Planet Tracker

AVOIDING Aquafailure

Aquaculture diversification and regeneration are needed **to feed the world**

aquafailure [ah-kwuh-feyl-yer]
the inability of aquaculture to produce enough seafood – sustainably or otherwise – to meet demand.

May 2023

CONTENTS

EXECUTIVE SUMMARY

Key takeaways

- A high **concentration** in species and geographic distribution increasingly characterises the current **aquaculture** sector.
- This leaves aquaculture companies vulnerable to the **biodiversity risks** they contribute to, leading to mounting financial losses, coastal conflicts, and regulatory scrutiny, **capping growth potential in the industry**.
- Without change, **aquaculture will fail to meet the world's growing demand** for seafood. Demand is expected to outstrip supply by 50 million tonnes by 2050, with worsening environmental impacts. This is 'aquafailure'.
- **Technology** (offshore, land-based or cultivated seafood) can help but **will not close this future demand gap** on its own, nor fully solve the sector's environmental issues.
- Instead, diversification away from fed aquaculture towards **regenerative aquaculture** for bivalves and seaweed can supply demand while benefitting biodiversity, but it requires capital investment.
- At least USD 55 billion in capital expenditures is needed to finance this regenerative transition, but our analysis of **57 listed aquaculture companies** reveals they generally **cannot afford to self-finance** it. External capital is therefore needed to avoid aquafailure.

DIVERSIFICATION away from fed aquaculture towards **regenerative** aquaculture for **bivalves** and **seaweed** can supply demand while **BENEFITTING BIODIVERSITY**, but it requires **capital** investment.

Why **Investors** and **Lenders** need to **PREVENT** ‘Aquafailure’

It was supposed to be a **REMEDY…**

Land and sea use change is the leading driver of biodiversity loss globally.[i] By now investors should know well how converting natural habitats on land to expand the production of monocultures, such as rainforest to cattle ranges, depletes biodiversity.

A similar trend affects the oceans with monoculture fish production, but this issue has not yet received the same level of investor attention.

As wild fish populations become increasingly exploited, aquaculture has developed to such an extent that it now generates more seafood than fishing. Aquaculture production, however, doesn’t replicate the extraordinary species and geographical diversity of wild marine ecosystems: it has concentrated on just a few species in a handful of geographic locations – see Table 1.

You can explore the species concentration issue in detail via our interactive dashboard.

Table 1: Relative concentration of the top 10 aquaculture producers 2019, ranked by decreasing production.[ii]

Country	China	Indonesia	India	Viet Nam	Bangladesh	South Korea	Philippines	Egypt	Norway	Chile
Total volume (million tonnes)	68.42	15.89	7.80	4.46	2.49	2.41	2.36	1.64	1.45	1.41
Number of species	89	46	30	27	31	71	32	19	16	26
Species concentration index (%)[1, 2]	5.9	**39.9**	21.6	19.0	9.7	20.1	**40.4**	**46.3**	**88.5**	**34.6**
Key species	Seaweed, Carp, Oysters, Whiteleg Shrimp	Seaweed, Tilapia, Milkfish, Whiteleg Shrimp	Catla, Carp, Whiteleg Shrimp	Catfish, Tiger Prawn, Whiteleg Shrimp, miscell-anous freshwater fish	Carp, Roho, Tilapia, Catfish	Kelp, Wakame, Laver (Nori), Oysters	Elkhorn sea moss, Tilapia, Milkfish	Tilapia, Mullets, Cyprinids	Atlantic Salmon, Rainbow Trout	Atlantic Salmon, Coho Salmon, Rainbow Trout, Chilean Mussel

[1] A figure calculated by squaring the share of each species – shown as a percentage - present in a given volume of national production and then summing the resulting numbers (max: 100).

[2] We consider a country with a species concentration index above 25% to have a highly concentrated aquaculture industry.

Left unchanged, aquaculture cannot feed the world, sustainably or otherwise

The increasing concentration of species not only makes the aquaculture industry more vulnerable, it perpetuates the biodiversity risks that cause this vulnerability. Some of the leading sources of biodiversity risks associated with the aquaculture industry are disease, nutrient pollution, non-native fish species escapes, etc. These issues are, for instance, very apparent in the Chilean salmon industry and the Thai shrimp industry. In both cases, concentration-related issues have led to material biodiversity impacts and financial losses for the industry.

Amidst a strong increase in competing claims for use of coastal space, new regulations restrict the expansion of unsustainable aquaculture. This caps the growth of the aquaculture industry. We forecast that **business-as-usual aquaculture will fail to produce enough seafood to meet the rising demand for seafood by 2050**. Yet, it will still harm the environment. **In terms of both commercial and environmental impacts, this is 'aquafailure'**[3] – see Figure 1.

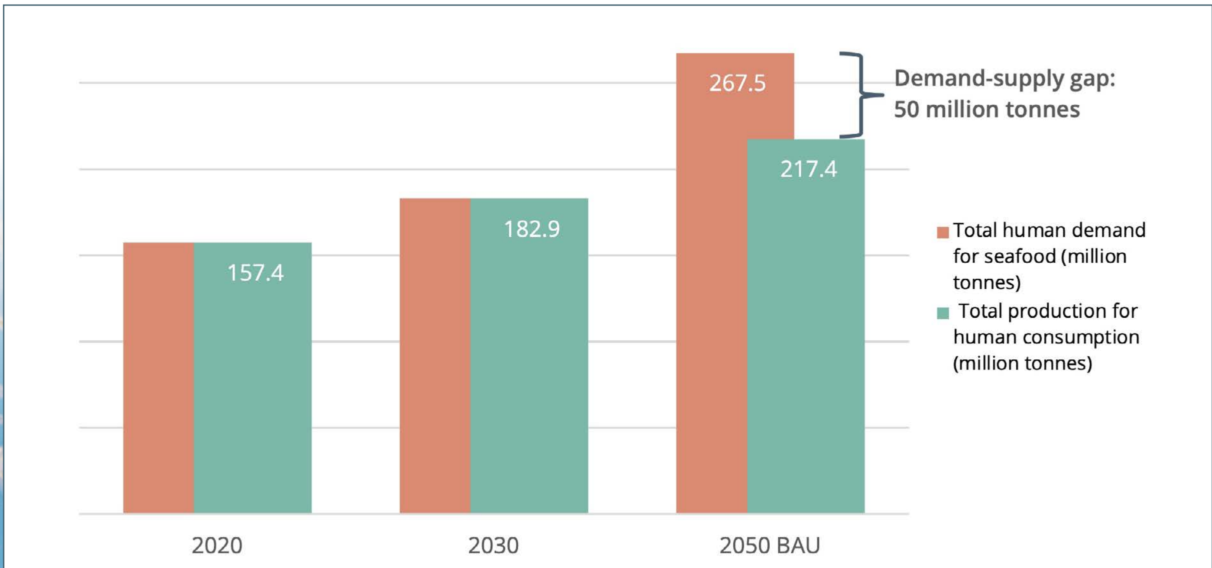

Figure 1: 'Aquafailure': towards a 50 million tonnes seafood demand gap in 2050 (live weight equivalent, in million tonnes).

[3] See 2050 seafood demand-supply gap estimation in Box 2, on page 19.

A technological solution will help but won't suffice

As with many environmental issues, the industry will likely attempt to apply a technological solution to mitigate this crisis.

Far from the coasts and waterways where 'conventional' aquaculture is sited, new aquaculture sites are being developed at sea through **offshore aquaculture**, on land through recirculating aquaculture systems (**RAS**)[4] and in labs as **cultivated seafood**. All three innovative practices will at least slightly reduce biodiversity risks and sometimes reduce concentration risks, although they typically do not reduce species concentration.

With added investments in capital expenditures totalling at least USD 30 billion, we calculate that these technological responses can together contribute 4.6 million tonnes of seafood by 2050, or about 2% of the total anticipated seafood demand. This still leaves a shortfall of 45.3 million tonnes to meet the rising demand.

Keep clam and eat mussels

To close the gap of 45.3 million tonnes, change is necessary. Since feed is by far the largest cost in aquaculture production, another solution is to concentrate on expanding the production of seafood that does not require feed. **Bivalves** (e.g.; mussels, oysters, clams, etc.) and **seaweed** are two prominent examples of non-fed aquaculture. In many cases, their production can even contribute to **regenerating ecosystems**, through the natural ecosystem services they provide like water filtering, carbon sequestration and habitat provision. These forms of regenerative aquaculture are positioned to produce an additional 45 million tonnes of seafood capable of feeding a global population of 9.7 billion – see Figure 2.

[4] Recirculating Aquaculture Systems, a technology that allows for recycling most of the fresh water used in land-based farming, see page 26.

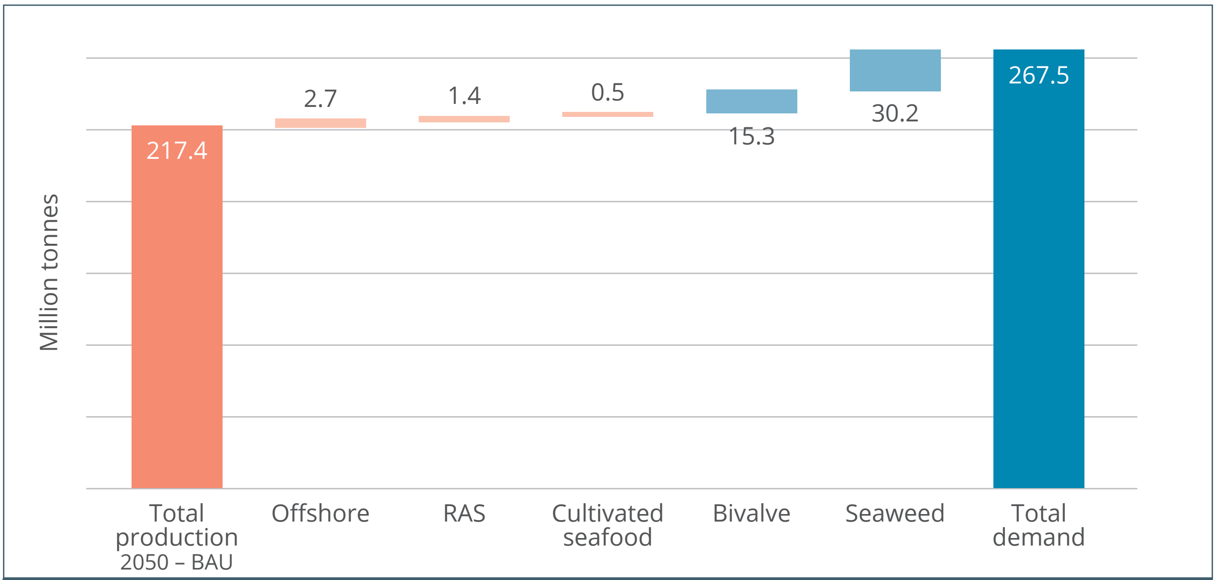

Figure 2: Closing the seafood demand gap in 2050 through technological progress (pale orange) and regenerative aquaculture (pale blue), estimated by Planet Tracker (million tonnes).

Producing more of this regenerative seafood is not without challenges like shifting consumer perceptions and industry fragmentation, but the start-up **investments are relatively cheap and there are significant opportunities for development**.

The potential for seaweed and bivalve production is so high, we forecast it can close the seafood demand gap anticipated in 2050, provided capital expenditure investments of at least USD 25 billion can be deployed – see Figure 3.

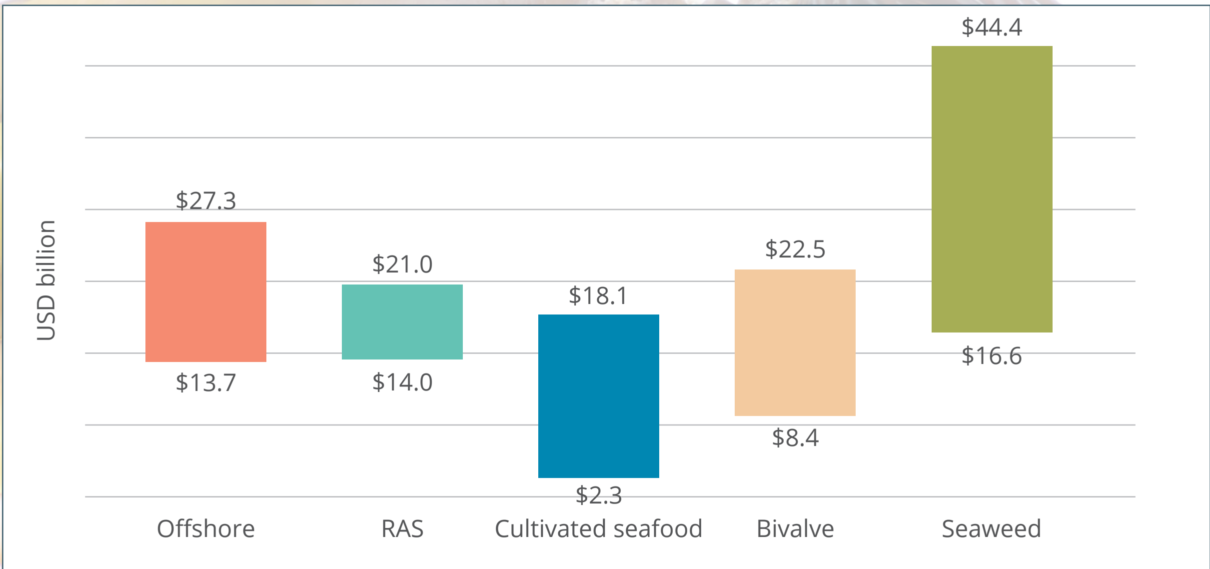

Figure 3: Estimated minimum and maximum capex costs by 2050 to finance the seafood demand gap by source, estimated by Planet Tracker (USD billion).

On their own, publicly listed aquaculture companies cannot finance this transition

Our analysis of **57 publicly listed aquaculture companies** suggests the aquaculture sector **cannot self-finance**[5] either technological solutions to conventional aquaculture or regenerative aquaculture, which will together cost at least USD 55 billion.

It is therefore crucial that investors and lenders finance technological and regenerative aquaculture solutions to simultaneously avoid the significantly widening gap between supply and demand for seafood, whilst improving the sustainability of the industry.

[5] i.e., fund it only with their own cash-flows or reserves

the sector cannot **self finance** **TECHNOLOGICAL SOLUTIONS** to conventional aquaculture or **regenerative aquaculture** which will together **COST** at least USD **55 billion**

AQUACULTURE HAS WORSENING CONCENTRATION RISKS

- In 2020, the top 10 aquaculture producing countries by volume accounted for 89% of total production, with China alone accounting for 57%.
- Species concentration is also high for aquaculture – much higher than for wild-catch – and it has been increasing. Over 75% of the 57 listed aquaculture companies we identified farm salmon, shrimp or pangasius.
- Key aquaculture markets where species concentration is high include Norway, Indonesia, the Philippines, Egypt and Chile.

High geographic concentration for aquaculture production

Between 2000 and 2020, global wild-catch and aquaculture production grew by 41% from 126 million tonnes to 178 million tonnes. While wild-catch production declined by 4%, aquaculture production increased significantly by 171%.

The global production of seafood has been highly concentrated among major producing countries. In 2020, the top 10 seafood-producing countries accounted for 70% of total production, with China (35.4% of the total) accounting for more than the next nine countries combined (34.4% of the total) as the largest market – see Figure 4.[iii]

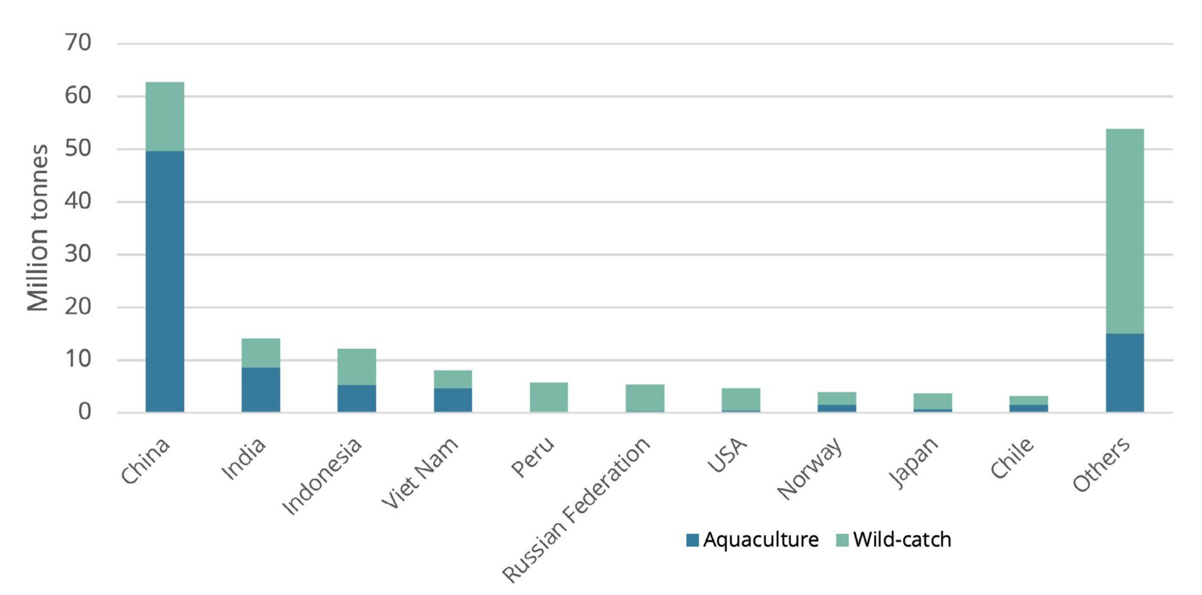

Figure 4: Total fisheries and aquaculture production (excluding seaweed) of the top 10 countries for seafood production in 2020. Source: FAO, 2022.

Aquaculture production is more concentrated than wild-catch. In 2020, the top 10 aquaculture producers by volume accounted for 88% of total aquatic animal production. China alone produced 56.7% of the global aquatic animals and 59.5% of algal production – see Figure 5.

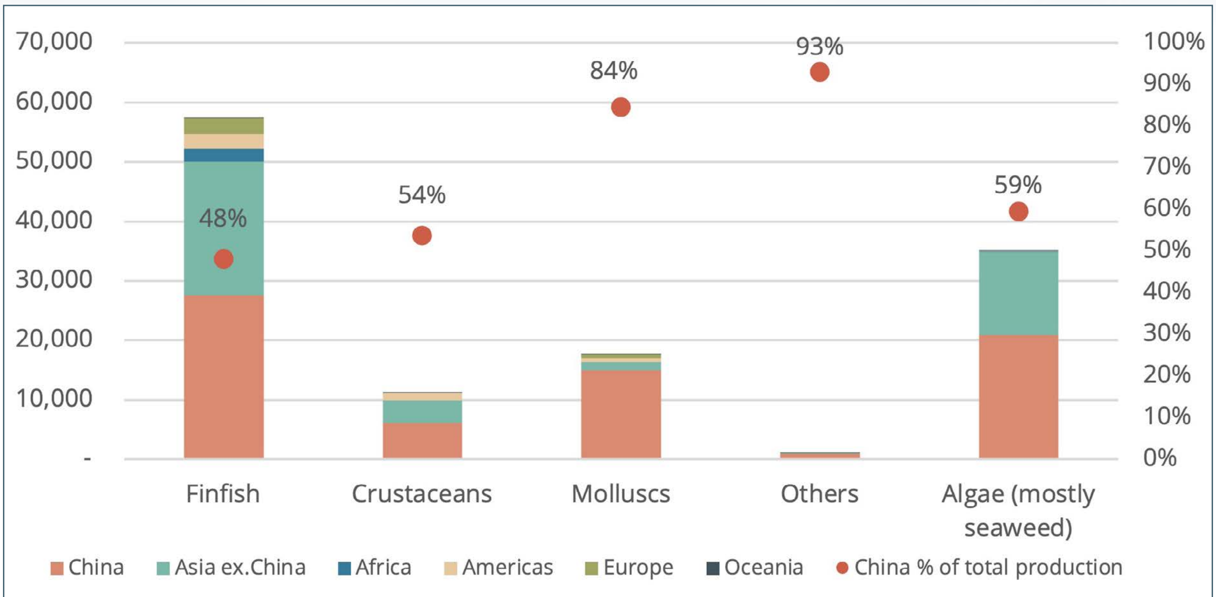

Figure 5: Aquaculture production of main species groups by continent in 2020 ('000 tonnes). Source: FAO, 2022.

China has been both the largest producer and consumer of aquaculture production since 1991. In 2019, the five largest consuming countries – China, Indonesia, India, USA and Japan – consumed 59% of the total aquatic foods available for food consumption worldwide. China alone accounted for 36%.[iv] The Food and Agriculture Organization (FAO) projects that China will continue to play a key role in the aquaculture industry between now and 2050.

Aquaculture or Monoculture? High Species Concentration for Farmed Seafood

Aquaculture production concentrates on fewer animal species than wild-catch fisheries. Whilst the top 20 named wild-catch species account for 32.4% of total wild-catch production,[v] the top 20 named farmed species account for 70.5% of total aquaculture production.

Aquaculture production is mostly centred on carp, shrimp, salmon and bivalves such as oysters, mussels and scallops – see Table 2.

Table 2: Aquaculture production by species in 2020. Source: FAO, 2022.

Rank	Name	ISSCAAP1 Group of species	Volume (mt)	% of total 2020
1	Whiteleg shrimp	Shrimp, prawns	5.8	6.64%
2	Grass carp	Carp, barbels and other cyprinids	5.8	6.62%
3	Cupped oysters	Oysters	5.5	6.23%
4	Silver carp	Carp, barbels and other cyprinids	4.9	5.60%
5	Nile tilapia	Tilapia and other cichlids	4.4	5.04%
6	Japanese carpet shell	Clams, cockles, arkshells	4.3	4.88%
7	Common carp	Carp, barbels and other cyprinids	4.2	4.84%
8	Catla, Catla catla	Carp, barbels and other cyprinids	3.5	4.05%
9	Bighead carp	Carp, barbels and other cyprinids	3.2	3.64%
10	Carassius spp.	Carp, barbels and other cyprinids	2.7	3.14%
11	Atlantic salmon	Salmon, trout, smelts	2.7	3.11%
12	Striped catfish	Miscellaneous freshwater fishes	2.5	2.88%
13	Roho labeo	Carp, barbels and other cyprinids	2.5	2.84%
14	Red swamp crawfish	Freshwater crustaceans	2.5	2.82%
15	Scallops nei	Scallops, pectens	1.7	2.00%
16	Clarias catfishes	Miscellaneous freshwater fishes	1.2	1.43%
17	Milkfish	Miscellaneous diadromous fishes	1.2	1.33%
18	Sea mussels	Mussels	1.1	1.27%
19	Tilapias nei	Tilapia and other cichlids	1.1	1.22%
20	Constricted tagelus	Clams, cockles, arkshells	0.9	0.98%
Top 20 species			61.7	70.5%
Total			87.5	100%

High species concentration of farmed seafood is not new but has slightly intensified. Figure 6 depicts the concentration change of aquaculture production within each species category over the past two decades, highlighting the change in share of production for the top species within each group.

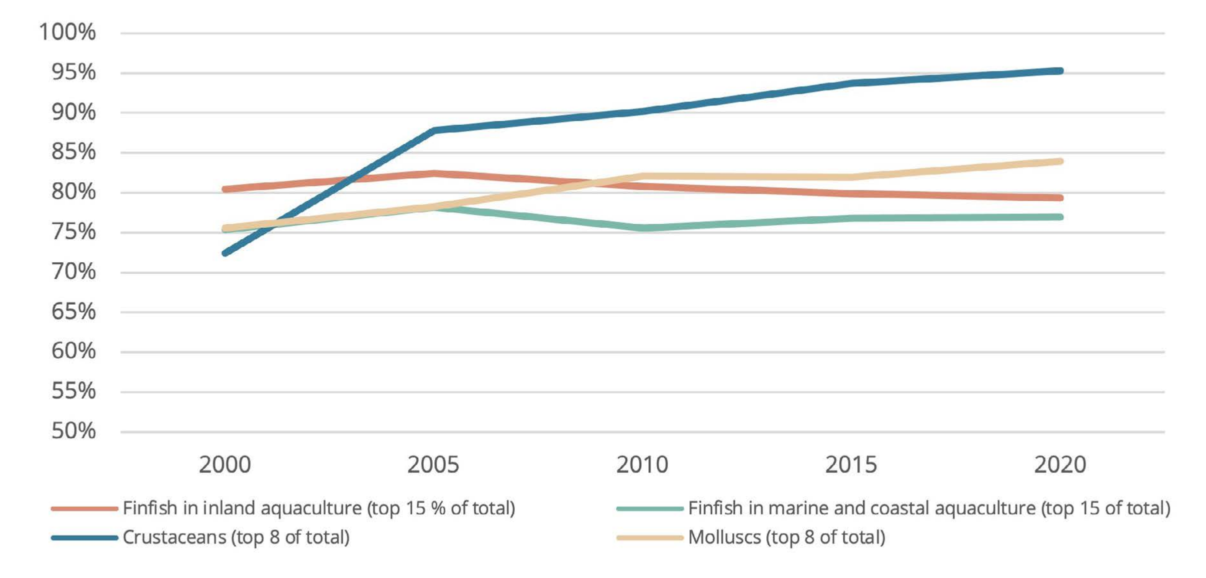

Figure 6: Concentration of aquaculture production by species (aggregated volume share of top 8 or 15 species). Source: FAO, 2022.

Identify species concentration risk with our interactive dashboard

Understanding the extent to which aquaculture production focuses on a few key species can provide us with insights into the future of production and sustainability. We therefore investigated the concentration of production in the top 10 aquaculture countries by species. We computed a species concentration index for each country, as shown in Table 3, following the methodology described in Box 1 below. You can access more details via our interactive dashboard.

Box 1: Determining species concentration risk for aquaculture producing nations

- We identified all farmed species with global production of over 10,000 tonnes in 2020 and deemed production below this level applicable only for niche markets. Using this method, we captured at least 96% of the total national production in every case.
- We calculated the species concentration index by squaring the share of each species – shown as a percentage – present in a given volume of national production and then summing the resulting numbers. This calculation derives from the Herfindahl-Hirschman Index (HHI)[6]. The maximum potential value is 100%, which would indicate that only one species is cultivated. The lower the index, the less concentrated a market is.
- The simple average for the top 50 countries representing 99.3% of global production was 39% and the median value was 30.5%.
- Typically, any industry with an HHI above 25% is considered to be highly concentrated. Using the same threshold, aquaculture markets where species concentration is high are Norway, Indonesia, the Philippines, Egypt and Chile.

Table 3: Relative concentration of the top 10 aquaculture producers 2019, ranked by decreasing production.[vi]

Country	China	Indonesia	India	Viet Nam	Bangladesh	South Korea	Philippines	Egypt	Norway	Chile
Total volume (million tonnes)	68.42	15.89	7.80	4.46	2.49	2.41	2.36	1.64	1.45	1.41
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[6] The Herfindahl-Hirschman Index (HHI) is a common measure of market concentration and is used to determine market competitiveness, often pre- and post-M&A transactions.

[7] A country with a species concentration index above 25% is designated a highly concentrated industry.

CONCENTRATED FISH MONOCULTURE IS VULNERABLE TO BIODIVERSITY AND WATER RISKS, AND COASTAL CONFLICT

- Amid a strong rise in competing claims for use of coastal space, regulation is coming on board to restrict the expansion of unsustainable aquaculture.
- Freshwater aquaculture is not immune to natural capital risks: water scarcity is a key issue.

Concentrated monoculture leads to financially material biodiversity loss

Research on the Chilean salmon industry and the Thai shrimp industry demonstrates how concentration-related issues have led to marine stock losses and/or the spread of disease which have resulted in financial losses material to the industry.

See **Appendix 2: Unsustainable Fish Monoculture Leads to Financially Material Biodiversity Loss: Lessons from Chile** and **Appendix 3: Concentrated Fish Monoculture Leads to Financially Material Diseases: Lessons from Thailand** for more details.

Unsustainable aquaculture is vulnerable to coastal conflict and regulation

These two case studies show how the concentration of aquaculture production exacerbates its vulnerability to biodiversity risk. This might make **aquaculture less attractive than other competing ocean-based activities** in the eyes of governments or regulators.

Indeed, areas suitable for aquaculture often overlap with rich fishing areas, shipping lanes or viable renewable energy areas, so it is likely for investors and other stakeholders to have conflicting plans or agendas for the areas. There can also be overlap between protected areas and the regions used for aquaculture production. In Chile, for instance, 30% of the total 1,407 salmon-farming concessions lie within protected marine areas.[vii]

In November 2022, the Taskforce on Nature-related Financial Disclosures (TNFD) released the third version of its nature-related risk management and disclosure beta framework. It features a short report illustrating how a hypothetical report preparer in Chile might apply the TNFD beta framework to aquaculture production. It demonstrates how TNFD disclosure can help institutional investors gain insights into the risk mitigation and business activities of aquaculture companies which could help investors assess and prioritize nature-positive investments.

As environmental and ecological concerns related to fish farming become more widely known, we expect aquaculture activities to receive greater scrutiny from both the private and public sectors.

Heightened regulatory scrutiny will also cap growth

Existing examples suggest that regulations can limit the growth of conventional aquaculture, as regulators restrict the industry's expansion.

- In the **UK**, The Trossachs National Park Authority rejected plans for a new fish farm in the park in October 2022, after it deemed the potential **escape of farmed fish** at the site 'a significant concern'.[viii]
- In **Argentina**, government officials in the southernmost province of Tierra del Fuego unanimously approved a **bill prohibiting salmon farming** in July 2021, citing the risk to native biodiversity.[ix]
- In **Canada**, a similar decision took place in 2020, in which **regulators committed to phasing out salmon aquaculture** due to its negative environmental impacts and moving to closed systems.[x]
- In **Norway**, the government has proposed introducing a new **40% 'resource rent' tax** on the country's large trout and salmon producers (those with production volumes above 5,000 tonnes), subject to the approval of the Norwegian Parliament. The announcement of the proposal caused the share prices of the leading publicly listed salmon corporations – SalMar, Mowi and Leroy Seafood – to plummet.

See **Appendix 4: Concentrated Fish Monoculture is Also Vulnerable to Rising Ocean Coastal Conflict** for more details.

Freshwater aquaculture is vulnerable to water scarcity

Freshwater aquaculture excluding algae represents 62% of aquaculture production[xi] and the industry is expected to grow to 2050 as its products are considered part of a sustainable diet.[xii]

Yet, freshwater fish farming is sensitive to a wide range of threats including biochemical, climatic and physical constraints caused by unsustainable agricultural practices, water extraction volumes and anthropogenic pollution – see Table 4.

For example, a recent drought in Thailand caused the closure of 200 fish farms due to the lack of available water resources, while flooding has destroyed pond farms.[xiii] This shows that freshwater aquaculture is vulnerable to the natural capital risks it often exacerbates, such as water risks.

Table 4: Variables used in the threat assessment for inland fisheries. Source: FAO.[xiv]	
Major threat	**Sub indicators**
Population-related	Population density; gross domestic product; road accessibility
Loss of connectivity	Dams; barrages, weirs, dykes and other barriers; channelization; dredging
Land use	Deforestation, land degradation; mining; sedimentation; nitrogen runoff; phosphorous runoff, agricultural land use
Climate variability	Temperature increase/decrease/variability; precipitation increase/decrease/ variability; predicted extreme climate events
Water use	Irrigation, agriculture; industry; urban and human consumption
Pollution	Pesticides, other chemical runoff; plastics, pharmaceuticals, other pollution; aquaculture effluents; urban sewage

The FAO in 2020 published a threat assessment map for inland fisheries, applicable for freshwater aquaculture sustainability, which assesses the severity of several threat indicators.[xv] Key areas of current and projected freshwater aquaculture production take place in mid- to high-risk areas – see Figure 7.

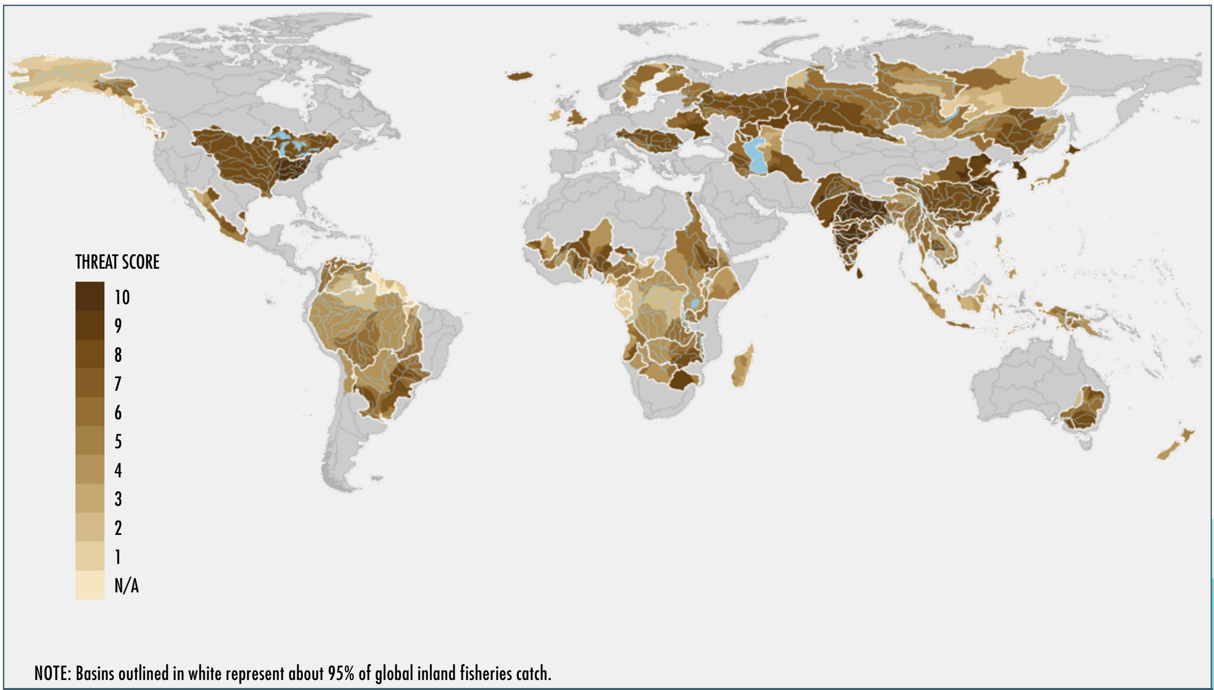


Figure 7: Global 'Status Map' based on the interaction of 20 pressures at basin level for the 34 indicative basins that support inland fisheries. Source: FAO, 2020.[xvi]

Increasing water scarcity for freshwater aquaculture means increasing volatility in production due to the following impacts: a greater level of nitrogen, phosphorus, pesticide or other chemical runoff, aquaculture effluent concentration and urban sewage. Water scarcity leads to slower growth and production losses.

It may also lead to an increase in the cost of fishing licences, as competition for freshwater use and abstraction intensifies.

Water is also a limiting factor for mariculture (marine aquaculture): while freshwater aquaculture consumes freshwater water supplies by requiring long term storage in ponds and sequestering it from other uses, mariculture open pen systems compete for water resources. For example, water flowing through seabass cages carries away waste, pollutants, pests and bacteria while supplying oxygen. This oxygen cannot be used by wild populations and, as studies have shown, reusing degraded waters in farms can increase stress levels in animals, making them more susceptible to bacterial and viral diseases. This must also be true for the wild populations surrounding aquaculture farms. The result of this 'fresh' water requirement in mariculture means that the water dependence of seabass is a thousand times larger than trout in a flow-through open freshwater system.[xvii]

Overall, both marine aquaculture and freshwater aquaculture are vulnerable to the natural capital risks they often exacerbate, such as water risks. These risks could receive heightened regulatory scrutiny leading to capped growth amidst competing investment interests. Given these challenges, will aquaculture still be able to feed the world?

BUSINESS-AS-USUAL AQUACULTURE UNABLE TO FEED THE WORLD IN 2050

- Due to overexploitation and climate change, long-term scenarios project wild-catch stagnation in a Business-As-Usual (BAU) scenario.
- A BAU scenario for aquaculture production creates a forecasted global seafood supply gap of 50 million tonnes compared to our estimates of global seafood demand in 2050.

Capped wild-catch production leaves aquaculture alone to feed an increase in seafood demand

Wild-catch production is expected to remain relatively flat into 2050, as the overexploitation of wild-catch fish stocks and the effects of climate change limit its growth.

Appendix 4: Why Wild-Catch Seafood Production Is Capped details why this is the case.

In contrast, aquaculture production is expected to continue to grow at an average annual rate of 1.6% from 2020 to 2050 – see Table 5.

Table 5: Projections of wild capture and aquaculture production by 2050 (live weight equivalent reflected in million tonnes unless otherwise specified). Source: FAO,2022.

	2019	2020	2030e	2050e business-as-usual
Aquaculture, aquatic animals (business-as-usual)	85.2	87.5	106.4	140
Wild-catch	92.2	90.3	95.7	98.3
Total fisheries and aquaculture production...	177.4	177.8	202.1	238.3
...of which for human consumption	158.1	157.4	182.9	217.4

In a Business-As-Usual (BAU) scenario, which is considered as most plausible by the FAO, the total production from fisheries and aquaculture is expected to reach 238.3 million tonnes by 2050.

Will that be enough to meet the growing demand for seafood?

We expect seafood consumption per capita to reach 27.5kg in 2050

Over the past three decades, global annual per capita consumption of aquatic foods grew from an average of 14.4kg in the 1970s to 20.2kg in 2020 with a record high of 20.5kg in 2019.[xviii]

By extending the short-term fish demand and supply projection work by the Food and Agriculture Organization (FAO) to 2050,[xix] Planet Tracker modelled global seafood consumption from 2020 to 2050 by integrating the main drivers of seafood demand: income growth, fish price and population growth as projected by the United Nations (UN).

Our **estimate shows the global consumption per capita of seafood will grow to 27.5kg per capita per annum** and the total worldwide demand for seafood for human consumption would reach 267.5 million tonnes for a total production of 294 million tonnes of live weight equivalent with the global population reaching 9.7 billion by 2050.

Box 2: Forecasting Human Demand for Seafood by 2050

- We conducted a time-series regression to estimate the impacts of income growth, adjusted for purchasing power parity (PPP), on per capita fish consumption using the historical data from 1990 to 2020.

$$\ln(C_{it}) = \alpha + \beta \ln(Y_{it}) + u_i + e_{it}$$

Where:

C denotes seafood consumption per capita

Y denotes income per capita, the global GDP per capita is used as a proxy

u_i denotes the random error item

e_{it} denotes the autoregressive error item that captures general shocks

- The estimated income elasticity coefficient, which is 0.64, is then used to estimate the per capita fish demand growth driven by the income growth by 2050 at the global level.
- The global population is projected to reach 9.735 billion by the United Nations by 2050.
- According to OECD Economic Outlook[8], the Gross Domestic Product (GDP), at constant 2015 PPP value is estimated at USD 205,428,660 million by 2050.
- Applying the global population projection, the GDP per capita by 2050 is estimated at USD 21,178 vs. the 2020 GDP per capita (adjusted for PPP) which was USD 12,992.

$$C_{future} = C_{benchmark} \times (Y_{future} / Y_{benchmark})^\beta$$

- Taking the seafood consumption per capita of 20.2 kg in 2020 as the benchmark consumption, 2020 GDP per capita USD 12,992 (adjusted for PPP) as the benchmark income, Planet Tracker estimates global seafood consumption demand to be 27.5 kg per capita per year.

[8] See "Long-term baseline projections," No. 109 (Edition 2021), OECD Economic Outlook: Statistics and Projections. (OECD database, 2022)

Seafood production unable to satisfy demand by 2050 in a business-as-usual scenario

Based on our forecasting model, we predict seafood demand to total 267 million tonnes in 2050, 50 million tonnes in excess of the 217.4 million tonnes expected to be produced for human consumption. This estimate uses UN population estimates.

In other words, a business-as-usual scenario could create a **seafood supply and demand gap of 50 million tonnes by 2050** – see Table 6.

Table 6: Estimating seafood demand and supply in 2050 (live weight equivalent reflected in million tonnes unless otherwise specified).

	2019	2020	2030e	2050e business-as-usual	Source
Population (global, million)	7,684	7,795	8,548	9,735	United Nations
Per capita consumption (kg/year)	20.5	20.2	21.4	27.5	FAO (2022), OECD-FAO[9], Planet Tracker
Total demand for seafood	**158.1**	**157.4**	**182.9**	**267.5**	Planet Tracker
Aquaculture, aquatic animals (business-as-usual)	85.2	87.5	106.4	140	FAO (2022), OECD-FAO
Wild-catch	92.2	90.3	95.7	98.3	FAO (2022), OECD-FAO
Total fisheries and aquaculture production...	177.4	177.8	202.1	238.3	FAO (2022), OECD-FAO
...of which for human consumption	**158.1**	**157.4**	**182.9**	**217.4**	FAO (2022), OECD-FAO
Demand-supply gap	0	0	0	**50.1**	Planet Tracker

Should unsustainable practices continue, which will result in a deterioration in many new ventures and limited growth of aquaculture, total production would increase by only 19 million tonnes from 2020 as per the FAO, leading to an even bigger supply gap of 87.5 million tonnes.

On the other hand, 269 million tonnes of total production would theoretically be possible through innovative and intensive aquaculture development and ambitious, effective management of all capture fisheries across the world. This is what the Food and Agriculture Organization (FAO) calls a 'high-road' growth scenario. Yet it would still leave a 19.8 million tonnes gap based on our estimates.

Given these estimates, even in a best-case scenario for aquaculture production, a supply gap still remains. This suggests there is a need for alternative production methods. Our research suggests that both technological and regenerative solutions can and should play a role in addressing this gap.

...could create a **seafood SUPPLY** and **DEMAND gap** of **50 million tonnes** by **2050**

[9] OECD-FAO Agricultural Outlook. 2021–2030.

TECHNOLOGY ALONE CANNOT PREVENT AQUAFAILURE

- Technologically enhanced alternatives to conventional aquaculture include at-sea (offshore aquaculture), inland (through recirculating aquaculture systems i.e., RAS aquaculture) or in-lab (cultivated seafood) production methods.
- All three can at least slightly reduce biodiversity risks and in some cases reduce geographic concentration risks, although typically not species concentration.
- We estimate these technological solutions can together contribute 4.6 million tonnes of seafood by 2050, or about 2% of total seafood demand, provided investments in capital expenditures total at least USD 30 billion can be achieved.

The Food and Agriculture Organization (FAO) 'high-road' growth scenario predicts that aquaculture production could result in 20.5 million tonnes more seafood in 2050 compared to business-as-usual production, reaching 160.3 million tonnes. **To achieve this high-road scenario, significant innovative technology and sustainability are needed**. Here we discuss the most promising technological solutions for bridging the supply and demand gap.

Offshore aquaculture and land-based recirculating aquaculture systems (RAS) are potentially transformative as they are designed to address (but not necessarily solve) the most significant issues that have been capping industry growth: biodiversity risk, coastal area usage conflicts and challenges of water security, as previously mentioned.

Offshore aquaculture: high capital, high risks, high value species

Offshore aquaculture means moving fish farms further to the offshore zone, to more exposed locations. Limited space at the coastline for conventional aquaculture (partly due to geographical concentration) has been the main driver for offshore aquaculture development: the new technology can access additional sea area and creates the potential to scale up production capacity – see Figure 8.

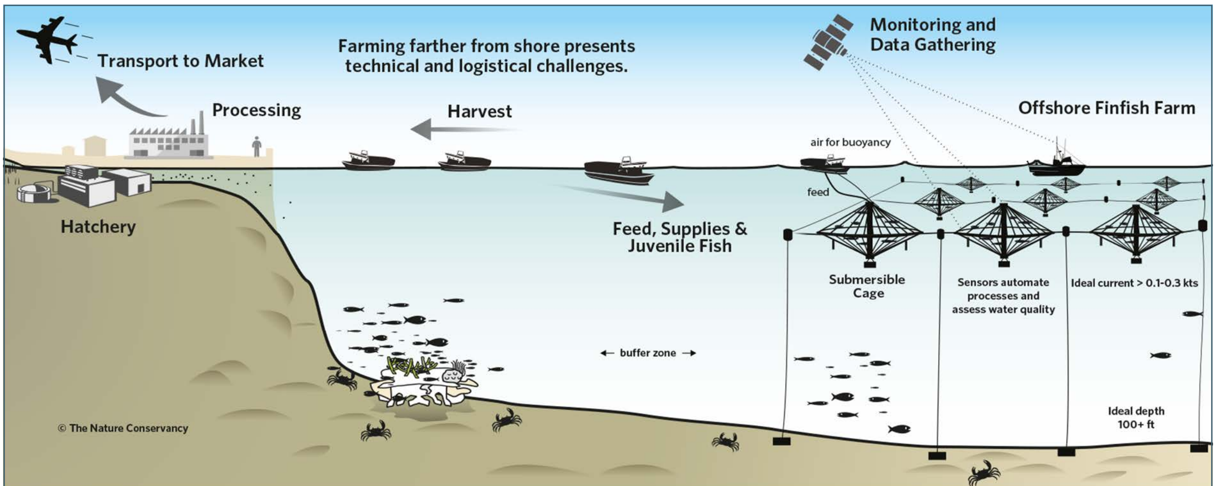


Figure 8: A visual representation of offshore finfish aquaculture. Source: O'Shea et al, 2019.[xx]

Pros and cons of offshore aquaculture

Offshore aquaculture can improve water quality, reduce disease infestation and enhance food quality, making it an attractive proposition. But offshore aquaculture is at an early stage of development, and it requires substantial investment in research and development and a regulatory environment that provides support and stringent requirements for adopting the technology.

Table 7 summarises the environmental and economic pros and cons of offshore aquaculture.

Table 7: Drivers, pros and cons of offshore aquaculture. Source: O'Shea et al., 2019.

Drivers	
• Regulatory constraints on conventional nearshore site expansion	
• Coastal conflicts with other users	
• Environmental sustainability	
Pros	**Cons**
Improved water quality: features fast currents and flow, wave action, greater water cycling and isolation from coastal runoff and pollution.	**High capital costs**: requires more durable and expensive structures, and higher operating costs arise from fuel use.
Better disease and parasite control: greater separation between farms, potentially limits the spread of disease.	**Escape risk**: escape due to rough weather in the open ocean is possible, but we have not been able to find data indicating that escape risk is higher/lower for offshore aquaculture compared to conventional aquaculture.
Reduced mortality: reduces the threat of catastrophic events like algal blooms due to water quality improvements.	**Unclear regulation**: has a high level of licensing and regulation uncertainty in the development phase, regulation has to be designed differently in various areas and regulations could varies greatly depending on the jurisdiction.
Improved feed conversion ratio: allows fish to grow faster and convert feed to biomass more efficiently due to better growing conditions.	
Improved product quality: animals experience lower stress and reduced exposure to pathogens and parasites.	
Optimised location: enables production facilities to be sited close to major markets, reducing air freight costs and greenhouse gas emissions.	
Reduced coastal conflicts: could reduce regulatory risk and conflicts with other users with an abundance of offshore sites.	
Lower impacts to the seafloor and habitats: reduces disturbance of ecosystems.	
Discussion / Comments	
Price premium to offset higher costs: Offshore aquaculture could become cost competitive if/when higher product quality leads to higher market prices to offset higher input costs.	
Lower cost per unit: Greater economies of scale, higher stocking densities and innovation lower the cost.	
Supportive regulation expected: In Norway, free development concessions are available for up to 15 years for projects promoting technology that can solve the environmental and acreage challenges facing the aquaculture sector, including offshore projects[10].	

[10] Norwegian Ministry of Fisheries and Coastal Affairs.

The high operational complexity, capital requirements and risks associated with offshore aquaculture mean that few examples of large-scale production exist today.

The Norwegian salmon industry has been an early adopter of the offshore technology and has the world's leading projects both in operation and under development.

Most pilot projects are operated by subsidiaries of publicly listed salmon giants, which are backed by expertise in offshore oil and gas or renewable energy – see Table 8.

Table 8: Pioneering offshore projects as of December 2022. Source: O'Shea et al., Pareto Securities, Planet Tracker.[xxi]

Project	Country	Species	Operator	Description
Ocean Farm 1	Norway	Salmon	SalMar, Aker	In operation, semi-submerged, annual production capacity of 6,000 tonnes
Smart Fish Farm	Norway	Salmon		Permit acquired in August 2022 designed annual capacity of 23,000 tonnes of salmon
Hafarm 1	Norway	Salmon	Nordlaks	Largest semi-submerged structure, permit acquired in 2022, designed capacity of 10,000 tonnes of salmon
Arctic Offshore Farm	Norway	Salmon	Norway Royal Salmon	Manufacturing, fully submerged, designed capacity of 1.2 million salmon
Shenlan 1	China	Salmon	Shandong Marine Group, Wanzefeng Group, Qingdao Ocean Investment Group	In operation, fully submerged, first harvest of 15,000 salmon in 2022
Shenlan 2	China	Salmon		Manufacturing, designed capacity of 1 million tonnes of salmon
Haixia 1	China	Large yellow croaker	China COSCO Shipping Co., Ltd.	In operation, semi-submersible, designed capacity of 2,000 tonnes of large yellow croaker

China is next in line to expand its offshore aquaculture industry, due to its congested coastline. Having developed expertise in manufacturing offshore farming systems for Norway's offshore salmon sector, the country is expected to become another significant developer of offshore fin fish farming. In June 2022, Shenlan1 made its first commercial harvest of 15,000 Atlantic salmon from its site off the coast of Qingdao and is growing a total of 100,000 fish.[xxiii]

By 2050, we expect offshore farming to achieve a major presence in Norway and China and gain momentum in emerging regions like the USA, Scotland, Canada, Chile, the Faroe Islands and Australia.[xxiv] This is not to say it will be a smooth journey. For instance:

- In 2019, Mowi decided to shut down its semi-closed offshore salmon farm "Egg" after the company struggled to keep the construction and production costs of the cage down.
- Havfarm 1, the world's largest semi-submerged offshore platform built in 2020, was refused permanent licenses in 2021 by Norway's Directorate of Fisheries. The production permit was finally granted in 2022.
- SalMar's Ocean Farm 1 experienced two escape incidents in 2020 and the fish that escaped were confirmed to have passed Heart and Skeletal Muscle Inflammation (HSMB) disease to an unknown number of fish.

2.7 million tonnes of high-value species expected to be produced offshore by 2050

In 2050, Det Norske Veritas (DNV) estimates suggest 2.7 million tonnes of marine finfish could be produced offshore (13% of the total farmed marine finfish).[xxv] This would be equivalent to 1% of the total seafood demand we forecast for 2050 and an increase in total aquaculture production in a business-as-usual scenario by 1.3%.

The need to amortize substantial fixed costs via economies of scale and higher price premiums means high-tech offshore aquaculture is likely to focus on high-value species.[xxvi]

Analysing offshore suitability, commercial readiness and the market value of species, **Planet Tracker expects offshore aquaculture to primarily produce Atlantic salmon farming globally and warm-water marine species (large yellow croaker, snapper and cobia) in China.**

Among the types of fish produced in conventional aquaculture, finfish is the most suited to offshore aquaculture, as opposed to freshwater species for instance. While in 2020, 22 species made up 75.6% of all finfish species of marine and coastal aquaculture only a few of these are suitable for offshore.

The finfish species with the highest value and quantity in conventional aquaculture is Atlantic salmon, accounting for 32.9% of total marine finfish production in 2020 – see Figure 9.

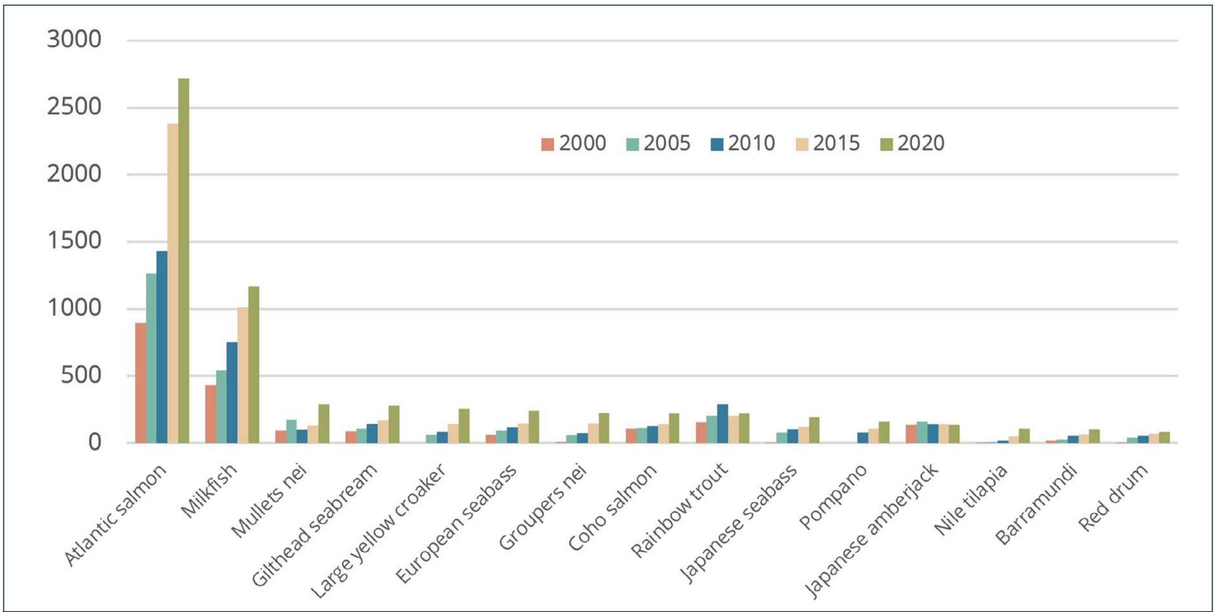


Figure 9: Estimated global production of major marine and coastal aquaculture species, 2000-2020, in thousand tonnes. Source: FAO, 2022.

China, Norway and Chile lead the global marine aquaculture of finfish species.

While Norway and Chile dominate the sea cage culture of cold-water species, particularly Atlantic salmon, China's mariculture mostly focuses on warm-water species with a more diverse composition[xxvii] – see Figure 10.

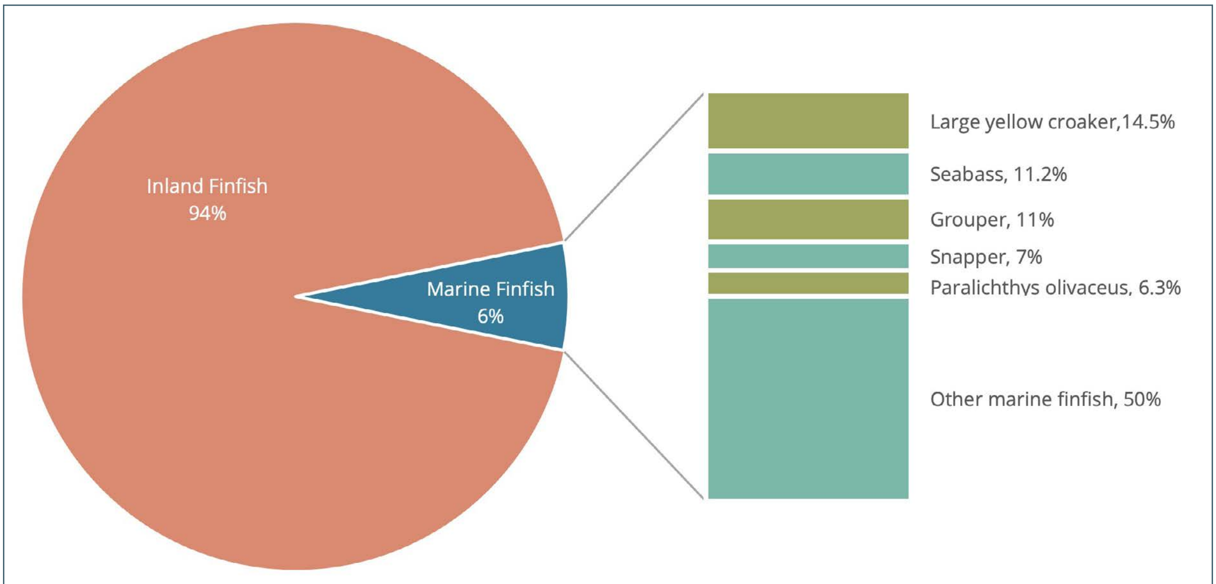


Figure 10: Top 5 marine finfish production in China, 2020. Source: China's Fishery Statistical Yearbook, 2021.

Overall, this means that **offshore aquaculture is unlikely to reduce species concentration** due to the high proportion of Atlantic salmon expected to be produced, but **it could reduce geographic risk at a local level, though it won't reduce country risk**.

USD 14-27 billion in capex required to produce 2.7 million tonnes of seafood offshore in 2050

Offshore aquaculture is capital-intensive. The tough environments of open waters significantly increase the complexity of building resilient cages and thus result in very high construction, operating and maintenance costs. Current capital expenditure investment required for offshore projects falls in the range of USD 8-17/kg for large-scale and high-tech farms.[xxviii]

Approaching 2050, we expect capex/kg to eventually drop down to USD 5-10/kg as the scale increases and best practices from earlier build outs are implemented.

Assuming that a total of 2.7 million tonnes of offshore production takes place in 2050, **the total Capex required for offshore by 2050 is estimated in the range of USD 13.7-27.3 billion**.

Compared to a business-as-usual scenario, that would still leave a gap of 48 million tonnes of seafood in 2050. For this reason, we assess the potential for other technological solutions.

RAS: Recirculating Aquaculture Systems are redoubling on Atlantic salmon

While offshore aquaculture moves fish farms to offshore locations, recirculating aquaculture systems (RAS) move the aquaculture process onshore.

RAS is essentially a technology for farming aquatic organisms by reusing water through continuous recirculation. The recirculation rate of RAS is typically higher than 95%. The water in this process flows from the outlet of the fish tanks to a mechanical filter followed by a biological filter before it is aerated and stripped of carbon dioxide then returned to the fish tanks[xxix] – see Figure 11.

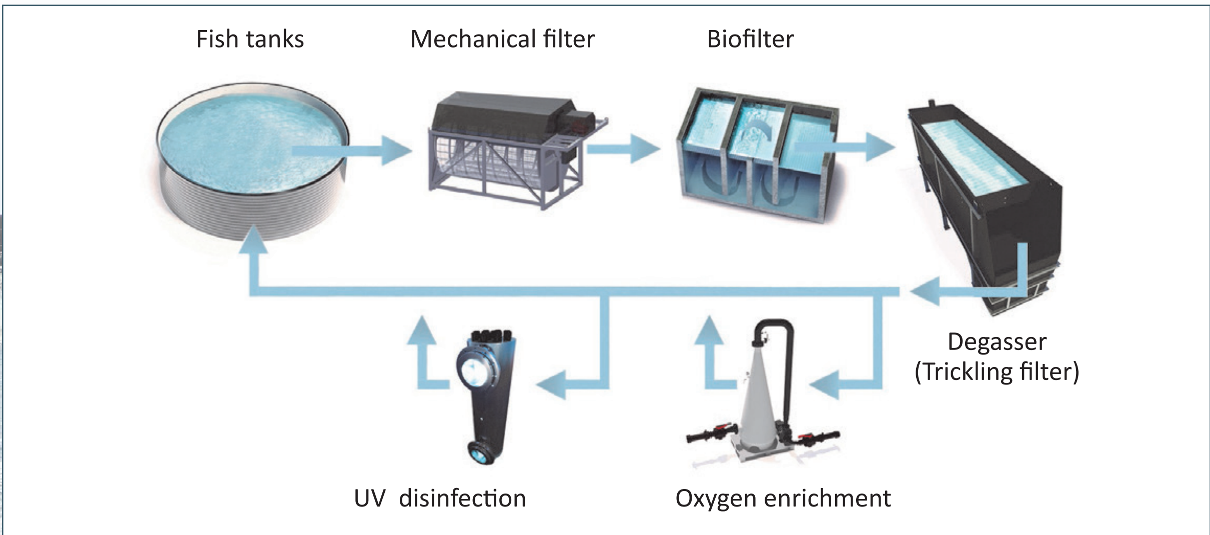


Figure 11: A visual representation of recirculation aquaculture . Source: FAO.[xxx]

Like offshore technology, RAS enables the aquaculture industry to expand its production capacity while reducing the impact on wild animals, improving water quality and animal health and minimizing fish escapes – see Table 9.

Table 9: Drivers, pros and cons of RAS. Source: O'Shea et al., 2019, Pareto Securities.	
Drivers	
• Strict project siting and licensing limits	
• Increasing coastal net pen license fee	
• High cost of animal health and disease prevention	
Pros	**Cons**
Increased control: features easier control of water temperature and inputs, reduced risk of sea lice and other bacteria, no mass escape, easier achievement of secure optimal growth conditions, product uniformity and quality.	**High capital and operation costs**: requires significant capital requirements, long project development timelines and higher energy and freshwater usage.
Optimised location: provides flexibility in siting production facilities close to major markets, enables significant greenhouse gas and air freight cost savings.	**Higher stress levels for fish**: see Box 3.
Reduced impact on wild populations: has minimal direct impact on marine macrofauna and no direct physical interaction with marine habitats.	**Operational risk**: few established track records of successful commercialisation and human capital scarcity, as very few experts in the industry can operate the complex systems.[xxxi]
Improved physical health for fish: see Box 3.	
Discussion / Comments	
Towards lower opex? In the longer term, the operational expenditure for RAS could potentially become lower despite high energy costs. This is because increased control and improved water quality in the RAS systems allow fish to be cultivated in higher stocking densities without jeopardising product quality and growth rates. This also significantly decreases costs for health and disease treatment.	
Favourable regulations: Since June 2016, the Norwegian government has issued a special licence for land-based fish farming with no specific limitations on the number of licenses and biomass per licence. It is free of charge and site-specific.	

Like offshore aquaculture, the **RAS technology requires significantly higher capex than conventional farms**, which makes upscaling a challenge. The systems consist of a sophisticated technology: water supply, backup generator, advanced monitoring, control system, effluent treatment and other processing facilities. High energy use is common.

Even though most of the current pioneering projects are struggling to achieve commercial viability, there are significant advantages to RAS. Increased control over a closed system enables higher stocking density while improving physical animal health and survival rates, though stress levels remain the same. Additional benefits include more efficient conversion and growth rates.

Studies on salmon and cobia raised via RAS suggest the stocking density could increase 2-3 times compared to net pen culture (e.g.; salmon density increases of up to 75-80 kg/m3 in RAS vs 15-30 kg/m^3 in net pens,[xxxii] cobia increases up to 30 kg/m^3 vs 10 kg/m^3)[xxxiii] without an adverse effect on production characteristics. Maximizing stocking density, however, raises the question of fish well-being – see Box 3.

Box 3: Is RAS better for fish health and well-being?

Scientists agree that fish **are sentient beings that feel pain**, just not the same pain we feel.[xxxiv] Since 2009, fish are recognized as conscious, sentient beings by the EU in article 13 TFEU.[xxxv] In all types of aquaculture, including RAS, the issue of confinement and the impossibility for fish to wander are welfare concerns. This is not the case for wild-caught seafood, but there are many other issues for them as well. In the future, more sophisticated systems could simulate geographical field-markers in order to satisfy the urge to wander, and RAS would of course be the most suitable form of aquaculture to implement it in, but this technology has not been developed. Higher stocking density used to make up for economic constraints driven by high initial investments and operation costs is likely to lead to **higher fish stress levels in RAS systems**, everything else being equal.

However, RAS systems can be managed so they prevent disease, and their sophisticated technology could even be designed to offer withdrawal opportunities and various stimuli. Overall, RAS does better than traditional sea-based aquaculture in terms of fish health. Fish farmed in RAS systems scored an average of 6/10 by SeafoodWatch on their Pathogens and parasite indicator compared to an average of 3.7/10 for fish farmed in net cages and marine net pens.[xxxvi]

Norwegian Atlantic salmon producers dominate RAS

As of 2022, a total of 80+ RAS projects have been announced globally with a total planned capacity of 1.7 million tonnes.[xxxvii] Norway expects the highest production of 641,000 tonnes. Besides Norway, the United States, China and European Union countries are leading RAS developers and producers – see Figure 12.

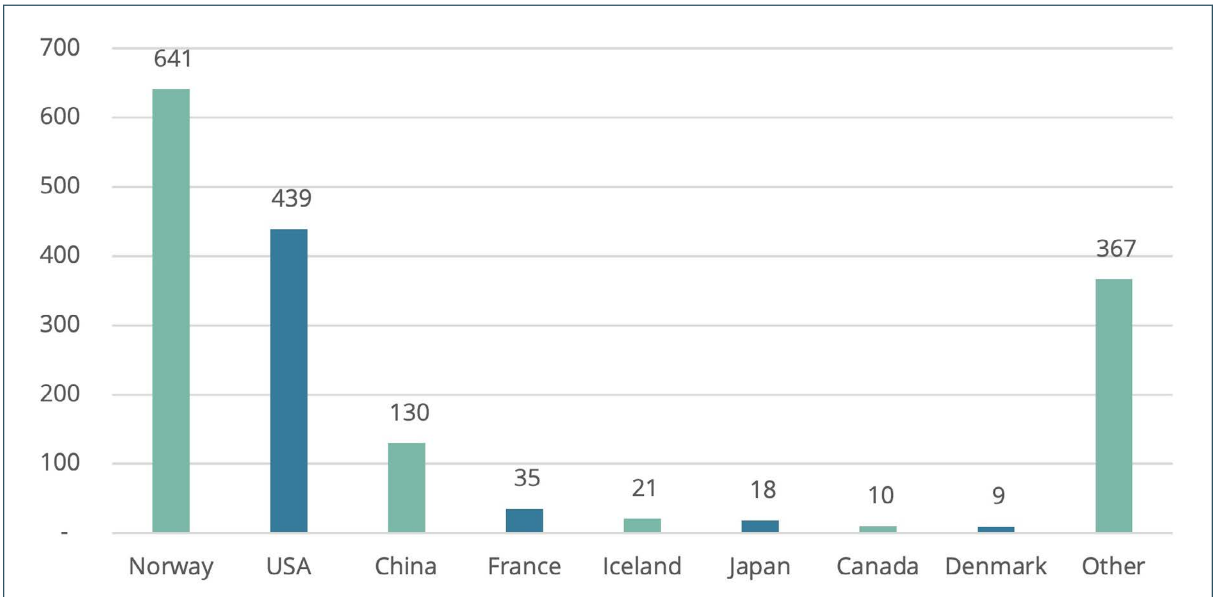


Figure 12: Planned RAS production worldwide ('000 tonnes). Source: Pareto Securities

Table 10 summarises the incumbent RAS salmon projects, which are mostly located in Norway, as Norwegian salmon pioneers have invested heavily in RAS technology research and development.

Table 10: Pioneering RAS farmers. Source: Planet Tracker.

Company	Region	Technology	Harvest stage
Atlantic Sapphire	Norway	RAS	First harvest completed in September 2020. Targets a production of up to 220,000 tonnes of Salmon per annum by 2031
Pure Salmon	United Arab Emirates, Poland	RAS	Global production target: 260,000 tons p.a. by 2025
Salmon Evolution	Norway	Hybrid of Flow-through System (30-35%) and RAS (65-70%)	Completed batch 1 harvest of ~340 tonnes HOG in Q4 2022, 'excellent' product quality confirmed. Batch 2 is scheduled for harvest in Q2 2023. On track for steady state production from late Q3 2023
Proximar	Norway	RAS	First egg input Q3 2022, expects first harvest in Q2 2024
Natural Shrimp	United States	RAS	First harvest completed in May 2022

Atlantic salmon to contribute half of RAS production by 2050

For now, **Atlantic salmon** is the most common species for RAS and the closest to realising commercial viability at scale. Applications for other species are gradually growing: **striped bass, cobia, barramundi, tilapia and European seabass** are deemed feasible in North America. AquaMaof, an Israel-based RAS system producer has also manufactured systems for **catfish, trout, grouper and yellowtail kingfish**.[xxxix]

The economic feasibility of RAS in **pangasius** farming in Vietnam has been confirmed for both medium and large farms,[xl] and the country has gradually introduced a few pilot projects. Several **shrimp** RAS producers have also achieved scale at a competitive cost.[xli]

Overall, Planet Tracker believes **whiteleg shrimp, pangasius**, and **groupers** could become the next generation of species to use RAS technology.

Current RAS projects are producing salmon with an average capex/kg of USD10-24. We expect a decrease in the scale of production as RAS technology progresses, to USD10-15/kg by 2050.

1.4 million tonnes of RAS-grown seafood in 2050, if USD 14-21billion of capex is invested

Rabobank has identified around 50 RAS projects that farm salmon with an estimated production of up to 700,000 tonnes by 2030.[xliii] While the bank suggests the combined production estimate of 700k tonnes is unlikely by 2030,[xliv] we assume that this amount can be reached by 2050.

Assuming that the combined RAS-based production of all other species would reach the same level as Atlantic salmon, we forecast a total of 1.4 million tonnes of RAS production by 2050.

For this to materialise, **the total capex required will range between USD 14 and 21 billion by 2050**.

Like offshore production, RAS does not solve the species concentration issue of aquaculture production. It similarly reduces the problem of geographic concentration at a local level, but not a country level.

Cultivated seafood: <0.5 million tonnes expected by 2050

Cultivated seafood production (also called cell-based or lab-grown seafood) is one of the most technology-dependent forms of seafood production – see Figure 13.

Figure 13: Examples of cultivated seafood. Source: BlueNalu.

Cultivated seafood promises to decrease the risk of disease, reduce overexploitation and biodiversity impacts and significantly decrease land use footprints and water use. Thus, it could feed more people with a greater variety of alternative proteins while alleviating pressure on both wild fisheries and aquaculture production.

The potential economic benefits of cultivated seafood are also substantial. Cell-based seafood may shorten cycle times, and cell cultures may require weeks to months to generate functional foods. By comparison, a genetically modified Aquabounty salmon requires 18 months to grow to market size (roughly half the time of a normal salmon).[xlv]

Forecasts for the cultivated seafood market are hard to come by. This market is often grouped either in the cultivated meat market or alternative seafood market, which also includes plant-based seafood. Overall, there is no consensus on the predicted size of the future alternative protein market – see Figure 14.

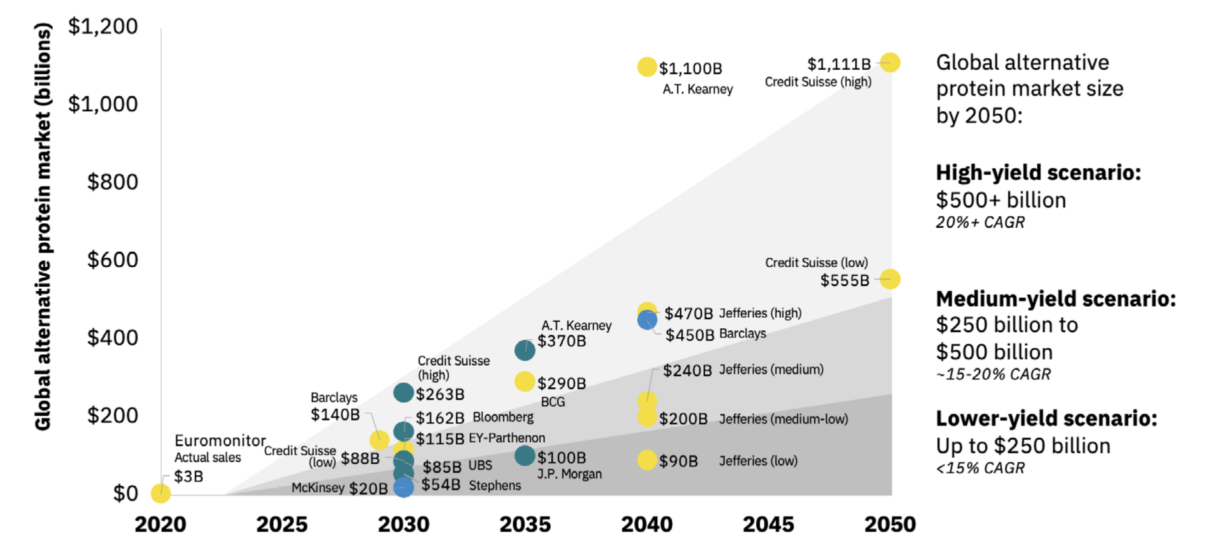


Figure 14: Making sense of forecasts for the alternative protein market. Source: GFI.[xlvi]

Still, the majority of experts interviewed in 2021 expect cultured meat (all types of meat, including seafood) to total less than 1 million tonnes in 2050[xlvii] – see Figure 15.

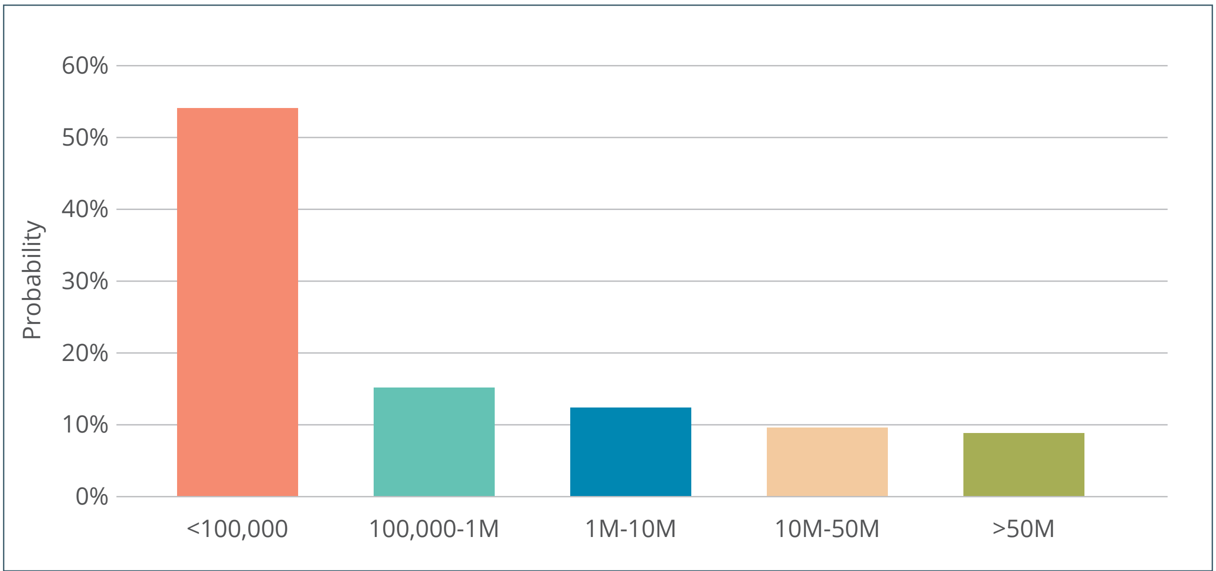


Figure 15: Expert-based assessment of the probability that cultured meat will reach a given production level by 2051 (effective altruism), metric tons.[xlviii]

This is because unlocking cell-based seafood technology's disruptive potential would require several key technological breakthroughs and infrastructure developments.

Techno-economics studies in 2020 and 2021 suggest the current production pathways are far from producing cost-competitive cell-based products, as the average costs of goods sold for animal cell-based meat remain exceedingly expensive at ca. USD 1,708 per kg, and capex remain at around USD 50 per kg (USD 450 million per 10,000 tons) – see Figure 16.[xlix]

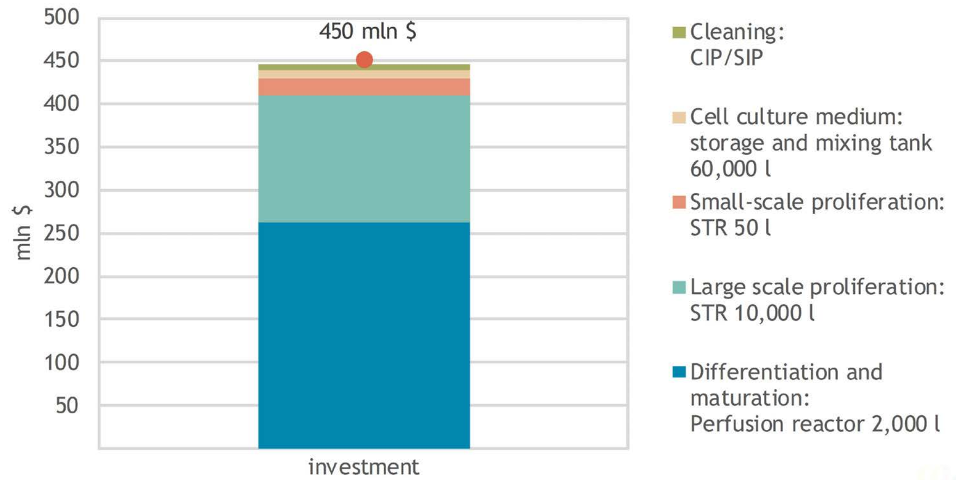


Figure 16 : Breakdown of investment costs for an industrial 10 Kton cultivated meat plant. Source: TEA of cultivated meat, CE Delft.

Cell-based meat production is forecast to only achieve economic viability at ca. USD 2 per kg when significant technological advancements on multiple fronts are overcome.[l]

Cultivated seafood production could be relatively less costly than other types of meat, as fish muscle tissue may be well-suited for bioreactor cultivation relative to mammalian muscle tissues. Still, it is not economically viable as a commodity at its current stage of development.[li]

Even though forecasts for cultured seafood are hard to come by, it is not unreasonable to **expect less than 1 million tonnes coming from cell-based seafood by 2050**. Most experts expect less than 1 million tonnes from the entire cultivated meat market. We forecast 0.45 million tonnes for cell-based seafood, which is just under a third of our estimate for RAS-based production, a comparatively mature technology, assuming that capex will range between USD 5 and USD 40 per kg, based on the speed of technological progress.

This means that the total capex required is likely to range between USD 2 billion and USD 18 billion for cultivated seafood by 2050.

Substantial investments, technological progress and regulatory approvals are needed to transform cell-based innovations into acceptable, available and affordable food products – see Box 4.

Box 4: Entrepreneurs, investors and regulators working on cultivated seafood

In 2021, cultivated seafood companies raised USD 115 million, more than doubling the cumulative investment in the industry. This accounted for 66% of alternative seafood investment in 2021[lii] including plant-based seafood. For instance, in April 2021, the Israeli start-up MeaTech raised $25 million through its listing on the NASDAQ.

Founded in 2018, Singapore-based Shiok Meats plans to seek regulatory approval to sell lab-grown shrimp by April 2023, with its products reaching restaurants in 2024. At present, its shrimp would cost two to four times more than conventional shrimp. To date, the company has raised about $30 million.[liii]

In October 2022, San Diego-based BlueNalu announced a plan for a large-scale cell-based seafood plant that it anticipates will be operational in 2027 with an estimated 75% gross margin. This estimate anticipates "single-cell suspension and lipid loading could result in 5x lower costs compared to other production methods."[liv] The company has raised $84.6 million since its founding in 2018.

Also in October, Singaporean cell-based seafood start-up Umami Meats filed a patent for single-stem cell technology. The method is said to drive down cell-based seafood costs and make it easier to scale so that seafood would be affordable for mainstream consumers.[lv]

The unique outlook for cell-based food production has drawn regulators' attention: the Food and Agriculture Organization (FAO) published three new documents discussing food safety aspects of cell-based food.[lvi] These share the terminology, the production processes and existing regulatory frameworks to support global policymakers in making informed decisions about cell-based food products in different jurisdictions.

Singapore is leading the race in the cultivated meat market. In December 2020, the Singapore Food Agency gave regulatory approval for Eat Just's cultured chicken. This was the first approval of its kind.

We foresee other countries catching up with Singapore soon: in November 2022, the US Food and Drug Administration (FDA) gave approval for cell-cultured chicken produced by Upside Foods, a competitor of Eat Just.[lvii]

When European cultivated meat producers will bring their products to the market is still not clear. However, the Good Food Institute (GFI) in Europe expects that the European Food Safety Authority (EFSA) will see its first application 'very soon'.[lviii]

Based on our estimates technological improvements will not meet the global demand for fish by 2050. Overall, our RAS, offshore and cultivated seafood production forecasts (a total of 4.6 million tonnes in 2050) suggest that these production methods can fill only 9% of the demand gap. How can we close the remaining 91% demand gap? In our opinion, developing non-fed aquaculture is the solution.

UNSUSTAINABLE FEED RESOURCES CAP FED AQUACULTURE GROWTH

- 70% of current aquaculture production relies on external sources of feed.
- Fed aquaculture growth has been capped by unsustainable fishmeal and fish oil production.
- Alternative feeds exist such as soy, but these have their own sustainability issues or are not ready at scale.

Feeding fish with fish is not sustainable

The problems with feeding fish with fish

Technologies such as RAS or offshore aquaculture mitigate some biodiversity risks and overcome some of the constraints limiting the growth of aquaculture. Yet, they still result in an estimated supply gap of roughly 45 million tonnes in 2050. We posit that this is because none of these two technologies address one of the key hurdles to higher aquaculture production volumes: feed availability limitations.

In 2020, **more than 70% of aquaculture production relied upon external sources of feed**. High-value aquaculture species such as farmed salmon and shrimp have relied on fishmeal and fish oil extracted from pelagic fish such as Peruvian anchoveta, mackerel and herring.

Aquaculture is the largest global consumer of fishmeal (86% as of 2020) and fish oil (73% as of 2020). **Around 20% of marine capture in fisheries was reduced to fishmeal and fish oil** in 2020.[lix]

While fish trimmings and other fish processing by-products are also used for fishmeal and fish oil, extracting these feedstocks from whole fish still accounts for more than half of fishmeal and fish oil (73% and 52%, respectively).[lx]

The rise in demand caused by a fast-growing aquaculture sector has caused an unsustainable extraction of resources, contributing to both fishery collapse and deforestation, as soy is often used as a component for feed. An increasing number of species that were for decades used for direct human consumption are being redirected into fishmeal production.[lxi]

The imbalance between feed supply and the high demand for aquaculture is about to worsen. By 2030, fishmeal and fish oil production are expected to increase by 11% and 13% respectively compared with 2020 levels, while aquaculture is expected to grow by 24.6%.

In **2020** more than **70%** of **aquaculture** production relied upon **EXTERNAL SOURCES** of **feed**

Sustainability in feed is a necessity for future growth in aquaculture

As a consequence of this imbalance, prices for both fishmeal and fish oil have soared over the last decades[lxii] – see Figure 17.

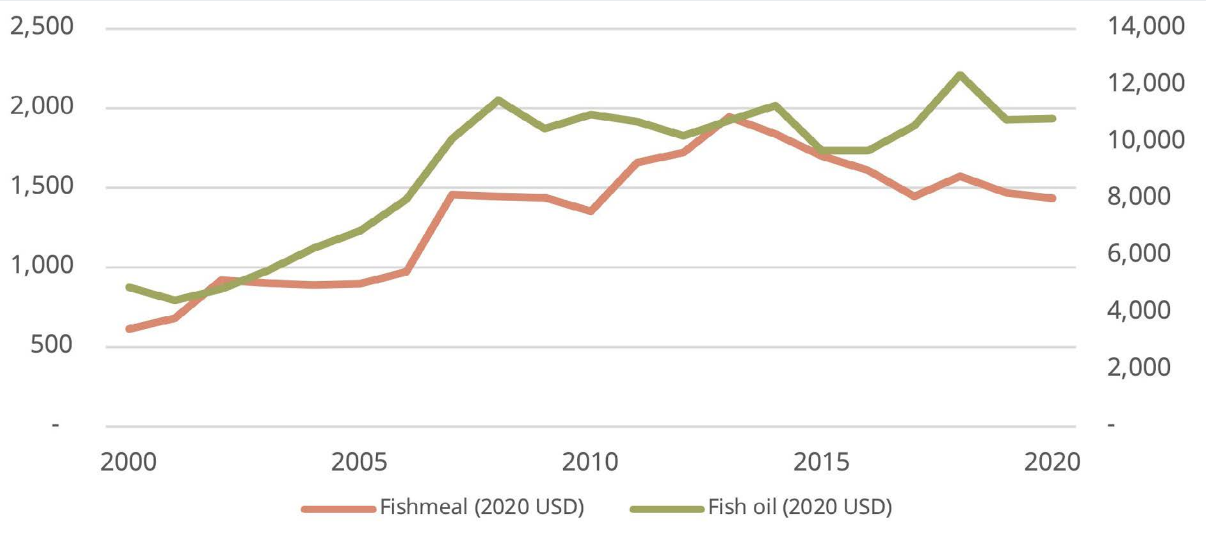


Figure 17: Fish meal (left axis) and fish oil prices (right axis), USD/tonne, 2000-2020. Source: World Bank, 2020 USD constant.

The World Bank has projected that prices for fish oil and fishmeal will increase by 70% and 90% respectively by 2030, relative to 2010 prices.[lxiii] A further increase is expected towards 2050 should the high demand and the unsustainable extraction continue.

The soaring price of fish protein has already directly impacted the profitability of feed companies and, by extension, aquaculture companies. **Feed is the largest input cost of aquaculture production**. For Atlantic salmon, for example, feed accounts for approximately 50% of the cost of production – see Figure 18.[lxiv]

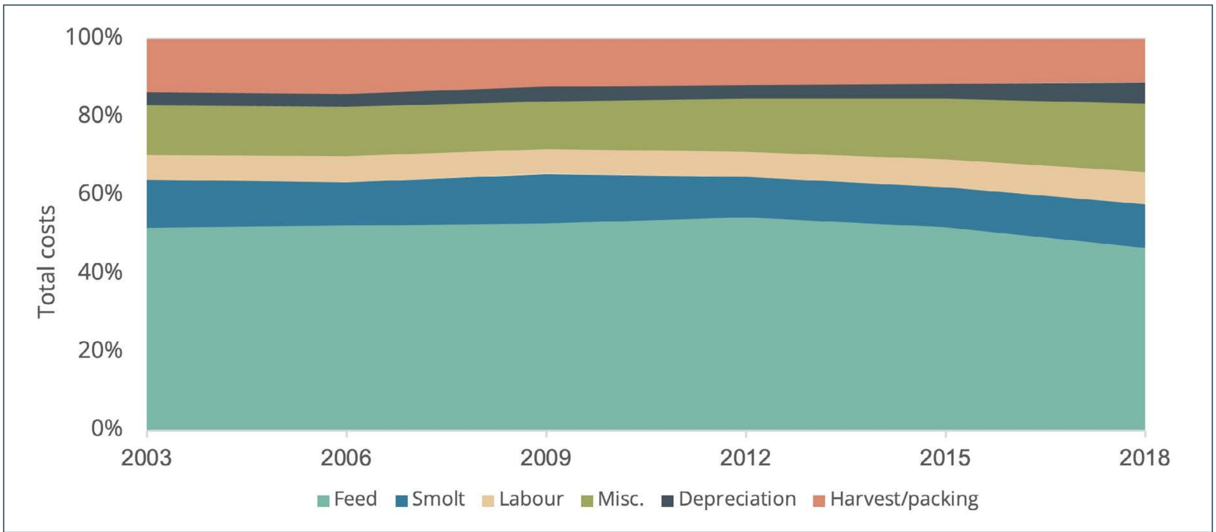


Figure 18: Averaged cost of production for salmon farming across Norway, Scotland, the Faroe Islands, Canada and Chile, 2003–2018 in USD/kg. Source: Iversen et al., 2020.

Reducing the dependence of aquaculture feed on wild-catch has become an imperative for the sustainable growth of global aquaculture. Removing the limitation of fish protein on aquaculture could lead to a sixfold increase in production – two-thirds of the edible meat-based protein requirements for the global population in 2050.[lxv]

But alternatives have their own issues or are not ready at scale

As a plant alternative protein source, soy is now a major component of aquafeed and is projected to have the largest share of any ingredient in the aquafeed market between 2019 and 2025. Soybean prices increased by nearly 50% from January 2020 to October 2022 – see Figure 19.

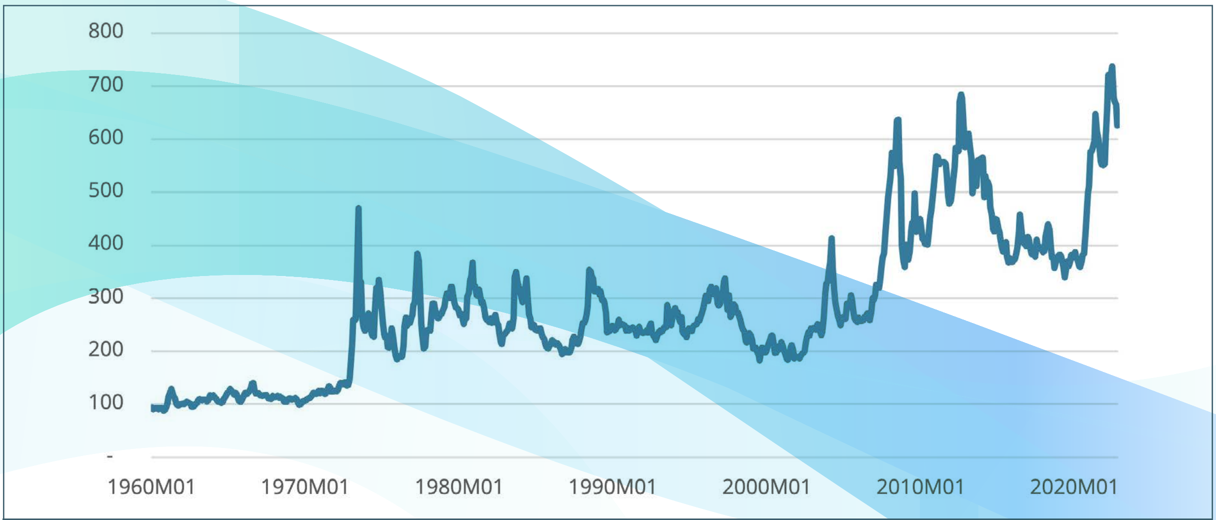


Figure 19: Soybean prices (USD per metric ton). Source: World Bank.

The implication of substituting greater ratios of fish-based with plant-based feed regimes in carnivorous species, such as salmon, is known to negatively impact growth due to the deficiency of essential nutrients (e.g., phosphates) in plant protein resources. The increased reliance on soy also led to another notable but unintended consequence: exposure to deforestation.[lxvi]

Alternative feed ingredients – scaling needed for development

Macro and microalgae, insects, single-cell proteins such as bacteria, and yeast, and microbial biomass are considered nutritious and less environmentally burdensome alternatives,[lxvii] but **these novel solutions are not currently scaled to commercial levels**. This is in part due to the difficulty of securing the necessary capital for upfront research and development to identify the most effective production pathways.

For more details on how green finance could contribute to scale sustainable aquafeeds, please turn to Bonds for Ponds.[lxviii]

Overall, the role of fish meal and fish oil in providing key nutritional elements and availability at scale means that **fed aquaculture**[11] **will remain reliant on fish protein until alternatives can be scaled**. This leaves non-fed aquaculture as potential alternative source of seafood protein[12].

[11] Aquaculture that focuses on species that need to be fed.
[12] Non-fed aquaculture refers to the farming of seafood species that do not need to be fed.

THE UNTAPPED POTENTIAL OF REGENERATIVE AQUACULTURE

- The production of bivalves and seaweed comes with multiple ecological benefits that often outweigh the negative impacts. We call it regenerative aquaculture.
- Producing more of this regenerative seafood still has challenges such as consumer perception and industry fragmentation, but investments are relatively cheap, and the development opportunities are massive.
- We predict regenerative aquaculture can close the seafood demand gap estimated for 2050, provided investments in capital expenditures totalling USD 25 billion can be deployed.

The many ecological benefits of seaweed and bivalve farming

Regenerative aquaculture, which is defined as 'Commercial aquaculture that supports initiatives to provide direct ecological benefits to the environment, leading to improved environmental sustainability and ecosystem services, in addition to the supply of seafood or other commercial products and opportunities for livelihood',[lxix] is where bivalves and seaweed aquaculture fits in.

Unlike the majority of aquaculture, bivalve and seaweed cultivation requires almost no feed or fertilizer, terrestrial land or freshwater.

In 2020, the total production of non-fed aquaculture was 59 million tonnes of which 53.3 million was used for human consumption. This included 35.1 million tonnes of seaweed, 16.2 million tonnes of marine bivalves and 8.2 million tonnes of filter-feeding finfish (mostly silver carp and bighead carp).[lxx]

Bivalves and seaweed as nutritious food sources for human consumption

Bivalves and seaweed can improve consumer nutrition, as both bivalves and seaweeds are generally low in fat and rich in omega-3 vitamins A, C, B12, and E as well as trace minerals like iron, zinc and selenium. Seaweed consumption is also associated with several health benefits, such as lowering blood pressure and preventing strokes[lxxi] – see Figure 20.

Figure 20: Photo credits: BBC Good Food (top left), Sydney Times (top right), Charles Haynes (bottom centre), Simply Delicious (bottom left), New Food Magazine (bottom right).

The farming of bivalves and seaweed also has net positive impacts on natural capital

Instead of exerting negative impacts on the environment and the ecosystem, bivalves and seaweed can contribute ecological benefits to the surrounding ecosystems – see Table 11. **This is only true if they are farmed, while harvesting them in the wild can lead to serious ecological damage** as is the case with scallop dredging.

Table 11: Discussion of the regeneration potential of bivalve and seaweed aquaculture.

Bivalves	Seaweed
Theoretical production limit: 3,485 million tonnes[lxxii]	Theoretical production limit: 700,000 million tonnes[lxxiii]
2020 production: 17.7 million tonnes (FAO, 2022)	2020 production: 35.1 million tonnes (FAO, 2022)
Environment and Ecosystem services	
Water quality: Nitrogen and phosphorus from the water column are assimilated into tissues and removed during harvest, mitigating eutrophication risk.	
Habitat provision: Both bivalves and seaweed create structured habitats for fish and other marine organisms, providing suitable areas for refuge, foraging and stress reduction.	
Overfishing reduction: There is no need to feed either source of seafood with fish products.	
Social: Farming bivalves or seaweed provides alternative livelihoods to fishing communities.	
Carbon sequestration: Seaweed is 20 times more effective than plants at carbon sequestration;[lxxiv] clam farming is a net carbon sink.[lxxv]	
Reduction in methane missions: Using certain types of seaweed as a feed supplement reduces cattle farming methane emissions.[lxxvi]	
More sustainable agriculture: Improved soil conditions and a reduction in agricultural pesticides can be achieved through seaweed-based biofertilizer or biostimulants.[lxxvii]	
Contribution to aquaculture	
IMTA cultivation: Through an integrated multitrophic aquaculture (IMTA) system, bivalves and seaweed could reduce nutrient emissions from fish aquaculture while providing a net input of oxygen to coastal waters, mitigating climate change, eutrophication and the biodiversity crisis across the fishery and aquaculture value chain.	
Supplemental fish feed: Some types of seaweed are also used as supplemental fish feed ingredients that provide necessary amino acids, beneficial polysaccharides, fatty acids, antioxidants, vitamins and minerals.[lxxviii]	
Potential risks	
Invasive species: Pacific oysters have been shown to impact native oyster species. They have been introduced into at least 45 ecoregions, both unintentionally and for aquaculture. The red alga Kappaphycus alvarezii has been imported into numerous tropical countries for aquaculture, where it spreads to coral reefs.	
Risks to seabirds: birds whose feeding and breeding habitats are suitable for bivalve farming might be affected by loss of habitat,[lxxix] but this is debated.[lxxx]	
Algal blooms: Due to its prolific nature, seaweed can also be highly invasive and serve as a vector for pathogens. Sites must be properly selected.	

Bivalves are filter feeders, meaning that they feed on suspended phytoplankton and remove organic detritus, solids and other nutrients in the water column. Seaweed absorbs carbon and nutrients like nitrogen and phosphorous through photosynthesis and produces oxygen. The strategic development of seaweed and bivalve aquaculture could therefore play a crucial role in supporting sustainable marine food systems.

Seaweed could serve as an important sustainable source for animal feed, as using certain types of seaweed in livestock feed could reduce methane emissions from cattle farming by 75-99%.[lxxxi] The global amount of animal feed for ruminants, poultry, pigs and fish is currently about 1 billion tons and is forecasted to increase by 60% by 2050.[lxxxii] If even 1% of this feed (in dry weight terms) was generated through seaweed farming, the ecological benefits would be substantial.

Researchers have also identified non-food applications for bivalves and seaweed. Their production has a strong potential for carbon sequestration. **Just 14%-25% of the seaweed currently farmed could fully offset the emissions of the entire aquaculture sector**.[lxxxiii]

Regenerative aquaculture benefits both species and geography diversity as bivalves and seaweed can be cultivated in a wide range of areas, including both coastal and offshore areas, but they also provide habitats for other marine organisms.

Regenerative aquaculture is underdeveloped and relatively cheap

In 2020, the global production of bivalves and seaweed was 17.7 million tonnes, and 35.1 million tonnes, respectively.

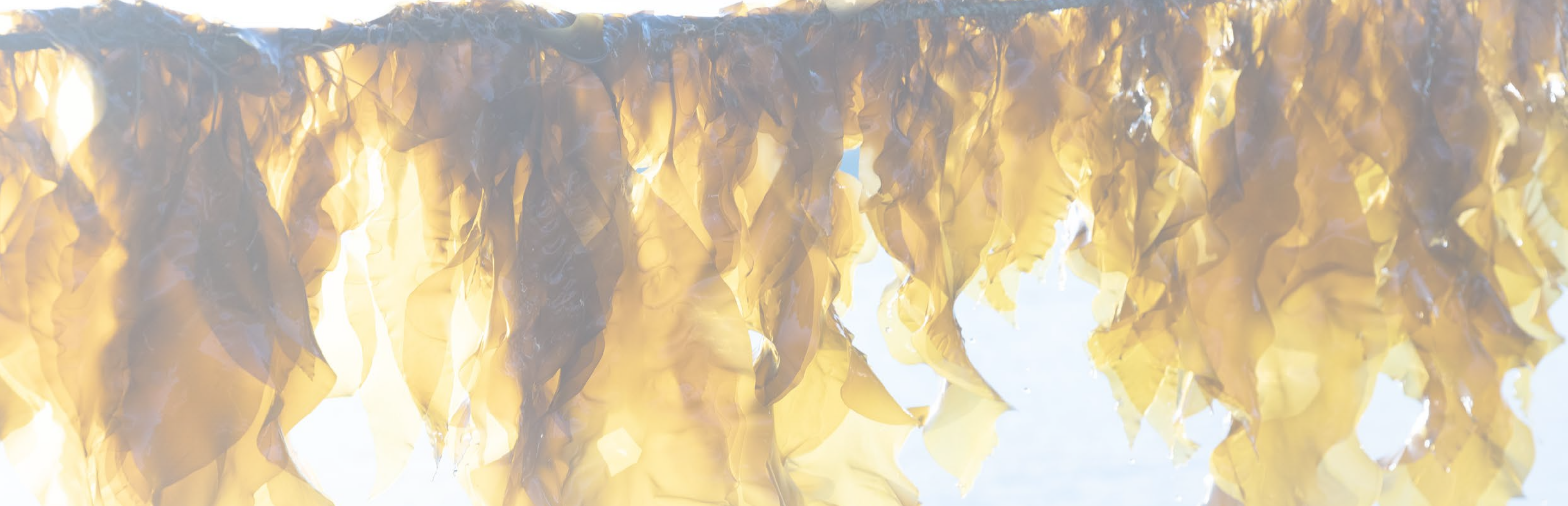
The marine space around the world for growing bivalves is an estimated 1.5 million km^2 while the space available for seaweed production is 48 million km^2. The theoretical limit for bivalve production is 3,485 million tonnes (whole animal) and 700,000 million tonnes (in fresh weight terms) for seaweed. These theoretical limits are estimations prior to considerations such as production and infrastructure costs, economic viability and possible adverse effects on marine ecosystems. Current production accounts for less than 1% of these theoretical limits, suggesting that there is ample space for regenerative aquaculture to expand.

The production of bivalves and seaweed is relatively simple. Methods include floating bamboo or mangrove stakes and nets, or bottom monoline cultivation on the sea floor.[lxxxiv] Capital and input costs are much lower than the other sustainable aquaculture technologies discussed in this report. **Current capex for bivalve and seaweed farming ranges from $0.55-1.47 per kg**,[lxxxv] **depending on the scale, equipment type and location** – see Table 12.

Table 12: Average capex/kg for offshore, RAS, cultivated seafood and regenerative aquaculture.

Average Capex/kg	Offshore	RAS	Cultivated seafood	Regenerative aquaculture
Current stage	$6.5-$20 per kg	$10-$24 per kg	$49.6 per kg	$0.55-$1.47 per kg
Source	O'Shea et al., 2019[lxxxvi] Rabobank 2021[lxxxvii]	O'Shea et al., 2019 AKVA Group[lxxxviii] Pareto Securities	TEA of cultivated meat, CE Delft[lxxxix]	O'Shea et al., 2019
By 2050[13]	**$5-10 per kg**	**$10-15 per kg**	**$5-40 per kg**	**$0.55-1.47 per kg**

[13] Estimates by Planet Tracker.



Food safety and lack of awareness deterring bivalve consumption

The production and consumption of bivalves and seaweed are overwhelmingly concentrated in Asia – see Table 13. **Food safety concerns and a lack of awareness in western markets** are the main constraints deterring the development of this industry.

Table 13: Asia's share of aquaculture production in 2020 by family of species (thousands of tonnes).

Aquaculture of	Asia	Africa	Americas	Europe	Oceania	World	Asia, % of world
Finfish	50,029	2,237	2,421	2,674	101	57,461	**87.1%**
Crustaceans	9,951	7.6	1,266	3.6	8.6	11,237	**88.6%**
Molluscs (mostly bivalves)	16,351	6.0	688	579	116	17,741	**92.2%**
Algae (mostly seaweed)	34,916	104	25	22	10	35,078	**99.5%**
Others	1,052	0.1	0.4	6.7	2.8	1,062	**99.1%**
Total aquaculture	112,301	2,354	4,401	3,284	239	122,579	91.6%
% World	91.6%	1.9%	3.6%	2.7%	0.2%	-	-

Food safety concerns stem from worries about algal toxins (e.g., harmful algal blooms that result from conventional aquaculture), bacteria, viruses, heavy metals in coastal growing sites and other environmental contaminants that may bioaccumulate in molluscan shellfish tissues as part of their filter-feeding behaviour.[xc]

A positive is that a range of highly effective depuration technologies have become available to ensure safe production, such as:

- UV light treatment (ultra-violet light kills bivalve parasites)[xci]
- ozonation[xcii] (direct application of ozone can destroy pathogens)
- antimicrobial peptides, polysaccharides and bacteriophages[xciii]

Finally, low-cost depuration treatments using *Citrus aurantifolia* and drying are effective in substantially killing bacteria in bivalves.[xciv]

Appropriate cultivation site and species site selection are crucial to avoid contaminants. Farming species native to specific regions can mitigate concerns about biological invasions. Offshore cultivation in nutrient-rich waters is another promising potential opportunity for both expansion and addressing the pollution concerns. It would also avoid intensified competition for nearshore areas with fishing and other activities. No outlay is required for feed and the farming structures for bivalves and seaweed are less expensive compared to offshore finfish aquaculture.

Consumer uptake could improve due to convenience and changing diets

Most bivalves have been traded regionally so far, since their short shelf life (typically 6-8 days at 5°C for oysters) makes their transport and storage more expensive and difficult at a global scale.

Bivalves are relatively easily and safety stored as high hydrostatic pressure[14] (HHP) processed,[xcv] frozen de-shelled or cooked processed products. In these forms, they can be distributed with lower transportation and storage costs than fish.[xcvi] The popularity of bivalves in terms of their convenience and safety has grown considerably thanks to societal changes and growing demand for healthy and convenient food in more advanced economies.[xcvii]

Consumers in western countries are starting to consume more seaweed with the growing awareness of its health benefits and popularity of Asian cuisine. It has been increasingly used in plant-based meats as a protein.

Seaweed is also the only plant-based source of iodine, a crucial mineral that helps make thyroid hormones and keeps human cells and the metabolic rate healthy. This is especially beneficial for vegans.[xcviii]

Closing the seafood demand gap in 2050 with regenerative aquaculture

We believe bivalve and seaweed aquaculture could be one of the best opportunities to simultaneously restore ecosystems and enhance the livelihoods of coastal communities but also provide a diverse and nutritionally complete set of foods and meet the mass market seafood demand by 2050. And this contribution would be significantly higher if seaweed production becomes more cost efficient by fulfilling other potential applications beyond food production such as carbon sequestration by then.

An added 45 million tonnes of bivalves and seaweed needed to bridge the gap by 2050

We estimate that bivalves and seaweed aquaculture could together provide an additional 45 million tonnes of seafood by 2050, based on the following assumptions:

- The barriers to the mass-market uptake for bivalves, such as food safety concerns, production inefficiencies and inconvenient products will be minimized with improvements in production and food processing.
- Safe, affordable and convenient bivalve food products meet consumers' changing diet preferences in seafood consumption on a global scale.
- Increased awareness about seaweed's health credentials outside of Asia.

However, we acknowledge that if these assumptions fail to materialise, there is a significant downside risk to our estimate.

[14] High hydrostatic pressure (HHP) treatment is an effective technique to destroy microorganisms and inactivate enzymes in order to enhance safety and shelf-life of foods. Classical HHP or single-pulsed HHP (spHHP) treatment can be applied as compression to target pressure, holding for a certain period of time at the target pressure and decompression to atmospheric pressure.

To produce that much seaweed and bivalves, an additional USD 25 to 67 billion is needed in capex by 2050 per our estimates. This is assuming the capex required for bivalve and seaweed cultivation is kept relatively flat at USD 0.55 to 1.47 per kg. We expect this due to the comparatively low technology requirements and the highly fragmented market landscape.

Regenerative aquaculture: substantial investments needed

Unlike finfish producers, **bivalve and seaweed markets are highly fragmented with small, private producers dominating the market**. In 2020, the mollusc market size reached USD 29.8 billion,[xcix] while the total seafood sales revenue generated by the 5 publicly listed bivalve producers[15] that we identified was less than USD 100 million in 2020. Most seaweed producers are start-ups or small family businesses.[c]

There are reasons behind the fragmented nature of the industry:[ci]

- The bivalve market is less regulated and less mature than that of other seafood species.
- It requires less technology and lower capital investment to achieve economies of scale compared to finfish aquaculture.
- It therefore has lower barriers to entry.

By 2050, we calculate that **at least a USD 25 billion investment** is needed for regenerative farming to meet the increasing seafood demand and provide substantial environmental benefits at the same time.

An altered seafood consumption outlook in 2050

Based on our estimates, the breakdown of the global average consumption of seafood by species group will change by 2050 – see Figure 21.

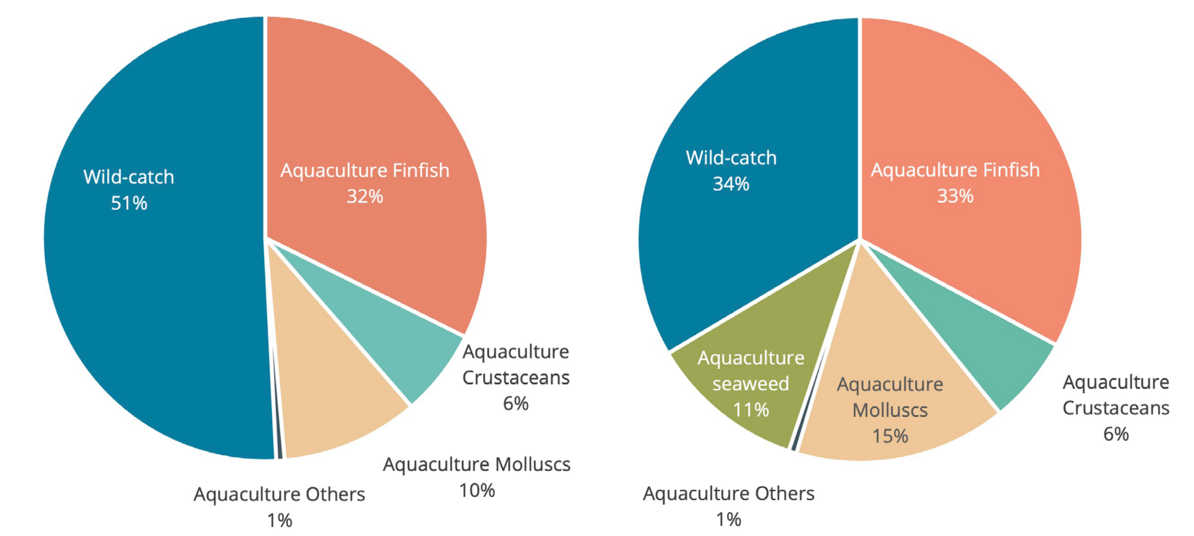


Figure 21: Seafood for human consumption in 2020 (left) and 2050 (right). Source: FAO 2022, Planet Tracker.

[15] Some publicly listed bivalve producers also catch bivalves in the wild and are engaged in other businesses. Our positive comments on the farming of bivalves under certain specific conditions should not be perceived as an appreciation of the business model or valuation of these companies.

Bringing our different estimates together, we conclude that the seafood demand gap we forecast for 2050 can be closed through a combination of technological progress and strong investment in regenerative aquaculture – see Figure 22.

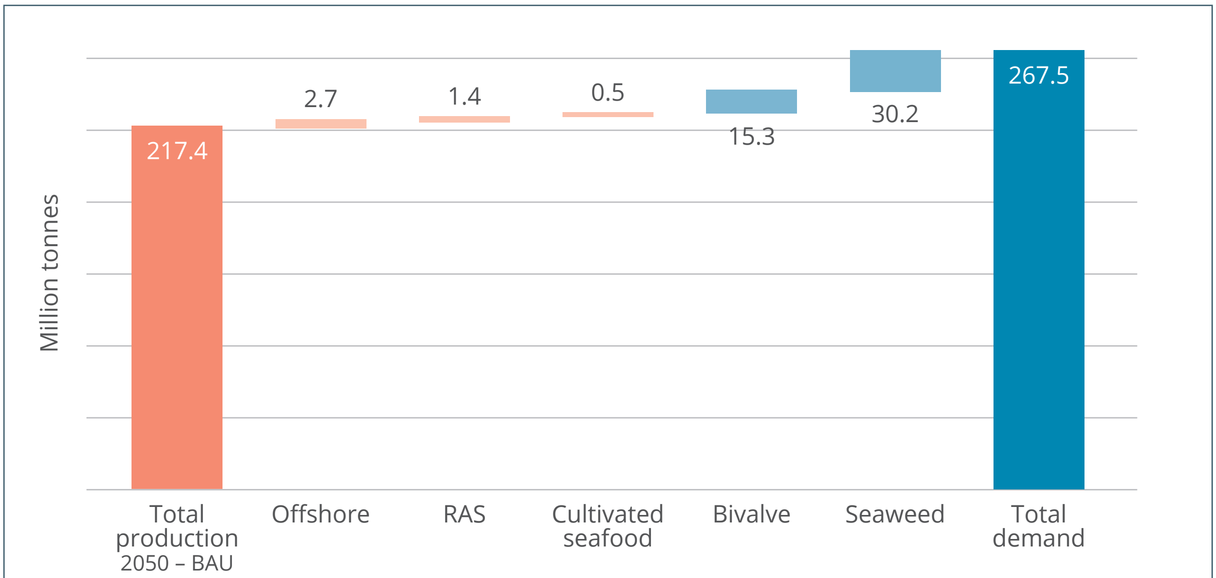


Figure 22: Closing the seafood demand gap in 2050 through technological progress (pale orange) and regenerative aquaculture (pale blue), estimated by Planet Tracker (million tonnes).

We expect that this will cost a minimum of USD 55 billion and a maximum of USD 134 billion – depending on location, scale, species and equipment, of which minimum capex investments of USD 30 billion in technological progress and USD 25 billion in regenerative aquaculture are achieved – see Figure 23.

Figure 23: Estimated minimum and maximum capex costs by 2050 to finance the seafood demand gap by source, estimated by Planet Tracker (USD billion).

AQUACULTURE COMPANIES CANNOT CLOSE THE SEAFOOD DEMAND GAP WITHOUT EXTERNAL FINANCING

- Planet Tracker calculates that at least USD 55 billion in capex is needed by 2050 to close the seafood demand gap expected from a business-as-usual scenario.
- Analysis of 57 publicly listed aquaculture companies shows companies cannot generally afford to close the gap without external funding.
- Investors and lenders can and need to help by understanding the increasing risks of a business-as-usual scenario and supporting the mitigation of these risks through diversification, environmentally sound technology and regenerative aquaculture investments.

Publicly listed aquaculture companies focus on a few high-value species

As of October 2022, Planet Tracker identified 57 publicly listed companies which actively derive income from direct aquaculture production – see Table 14[16].

[16] Where larger corporations have identifiable subsidiaries, the parent has been excluded. For instance the Cia Pesquera Camanchaca SA (CAMANCHACA.CL) has been excluded as its subsidiary Salmones Camanchaca SA is also included in the list: SALMOCAM-CL.

Table 14: Identified publicly listed aquaculture companies ordered by main species farmed.[cii] Source: Planet Tracker, FactSet.			
Ticker	Entity Name	Country	Main Species
Bivalves			
RFA.AX	Ocean Grown Abalone Ltd	Australia	Bivalves
002069.SZ	Zoneco Group Co., Ltd. Class A	China	Bivalves
3224.T	General Oyster, Inc.	Japan	Bivalves
SAN.NZ	Sanford Limited	New Zealand	Bivalves
SHG.JO	Sea Harvest Group Ltd.	South Africa	Bivalves
Grouper			
8465.TWO	Tekho Marine Biotech Co., Ltd.	Taiwan	Grouper
4712.TWO	Nan Tsan Co Ltd	Taiwan	Grouper
Mixed / Others			
MCA.AX	Murray Cod Australia Limited	Australia	Mixed, others
CSS.AX	Clean Seas Seafood Limited	Australia	Mixed, others
002696.SZ	Baiyang Investment Group, Inc. Class A	China	Mixed, others
JPFA.JK	PT Japfa Comfeed Indonesia Tbk Class A	Indonesia	Mixed, others
1333.T	Maruha Nichiro Corp.	Japan	Mixed, others
1332.T	Nippon Suisan Kaisha, Ltd.	Japan	Mixed, others
9955.T	Yonkyu Co., Ltd.	Japan	Mixed, others
NCOD.OL	Norcod AS	Norway	Mixed, others
CRBN.AS	Corbion N.V.	The Netherlands	Mixed, others
DD	DuPont de Nemours, Inc	United Sates	Mixed, others
Pangasius			
ABT	Bentre Aquaproduct Import & Export Joint Stock Co.	Viet Nam	Pangasius
ACL	Cuulong Fish JSC	Viet Nam	Pangasius
HVG	Hung Vuong Corporation	Viet Nam	Pangasius
IDI	I.D.I International Development & Investment Corp.	Viet Nam	Pangasius
AAM	Mekong Fisheries JSC	Viet Nam	Pangasius
ANV	Nam Viet Corp.	Viet Nam	Pangasius
ATA	NTACO Corp.	Viet Nam	Pangasius
VHC	Vinh Hoan Corp	Viet Nam	Pangasius
Salmon			
TGR.AX[17]	Tassal Group Limited	Australia	Salmon
BLUMAR.SN	Blumar S.A.	Chile	Salmon
SALMOCAM.SN	Salmones Camanchaca SA	Chile	Salmon
BAKKA.OL	Bakkafrost P/F	Faroe Islands	Salmon
ISLAX.OL	Icelandic Salmon AS	Iceland	Salmon
IFISH.OL	Ice Fish Farm	Iceland	Salmon
AFISH.OL	Arctic Fish	Iceland	Salmon
NZK.NZ	New Zealand King Salmon Investments Ltd.	New Zealand	Salmon

[17] Tassal Group limited was taken over by Coke Aquaculture in November 2022.

Table 14: ... continued			
Ticker	Entity Name	Country	Main Species
Salmon ... continued			
MOWI.OL	Mowi ASA	Norway	Salmon
LSG.OL	Leroy Seafood Group ASA	Norway	Salmon
SALM.OL	SalMar ASA	Norway	Salmon
GSF.OL	Grieg Seafood ASA	Norway	Salmon
NRS.OL[18]	Norway Royal Salmon ASA	Norway	Salmon
NTS.OL	NTS ASA	Norway	Salmon
AUSS.OL	Austevoll Seafood ASA	Norway	Salmon
ASA.OL	Atlantic Sapphire ASA	Norway	Salmon
ANDF.OL	Andfjord Salmon AS	Norway	Salmon
SALME.OL	Salmon Evolution Holding ASA	Norway	Salmon
PROXI.OL	Proximar Seafood AS	Norway	Salmon
Shrimp			
SFG.AX	Seafarms Group Limited	Australia	Shrimp
600257.SS	Dahu Aquaculture Co., Ltd. Class A	China	Shrimp
300094-SZ	Zhanjiang Guolian Aquatic Products Co., Ltd. Class A	China	Shrimp
600467.SS	Shandong Homey Aquatic Development Co., Ltd. Class A	China	Shrimp
BKV.BO	BKV Industries Limited	India	Shrimp
ZEAL.BO	Zeal Aqua Ltd	India	Shrimp
APEX.BO	Apex Frozen Foods Ltd.	India	Shrimp
CPRO.JK	PT Central Proteina Prima Tbk	Indonesia	Shrimp
6090.SR	Jazan Energy and Development Company	Saudi Arabia	Shrimp
579.SI	Oceanus Group Limited	Singapore	Shrimp
TU.BK	Thai Union Group Public Company Limited	Thailand	Shrimp
CPF.BK	Charoen Pokphand Foods Public Co. Ltd.	Thailand	Shrimp
SHMP	NaturalShrimp, Inc.	United Sates	Shrimp

The geographical and species concentration we identified for aquaculture production is apparent when looking only at publicly listed companies. We segmented the 57 companies we identified into six groups. Each company was tagged by its primary aquaculture species, although revenue may be derived from other species or revenue streams, such as wild-catch fishing or seafood processing.

[18] Norway Royal Salmon ASA merged with Salmar ASA in November 2022.

Most listed aquaculture companies' production is heavily weighted towards three species – salmon, shrimp and pangasius. The mixed/other segment is comprised of 10 companies across the world: mainly conglomerates and other companies farming species such as cod, yellowtail kingfish, bluefin tuna, jellyfish and seaweed.

Even though freshwater fish accounts for 75% of global edible aquaculture volume, with carp as a significant part of this group,[ciii] only one publicly listed company engaging in carp cultivation was identified[19].

While Vietnam was not identified above as a country with a high species concentration risk, the listed pangasius companies are exclusively domiciled in Vietnam, where the majority of global pangasius production takes place.

Financial health partly linked to species specialisation

China, Japan, Norway and Thailand account for 88% of the combined revenue of these 57 companies, and 80% of their combined market capitalisation[20]. Note that our analysis is limited by the fact we take all a company's revenue into consideration, not aquaculture-only revenue.

Salmon and shrimp are the dominant species in terms of revenue generation for these 57 companies – see Figure 24.

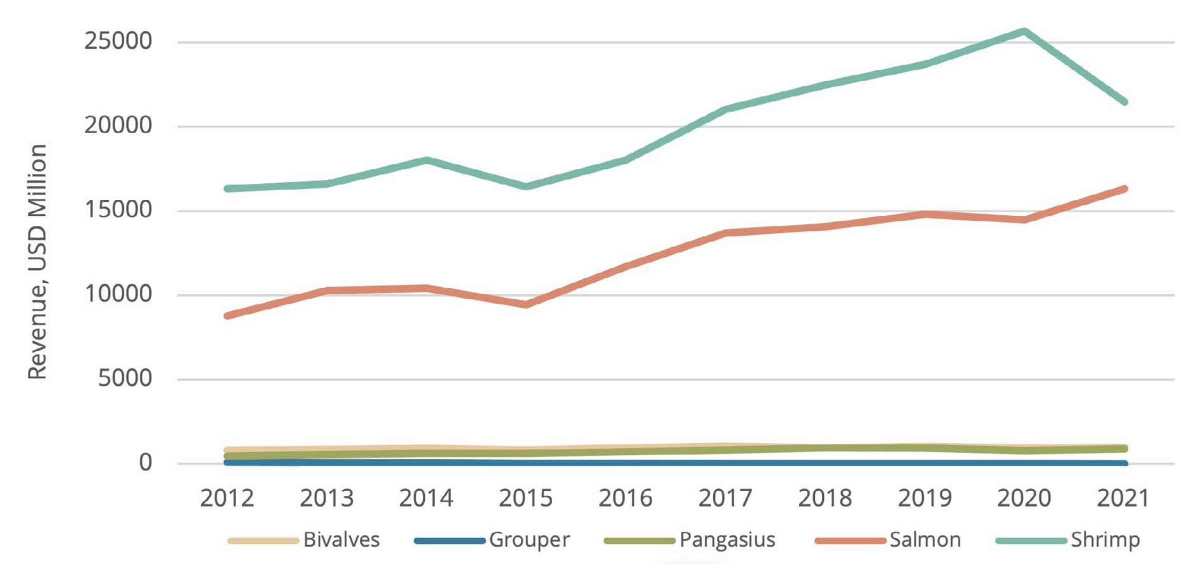


Figure 24: Revenue change by species grouping, 2012–2021, USD million. Source: FactSet.[clv]

On average, these companies have grown their revenue at an average of 25.8% p.a. over the 2012–2021 period.

[19] Dahu Aquaculture in China. The company farms bighead carps, silver carps, shrimps, soft-shelled turtle and crabs, alongside other products such as wine, honey and aquatic pearls.

[20] Companies in m the mixed/other category are not included in our financial analysis since a large portion of revenue generated was not related to aquaculture.

Listed aquaculture companies cannot afford to self-finance the closing of the seafood demand gap

The 57 publicly-listed companies we identified have varied capability to self-finance our recommended changes. This is partly because different species make up the majority of their farming and their current investment levels vary widely – see Figure 25.

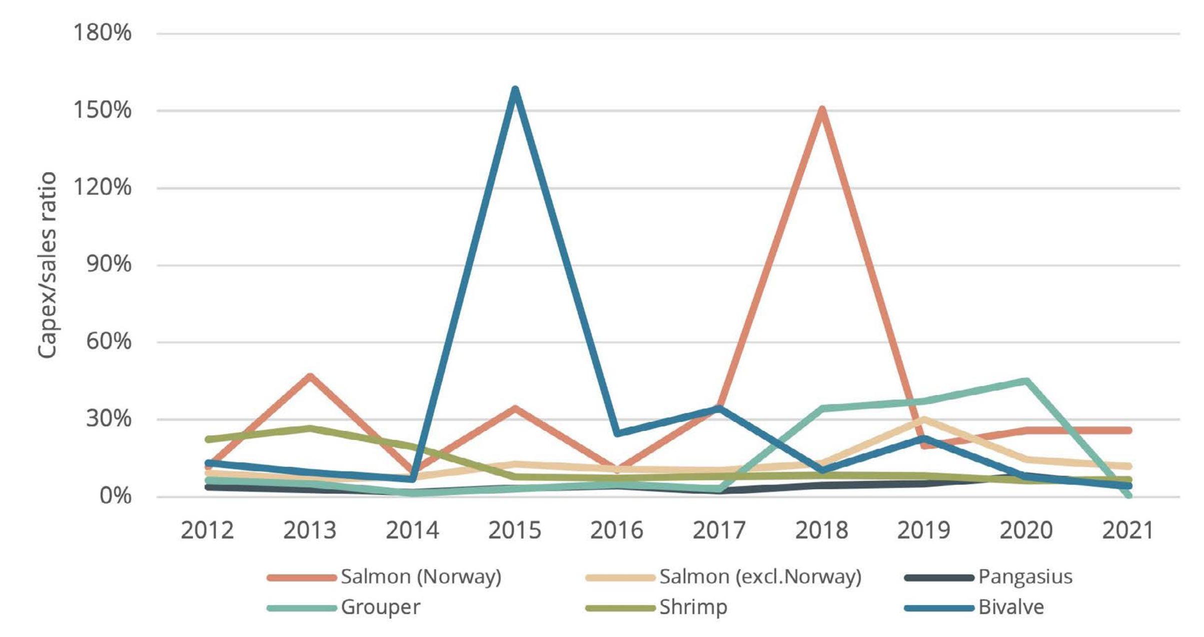


Figure 25: Capex/sales ratio by species type, 2012–2021.

Salmon producers already invest a lot, but could slightly increase investments

Salmon producers are the world's leading seafood farmers in terms of technology and research and development. They generally exhibit higher financial performance.

Between 2012 and 2021, Norwegian salmon companies achieved the highest profitability within the global salmon industry, on average with an 11.8% net profit margin and a 16% EBIT margin. They were followed by other salmon companies from the rest of the world, with net profit margins and EBIT margins averaging 8% and 8.2%, respectively – see Table 15.

Table 15: Total revenue, operating cash flow, average profit margin and capex/sales ratio of the salmon industry, 2012–2021 (USD million). Source: Refinitiv.										
Salmon	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Revenue	8,500	10,020	10,164	9,195	11,375	13,343	13,706	14,379	14,048	15,781
EBIT margin	3.8%	14%	15%	9.1%	16%	13%	17%	14%	9.3%	9.7%
Net profit margin	5.5%	13%	8.5%	8.1%	18%	8.3%	17%	11%	3.2%	11%
Operating cash flow	634	1,199	1,524	878	2,110	2,617	2,218	2,360	1,857	2,885
Capex/sales	11%	38%	9.1%	30%	10%	12%	14%	20%	21%	23%
OCF/Capex	1.0	1.9	2.4	1.1	2.6	1.9	1.6	1.4	0.8	1.6

In the same period, Norwegian salmon producers invested the most capex out of all species and countries totalling **19% of sales revenue** on average. **Salmon companies across the world invest approximately two-thirds of operating cash flow in capex on average**. This suggests that an increase in self-financing capex is in theory possible for salmon producers but is relatively limited.

Shrimp companies: low profitability affects ability to invest

Public companies in shrimp aquaculture are mainly located in China, India and Thailand. Over the past decade, the shrimp industry realised an average net profit margin of 4.6%, and invested an average of 12% of the revenue in capex.

Shrimp companies across the world invest 72% of operating cash flow in capex on average. This suggests a possible but limited capacity of further raise funds in capex – see Table 16.

Table 16: Total revenue, operating cash flow, average profit margin and capex/sales ratio of the shrimp industry, 2012–2021 (USD million). Source: Refinitiv.										
Shrimp	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Revenue	16,393	16,696	18,124	16,560	18,143	21,162	22,611	23,836	25,764	21,522
EBIT margin	-3.7%	-5.0%	4.9%	5.6%	5.2%	5.2%	6.5%	4.5%	7.4%	7.6%
Net profit margin	-4.3%	-3.2%	3.9%	3.3%	0.8%	-1.7%	4.0%	-1.9%	3.9%	5.3%
Operating cash flow	165	334	1,066	1,089	1,157	732	935	1,851	2,885	503
Capex/sales	22%	27%	19%	7.8%	7.2%	7.8%	8.3%	8.1%	6.3%	6.6%
OCF/Capex	0.4	-0.3	4.8	1.7	1.0	0.2	0.6	2.0	1.4	1.9

Bivalves: in need of external investment

In a highly fragmented market, small bivalve and seaweed producers have limited access to finance and are often indebted to traders. Often, this prevents them from generating enough funds to purchase advanced equipment, tools and better seed stock to improve yields.[cv] As a result, they are unlikely to be able to scale up their production to match the anticipated rapid growth in demand through self-financing alone. External financing is crucial.

Investments are growing fast in the seaweed sector

As currently practiced, bivalve and seaweed production are relatively low-tech industries, presenting substantial opportunities for integration and improvements inefficiency and yields.

Investments in the seaweed sector are growing fast outside of Asia. Since 2020, a total of 100 seaweed investment deals in the European seaweed industry have been compiled by Phyconomy, with a total investment amount of USD 366 million – see Figure 26.[cvi]

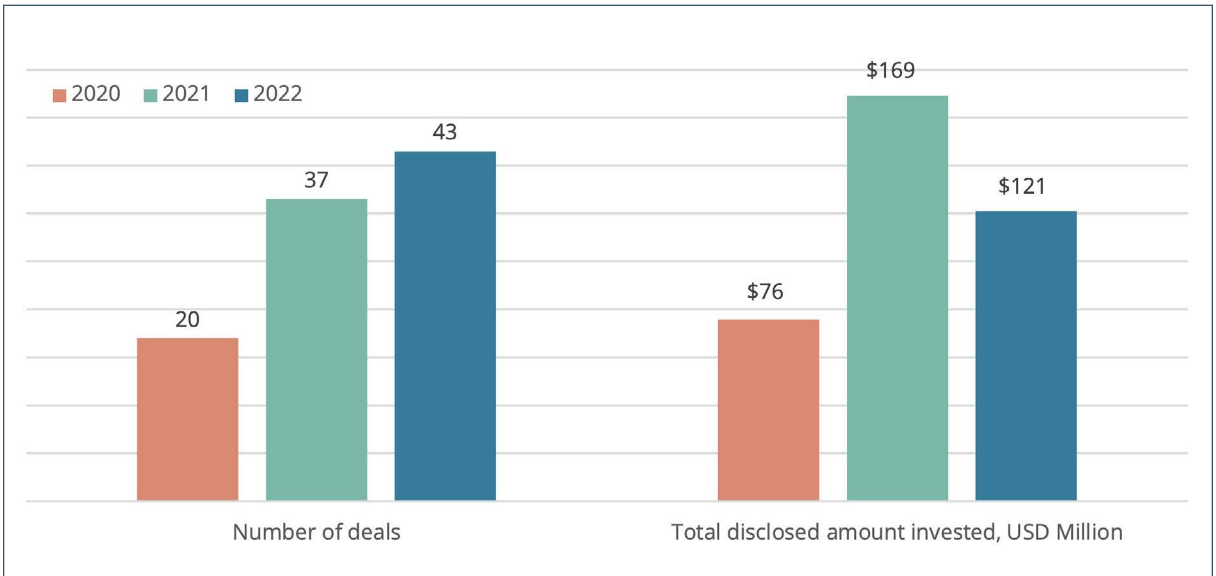


Figure 26: Seaweed investments 2020–2022. Source: Phyconomy as of January 2023.

Of these, more than half were pre-seed and seed rounds. Food, bioplastics, animal feed, fertilizers and nutraceuticals are the top 5 applications of interest.

Loss-making pangasius companies are vastly underinvesting and are unlikely to help close the demand gap we identified

The pangasius industry provides an interesting case study of the financial impact of environmental issues in conventional aquaculture. Indeed, the production of pangasius in Vietnam has been dominated by pond farming since 2003, where negative impacts on the environment from eutrophication, disease and economic losses created substantial challenges for the industry. Over the last decade, the sector has experienced significant losses: -15% EBIT margins and -60% net profit margins on average.

The operating cash flow to capital expenditure ratio averaged at 3.7, suggesting the industry has been largely underinvested overall. Indeed, out of all the species we looked at, pangasius companies invested the least: 4.1% of sales on average – see Table 17.

Table 17: Total revenue, operating cash flow, average profit margin and capex/sales ratio of the pangasius industry, 2012-2021 (USD million). Source: Refinitiv.

Pangasius	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Revenue	474	558	617	604	712	803	950	953	790	874
EBIT margin	6.6%	6.5%	6.3%	-15%	5.8%	-25%	-30%	-31%	-78%	2.5%
Net profit margin	4.0%	3.1%	3.5%	-68%	3.8%	-408%	-32%	-30%	-78%	2.2%
Operating cash flow	-2.2	4.9	-4.2	3.3	47	76.9	74.5	69.9	4.2	54.4
Capex/sales	3.7%	2.9%	1.8%	3.3%	4.2%	2.4%	4.4%	5.1%	8.2%	4.5%
OCF/Capex	3.3	1.2	-9.8	-0.5	5.6	7.1	3.1	-1.8	-4.3	33

Pangasius production is suitable for RAS systems but a high degree of investment in this technology is unlikely without significant external funding, given the significant financial losses incurred over the years.

Grouper is a high-value species ideal for RAS cultivation but self-financing will be tough

Grouper production is concentrated in Asia, with only two publicly listed Taiwanese companies identified. The sector has experienced significant financial loss over 2019–2021 due to the Covid-19 and political risks with mainland China. The closure of 'The Three Links' which enables shipments of seafood from Taiwan to Mainland China challenged the sector.

Much like pangasius, grouper is potentially the optimal species for RAS production but producers are unlikely to afford to invest without external funding – see Table 18.

Table 18: Total revenue, operating cash flow, average profit margin and capex/sales ratio of the grouper industry, 2012-2021 (USD million). Source: Refinitiv.										
Grouper	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Revenue	83	70	71	46	26	13	9	6.1	3.4	3.1
EBIT margin	-1.6%	-4.8%	-2.8%	-4.8%	-7.3%	-16%	-53%	-187%	-174%	-230%
Net profit margin	-0.6%	-11%	-5.5%	-5.1%	-19%	-16%	-53%	-426%	-294%	-324%
Operating cash flow	-1.9	-5.7	-5.3	-0.5	2.2	-4.2	0.1	-1.4	-1.8	-1.5
Capex/sales	6.3%	5.0%	1.3%	3.1%	4.8%	3.2%	34.2%	37%	45.2%	0.5%
OCF/Capex	-0.7	-2.0	-3.4	-0.3	4.2	-17.6	-1.6	-3.9	-4.6	-151.3

Financing the seafood demand gap

We estimate that capex of at least USD 55 billion up to USD 134 billion is required for technology and regenerative sustainability solutions to close the seafood demand gap and build out the infrastructure needed to feed a population of 9.7 billion by 2050 with sustainably farmed seafood. Given the limited self-financing abilities of many sub-sectors, with salmon as a notable exception, we found that investors and lenders will likely need to finance the majority of these solutions.

Growth in the capital invested in aquaculture has been strong. CREO, a New York-based non-profit organization[cvii] suggests that the total investment in the aquaculture sector is estimated to be USD 3.15 billion in 2022 compared to USD 150 million in 2020[cviii] – see Figure 27.

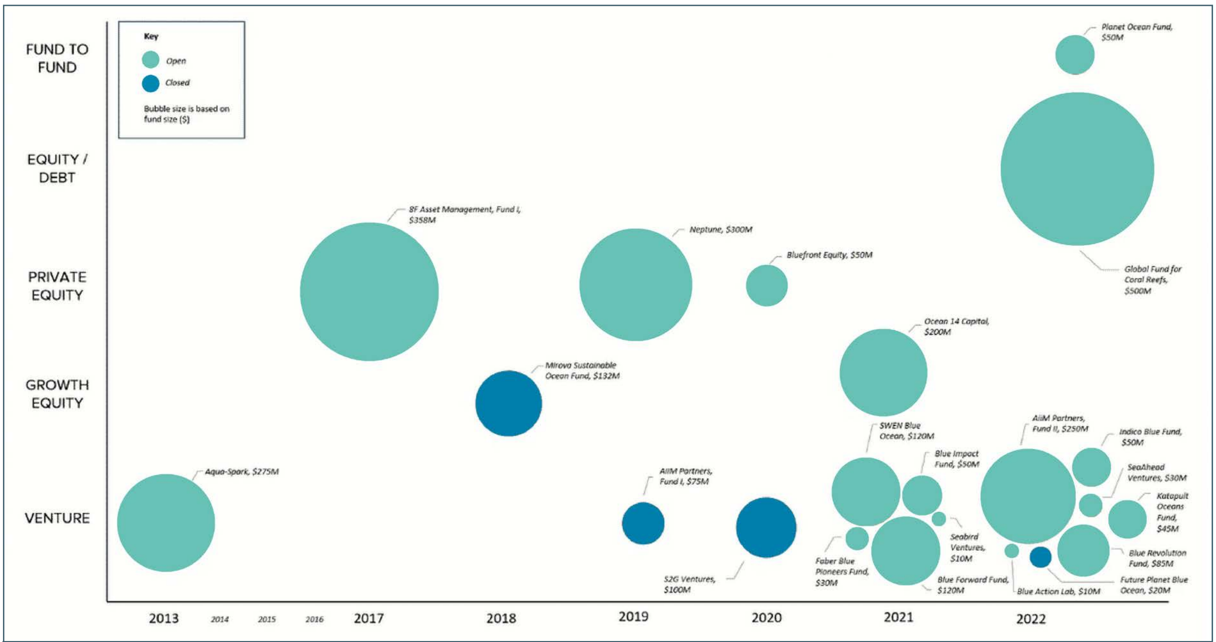


Figure 27: Aquaculture-related investment funds 2013-2022. Source: CREO/OSAIC.

Aquaculture financing: equity vs debt

Overall, the aquaculture sector has been financed by debt more than by equity. The average debt/equity ratio in the sector was 116% over the past decade.

Shrimp-related companies had the highest level of debt with a debt-to-equity ratio of 216% from 2012 to 2021. In other words, the shrimp industry has been financed with approximately 70% by debt and 30% by equity – see Figure 28.

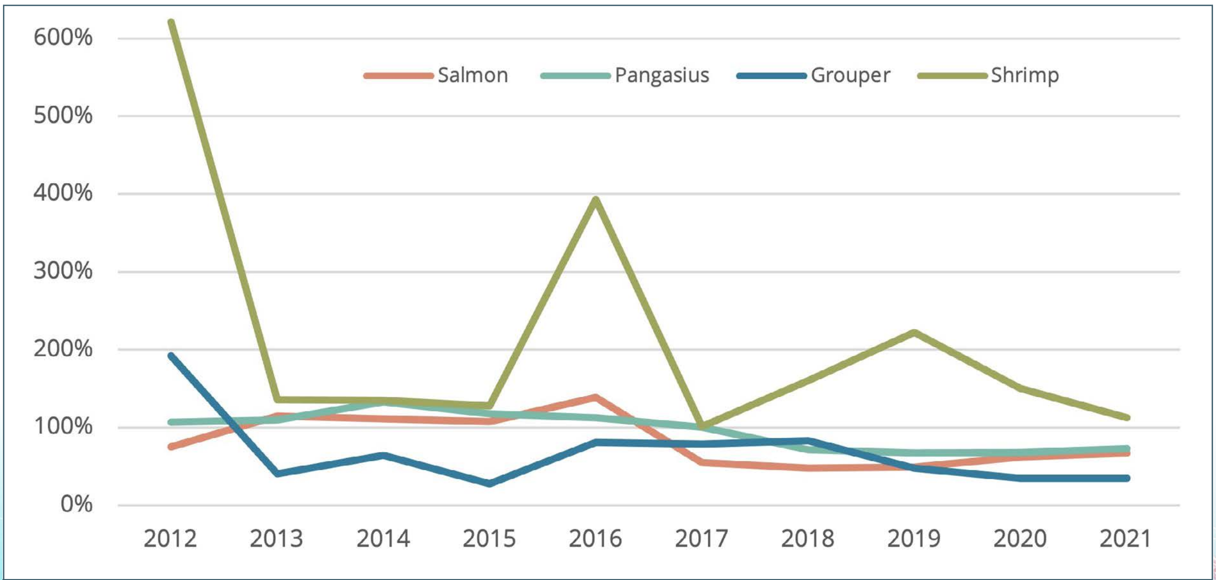


Figure 28: Debt/equity ratio by species type, 2012–2021.

Green debt for technology-based diversification, SLBs for regeneration?

Within debt instruments, the popularity of green bonds and sustainability-linked credit facilities shows that lenders to the aquaculture sector can and do engage with aquaculture companies.

When it comes to green bonds, corporates are required to issue reports outlining how the proceeds have been used in accordance with the green bond framework.

Green bonds make up 45% of the debt of Norwegian salmon companies, for instance. The ratio is lower in the shrimp industry at 14%, while the rest of the industry heavily relies on bank/syndicated loans – see Table 19.

Table 19: Debt instruments by species type. Source: Companies' financial reports, compiled by Planet Tracker.

	Salmon (Norway)	Salmon (ex. Norway)	Pangasius	Grouper	Shrimp	Bivalve
Bank loan as % of total non-current borrowings	29%	71%	91.3%	100%	65.6%	100%
Green bonds as % of total non-current borrowings	45%	0%	0%	0%	14%	0%

Green bonds could be suitable instruments to finance technology-based diversifications away from conventional aquaculture such as offshore, RAS or cultivated seafood.

Such bonds are probably less suitable for financing investments in bivalves and seaweed unless a bond is used to finance multiple investments at once, since these tend to be small in nature despite them having more sustainable characteristics.

In sustainability-linked credit facilities, a company's interest rate is linked to its performance against certain sustainability KPIs, such as the survival rate, economic feed factor and greenhouse gas emission intensity for Scopes 1 and 2, taking SalMar ASA as an example.[cix]

Sustainability-linked bonds could also be used by aquaculture companies to finance diversification towards regenerative aquaculture. For instance, one can imagine a KPI being: ***"by 2025, [x]% of our production volume will come from regenerative aquaculture."*** This would allow corporates to incur lower interest costs to finance their transition. Please see Bonds for Ponds for more examples of how bonds can be used to scale sustainable aquaculture production.

CALL FOR ACTION: CONVENTIONAL AQUACULTURE NEEDS TO CHANGE

Given the pressures of rising seafood demand on the planet's ecosystems, the financial risks associated with these pressures and the gap that seafood supply will face by 2050, it is clear that change is needed.

Concentrated, conventional fish monoculture needs to change to be more diversified, resilient, productive and environmentally sustainable – if not outright nature positive. The best example of nature positive aquaculture is regenerative aquaculture.

Aquaculture companies should therefore invest in raising the environmental standards of their production, and investors and lenders have a responsibility to assist them in doing so. At the same time, this presents them with many economic opportunities.

The risks of inaction are clear:

- Inability to feed the world with enough seafood protein
- Destruction of key ecosystems
- Reputational and financial risks
- Limits to growth, including legislative barriers
- Increase in costs due to increased biodiversity and other risks
- Punitive regulations or taxation

Actions for investors and lenders in aquaculture to take

- **Be aware of the increasing risks to production in a business-as-usual scenario** due to concentration, coastal conflict, production at intensities above sustainable limits and upcoming regulatory pressures
- **Demand better disclosure, transparency and traceability procedures** from companies to assist in better quantification and mitigation of these risks
- **Support the mitigation of these risks through diversification** of species and geographic distribution, especially if the species involved allow ecosystem restoration and provided that expansion in new areas does not increase the company's impact on biodiversityinvestments.
- **Support the mitigation of these risks through technology** which enables offshore, RAS and cultivated seafood, but **only if it is environmentally sound to do so**
- **Support regenerative aquaculture investments**
- **Offer cheaper capital for sustainable expansion** using the model discussed in "Bonds For Ponds" for novel feed or using sustainability-linked bonds.

Regulators can speed up the change

It is important to regulate for the optimal and equitable use of oceanic space, well before 2050. Regulations should be designed to balance energy production, wild-catch fishing, aquaculture production and conservation. This is a challenge which will require vast amounts of data for monitoring and reporting on oceanic conditions and flows into the natural environment such as sewage, plastic and agricultural runoff. **Increased monitoring will assist in boosting both aquaculture growth and the wild-catch recovery potential. Regulators are advised to deploy systems which can accurately inventory the impact of coastal actors, and legislate accordingly**.

Even without regulatory intervention, investors and lenders can and must help aquaculture companies transition. A business-as-usual demand gap of 50 million tonnes with worsening environmental impacts is too big a burden to bear by 2050.

APPENDIX 1:
UNSUSTAINABLE FISH MONOCULTURE LEADS TO FINANCIALLY MATERIAL BIODIVERSITY LOSS: LESSONS FROM CHILE

Chile's salmon industry has caused significant biodiversity loss

Chile is home to the second-biggest salmon-farming industry in the world behind Norway, and it is one of the top 10 aquaculture producing countries with the highest species concentration risk, as identified in the main report.

The combination of marine aquaculture and bivalve extraction (as opposed to aquaculture) led to a 70% reduction in rock crustaceans over just 10 years in the surveyed areas around the Comau Fjord in Chilean Patagonia.[cx] This has been attributed to not only the deoxygenation and eutrophication effects of marine aquaculture, but it also highlights the impact of products needed to sustain high-intensity aquaculture – in this case the use of antibiotics.

Although progress has been made over the last two decades, Chile's antibiotic use in 2007 provides a prime example of the impact aquaculture growth can have on ecosystems. In 2007, the volume of antibiotics used in Chile was more than 1,400 times the volume used in Norway per kg of salmon produced in the same year[21]. The comparative difference is only amplified when considering the application area for each nation: Chile's application area was 75% smaller than that of Norway. Disease and lice play a role in lowering production potential, and expansion beyond sustainable limits also threatens to undercut abiotic factors such as oxygen levels. These combined factors result in physical ecosystem limitations leading to farming mortalities while exacerbating disease and lice issues caused by higher stocking densities.[cxii]

Biodiversity loss can result in hefty financial losses

Unsustainable aquaculture practices have impacted Chile's aquaculture industry financially. Notably in 2012, volcanic activity reacted with salmon farm waste leading to fish mass-mortality and a coral-die off along 8.4 km of coastline and down to at least 70 meters in coastal waters.[xciii]

Many related incidents have occurred. In 2020, Mowi reported that 15,000 one-kilogram fish died due to low oxygen conditions in Los Lagos, Chile.[cxiv] Fisheries and the aquaculture service Sernapesca reported another fish die-off, a mass mortality of 1,600 tonnes in Chile's Aysen region, due to either low oxygen or harmful agal blooms in 2021.

As for farms themselves, expansion beyond natural limits negatively impact the economic productivity of ocean assets and undercut the ability for cost-effective growth and continued production for the sector and related sectors. In 2020, research from The Changing Markets Foundation highlighted the detrimental effect salmon production had on the productivity of the surrounding environment – see Table 20.

Table 20: Estimated welfare loss to households from destruction of wild salmon stocks attributable to aquaculture (USD million). Source: Changing Markets.

Region	2013	2014	2015	2016	2017	2018	2019
Norway	7.2	7.3	7.4	7.5	7.7	7.8	7.8
Scotland	9.6	9.7	9.7	9.8	9.9	9.9	10
Chile	24.9	24.9	24.9	28.1	28.1	28.1	28.1

[21] Chile 732 and 560 g/t versus Norway 0.02 and 0.07 g/t production

The Changing Markets report detailed significant concerns about the environmental impacts of farming non-native species in Patagonia, which is one of the world's most pristine ecosystems.

Oxygen injection shows that part of the Chilean salmon industry operates beyond sustainable limits

Currently, the integration of oxygenation technology in the Chilean salmon industry demonstrates expansion beyond sustainable limits, either due to ecosystem degradation caused by aquaculture, or stocking densities above sustainable limits. Oxygen injection is becoming more common in the industry, and is important for supporting production in more intensive or larger cage systems.[cxvi] Demand for these systems will only increase when paired with other mitigation technologies, such as lice skirts[22], and confidence in market uptake for salmon producers has led to more aggressive marketing strategies outside of Chile.[cxvii]

The conditions for success, therefore, are to innovate in the face of deteriorating environmental conditions through greater technological uptake or build aquaculture infrastructure with ecological parameters in mind.

[22] Lice skirts are a sheet of tear-resistant material, which encircle open net pens to keep pests and lice out of pen enclosures.

APPENDIX 2:
CONCENTRATED FISH MONOCULTURE LEADS TO FINANCIALLY MATERIAL DISEASES: LESSONS FROM THAILAND

The seafood industry in Thailand is currently facing a shortage of shrimp

Shrimp production in Thailand fell to 280,000 tonnes in 2022 due to disease issues vs a peak of 600,000 tonnes in 2011.[cxviii] Thailand's shrimp production volumes were among the largest in the world until 2012, when a disease called early mortality syndrome (EMS) began to damage the industry.

Due to shortages of available domestic shrimp causing processing factories to cut production, in August 2022 the Thai government announced a plan to import about 10,000 tonnes of shrimp from India and Ecuador.[cxix]

Out of the 280,000 tonnes of shrimp that Thailand produced in 2022, 264,000 tonnes were Pacific whiteleg shrimp (*Litopenaeus vannamei*) and 16,000 tonnes of black tiger shrimp, highlighting the very high species concentration of that industry.[cxx]

The EMS/AHPND disease that caused the heavy shrimp mortality is closely linked to concentration and biodiversity issues

The EMS disease, also called acute hepatopancreatic necrosis disease (AHPND) disease is deadly for shrimp with a 100% mortality rate for juvenile shrimp and has had a huge impact on the Thai shrimp industry. Between 2010 and 2016, **it caused financial losses of USD 11.58 billion in Thailand** and more than 100,000 job losses.[cxxi]

Importantly, while the bacteria that cause the disease are naturally found in coastal and estuarine waters, shrimp are more susceptible to infection given certain conditions, such as:

- High levels of nutrients in pond water from the addition of fertilisers or molasses
- Poor water circulation and low plankton biodiversity
- Build-up of organic sediments, such as unconsumed feed and shrimp carcasses

Other studies show that the **disease is less prevalent** in ponds colonized by copepods, small crustaceans used as live feed for the larvae of aquaculture animals. Copepod presence is an indicator of a **naturally mature or stable ecosystem**, as it requires constant amounts of phytoplankton and bacteria as feed.[cxxii]

APPENDIX 3:
CONCENTRATED FISH MONOCULTURE IS VULNERABLE TO RISING OCEAN COASTAL CONFLICT

Chile's salmon industry significantly overlaps with its marine protected areas

Enforced Marine Protected Areas (MPAs), rather than 'paper parks'[23], and no-take zones are key tools to support the recovery of oceanic ecosystems.

Chile has the largest marine area among Latin American countries under some category of protection: 41.5% of its maritime territory.[cxxiii] There is, however, a **significant overlap between the protected marine areas of Chile and its salmon production sites**: of the total 1,407 salmon-farming concessions in the country, 416 or **30%**, lie within protected marine areas[24].[cxxiv] The 416 concessions inside marine protected areas belong to 32 companies, with the top three responsible for more than a third of the concessions – see Figure 29.

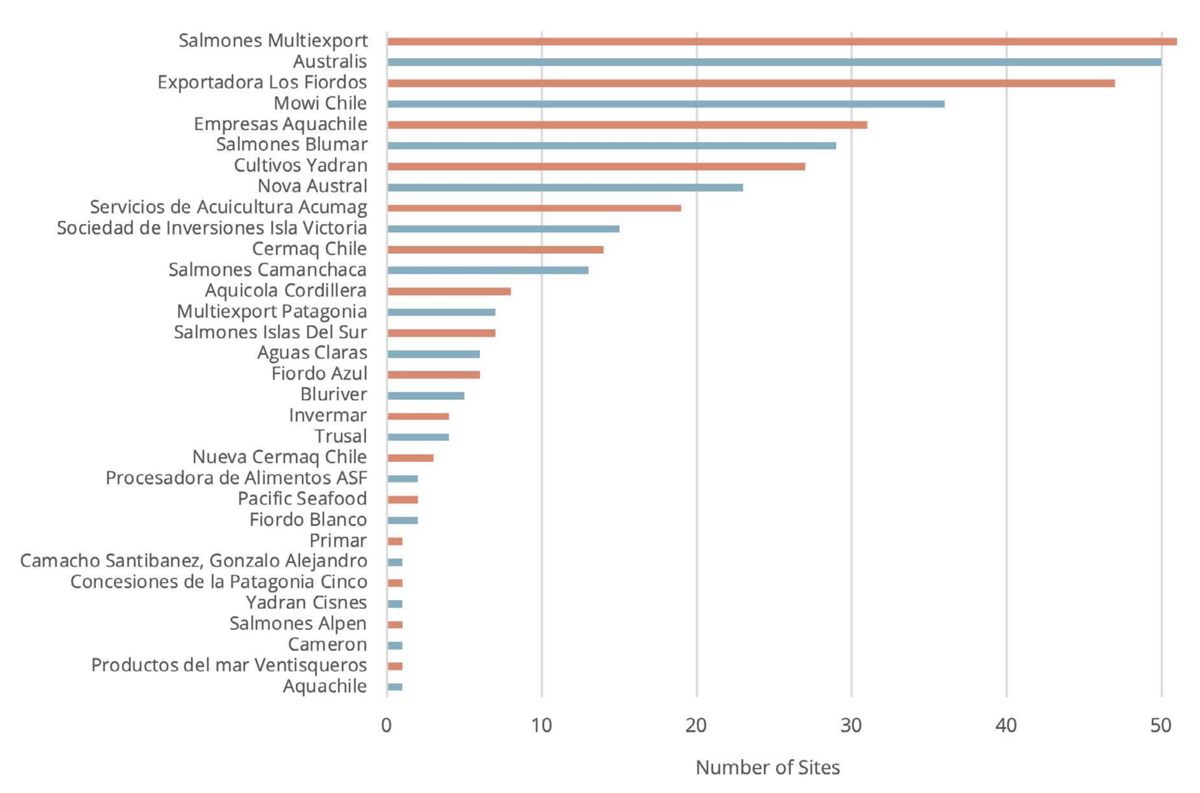


Figure 29: Ranking of companies with granted concessions within natural protected areas. Source: Chilean Undersecretariat of Fisheries, via Mongabay.[cxxv]

[23] 'Paper Parks' are Marine Protected Areas, which, while they are designated as protected, offer limited or poorly enforced measures to prevent commercial activity.

[24] The source data refers to granted concessions, not all of which are necessarily operating.

Globally, a strong growth in competing ocean claims

Incidences of aquaculture occurring within protected areas demonstrate that accessible space is conflicted, and commercial growth comes at the cost of the degradation of the volume or regenerative capacity of wild natural capital, or vice versa.

More than 40% of the global population lives in areas within 200 km of the ocean, and 12 of 15 megacities are coastal. This will increase competition for coastal resources while negatively impacting biodiversity along coasts due to intensifying anthropogenic pollution.[cxxvi]

The complex requirements for the maintenance and continuation of current consumption trends, such as food, shipping, energy production, alongside commitments to protect biodiversity through marine protected areas and no-take zones, means that competition for nearshore real estate will continue to become more intense. A growing number of claims on maritime resources have been split into food provision, material requirements and space – see Table 21 and Figure 30.

Table 21: Competing ocean claims. Source: Jouffray et al., 2019.[cxxvii]

Food	Material	Space
Seafood	Hydrocarbons	Shipping
Feed and nutraceuticals	Minerals	Pipelines and cables
	Desalinated water	Tourism and recreation
	Ornamental resources	Land reclamation
	Genetic resources	Renewable energies
	Scientific information	Geoengineering
		Waste disposal
		Conservation
		Territorial boundaries
		Military activities

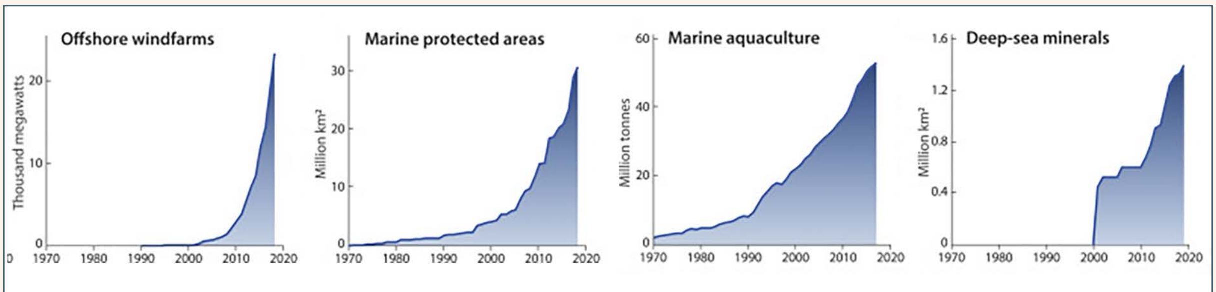


Figure 30: Growth of commercial activities in the ocean space. Source: Jouffray et al., 2019.[cxxviii]

Areas suitable for aquaculture often overlap rich fishing areas, shipping lanes or viable renewable energy areas, so conflict for space between these areas is likely. For an example of how wind farms and seafood farms overlap – see Figure 31 or see the online version of the map for greater detail.

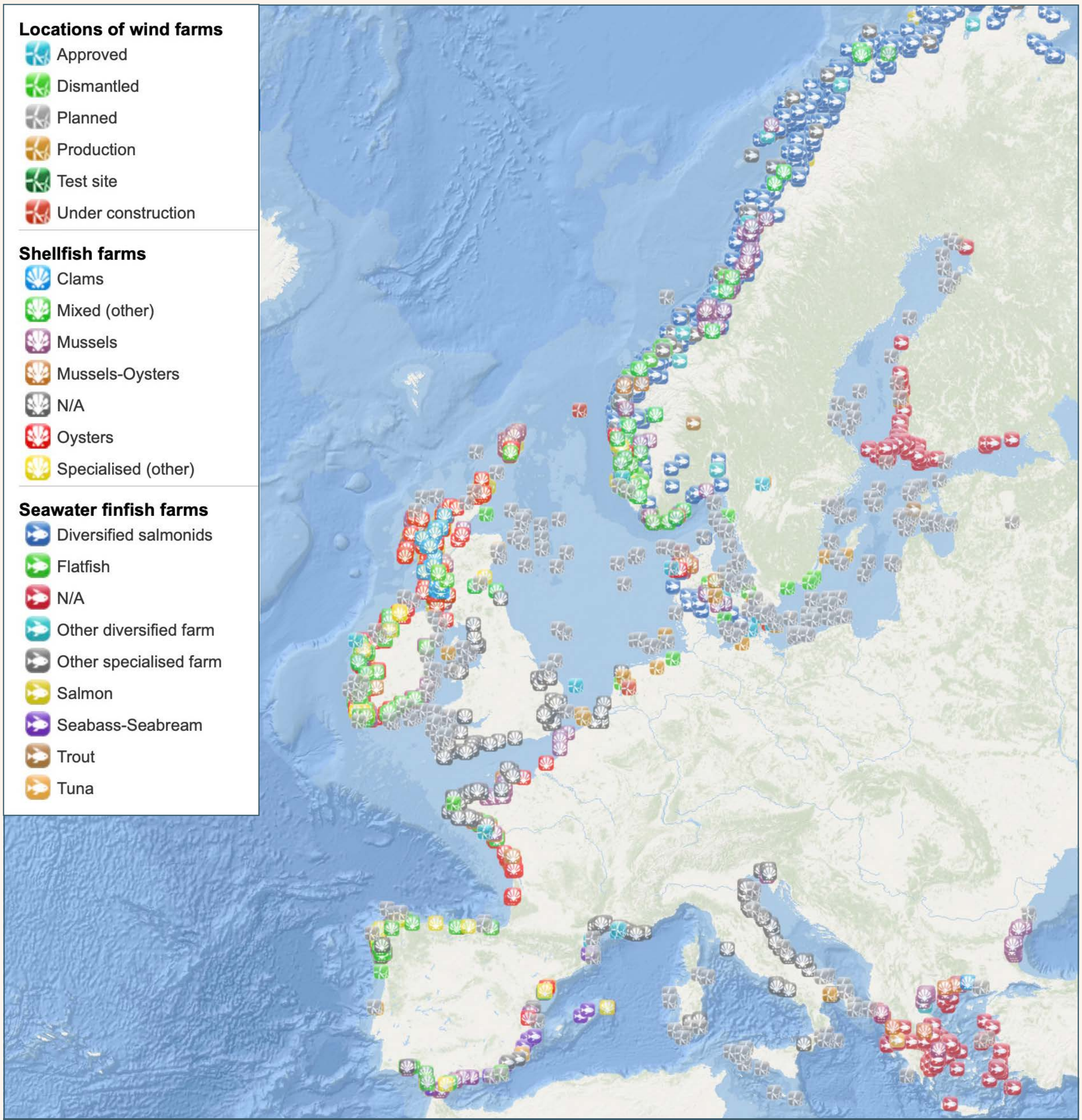


Figure 31: Overlap between aquaculture farming and wind farms in Europe.[cxxvix]

As stated above, conflicts already exist between conservation and commercial interests, but friction is also building between different industries. In 2021, American fishers filed a legal challenge against the United States' first large-scale wind project due to the disruptive effect it will have on seafood production,[cxxx] a story repeated in the United Kingdom's Shetland Islands.[cxxxi] Offshore wind production is expected to be a major driver in coastal space use to 2050 – see Figure 32.

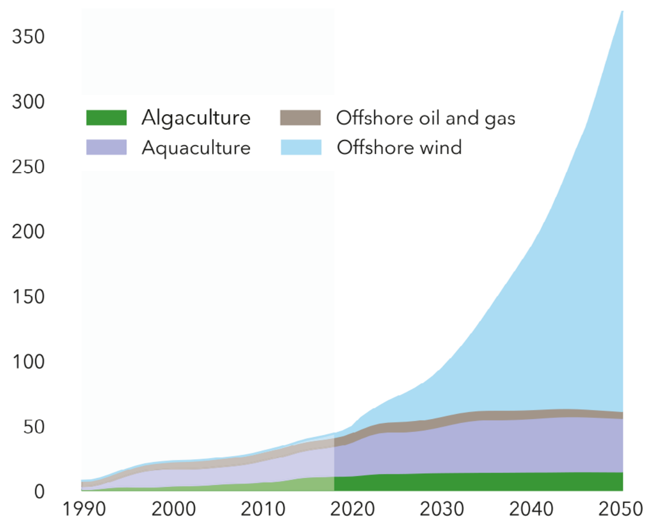


Figure 32: Spatial requirements for coastal installations in thousand square kilometres, 1990–2050.[cxxxii]

Conflict between ocean actors is not limited to legal risk. In 2021, 70 local fishing boats surrounded a wind farm installation vessel to protest the construction of the Saint-Brieuc offshore wind farm in France.[cxxxiii] Poorly optimised coastal space may spark conflict which creates operational risk, and in the case of aquaculture production this may lead to higher production losses on site. Poor coastal siting may also have an adverse effect on the surrounding biodiversity, and this is often most pronounced around keystone or sensitive ecosystems.

In sum, the concentration of aquaculture production exacerbates its vulnerability to biodiversity risk, which might make it less attractive than other competing ocean-based activities in the eyes of governments or regulators.

Regulatory risk drives coastal site scarcity

Competition for aquatic real estate has led to the introduction of regulation which will limit the expansion of aquaculture and set the threshold for acceptable impacts to the environment. In Europe, Denmark introduced legislation that came into force in 2021, which removed the option to offset impacts of fish farming developments and placed regulating fish farming under the Environment Ministry's control in order to restrict the growth of the nation's mariculture sector to protect ocean health.[cxxxiv] A similar system exists in Norway. It restricts the level of maximum allowable biomass due to biological factors (i.e., sea lice).

This is not limited to Europe. AquaChile, Chile's largest salmon farmer, is reportedly contemplating leaving all its concessions located in national parks after conversations with Chile's Undersecretaries of Fisheries and Aquaculture in November 2022, as a result of the government's sustainable aquaculture development initiative – moving salmon farming away from protected areas.[cxxxv] In Argentina, the southernmost province of Tierra del Fuego unanimously approved a bill prohibiting salmon farming in July 2021, citing the risk to native biodiversity.[cxxxvi] In Canada, a similar decision took place in 2020 in which regulators committed to phasing out salmon aquaculture and moving to closed systems due to the associated environmental impact.[cxxxvii]

Marine aquaculture production which exceeds natural thresholds, in particular concentrated, intensive aquaculture, will therefore face intensifying regulatory pressure to 2050.

APPENDIX 4:
WHY WILD-CATCH SEAFOOD PRODUCTION IS CAPPED

Oceanic seafood populations are exploited faster than they can regenerate

In marine ecosystems, the direct exploitation of organisms, mainly via fishing, now covers over half the surface of the oceans.[cxxxviii] Only 13% of the oceans are regarded as wilderness.[cxxxix]

It now takes five times the effort (in kilowatt-hours) to catch the same volume of fish as it did in 1950 due to declining fish biomass, despite efficiency increases (see Figure 33 below) such as better fishing gears, vessels, navigation systems and fish-finding methods.[cxl] This is because technology also exacerbates overfishing in poorly regulated fisheries by allowing fishers to obtain profits at progressively lower fish abundance and repeatedly downshifting the equilibrium of fish biomass in open access[25] agreements to lower and lower levels.[cxli]

Downward shifts in ecological equilibriums towards low trophic species creates a vicious circle in and of itself. Overfishing can lead to jellyfish blooms. Jellyfish in turn feed on fish larvae and juveniles, further reducing the resilience of fish populations already impacted by overfishing.[cxlii] Downward trends in wild stock biomass, despite technological improvements, mirror a similar increase in the operational expenditure required to catch fish – see Figure 33 and Figure 34.

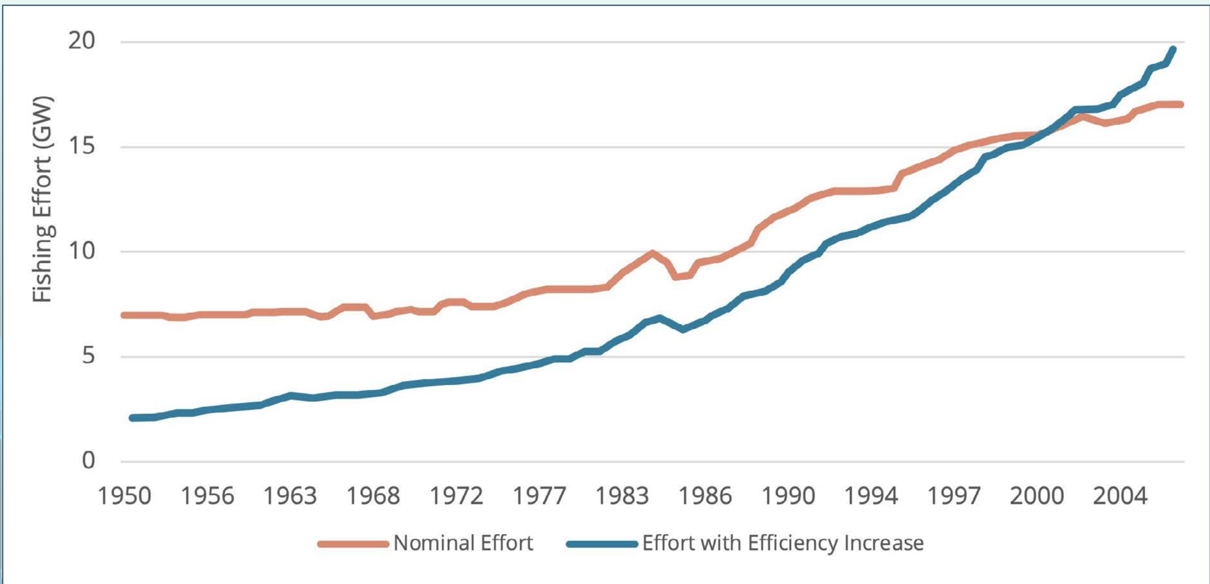


Figure 33: Reconstructed global catch and effort. Estimated nominal effort and effective effort assuming an increase in efficiency of 2.4% per year.[cxliii]

[25] Open access is the condition where access to the fishery for the purpose of harvesting fish is unrestricted, (i.e., the right to catch fish is free and open to all).

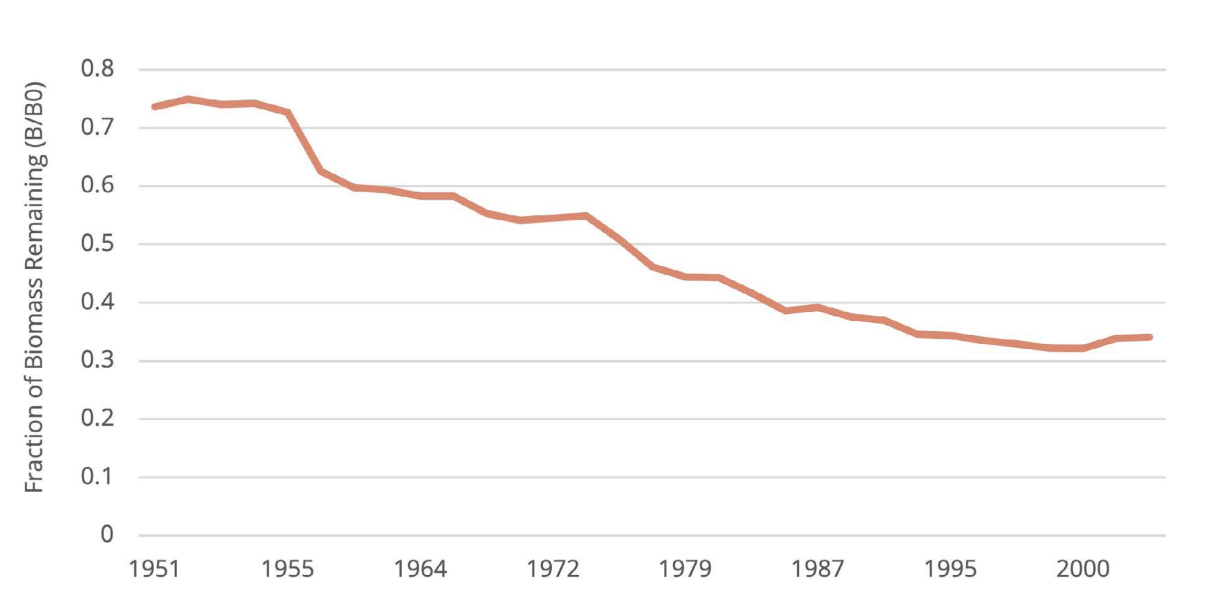


Figure 34: Estimated biomass as a fraction of pristine biomass from stock assessment data.[cxliv]

Climate change increases the challenge in managing seafood biomass

Managing wild fish stocks effectively is becoming more challenging as the effects of climate change are felt to mid-century – as discussed in Pollockonomics. Climate change, including increases in frequency and intensity of extreme weather events has been impacting the availability and trade of seafood, creating a plethora of country-specific risks. These risks shown in Figure 35, are exacerbated by poor governance causing environmental degradation and habitat destruction, leading to:[cxlv]

- Pressure on resource bases
- Overfishing
- Illegal, Unreported and Unregulated (IUU) fishing
- Disease (in both farmed and wild species)
- Impact from fish escapes and non-native species
- Change in accessibility and availability of sites and water resources for aquaculture
- Access to credit, seeds and expertise for aquaculture

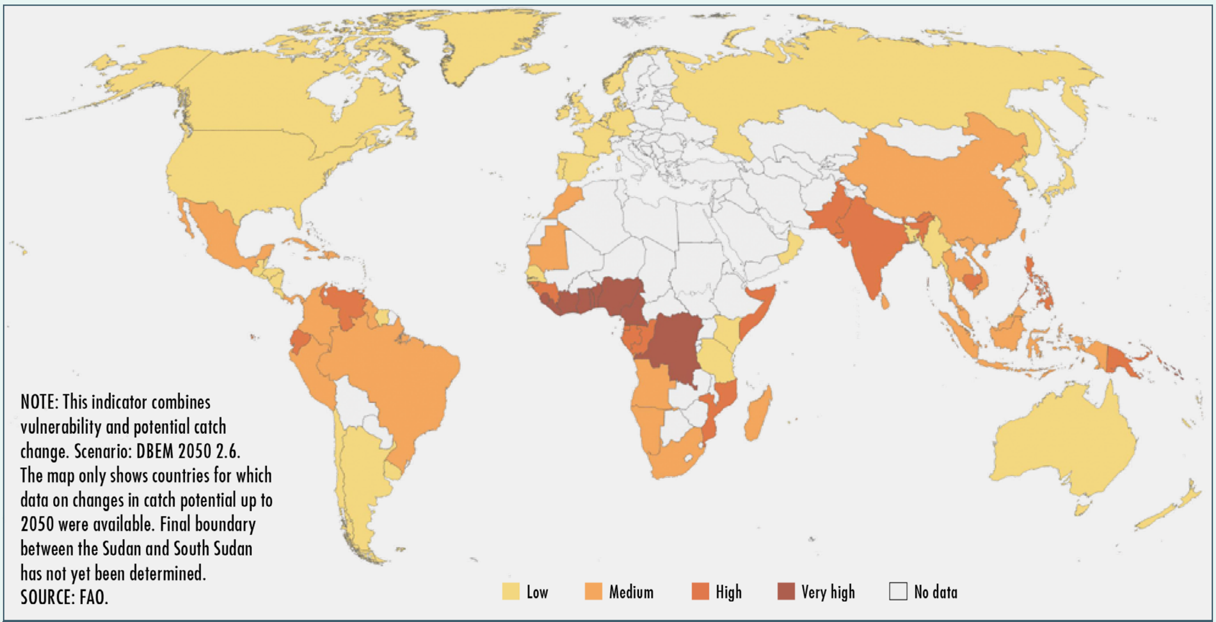


Figure 35: Climate change impact on marine capture fisheries and vulnerability: risk by country. Source: FAO.[cxlvi]

Moreover, impaired regulatory processes caused by habitat destruction and biodiversity loss, paired with higher ambient temperatures due to climate change decrease resilience against shocks, such as heatwaves. Since 1990, marine heat wave days (MHWs) have increased by over 54%, and these have amplified – and have sometimes been caused by[26] – biodiversity loss.[cxlvii] See Pollockonomics for an example of how a MHW impacted a whole industry, causing hefty financial losses.

Capped production potential for wild-catch

Exploitation of wild fish stocks at or beyond sustainable levels is high and rising. Improved fishing technology paired with rising wild-catch seafood consumption and a growing population will likely continue to increase the proportion of overexploited and collapsed stocks – see Figure 36.

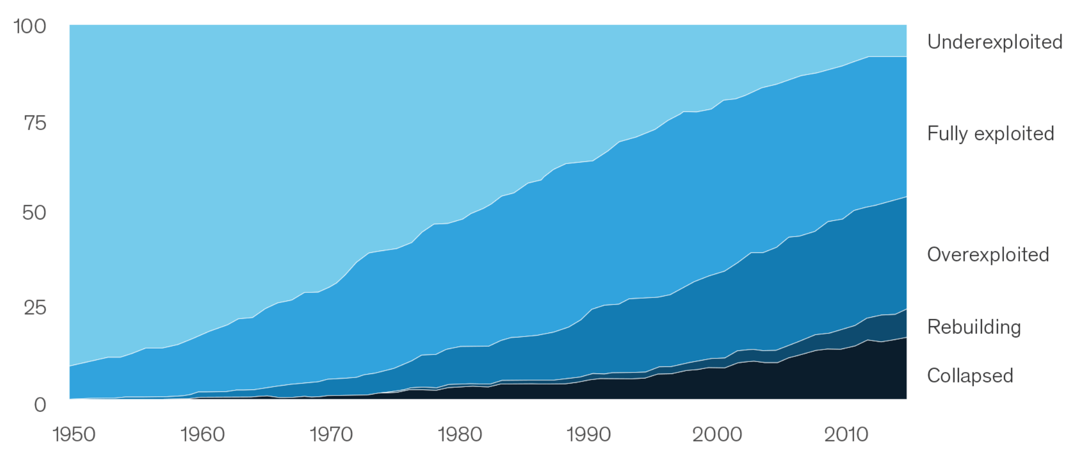


Figure 36: Status of wild-catch fish stocks, 1950-2020.[cxlviii] *Source: McKinsey & Company.*

[26] This refers to anomalous warming events associated with influx of invasive non-native species.

As a result, wild-catch production is expected to remain relatively flat. According to the FAO, 2050 wild-catch production will reach 98.3 million tonnes (live weight equivalent) while the numbers in 2020 and 2000 were 90.3 and 95.4 million tonnes, respectively.[cxlix]

Yet, maintaining healthy populations of fish would not just improve wild-catch production numbers but also create positive feedback loops to permit optimal oceanic conditions for wild-catch fisheries and aquaculture despite climate change impacts.

Research published in *Nature* in 2020 states that maintaining high biodiversity may mitigate the impact of seabed acidification on otherwise highly vulnerable key organisms such as corals, sponges and algae by 50% to more than 90%, depending on the species. Higher biodiversity is associated with higher availability of food resources and healthy microbe-host associations, which increase host resistance to acidification, while contrasting harmful outbreaks of opportunistic microbes.[cl]

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ABOUT PLANET TRACKER

Planet Tracker is a non-profit financial think tank producing analytics and reports to align capital markets with planetary boundaries. Our mission is to create significant and irreversible transformation of global financial activities by 2030. By informing, enabling and mobilising the transformative power of capital markets we aim to deliver a financial system that is fully aligned with a Net Zero, nature-positive economy. Planet Tracker proactively engages with financial institutions to drive change in their investment strategies. We ensure they know exactly what risk is built into their investments and identify opportunities from funding the systems transformations we advocate.

SEAFOOD TRACKER

Seafood Tracker investigates the impact that financial institutions can have on sustainable corporate practices through their funding of publicly listed wild-catch and aquaculture companies. Our aim is to align capital markets with the sustainable management of ocean and coastal marine resources. Seafood Tracker is a part of the wider Planet Tracker Group of Initiatives.

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