farming occurs in freshwater pond systems owned by smallholder farmers. Pond culture accounts for 73.4 percent of China's total freshwater aquaculture production, typical pond sizes ranging from 0.5 to 5 hectares. The industry relies heavily on feed, which represents 60 to 75 percent of production costs.

The annual growth rate has declined since the 1980s and 1990s due to lower population growth, stricter environmental protection policies, and changing consumer preferences. Disease outbreaks pose significant threats, economic losses amounting to CNY 58.9 billion (USUS$8.2 billion) in 2020, some 5.8 percent of total output value (Zhao 2023). The COVID-19 pandemic disrupted transportation, supply chains, production, and market access. Natural disasters and climate change further threaten the sector, typhoons being responsible for an estimated 32 percent of stock losses.

Environmental concerns include water pollution, biodiversity loss, and risks associated with antibiotic resistance. Social challenges include an aging farmer population and declining interest from younger generations in agricultural work.

The industry's financing has evolved from personal savings and family loans to diverse funding sources. Government support has been crucial through investments in infrastructure, subsidies, and fiscal support aimed at food security and economic development.

Market dynamics show that although carp remains an important protein source domestically, international trade is limited. The total export volume has remained static at around 50,000 tons annually for the past decade. This is largely due to the bony nature of carp, which has limited its appeal outside China.

The industry's development has relied heavily on government support, but recent regulations have begun restricting land use for aquaculture purposes. Beijing continues to support aquaculture development while guiding farmers toward more sustainable practices.

To ensure future success, the industry needs to optimize farming techniques, reduce costs, improve efficiency, and strengthen environmental protection facilities. Technological innovations in genetics, breeding, feed formulation, and disease management offer pathways for sustainable growth.

3 BANGLADESH: BLACK TIGER SHRIMP

Bangladesh's black tiger shrimp (*Penaeus monodon*) industry is a cornerstone of the country's aquaculture sector. In 2021 and 2022, it accounted for 75 percent of the country's USUS$530 million seafood export earnings. Production is centered in 263,000 hectares of farming area in coastal districts. The industry has evolved from large-scale commercial operations to predominantly smallholder farming averaging between 2 and 3 hectares (Azad and Azad 2022).

Production efficiency remains a significant challenge. The industry yields on average only 0.37 tons per hectare, versus potential yields of 2 tons in feed-based systems. The supply chain is notably complex, involving multiple intermediaries, which limit farmers' capacity for reinvestment and adoption of technology.

Disease outbreaks, particularly white spot syndrome virus, have historically devastated production. The industry faces ongoing challenges with seed quality: hatchery-produced postlarvae are available, but despite the Government banning seed sourced from the wild, this practice remains prevalent given their perceived better survival rates. Additionally, only about 10 percent of postlarvae comes from specific pathogen-free hatcheries.

Climate change poses significant threats. The industry suffered major losses, for example, from Cyclone Sidr in 2007 and Cyclone Aila in 2009. Farmers have adopted crop diversification and improved infrastructure, but vulnerability remains high.

Financial access is a major constraint. Commercial financing is available, but stringent eligibility criteria and collateral requirements often exclude smallholders. More than half of shrimp farmers are reportedly overindebted (Mahmud et al. 2022).

Export markets value Bangladesh's black tiger shrimp for its taste, color, and texture. However, the country holds only 2 percent of the global export market, and its share in the U.S. market has declined from 43 percent in 2009 to 7 percent in 2022 in the face of competition from cheaper whiteleg shrimp.

The government provides various support measures, including tax holidays, accelerated depreciation allowances, and reduced interest rates for working capital loans to exporters and hatchery owners. The Government has embarked on a consultative process of reviewing the policy and regulations guiding the sector. Policy implementation and coordination among agencies, however, still need strengthening.

Environmental impacts are relatively low because of extensive smallholder farming practices, but salinization effects are a concern. Unlike other major shrimp-producing countries, less than 2 percent of total mangrove forests in Bangladesh have been converted to shrimp farms from 1975 to date (Boyd et al. 2021) though ongoing land-use changes are concerning. Social issues include gender disparities in employment and uneven distribution of benefits.

Looking forward, the industry's transformation requires addressing several key challenges: improving infrastructure, increasing specific pathogen-free postlarvae availability, developing better disease management practices, and providing more accessible financing options. Success will demand coordinated efforts from government, the private-sector, donor agencies, and civil society.

4 THAILAND: GIANT FRESHWATER PRAWN

Thailand has long been a significant producer of its native giant freshwater prawns (*Macrobrachium rosenbergii*), an industry that has evolved over decades. Initially reliant on wild-caught juveniles, the industry expanded significantly after the development of hatchery technology in the 1970s. In 2021, Thailand produced 294,000 tons, accounting for 2.6 percent of global crustacean production.

Early farming challenges such as overfishing and habitat destruction prompted domestication efforts. Technological innovations have been crucial. Companies have developed strains of prawns that grow 45 percent faster and weigh 24 percent more than traditional stocks. Hatcheries have evolved to produce specialized seed, including all-male and all-female monosex prawns, which improve farming efficiency and market appeal.

Production fell sharply with the emergence of the *Macrobrachium rosenbergii* nodavirus, which caused significant losses. Farmers now carefully manage stocking densities and use techniques such as partial harvesting to optimize growth. Recent advances in selective breeding, improved feed efficiency, and farm management techniques have been key.

Economically, freshwater prawns are a premium product, particularly valued in domestic cuisine. Although local production has struggled to meet domestic demand, prawns command higher prices than marine shrimp. In 2023, production peaked at an estimated

45,815 tons with a market value of approximately THB 9,650 million (approximately USUS$287 thousand).

The industry faces significant challenges. Disease risks, exacerbated by climate change, are a major concern. Environmental considerations are increasingly important, and although freshwater prawn farming has a lower environmental impact than marine shrimp farming, sustainable practices are still crucial.

Financial and social challenges are also notable. Small-scale farmers often struggle to access credit. Labor shortages are becoming critical as younger generations move away from agricultural work and farms increasingly rely on migrant labor from Myanmar and Cambodia.

Government support has been instrumental. The Royal Ordinance on Fisheries of 2015 established a comprehensive regulatory framework, and the Board of Investment offers incentives for aquaculture development. The Department of Fisheries continues to support research, development, and standardization of prawn farming practices.

Export markets—China, Myanmar, and the United States—have also developed. The domestic market, however, remains the primary focus.

Continued genetic improvements, more efficient farming techniques, and a focus on sustainability could drive further growth. The sector represents more than just an economic opportunity—offering a more environmentally responsible and socially sustainable alternative to coastal shrimp farming. The Thai freshwater prawn industry demonstrates how strategic government support, technological innovation, and adaptive farming practices can transform an agricultural sector.

5 CHILE: ATLANTIC SALMON

Salmon aquaculture in Chile began in the late 20th century and today the country is the second-largest producer, after Norway, of farmed salmon. By 2022, exports (valued at USUS$6.61 billion) had become the top export after copper. In 2023, production reached 1.08 million tons, industry growth propelled by strategic government support, international collaboration, and technological innovation.

Advances include aquaculture feed research, enhanced salmon genetic lines, sophisticated hatchery methods, and grow-out technologies. Recirculating aquaculture systems have gained significant traction: 60 percent of hatcheries currently use these systems and expectations are that 100 percent will during 2025.

The industry has faced criticism over environmental impacts, regulatory issues, and conflicts with local communities. Concerns have included water pollution and benthic degradation from uneaten feed and waste accumulation, high antibiotic use, escapes of farmed salmon, and conflicts with Indigenous communities.

A turning point came after the infectious salmon anemia crisis of 2007 to 2009 halved production, prompting stricter biosecurity measures and environmental regulations.

Environmental sustainability has become a key focus. In response, companies—six large companies controlling more than 60 percent of production—have worked to minimize nutrient pollution, improve feed efficiency, and develop integrated multitrophic aquaculture approaches. The industry is also actively pursuing carbon neutrality: the carbon footprint of transporting processed salmon is estimated at 4.8 tons of CO_2 equivalent per ton of product.

The introduction of green loans and sustainability-linked financing instruments has encouraged more environmentally responsible practices. However, uncertainty around concession renewals and stricter regulations has created investment risks, particularly as marine protected areas expand. Despite financial growth, small and mid-sized farmers struggle to access credit because banks favor larger, well-established firms with lower risk profiles. Major players in Chilean aquaculture have also invested in vertical integration, owning hatcheries, farms, processing plants, and distribution channels, which has improved efficiency and cost control.

Climate change is emerging as a long-term challenge. Rising ocean temperatures and increasing harmful algal blooms have caused significant salmon mortalities, affecting productivity and profitability. The industry has begun investing in early warning systems, improved feed efficiency, and biosecurity measures to mitigate these risks.

Socially, the sector has created approximately 71,000 jobs. The industry has improved infrastructure, employment opportunities, and living conditions in these areas, becoming a critical economic driver.

Looking forward, the Chilean salmon industry needs to focus on sustainable expansion, climate resilience, global market diversification, financial inclusion, investment stability, and engagement with local stakeholders to prevent regulatory conflicts.

6 EGYPT: NILE TILAPIA

Egypt's tilapia aquaculture industry dates back thousands of years. Today, Egypt is one of the world's leading producers of farmed tilapia, which accounts for 57 percent of the country's total aquaculture production. In 2022, production reached 964,196 tons.

Tilapia farming has expanded significantly since the 1980s, largely driven by private-sector investments and government initiatives. Farms have increasingly adopted more efficient farming techniques, including integrated polyculture systems with mullet and carp, and has benefited from genetic improvements in tilapia strains, better feed quality, and improved water management practices.

Despite operating in an arid climate with limited freshwater resources, farms have optimized the use of brackish water from the northern delta lakes and agricultural drainage systems. In 2019, 89 percent of Egypt's farmed tilapia was produced in saline water.

Tilapia farming plays a crucial role in Egypt's food security, employment, and rural economic development. Per capita fish consumption (nearly 38 percent of the country's total animal protein intake) increased from 12.6 kilograms per year in 2005 to 16 per year in 2021. The sector supports more than 580,000 jobs and provides additional indirect employment in feed production, processing, and distribution.

The industry primarily serves the domestic market: only about 10,000 tons are exported annually. Until 2024, Egypt was not permitted to export farmed fish to the European Union. However, given rising demand in the Middle East and North Africa, opportunities for value-added processing and exports are emerging.

The majority of Egypt's tilapia farms operate semi-intensively, relying on low-cost production methods. In 2021, output reached 1.6 million tons across 126,000 hectares, an average yield of 12.5 tons per hectare. The adoption of improved tilapia strains and aeration systems has increased productivity, but rising feed costs and fluctuating fish prices have made profitability more volatile. Financial constraints remain a significant barrier to further intensification. Egypt's aquaculture expansion has raised concerns about water resource management, habitat degradation, and nutrient pollution. The conversion of natural wetlands into fish farms has altered local ecosystems, and increased salinity intrusion in freshwater aquifers poses risks to both aquaculture and agriculture.

Climate change poses additional challenges. To address these risks, Egypt is investing in sustainable aquaculture solutions, including integrated multi-trophic systems, improved water recycling, and in-pond raceway technology.

The Egyptian government has played a crucial role in developing the industry, establishing regulatory frameworks, hatchery programs, and land-leasing policies to encourage private-sector investment. However, policy challenges remain around complex licensing procedures involving multiple agencies, land tenure rights, and access to financial services for small and medium enterprises.

7 VIET NAM: PANGASIUS

Viet Nam is the world's leading producer of farmed pangasius, accounting for more than 50 percent of global production. Farming evolved from backyard ponds into a major commercial industry in the late 20th century. Viet Nam now exports to more than 140 countries.

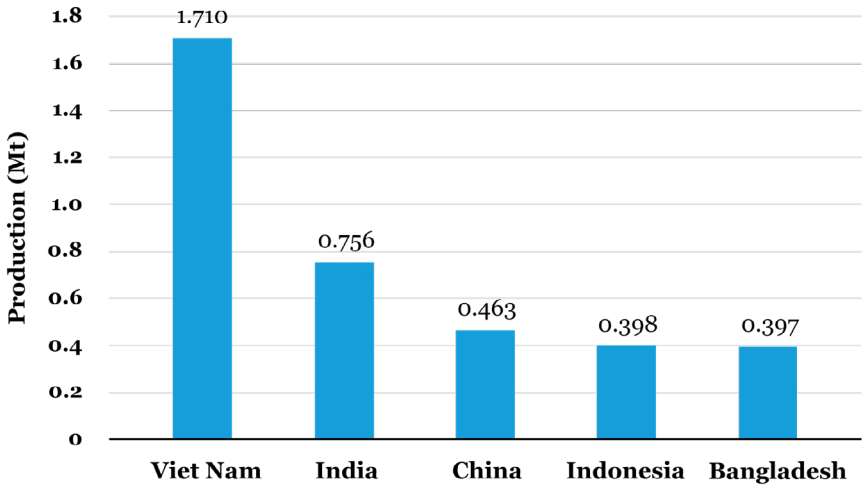
The pangasius supply chain begins with hatcheries, which produce approximately 30 billion larvae annually. Nurseries—most are in the Mekong Delta—rear fry into fingerlings, survival rates ranging from 10 to 60 percent. Grow-out farms occupy around 5,400 hectares, producing 1.67 million tons of pangasius annually. Water quality management remains a key challenge given the large volumes of water needed to maintain pond health.

The industry has become highly consolidated. Major processors dominate exports and maintain compliance with international standards, and the government plays a central role

in regulating the sector. Certification schemes have driven sustainability efforts, but compliance costs can be prohibitive for smaller farms. Financial access remains a challenge.

Vietnamese pangasius is cost competitive, typically between US$1.10 and US$1.20 per kilogram. Feed accounts for 80 percent of production costs, which remain low relative to other aquaculture sectors. The industry has invested in alternative feed sources to improve sustainability. Disease management is a critical concern. Partnerships between pharmaceutical companies and major processors have expanded vaccine coverage, reduced antibiotic use and improved farm productivity. Accounting for more than 50 percent of worldwide pangasius production and harvesting 1.67 million tons annually, Viet Nam's industry, which produces more than twice its nearest competitor (India), exemplifies how a relatively new sector can achieve global market dominance using focused development strategies (Figure 12).

Figure 12. Top Five Pangasius-Producing Countries in 2023



Source: Chung et al. (2024).

Despite its success, the industry faces challenges from international competition and climate change. Water scarcity and salinity intrusion in the Mekong Delta pose long-term risks. Research institutions are developing salinity-tolerant pangasius strains and improving water management practices to address these challenges.

Trade policies also affect the sector. Viet Nam benefits from free trade agreements that have reduced tariffs and improved market access. Market diversification has been key, and China has emerged as the largest importer (31 percent). The European Union and United States remain important markets, but demand in Latin America and the Middle East is growing.

Environmental concerns have driven improvements in sludge treatment, water monitoring, and greenhouse gas reduction initiatives. Large-scale farms increasingly use aerators to enhance water quality and reduce feed conversion ratios and water quality monitoring is gaining traction.

Branding remains a major challenge. Exporters have countered negative media campaigns

with certification and marketing initiatives, but the industry lacks a strong unified brand. Efforts towards strengthened marketing campaigns help reposition pangasius as a premium product rather than a low-value commodity.

Looking ahead, Viet Nam's pangasius sector needs to balance production growth with sustainability and market positioning. Technological advancements will be crucial for maintaining competitiveness. Expanding value-added products and coproducts, such as collagen and gelatin, could enhance profitability.

Together, these seven aquaculture powerhouses illustrate not just impressive production figures but also a rich tapestry of human adaptation, technological innovation, and cultural practices. Each region has developed unique approaches reflecting their environmental conditions, historical contexts, and market opportunities. As global demand for seafood continues to rise amid dwindling wild fisheries, these diverse aquaculture systems offer a glimpse into how humanity might sustainably harvest protein from water. Their collective story is not merely about tons produced but also about the resilience and ingenuity of communities who have learned to farm the waters as effectively as others farm the land. This global aquaculture landscape—spanning continents, species, and cultures—is one of the most promising frontiers in our ongoing quest to feed the world while preserving our planet's precious ecosystems.

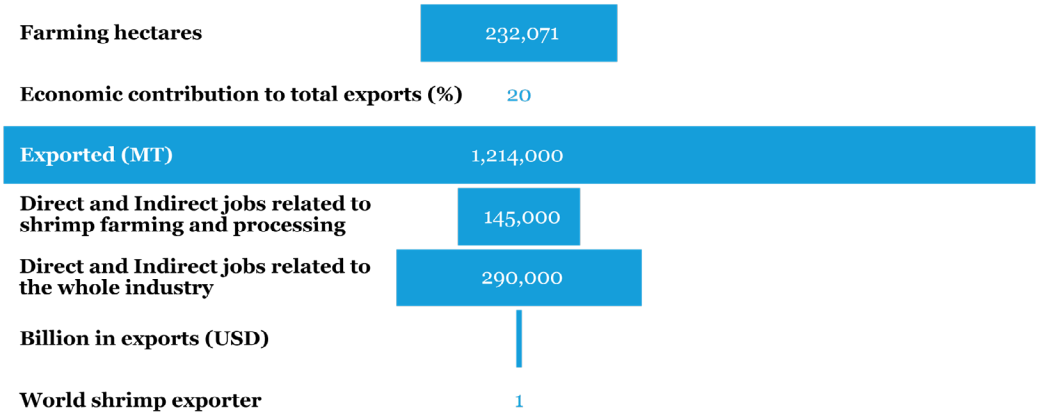
Production Efficiency

Production methods reflect regional adaptations and technological advancement. Ecuador focuses on sustainable practices with moderate yields and feed conversion ratios as low as 1.4. The country has maintained its competitiveness through improvements in production efficiency, despite falling global shrimp prices due to oversupply. Rather than pursuing the high-intensity farming approaches of Asia, Ecuador focused on moderate yield increases through reasonable stocking densities, improved feed management, and effective water quality and disease control. This has allowed for increased production efficiency, with leading producers achieving feed conversion ratios as low as 1.4 and producing up to three shrimp cycles per year.

Feed production is a crucial component of Ecuador's shrimp farming success; major international companies such as Nutreco, Cargill, and Biomar operate in the country. These firms have developed functional diets and advanced feeding systems that improve shrimp growth and efficiency. Shrimp farming has also shifted toward greater use of electric aeration, reducing dependency on diesel and lowering costs, though recent subsidy cuts on fuel have introduced some uncertainty. The industry's processing and export sector is well-developed, with vertically integrated companies handling shrimp from hatchery to export. The top 10 exporters account for over 60 percent of exports. Ecuador's ability to produce high-quality shrimp with lower costs than competitors in India, Viet Nam, and Indonesia gives it an edge in global markets. Today, Ecuador is the world's number one shrimp exporter employing 145,000 people in the production and processing industry and 290,000 jobs overall (Figure 13).

China has evolved from semi-intensive methods to high-density monoculture in ponds typically 0.5 to 5 hectares. Pond culture accounts for 73.4 percent of China's total freshwater aquaculture production, and the industry relies heavily on feed, which represents 60 to 75 percent of production costs. Grass carp is the most popular species, with annual production of about 5.5 million tons, chosen for its low production costs and ability to survive in a range of environmental conditions (Qiao, et al., 2024).

Figure 13. Ecuadorian Shrimp Industry Numbers, Including Direct and Indirect Jobs (2024)



Source: CNA, Central Bank of Ecuador, Undersecretariat of Aquaculture.

The annual growth rate has declined since the 1980s and 1990s due to lower population growth, stricter environmental protection policies, and changing consumer preferences. Disease outbreaks pose significant threats, with economic losses in China's aquaculture sector amounting to CNY 58.9 billion (US$ 8.2 billion) in 2020, which represented 5.8 percent of total aquaculture output value.

Bangladesh, extensive, semi-intensive, and intensive systems cover 9.7 percent, 63 percent, and 28 percent of the total aquaculture area, respectively, but struggles with efficiency, averaging only 0.37 tons per hectare against a potential of 2 tons. Inland aquaculture in Bangladesh is rich with resources, and floodplain aquaculture has become very popular, supported by community efforts.

Thailand uses earthen ponds with polyculture techniques and partial harvesting strategies. Chile represents technological advancement with 60 percent of its hatcheries using recirculating systems. Egypt maintains semi-intensive operations with average yields of 12.5 tons per hectare using low-cost methods. Viet Nam achieves high productivity through dense stocking in a relatively small area of 5,400 hectares, with a feed conversion ratio around 1.6 (Ho, Do, and Eggert 2025). Viet Nam has seen both consolidation and integration. Processing companies have taken over smaller farms and feed mills intending to build a complete supply chain from hatchery to production and processing and fulfil sustainability and to facilitate certification requirements of importers. Through feed subsidiaries, the processing company control feed supply to their contract farmers.

Market Position and Export Value

Export markets and values vary significantly across aquaculture sectors. Ecuador's shrimp exports are valued at US$ 6.3 billion, 60–70 percent of which goes to China (Minda, 2024). China's carp industry, valued at USUS 46 billion, focuses on domestic consumption with exports in 2023 of only 26,000 tons annually, valued at US$93.7 million according to the World Bank (Figure 14).

Bangladesh earns US$530 million from seafood exports but holds just 2 percent of the global market. Thailand's prawn industry, valued at approximately US$ 277.6 million, primarily serves domestic demand. Chile's salmon exports, worth US$ 6.61 billion, represent the country's second-largest export after copper. Egypt's tilapia production predominantly supplies domestic markets: only 10,000 tons are exported annually. Viet Nam exports pangasius to more than 140 countries, China being its largest market at 31 percent of exports.

Figure 14. Leading Exporters of Carp, 2023

Source: oec.world.
Note: US$, millions.

Key Challenges in Case Study Countries

As we face more and more climatic and environmental challenges, aquaculture has stepped up as a vital resource for crop-farming communities. As rising temperatures, erratic rainfall, soil degradation, and extended droughts put traditional farming methods at risk, food security and livelihoods are in jeopardy. To tackle these issues, communities are embracing aquaculture—not just to diversify their income but also to boost resilience by making better use of resources and fostering sustainable farming practices.

Aquaculture industries face common challenges with regional variations. Disease outbreaks affect all sectors, costing China US$ 8.2 billion in 2020 and devastating Chile's salmon industry during the ISA crisis. Climate change threatens operations everywhere: Bangladesh is particularly vulnerable to extreme weather (Mitra et al. 2024), and Viet Nam facing salinity intrusion in the Mekong Delta. Financial access remains difficult, especially in Bangladesh and Egypt, where formal financing is limited. Environmental concerns include water pollution in China and Chile, and resource constraints in Egypt's water-limited operations. Ecuador faces market concentration risks with its heavy dependence on Chinese buyers, and Viet Nam contends with increasing international competition.

On the other hand, aquaculture, is increasingly being woven into crop farming through methods like integrated aquaculture-agriculture and rice-fish farming. These approaches create a mutually beneficial relationship where the by-products of one system enhance the other, leading to better resource use and less waste (Ibrahim et al. 2023). Compared to Alternate Wetting and Drying approach, which is labor-intensive and demands frequent monitoring, and manual intervention, rice-fish farming system is easier to adopt and with better benefits.

Sustainability and Environmental Impacts

Environmental impacts and sustainability efforts vary across countries. Sustainability in aquaculture is a pressing concern across various regions, especially in countries where this industry plays a significant economic role (Garlock et al. 2024). In Ecuador, although early mangrove deforestation raised alarm, the implementation of government regulations mandating mangrove restoration has encouraged a shift toward more sustainable practices, including decreased reliance on mangrove areas and enhanced electric aeration technologies (Viera-Romero et al. 2024).

Meanwhile, China's aquaculture sector grapples with environmental issues such as water pollution and biodiversity loss, prompting stricter regulations and a strategic focus on increasing efficiency while reducing production volume (Liu et al. 2025). Bangladesh shows a relatively low environmental impact from shrimp farming, though concerns regarding salinization and climate-induced disasters remain (Woźniacka, et. al. 2025). Thailand's giant freshwater prawn industry aims to minimize environmental harm through sustainable practices, challenged by the impacts of climate change. In Chile, the Atlantic salmon industry faces significant hurdles, including nutrient pollution and the pressing need for carbon neutrality, all while responding to the effects of climate change. Egypt's Nile tilapia farming is closely linked to water resource management challenges, compounded by salinity intrusion and wetland conversion, whereas Viet Nam's pangasius industry confronts notable water quality management issues and is actively improving its sustainability through innovative feed alternatives and better environmental practices (Tram et al. 2023). Collectively, these countries illustrate the complex interplay of economic growth and environmental stewardship in global aquaculture, emphasizing the critical need for continuous search and use of sustainable solutions moving forward.

Fixing Financing and Investment Challenges

Financing structures reflect industry maturity and economic contexts. Ecuador has evolved from informal entrepreneur-driven funding to structured commercial banking with international investment. The sector's financing landscape also includes major investments from feed producers, and development finance institutions such as the World Bank's International Finance Corporation. Early funding often came from established businessmen, particularly in the banana industry, who leveraged their plantations as collateral, and factoring played a key role when working capital loans were scarce. Today, the aquaculture industry benefits from diverse financing sources, including commercial banks, international investors, and specialized financial products. However, access to capital remains a challenge for mid-sized operations and ventures focused on new species or value-added processing (Rodriguez-Mañay 2024).

China benefits from diverse funding sources and significant government infrastructure support. The industry's financing has evolved from relying on personal savings and family loans to accessing diverse funding sources, including rural credit co-ops, joint-stock banks, and specialized loans from institutions such as the Agricultural Bank of China. Government support has been crucial through investments in infrastructure, subsidies, and fiscal support aimed at food security and economic development. Bangladesh faces major financial access challenges, and more than half of its farmers are overindebted (Mahmud et al. 2022). To resolve upscaling of training on financial literacy through farmer organizations and the Missing Middle Initiative launched by the Global Agriculture and Food Security Program may offer viable solutions (FAO, 2023). Thailand's small-scale farmers struggle with credit access despite government support mechanisms.

Chile has transitioned from state-backed development to sophisticated private-sector financing including green loans and sustainability-linked instruments. The industry's growth was propelled by strategic government support, international collaboration, and technological innovation. The Norwegian salmon sector initially served as a model, and the Japan Chile Salmon Project facilitated knowledge and technology transfer. Fundación Chile, a public-private institution, played a pivotal role by establishing Salmones Antártica in 1982, which demonstrated the viability of salmon farming in Chile and built a knowledge base about salmon production technologies.

Early investments ranged from US$2 to US$15 million, offering high internal rates of return of between 30 percent and 60 percent. By 2023, salmonid harvests had reached 1,080,900 tons, comprising Atlantic salmon, Pacific salmon, and rainbow trout. The ISA crisis from 2007 to 2009, which halved production, became a turning point, prompting the implementation of stricter biosecurity measures and environmental regulations (Thomas 2024). From its early days, the sector benefited from public-private partnerships, tax incentives, and cofinancing mechanisms, which encouraged private investment. Over time, the industry became increasingly consolidated. Today, as noted, six large companies control more than 60 percent of production, many of them backed by foreign investment from Norwegian, Japanese, and American firms.

Egypt's farmers rely heavily on informal financing given their limited access to formal credit systems. Financial constraints remain a significant barrier to further intensification. Small and mid-sized farms struggle to access credit, because commercial banks consider aquaculture a high-risk sector. Most farmers rely on informal financing from feed suppliers and fish traders, often on unfavorable terms. The absence of aquaculture-specific insurance and risk-mitigation mechanisms further complicates access to financing. However, the Egyptian government has played a crucial role in developing the aquaculture industry, establishing regulatory frameworks, hatchery programs, and land-leasing policies to encourage private-sector investment (Sebaq and Mandour 2025). Bureaucratic hurdles, fragmented governance, and outdated land-use policies continue to hinder sector growth. Policy challenges include complex licensing procedures involving multiple government agencies, unclear land tenure rights, and limited access to formal financial services. The Lake and Fisheries Resources Protection and Development Agency oversees the sector, but coordination between ministries remains weak. Recognition is growing of the need to streamline regulatory processes and enhance support for smallholder farmers.

Viet Nam's operators depend on self-financing or bank loans requiring substantial collateral, with interest rates between 4 percent and 8 percent, with large processors securing loans more easily because of their assets and export revenues (Nguyen et al. 2025).

To further strengthen and ensure the long-term sustainability of the aquaculture industry, investors can play a pivotal role by directing capital to innovative technologies, sustainable farming practices, and improved infrastructure. Investment in advanced water management systems, biosecurity solutions, and disease prevention technologies can significantly enhance farm productivity while minimizing environmental impact. Additionally, funding research and development of alternative feed sources can reduce reliance on traditional fishmeal, making aquaculture more sustainable. Supporting infrastructure development, including modern cold chain logistics and processing facilities, can enhance supply chain efficiency and product quality. Moreover, providing financial resources and technical expertise to small and medium-scale farmers through microfinancing, capacity-building programs, and digital technologies can promote inclusive growth and empower local communities, ensuring a more resilient and competitive aquaculture industry.

Government Role and Regulation

Aquaculture is governed by a complicated arrangement of international agreements, national legislation, market-based certification systems, and the conditionalities on loans and development finance. Contributing to this are several factors that can shape the way aquaculture is planned, monitored, practiced, and developed in different regions. The relationship to regulation is complex and problematic, but includes: regulations on site selection, the inclusion and protection of sensitive environments (such as wetlands), chemical and antibiotic use, disposal of effluent into natural water bodies, labor regulations in hatcheries and processing agricultural plants, and, regulations related to trade of exports and imports. These examples of regulation are often seen as a circular approach to enforcement that include certification systems such as Best Aquaculture Practices (BAP),

GLOBALG.A.P., and the Aquaculture Stewardship Council (ASC) which are usually government mandated or imposed by private international buyers of aquaculture. They comply with government standards to obtain their dance license and with BAP, ASC and other private certification protocols that may reflect prevailing standards at harvest but are considered noncompliance. Generally, the systems do not operate on the 'honor system', and enforcement is limited. Inconsistency in enforcing regulations is often a function of the relative lack of capacity given the institutional landscape of regulatory authorities and resistance from producers who view enforcement as misaligned with local issues and profit margins.

Ecuador is a great model for how regulation can change to deal with the environmental effects of aquaculture. Historically, Ecuador's shrimp industry was one of the leading drivers of mangrove loss, and the resulting environmental destruction drew significant domestic and international criticism. Starting in the early 2000s, Ecuador has developed a legal and regulatory framework to mitigate environmental harm,. One of the most important developments was the creation of the National Control Plan for the mangrove value chain aimed at protecting mangroves, that comprised designated conservation areas, a system of fines for illegal conversion to aquaculture, and in 2021 amendments to the regulatory structure that included a presidential decree stipulating a monetary value for a hectare of mangrove. In 2002, Ecuador addressed wild capture of shrimp larvae with an outright ban on the practice in the name of protecting ecosystems and biodiversity and to try to halt the spread of infectious aquatic diseases. Coordination with the industry improved with the creation of the Cámara Nacional de Acuicultura (CNA) in 2001, which has played a crucial role in steering regulation in line with market requirements.

Bangladesh offers various support measures but suffers from policy implementation gaps and interagency coordination. The government provides various support measures, including tax holidays, accelerated depreciation allowances, and reduced interest rates for working capital loans to exporters and hatchery owners. However, policy implementation and coordination among agencies could be further improved. Thailand established a comprehensive regulatory framework through the Royal Ordinance on Fisheries in 2015 and provides investment incentives. Chile developed successful public-private partnerships and implemented stricter regulations following disease crises (Carrasco-Bahamonde and Casellas 2024). Egypt established regulatory frameworks but struggles with fragmented governance and bureaucratic hurdles.

China demonstrates significant government involvement in research, infrastructure development, and environmental regulations. Viet Nam's Ministry of Agriculture and Environment (formerly Ministry of Agriculture and Rural Development) promotes certification schemes to improve standards and market access. Trade policies also affect the sector. Viet Nam benefits from free trade agreements such as the Comprehensive and Progressive Agreement for Trans-Pacific Partnership and the European Union -Viet Nam Free Trade Agreement, which have reduced tariffs and improved market access. Market diversification has been key to mitigating trade risks, China emerging as the largest importer, accounting for over 31 percent of Viet Nam's pangasius exports. The EU and United States remain important markets, but growing demand in Latin America and the Middle East presents new opportunities.

GROWTH & INVESTMENT OUTLOOK

Global demand for animal protein continues to rise alongside population growth and shifts in dietary preferences driven by middle-class expansion in emerging markets. At the same time, consumers, regulators, and investors are paying closer attention to the resource intensity, environmental, and climate impacts associated with major sources of animal protein. These dual pressures are intensifying the need for protein sources that can dramatically increase production efficiently and sustainably to meet the needs of a more populated and resource constrained world.

Among animal protein sources, aquaculture is in a favorable position to sustainably expand production to help satisfy demand going forward. Aquaculture is the fastest-growing source of animal protein over the past 20 years and has already surpassed wild fisheries as the main source of global seafood production. Other major animal protein sources, such as beef, face rising consumer and regulatory pressure for their carbon footprints and have the potential for significant upward pressure on the cost to consumers going forward.

The challenge and opportunity for investors lies in gaining a clearer understanding of which markets are poised to offer the best opportunities for the exposure aquaculture provides to growth in protein demand, emerging markets, environmental impact and green growth, and related investment themes. This report proposes a few indicators of credible pathways toward developed and sustainable aquaculture, drawing from current and emerging leaders in aquaculture production. The sections that follow outline the elements that have contributed to the development of resource-efficient and competitive aquaculture sectors in key producer nations.

The report then looks to the future of aquaculture, projecting the growth of the global sector out to 2050. These forecasts allow for a bottom-up estimation of the new capital investment that will be required to finance the growth of aquaculture over the next 25 years, and which new markets outside current top producers will emerge as key investment destinations for sustainable aquaculture.

EMERGING MARKET ACCELERATION

Global protein demand continues to grow at a rapid pace, driven by population growth and rising incomes among the middle class in emerging markets on top of a consistent protein demand base from developed markets. China (first), India (third), Indonesia (fourth), Brazil (eighth), Mexico (11th), Egypt (12th), and Nigeria (15th) are projected to be among the top 15 economies by gross domestic product (GDP) in 2050 (Goldman Sachs, n.d.). By comparison, as of the end of 2022, China sits in second place, India fifth, Brazil 11th, and Mexico 14th; Indonesia, Egypt, and Nigeria do not feature among the top 15 economies. This shift toward a significantly greater proportion of global GDP coming from current emerging markets will have a variety of profound effects, including greater protein demand, because the largest economies of the future will also be among the most populated countries in the world.

As of 2022 the world's 15 largest economies had a total population of just over 4 billion (4.190). By 2050, they will have a population count of just over 5 billion (5.110). Underlying these statistics are some notable facts and trends:

- The 902 million population share increase of the top 15 economies as of 2050 over 2022 accounts for 34 percent of the total projected population increase over the same period.
- The three new projected entrants in the top 15 economies list as of 2050—Indonesia, Egypt, and Nigeria—are projected to rank sixth, 11th, and third, respectively, in country population.
- India, projected to rank third by GDP and first by population as of 2050, is approximately 80 percent Hindu, a religion wherein cows are considered sacred, resulting in beef not constituting a significant part of India's animal protein demand.
- Indonesia, projected to rank fourth in GDP and sixth by population as of 2050, is approximately 80 percent Muslim, and therefore pork is not a significant contributor to its animal protein demand.

Table 4 is focused on the top 15 economies, but many of the trends apply in equal measure to the broader global economy as more markets broaden their middle-class populations. As increased affluence shifts dietary options in emerging markets from mainly plant-based protein toward animal protein, ensuring reliable sources of increased animal protein production will present compelling market and investment opportunities. The challenge within this opportunity is whether enough animal protein can be produced sustainably within existing and impending regulatory frameworks and environmental limits.

Table 4. GDP and Population Rankings, 2022 Versus 2050 Projections, in Millions

2022 GDP Ranking		2022 Population (m, (rank))	2050 GDP Ranking, projected		2050 Population (m, (rank))
1	United States	333 (3rd)	1	China	1,290 (2nd)
2	China	1,412 (2nd)	2	United States	368 (5th)
3	Japan	125 (11th)	3	India	1,670 (1st)
4	Germany	84 (19th)	4	Indonesia	317 (6th)
5	India	1,417 (1st)	5	Germany	79 (23rd)
6	United Kingdom	67 (22nd)	6	Japan	105 (17th)
7	France	68 (21st)	7	United Kingdom	72 (28th)
8	Canada	39 (37th)	8	Brazil	231 (7th)
9	Russia	143 (9th)	9	France	69 (29th)
10	Italy	59 (25th)	10	Russia	133 (14th)
11	Brazil	215 (7th)	11	Mexico	144 (13th)
12	South Korea	52 (29th)	12	Egypt	160 (11th)
13	Australia	26 (56th)	13	Saudi Arabia	48 (43rd)
14	Mexico	128 (10th)	14	Canada	47 (46th)
15	Spain	48 (30th)	15	Nigeria	377 (3rd)
		4,190			**5,110**

Source: World Bank Group Databank.

OPPORTUNITY AND RISK

Looking across the spectrum of animal protein sources, aquaculture is well positioned for rapid expansion in production to meet global demand. Aquaculture is already the fastest-growing segment of the global food production industry. Between 2000 and 2020, global aquaculture production more than doubled, rising from 34 million tons to more than 85 million tons (FAO 2024b). A credible case can be made that aquaculture has the greatest capacity among protein sources to significantly expand production while factoring in land-use constraints, existing and incoming climate-related regulation, and related industry and corporate sustainability commitments.

Beef production is the most significant contributor to deforestation among animal protein sources, having the largest carbon footprint, spanning extensive land clearing, intensive feed production requirements, and methane emissions from cattle. The European Union has enacted regulation targeting production that contributes to deforestation, including the financing of activities that cause deforestation. Investors with exposure to the beef industry take on increased financial risk and greater public scrutiny, and the beef sector is likely to face even greater regulation going forward. Pork and poultry production are closer to the resource efficiency and carbon footprint of aquaculture production but do not provide investors with the same upside potential from production growth as aquaculture production. Additionally, intensive and semi-intensive aquaculture are relatively new production technologies that have significant room for efficiency and yield improvements relative to pork and poultry production.

For investors looking to invest in the growth of long-term protein demand, aquaculture production provides distinct benefits alongside or in place of other animal protein sources. These include lower regulatory and environmental risk than beef production, and higher growth upside than pork and poultry production. Production from wild fisheries is severely constrained: 37.7 percent of wild fisheries operate near or beyond depletion levels (FAO 2024b), evidenced in part by the low growth rate in fishery production relative to aquaculture over the past 20 years. Taken together, these production, regulatory, and ecosystem constraints point to aquaculture production as the most viable source of incremental animal protein production in the medium to long term.

Rapid growth in aquaculture production is not without risks, however. The efficiency and profitability of production vary widely in terms of tons of seafood produced relative to the amount of land, feed, energy, and other inputs. Unchecked expansion of low-yield production typically results in low-profitability operations. Low profitability in turn results in little or no investment in operational improvement, unreliable production volumes, and low regulatory and environmental compliance. Investors considering the aquaculture sector will need a clear sense of the indicators of sustainably profitable aquaculture operations, both within production and across the value chain, and the extent to which the enabling environment within the jurisdiction enhances the financial viability and sustainability of the aquaculture sector.

DEVELOPMENT PATHWAYS

Sustainable aquaculture operations come in various forms, depending on factors including the species being farmed, geographic location, production methods, and other operational features. A useful lens through which to explore sustainable aquaculture operations as investment opportunities is the stage of operational maturity they have achieved or could potentially achieve in the near to medium term.

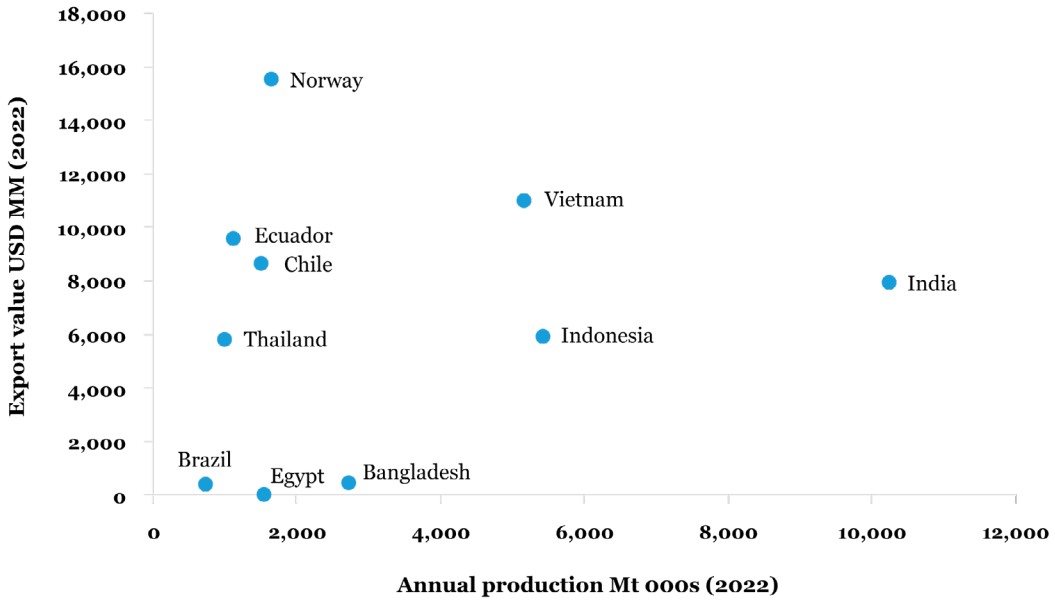
Developed sustainable aquaculture operations are defined as those that have reached levels of operational efficiency at high production yields to be able to generate significant profits over time. They have also embedded sustainability in their operations such that they can produce at high volumes while maximizing their capacity to reduce their carbon footprint and other negative environmental impacts.

An example of a developed sustainable aquaculture operation is Industrial Pesquera Santa Priscila (Santa Priscila), the leading shrimp aquaculture producer and exporter in Ecuador. Santa Priscila is vertically integrated across breeding, hatchery and nursery facilities, production, processing, and packaging for export. Santa Priscila's shrimp farms follow Aquaculture Stewardship Council or Best Aquaculture Practices certification standards, and have export clients across Europe, the United States, and Asia. Santa Priscila more than doubled its production over four years, from 77,000 tons in 2018 to 177,000 tons in 2022. It has been able to finance its growth with investment from climate- and environment-focused development finance institutions and impact investment funds, in addition to mainstream financing from commercial banks and other private investors.

Emerging sustainable aquaculture operations are still operating at low operational efficiency and production yield with moderate capacity to limit or reduce their carbon footprint and other negative environmental and social impacts and are unable to consistently generate meaningful profits. These are typically farms producing less than 1,000 tons annually, that have limited vertical integration beyond production. Given their limited scale, most of these operations produce for nearby local markets or sell to middlemen rather than for direct sales to export or domestic wholesale markets.

One of the country-level indicators of developed, efficient aquaculture production is the relationship between total aquaculture production volume and the value of aquaculture exports. Significant export volume indicates consistent production of higher-quality seafood that complies with international regulations and food safety standards. Figure 15 shows this country-level indicator for the top 10 aquaculture producer nations, excluding China, which accounts for over 60 percent of global aquaculture production.

Figure 15. Annual Production Versus Export Value for Top Producer Nations (excl. China) in 2022 (Duplicate of Figure 3)



Source: FAO 2024b.

Norway is an outlier among the producer nations, showing very high export value in 2022 (US$ 15.5 billion) relative to its annual production (1.6 million tons). At the other end of this spectrum is Egypt, with US$ 34 million of export value at a level of production similar to that of Norway. Numerous interconnected factors help explain a producer nation's domestic consumption versus export orientation, including species farmed, prices for globally traded seafoods, nature of land availability, and application of technological advancements in production. This indicator, however, does capture for investors Norway's ability to efficiently produce high-value aquaculture products. Whereas Norway presents investment opportunities in highly developed aquaculture production today, in the context of ever-growing protein demand, investors are well served in looking to where incremental sustainable production will most likely originate.

The cluster of countries near the middle of the Figure 14 presents a mix of developed and emerging sustainable aquaculture investment opportunities. Ecuador is second to Norway in export value to total production ratio. Thailand and Chile have similar export value ratios, followed by Viet Nam. Indonesia and India are in their own category, having relatively low export value ratios in 2022. If China were included, it would rank lower than India on export value relative to total production given its high proportion of domestic consumption. Egypt and Bangladesh have similar or higher annual production than Thailand, Chile, Ecuador, and Norway; most of their production, however, is for domestic consumption.

Although each country's aquaculture industry has its own comparative advantages and has followed its own development pathway, the market leaders in aquaculture export have elements in common that led to the development of domestic champions that are now among the global leaders in sustainable aquaculture production. These include:

- country-level strategies focused on aquaculture development and relatively effective implementation of policies and public-sector support to create a supportive enabling environment for aquaculture production;
- public support for private investments in R&D to improve quality and efficiency of feed and other inputs, and overall enhancement of production yields;
- public-private initiatives to improve resilience of aquaculture production, including effective responses to production shocks, such as management of disease outbreaks;
- industry-level collaboration, often in conjunction with government agencies, to aid in the development of export markets for the country's aquaculture producers.

Countries with development pathways that have featured these types of public-private coordination have been more likely to have broader ranges of financing available for aquaculture production (see Table 5). Stronger regulatory frameworks and public-sector support coupled with a focus on stabilizing production, improving efficiency, and developing export markets have enabled greater access to commercial sources of financing. These markets are characterized by the presence of larger aquaculture producer companies, often vertically integrated into inputs, processing, or trading. These developed producer companies typically have access to financing from domestic and international investors, including strategic equity investments from other corporates in the global food value chain. Larger developed producers can also access capital markets investment through corporate bond or public equity issuances.

Many developed producers have enough operational maturity to meet the minimum investment ticket size and level of risk-adjusted returns required by private investors, yet retain the option to take in concessional or risk-sharing capital from impact investors and public finance groups. These producers currently attract the broadest range of investors interested in aquaculture investment and can issue more sophisticated financial instruments to finance their growth plans. A recent example is the green bond issued by IDI Sao Mai, a leading sustainable seafood export company in Viet Nam (see Table 6).

Table 5. Progression of External Financing Availability by Maturity of Production

	Small Scale Producers	Emerging Producers	Developed Producers
Production intensity	Extensive	Semi-Intensive	Intensive
Sales	Local / domestic	Mix of domestic and export	Export orientation
Financing	Low OpEx, low CapEx	USD 1–3m annually	USD 3m+ annually
External financing sources	Informal Loans Value chain input finance Microfinance loans	Cash from Other Businesses Commercial bank loans Impact investment	Commercial bank loans Impact investment DFI / Public finance loans Private debt investment Value chain corporate equity Private equity Corporate bonds Public equity

Table 6. IDI Sao Mai Green Bond

Instrument	Corporate Green Bond
Issuer	International Development and Investment Corporation (IDI), a subsidiary of Sao Mai Group
Jurisdiction	Viet Nam
Amount	USD 40 million equivalent (VND 1,000 billion)
Initial Investors	Manulife Vietnam, AIA Vietnam
Use of Proceeds	Financing the next stage of the company's growth through the development of pangasius fish processing, as well as seeding and hatching facilities. IDI will commit to allocating capital raised from the green bonds to eligible green projects with the goal of promoting sustainable and environmentally friendly pangasius farming and production. The sustainable fish processing practices are in alignment with international sustainability standards set by the Aquaculture Stewardship Council (ASC) and Best Aquaculture Practices (BAP).
Issue Date	November 2024

Source: GuarantCo, n.d.

IDI Sao Mai's green bond was the first such transaction in the aquaculture sector in Asia. Another notable feature is that GuarantCo, part of the Private Infrastructure Development Group, provided a credit guarantee for the green bonds, a first for GuarantCo in the agricultural infrastructure space. IDI was established in 2003 and was publicly listed on the Ho Chi Minh Stock Exchange in 2011. IDI is vertically integrated across hatchery, feed, farming, harvesting, and processing for export activities, and has clients across more than 50 countries. The success of IDI Sao Mai's green bond issuance is likely to encourage other similar aquaculture companies in Asia and beyond to extend their sources of financing to capital markets instruments.

Investors looking to participate in the growth of the aquaculture sector beyond the developed producers will need a keen understanding of what an appropriate investment in an emerging or small-scale producer looks like, what financial instruments are best suited to the higher-risk profile and smaller scale of these investments, and which market development pathway indicators are in place or being put in place to suggest a supportive enabling environment for sustainable aquaculture. As Table 5 shows, emerging and small-scale producers are more constrained in their external financing sources, which include forms of value chain finance and informal loans from middlemen that can be predatory in their pricing and repayment terms. This lack of financing options is due in part to the cost, complexity, and risk of making small investments in small producers in emerging markets that present their own jurisdictional investment challenges.

However, an increasing number of alternate investment pathways channel financing to small-scale and emerging aquaculture producers. These include sustainability-focused loan facilities or bonds, typically issued by banks, which then on-lend the investment proceeds to various companies in their jurisdiction that meet the specific criteria of the loan facility or bond in question. Aggregating individual company loans into a loan facility or bond overcomes a number of traditional barriers to investing in emerging or small-scale producers by providing investors with (a) adequate investment ticket size per transaction, (b) risk diversification across multiple companies and sectors depending on the instrument mandate, (c) exposure to a more creditworthy financial institution as the counterparty, and (d) the benefit of investing via established institutions that are better equipped to understand and manage the counterparty and market risks prevalent in the jurisdiction.

Financial instruments that aggregate or pool smaller investment assets under specific investment mandates, such as a sustainable agriculture facility, can be thought of as transition finance investments for the aquaculture, blue economy, or broader agriculture sector. What is "lost" in not having an investment focused only on aquaculture is gained by the opportunity to invest at scale in supporting the transition to sustainable aquaculture. Table 7 is an example of a blue bond issued by a bank to generate funds that are then on-lent to customers and projects that qualify under the terms of the bond.

Table 7. Banco Bolivariano Blue Bond

Instrument	Blue Bond
Issuer	Banco Bolivariano
Jurisdiction	Ecuador
Amount	USD 80 million
Initial Investors	IDB Invest (USD 40 million), FinDev Canada (USD 40 million)
Use of Proceeds	The resources from the bond placement of the bond have as their main purpose the conservation of the oceans, through the promotion and expansion of access to credit for the sustainable production of seafood; water and wastewater management; and solid waste management and the circular economy. Likewise, the issuance includes a fair transition component by promoting the participation of micro, small, and medium-sized enterprises (MSMEs) in the supply/value chain in the different uses of funds
Issue Date	July 2023

Source: IDB Invest.

As Table 7 shows, bond and loan facilities issued or managed by banks often feature development finance institutions or impact investors as initial investors. This is in large part because of the capacity of these investors to patiently develop the financial instrument with the issuing bank and to provide technical assistance for investment instrument preparation activities such as impact verification or development of the thematic bond framework. Because the foundational work is completed with the support of the initial investors, other private investors are then able to participate as co-investors at the time of issue or to participate in follow-on investment tranches.

THE ROLE OF PUBLIC FINANCE

A growing world population and a stagnating or dwindling wild-caught fishery industry have increased the demand for aquatic food beyond what can be provided without the intervention of aquaculture. Governments are increasingly seeing aquaculture as an alternative source of aquatic food and a source of employment and national and rural economic growth. However, among countries, the interest and the extent of government involvement in aquaculture development differ in many respects depending on prevailing socioeconomic needs and often occur without planning or strategic thinking. Lack of understanding of aquaculture and equating aquaculture to fisheries when it requires a different set of inputs have traditionally led to a lack of appropriate infrastructure such as hatcheries, feed mills, research and extension support, an effective cold chain network,

and marketing considerations in many jurisdictions. Only when some governments realized aquaculture's utility as a commercial venture did public-sector financing become available, and some strategic development was considered at the policy level.

Commercial-level aquaculture is dominated by Asian countries, led by China, Indonesia, India, and Viet Nam. Latin America is the second-largest production region, featuring Ecuador, Chile, and Brazil as the leading markets; in Africa, Egypt and Nigeria are more prominent. Gleaning the development pathway from these countries and those selected for this report surfaces some patterns in the role played by governments in aquaculture development. These roles highlight the comprehensive approach required by governments to support and regulate the aquaculture sector effectively. Noting that aquaculture will rarely if ever develop effectively without the intervention of governments, good governance and investment of public funds are necessary for aquaculture to develop and realize its full potential.

The following key governance roles, when effectively performed, have enabled the development of a competitive aquaculture sector:

- **Regulatory framework and permits.** Governments grant permits, authorizations, and licenses for aquaculture activities. They also work on simplifying and disseminating the regulatory framework to promote increased investment in aquaculture.
- **Capacity-building.** Government support to empower the communities and the private-sector to undertake aquaculture activities can be seen in the training of national personnel and upgrading of facilities, creating a multiplier effect for various assistance programs and ensuring continuity and upscaling of project-initiated interventions.
- **Environmental management.** Governments play a crucial role in managing the environmental impacts of aquaculture. This includes conducting strategic environmental assessments and strengthening the environmental impact control framework through specific directives. The aim is to manage the environmental footprint of the sector and contribute to sustainable development.
- **Promotion of research and extension services.** Government support in this area includes developing new technological models for aquaculture in collaboration with research and educational institutions and the private-sector.
- **Infrastructure development.** Governments are involved in the development of shared infrastructure for aquaculture parks and hatcheries. This includes expanding land-use planning in areas with high aquaculture potential and improving the management and restocking of endangered species.

Successful aquaculture development also requires a balance between government intervention and private-sector initiative. Governments provide resources management, research, technology transfer, and infrastructure, and the private-sector brings flexibility, risk-taking, and initiative. To facilitate private-sector risk-taking, governments also play a key role in providing financial support programs and incentives to encourage

participation and private investment in the sector. Government financial support is deployed via differing mechanisms depending on the jurisdiction, but broadly features in one of the following categories:

- **Corporate and project tax incentives**—tax breaks to incentivize capital investment in production, value-added processing, or other pre- and post-production facilities.
- **Insurance programs**—provision or cost subsidization of insurance programs covering harvest loss resulting from widespread disease or other significant production disruptions.
- **Export support and incentives**—lower tax rates on export activities and other export promotion incentives such as international marketing and trade support.
- **Access to finance and credit enhancement**—credit guarantee schemes to facilitate commercial bank lending, and provision of concessional financing via low interest loans or risk sharing.

Not all forms of government support are inherently beneficial or deployed effectively. A key indicator for investors to look out for with respect to governance and government financial support is whether the aquaculture sector is improving in terms of yield and efficiency, which captures improvement or lack of it in existing farms, and whether government support or inaction is enabling inefficient capacity expansion. This comes back to whether government incentives are putting the country on a pathway to more efficient, intensive aquaculture production that is better equipped for financial and environmental sustainability or simply promoting continued proliferation of inefficient extensive farming.

Extensive farming that supports domestic food security and rural livelihoods can have significant social impact. Extensive aquaculture farming does however carry greater downside risks of environmental degradation and places greater dependence on sound country- and regional-level planning and governance to avoid overexpansion of inefficient aquaculture operations, which in turn carry greater financial risks. Social impact investors looking to support small and medium-sized farmers can invest in the microfinance institutions that lend to the sector while avoiding the nondiversified risk and cost inefficiency of direct investments in small producers.

For investors interested in financing the transition to more sustainable aquaculture production, the nature of government involvement and support for the sector takes on increased prominence in terms of the development pathway for companies in the aquaculture value chain—ultimately, if well executed, manifesting in more efficient aquaculture companies better equipped to operate sustainably in the long term.

MULTILATERAL DEVELOPMENT BANK ACTIVITY

Multilateral development bank (MDB) activity in the aquaculture sector can be instructive for investors to review as they consider which markets to invest in. Entities such as the World Bank Group, the Inter-American Development Bank (IDB), the Asian Development Bank (ADB), and the African Development Bank (AfDB) each comprised of institutions or business units that support or invest in government entities on the one hand and private-sector entities on the other. For example, the World Bank Group, which consists of the International Bank for Reconstruction and Development (IBRD), International Development Association (IDA), International Finance Corporation (IFC), and Multilateral Investment Guarantee Agency (MIGA), supports both the public and private sectors in countries at different levels of development. Government activities and policy frameworks for aquaculture are often supported by loans and technical assistance from the public-sector arms of the MDBs.

As an example, the World Bank offers several options for public-sector funding for aquaculture, tailored to the specific needs and contexts of different countries. These options include:

- **Project Preparation Facility (PPF)**, which provides funding for the design and start-up of projects, including the development and delivery of training programs;
- **Program-for-Results (PforR)** financing, which supports government programs by disbursing funds based on the achievement of specific program results; and
- **Project-Based Guarantees**, which support project financing and operations by allowing risk sharing between private-sector lenders and public-sector participants.

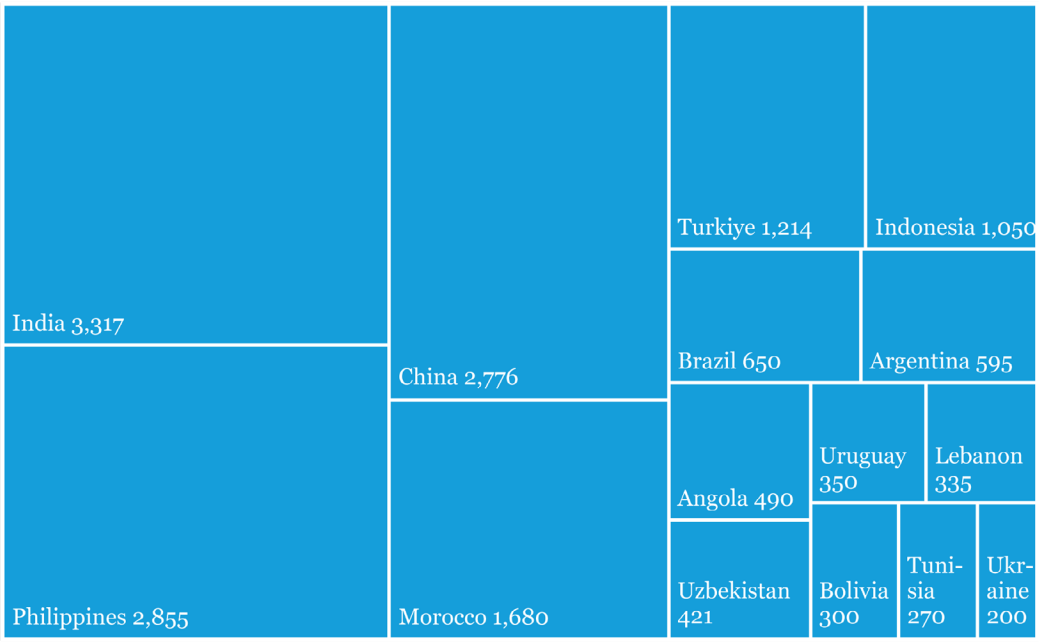
The IBRD otherwise known as the World Bank and IDA support the World Bank Group's mission by providing loans, guarantees, risk management products, and advisory services to middle-income and creditworthy low-income countries. IBRD is the largest development bank in the world, and has a long history of providing loans and other financial support to member countries in support of project and activities that directly or indirectly benefit the aquaculture sector. Figure 16 shows the top 15 country recipients of aquaculture related IBRD loans over the 10-year period from 2015-2024.

IBRD provided a total of US$ 18 billion in financing to aquaculture in 37 countries over the 10 years from 2015 to 2024. This financing was directed either directly at the aquaculture sector, or in adjacent industries such as fisheries, or market infrastructure and capacity-building beneficial to the development of the aquaculture sector. India tops the list; the Philippines, China, Morocco, and Turkey round out the top five. These loans are typically long term, linked directly to country development strategies and fiscal policies that are also supported by the IBRD via advisory services or other member institutions of

the World Bank Group. Other MDBs are also active in providing loans that support the development of the aquaculture sector and adjacent industries, albeit typically at lower levels and to fewer countries than IBRD.

Public-sector financing from MDBs is often a precursor to private-sector investment from the same or other MDBs. With a more developed enabling environment for aquaculture, DFIs such as IFC (the private-sector financing arm of the World Bank Group), IDB, and the private investment arm of ADB are more likely to make investments in companies in the aquaculture value chain. These investments are subject to the unique investment policies of each DFI, but it is nevertheless a useful indicator for private investors to note where the DFI investment activity in aquaculture has been concentrated in recent years.

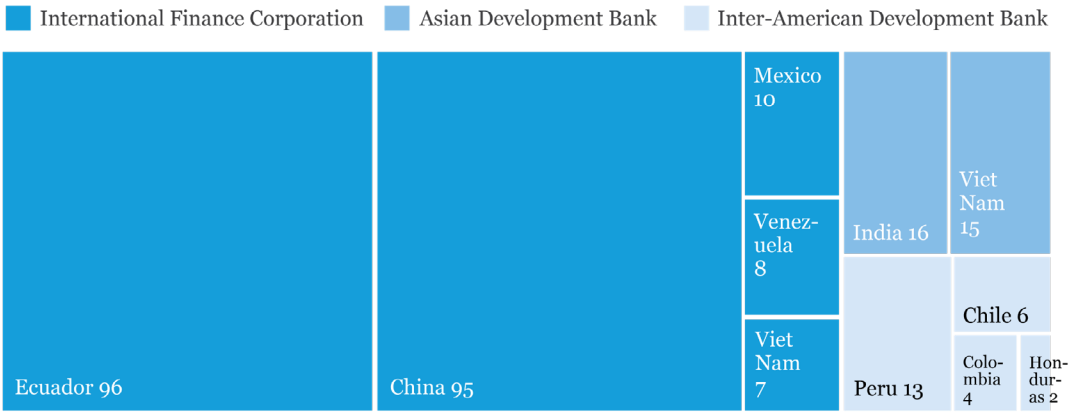
Figure 16. IBRD Aquaculture Related Investments, Top 15 Markets, 2015–24



Source: IBRD n.d.

Note: US$, millions.

Figure 17. Snapshot of Select DFI Aquaculture Direct Investments, 2000–24



Source: IFC n.d.; IDB n.d.; ADB n.d.

As Figure 17 illustrates, IFC with its multi-regional mandate (subject to classification as a developing country, which excludes Chile) has over the past 20-plus years invested almost equally in China, the dominant aquaculture producer and second-largest economy globally, and Ecuador, the 64th-largest economy by GDP in 2023. Many factors including strategic preferences and variations in investment appetite over time play into this investment allocation pattern, which does point to Ecuador despite its relatively small size producing attractive private investment opportunities in aquaculture. The pattern is also a reflection of the dynamic shown in Figure 14 earlier of Ecuador's having a high export value share relative to its annual aquaculture production.

Markets such as Ecuador and Chile have been able to create an environment in which a competitive aquaculture sector has emerged. Strategic government planning and support, coupled with effective coordination with the private sector, have played a key role in this development. This, alongside other positive jurisdictional factors, has over time created an attractive investment environment for private investors to deploy capital into aquaculture—the sustainability credentials of the aquaculture companies in those markets being a key factor in providing comfort to investors in making long-term-growth investments.

Investors interested in where the next wave of investable aquaculture opportunities will come from should pay attention to the regulatory initiatives and public finance investments being made in significant aquaculture producer nations. Markets with coordinated public-private initiatives to develop their aquaculture sector will be better positioned to enable the growth of more competitive and sustainable aquaculture companies.

2050 GROWTH OUTLOOK

Global aquaculture production reached 94 million metric tons in 2022 (FAO 2024b). This represented a 5.1 percent compound annual growth rate (CAGR) over the prior 25 years, China in particular showing strong output growth to end 2022 at 57.5 percent of total global production. In the sections that follow, we forecast forward to 2050, projecting growth patterns for individual producer nations to arrive at distinct global production scenarios. Using these scenarios, we then explore the investment opportunity in global aquaculture growth under business as usual) and upside growth cases (see Figure 18).

In the BAU growth case global aquaculture production is forecast to total 159 million metric tons by 2050, at an aggregate CAGR of 1.9 percent resulting in a growth multiple of 1.6 over the 25 years period from 2025 to 2050. To arrive at this forecast each significant producer nation was assigned distinct annual growth rates in the 2025–2030, 2030–40, and 2040–50 periods based on their historical production growth rates over the prior 25 years, and their potential for sustainable production growth through expansion of hectares under production, first-level yield improvement through application of better production practices, and second-level yield enhancement via application of more advanced production technologies.

The BAU growth case maintains the same global production market structure, the existing top 10 producer nations representing approximately 90 percent of global production as of 2050. Under the BAU growth case the top producer nations experience a deceleration in their growth rates as they reach a maturity plateau based on existing production methods and current sources and levels of investment. Producer nations outside the current top 10 do not undertake or benefit from significant investments in capacity expansion in this case. Nevertheless, even under a status quo market structure and investment environment, the supply and demand fundamentals of aquaculture production result in a material year-on-year growth forecast, with an additional 64 million metric tons of annual production achieved by 2050.

The supply and demand characteristics of overall protein production, however, point to a more substantial upside case for aquaculture production. Aquaculture is the protein source with the strongest combination of production growth potential that can substantively match global demand growth and whose production can be expanded sustainably within regulatory frameworks and current ecological carrying capacity compared to the carbon footprint of other major protein sources.

The upside growth case incorporates the following key elements over and above BAU growth:

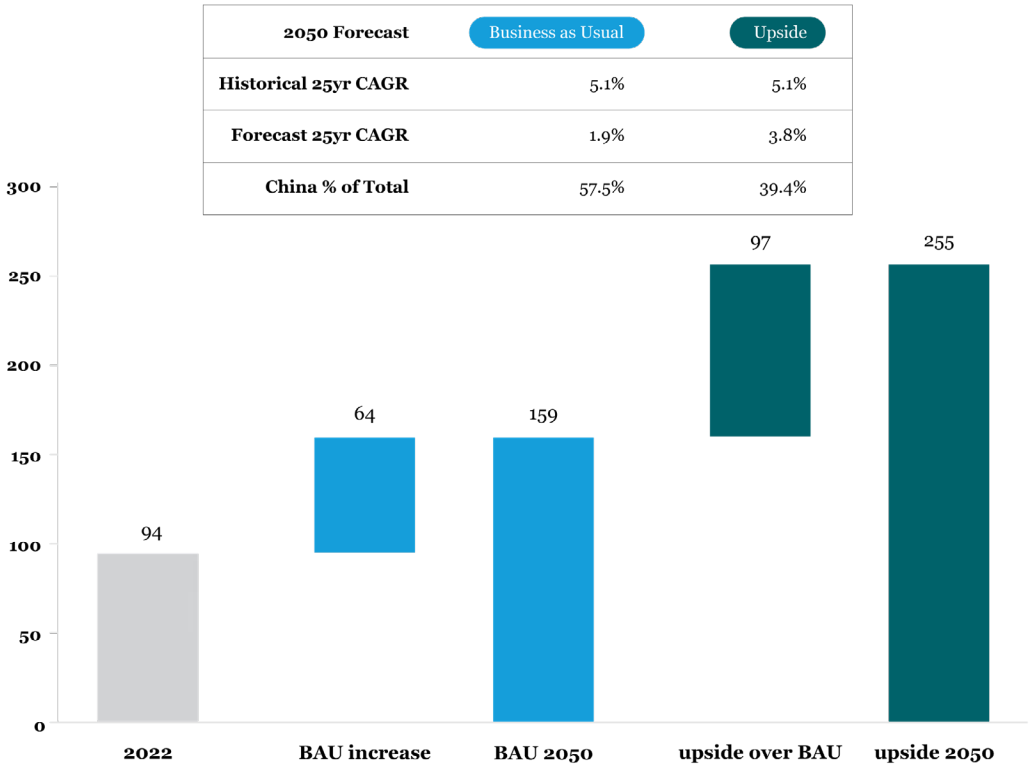
1. significant investment in markets outside the current top 10 producer nations, adding new production sources in response to continuous global protein demand growth;
2. existing top producer nations invest in more advanced technologies and production methods to grow production within limited growth in hectares under production, ushering in new phases of growth beyond the initial maturity plateau; and
3. capital investment and technology transfer in the second half of the 25-year forecast period to markets with little or no current production but with favorable attributes such as available land or infrastructure investments that will enable greater manufacturing, processing and logistics capabilities, and proximity to or trade relationships with large consumer markets.

The upside case forecasts global aquaculture production reaching 255 million metric tons by 2050, almost 100 million metric tons higher than the BAU growth case. Global production of 255 million metric tons would represent a 3.8 percent CAGR over the 25-year forecast period relative to the historical CAGR of 5.1 percent. The upside case does not depend on China, given that China's production is forecast to grow at a 2.3 percent CAGR relative to its historical CAGR of 4.4 percent. China's proportion of total production drops to just under 40 percent relative to its current level of close to 60 percent due in large part to aquaculture production growth outside the current top 10 producers.

Notable markets that currently produce less than 1 million metric tons that feature among the top 20 producers in the upside case include Brazil, Turkey, Mexico, Colombia, Nigeria and Ethiopia. Although some of these markets are forecast to require more time than

others to put enabling infrastructure and policies in place before aquaculture production ramps up, they have in common the physical capacity for new production, large domestic markets, existing or rapidly expanding agriculture production expertise, and the ability to attract foreign investment and technology transfer going forward.

Figure 18. 2050 Business as Usual and Upside Case Global Aquaculture Production Projections (Duplicate of Figure 4)



Source: World Bank.

THE TRILLION DOLLAR UPSIDE

The BAU growth forecast projects an additional 60 million metric tons of annual aquaculture production by 2050 over 2025. The Upside growth scenario projects an additional 97 million metric tons of annual production over and above the BAU forecast over the same period. For the purpose of forecasting the investments required for incremental production we adjust our analysis range going forward to the end of 2025 through to the end of 2050.

To project the investment capital required to finance incremental production, we use a range of investment dollars per metric ton based on recent precedent aquaculture investments in existing top 10 producer nations. The range allows for regional and investment specific variations in the amount of working capital required alongside capex investment

in production, and the amount of ancillary investment required alongside the core production capex to enable storage and handling, logistics and trade. Table 8 summarizes the total investment required to finance BAU growth, and the upside growth above BAU.

As shown in Table 8, financing BAU growth is projected to require between US$325 billion to US$740 billion over the next 25 years. Under the BAU scenario, this financing requirement covers both refinancing existing capital and deploying capital to new production capacity. Given the scale of capital required this will entail new investors in addition to existing sources of financing.

The upside scenario projects a financing need of between US$560 billion to US$1.3 trillion over the next 25 years for additional production above the BAU case. Because most of the upside growth is forecast to come from production markets outside the current top 10, the requirement is greater in the upside case for ancillary investments beyond direct production to build out the supply chain in new markets. In several new markets these ancillary investments such as transportation infrastructure, cold chain logistics and distributed energy connections will need to be made alongside or prior to significant investment in new aquaculture production for these markets to realize their production potential.

Ten emerging markets currently outside the top 20 producer nations are projected to account for more than one-third of the incremental production above the BAU case by 2050. These markets represent 36 million metric tons of the incremental 97 million metric tons projected in the upside case. Ranked by incremental growth these are Brazil, Turkey, Mexico, Colombia, Peru, Nigeria, South Africa, Tanzania, Democratic Republic of Congo, and Ethiopia (Figure 19).

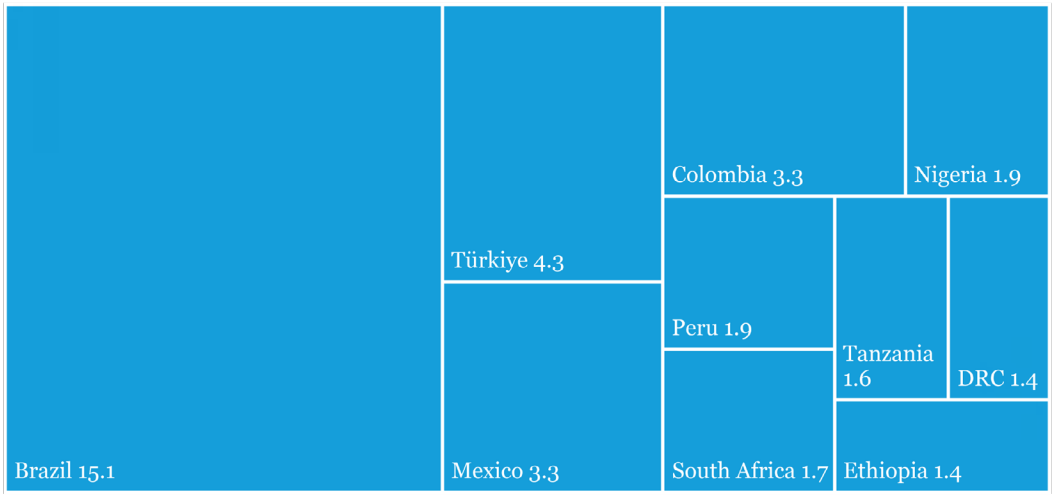
Taken together, BAU growth plus the upside scenario are forecast to require between US$900 billion to US$2 trillion of investment between 2025 and 2050. To realize this scale of investment opportunity will require thoughtful transitions between public finance enabling investments and private investment at scale, facilitated by various forms of concessional investment and derisking mechanisms.

Table 8. Projections of Aquaculture Production and Investments to 2050

	Incremental Production (Mt 000s)	Total Investment 2025–50, US$ billion (Capex + Working Capital + Ancillary Investment)		
	(2025–50)	Low	Median	High
BAU Case	60,040	325	550	740
Upside Growth	96,570	560	940	1,300
BAU + Upside	156,610	885	1,490	2,040

Source: World Bank.

Figure 19. Top 10 New Producer Emerging Markets, 2050 Projected Production Volume



Source: World Bank.

Note: Metric tons, millions.

MARKET OPPORTUNITY VERSUS MARKET RISK

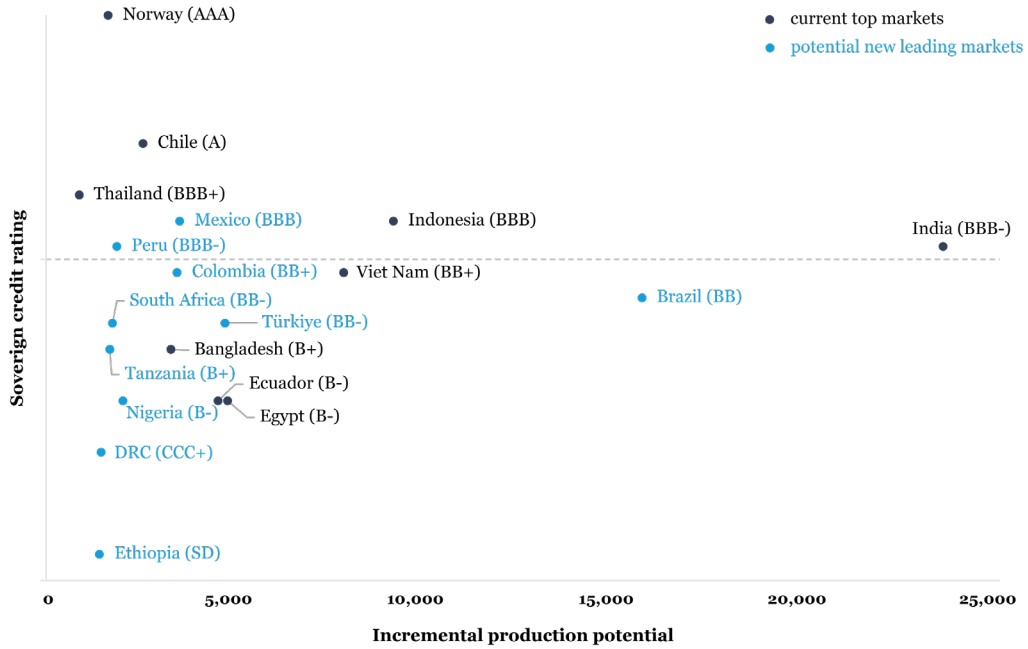
Figure 20 compares the potential new production by 2050 of the current top producer nations and potential new leading markets under the upside scenario against the country's sovereign credit rating using the Standard & Poor's (S&P) rating scale. The potential new leading markets are indicated in blue. China is excluded from the chart given its self-sufficiency in financing its agricultural sector, presenting limited opportunity for international investors to engage meaningfully in China's aquaculture sector.

Figure 18 can serve as an initial filter of present-day investment attractiveness of the jurisdiction to international investors, with investment-grade markets above the dotted line and sub-investment-grade markets below. The chart compares current sovereign credit ratings to future production potential and credit ratings can change over time; however some useful observations can be made regarding current market risk and market opportunity for aquaculture growth.

Investors that can invest only in investment-grade jurisdictions can look to Norway (rated AAA), Chile (A), Thailand (BBB+), Indonesia (BBB) and India (BBB-) for current aquaculture production opportunities. India shows by far the greatest growth potential to 2050 among current investment-grade markets.

Mexico (BBB) and Peru (BBB-) are investment grade markets with limited aquaculture production to date but with the potential to expand rapidly. Both markets have sophisticated production and processing companies in other agricultural sectors, evidencing the foundational enabling environment conditions, operational capabilities, logistics infrastructure and trade linkages that could be leveraged toward the establishment of high-growth aquaculture operations.

Figure 20. Sovereign Credit Rating and Incremental Production Potential by 2050 for Current Top Producer Markets and New Producer Markets



Source: World Bank.
Note: S&P credit rating; metric tons, millions.

Four of the five markets just below investment-grade, Brazil (BB), Turkey (BB-), Colombia (BB+) and South Africa (BB-), are potential new leading markets going forward with Viet Nam (BB+) as the lone current top producer in this sovereign credit rating tier. The four potential new markets each have established track records in large-scale agricultural production and processing; Brazil is the outlier in terms of incremental production potential reflecting amongst other factors its geographic size, economic growth potential, and relatively sophisticated agricultural finance market.

Jurisdictions with single B credit ratings are typically viewed as high risk by investors, limiting the pool of capital available for companies in these markets. High-risk sovereign ratings typically reflect structural weaknesses in a country's enabling environment - policy frameworks, rule of law and ease of doing business, physical infrastructure, financial market depth, and so on to attract external capital to their aquaculture sector. Ecuador (B-) stands out as a success story despite this limitation, its top aquaculture producer companies attracting significant domestic and international investment despite the country's high-risk classification. This is a testament to the focused development of Ecuador's aquaculture sector enabling the emergence of high-growth global leaders with risk-return profiles compelling enough to overcome the real and perceived risks of investing in a jurisdiction classified as high risk.

Although other high-risk jurisdictions can draw lessons from Ecuador to accelerate the development of their aquaculture sectors, the upside case assumes sub-Saharan markets such as Nigeria (B-), Tanzania (B+), and Democratic Republic of the Congo

(CCC+) will require five to 10 years or more of aquaculture focused capacity-building and strengthening of the enabling environment before meaningful production can be built up in these new markets.

One of the elements of a jurisdiction's enabling environment, financial market depth, can greatly help in mitigating the risk profile of aquaculture investments. Credit enhancement at the individual investment level or via pooled investment structures can play a critical role in bringing aquaculture investments to risk-return levels that satisfy the requirements of a broader set of investors. Markets that have more developed financial markets-featuring securitization vehicles, credit-enhanced facilities and structured lending products tailored to agricultural production will have more potential to channel capital towards aquaculture production. This is one of the reasons for the higher production potential for new markets such as Brazil and Turkey in the upside case.

Overall, with emerging markets representing the present and future of aquaculture production growth, the development and deployment of credit-enhancement instruments will be a critical success factor in broadening the capital pools available for aquaculture, particularly in sub-investment-grade markets.

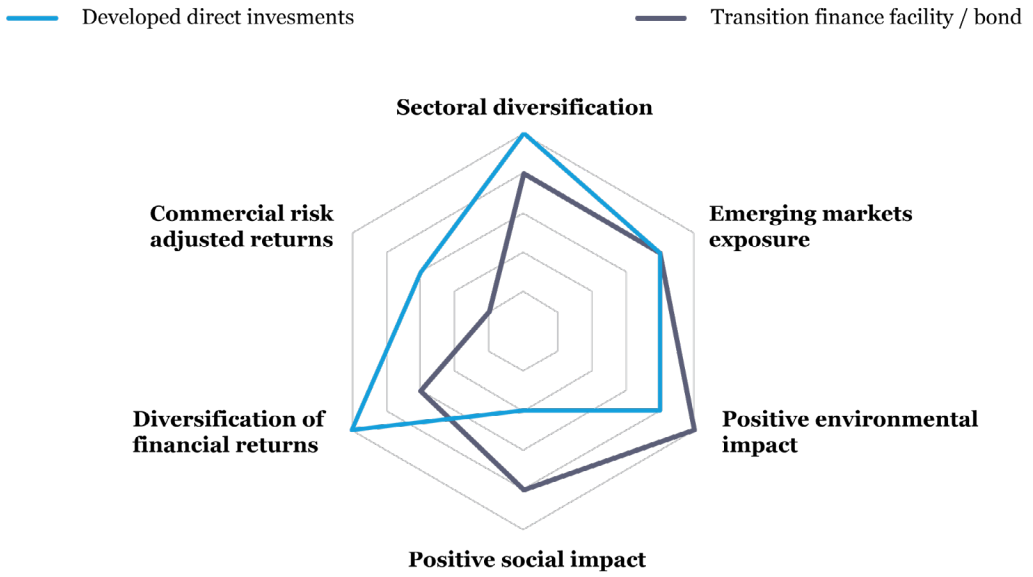
INVESTMENT PORTFOLIO ATTRIBUTES

For investors, adding sustainable aquaculture investments to their portfolios will have varying effects depending on the portfolio composition to which the investment is allocated and the nature of the investment itself. Figure 21 presents an illustrative comparison of the potential portfolio effects of an investment in a developed sustainable aquaculture company versus a transition finance investment in emerging sustainable aquaculture assets. Despite nuances in each individual investment that could affect this type of relative portfolio effect scoring, Figure 21 presents a generalized assessment across representative investments in each category.

Both developed and transitioned finance investments in sustainable aquaculture provide sectoral diversification comparable to traditional farmed seafood assets. This applies to generalist investors adding to their agriculture and food portfolio and to specialist investors diversifying their agriculture portfolio by production method. Given the relatively low share of agriculture and food investment for most investors, this alone is additive to their portfolio diversification. A similar premise holds for geographic diversification, via the emerging markets exposure that is more pronounced in aquaculture production than most asset classes.

The developed and transition finance investment categories featuring sustainable aquaculture both score similarly on positive environmental impact, and both compare favorably to other animal protein production sources on environmental and climate attributes. As true of other categories, this is a necessary simplification for the purpose of comparison. Asset-level due diligence is critical in assessing the nature and scale of direct and indirect environmental impacts for aquaculture investments.

Figure 21. Illustrative Investment Portfolio Effect Scoring



Source: World Bank.

The other portfolio scoring categories highlighted start to illustrate the differences between developed and transition finance investments in sustainable aquaculture. Transition finance in sustainable aquaculture by its very nature scores higher on social impact given the scale of the potential to secure and uplift livelihoods for larger numbers of individuals engaged in smaller-scale aquaculture. Investors should pay close attention to the type of transition being financed and have a more nuanced social impact scoring beyond employment figures. In many instances, a smaller number of more resilient aquaculture farmers producing at higher yields has greater medium-to-longer-term social impact on livelihoods than financing inefficient and unsustainable practices across a larger number of subsistence farmers.

Agriculture investments are broadly understood to provide more diversification of returns than most other asset classes. Developed aquaculture investments are attributed a higher score in Figure 21, because these would typically be larger individual investments than transition finance opportunities, thereby contributing more of the low or negative correlation effect to most investment portfolios. Some pooled transition finance opportunities may offer the same correlation effect depending on the composition of the underlying basket of individual assets. However, most transition finance investments would be limited in this respect by their relative size.

The risk-adjusted return comparison also reflects the difference in the scale and maturity of investments in developed sustainable aquaculture. Although these investments can still benefit from risk-sharing investment structures and other concessional finance given their environmental and social impact attributes, they are better positioned to offer levels of risk-adjusted returns suitable for private investors. Developed aquaculture investments mainly feature production for export, providing hard currency earnings that match or are easily hedged against the base currency of international investors.

Transition finance opportunities, by contrast, often have a domestic production focus with local currency earnings. This presents currency risk for either the investor accepting local currency returns or the investee repaying a hard currency investment using local currency earnings. Developed sustainable aquaculture opportunities also typically feature higher levels of vertical integration, enabling the operational resilience that is crucial in agricultural markets, where output price volatility and input cost inflation can impair the return profile of less mature operations. Transition finance investments, by comparison, feature aquaculture operations that require further scaling in operational efficiency and profitability levels, and are therefore more suited to investors with mandates that can accommodate lower risk-adjusted returns in exchange for broader development impact.

KEY TAKEAWAYS FROM INVESTORS

Protein demand shows no signs of slowing down in the foreseeable future and the upside case for aquaculture to sustainably satisfy continuously rising demand for animal protein is compelling. For this sustainable aquaculture growth to materialize, a greater proportion of current aquaculture production will need to transition from small-scale, extensive production to larger-scale intensive production. This will require transition investment capital in existing significant production markets, and greenfield investment in both new and existing production markets.

Aquaculture is potentially the largest sustainable food investment opportunity over the next 25 years. Given a median projection of between US$0.5 trillion to US$1.5 trillion of financing required between 2025 and 2050 under the business as usual and upside cases respectively, a deep and diverse ecosystem of complementary investors will be needed to meet the potential for sustainable aquaculture production.

The growth and upside potential of aquaculture is rooted in emerging markets, particularly countries that will be among the largest economies or the most populous countries by 2050. Aquaculture today is dominated by countries in Asia (85 percent of total), with only two markets in Latin America (Chile and Ecuador) and one in Africa (Egypt) producing more than one million metric tons as of 2022. Under the 2050 upside case, projections of Asia's share in global production could drop to 70 percent as a result of 34 percent of the new production capacity coming from Latin America, sub-Saharan Africa, Mexico and Turkey.

Employment generation is a powerful social impact of sustained aquaculture growth, BAU growth generating between 8 million to 14 million new aquaculture jobs by 2050, and the upside case adding an additional 13 million to 22 million jobs globally. These employment forecasts are based on estimates from Egypt (Nasr Allah et al. 2020) and Ecuador (CNA 2024) in addition to aggregate figures for the global aquaculture sector. The high end of this employment projection maintains current ratios of full time equivalent per metric ton whereas the low end assumes significant efficiency gains as aquaculture operations scale up and production methods improve over

time. Even at the low end of the projection, the addition of 21 million jobs (BAU + upside) would represent a doubling of the number of people employed in aquaculture globally by 2050. The level of development impact this would generate, particularly in the rural areas of emerging markets where aquaculture production is concentrated, further aligns the investment upside and environmental impact of sustainable aquaculture with the social imperative of accessible employment and income generation in emerging markets.

Aquaculture production has tremendous untapped potential for technology applications to boost production yields and sustainable practices. The first level of untapped potential in aquaculture production lies in the initial efficiency and sustainability gains via investments in feed, aeration, pond maintenance and renewable energy. This is vital for the large base of small-scale producers across developing markets to intensify their own production to achieve long-term financial viability and sustainability. Beyond this first level efficiency and sustainability gains, technology transfer between markets to progress to more advanced intensive production systems is achievable to enable further production growth with limited growth in the production footprint.
Aquaculture production growth will have a multiplier effect on aquaculture feed production and investment. This demand multiplier will be more pronounced for nonfish based feed ingredients. Fishmeal and fish oils currently account for approximately 22 percent of aquaculture feed ingredients, down from 90 percent in 1990. Alternative feed sources from vegetable and carbohydrate sources have largely replaced the prior dependence on fish meal and oil. However, to meet the demand generated by the projected aquaculture growth new and emerging alternative feed sources will be required. Holding fish meal and fish oil usage in aquaculture feed constant would require production volume of alternative feed sources to double by 2050 under the BAU scenario, and to triple under the upside case. This multiplier effect will spark exponential growth in investment opportunities for alternative feed sources such as algae, insect meal and other non-fish sources that can scale up substantially to fill the coming feed supply gap.

The growth and investment opportunity in aquaculture is currently constrained by challenges that cannot be solved by one group of investors alone. These challenges include:

1. the financing and capacity-building required to transition from small-scale extensive farming to a greater proportion of more financeable large-scale intensive or integrated farming;
2. continuous investment in R&D and technology applications required to sustainably solve bottlenecks in feed, yield improvements, efficient land-use carbon footprint reduction;
3. broadening the base of domestic credit and international investment available to aquaculture operations through stages of growth and operational maturity;
4. credit-enhancement and risk-sharing instruments to help investors manage real and perceived risks of investing in aquaculture—particularly to attract investors new to aquaculture, and especially in emerging markets;

5. aggregation of aquaculture assets into larger investment vehicles, to solve for financing smaller aquaculture operations as they scale up by providing asset diversification and larger ticket sizes for institutional investors.

Investors interested in aquaculture's financial upside potential and positive sustainability attributes are encouraged to seek out opportunities to collaborate with other investors in the aquaculture space to maximize the return and utility of their capital. At a minimum, investors should be aware of which forms of financing and investment should optimally precede their investment, which ones work well alongside their investment, and for mission-driven investors in particular, what their investment enables in terms of crowding in future financing for sustainable aquaculture.

Public Investors

Public investors have a critical role to play in the development and financing of aquaculture, particularly in emerging markets. This is not unique to aquaculture. In their earlier growth phases, the broader agriculture sector and the renewable energy sector in emerging markets also relied on development finance to transition from small-scale to larger-scale production, to fund early innovations, and to help reduce risk levels to enable private institutional investment.

Multilateral development banks are needed to connect the domestic policy and regulatory environment to the market infrastructure investments required to create the enabling environment for viable aquaculture sectors across the globe. Most investors do not have the combination of financial capacity, mission-driven risk tolerance, investment time horizon and leverage with domestic governments to develop, finance, and project manage the foundational market initiatives required to help markets achieve their potential for sustainable aquaculture production. MDBs would optimally focus their market infrastructure efforts on either the transition to sustainable production in existing markets, or the establishment and scaling of aquaculture in new markets.

MDB investments in a country's enabling environment and market infrastructure set the essential foundation for development finance institutions to make direct and indirect investments in aquaculture companies. These MDB investments help to derisk the jurisdiction, supporting governments in providing a framework for the sustainable development of economically and socially important sectors such as aquaculture.

Development finance institutions can enable accelerated growth of the sustainable aquaculture sector by focusing on investments that establish or stabilize the financial innovations required to solve bottlenecks holding back the aquaculture sector. Direct investments in top aquaculture producers in emerging markets do have positive impacts but are often limited to a narrow group of scaled up,

relatively well-funded companies. For more systemic impact towards achieving aquaculture's financial and sustainability upside, DFIs should look to place greater capital and focus on key issue areas including the following:

1. **Domestic commercial credit availability.** Most commercial banks in emerging markets lend to aquaculture producers based on collateral, often land and property in emerging markets. This has several limiting effects including gender bias and pushing producers toward predatory value chain financing. Small and medium-sized producers need to access capital to expand their operations, enabling them to invest in their business and thereby create an asset base they can borrow against in the future. For commercial banks to provide loans with less reliance on land-based security they would require years of operating and credit history on aquaculture producers, which can be generated within pooled sustainable loan facilities outlined in this report.
2. **Credit guarantee or risk mitigation for sustainable loan facilities.** The types of sustainable loan facilities referenced in this report are better positioned to attract investors when structured with credit guarantee or first loss features. The credit guarantee feature is not a solution for lack of financial viability of the aquaculture operations receiving the financing, but allows for the establishment of credit history by viable, growing aquaculture operations. DFIs and other public finance institutions that offer credit guarantee products to commercial lenders in emerging markets should explicitly include aquaculture loans as eligible for their coverage to accelerate this transition toward unsecured lending to the aquaculture sector.

Similar to the foundation-setting role of MDBs, DFI investments provide a platform for private investors, both concessional and commercial, to invest in aquaculture production companies. DFIs help derisk aquaculture companies through providing much needed growth capital and an important signaling effect and assurance to private investors. The assurance often plays an important role in the investment decision-making process for private investors new to the market in question or to emerging markets as whole.

Private Investors

Philanthropic and concessional investors are crucial for the early scale-up of sustainable aquaculture operations and in the development and seeding of aggregation and derisking facilities. Given their focus on impact and innovation, these investors are well positioned to take venture risks in two ways:

1. First, in helping create and capitalize the transition facilities to aggregate small producers into larger pools of sustainable food production and green growth assets. Given their access to credit via these pooled facilities, small producers would have the opportunity to grow into more stable small and medium-sized enterprises and small corporates with access to standalone financing

2. Second, providing early growth financing for aquaculture producers to enable them to adopt sustainable production practices at higher efficiency levels. These emerging producers requiring US$1 to US$3 million of financing currently still find themselves below the threshold of many DFIs and often face stringent conditions from or limited access to commercial bank lending.

One key attribute that can differentiate philanthropic investors is their appetite for the development phase of financial innovations such as credit-enhanced sustainable investment instruments. In many instances, once these facilities are developed DFIs and other investors can be brought in to structure the instruments and deploy the initial capital required. The innovation bottleneck is often the gap between concept and viable financial instrument. By focusing on the development phase of the financial instruments required to enable sustainable aquaculture growth philanthropic investors can better maximize the impact of their capital and risk appetite in deepening the financing market for sustainable aquaculture.

Private investors have multiple current and future entry points to participate in the explosive growth of aquaculture. Existing large producer markets such Norway and Chile provide current investment opportunities for private investors, particularly in advanced intensive production systems. Beyond these investment-grade markets, private investors can look to high-growth investment markets such as India and Viet Nam. Investors limited by mandate from investing in smaller emerging markets can look to the larger markets poised to become future leaders in aquaculture production, such as Brazil, Mexico, and Turkey. These markets feature large established agricultural producers and processors that are among the most likely future aquaculture producers. Private investors can also focus on the feed inputs market if direct agricultural production exposure is outside their mandate, in particular new feed formulations not reliant on fish by-products.

Overall, the aquaculture sector provides investment opportunities for a range of investors, whether mandated to finance early innovations, transitions to sustainable production, or growth of more mature sustainable aquaculture operations. Because aquaculture producer nations are at different stages of development, investors can also select from existing investable opportunities in developed jurisdictions or invest in emerging leaders in high-growth markets. Aquaculture provides a diversity of impact themes, and sustained global demand growth is poised to propel aquaculture from a niche investment area to a mainstream long-term investment strategy.

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