WHEN TRUST MATTERS

SEAFOOD FORECAST

Ocean's Future to 2050

DNV is an independent assurance and risk management provider, operating in more than 100 countries, with the purpose of safeguarding life, property, and the environment. Whether assessing a new ship design, qualifying technology for a floating wind farm, analysing sensor data from a gas pipeline or certifying a food company's supply chain, DNV enables its customers and their stakeholders to manage technological and regulatory complexity with confidence. As a trusted voice for many of the world's most successful organizations, we use our broad experience and deep expertise to advance safety and sustainable performance, set industry standards, and inspire and invent solutions.

CONTENT

FOREWORD

To achieve sustainable industry trajectories in the Blue Economy, we need a greater understanding of the ocean and the potential impacts of ocean-related activities, based on reliable data and scientific knowledge.

In 2021, at the start of the UN Decade of Ocean Science for sustainable development, we developed our first Blue Economy model to be able to address challenges and opportunities associated with a sustainable and equitable ocean economy through a series of forecasts. We published a *Marine Aquaculture Forecast* (DNV, 2021a) highlighting the critical role of farmed seafood in securing supplies of food for a global population that will exceed nine billion by 2050. Subsequently, in our *Ocean's Future to 2050* outlook (DNV, 2021b), we placed seafood production into a wider context of other ocean industries. There, we identified the key trends shaping the development of the Blue Economy and highlighted the urgent need for sustainable ocean management. Further, in our *Spatial Competition Forecast* (DNV, 2023b) we drew attention to a 'race for space' with increased pressure and congestion, particularly along coastlines, which must be carefully managed.

Mindful of the need to tackle the large system transitions in the Blue Economy, this *Seafood Forecast* provides further insight into the interactions between seafood value chains and other food systems, between the need for sustainable feed in balance with food, and between food security and growing supply-demand imbalances across different regions.

We forecast an increase in overall marine seafood production of about 20% to 2050. While capture fisheries output is stagnant, marine aquaculture will double and finfish production almost triple in this period. We do not, however, see any significant change in protein consumption patterns. Scaling up land-based food production to meet global food demand is facing significant challenges due to, among other issues, climate change and other sustainability concerns. A future shift in demand towards a more seafood-based diet could relieve some of this pressure, but this is a slow-moving process influenced by affordability, food culture, and other consumer preferences. Given a sufficient change in demand, expanding marine aquaculture represents a significant worldwide opportunity in the Blue Economy.

As capture fisheries output globally remains stagnant, we point to a supply-demand gap for wild-caught seafood that marine aquaculture production will not close by 2050. Some regions, particularly across Africa and Asia, will see large increases in demand due to growing populations and rising living standards. However, these regions are not necessarily the same as those that will see an improvement in the availability of wild-caught seafood. We forecast that the supply-demand imbalances will drive a 50% increase in trade by 2050 and that seafood will remain among the world's most traded food products. These imbalances are tainted by illicit trading and lack of transparency, emphasizing the urgency of global measures that address sustainability challenges and safeguard both food security and livelihoods.

Marine aquaculture must maintain an intense focus on fish health and welfare, technological innovation, and sustainability measures to meet future growth. One key priority will be to meet the demand for feed ingredients by decoupling it from sources of food for human consumption. We forecast that feed supplies will improve on sustainability by transitioning to novel ingredients. Our study shows that the share of novel ingredients will rise from negligible levels today to reach 26% of the ingredient mix for feed for marine finfish and 37% of the mix for crustaceans. These developments are crucial for the long-term sustainability of fed aquaculture in our seafood mix.

Our aim has been for this forecast to serve as input towards greater transparency as well as understanding of the development of seafood in the Blue Economy at both the global and regional scale. I hope that you find our insights of value and look forward to your feedback.

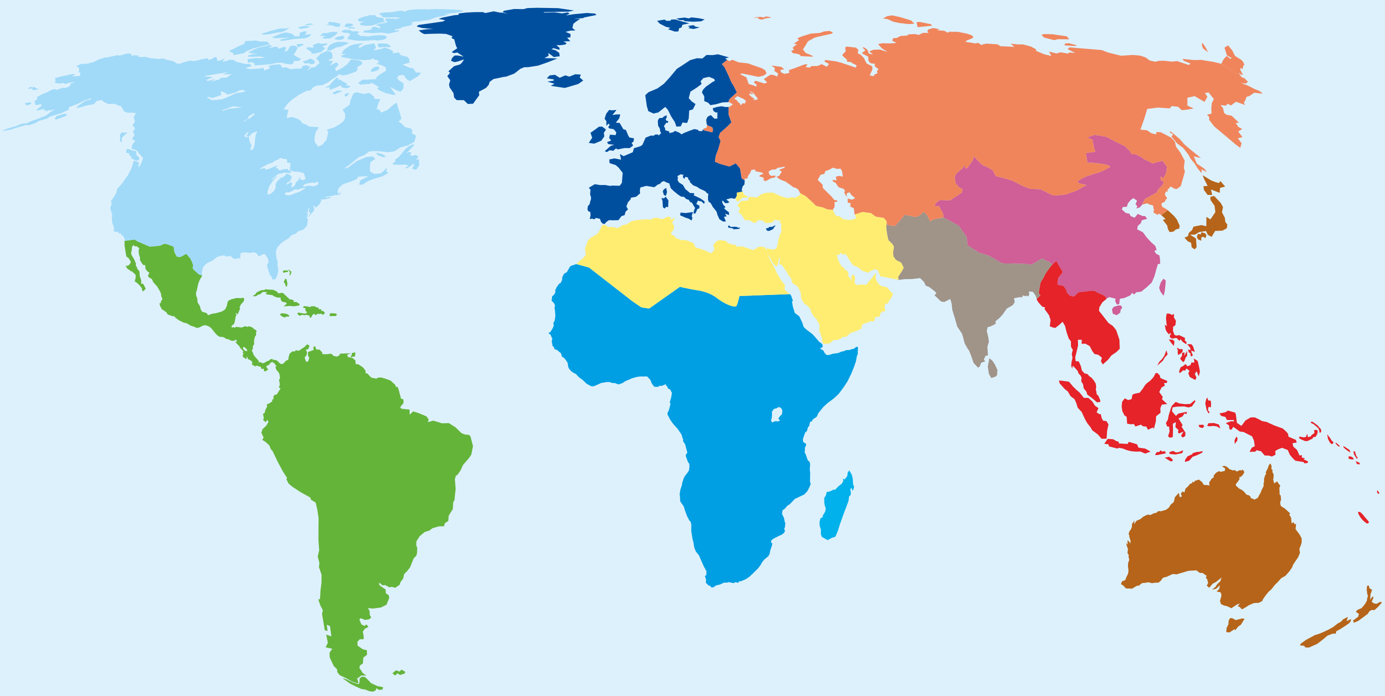
Bente Pretlove

Programme Director, Ocean Space

DNV Group Research and Development

The ten world regions

Key socio-economic drivers for our analysis are derived for the 10 regions shown in the map. See further explanation of our approach in the appendix.



- North America (NAM)
- Latin America (LAM)
- Europe (EUR)
- Sub-Saharan Africa (SSA)
- Middle East and North Africa (MEA)
- North East Eurasia (NEE)
- Greater China (CHN)
- Indian Subcontinent (IND)
- South East Asia (SEA)
- OECD Pacific (OPA)

Highlights – developments to 2050

1. **Seafood demand is on the rise, but there is no indication of large-scale dietary shifts**
   - The growth in seafood demand per capita will be larger than that of terrestrial meat and vegetarian foods in all regions except Latin America and OECD Pacific
   - Per capita seafood demand will be highest in South East Asia, where marine and freshwater seafood combined grows to comprise more than 30% of the protein demand
   - In absolute numbers, Greater China will be the biggest market for marine seafood
   - Seaweed production will grow rapidly in Europe and North America, driven by demand for industrial and food additives, but consumption as direct food will be low

2. **Marine aquaculture of finfish triples and overtakes molluscs as the leading farmed species type**
   - Global production of marine seafood increases 20% when considering both farmed and wild-caught finfish, crustaceans, and molluscs
   - Capture fisheries output globally remains stagnant, while marine aquaculture production doubles
   - Marine finfish production expands from sheltered waters to onshore and offshore facilities, which reach a global share of 12% and 7%, respectively

3. **Seafood trade patterns change, driven mainly by increasing supply-demand imbalances in the capture fisheries**
   - Seafood trade grows faster than production, implying that regions will become more dependent on imports
   - Sub-Saharan Africa will be the biggest seafood importer, due to declining regional captures and fast-growing food demand
   - Europe will be the leading exporter of marine seafood with Sub-Saharan Africa and the Middle East and North Africa as the major destinations
   - Latin America will be the largest exporter of marine aquaculture products (finfish and crustaceans) with North America as the major destination

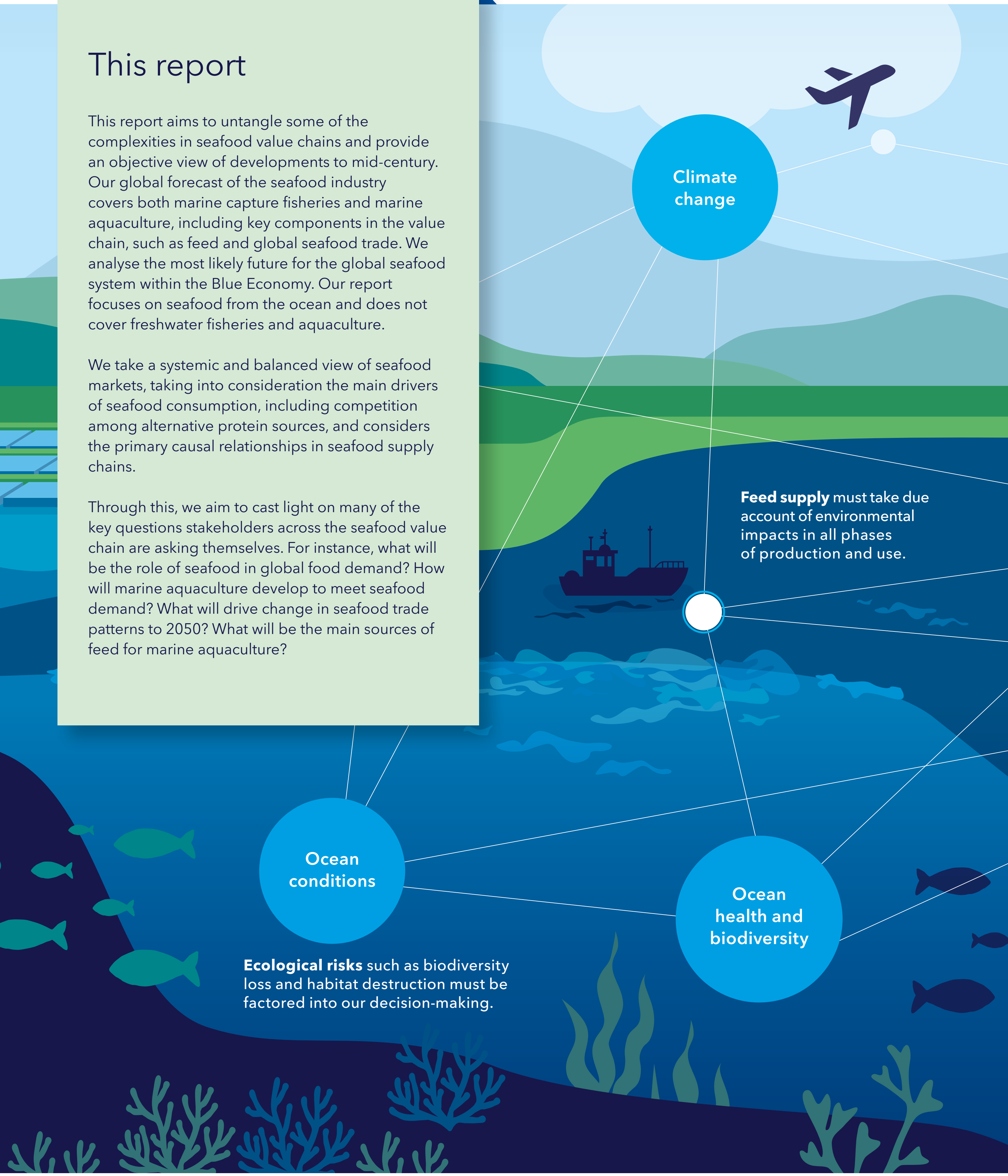
4. **Aquaculture feed supplies will diversify further, reducing the dependence on marine and agriculture-based ingredients**
   - Inclusion of novel ingredients such as single-cell proteins, insect meal, and algal oil will reach 30%
   - The combined share of fish meal and fish oil in the feed decreases from 18% in 2020 to 9% in 2050
   - Plants will remain the largest source of ingredients by volume, but the share decreases from 66% in 2020 to 50% in 2050

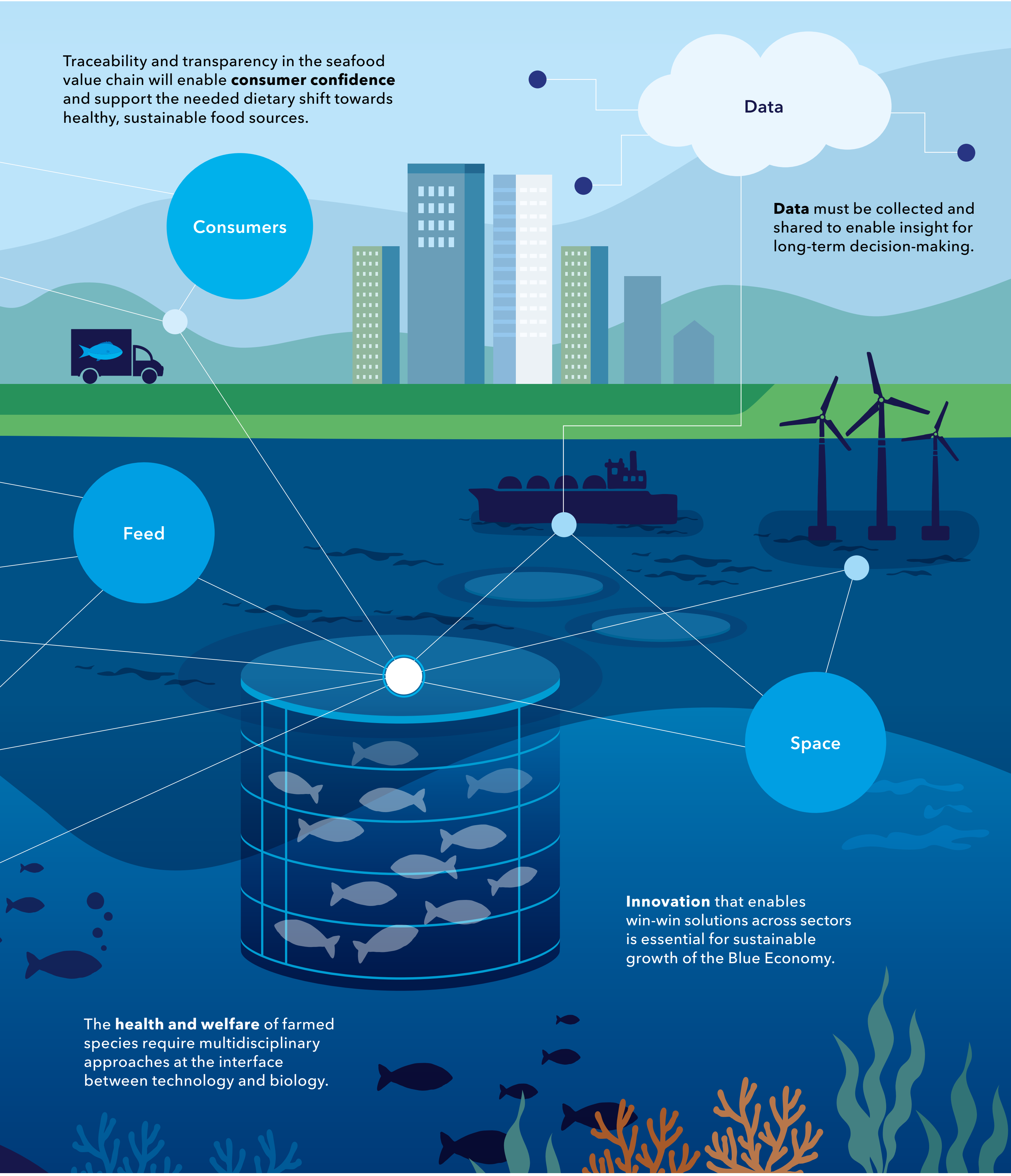
This report

This report aims to untangle some of the complexities in seafood value chains and provide an objective view of developments to mid-century. Our global forecast of the seafood industry covers both marine capture fisheries and marine aquaculture, including key components in the value chain, such as feed and global seafood trade. We analyse the most likely future for the global seafood system within the Blue Economy. Our report focuses on seafood from the ocean and does not cover freshwater fisheries and aquaculture.

We take a systemic and balanced view of seafood markets, taking into consideration the main drivers of seafood consumption, including competition among alternative protein sources, and considers the primary causal relationships in seafood supply chains.

Through this, we aim to cast light on many of the key questions stakeholders across the seafood value chain are asking themselves. For instance, what will be the role of seafood in global food demand? How will marine aquaculture develop to meet seafood demand? What will drive change in seafood trade patterns to 2050? What will be the main sources of feed for marine aquaculture?





Traceability and transparency in the seafood value chain will enable **consumer confidence** and support the needed dietary shift towards healthy, sustainable food sources.
Data
Data must be collected and shared to enable insight for long-term decision-making.
Consumers
Feed
Space
Innovation that enables win-win solutions across sectors is essential for sustainable growth of the Blue Economy.
The **health and welfare** of farmed species require multidisciplinary approaches at the interface between technology and biology.

1 INTRODUCTION

With a world population reaching beyond nine billion people by 2050, demand for sustainably sourced food will soar.

Seafood in the Blue Economy

Throughout history, humankind has turned to the ocean for food. To meet the need for seafood, the industry has grown from a traditional fisheries sector deeply ingrained in local coastal cultures into a global value chain covering a multi-faceted range of suppliers, vast trade networks, and increasingly complex production practices. Through the emergence of industrial fisheries and aquaculture, seafood is a key component of the Blue Economy and interlinks with numerous other ocean industries and ecosystem services provided by the ocean itself.

The Organisation for Economic Co-operation and Development (OECD) defines the Blue Economy as "the sum of the economic activities of ocean-based industries, together with the assets, goods, and services provided by marine ecosystems" (OECD, 2016). The concept of a Blue Economy allows stakeholders to pursue an integrated approach to human activities in the ocean and develop policies that account not only for the interests of specific sectors, but also the interlinkages between them. Beyond seafood, the ocean is also quickly becoming the frontier for renewable energy growth, with offshore wind forecast to contribute 50% of investment in the Blue Economy in 2050 (DNV, 2021). This will have significant impacts on the availability of space in the open ocean for other users, including fisheries and aquaculture (DNV, 2023b).

The overall seafood industry in 2020 was estimated to be worth more than USD 350 billion in 2020.[1] Global trade in fish and other aquatic resources in 2020 was estimated at USD 113 billion, more than 9% of the global trade in agricultural products and more than 2% of the global commodities trade (Chatham House, 2023). The role of seafood in national economies varies greatly. In some smaller island states, the industry contributes more than 5% of total GDP (Gross Domestic Product) (FAO, 2022a). The seafood value chain accounted for around 7% of the gross value added (GVA) by the ocean economy in 2010, not counting artisanal fisheries and aquaculture (OECD, 2016).

While seafood does not match offshore energy or maritime transportation by GVA, seafood is the most important provider of livelihoods in the Blue Economy, and is far bigger on this measure than the other ocean industries (OECD, 2016). According to the FAO (2022a), seafood contributed almost 60 million jobs globally in 2020 counting direct employment, with 65% of these in fisheries.

When looking at the broader value chain, this estimate grows by many times, with total employment in fisheries estimated at 260 million people in 2013 (Teh & Sumaila, 2013). This estimate also covers supporting services like shipbuilding, provisioning of equipment, maintenance and repair, as well as downstream value chain activities like processing, distribution, and marketing.

Species consumed as seafood depend on a complex food web that is under threat from numerous stressors like climate change and ocean pollution. Fisheries also contribute to stock depletion through excessive catches and fishing of juveniles, and overfishing has become the primary driver of extinction risk for marine fish (Stuchtey *et al.*, 2023). Overfishing is hence not only a threat to long-term human prosperity through reduction in catch but can also reduce biodiversity and irreversibly alter the composition and functioning of ocean ecosystems.

As of 2019, around 40% of fish stocks were either overexploited or collapsed (Pauly *et al.*, 2020). These fish stocks combined still constituted 13% of the catch, whereas more than 60% of the catch came from fully exploited stocks (Pauly *et al.*, 2020). With optimal fisheries management, where each of the stocks currently targeted by the fisheries is exploited at their Maximum Sustainable Yield (MSY), the total fisheries catch could increase up to 20% (Costello *et al.*, 2020; FAO, 2022a). As optimizing fisheries management everywhere is difficult, increases in the demand for food from the ocean will need to be met by scaling marine aquaculture.

Expanding marine aquaculture represents a significant opportunity in the Blue Economy around the world. Marine aquaculture has been increasing rapidly for 30 years. From 1990 to 2020, it saw 6-fold growth from 5.3 Mt to 32.6 Mt, measured in live weight. In the case of Atlantic salmon, the industry has undergone rapid industrialization and significant consolidation to the point where vertically integrated corporations with ownership of the value chain from hatchery to exports control a large portion of the overall market (Olafsdottir *et al.*, 2020).

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1 Assuming 178 Mt global fish production in 2020 (FAO, 2022a) and a global average price of 2 USD/kg across all fish commodities (including finfish, crustaceans, molluscs and others).

One billion people already receive most of their animal protein from the ocean.

Seafood in the global food system

The global food system will need to evolve and adapt to meet the nutritional needs of 9.6 billion people in 2050. In 2021, terrestrial meat production stood at 340 Mt, having more than quadrupled since the 1960s, with more than 90% coming from a few species groups like poultry, pork, and beef (Ritchie *et al.*, 2021). In comparison, seafood encompassed more than 2,500 species including aquatic animals and algae (Tigchelaar *et al.*, 2022). With demand for meat globally estimated to grow to more than 500 Mt by mid-century (Costello *et al.*, 2020), a dietary shift towards seafood in many world regions would greatly contribute to reaching global goals relating to human and planetary health.

Seafood is seen by many as a vital contributor to future food security around the world, given the constraints faced by land-based protein production (FAO, 2022a; Tigchelaar *et al.*, 2022). Production of terrestrial crops and meat puts significant stress on the environment and faces challenges due to scarcity of land and water resources (Costello *et al.*, 2020). There are large regional variations in the sustainability of terrestrial meat production. The species involved are generally much less efficient in terms of converting feed inputs to food product and generally have a higher carbon footprint than seafood.

One billion people already receive most of their animal protein from the ocean (Stuchtey *et al.*, 2023), and seafood is also seen as an important lever in shifting wealthy countries towards more healthy and sustainable diets. The EAT-Lancet Commission (Willett *et al.*, 2019) proposed a dietary shift towards a universal healthy diet, and suggested targets for sustainable food production that underpin a "safe operating space for food systems" and result in a win-win for health and the environment.

In the EAT-Lancet reference diet, which mainly suggests the replacement of meat by plants, seafood is considered the one set of animal protein sources for which consumption should increase (Willett *et al.*, 2019). To align the future food system with this reference diet globally would require more than doubling (+120%) seafood production (Willett *et al.*, 2019). Still, policy decisions surrounding food systems focus mainly on agriculture and livestock, often placing less emphasis on seafood (Tigchelaar *et al.*, 2022). Seafood needs to be better integrated in global, regional, and national food system strategies to ensure food security and nutrition (FAO, 2022a).

The FAO (2022) and global initiatives like the High Level Panel on the Sustainable Ocean Economy (Stuchtey *et al.*, 2023) highlight the potential for greatly expanding the supply of seafood, pointing to aquaculture as the solution due to the limited possibilities for scaling fisheries.

Costello *et al.* (2020) estimate that the ocean could increase its provision of food 6-fold in an optimistic scenario that would require major global policy interventions. They suggest that this additional food supply should primarily come from molluscs, rather than fed aquaculture (finfish and crustaceans), as molluscs are filter-feeders which extract nutrients from the water instead of relying on feed inputs that also pollute. Gentry *et al.* (2017) use geospatial modelling and find that only a very small share of the potential area for marine aquaculture is actually exploited. Their results suggest that countries with ample marine space, like Australia and Indonesia, can theoretically produce between 16 and 24 Mt of marine aquaculture products annually. Such developments would however lead seafood into more competition for space with nature and other ocean users.

Research on the future of seafood reveals that what is realistic in terms of underlying drivers like food demand and affordability is often obscured by what is perceived to be technically possible. Popular products of marine aquaculture, like farmed salmon and shrimp, remain relatively expensive, and are hence out of reach for consumers in the least wealthy countries (Sumaila *et al.*, 2022). These products also require large material inputs in the form of feed compared with non-fed aquaculture alternatives (molluscs and seaweed), and shed nutrients to the environment. Furthermore, risks of fish escape and disease transmission to wild fish populations can have a negative impact on biodiversity. Whereas studies of the technical potential point to bivalves and seaweed as the most sustainable solution (Costello *et al.*, 2020; Gentry *et al.*, 2017), these protein sources have not yet seen the same favourable trends in demand as fed marine aquaculture species (e.g. farmed salmon and shrimp) and therefore remain less impactful in terms of contribution to food supplies (Belton *et al.*, 2020; Edwards *et al.*, 2019).

The seafood value chain

Inbound logistics in aquaculture encompass hatching, smolt production, and in some cases capture of juveniles for sales to ongrowers. They also include fish feed, requiring wild-caught fish. In salmon farming, smolt sizes have been trending upwards due to the influx of more exposed sites with harsher conditions, requiring sturdier fish at transfer to seawater. In turn, this has generated a boom in development of recirculating aquaculture systems (RAS) which will impact ongrowing operations and makes it possible to grow salmon to slaughter in onshore facilities. For capture fisheries, the equivalent of the inbound logistics is the dependency of the sector on ecosystem services for the replenishment of stocks.

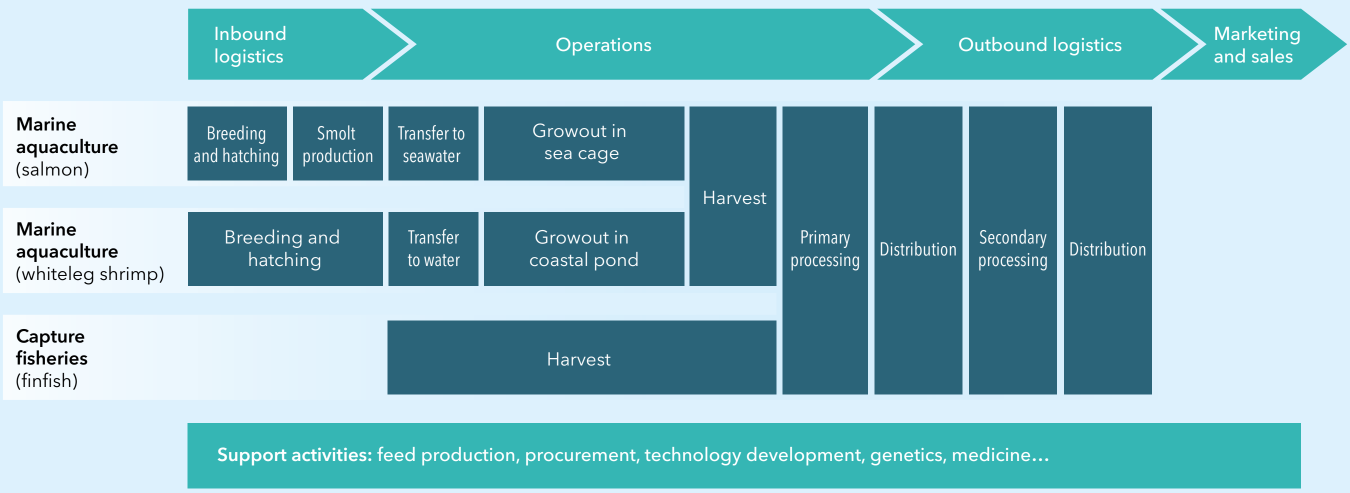
The main operations in the seafood value chain encompass growout operations in the sea in marine aquaculture, and the harvesting of wild catch by fishing vessels. Fishing vessels range from small artisanal boats to large, industrialized factory trawlers. The world fishing fleet has millions of boats (FAO, 2022a). Aquaculture systems for growout range from sea cages of varying complexity for marine finfish, to coastal ponds for some finfish and most crustaceans, to long line structures for non-fed aquaculture (seaweed and molluscs). Technical solutions like open net-pens for marine finfish cause numerous environmental impacts, including nutrient discharge into the environment, transmission of pathogens between fish farms and wild fish stocks, risk of fish escapes, and chemicals used for antifouling and in salmon delicing operations.

Outbound logistics encompass primary processing, distribution, secondary processing, marketing and sales. The outbound logistics chain can be very complex, with some seafood products being exported from the country of origin for secondary, value-added processing, before being shipped to yet another country for sale to the end consumer. Increasingly strict requirements emerging from the HoReCa (hotel, retail, and catering) and consumption sides impact the main operations beyond minimum government requirements. Several certification schemes exist to ensure food safety and sustainability. Standards such as the Marine Stewardship Council (MSC), the Aquaculture Stewardship Council (ASC) and Global G.A.P. (Good Aquaculture Practices) provide the market with insight on the sustainability of seafood products, with some retailers buying only certified seafood (Olafsdottir *et al.*, 2020).

Support activities include aquaculture feed, pharmaceuticals, logistics and maintenance operations, and provision of enabling technologies for improving farming (see text box on digital technologies). Representing half of the production costs per kilo, the feed industry plays a particularly important role (Iversen *et al.*, 2020). Feed ingredients also enter other food supply chains (e.g. animal feed), and in many cases are used directly as human food. The bargaining power of fish feed producers can be limited in a context where feed for aquaculture constitutes only 4% of the overall supply (Sandström *et al.*, 2022).

FIGURE 1.1

Seafood value chain examples – salmon aquaculture, whiteleg shrimp aquaculture, and capture fisheries



Current status of seafood

According to the FAO, global production of aquatic (including both freshwater and saltwater) animals was estimated at 178 Mt live weight in 2020[2], while global production of algae was estimated at 36 Mt live weight when counting both marine and freshwater varieties (FAO, 2022a). Of this aquatic animal production, capture fisheries contributed 90 Mt (51%) – a number that has been reasonably stable – and aquaculture 88 Mt (49%), the largest share yet, which is a result of worldwide industry growth. The FAO, however, does not include illegal, unreported and unregulated fishing in its estimates, so the capture fisheries number is higher, up to 98 Mt in 2019, as estimated by Sea Around Us (Pauly *et al.*, 2020).

When considering the contribution to food supplies, we must also account for the edible weight of aquatic animals, which is much lower than their live weight. Capture fisheries therefore provide much more food than marine aquaculture, as finfish dominates in capture fisheries. On the other hand, molluscs are the predominant species group in marine aquaculture, measured in live weight. Only 17% of the live weight of a mollusc is edible meat, which makes its contribution to food much lower than finfish and crustaceans (Edwards *et al.*, 2019). When discussing production, we will still refer to live weight unless otherwise described.

Seafood is highly diverse, with more than 2,500 species consumed by humans, including both aquatic animals and algae.

China has the largest capture fisheries industry, followed by Indonesia and Peru. Most of this catch goes towards human consumption, with 11% left for non-food use, mainly to produce fish meal and fish oil. China and Indonesia lead the world in terms of aquaculture production, while Chile leads in Latin America and Norway in Europe (FAO, 2022a).

In terms of the split between freshwater and marine production, nearly two-thirds were harvested from marine waters. Freshwater capture and aquaculture are outside of the scope of our analysis. Of the marine waters production, 70% came from capture fisheries, and the rest from aquaculture. On a species level, finfish make up around 85% of marine capture production, whereas molluscs constitute over 50% of marine aquaculture output when measured in live weight (FAO, 2022a).

In marine aquaculture, the most important species are Atlantic salmon and whiteleg shrimp, when looking at the global market value. Other high-value species groups such as tuna, cephalopods, shrimps and lobsters also continue to be the most sought-after wild-caught species, though their catch levels have remained steady or declined slightly (FAO, 2022a).

Though much smaller, algal production still came in at 36 Mt in 2020, more than 97% of this from aquaculture, with Japanese kelp as the most farmed species, followed by species of Eucheuma and Gracilaria. Asian countries dominate production of algae, with China as the leading producer, followed by Indonesia and South Korea (FAO, 2022a). However, there are reporting gaps in quantifying seaweed production, and these numbers may not reflect the actual supply (Belton *et al.*, 2020).

2 Only capture and aquaculture of finfish, molluscs, and crustaceans (176 Mt) are shown in Figure 1.2. Smaller volumes of turtles, frogs, jellyfish, sea urchins and sea cucumbers add up to 2 Mt, but are not shown in Figure 1.2, as these species types are not covered further in the report.

FIGURE 1.2

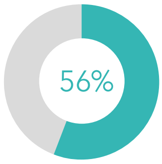
Year 2020 at a glance

Finfish

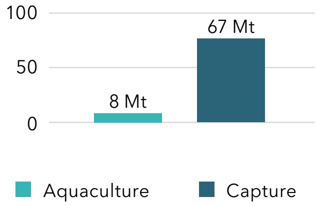
135 Mt

Total production from freshwater and marine waters

Production from marine waters



Marine production by source



Top five producers

Main producers	LAM	EUR	MEA	CHN	SEA
Aquaculture [Mt]	1.1	2.1	0.7	1.8	1.7

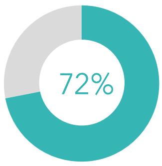
Main producers	LAM	EUR	NEE	CHN	SEA
Capture [Mt]	10.1	7.9	4.9	9.0	14.4

Crustacean

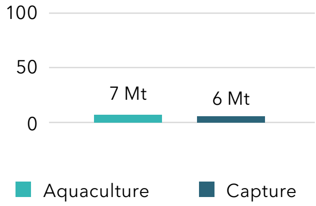
17 Mt

Total production from freshwater and marine waters

Production from marine waters



Marine production by source



Top five producers

Main producers	LAM	MEA	CHN	IND	SEA
Aquaculture [Mt]	1.2	0.1	1.8	1.0	2.6

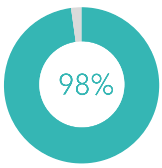
Main producers	LAM	EUR	CHN	IND	SEA
Capture [Mt]	0.5	0.6	1.9	0.6	0.9

Mollusc

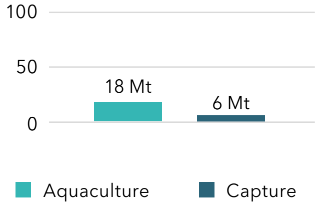
24 Mt

Total production from freshwater and marine waters

Production from marine waters



Marine production by source



Top five producers

Main producers	LAM	EUR	CHN	SEA	OPA
Aquaculture [Mt]	0.5	0.6	14.9	0.5	0.8

Main producers	NAM	LAM	CHN	SEA	OPA
Capture [Mt]	0.5	1.1	1.4	1.0	0.8

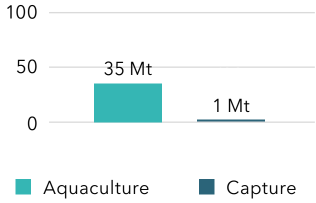
Seaweed / Aquatic plant

36 Mt

Total production from freshwater and marine waters

Production from marine waters

Marine production by source



Top five producers

Main producers	SSA	NEE	CHN	SEA	OPA
Aquaculture [Mt]	0.1	0.6	20.8	11.3	2.2

Main producers	LAM	EUR	CHN	SEA	OPA
Capture [Mt]	0.5	0.3	0.2	0.1	0.1

Digital technologies driving transformation in seafood value chains

Digital solutions are rapidly transforming the seafood industry and are expected to contribute to further efficiency gains in seafood production. Artificial intelligence (AI) and other digital technologies open new possibilities to gather and make use of near real-time operational data for improved decision-making, and to provide traceability along the supply chain. Applying digital tools in seafood value chains creates a win-win economically and biologically, as automation of labour-intensive processes saves cost. Moreover, automated detection often has higher precision than human monitoring, is more scalable, and frees up operator time to focus on decision-making.

In the aquaculture sector, digital solutions are currently being used to predict and provide insights across the value chain. Applications in the growout phase range from new methods for water-quality measurement, biomass estimation, automated feeding, underwater inspection, and detection of sea lice, disease, and algal blooms, to name a few. Remote sensing, computer vision, and machine learning techniques are already contributing to precision fish farming that allows farmers to optimize production cycles while providing individualized health monitoring that greatly improves animal welfare. Cloud-based digital ecosystems are being introduced to connect multiple players across the supply chain, including aquaculture producers, feed manufacturers, technology providers and ingredient suppliers (Couturier, 2023).

AI is increasingly being applied to data from Earth Observation Systems (EOS) for monitoring and assessment of both capture fisheries and aquaculture. In the feed supply chain, monitoring of agricultural operations by satellite enables feed producers to verify that sourcing of soy happens without land-use impacts like deforestation (Proterra, 2023).

In fisheries management, AI-based solutions in fisheries monitoring and research include automatic fish detection, marine ecosystem monitoring, and fish species classification. Moreover, AI-powered tools can detect illicit fishing activities (IUU), identify fishing gear used, and report the presence of trans-shipment vessels and fishing in marine protected areas (Global Fishing Watch, 2023). Electronic monitoring (EM) using cameras and other reporting tools are widely used for fisheries monitoring in the industrialized fishing fleet and provide ample opportunity for further AI integration. Standards for EM will therefore need to consider future use of AI in EM systems, and policies must be in place to ensure transparency, fairness, responsibility, good faith, trust and sustainability to prevent loopholes that allow undesirable actions – e.g. respect for human autonomy, protection against discrimination and protection of human rights (Fernandes-Salvador *et al.*, 2022).

2 GLOBAL SEAFOOD MARKET

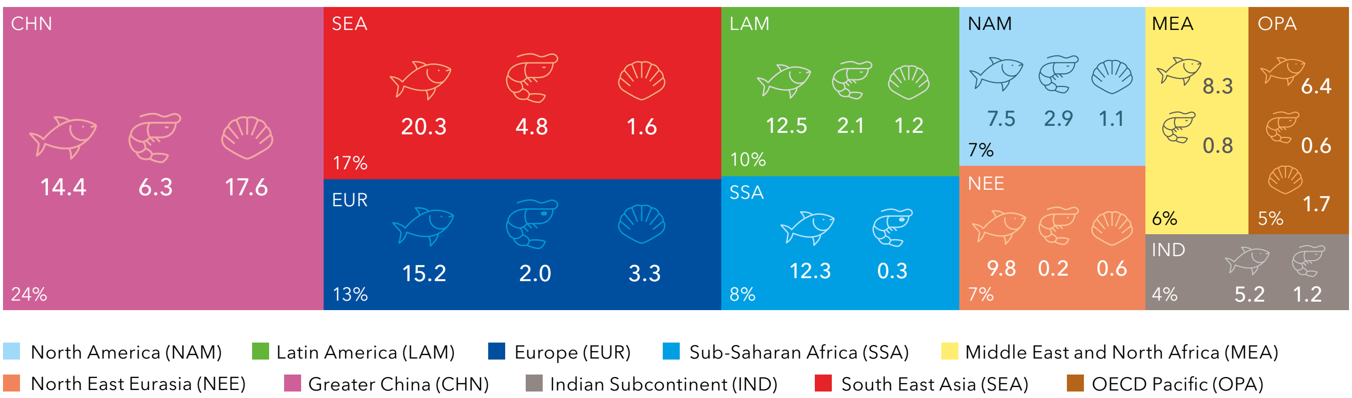
We forecast around a 20% increase in overall marine seafood production to 2050, when considering finfish, crustaceans, and molluscs. Marine aquaculture will double, led by marine finfish, which triples in this period. Meanwhile, the capture fisheries output is stagnant.

There is little evidence of a general dietary shift away from terrestrial meat, but strong signals that seafood will play an increasingly important part in the global supply of animal protein.

Increasing demand followed by an increasing production deficit in many regions means production and trade of marine seafood will grow in coming decades. Finfish will maintain its position as the most preferred seafood item with the demand in 2050 accounting for about 70% of the total market for seafood products produced from marine waters. South East Asia will remain the largest market for finfish while Greater China will continue to be the largest market for both crustaceans and molluscs, and hence the leading market for about 24% (37 Mt) of the marine seafood harvested globally. Additionally, Greater China is the leading region in the seaweed sector. Greater China together with South East Asia and Europe will account for over half of the global market share. The total demand volumes by region and species are shown in Figure 2.1.

FIGURE 2.1

Regional seafood markets ranked by consumption in 2050 [Units: Million tonnes]



Changes in protein consumption

Total protein consumption per capita will still increase in most regions to 2050 (see Figure 2.2), driven by the strong relationship between rising living standards and food consumption. By the late 2020s, Greater China will pass North America as the region with the highest per capita protein consumption, including food waste at the consumer level, experiencing almost a doubling by 2050, compared to 1990. In 2050, each person in China will on average consume 124 g/day of protein. Per capita consumption of protein plateaus in North America in 2020 at around 118 g/day and remains stable at this level. Likewise, Europe's per capita consumption level will remain broadly stable at around 102 g/day. Besides Greater China, other regions with considerable increases in daily protein consumption per capita are Latin America and South East Asia, reaching 103 and 95 g/day, respectively, in mid-century.

Where wealthy regions have met their nutritional needs and face challenges such as obesity, developing regions tend to consume more when living standards improve. The estimates of consumption in this report include food waste at the retail and consumer stages. Around 30% of food is currently lost or wasted throughout the supply chain (UNEP, 2021). High-income countries typically waste more at the consumer level, whereas in developing countries seafood is lost prior to retail at the post-harvest and processing level.

The lowest food consumption is observed in Sub-Saharan Africa, the Indian Subcontinent, and North East Eurasia at 59, 67, and 67 g/day/capita of protein in 2020, respectively. Sub-Saharan Africa and the Indian Subcontinent rise to a little over 70 g/day/capita in 2050. At that time, North East Eurasia will have the lowest protein consumption, at 69 g/day/capita. This is still above what the World Health Organization (WHO) recommends as a minimum daily intake (WHO, 2007). The WHO refers to a safe protein intake of 0.75 g/day per kg of a person's weight, in other words around 45 g/day/capita for an average person.

The decision structure underlying our demand modelling

The demand for food sources providing protein is set up in a hierarchy with decisions between alternative sources on each level (see Figure 2.2). The top level gives the total consumption in grams of protein per day per capita and is determined with a logarithmic regression for the 10 regions based on historic consumption and GDP per capita. The purpose of our demand hierarchy is to forecast the per capita demand for protein for farmed and wild marine animals split between finfish, crustaceans, and molluscs.

The first decision level in the hierarchy is a choice between meat and vegetarian (e.g. plants, eggs, milk) sources of protein, based on a logarithmic regression on GDP per capita and adjusted for cost differences between alternatives and considering the sustainability impact when making decisions. Decisions further down in the hierarchy are all based on the same principles.

For consumers selecting meat as a protein source, the next choice is between terrestrial animal or aquatic protein sources, then between freshwater or marine, and finally between farmed or wild catch. At this level, the decision is made on which type of marine animal (finfish, crustacean, mollusc) will provide protein based on regression, and relative cost and sustainability differences.

Note that the wild catch demand exceeding available catch is redistributed on the higher levels in the demand hierarchy. When we refer to protein demand measured in g/day/capita, we refer to demand before correcting for availability. When referring to seafood demand measured in tonnes, we refer to demand after correcting for availability of wild catch.

FIGURE 2.2

Demand hierarchy with protein demand before correcting for wild catch availability [g/day/capita]

Total

year	NAM	LAM	EUR	SSA	MEA	NEE	CHN	IND	SEA	OPA
2020	118	87	100	59	85	67	110	67	74	93
2050	116	103	102	71	92	69	124	73	95	87

Meat

year	NAM	LAM	EUR	SSA	MEA	NEE	CHN	IND	SEA	OPA
2020	48	29	36	10	17	28	34	5	25	39
2050	49	50	36	13	25	36	45	8	42	40

Categories not considered in our model

Vegetarian*

year	NAM	LAM	EUR	SSA	MEA	NEE	CHN	IND	SEA	OPA
2020	70	57	64	49	69	39	75	62	50	53
2050	67	53	66	58	68	33	77	65	52	46

Seafood**

year	NAM	LAM	EUR	SSA	MEA	NEE	CHN	IND	SEA	OPA
2020	6	3	7	3	4	6	10	3	13	16
2050	7	4	11	5	13	10	16	6	30	12

Terrestrial meat

year	NAM	LAM	EUR	SSA	MEA	NEE	CHN	IND	SEA	OPA
2020	42	26	29	7	13	22	24	3	12	23
2050	42	46	26	8	12	26	29	2	12	29

Marine seafood**

year	NAM	LAM	EUR	SSA	MEA	NEE	CHN	IND	SEA	OPA
2020	4	2	6	2	2	4	3	1	8	14
2050	6	3	9	3	6	7	4	1	11	11

Freshwater seafood**

year	NAM	LAM	EUR	SSA	MEA	NEE	CHN	IND	SEA	OPA
2020	2	1	1	1	2	1	7	2	5	1
2050	1	1	2	2	7	3	12	5	19	1

Marine aquaculture

year	NAM	LAM	EUR	SSA	MEA	NEE	CHN	IND	SEA	OPA
2020	0.7	0.3	1.2	0.0	0.4	0.1	1.4	0.1	1.0	2.1
2050	1.4	1.0	3.3	0.0	1.7	0.4	2.0	0.1	2.7	2.6

Marine capture

year	NAM	LAM	EUR	SSA	MEA	NEE	CHN	IND	SEA	OPA
2020	3.1	1.7	4.8	1.5	2.1	3.8	2.0	0.5	6.4	11.5
2050	4.7	2.4	5.8	2.8	4.9	7.1	2.4	0.6	8.6	8.0

NAM North America
LAM Latin America
EUR Europe
SSA Sub-Saharan Africa
MEA Middle East and North Africa
NEE North East Eurasia
CHN Greater China
IND Indian Subcontinent
SEA South East Asia
OPA OECD Pacific

* Vegetarian protein comprises plants and non-meat animalic protein (egg, milk, honey, etc.)

** Seafood here comprises finfish, crustaceans, and molluscs. Seaweed is modelled as part of the vegetarian protein (not shown here).

What will be the role of seafood in global food demand?

Seafood compared with terrestrial meat and vegetarian diets
Our demand model considers the choice between meat-based and vegetarian protein uptake as the first in a sequence of choices among alternative sources of food (see Figure 2.2). Figure 2.3 shows the resulting mix of protein demand in our model's 10 global regions, split among terrestrial vegetarian protein, terrestrial meat, seafood (finfish, crustaceans, and molluscs) and algae.

Our forecast does not indicate a general shift to more vegetarian diets on a global scale. The exception is Europe which sees an increase in the consumption of vegetarian food products and a slight reduction in meat as a share of total protein consumption. European food policies incentivize alternatives with lower environmental footprint than meat (European Commission, 2020). The Indian Subcontinent already has a large vegetarian population. Many regions will see improvements in living standards leading to terrestrial meat becoming more affordable.

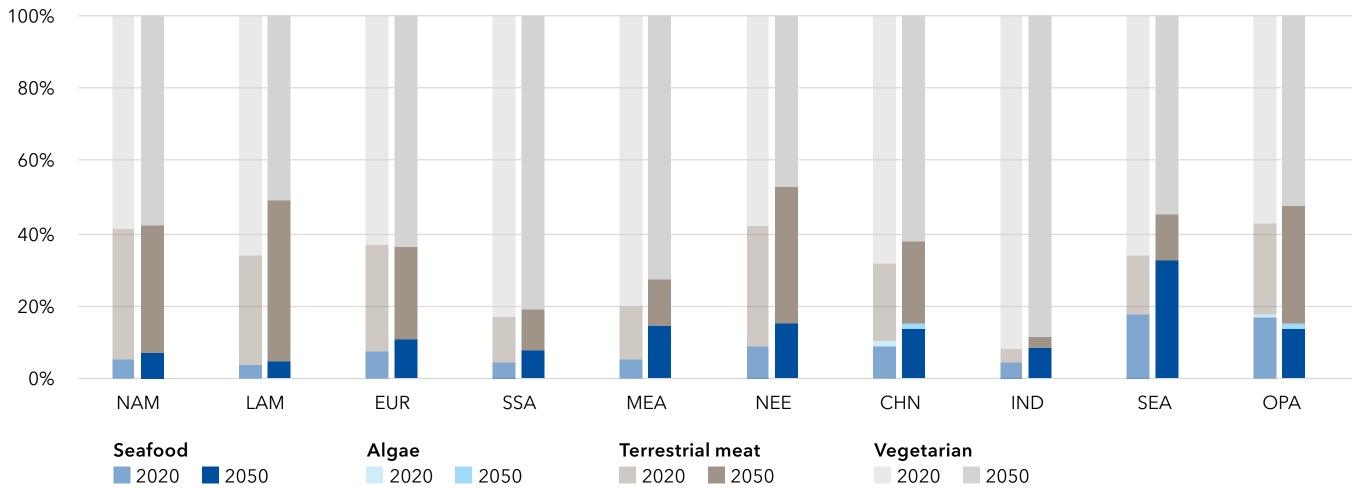
For instance, Latin America doubles its per capita demand for terrestrial meat, with meat's share in the region's overall protein demand rising from 30% to more than 40%. In this region, rising living standards or food policies do not sufficiently trigger a shift towards seafood consumption.

Whereas we find little evidence for a shift to vegetarian diets, the share of protein demand from aquatic animals (including freshwater species) will rise from 7% in 1990 to nearly 12% in 2050. Algae will still contribute only a negligible share of diets in 2050 – only 1% in leading regions like Greater China and OECD Pacific.

Every region sees a growing share of seafood in protein demand, except OECD Pacific. In South East Asia, seafood will account for more than 30% of the protein demand, including both freshwater and marine, far higher than in other regions.

FIGURE 2.3

Shares of vegetarian food, terrestrial meat, seafood and algae in protein demand before correcting for wild catch availability



The share of seafood in protein demand will be above 12% across all regions in Asia, except for the Indian Subcontinent, where vegetarian food will still contribute nearly 90% of the protein by 2050. In the Middle East and North Africa, seafood demand starts from a share of 5% of protein – slightly more than Sub-Saharan Africa – but rises to 14% by mid-century. By comparison, seafood will contribute 10% of protein in Europe, and around 6% in North America, in 2050.

Compared to terrestrial meat, consumption patterns in seafood are significantly more diverse, with more than 2,500 species contributing to food supplies. This diversity contributes to the resilience of the food supply, as the vulnerability of a single species will not necessarily translate into a vulnerable food system as a whole (Metian *et al.*, 2020). Similar to plants, it is argued that an increased uptake of seafood contributes to solving many nutritional challenges and will reduce the environmental footprint of the food system (Tigchelaar *et al.*, 2022; Willett *et al.*, 2019).

Marine seafood protein demand

Seafood can be sourced from both marine and fresh-water sources. In Figure 2.4, we zoom in on seafood demand from marine waters, and how it is split between aquaculture and capture fisheries.

The per capita consumption of marine protein will rise in all regions, except for OECD Pacific, where demand is reducing with an aging population. Even with a decline, OECD Pacific remains the region with the highest per capita consumption of marine seafood in 2050. In terms of per capita marine protein demand, South East Asia reaches a similar level. However, that region will struggle to fully meet demand due to limited wild catch availability.

The contribution of marine aquaculture versus fisheries to protein from marine seafood
Despite growth in consumption of marine aquaculture products, every region will still demand more protein from marine fisheries than marine aquaculture in 2050 (see Figure 2.4). Greater China and Europe are the two regions with the highest demand for protein from marine aquaculture relative to fisheries. Marine aquaculture demand will remain negligible in Sub-Saharan Africa and North East Eurasia.

Fisheries output to 2050 will be constrained by the carrying capacity of the marine ecosystem. With improvements in fisheries management, global catches can only slightly increase over the next 30 years without exceeding the maximum sustainable yield (Costello *et al.*, 2020). Stressors like climate change will have significant regional impacts, varying by sea basin, and generally indicating a poleward expansion of catch potentials (FAO, 2018; IPCC, 2019).

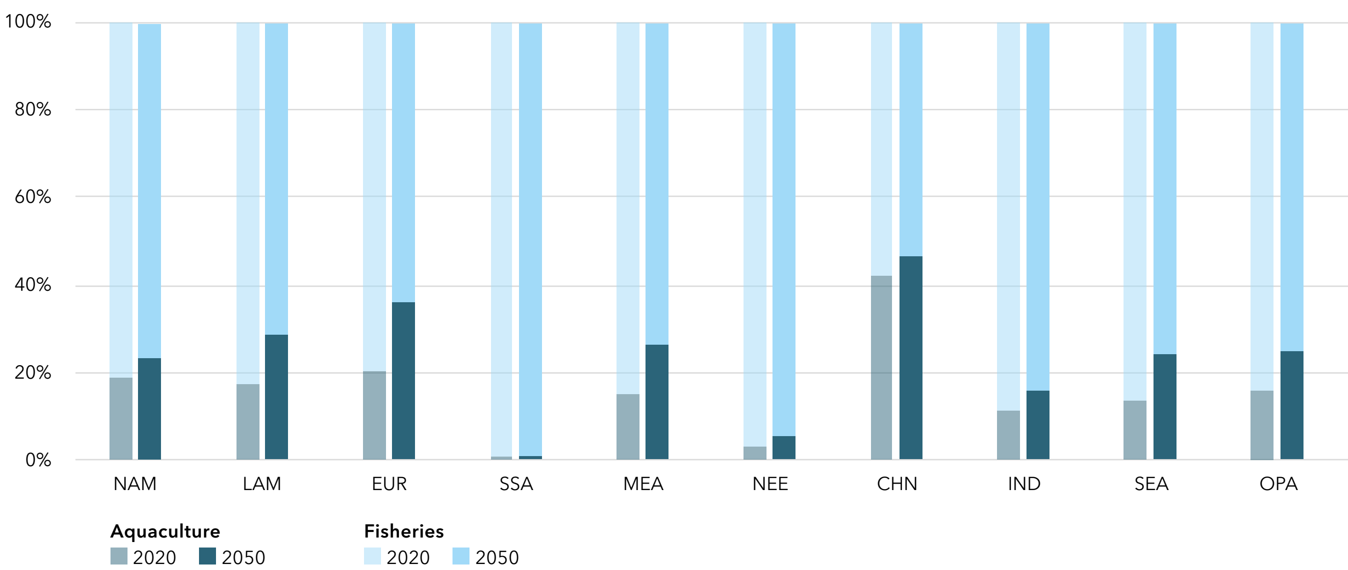
Capture fisheries will see a significant price hike as the supply will be unable to follow the demand, in turn leading to consumers looking for more affordable alternatives. The choice between alternatives to wild catch depends on the availability, which is linked to economic development. For instance, marine aquaculture products tend to be more readily available in mature economies in the OECD and Eastern Asia than in Sub-Saharan Africa and the Indian Subcontinent. Most marine aquaculture products remain a relatively expensive source of protein and will see limited uptake in less-developed regions, despite improving living standards. Developing regions will therefore still be substantially more likely to opt for terrestrial protein sources or freshwater aquaculture products in the absence of affordable marine seafood options.

Even though there is growth in many regions' demand for marine wild catch, except for in OECD Pacific, the marine aquaculture demand rises much more. Compared with wild catch, marine aquaculture will increasingly be favoured relative to wild catch due to a growing focus on sustainability, and in price competition with wild catch. Marine aquaculture will not suffer from the same price increases, as the input of fish-based feed ingredients will decline and will see a reduction in impact on aquaculture production cost (see Chapter 3 for our analysis of feed). Still, per capita demand of marine aquaculture will not fully catch up with wild catch in any region.

The role of seaweed in the dietary shift
In discussions about transitioning to a healthier and more sustainable food system, seaweed is often mentioned as an emerging alternative. In our model, we consider seaweed as an alternative source of plant-based protein, meaning consumers also make a choice between terrestrial and aquatic plants, similar to the decision logic illustrated in Figure 2.2. Seaweed is also used in many products beyond direct food, such as in industrial and food additives. We find that direct food use of seaweed will constitute just below 40% of the seaweed demand in 2050.

FIGURE 2.4

Shares of marine protein from aquaculture and fisheries before correcting for wild catch availability



Population growth and improving living standards drive food demand

When predicting seafood demand, it is essential to consider the population that requires food. We rely on the Wittgenstein Centre for Demography and Global Human Capital (2023) for population forecasts. These are produced independently from the most-used UN forecasts. Compared to the UN, the Wittgenstein Centre places greater emphasis on the relationship between female education and fertility rates. Fertility rates are currently low in the OECD and China and declining in non-OECD regions. Sub-Saharan Africa has seen a slower decline in fertility rates than the rest of the world, with the region's fertility rate remaining around 4.5 births per woman and falling by approximately 0.6 births per woman per decade. As urbanization and female education levels rise in SSA as well, the decline in fertility rates will accelerate.

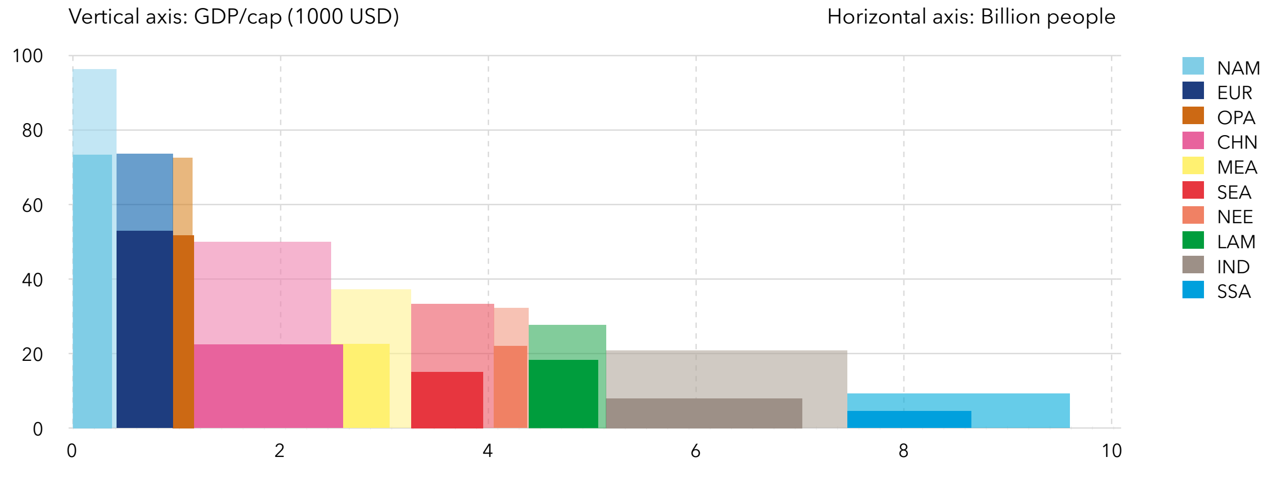
The Wittgenstein Centre employs multiple scenarios that are associated with the five different 'storylines' established by the Intergovernmental Panel on Climate Change (IPCC) in 2011, and which are known as 'Shared Socioeconomic Pathways (SSPs)'. We follow the central scenario (SSP2) for population, using it as a reference point for other inputs. Based on the 2020 estimate of 7.7 billion, the global population is expected to surpass 9.5 billion by 2050, an increase of more than 25% (Wittgenstein Centre for Demography and Global Human Capital, 2023). The Indian Subcontinent is projected to have the largest population, slightly more than 2.3 billion by mid-century (Figure 2.5). Greater China's population is currently peaking at nearly 1.5 billion before it slowly decreases, while Europe's will remain steady at approximately 540 million.

GDP per capita provides insight into how the population is faring in terms of economic growth and development, crucial factors for determining living standards. Mature economies allocate a higher proportion of GDP to the service sector, which includes financial services and healthcare. While technological advancements enhance these services, productivity increases tend to improve the quality rather than the quantity of output. Consequently, as economies approach maturity, productivity growth is expected to slow down.

Figure 2.5 presents the change in population and GDP per capita growth. The fastest growth in GDP per capita between 2022 and 2030 will be in Asia and in Sub-Saharan Africa. The Indian Subcontinent will have the highest growth rate, at an average of 6.0%/yr, followed by Sub-Saharan Africa and Greater China both at 4.6%/yr, and South East Asia at 4.5%/yr. Improvements in the standard of living in economically developed regions will reduce to 1.1%/yr or lower in the 2030–2050 period. The forecast beyond 2030 does not include any larger changes in the relative positions among the productivity of the different regions.

FIGURE 2.5

Change in population, GDP per capita, and GDP between 2022 and 2050 by region



Darker boxes represent 2022, lighter boxes represent 2050. Historical data source: OECD (2022), UN (2022), IMF (2023), Wittgenstein Centre (2023)

How will marine aquaculture develop to meet seafood demand?

We forecast that finfish, crustacean, and mollusc production from marine waters will reach 160 Mt in 2050, corresponding to a growth of around 20% from 132 Mt in 2020 (see Figure 2.6). The production is split between a stagnant fisheries sector producing 101 Mt when including illegal, unreported and unregulated fishing, and a marine animal aquaculture sector that nearly doubles its output to 59 Mt (see Figure 2.7). With a near-doubling of output, marine aquaculture will not grow sufficiently to meet the demand for protein from marine seafood.

Marine aquaculture grows across all species groups modelled, as shown in Figure 2.7. Finfish production grows the strongest, tripling over the period from 2020 to 2050, from 8.3 Mt to 23.2 Mt. Finfish thereby overtakes molluscs as the single biggest species group, measured in live weight. Nearly an eighth (12%) of finfish aquaculture will come from onshore facilities using recirculating aquaculture systems (RAS) and similar new technologies, and another 7% from offshore structures in the open ocean (see Figure 2.8). Crustacean farming doubles, reaching an output of 13.0 Mt, up from 6.8 Mt in 2020. Mollusc farming grows very slowly in comparison, only reaching 22.5 Mt, 25% higher than the 2020 production of 17.5 Mt. These production numbers are reported in live weight.

Measured in edible rather than live weight, the food supply resulting from marine aquaculture reaches 24 Mt, up from 11 Mt (see Figure 2.6). Hence, food supplies from marine aquaculture grow more strongly than the production in live weight terms, due to finfish aquaculture growing much faster than mollusc production. The reason for this is the large difference in live-to-edible weight ratios for the species types. To varying extents, the inedible parts of the products are utilized for purposes other than human consumption, including animal feed.

The edible yield of capture fisheries remains much higher than that of marine aquaculture. With 90% of capture coming from finfish, which have the highest edible-to-live weight ratios, the contribution to food supply from marine capture will rise slightly from 60 Mt to almost 62 Mt. Hence, 72% of overall seafood supply from the ocean will still come from capture in 2050, down from 84% in 2020.

Our estimates of capture fisheries are based on exogenous forecasting of catch potential from the Transboundary Waters Assessment Programme (TWAP, 2022). They consider a wide range of factors like overfishing in combination with climate-change effects to estimate how much can be caught in each of the world's large marine

FIGURE 2.6

Seafood production from marine aquaculture and fisheries

Units: Million tonnes

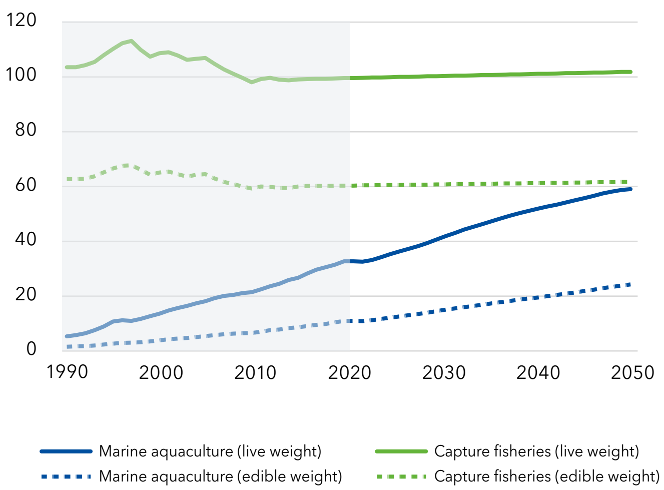
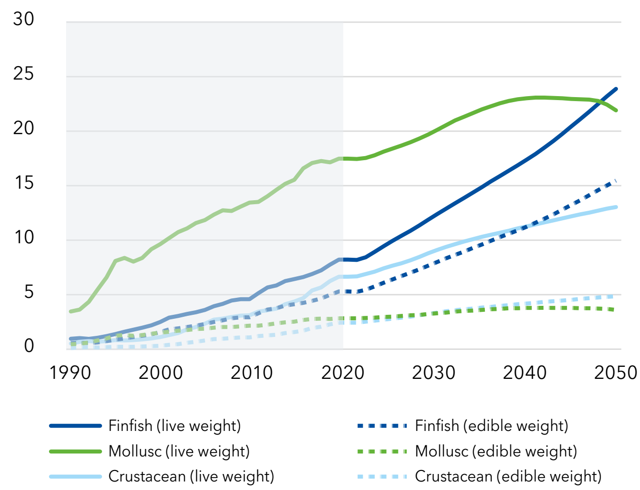


FIGURE 2.7

Marine aquaculture production of finfish, crustaceans, and molluscs

Units: Million tonnes



ecosystems (LMEs). Hence, excess demand for wild-caught seafood that cannot be met within the boundaries of estimated catch potential will re-enter our model's demand hierarchy and be spread across alternative protein sources, with some assigned directly to aquaculture (see Figure 2.2).

In addition to marine animal capture and aquaculture, seaweed production will more than double from 32 Mt in 2020 to 71 Mt in 2050 (see Figure 2.9). Compared to other types of marine aquaculture, seaweed is more strongly driven by demand for non-food products and not as interlinked with fisheries on the food demand side. Seaweed also sees relatively small volumes of harvest from the wild, which has been stable at around 1 Mt and for which we see little change. Seaweed aquaculture will remain mostly Asian, but there will be rapid growth in production in Europe and North America, whose outputs both bypass that of OECD Pacific, primarily driven by demand for additives.

Note that our forecast of seaweed production is calibrated against FAO production data. There is little consensus about the accuracy of seaweed production, with some experts claiming that the FAO estimates are twice the actual production (Belton *et al.*, 2020).

Potential disruptive seafood technologies

Cell-cultured seafood and plant-based fishless seafood alternatives may disrupt and reshape the seafood industry. With the US and the Netherlands following the pioneer Singapore in giving approval to cell-culture companies to sell their products, the industry may see increasing investment. More than 20 companies are currently invested in the production of cell-cultured seafood products.

There are many challenges ahead in terms of regulatory approval, labelling guidelines, consumer acceptance of laboratory-grown products, and high production costs, but investors are optimistic about the prospects for these disruptive food technologies (Gezelius, 2023).

FIGURE 2.8

Marine finfish aquaculture split between sheltered, onshore, and offshore

Units: Million tonnes

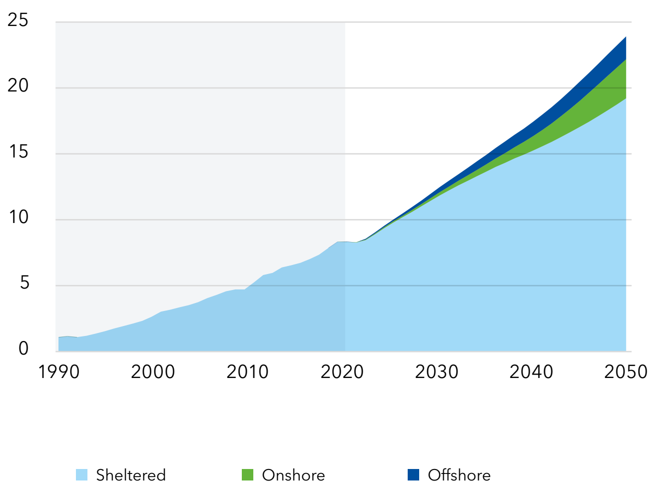
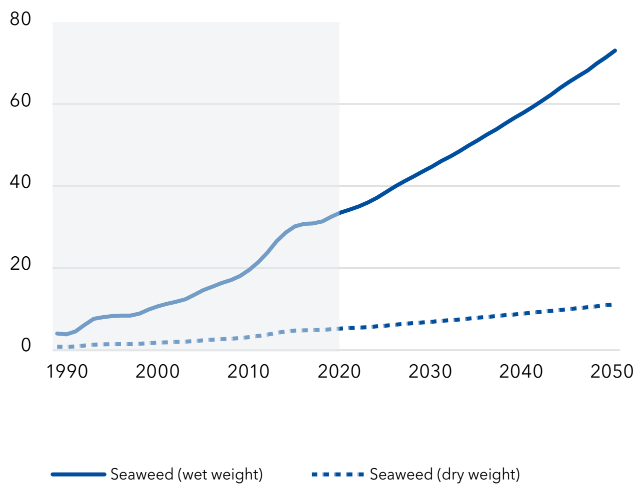


FIGURE 2.9

Seaweed production

Units: Million tonnes



Sustainability challenges in seafood production

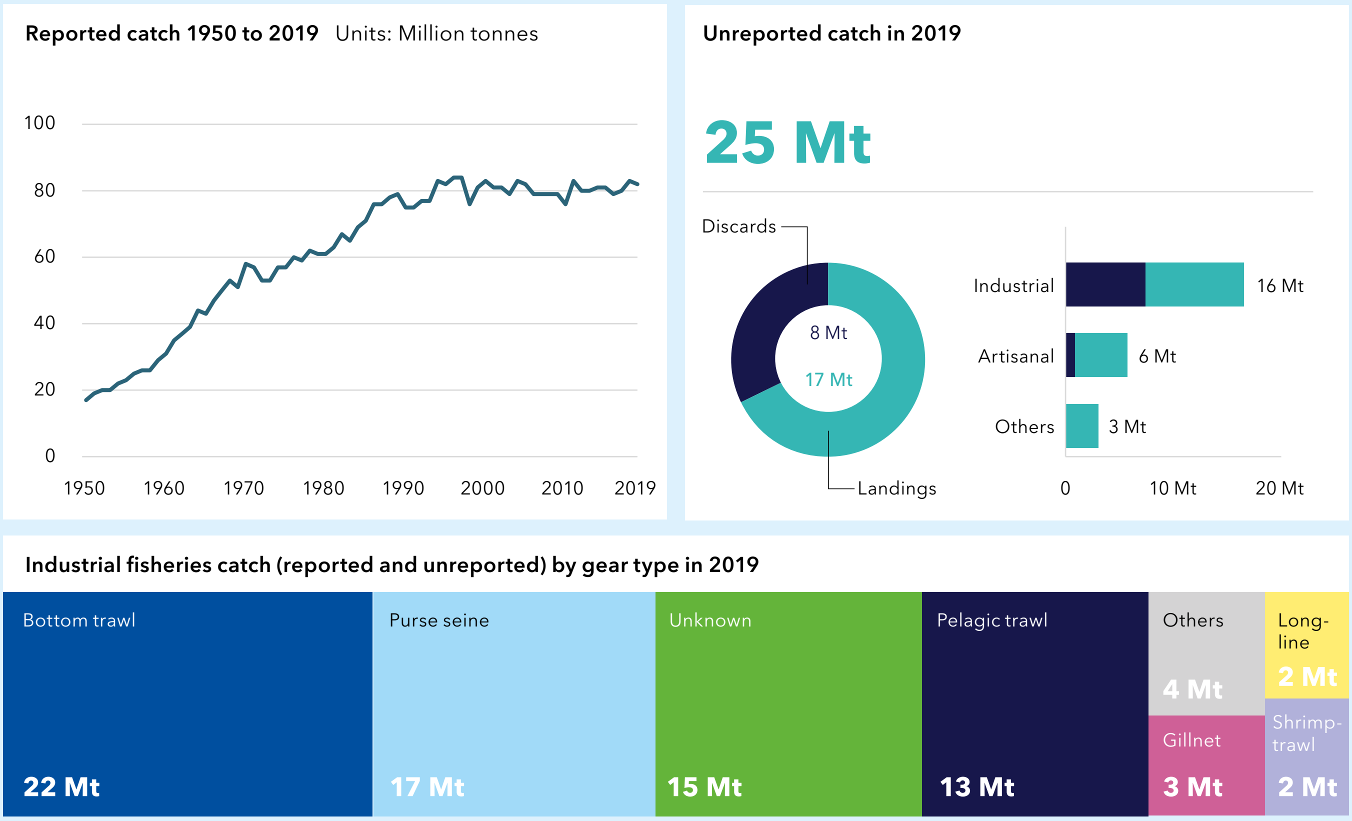
Sustainable seafood production requires the sustainable harvesting of wild-caught seafood; that is, to avoid overexploitation of stocks, high bycatch, and habitat destruction. Sustainable marine aquaculture must not compromise on water quality in farmed areas, should prevent habitat destruction, and ensure that farmed species do not escape and expose wild populations to increased infection pressure or genetic interference.

Sustainability of fisheries worldwide is threatened by biodiversity loss, overfishing, IUU (illegal, unreported and unregulated) fishing, climate impacts, emissions, and modern slavery on fishing vessels.

Due to the open access and transboundary nature of fisheries, fisheries management by setting and enforcing catch limits through allocations of the quota for each fish stock through scientific stock assessment (Garlock *et al.*, 2022) alone cannot make fisheries sustainable. There is a need for a broader consideration about delegitimizing destructive fishing practices, restoring ecosystems, addressing overcapacity, eliminating fisheries subsidies, reducing impacts of climate change, and improving knowledge of fish biology (Jacquet & Pauly, 2022). The problem of overfishing started with the advent of the first fleet of industrial fishing vessels in 1890s.

FIGURE 2.10

Reported catch, reporting status, and industrial fisheries catch by gear type



Within two decades, collapse of fish stocks from overfishing became a recurring event followed by compensatory geographic expansion to distant regions making fisheries truly global (Jacquet & Pauly, 2022).

Illegal activities and under-reporting of catch volumes due to limitations in the monitoring and control of actual catch volumes cause overexploitation of species. While the reported landings in 2019 were 83 Mt, unreported catch was 25 Mt, including 8 Mt of discards (Pauly *et al.*, 2020), as shown in Figure 2.10. Widespread IUU fishing remains one of the greatest threats to food security, livelihoods, and marine ecosystems due to its potent ability to undermine national and regional efforts to manage fisheries sustainably as well as endeavours to conserve marine biodiversity (FAO, 2022a).

While targeted fishing leads to collapse of specific fish stocks, fishing practices like bottom trawling and discard of bycatch cause disruptive ecological impacts such as biodiversity loss. An estimated 8 Mt of bycatch, mainly from industrial fishing, was discarded in 2019. More than 75% of the total industrial catch comes from non-selective fishing methods like trawling and purse seining (Pauly *et al.*, 2020), representing a risk to sea turtles, marine mammals, and non-target fish. Measures to reduce bycatch, to avoid pollution caused by abandoned, lost and discarded fishing gear, and using selective fishing technology, are all integral to minimizing adverse impacts of fishing on ecosystems (FAO, 2022a). There should be regulatory measures to assess and avoid negative consequences from technological innovation in fishing vessels and gear that increase fishing effort (Torres Cañete *et al.*, 2022).

Forced labour and occupational fatalities are still major concerns in the fisheries. Forced labour risks are especially pronounced in IUU fishing, but not limited to it. The remote nature of work at sea, lack of oversight and accountability, complicated legal jurisdiction, increased effort per unit of catch with declining fish stocks, and cost pressure with rising input costs and lower financial returns, all contribute to exploitative work conditions (ILO *et al.*, 2022). While there are efforts and progress in some regions and countries to counter this abuse, an estimated 128,000 fishers are trapped in forced labour situations at sea worldwide (ILO *et al.*, 2022). An estimated 100,000 deaths occur yearly in fishing-related activities globally (Willis & Holliday, 2022).

Fish escapes from marine fish farms are considered a major concern as interbreeding of farmed and wild stocks could contribute to ecological and genetic impacts on wild populations. Escapees may also invade areas as non-indigenous species, potentially impacting biodiversity and genetic diversity. For production of high-value species, the influence on wildlife is an important driver for development of closed containment systems in sheltered water, offshore aquaculture, and recirculating aquaculture systems onshore (DNV, 2021a).

Intensive use of pharmaceuticals, including antibiotics, remains common in many countries' fish farm operations due to the high density of potential disease hosts, and high infection rates (Lulijwa *et al.*, 2020). Continued use of therapeutics accelerates antimicrobial resistance in surrounding pathogens (e.g. bacteria and parasites) as residue from oral administration through fish feed or immersion treatments often ends up in the environment. A continued focus on developing vaccines against common diseases in aquaculture is essential to reduce the discharges of medicinal residue, including antibiotics, and the use of chemical treatments.

Nutrient discharge from animal excreta and feed from open aquaculture facilities could affect the seabed habitat and kill algae and animals responsible for its ecological functions. Continued efforts to improve its feeding systems and continuous seabed monitoring is important to avoid negative impacts. Crustacean farming is a major cause of mangrove deforestation. Nearly a third of the loss of mangroves in South East Asia between 2000 and 2012 is traced to aquaculture (Richards & Friess, 2016). The sustainability issues related to feed is discussed in Chapter 3. Human fatality estimation for aquaculture at a global level is lacking due to lack of primary data collection systems in many regions. In Chile, aquaculture ranked second after mining in terms of sectoral fatality rates (Garforth *et al.*, 2021). Fatalities in Norwegian aquaculture are mainly due to organizational factors such as inadequate risk assessment of operations, and insufficient training (Holen *et al.*, 2018).

Stakeholder support, preventive measures to avoid negative environmental impacts, and widespread adoption of digital technologies to make seafood production transparent and traceable play a vital role in tackling challenges and making it sustainable.

What will drive change in seafood trade patterns to 2050?

Seafood trade has increased markedly in recent decades, making fish and fishery products one of the most highly traded food commodities internationally. By 2050, we forecast that the total interregional trade of seafood products will grow by 50%. Interregional trade of marine aquaculture products will reach 7.3 Mt, up from 2.9 Mt in 2020, consistent with the overall growth in the sector. Interregional trade of wild-caught fish (including marine aquaculture feed ingredients) will increase, from 17.8 Mt in 2020 to 24.7 Mt in 2050. However, during the same period, there will be no increase in output from the capture fisheries, meaning that an increasing share of wild catch is traded interregionally. Note that for wild catch, the landing region is counted as the producer even though the fishing might have happened in waters offshore or in another region's EEZ.

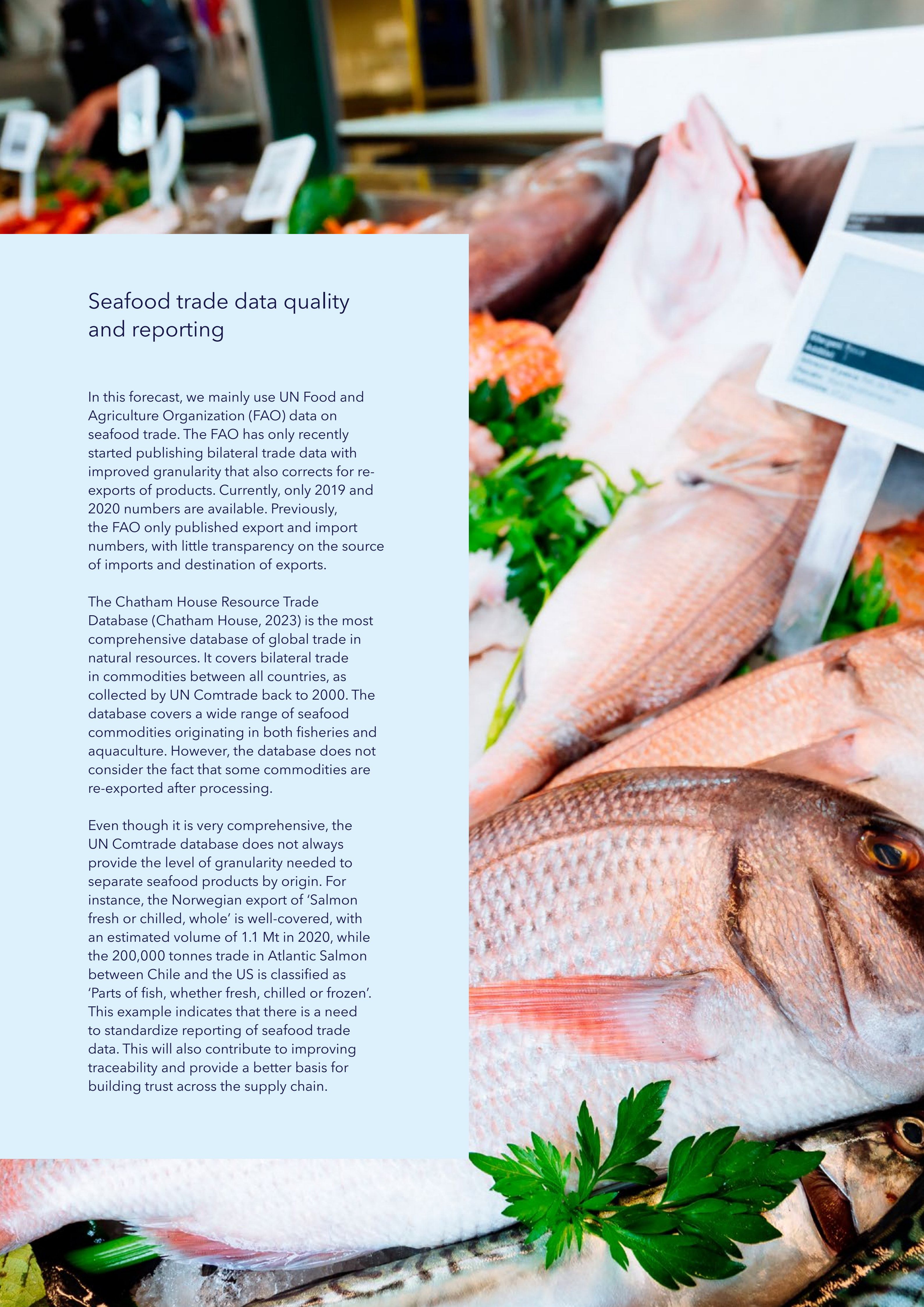
Seafood trade patterns will change by 2050, driven by regional changes in demand and in capture fisheries' catch potential. The largest trade flows for seafood overall are shown on pages 34–35 in volume terms. Counting all marine aquaculture and fisheries trade, the 2.5 Mt flow from Europe to Sub-Saharan Africa will be the biggest in 2050, driven by Africa's rise in demand and European increases in catch potential. All of Sub-Saharan Africa's imports will still be sourced from capture fisheries in mid-century. Sub-Saharan Africa rises to import 21% of the overall 2050 traded seafood, up from 9% in 2020, becoming the biggest importer. Europe will contribute 19% of the total exports and will be the largest exporting region. Second only to its exports to Sub-Saharan Africa, Europe ships 1.6 Mt of seafood to the Middle East and North Africa in 2050.

The second largest trade flow will be Latin America to North America at 2.4 Mt, with more than half of this trade sourced from marine aquaculture. North America will be the second biggest importer at 16% of the total interregional imports, and will also buy large quantities of seafood from South East Asia.

Latin America will be the second largest exporter in 2050, accounting for 18% of interregional exports. The second and third largest destinations for Latin American seafood products will be Europe and Sub-Saharan Africa. OECD Pacific, the largest importer (19%) in 2020, will receive only 8% of the imports in 2050.

The trade in marine aquaculture products is dominated by high-value species of salmon and shrimp (Naylor, Hardy, *et al.*, 2021). In marine aquaculture, Latin America continues to dominate exports, at more than one third of interregional exports by volume. The most important flow by far will be trade from Latin America to North America. Currently, the majority of this trade is Ecuadorian warm-water shrimp and Chilean salmon. This indicates that North America will be unable to reduce its import dependency in high-value aquaculture species. Hence, attempts to upscale North American production through onshore RAS farms will not make imports redundant. In 2050, North America will import around one third of the globally traded marine aquaculture products, a share that remains similar to today. European export shares rise to 20% of the marine aquaculture trade, up from 10% in 2020, not counting the significant trade in Europe's internal market. As an importer of marine aquaculture products, the Middle East and North Africa will overtake Europe by 2050.

Seaweed sees relatively little global trade, and there is little available data on seaweed trade to base our forecast on. Asian countries like China, Indonesia, and South Korea are among the leading exporters of algae and derivative products.



Seafood trade data quality and reporting

In this forecast, we mainly use UN Food and Agriculture Organization (FAO) data on seafood trade. The FAO has only recently started publishing bilateral trade data with improved granularity that also corrects for re-exports of products. Currently, only 2019 and 2020 numbers are available. Previously, the FAO only published export and import numbers, with little transparency on the source of imports and destination of exports.

The Chatham House Resource Trade Database (Chatham House, 2023) is the most comprehensive database of global trade in natural resources. It covers bilateral trade in commodities between all countries, as collected by UN Comtrade back to 2000. The database covers a wide range of seafood commodities originating in both fisheries and aquaculture. However, the database does not consider the fact that some commodities are re-exported after processing.

Even though it is very comprehensive, the UN Comtrade database does not always provide the level of granularity needed to separate seafood products by origin. For instance, the Norwegian export of 'Salmon fresh or chilled, whole' is well-covered, with an estimated volume of 1.1 Mt in 2020, while the 200,000 tonnes trade in Atlantic Salmon between Chile and the US is classified as 'Parts of fish, whether fresh, chilled or frozen'. This example indicates that there is a need to standardize reporting of seafood trade data. This will also contribute to improving traceability and provide a better basis for building trust across the supply chain.

Seafood trade flows in 2050
(Marine capture and aquaculture)

This map shows the 10 most important trade flows in 2050 for marine animals (finfish, crustaceans, molluscs), considering both capture fisheries and aquaculture. The 10 most important 2020 trade flows are provided in the small table below for reference. All numbers are given in million tonnes live weight. The development of the seafood trade flows is driven by changes in the demand-supply imbalances to 2050. We assume that seafood is traded directly between producing and consuming region, and correct for re-exports (e.g. due to processing). Some regions will see large increases in demand due to increasing population and living standards. These regions are not necessarily the same as those that see an improvement in the availability of wild-caught fish.

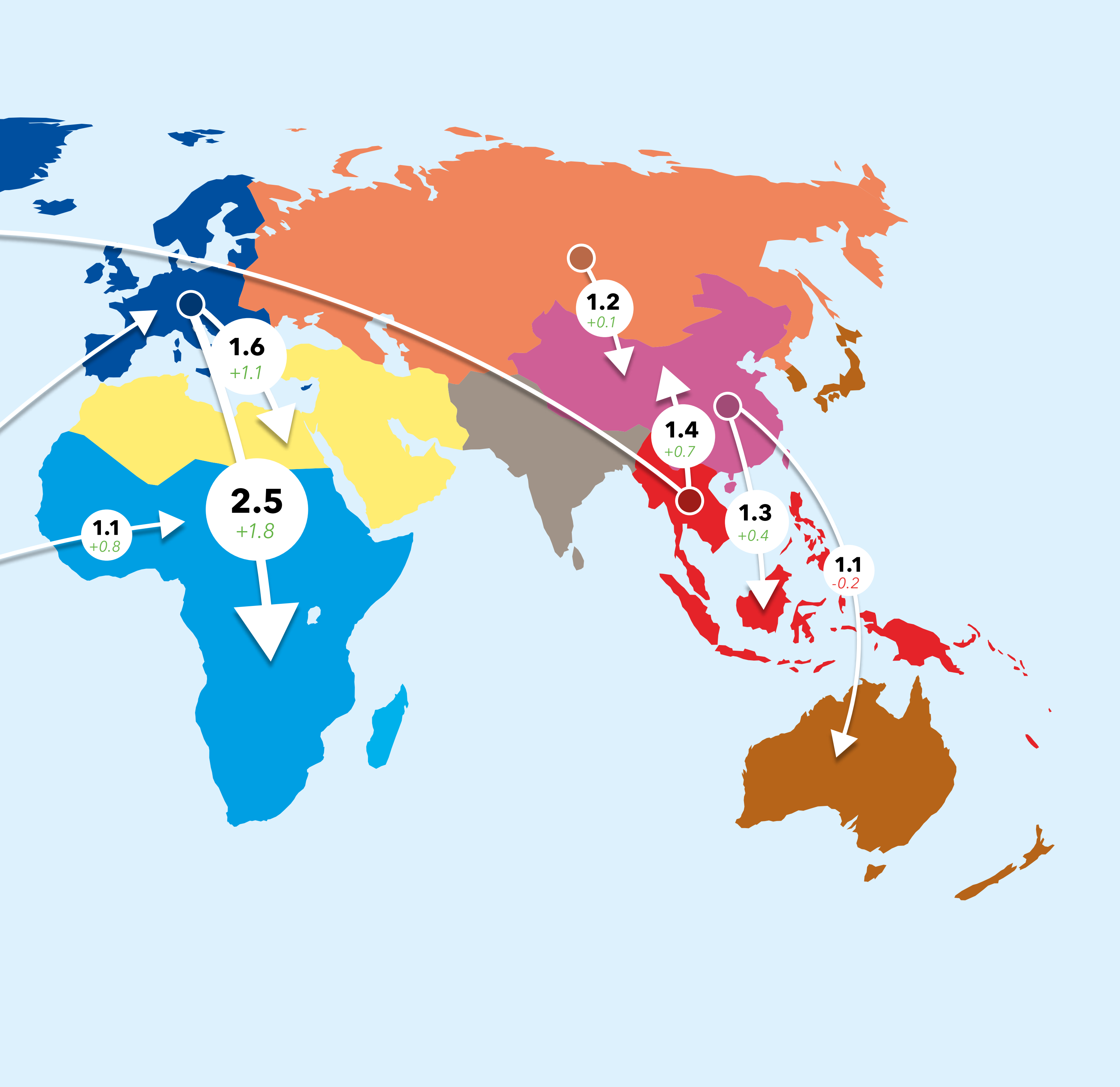
The major trade flows showing imports to Sub-Saharan Africa, South East Asia, OECD Pacific, and Greater China are mainly due to demand for wild-caught fish. Marine aquaculture forms a large fraction in the major import trade flows to North America, Europe, and the Middle East and North Africa. If shown in value terms, the economic importance of marine aquaculture species like salmon and shrimp would likely shift the picture of important trade flows. As discussed in the text box on data quality, there is a high degree of uncertainty surrounding the actual magnitude of the trade flows shown.

Ten biggest trade flows between the regions in 2020

Exporter	Mt	Importer
CHN	**1.3**	OPA
NEE	**1.1**	CHN
SEA	**1.0**	NAM
CHN	**0.9**	SEA
SEA	**0.8**	OPA
SEA	**0.7**	CHN
LAM	**0.7**	EUR
EUR	**0.7**	SSA
LAM	**0.7**	CHN
LAM	**0.6**	NAM

Trade flows [Unit: Million tonnes]

2050 shown in bold.
Change from 2020 to 2050 shown in italics



- North America (NAM)
- Latin America (LAM)
- Europe (EUR)
- Sub-Saharan Africa (SSA)
- Middle East and North Africa (MEA)
- North East Eurasia (NEE)
- Greater China (CHN)
- Indian Subcontinent (IND)
- South East Asia (SEA)
- OECD Pacific (OPA)

The sustainability impact of seafood trade

Blue foods are globally among the most traded food products. Global supply chains are complex and often opaque, making it difficult or impossible for buyers to ascertain environmental impacts and human rights abuses in production. In some areas, harvesting and trade of seafood for high monetary-value global markets have undermined production that is important for local food security and livelihoods (Tigchelaar *et al.*, 2022).

Some key sustainability challenges associated with trade are the carbon footprint of air-freighted export, food loss from export refusals, lack of transparency and traceability to stop illegal products from IUU fishing, deforestation in the supply chain, and unequitable export.

Air-freighted import of seafood substantially increases the carbon footprint of otherwise low-footprint seafood. For example, salmon production in traditional open net-pen systems in Norway has a much lower footprint than that estimated for salmon production in RAS in the US (3.4 kg versus 7.0 kg CO_2e/kg). Airfreight from Norway to the US triples the carbon footprint of the salmon so that it would exceed that of RAS-produced salmon in the US (15.2 versus 7.4 kg CO_2e/kg) (Liu *et al.*, 2016). A shift in trade patterns increasing import from geographically closer regions can therefore reduce carbon emissions.

Complex trade networks including exports and re-exports introduce challenges in eradicating seafood tarnished with IUU, deforested products, modern slavery, and products from trade-sanctioned countries. Globally, between 8 and 14 Mt of unreported catches are potentially traded illicitly annually, and the estimated loss in annual economic impact due to the diversion of fish from the legitimate trade system is USD 26 billion to USD 50 billion (Sumaila *et al.*, 2020).

Food safety is a common reason for refusing seafood exports. To avoid such refusals and the resulting food loss, and to enable more seamless trade, there is a need for significant capacity-building in low-income countries, particularly among artisanal fishers and small-scale aquaculture producers, as well as continued development of infrastructure. Among the main reasons for refusal were the detection of pathogenic microbes, heavy metals, other chemical contamination, veterinary drug residues, excessive use of additives in shrimp, and histamine formation in tuna (Indrotristanto *et al.*, 2022).

To meet the Sustainable Development Goals (SDG), it is also important to understand, monitor, and prohibit diversion of fish from direct human consumption in low-income regions to marine ingredient production and export. In some Sub-Saharan African countries, large quantities of small pelagic fish from both artisanal and industrial fishing are processed into fish feed ingredients and exported to China and Turkey (Thiao & Bunting, 2022). This has a considerable negative impact in countries like Senegal and Gambia where the local population is strongly dependent on fish consumption (Thiao & Bunting, 2022).

Trade mechanisms and related collaboration also work towards a sustainable transformation of the seafood industry. One of the recent developments is the WTO (World Trade Organization) Agreement on Fisheries Subsidies, the first multilateral trade agreement focusing on sustainability. It has been accepted by at least 34 countries so far, including the 27 EU Member States, but will only enter into force once two-thirds of the 164 WTO members have ratified it (European Commission, 2023b). The efforts of the FAO and other international organizations together with policymakers to stop unequitable export of seafood and protect and build the capacity of artisanal farming and fishing are crucial for sustainability in seafood supply chains from production to trade to consumption, protecting both food security and the environment.

Trust in seafood supply chains is crucial for achieving sustainability

Numerous stakeholders demand evidence for the sustainability of the industry's actions when they have an impact on the environment and society. Investors, financiers, retailers, consumers and regulators need to have trust in decisions they make in approvals, investments, sourcing and purchasing, impacting seafood companies' commitment towards sustainability.

Attempts to incentivize sustainability through direct financial incentives such as sustainability-linked loans and price premiums on lending or insurance are increasing. The need to credibly demonstrate sustainability commitments is mounting for companies with stricter ESG-related (Environmental, Social and Governance) stock market listing requirements and climate-related financial disclosures (Österblom *et al.*, 2022).

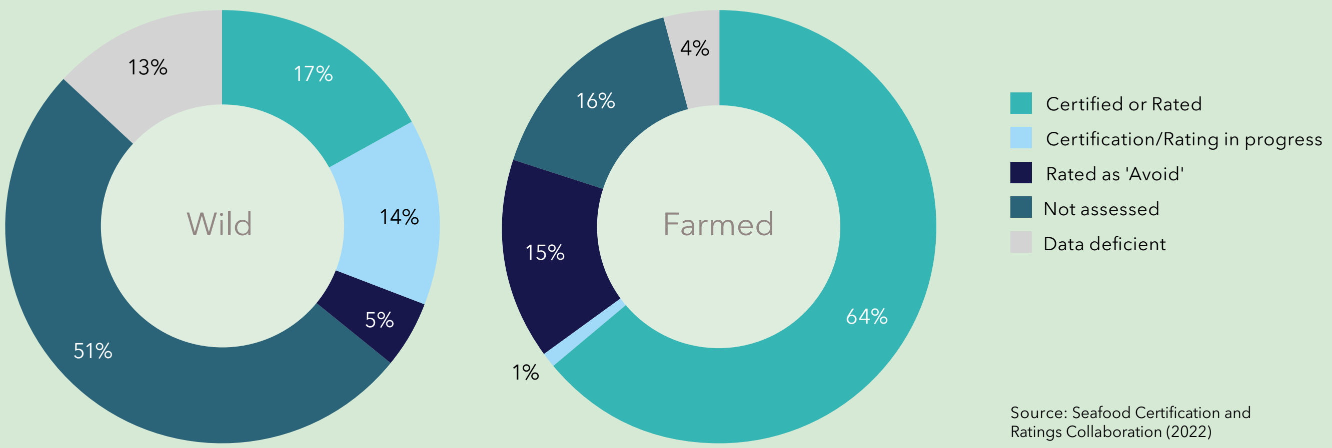
Ecolabelling schemes from the Marine Stewardship Council (MSC) and the Aquaculture Stewardship Council (ASC) are the most widely trusted evidence for sustainable fisheries and aquaculture. Certification schemes have generally been less successful in Asia than in the Western world. In Asia, the value chain is typically more fragmented and there are a larger number of small-scale fisheries and farmers with limited ability to comply with private third-party certifications like MSC and ASC (Tsantiris *et al.*, 2018). As shown in Figure 2.11, only 21% of the total marine wild catch is 'certified or rated', while about 79% of farmed marine species comes from 'certified or rated' sources. More than 60% of marine wild catch is classified as being 'data deficient' or 'not assessed' (Seafood Certification and Ratings Collaboration, 2022) .

Sustainable production is a term that is difficult to define and cover under the scope of existing certification schemes. Class action lawsuits against seafood companies supplying farmed salmon marked as 'sustainable' illustrate this (Sapin & Cherry, 2021). Such conflicts impact brand reputation and might negatively affect consumer trust in seafood. In the EU, regulators are increasingly making it more difficult for companies to make misleading green claims (European Commission, 2023a).

Supply chain traceability is essential for increasing consumer confidence and improving sustainability assessment in seafood. The Norwegian Directorate of Fisheries is implementing an automated documentation system to collect data from the fisheries value chain and distributing it to relevant public agencies. It is expected to increase transparency and efficiency, reduce reporting fraud, and improve the knowledge foundation for stock assessment. Gains can also be won through improved competitiveness in high-end markets with strict requirements on product quality and documentation (Norwegian Directorate of Fisheries, 2023).

FIGURE 2.11

Certification status of marine fisheries and aquaculture, except seaweed



Source: Seafood Certification and Ratings Collaboration (2022)

3 FEED SUPPLY CHAINS

Demand for feed will rise faster than the production of fed aquaculture like finfish and crustaceans. Feed production grows from 20 Mt to 61 Mt, more than tripling by 2050.

How will demand for feed develop?

Slightly rising mortality rates resulting from intensification create an upward trend in the global average of economic feed conversion ratios (FCR). The development in demand for feed is shown in Figure 3.1.

Recent research shows that biological risk is a large and growing cost contributor in aquaculture (Misund, 2022). At the same time, the price of feed ingredients currently in use is expected to continue increasing. Hence, improving the health of farmed species will be an even more important lever for cost reductions in years to come. Additional calls for more organic farming – for instance, by major retailers and as part of the EU Green Deal (EU Commission, 2021) – could drive up feeding requirements, and thereby costs (Ahmed *et al.*, 2020).

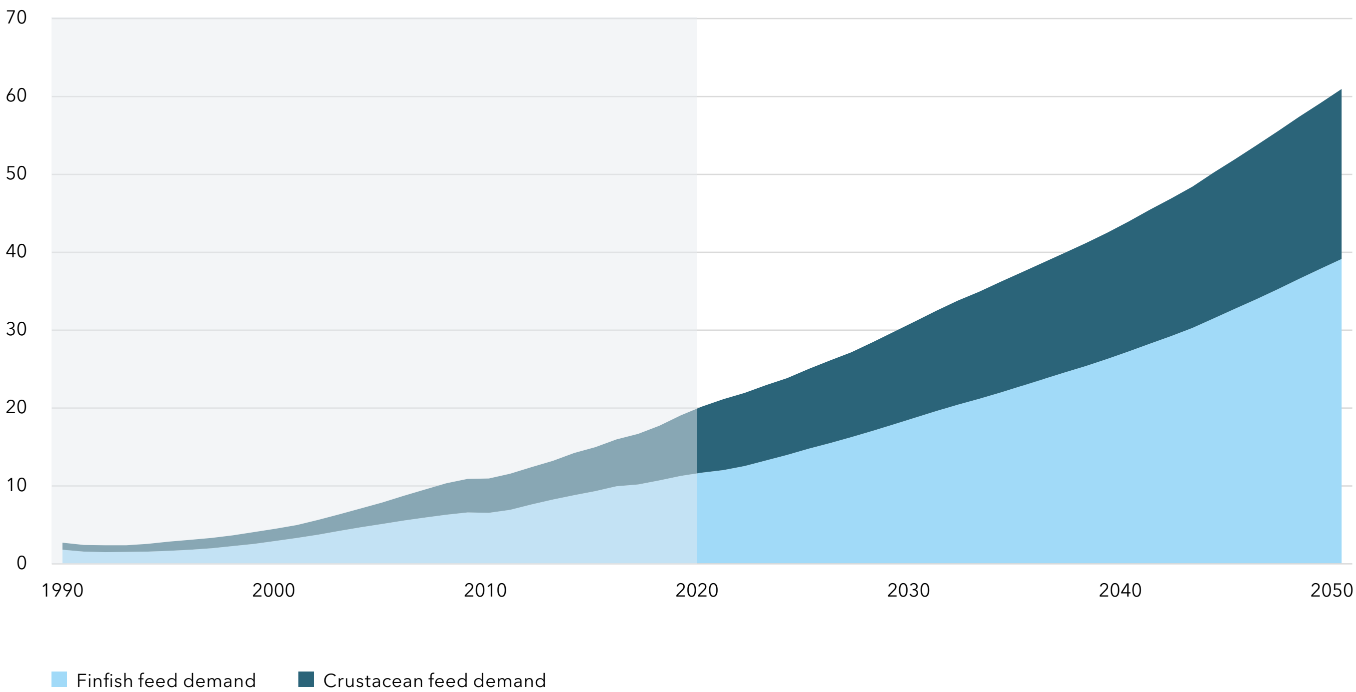
Precision farming technologies offset some of these inefficiencies, but the greatest potential for feeding technology improvements exists in regions where the industry has yet to industrialize.

Compared with 84% in 2020, nearly 92% of finfish and crustaceans farmed in 2050 will be fed on compound feeds. The aquaculture feed sector will see its market share grow with further industrialization, especially in Asia. Both South East Asia and Greater China, which today still largely rely on farm-made feeds and low-value feed-grade fish for feed (Naylor, Hardy, *et al.*, 2021), will increasingly transition to compound feeds by mid-century.

FIGURE 3.1

Feed for marine aquaculture

Units: Million tonnes



What will be the main sources of feed for marine aquaculture?

Historically dependent on fish meal and fish oil produced from wild catch, aquaculture will continue its transition to utilizing more sustainable and circular feeds. Major innovations in compound feed formulation already allow greater inclusion of plant-based ingredients (wheat, soy, canola, legumes), animal by-products (meal and oil from animal and seafood production), and supplementary ingredients like vitamin pre-mixes.

Figure 3.2 shows the shifting feed ingredient mix from now to 2050, based on the primary ingredient groups. Plant ingredients remain the leading ingredient group at 50% of the 2050 mix. Plant ingredients more than double to 30.3 Mt. The shares of most plant ingredient types decrease, except for vegetable oils, for which the share increases. Among plant ingredients, the soy share declines the fastest. Ingredients based on terrestrial animal by-products will contribute almost 4.6 Mt, also doubling from their current levels. For reference, Figure 3.3 shows the major material flows included in our modelling of feed supply chains.

Novel ingredients reach a total volume of more than 20 Mt in 2050, a 30% share overall. The share of novel ingredients will rise from negligible levels today to reach 26% of the ingredient mix for feed for marine finfish. For crustaceans, novel ingredients will rise even higher, reaching 37% of the mix in 2050.

Marine ingredients will increase 50% in terms of volume, from 3.7 Mt in 2020 to 5.4 Mt in 2050 (see Figure 3.2). This implies that the share of fish meal and oil will reduce to 9% of the ingredient mix, from 18% in 2020. Fish oil will retain a larger share in the ingredient mix than fish meal, as the former is a source of omega-3 fatty acids, and therefore more difficult to replace by using novel ingredients.

The dependency of marine ingredients on wild caught fish will reduce to 2050, making the sector more resilient to variability in the catch of key species used in fish meal and oil. As of 2020, almost 70% of fish feed's marine ingredients came from wild catch. The rest came from aquaculture and wild catch by-products, which supply 27% of fish meal and 48% of fish oil (FAO, 2022a). By 2050, the combined share of fish meal and oil derived from by-products will increase to more than 50% . This means that the use of wild catch will grow from 13 Mt in 2020 to peak at 15 Mt in 2032 before declining to 10 Mt in 2050. In mid-century, wild catch for feed will constitute around 10% of total catch.

Climate change is expected to have adverse impacts on the production of both fisheries and crops (IPCC, 2023), though the severity is not yet fully known and is likely to differ between regions. For instance, in the northern parts of Europe and North America, climate change is predicted to have both adverse and positive impacts on production of both fisheries and crops (IPCC, 2023; Kjesbu *et al.*, 2022). Commercialization of novel feed ingredients improves the resilience of the feed supply chain.

FIGURE 3.2

Marine aquaculture feed ingredient mix showing shares of main ingredient groups

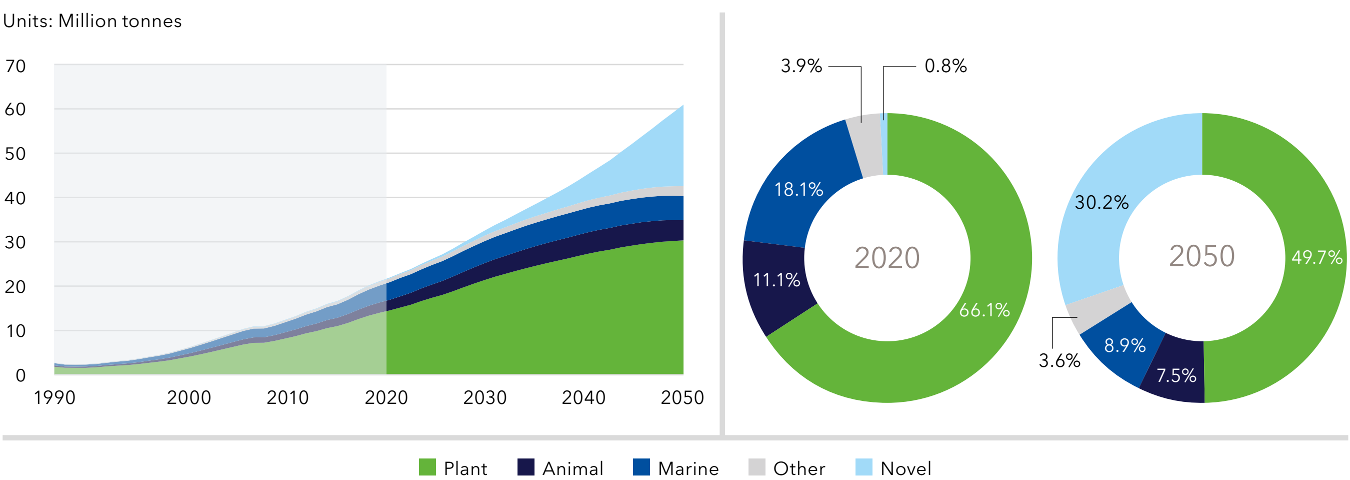
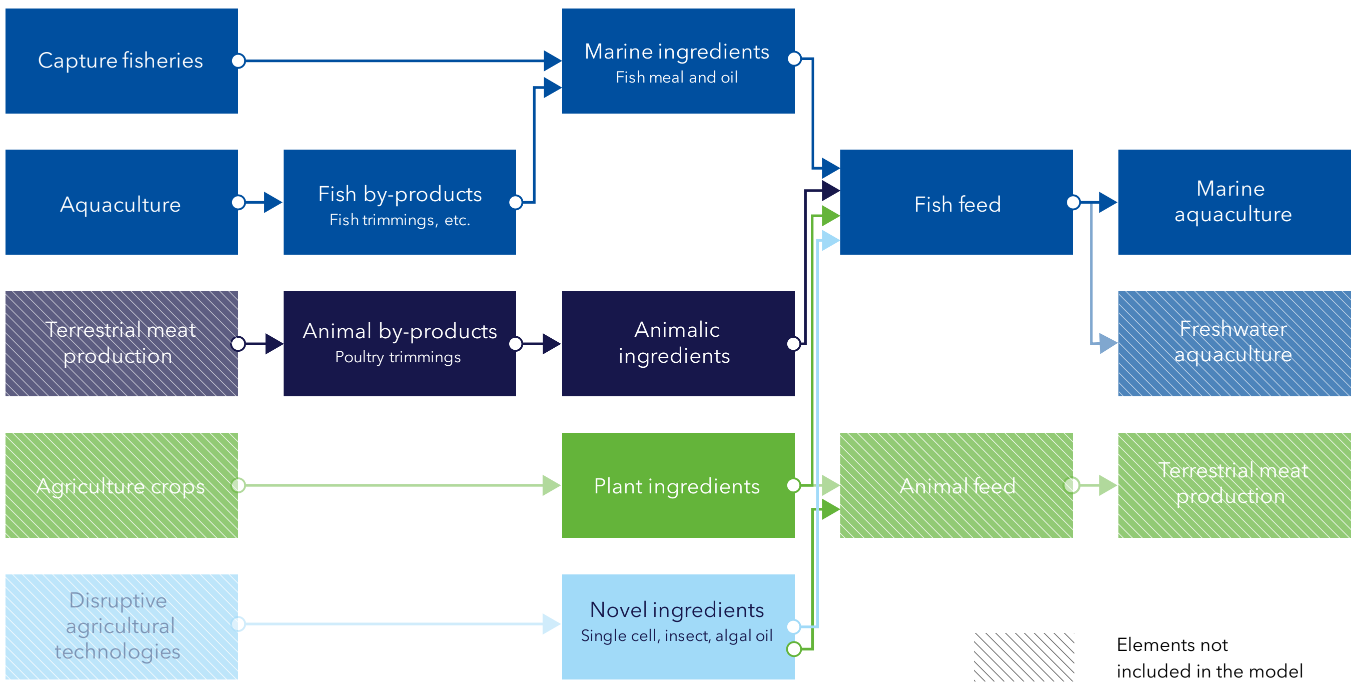


FIGURE 3.3

Key material flows in the feed supply chain, including feed to livestock



Novel ingredients

The novel ingredient types include single-cell proteins, insect meal, camelina oil and algal oil, representing new sources of both protein and fat in the feed. The estimated rapid uptake of novel ingredients towards 2050 in our model is caused by cost-learning effects. By scaling production, costs will come down, making these novel alternatives economically competitive over time. Globally, we anticipate a 30% inclusion of novel ingredients in marine aquaculture feed formulations by mid-century.

Due to the higher willingness to pay in other markets, there is a risk of pioneering novel ingredient types like insect meal ending up in pet food, human nutritional supplements, and fertilizers, rather than being prioritized for fish feed (Reuters, 2023).

Novel ingredients can provide some of the benefits from marine ingredients that have so far been difficult to replace, like feed digestibility and nutritional composition. The feed industry has so far adapted to declining catch volumes by producing marine ingredients from agriculture and fishery by-products, a trend that will continue. However, demand for marine ingredients (particularly for marine-derived oil) is increasing faster than the limited supply of marine by-products can cover. To meet demand for oils with similar characteristics as fish oil, we will see a considerable increase in the production of novel ingredients like microalgal oil and fortified vegetable oil containing omega-3 fatty acids.

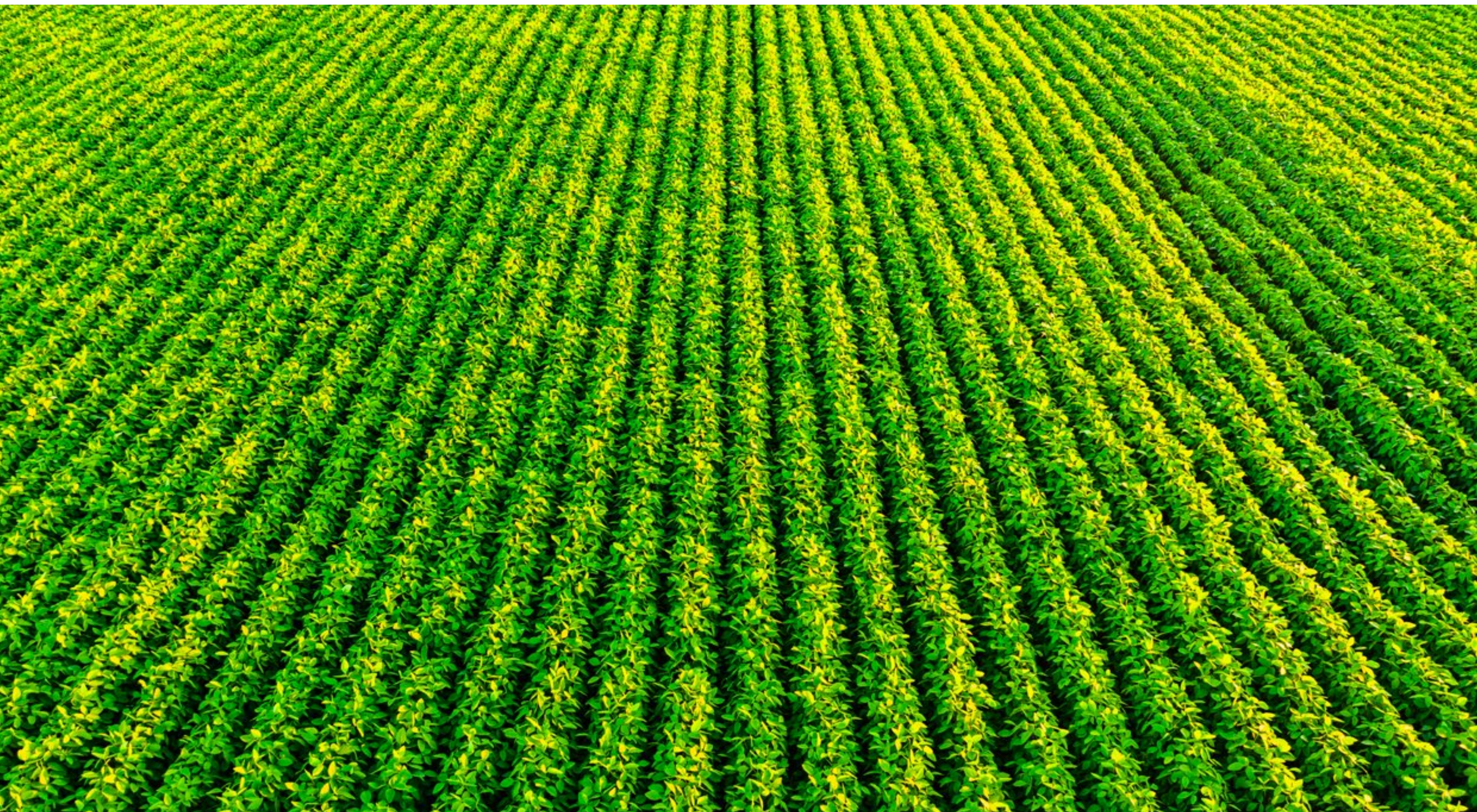
Sustainability challenges of feed

Feed-food competition
The utilization of cereal crops and locally consumable wild fish for feed ingredient production is in direct conflict with food for human consumption and feed for livestock (the latter competition for inputs is shown in Figure 3.3). Up to 40% of all arable land and more than 30% of cereal crop production is currently used for feed crops (Sandström *et al.*, 2022). Land availability and land-use change associated with increased farming are a limitation to increasing the inclusion of agriculture-based ingredients in aquafeed. In Latin America and Europe, marine ingredients are produced from fish that are not locally consumed (e.g. anchoveta in Peru, sand eel in Norway); but in Sub-Saharan Africa, using wild catch in feed conflicts directly with access to food and livelihoods (FAO, 2022a).

Meeting the demand for feed ingredients by decoupling it from sources of food for human consumption will be increasingly necessary. This is already being achieved using by-products from animal and seafood production in aquaculture feed, and the volumes of by-product derived feed ingredients will increase by 2050. The increase of novel feed ingredients, like insects, that can utilize waste streams as feedstock will also contribute.

Environmental footprint of feed production
Environmental impacts of feed production and use include a significant carbon footprint and nutrient waste entering the water column. Up to 90% of the environmental impact from fed aquaculture has been traced to the production of feed (Naylor, Hardy, *et al.*, 2021). A reduction of the climate footprint is therefore highly reliant on reducing that of the feed. In this report, we anticipate an increase in aquaculture FCR by 2050, which makes decreasing the emissions of feed even more vital for reducing the total climate footprint from the aquaculture industry.

The carbon footprint of aquaculture feed depends on the type and origin of the feed ingredients. The carbon footprint of a salmon diet produced in Canada (1.6 CO_2e/kg) has a lower footprint than that produced in Norway



(2.2 CO_2e/kg) and Chile (2.4 CO_2e/kg) due to the inclusion of proteins derived from animal by-products and locally sourced vegetable-based proteins and oils (Skretting, 2022). The use of some vegetable ingredients associated with land-use change gives the Norwegian and Chilean diets a higher footprint. Shrimp feed produced in Vietnam has an even higher carbon footprint (2.9 CO_2e/kg), largely due to the higher inclusion of soy-based ingredients from South America, which comes with higher emissions due to land-use change. In comparison, the sourcing of vegetable-based ingredients from diverse regions and more energy-efficient processes gives Ecuadorian shrimp feed a much lower footprint of 1.2 CO_2e/kg (Skretting, 2022).

Consumer acceptance and regulation restrict the use of certain ingredients with lower carbon footprints. For example, by-products from poultry and pork are used in Chilean and North American markets while, though legal, they are not accepted in the European consumer market. Another challenge is that animal by-products are also sought by the petfood industry, which is often willing to pay more for raw feed ingredients (FAO, 2011). Sourcing environmentally friendly ingredients, increasing the utilization of by-products, further improvements in feed conversion, and market acceptance are keys to reducing the carbon footprint of feed.

We forecast that the search for sustainable feed ingredients will continue, going in new directions as plant-based ingredients like soy also come under pressure from regulators, retailers, and consumers. The EU Deforestation Act will require market players in fish feed to prove their products are deforestation-free, given that inputs associated with deforestation or forest degradation are used. With aquaculture feed constituting less than 4% of the overall animal feed market (Hua *et al.*, 2019; Sandström *et al.*, 2022), it faces tough competition for deforestation-free soy from other buyers, the major ones being production of poultry (37%), pig (20%), and human food (20%) (Ritchie & Roser, 2021). Hence, the industry is on a path towards increased collaboration with soy suppliers (Norwegian Seafood Council, 2022).

The EU Deforestation Act will require market players in fish feed to prove their products are deforestation-free.

Interdependence of marine fisheries and aquaculture beyond feed

An estimated 20% of total marine aquaculture production is dependent on collecting live seed from the wild (capture-based aquaculture). A full transition to hatchery-based aquaculture is unlikely to happen, as the quality of seedlings may be perceived as too low by farmers (Lovatelli & Holthus, 2008), or the early production stages may be technically and biologically challenging (Pettersen *et al.*, 2023). Capture-based aquaculture has implications for wild populations, their habitats, and non-targeted species, and limits are set on the characteristics of juveniles that can be caught for aquaculture (Lovatelli & Holthus, 2008).

Examples of commercial species that are dependent on some forms of capture-based aquaculture are mullet in Middle East and North Africa; bluefin tuna, European eel, and cod in Europe; mud crab, oysters, and yellowtail in OECD Pacific; and grouper and milkfish in South East Asia (Lovatelli & Holthus, 2008).

4 REGIONAL SEAFOOD OUTLOOK

There will be large differences in the growth in population, demand and production across the 10 regions (Figure 4.1). This illustrates that meeting food security targets will require further action to scale production sustainably and ensure equitable distribution.

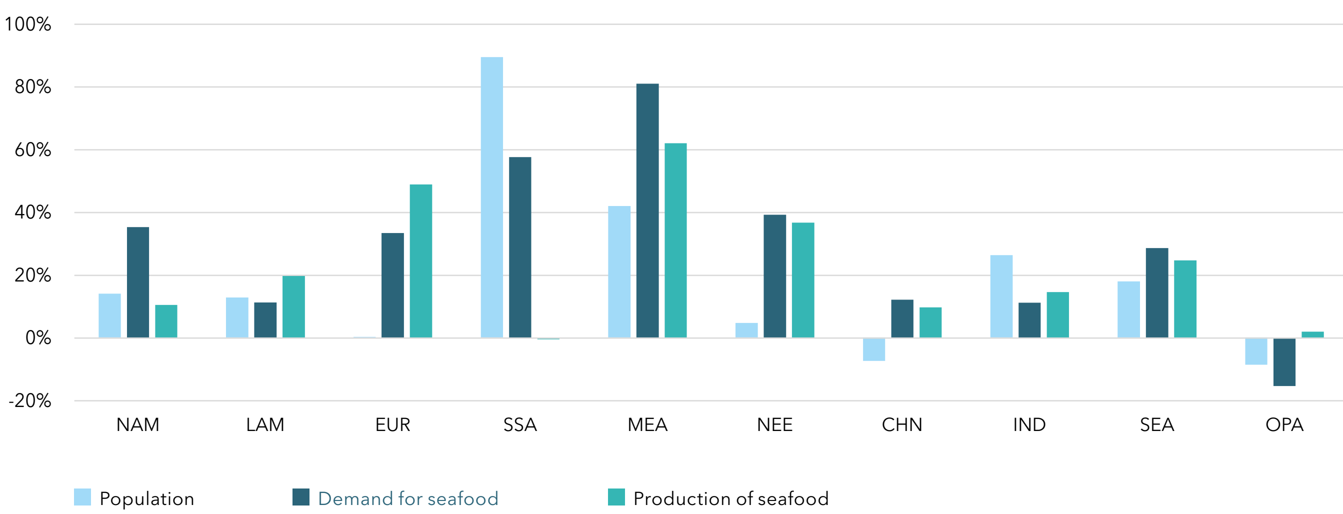
North America, Europe, and OECD Pacific are already at the limits of per capita food consumption and see limited population growth. In North America, growing demand for seafood will largely be met through imports of aquaculture products. In Europe, the world's biggest integrated seafood market will grow further, displaying innovation in the production of high-value species for seafood.

Latin America, Greater China, and South East Asia are emerging and fast-growing economies. Latin America will largely follow North American food consumption patterns and become the leading consumer of terrestrial meat. However, Latin America will increase its importance as a seafood exporter, particularly considering marine aquaculture. Greater China remains both the leading consumer and producing region. South East Asia intensifies production, driven by the need to meet demand from regional and international markets.

Sub-Saharan Africa, the Middle East and North Africa, North East Eurasia, and the Indian Subcontinent are only briefly considered in this chapter. Sub-Saharan Africa will see no growth in fisheries catch volumes, increasing its reliance on imports. North East Eurasia will be among the regions facing the most favourable developments in capture fisheries. The Middle East and North Africa's marine aquaculture sector will be the fastest growing in the world, with several countries ramping up production to improve food security. The Indian Subcontinent will remain the smallest market for seafood but will increase its production to meet the export demand for crustaceans.

FIGURE 4.1

Change in population, demand and production from 2020 to 2050



North America – the leading aquaculture importer

North America is a leading consumer market, a large importer of seafood, and will remain so through to 2050. The average North American consumer will eat 35% more marine seafood in mid-century. By then, the population will have increased 14%. Fisheries production in the region has been trending downwards since the collapse of the Grand Banks fisheries off Newfoundland, Canada in the early 1990s (Pauly *et al.*, 2020). For North America as a whole, capture fisheries will see stable output of just under 7 Mt to 2050 (see Figure 4.2), while marine aquaculture almost triples from 365,000 tonnes to 900,000 tonnes (see Figure 4.3). In total, the region's overall production in 2050 will still be lower than in 1990.

Interregional imports will remain a prerequisite for meeting North American demand for seafood. By 2050, the import of fish products will almost double to 5.3 Mt, mainly from Latin America. Around 43% of the imports will come from aquaculture products. The trade numbers do not consider the substantial trade flows between Canada and the US, with the latter being the top destination for Canadian seafood exports overall (Cross, 2022). Figure 4.2 compares North America's combined output of marine fisheries and aquaculture with its imports and exports.

Several trade agreements will shape the future of North American seafood markets. In 2018, the US, Canada, and Mexico negotiated the United States of America–Mexico–Canada Agreement (USAMC), replacing the 1994 North American Free Trade Agreement (NAFTA). The USAMC will maintain the pre-existing positive trading relationship between the three (Cross, 2022). Additionally, Canada signed the Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP) after the US withdrew from the original Trans-Pacific Partnership negotiations. The removal of tariffs through the CPTPP will introduce new opportunities for Canadian trade with many countries in Latin America, OECD Pacific, and South East Asia.

High regulatory costs and uncertainty confronting the regional aquaculture industry are major reasons why North America will remain highly reliant on seafood imports. While many US states regulate shellfish farming, only a handful (e.g. Florida, Hawaii, Maine, and Washington State) have frameworks for marine finfish farming (Rubino, 2023). To preserve and protect native salmon, states like Alaska, California, and Oregon have banned open net-pen fish farming (Knapp & Rubino, 2016). Washington will follow suit in 2025 (Rubino, 2023). Most US marine aquaculture occurs in state waters within three miles of shore and is subject to a combination of state, federal, and sometimes local, requirements (Rubino, 2023).

FIGURE 4.2

North America seafood production, export, and import

Units: Million tonnes

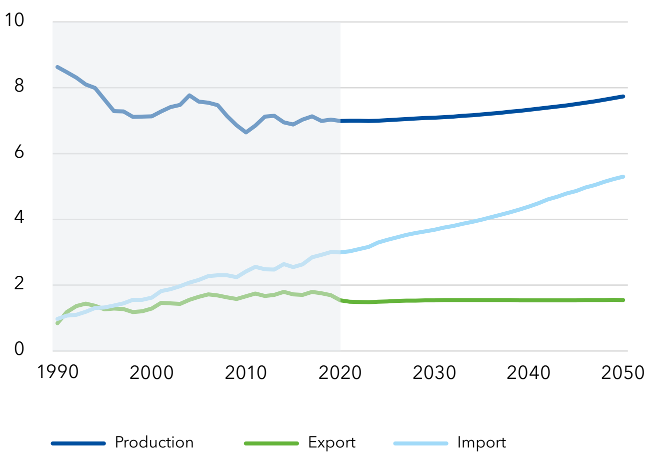
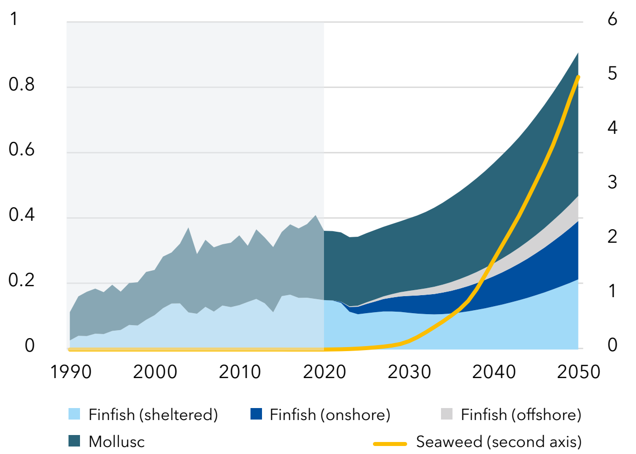


FIGURE 4.3

North America marine aquaculture

Units: Million tonnes



NAM

	Population (million)	GDP/cap (1,000 USD)	Marine seafood demand (Mt)	Marine seafood production (Mt)
2020	368	68.8	8.5	7.0
2050	419	96.4	11.5	7.7

To ease the scientific data-gathering and stakeholder consultation processes needed for permitting, the National Oceanic and Atmospheric Administration (NOAA) became responsible for identifying Aquaculture Opportunity Areas (AOAs) in 2020, with the two first sites being studied in the Gulf of Mexico and off Southern California (Rubino, 2023). In federal waters 3 to 200 miles offshore there is still no single lead government agency coordinating siting, permitting, monitoring and enforcement, making it challenging to obtain regulatory approval for aquaculture (Rubino, 2023).

As in the US, Canadian marine aquaculture faces similar regulatory challenges. Canada's aquaculture sector is managed under the federal Fisheries Act, with up to 17 federal agencies involved in governance in addition to provincial regulatory bodies (Noakes, 2018). Industry calls to create an Aquaculture Act to simplify the complex regulatory framework have not yet succeeded in achieving a change that would create growth opportunities for the sector (Wiber *et al.*, 2021).

The need to protect wild salmon stocks is a challenge for Canadian aquaculture. The federal government recently decided to phase out most salmon farms in the Discovery Islands area of British Columbia (CBC News, 2023), the leading producer province in Canada. Indigenous rights are at the centre of the conflict between fish farmers and environmental NGOs. A substantial majority (80%) of farmed salmon is produced in partnership with local First Nations who also hold a significant share of jobs in the sector (Noakes, 2018). On the other hand, the traditional livelihoods of the First Nations based on wild salmon fisheries are considered directly at risk from open net-pen fish farms (Noakes, 2018).

The substantial reliance on imports and difficulty of scaling traditional farming technologies make North America an attractive testing ground for new aquaculture technologies that see fewer regulatory barriers. RAS has the potential to move a large share of marine finfish aquaculture onshore. This new technology has attracted significant investor interest in North America with plans to add hundreds of thousands of tonnes of production capacity. We forecast that North America will produce 180,000 tonnes of finfish onshore annually in 2050, and 80,000 tonnes offshore, together constituting more than 50% of marine finfish aquaculture in the region.

The region will also see substantial growth in seaweed production from negligible amounts today to almost 5 Mt in 2050, substantially more output than forecast for marine animals. Molluscs and algae can scale without contributing to many of the problems associated with North American farming of finfish, and are seen as an important growth opportunity on the Pacific coast (Cross, 2022). Unlike fish farming, demand for industrial and food additives constitutes the most important driver for seaweed production.

The reliance on imports and difficulty of scaling traditional farming technologies make North America an attractive testing ground for new aquaculture technologies.

Latin America – the leading aquaculture exporter

Latin America is a significant exporter in the global seafood system, with relatively low local consumption of seafood. Marine aquaculture of finfish, crustaceans, and molluscs has grown steeply since 2000 and plays important economic and employment roles in the region.

The entire growth in marine seafood protein from 2020 will be met by aquaculture products, as wild catch will see a slight decline towards 2050. In total, production from marine capture and aquaculture will reach more than 20 Mt in 2050, of which 5.8 Mt are exported, while 1.1 Mt are imported (see Figure 4.4). These figures include wild catch used for fish meal and oil, for which exports will drastically reduce.

Annual aquaculture production in 2020 was at 2.8 Mt in Latin America and will reach almost 7 Mt in 2050 (see Figure 4.5). The region will then be the fourth largest by production volume, almost at European levels and surpassed only by Greater China and South East Asia. In 2020, marine aquaculture volumes of crustaceans and finfish were at the same level, with whiteleg shrimp from Ecuador and Atlantic salmon from Chile representing most of the production. Production of crustaceans will more than double (+122%) to 2.7 Mt by 2050, some 400,000 tonnes less than for finfish. Mollusc production will double to 1.2 Mt 2050 from just under 500,000 tonnes in 2020.

Chile dominates marine finfish production (Atlantic salmon) in the region today and is second only to Norway globally. The country faces challenges both when it comes to claiming ocean area for fish farms – as there is already a significant overlap between protected areas and fish farms – and because of disease outbreaks. Still, Latin America will seek to greatly increase its production in response to rising demand. By 2050, a small fraction of the region's marine finfish production will move onshore and further offshore as new technologies become more competitive, reducing some of the risks discussed above.

Latin America will continue its growth as a major shrimp producer and exporter, supplying consumers in Greater China, Europe, and North America. Stricter regulations are being imposed to halt habitat conversion due to shrimp farming (WWF, 2022). This will make the farming more sustainable, but the potential production increase remains strong through improved disease control, higher stocking density, and by utilizing new area within regulations. Ecuador and other countries in the region, such as Guatemala and Honduras, will drive the growth in shrimp production.

High production volumes combined with relatively low local demand make Latin America a major player in the global trade of marine aquaculture products with interregional export nearly tripling to 2.6 Mt by 2050,

FIGURE 4.4

Latin America seafood production, export, and import

Units: Million tonnes

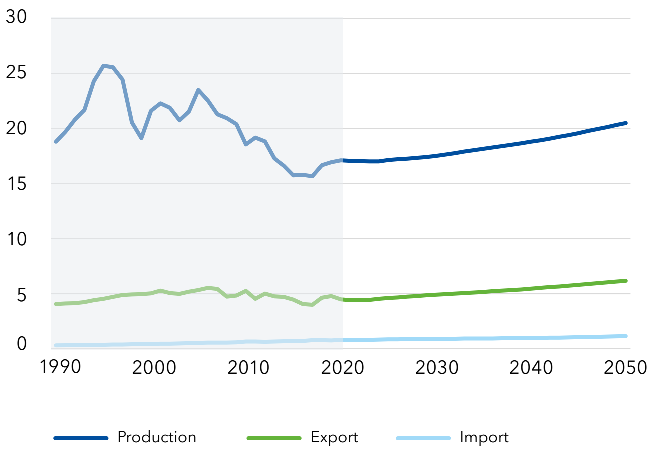
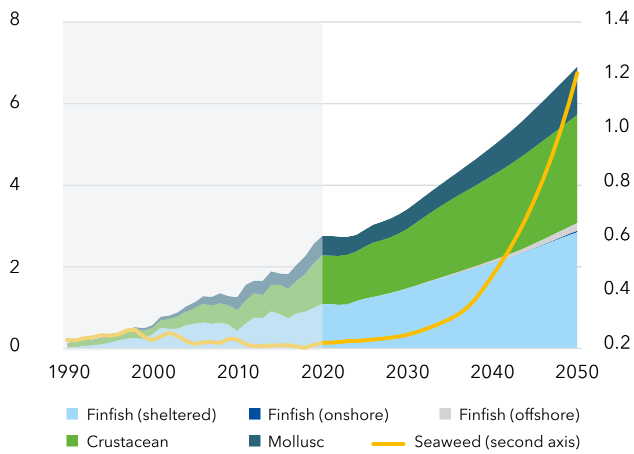


FIGURE 4.5

Latin America marine aquaculture

Units: Million tonnes



LAM

	Population (million)	GDP/cap (1,000 USD)	Marine seafood demand (Mt)	Marine seafood production (Mt)
2020	660	16.8	14.2	17.1
2050	744	27.8	15.8	20.5

exceeding European exports by 1.2 Mt. More than 40% of Latin America's production of both crustaceans and finfish from marine aquaculture will be exported to other regions. The largest-by-far importer of marine aquaculture products from Latin America will be North America, increasing its import volume 4-fold to 1.3 Mt by 2050. Europe and Greater China are the second and third largest importers of marine aquaculture products from Latin America in mid-century.

The poleward migration of fish stocks due to climate change will have the largest impact on countries close to the equator such as Ecuador, Colombia, and Brazil. Still, the aggregated reduction in catch potential is forecast to be very small, and wild catch landings remain close to 14 Mt. The export of wild catch for direct food use will reach 2.9 Mt with 50% coming from finfish. As with aquaculture, North America remains the primary destination for wild catch exports in 2050, taking more than 1.1 Mt, of which more than 60% is finfish and the rest crustaceans.

Besides the challenge from climate change, fish stocks in Latin American waters are under significant fishing pressure from local and foreign actors (the latter not counted in the above estimate as landings will be counted in other regions). The Chinese distant-water fishing fleet contributes a large fraction of the fishing effort in the Pacific, offshore from Ecuador and Peru, and in the Atlantic outside Argentina (Abbott *et al.*, 2021; Montecalvo *et al.*, 2023). Actions to provide increased transparency through technology and regulations are ongoing in the region. The UNDP (UN Development Program) with the support of the FAO leads the Coastal Fisheries Initiative, seeking more holistic processes and promoting more integrated approaches to the coordination and management of coastal fisheries in Ecuador and Peru (Ryan, 2020).

Latin America plays an important role in the supply of feed ingredients for the global aquaculture industry, both from its fisheries and its agricultural sector. Latin American fisheries provide Peruvian anchoveta and other regional pelagic fish to be used in aquaculture feed. Most fish meal and oil from Latin America are used to produce fish feed in the region, with some volumes still exported to Europe, Greater China, and North America. The exports of marine ingredients for feed will reduce from 1.4 Mt in 2020 to 340,000 tonnes in 2050. Apart from the important role Latin America plays in providing fish meal and oil for aquaculture feed, Brazil is a significant provider of soy for the industry. Soy production is under pressure due to the severe deforestation that results from clearing new land for agriculture, and imports to the EU will become subject to increasingly strict regulations regarding land-use change (Sotirov *et al.*, 2022).

Current seaweed production in Latin America is almost solely from capture at around 450,000 tonnes. Farmed seaweed will be introduced when offshore technologies can be applied for cost-competitive seaweed production. Offshore seaweed farming pilots are ongoing in Brazil and large-scale production will take off from the early 2030s. By 2050, Latin America will be producing 1.2 Mt of farmed seaweed annually. By then, this will make Latin America self-sufficient for hydrocolloids being used as food additives.

Europe – first mover in new technologies for high-value species

Europe is home to the world's biggest producer of salmon, Norway, and the region's aquaculture sector will see continued strong demand and production growth towards mid-century. The average European consumer will demand around 50% more protein from marine seafood in 2050. Aquaculture's share in this consumption will increase to more than 30% as Europe's per capita consumption of marine aquaculture products almost triples (+160%). European seafood production overall increases 50% to 22 Mt, with growth in both capture production and in marine aquaculture, enough to support growth in local demand as well as a strong export growth (see Figure 4.6).

Finfish will continue to dominate marine aquaculture, with production nearly tripling to 5.8 Mt in 2050, up from approximately 2 Mt today (see Figure 4.7). High-value species like Atlantic salmon produced in Norway, Scotland, the Faroe Islands and Iceland remain the sector's backbone, along with smaller volumes of seabass and seabream in the Mediterranean. The primary demand driver behind this expansion is Europe's internal market. Today, the dominant trade flow is in Atlantic salmon between Norway and the EU at more than 1 Mt. The farmed finfish export from Europe to other regions was around 280,000 tonnes in 2020. We forecast that interregional trade will surpass Europe's intraregional trade, seeing 5-fold growth to 1.4 Mt in 2050, with exports to Middle East and North Africa alone reaching 670,000 tonnes.

Salmon farming will take place in sheltered waters like fjords and bays, with new closed systems limiting the free exchange of sea water with the surrounding environment. Salmon production will also continue on its journey towards more exposed waters further offshore to escape spatial constraints related to the transmission of disease and sea lice (DNV, 2018, 2021a, 2023b). Europe is the first mover in this domain, but these new technologies see uptake globally.

A first batch of technically advanced fish farms are already operating in exposed waters following the Norwegian development licence scheme (Afewerki *et al.*, 2023). Applications for additional production capacity offshore can be made under the current regulatory regime. Permanent special licensing schemes for technological innovation and environmentally friendly salmon farming have not yet been launched, and the resulting regulatory complexity can prolong the time it takes to award licences (Osmundsen *et al.*, 2022). Additionally, the recent introduction of a ground rent tax in Norway is taken as a signal of regulatory uncertainty in the main finfish-producing country in Europe, but this is likely to be resolved and will have little long-term effect.

FIGURE 4.6

Europe seafood production, export, and import

Units: Million tonnes

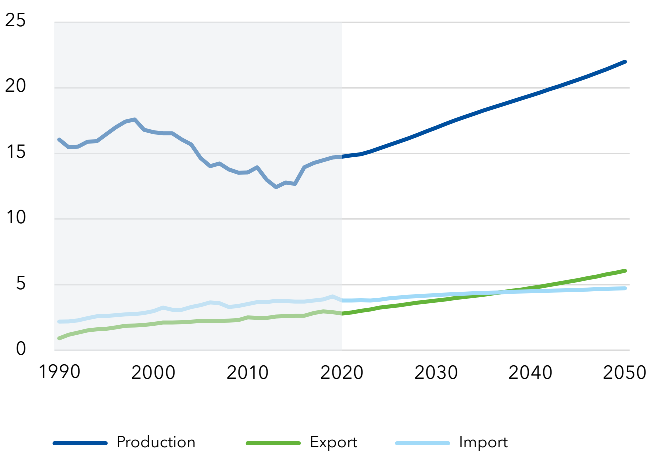
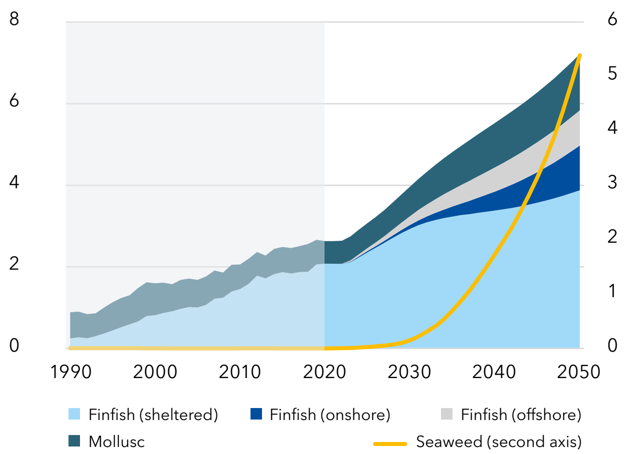


FIGURE 4.7

Europe marine aquaculture

Units: Million tonnes



EUR

	Population (million)	GDP/cap (1,000 USD)	Marine seafood demand (Mt)	Marine seafood production (Mt)
2020	541	48.6	15.4	14.8
2050	542	73.2	20.5	22.0

We forecast that finfish production offshore in Europe will exceed 860,000 tonnes in 2050, while onshore farming of marine finfish reaches 1.1 Mt. With a growing offshore fish farming sector, more technically sophisticated well-boats and other service vessels will be introduced. Offshore and onshore production of marine finfish becomes more competitive because of cost reductions from learning effects, and through favourable licensing costs compared with those for sheltered waters which have seen steep auction prices due to strict regulations on the intensification of production.

The demand for farmed shrimp will also impact the European seafood market as imports rise from 340,000 tonnes now to almost 620,000 tonnes in 2050. Of these, 300,000 tonnes will come from Latin America, with smaller volumes from South East Asia and the Indian Subcontinent. The demand for farmed shrimp from Asia will stagnate, while the main growth comes from Latin American produce. Sustainability concerns relating to land-use change and deforestation impact the demand for product among European consumers. EU food safety and sustainability regulations will force producers in shrimp-exporting countries to professionalize further.

Non-fed aquaculture grows significantly towards 2050. For Europe's seaweed sector, we also forecast strong growth in production to around 5.4 Mt, with new production technologies making seaweed farming feasible in offshore waters. Seaweed forms an important part of the EU's strategic guideline for its aquaculture industry (EU Commission, 2021), and represents an 'untapped resource' which contributes towards several objectives within the EU Green Deal (EU Commission, 2022).

Future seaweed aquaculture is likely to include projects that combine renewable energy production with the provision of ecosystem services; for instance, using seaweed to remove nutrients in Baltic and North Sea areas suffering from eutrophication. Other alternatives include integrated multi-trophic aquaculture systems (IMTA) with joint finfish and seaweed production, or seaweed farming to capture carbon (DNV, 2023a). Seaweed farming will surpass the farming of molluscs in European waters by 2040. A small amount of the increased production will go towards human consumption. Seaweed grows to meet increasing demand for additives in industrial products and foods.

While our forecast shows the growing importance of marine aquaculture to 2050, fisheries maintain an important role in the food supply, with relatively stable per capita demand over the period. Commercial fisheries will see a poleward migration with catch potentials increasing in the sea areas adjacent to northern Europe, causing regional wild catch to increase from 12 Mt to 15 Mt. As a result, exports rise to eliminate the European seafood trade deficit by 2037, increasingly contributing to meeting demand in regions like Sub-Saharan Africa which experience declining catch potential. By 2050, Europe will see a trade surplus of 1.5 Mt in marine seafood.

European fisheries management in recent years has seen bouts of uncertainty due to the United Kingdom leaving the EU, and to responses to the war in Ukraine potentially impacting the Norway-Russia fisheries agreement. In the longer term, these developments will have little effect on the sector.

Greater China – leading seafood producer and processing hub

Greater China will still be the world's leading seafood producer in mid-century. It will remain easily the biggest marine aquaculture producer by volume, and second only to South East Asia for wild catch in 2050. Greater China's overall fish production – counting all marine aquaculture and capture fisheries but excluding seaweed – will only grow slightly to 37.7 Mt by then, up from 34.3 Mt in 2020 (see Figure 4.8). Seaweed will contribute another 29.4 Mt in mid-century, up 50% from today's 20.5 Mt.

Greater China will still see its living standards improve significantly to mid-century, with GDP/capita rising another 150% and supporting further increases in demand for high-quality seafood. Over the same period, the region's population declines slightly.

With fast-improving living standards, food preferences will change in Greater China. Consumers will increasingly prefer seafood perceived as safe and high quality (Crona *et al.*, 2020), for instance by choosing wild-caught rather than farmed seafood. As the growth potential of global fisheries is limited, the growing middle classes are likely to seek imported farmed fish like salmon and other high trophic species in addition to shrimp. However, affordability remains a core concern for Chinese consumers, and the region will see a more rapid growth in consumption of protein from freshwater aquaculture than from marine aquaculture.

China's 14th Five-Year Plan (FYP) for Fishery Development formulated goals for further improving aquaculture production in quantity and quality while reducing the wild catch volume from 13 Mt in 2020 to below 10 Mt in 2025 (Montecalvo *et al.*, 2023). This does not include the Chinese distant-water fleet fishing offshore in other regions. We forecast that Greater China's fisheries will remain around 15 Mt, including fishing activity in other sea areas.

The region will see aquaculture of marine animals (finfish, crustaceans, molluscs) grow to 22.7 Mt in 2050. Although Greater China will see large, continued growth in marine aquaculture production, the growth rate will eventually slow by 2030, with a contraction of output in the 2040s mainly due to a reduction in population. Local factors that inhibit further growth will also play a part. They include competition for space with other industries, and degraded water quality in coastal areas due to pollution from land (Crona *et al.*, 2020).

To meet the goals for aquaculture in the 14th FYP, there will be a need for improved regulations to reverse the trend of increasingly degraded water quality in China's

FIGURE 4.8

Greater China seafood production, export, and import

Units: Million tonnes

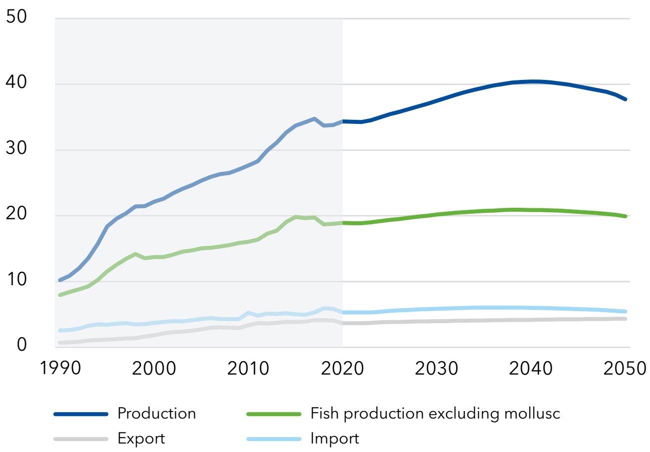
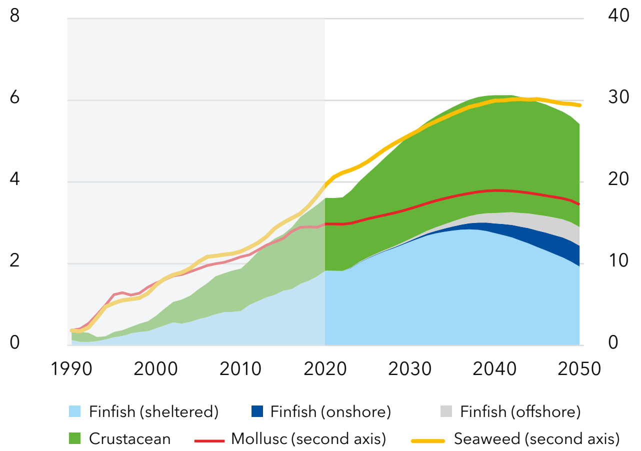


FIGURE 4.9

Greater China marine aquaculture

Units: Million tonnes



CHN

	Population (million)	GDP/cap (1,000 USD)	Marine seafood demand (Mt)	Marine seafood production (Mt)
2020	1,445	20.1	34.1	34.3
2050	1,337	49.9	38.3	37.7

coastal areas, and offshore technology to expand into new ocean space. Chinese coastal waters are increasingly busy (DNV, 2021b). Offshore finfish farming technology has already been implemented in China; for example, the Conson No. 1 Aquaculture Ship, an aquaculture vessel producing large yellow croaker (ASC, 2023). Offshore finfish production will contribute around 450,000 tonnes by 2050, or approximately one sixth of the overall output of marine finfish aquaculture in the region. Marine finfish aquaculture overall increases 60% from 1.8 Mt to 2.9 Mt (see Figure 4.9).

Greater China's crustacean production will increase 40%, from 1.8 Mt in 2020 to 2.5 Mt in 2050 (see Figure 4.9). This is not enough to meet local demand, and the region will see crustacean imports on a par with North America until the 2030s. At that time, North American shrimp imports will continue growing while Greater China's imports will plateau. Most of the imports will be supplied by Latin America, but India and South East Asia will also be large contributors.

Greater China's reliance on imports of marine-fish feed ingredients continues, and the region remains the world's top importer, in support of finfish and crustacean farming. Note that China's massive freshwater aquaculture industry also drives demand for marine feed ingredients. It will by far lead in terms of wild catch import for fish meal and oil, at more than 550,000 tonnes, though this is just above half the 930,000 tonnes seen in 2020.

Greater China's seaweed production is significantly higher than that of other regions today and will continue to be so. The seaweed is consumed directly as food, as hydrocolloid food additives, and as industrial additives. Greater China will reduce its dominance in the unfed aquaculture production market for both seaweeds and mussels from 60% and 84% market share in 2020, to 41% and 76% in 2050, respectively. Molluscs make up almost half of the marine animal aquaculture of Greater China and are traded to a very small extent.

When considering the impact of Greater China on the seafood market, it is also necessary to understand the role the region plays in fish processing. A high proportion of Chinese wild catch imports and distant-water catches never reach end consumers in the region but are instead re-exported as value-added products for consumption elsewhere. Asche *et al.* (2022) estimates this proportion at almost 75% and argue that this resembles the role China is taking in manufacturing. This phenomenon largely obscures the original source of food from the consumed products and complicates traceability efforts for wild-caught fish. It also introduces significant global vulnerabilities into seafood supply chains, as they are surprisingly dependent on Greater China as a processing hub (Abbott *et al.*, 2021). Note that the FAO, which is our source of trade data, corrects for re-export.

A high proportion of Chinese wild catch imports and distant-water catches are re-exported as value-added products.

South East Asia – coastal ecosystems under pressure

South East Asia is among the leading regions for coastal and marine aquaculture. It is currently the region with the second highest per capita marine seafood consumption after OECD Pacific, with seafood contributing more protein than terrestrial meat. To 2050, South East Asia remains among the leading marine seafood consuming regions, but will struggle to fully meet demand. By then, the region's population will have grown 18%, and GDP/capita by 130%, third fastest among all our regions after the Indian Subcontinent and Greater China.

Production in South East Asia will reach 28.0 Mt in 2050, a quarter (25%) more than in 2020 (see Figure 4.10). Fisheries output contracts by 10%, whereas marine aquaculture increases 165%, not counting seaweed. Seaweed adds another 21.5 Mt, up from 9.9 Mt in 2020. Currently, Indonesia ranks second behind China in seaweed production globally, and is a large exporter of seaweed for food and industrial additives. Overall exports grow at a slightly slower pace than production, but the region will see a seafood trade surplus, particularly due to shrimp exports. At the time same time, the region will not prioritize importing enough wild-caught fish to meet demand for that, due to the relatively high cost of these protein alternatives.

The contraction in fisheries is not evenly distributed across South East Asian seas. In some, catch will reduce up to 30% in response to global ocean warming and changes in primary production (Cheung *et al.*, 2016). South East Asian fisheries are dominated by small-scale producers whose contributions to food security are often underestimated as their catches go unreported (Teh & Pauly, 2018).

In Indonesia, the main objective underpinning fisheries management relates to food security. The country aims to increase domestic production to increase seafood availability in the country and support the livelihoods of artisanal fishers and aquaculture producers (OECD, 2017). Government programmes have been put in place to address illegal industrial fishing, promote modernization of the artisanal fishing fleet, and restrict imports to protect domestic producers and fishers from international competition.

Marine aquaculture grows from 4.8 Mt to 12.1 Mt, as shown in Figure 4.11. Marine finfish and crustacean farming produce roughly the same quantities in 2050, both a little over 5.5 Mt. Whereas finfish triples, crustacean farming doubles. This is consistent with finfish, but not crustaceans, moving away from pond-based farming towards a greater use of sea cages, escaping the limits of

FIGURE 4.10

South East Asia seafood production, export, and import

Units: Million tonnes

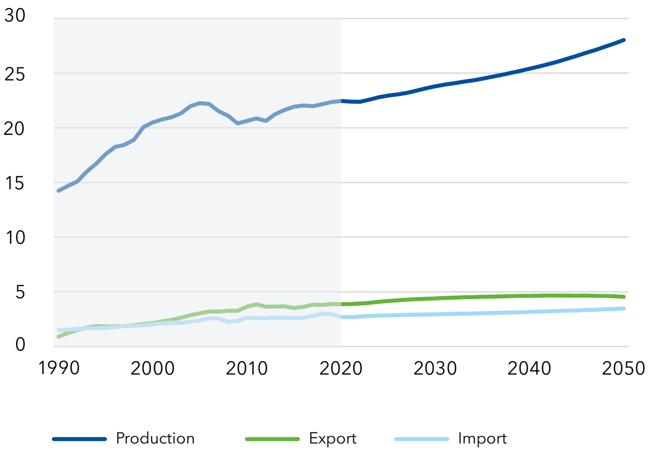
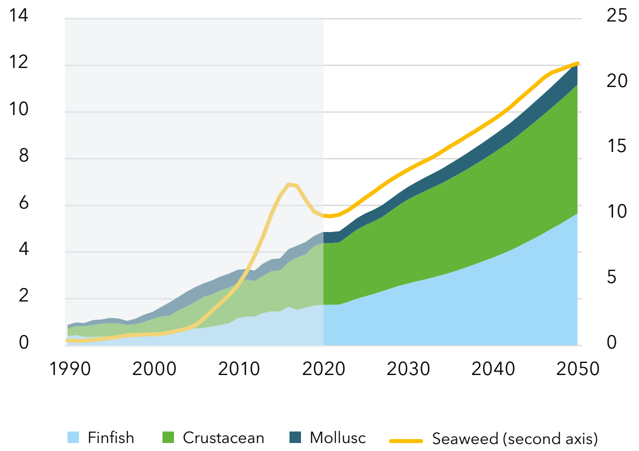
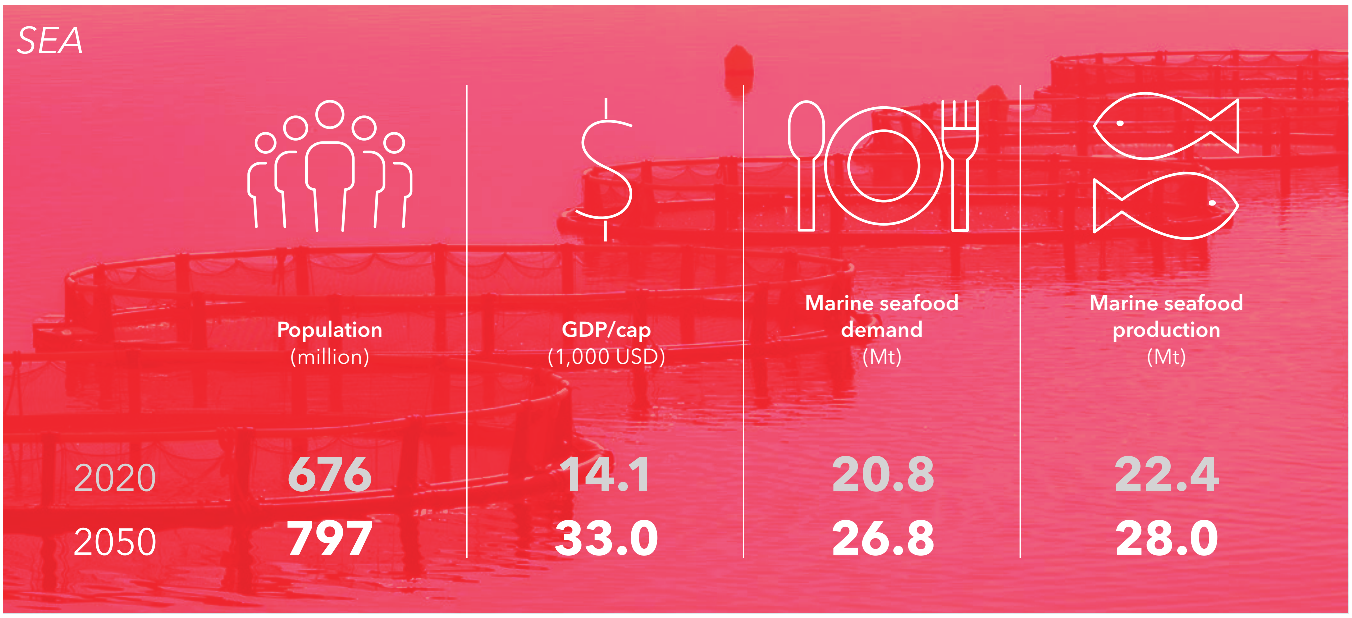


FIGURE 4.11

South East Asia marine aquaculture

Units: Million tonnes





coastal areas. Still, none of the region's finfish production will move to offshore farming.

South East Asian aquaculture must rise to the challenge of feeding a growing population against a backdrop of natural resource constraints and biodiversity loss. It must also adapt to the pressures of climate change and enhance system resilience. Aquaculture expansion requires additional natural resources, mainly land and water, which may result in or exacerbate environmental and social conflicts arising from competing uses. To accommodate the growing demand in this context, marine aquaculture in South East Asia will need to diversify and intensify production.

A strong driver for intensification of the sector is the growing awareness of the adverse environmental effects of land-use change, particularly in sensitive coastal ecosystems like mangroves. Moving from extensive to intensive production systems yields higher production per hectare, making it possible to increase production without a similar increase in land use. The land-saving potential of intensification can then allow for restoration of mangrove areas and the associated ecosystem services (Schuur *et al.*, 2022). Additionally, intensive shrimp farming uses less water per tonne, meaning that sediment-trapping in ponds declines, thereby reducing the contribution of the sector to erosion (Schuur *et al.*, 2022). Still, intensification does not come without risks, including increasing disease pressure, pollution, and reduction in water quality. Past disease outbreaks in shrimp farming have decimated production, with Thailand being hard-hit recently (FAO, 2022a).

Regional industrialization is best reflected in the shrimp farming sectors of Indonesia, Thailand, and Vietnam, which are large exporters to markets like the EU, Japan, and the US (FAO, 2022). The region's export of farmed crustaceans will reach 1.2 Mt in 2050, up from slightly less than 800,000 tonnes in 2020, being surpassed by mid-century by Latin America and the Indian Subcontinent. Exporters in the region will face increasing pressure from buyers to improve their sustainability records. This will require further adaptation to production practices that meet an increasing focus on traceability and address concerns relating to human health and environmental impacts. The current structure of the sector, with a large number of small-scale, extensive operations, and decentralized downstream logistics, makes controlling shrimp farming virtually impossible in practice (Schuur *et al.*, 2022; Suzuki, 2021), unless further consolidation happens. Similar structural issues also persist in Indonesian algaculture, with the implication that their seaweed exports are at risk of being outcompeted by seaweed derivatives produced by the expanding seaweed sector in Europe and North America.

Several national initiatives are shaping the response to sustainability challenges that shrimp farming faces. Indonesia has introduced aquaculture villages to co-locate farms, driving cooperation, efficiency gains, and innovation while providing social benefits (Suriyani & Ambari, 2022). Vietnam's National Program on Aquaculture Development sets forth objectives to scale aquaculture production (including freshwater) to 7 Mt by 2030 in a way that improves efficiency, sustainability, and enables climate-change adaptation (FAO, 2022b). The Vietnamese plan includes goals of increasing the local supply of broodstock for key shrimp species and investing in production and processing infrastructures, thereby improving the resilience of aquaculture supply chains.

OECD Pacific – seafood consumption in decline

OECD Pacific currently consumes more seafood protein per capita than any other of our 10 regions. In 2020, it consumed twice as much per person as South East Asia, the second biggest per capita consumer. OECD Pacific consists of some of the countries with the most pronounced marine-food cultures – Japan, South Korea, and Australia and New Zealand with their Western cuisines.

Per capita consumption of seafood protein in OECD Pacific has declined from around 18 g/day in 2000 to 16 g/day in 2020, including freshwater fish. This trend will continue to mid-century, but the rate of decline will reduce in the coming decades. We forecast per capita demand for marine animal protein reaching 11 g/day in 2050, substituting for terrestrial meat so that total animal protein consumption will remain around 40 g/day/capita. Additionally, the populations of both Japan and Korea will reduce, meaning that the region's overall demand for seafood will reduce greatly.

Diets are changing, particularly in Japan, in tandem with rising seafood prices, and with consumers increasingly seeing terrestrial meat substitutes as easier to cook than traditional seafood dishes (Kitano & Yamamoto, 2020; Oishi *et al.*, 2017). Dependence on increasing imports and aquaculture products may also play a role in the reducing Japanese demand, with consumers seeing Japanese fisheries as key to their cultural identity and often putting less emphasis on aspects like overfishing (Swartz *et al.*, 2017).

Fish landings in OECD Pacific have been falling since the early 1990s. The region produced 13.7 Mt in 1990, and this reduced by half to 6.3 Mt in 2020. This reduction is partially attributed to the collapse of the Japanese sardine stock (Swartz *et al.*, 2017; Yang *et al.*, 2023), and to the loss of fishing grounds historically used by Japanese vessels to other countries' exclusive economic zones after the implementation of UNCLOS (UN Convention on the Law of the Sea) (Ganapathiraju *et al.*, 2019). We forecast that the overall seafood production will remain at this level to 2050 (see Figure 4.12), with a small increase in marine aquaculture and a small decline in marine fisheries.

Marine finfish aquaculture increases 50% to 660,000 tonnes by 2050, while mollusc farming grows only 10% to almost 960,000 tonnes (see Figure 4.13). Japan is currently the largest single producer in the region, focusing on production of the high-value species

FIGURE 4.12

OECD Pacific seafood production, export, and import

Units: Million tonnes

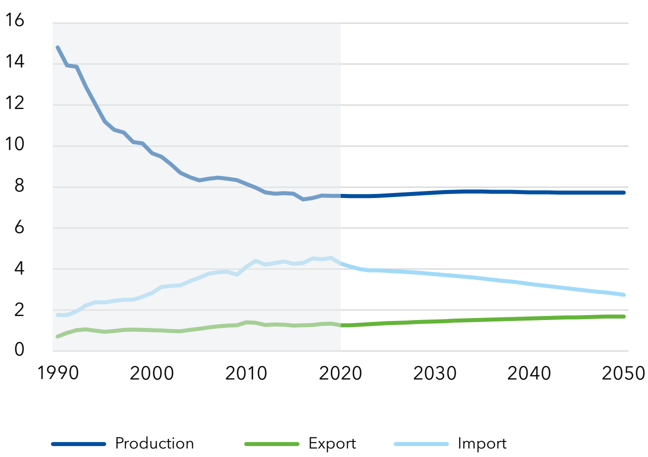
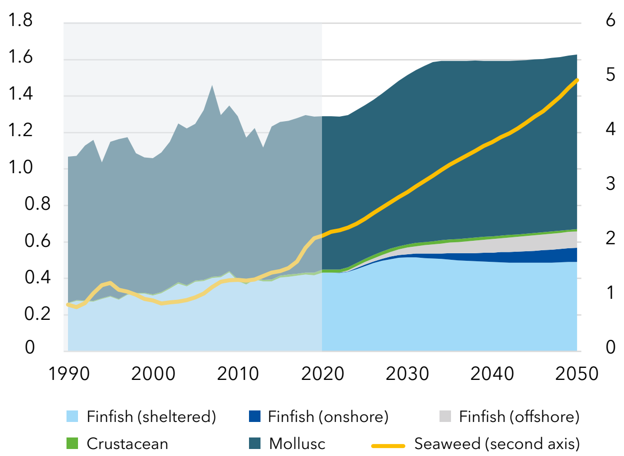


FIGURE 4.13

OECD Pacific marine aquaculture

Units: Million tonnes



OPA

	Population (million)	GDP/cap (1,000 USD)	Marine seafood demand (Mt)	Marine seafood production (Mt)
2020	**207**	**49.1**	**10.4**	**7.6**
2050	**189**	**72.4**	**8.8**	**7.7**

Japanese amberjack, whereas Australia is a fast-growing producer of Atlantic salmon off the coast of Tasmania. Australian Atlantic salmon is farmed in significantly warmer water than elsewhere in the world. A major advantage for Australian produce is shorter transportation distances to markets in East Asia compared with salmon from Europe or Latin America. Additional measures to reduce reliance on imports will also be considered. We forecast that in the whole region, 12% of marine finfish production will move onshore, and 14% offshore.

Seaweed production in OECD Pacific fares better than the region's production of fish. We forecast that seaweed production in the region will reach 5.0 Mt by 2050, up from 2.1 Mt in 2020 (see Figure 4.13). The main driver behind the growth in seaweed is demand for additives, rather than food. Consumption of protein from algae in OECD Pacific will go from 0.6 g/day/capita to 0.9 g/day/capita, which means that the amount of seaweed demanded for food will go from 1.6 Mt to 2.4 Mt.

As a high-income region, OECD Pacific responded to the rapid decline in capture fisheries in the 1990s by greatly increasing imports. Fish imports from other regions doubled between 1990 and 2020, with Japan becoming one of the biggest export markets for seafood globally (Oishi *et al.*, 2017), including the introduction of Atlantic salmon for sashimi. The trend of growing imports will now reverse (see Figure 4.12). As consumption declines, we forecast that OECD Pacific imports will almost halve from 4.3 Mt in 2020 to 2.7 Mt in 2050. Over the same period, the exports from the region will increase 30% to 1.7 Mt. The regional seafood trade deficit thereby declines by nearly two-thirds from 3.0 Mt to 1.1 Mt.

The seafood supply chain in OECD Pacific is significantly more fragmented and decentralized than in other industrialized regions. For instance, the downstream logistics of Japanese seafood is characterized by a much larger number of small-scale actors across processing and distribution. The high costs associated with certifying every step in this complex supplier network has significantly limited uptake of international certification schemes in Japan (Swartz *et al.*, 2017). With seafood producers in OECD Pacific increasingly prioritizing exports as local demand reduces, these actors will progressively be forced to reconsider adopting certification schemes required among retailers in other industrialized countries (Blandon & Ishihara, 2021).

> A major advantage for Australian salmon farming is shorter transportation distances to markets in East Asia compared with salmon from Europe or Latin America.

Other regions

Sub-Saharan Africa

Sub-Saharan Africa is the fastest-growing region in terms of population and will also see large improvements in living standards. Still, it remains the region with the lowest per capita GDP and sees little growth in uptake of marine seafood to 2050. High-value marine species will remain unaffordable to most of the population, and marine aquaculture will only reach 67,000 tonnes in 2050 while capture fisheries remain at 6.8 Mt.

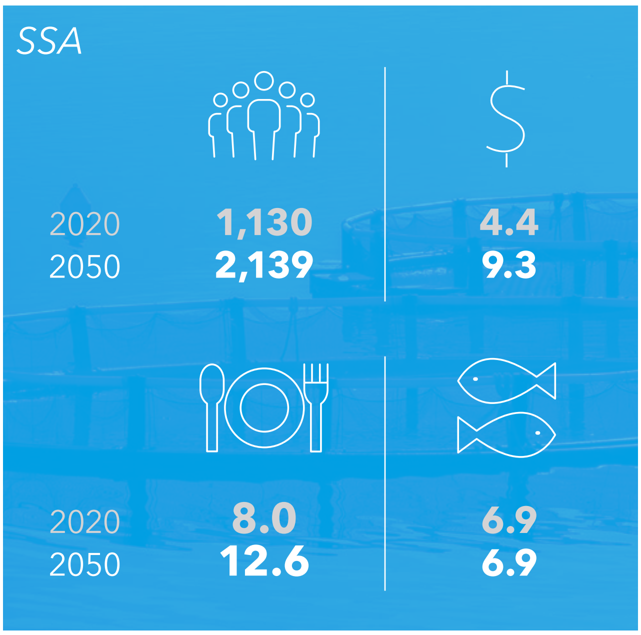
Fisheries in Sub-Saharan Africa will be unable to meet a coming demand surge following increased living standards, and imports will only suffice to satisfy parts of the demand rise. In 2050, Sub-Saharan Africa will import 6.7 Mt, up from 1.9 Mt in 2020, likely necessitating further buildout of cold-chain logistics systems across the region. The rising supply deficit for food from the ocean will be met by a combination of terrestrial protein sources and an expansion of freshwater aquaculture. However, the continued reliance on local freshwater aquaculture and imported terrestrial foods indicates that sourcing seafood from the sea will have a limited impact on food security challenges facing Africa.

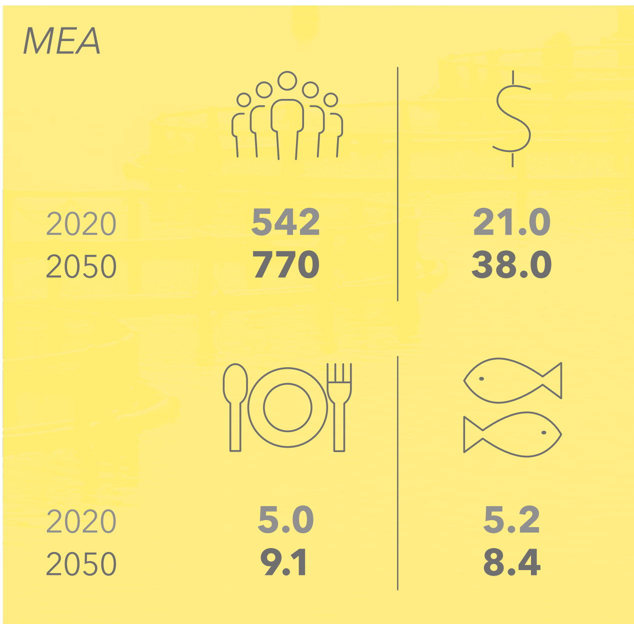
Middle East and North Africa

The Middle East and North Africa will undergo a transformation of its seafood system by 2050. We forecast that the region's marine aquaculture sector will produce approximately five times more in 2050 than today, growing to 4.3 Mt in response to rapidly rising demand for seafood. The growth in aquaculture will more than make up for the slightly reducing catches, which will fall to 4.2 Mt.

Several new entrants to the marine aquaculture sector are seizing the opportunity to scale up seafood production across the Middle East. In several Gulf States, aquaculture is becoming a key element in a strategy to improve national food security and diversify the economy away from oil and gas (Dickson, 2022). For instance, Saudi Arabia's Vision 2030 aspires to drastically increase domestic seafood production to 600,000 tonnes by then (Arab News, 2022).

Despite scaling up regional production dramatically, the Middle East and North Africa will not reduce its seafood trade deficit as demand grows more quickly than local production. Imports will grow around 160% by 2050, while exports grow 120%.





North East Eurasia

North East Eurasia consists of the former Soviet Union, except the Baltics, and North Korea. Russia dominates the region in terms of access to the ocean and marine resources. North Korea is the leading aquaculture producer in the region, mainly farming molluscs.

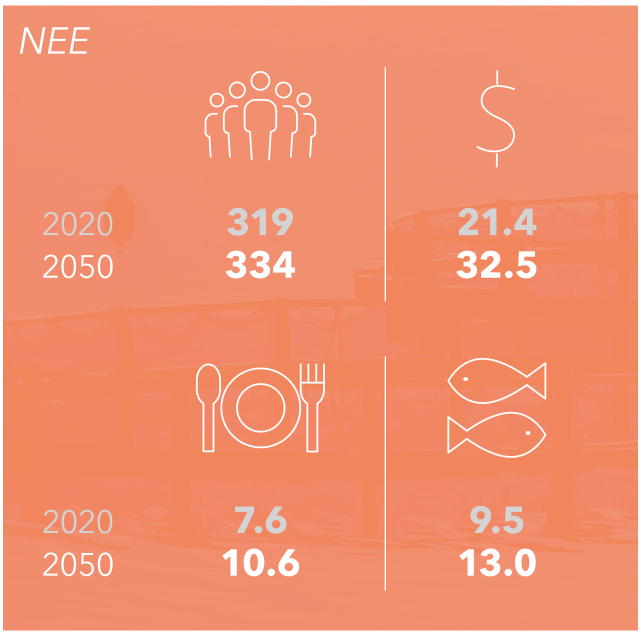
Production in the North East Eurasian fisheries sector will grow nearly a third (30%) from an estimated 9.4 Mt in 2020 to 12.6 Mt in 2050. Fisheries in Russia's Far East region and in the Russian Arctic will be among the beneficiaries of climate change as fish stocks migrate north (Barange *et al.*, 2018). As of 2019, the FAO-reported catch from Russian fisheries stood at 4.8 Mt, while Sea Around Us estimated that another 3.5 Mt went unreported, indicating that less than 60% of Russian capture is reported (Pauly *et al.*, 2020).

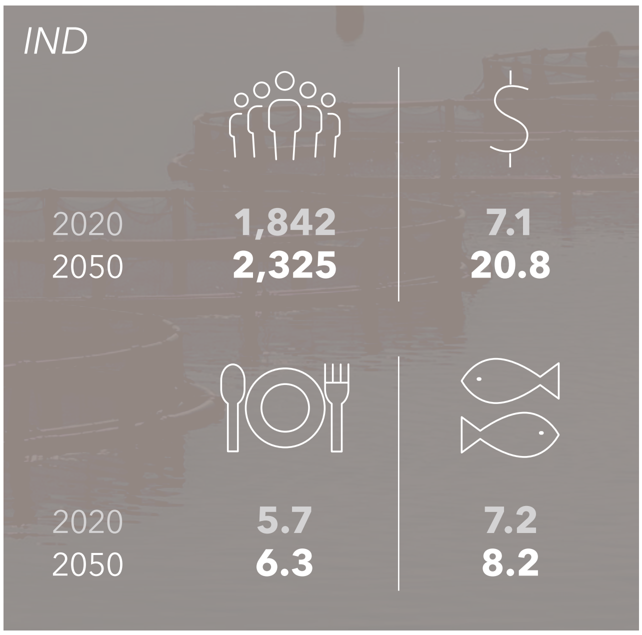
As the region will see growing capture in a time when captures will decline in many other parts of the world, North East Eurasia will expand its seafood exports. From exporting 2.1 Mt in 2020, exports will grow more than 35% to 2.9 Mt in 2050. In the short term, North-East Eurasia's seafood sector is impacted by international sanctions following the Russian invasion of Ukraine. The deteriorating relationship with European countries also hampers common fisheries policy.

Indian Subcontinent

The Indian Subcontinent has large internal variations in food culture. Some Indian states are mainly vegetarian, whereas many coastal regions consume a lot of seafood (Naylor, Kishore, *et al.*, 2021). Capture fisheries will remain stable at around 5.8 Mt, which is consistent with lower catch potentials in some of the waters adjacent to the subcontinent. Marine aquaculture in the region remains focused on exports of farmed crustaceans, and the shrimp farming sector reaches 1.9 Mt.

Freshwater aquaculture will be the main source of farmed seafood consumed in the Indian Subcontinent to 2050. With major population concentrations located mainly inland, a lack of freezing and cooling infrastructure and limited outbound logistics capacities are significant barriers to scaling up local supply chains for marine seafood across the region. In contrast, freshwater aquaculture can be produced locally, closer to the main inland population centres. Climate-change effects including heatwaves and droughts constitute a major uncertainty in how freshwater aquaculture will contribute to local food security.





5 CONCLUSIONS

In this Seafood Forecast, we have provided our 'most likely' forecast of the future of seafood, taking an objective view on what will happen by 2050.

Our forecast shows a clear difference between many optimistic projections and what we deem to be the most likely future. The world's supply of seafood sourced from the ocean will rise 20% over a period in which the global population will increase by a quarter. While seafood demand is on the rise, there is no indication of a large-scale dietary shift.

The entire increase in food from the ocean will come from marine aquaculture. There is a doubling in marine aquaculture production – finfish, crustaceans, and molluscs – with a marked tripling in finfish output. Finfish strengthens its position as the preferred type of seafood from marine aquaculture and overtakes molluscs as the leading farmed species in terms of live weight. Technical developments like producing marine finfish further offshore or onshore can reduce the exposure of the fish to biological stressors such as sea lice. These new production technologies will account for a fifth of the finfish market in 2050. Seaweed production also rises but driven mainly by demand for industrial and food additives. Seen globally, capture fisheries will produce approximately the same amount of food in 2050 as today, but there will be large regional shifts due to climate change.

Dynamics driving seafood demand include population growth and improving living standards, as well as cost and sustainability considerations. The supply-side dynamics remain largely dependent on favourable environmental conditions, well-managed fisheries, and sustainable aquaculture production practices. These dynamics drive supply-demand imbalances that make global seafood trade increasingly important.

Our results show that seafood supply chains largely remain long, global, and complex. There will be changes in terms of what trade flows dominate, despite calls for enhancing food security through self-sufficiency. To meet the demand for trust and transparency emerging from regulators and investors, the global seafood industry will increasingly need to invest in traceability throughout the supply chain.

In marine aquaculture, fed species will see much faster growth than unfed ones, resulting in a tripling of demand for feed. Feed production will see changes in the sourcing of ingredients, with reduced shares for both plant and marine ingredients. Plant ingredients double to 2050, whereas marine ingredients peak in the 2030s. New technologies will make an impact on feed production, as novel ingredients capture 30% of the market by 2050.

APPENDIX

Our approach

What will the Blue Economy look like towards 2050? How can the Blue Economy contribute to serving a world population beyond nine billion in 2050? What are the key interlinkages between ocean-based industries, and the barriers to productivity arising from global ocean health challenges? What are the spatial requirements of the Blue Economy in 2050? To try to answer these questions, we have developed this forecast providing a systemic and balanced view of ocean-based industries between now and mid-century.

To support strategy and decision-making, this report offers insight into these industries' futures. In contrast to scenario-based outlooks, we present a single 'best estimate' forecast. The work is part of DNV's broader commitment to provide insight and transparency into the Blue Economy through foresight activities considering sector interlinkages and barriers to productivity, as described above. This is the fourth instalment in the *Ocean's Future to 2050* series of publications to follow this methodology. The previous three include the *Ocean's Future to 2050* published in 2021 as a complete overview of the Blue Economy; *Marine Aquaculture Forecast* published in 2021 as a deep-dive into marine aquaculture; and the *Spatial Competition Forecast* published in 2023 as an in-depth analysis of the spatial competition arising among ocean industries to 2050.

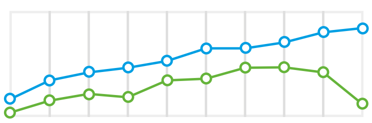
Model description
We develop a system dynamics simulation model that mirrors key supply-demand relationships and interactions between ocean industries. The illustration on pages 64 and 65 shows the model's most important feedback loops. Global trends like population growth and improving living standards drive the forecast of demand for the goods and services provided by the ocean economy.

For most industries, the model considers feedback between demand, production, and infrastructure capacity, also moderated by interrelations between ocean industries and by barriers to growth, like climate change. For energy-intensive sectors of the Blue Economy, we look to the DNV *Energy Transition Outlook* (DNV, 2021b) for input data, with examples being ocean energy production and the maritime sector.

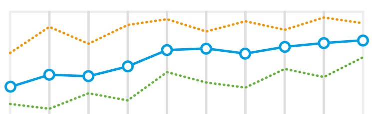
The model includes existing and emerging sectors of the ocean economy, including capture fisheries, marine aquaculture, offshore oil and gas production, fixed and floating offshore wind, the maritime sector, tourism, and desalination. Both industrial and artisanal activity are included in the forecast.

The seafood sectors in the model cover the fish and seaweed lifecycles, as well as infrastructure required to farm or catch fish. Infrastructure along the value chain up to quayside primary processing is considered, but not downstream transportation infrastructure or secondary processing. The sustainability considerations and costs associated with investing in and operating infrastructure play a major role in the modelling of demand, in which consumers make a sequence of binary choices between food alternatives. The feed supply chain interlinks wild catch with aquaculture, but also considers interfaces with land-based feed ingredients. The seafood trade between all regions corrects for any supply-demand imbalances, and accounts for transportation costs.

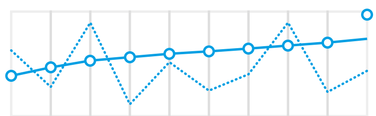
The model is populated with data from databases providing historical time series for supply and demand; industry reports; scientific articles; and the judgement of domain experts.



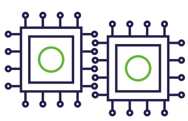
Our **best estimate**, not the future we want



A single forecast, not scenarios



Long-term dynamics, not short-term imbalances



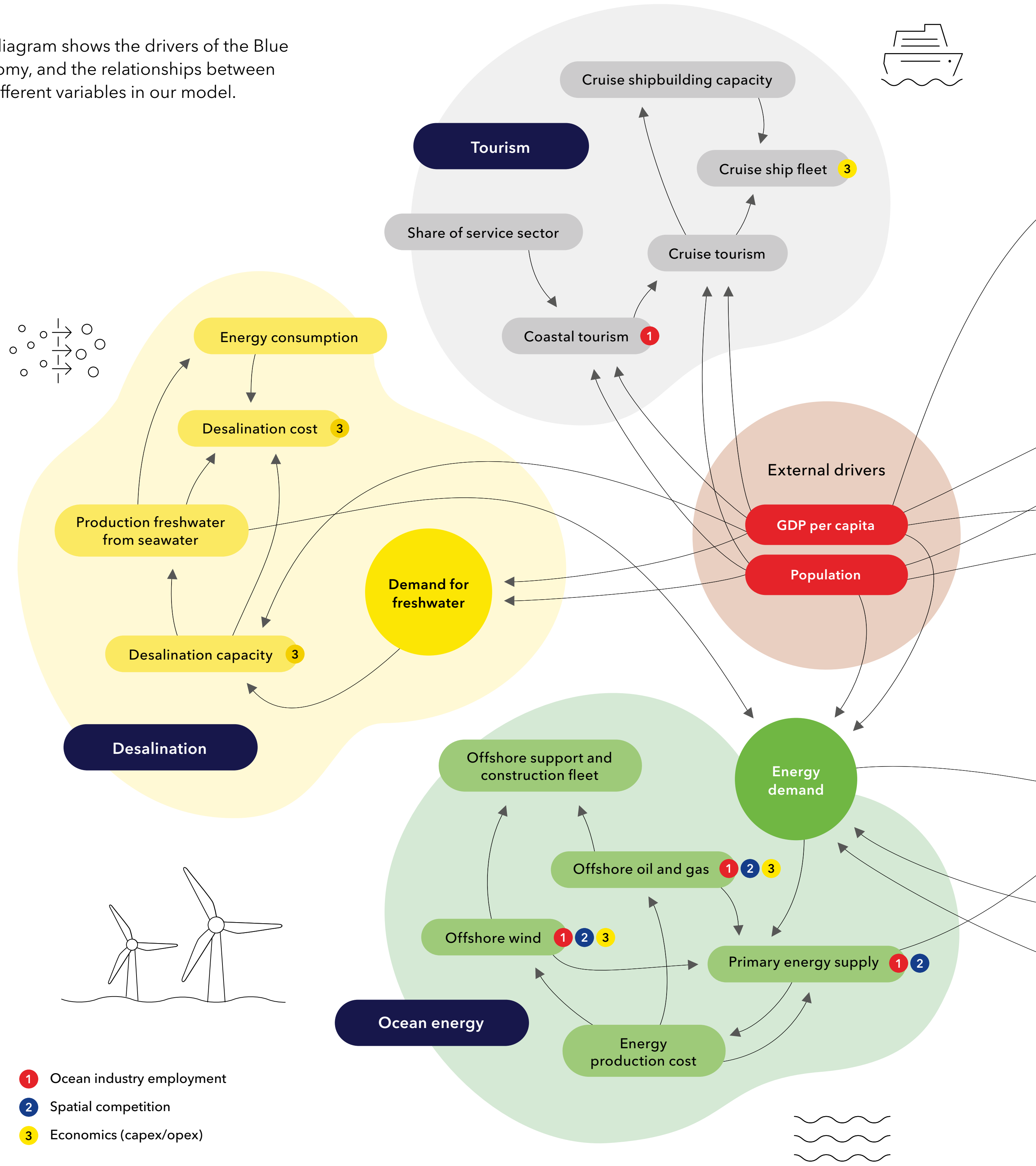
Continued development of proven **technology**, not uncertain breakthroughs

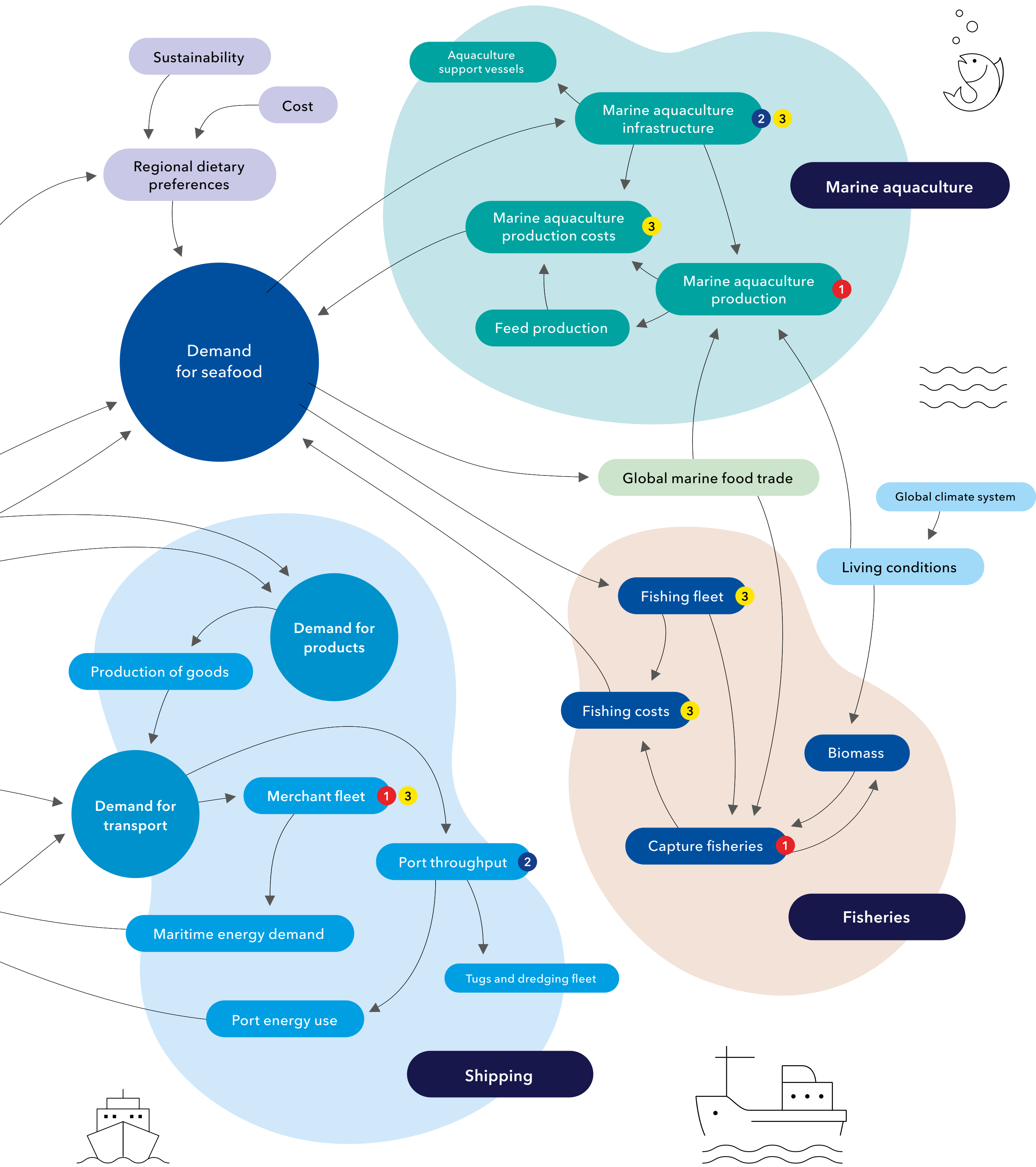
Main **policy** trends included; caution on untested commitments.

Model **consumer behaviour** based on changes in costs and sustainability

SIMPLIFIED OVERVIEW OF OUR SYSTEM DYNAMICS SIMULATION MODEL

This diagram shows the drivers of the Blue Economy, and the relationships between the different variables in our model.




Sustainability
Cost
Regional dietary preferences
Demand for seafood
Aquaculture support vessels
Marine aquaculture infrastructure 2 3
Marine aquaculture production costs 3
Feed production
Marine aquaculture production 1
Marine aquaculture
Global marine food trade
Global climate system
Living conditions
Fishing fleet 3
Fishing costs 3
Biomass
Capture fisheries 1
Fisheries
Demand for products
Production of goods
Demand for transport
Merchant fleet 1 3
Port throughput 2
Maritime energy demand
Tugs and dredging fleet
Port energy use
Shipping

ABBREVIATIONS

AI	Artificial Intelligence
AOA	Aquaculture Opportunity Areas
ASC	Aquaculture Stewardship Council
CPTPP	Comprehensive and Progressive Agreement for Trans-Pacific Partnership
EM	Electronic Monitoring
EOS	Earth Observation Systems
ESG	Environmental, Social and Governance
FAO	UN Food and Agriculture Organization
FCR	Feed Conversion Ratio
GDP	Gross Domestic Product
GAP	Good Aquaculture Practice
GVA	Gross Value Added
HoReCa	Hotel, Retail, and Catering
IMTA	Integrated Multi-Trophic Aquaculture
IPCC	Intergovernmental Panel on Climate Change
IUU	Illegal, Unregulated and Unreported fishing
MSC	Marine Stewardship Council
MSY	Maximum Sustainable Yield
NAFTA	North American Free Trade Agreement
NGO	Non-governmental organization
NOAA	National Oceanic and Atmospheric Administration
OECD	Organisation for Economic Co-operation and Development
RAS	Recirculating Aquaculture Systems
SDG	UN Sustainable Development Goals
SSP	Shared Socioeconomic Pathway
UNCLOS	UN Convention on the Law of the Sea
UNDP	UN Development Programme
USAMC	United States of America-Mexico-Canada Agreement
WHO	World Health Organization
WTO	World Trade Organization

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