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FACTS ABOUT FINFISH AQUACULTURE

Additional information and references to the FEAP infographics

Version: 20 December 2024, Author: Tamás Bardócz

FISH FARMING PRODUCTION

The global finfish aquaculture sector experienced an average annual growth rate of 3.82% between 2012 and 2022. During the same period, European finfish aquaculture grew at an annual rate of 3.3%, resulting in an increase of nearly 1 million tonnes. Within the EU-27 member states, the annual growth rate was 2.03%, contributing an additional 101 thousand tonnes to total finfish production[1] (Table 3Table 1).

Currently, the finfish production of the EU-27 accounts for 30% of the apparent consumption of aquaculture fish products within the EU. These figures highlight the EU aquaculture sector's significant production growth capacity and strong market potential for further expansion. (Table 3)

Table 1. Production volumes of the main European finfish aquaculture species and FEAP member's production (including Türkiye) in 2022 (tonnes)

	FAO FISHSTAT J Data.[1]			FEAP report	FEAP share from world production
	World production	**European production**	**EU 27 production**	**FEAP production**	
Atlantic salmon	**2,869,418**	1,910,055	**13,081**	**1,899,674**	66%
Rainbow trout	**1,004,300**	334,723	**169,930**	**402,551**	40%
Gilthead seabream	**344,393**	110,947	**106,837**	**245,402**	71%
European seabass	**293,619**	93,597	**90,882**	**256,577**	87%
Common carp	**4,012,665**	155,816	**63,866**	**53,464**	1%
Turbot	72,634	12,632	12,632	12,721	18%
Sole (Solea solea and Solea senegalensis)	1,730	1,728	1,728	1,728*	100%
Atlantic Bluefin Tuna	37,107	32,231	32,231	25,700	69%
Meagre	49,724	11,489	11,431	12,108	24%
North african catfish	252,870	10,562	10,012	7,901	2%

[1] Data reference: FAO. 2024. FishStat: Global aquaculture production 1950-2022. [Accessed on 29 March 2024]. In: FishStatJ. Available at www.fao.org/fishery/en/statistics/software/fishstatj. Licence: CC-BY-4.0.

Table 2. EU 27 self-sufficiency data for fishery and aquaculture products (EUROSTAT 2022 data) (EUMOFA., 2024)

	Fishery and aquaculture products (t)	Aquaculture products (t)	Finfish aquaculture products (t)
Apparent consumption	10,551,630	3,040,207	1,906,257
EU production	3,927,128	1,088,672	564,782
Share of EU production	**37%**	**36%**	**30%**

Table 3. Aquaculture production volumes in 2022 (tonnes), growth rate and growth volume since 2012 1

	Total production in 2022 (t)	10 years avg. growth rate (%)	Increase since 2012 (t)
World aquaculture production	130,920,757	4.04%	42,728,568
World finfish production	61,566,804	3.82%	19,215,818
Europe total production	4,055,850	2.91%	997,858
Europe finfish production	3,406,483	**3.33%**	**934,269**
EU 27 aquaculture production	1,121,308	1.01%	100,803
EU 27 finfish production	570,273	**2.03%**	**101,228**

CONTRIBUTION OF FISH FARMING TO SDGs

Troell et al. (2023) investigated how the diverse aquaculture sector contributes to achieving the United Nations' Sustainable Development Goals (SDGs) and its potential to expand these contributions.

Aquaculture is a unique sector that encompasses all aquatic ecosystems (freshwater, brackish/estuarine, and marine) and is also tightly interconnected with terrestrial ecosystems through, for example, feed resources and other dependencies. Understanding environmental, social, and economic characteristics of the multifaceted nature of aquaculture provides for more context-specific solutions for addressing both opportunities and challenges for its future development. In this paper the contributions of aquaculture to SDGs were summarised as follows:

Direct contributions are linked to the aquaculture food production capacity eliminate hunger and improving human health (SDGs 2, 3).

Sustainable aquaculture technologies indirectly contribute to SDGs with increased environmental sustainability of oceans, water, climate and land through responsible production and consumption (SDGs 6, 12, 13, 14, 15).

Associated contributions of aquaculture to SDGs can reduce poverty, help to achieve gender equality while also improving livelihoods and reducing inequalities (SDGs 1, 5, 8, 10)

Contributions related to aquaculture technologies are the potential for energy production (e.g. Multiple Use of Marine space and land), food production possibility in cities (e.g. RAS, Aquaponics), contribution to technology development and development of various partnership (local to global) (SDGs 7,9,11,17)

FISH FEED INGREDIENTS

Due to the result of intensive R&D work, the composition of salmon feed has changed significantly since 1990. In 1990, the average **salmon feed** consisted **of 65.4% marine protein**, which decreased **to 24.8% by 2010** and further dropped to just **12.1% in 2020** for salmon feeds produced in Norway (Aas et al., 2022a).

The expected increasing use of novel, alternative feed ingredients, from circular economy processes also will improve the sustainability of fish feeds. In 2020 the ratio of new, alternative ingredients like insect meal, single cell protein, fermented products, and microalgae in all Norwegian salmon feed was 0.4%, 8126 tonnes. (Table 4)

FIFO (Fish In Fish Out) and FFDR (Forage Fish Dependency Ratio) are important metrics used to **assess the dependency of aquaculture on marine resources**, particularly with regard to fish feed.

The FIFO ratio represents the amount of fish used to produce 1 kg of farmed fish. The amount of fish required is dependent on the amount of feed necessary to support 1 kg of growth, which is also known as the (economic) Feed Conversion Ratio (eFCR). (Kok et al., 2020)

The FIFO does not differentiate between cut-offs or forage fish. FIFO is not an indicator of sustainability, it only shows the amount of ingredients originating from the marine environment. (Aas et al., 2022a)

The overall fed aquaculture figure shows a marked decrease from 0.47 to 0.19, essentially meaning that for every 0.19kg of whole wild fish used in fishmeal production, a kilo of farmed fish is produced. (https://www.iffo.com/fifo-data)

The Forage Fish Dependency Ratio (FFDR) is another simple metric for calculating the quantity of wild (forage) fish used in feeds in relation to the quantity of fed animal production. A similar calculation is used by the salmon industry described as Recaptured Fish in fish out (rFIFO) which excludes the trimmings and the fish meal and oil produced from by-products of salmon processing from the calculation of these ingredients required to produce 1 kg of salmon. (https://www.iffo.com/fifo-data) (

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Table 5)

The Forage Fish Dependency Ratio **(FFDR) value for salmonids in 2020 was 0.64**, for marine fish 0.52 and 0.01 for cyprinids. (www.iffo.com/fifo-data)

Table 4. Sources of feed ingredients (% of feed) in Norwegian salmon feed (Aas et al., 2022b, 2022a)

	1990	**2000**	**2010**	**2012**	**2013**	**2016**	**2020**
Marine protein sources	65.4	33.5	24.8	19.5	18.3	14.5	12.1
Vegetable protein sources	0	22.2	35.5	36.7	36.7	40.3	40.3
Marine oils	24	31.1	16.6	11.2	10.9	10.4	10.3
Vegetable oils			12.5	18.3	19.2	20.2	20.1
Carbohydrate sources	9.5	11.2	8.4	11.1	11.2	10.6	12.5
Micro ingredients	1	2	2.2	3.1	3.7	4	4.1
Other ingredients							0.4
Total Marine ingredients	89.4	64.6	**41.4**	30.7	29.2	24.9	**22.4**
Total Plant based ingredients	9.5	33.4	56.4	66.1	67.1	71.1	72.9

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Table 5. Forage Fish Dependency Ratio (FFDR) of various aquaculture species groups (IFFO data)

Species	2000	2010	2020
Crustaceans	1.29	0.62	0.31
Marine Fin Fish	1.77	0.74	0.52
Salmonids	2.43	1.4	0.64
Eels	2.29	1.13	0.93
Cyprinids	0.08	0.02	0.01
Tilapias and other cichlids	0.5	0.19	0.08
Freshwater Fish	0.57	0.33	0.2
Turtles and Frogs	1.07	0.63	0.5
Total Fed Aquaculture	0.38	0.15	0.13

Table 6. Main feed ingredient sources % of fish feed

Source	Industry data average in Norway (Aas et al., 2022a, 2022b)		Model feed in various trials, FEAP feed price estimations	Research recommendation (Roy and Mraz, 2021)
Species	**Atlantic salmon**	**Rainbow trout**	**Sea bass and Sea bream**	**Carp**
Marine protein sources	12.1	13.4	18	10
Other Animal proteins			24.95	35.31
Vegetable protein sources	40.5	39.7	18.38	0
Marine oils	10.3	10.8	7	0
Vegetable oils	20.1	19.9	7.34	1.53
Carbohydrate sources	12.5	12.1	22.09	52.04
Micro ingredients	4.1	3.9	2.24	1.12
Other ingredients	0.4	0.2		

Feed-food competition is the allocation of resources that can be used to feed humans to animal feed instead. To gain insight into feed-food competition is to use the human-edible protein conversion ratios (HePCR) to quantify the net contribution of farmed fish to the supply of human edible protein. The HePCR equals the ratio of human edible protein in feed (input) to the human edible protein in the animal product (output). (Van Riel et al., 2023)

HePCR ratios of aquaculture species (HePCRe:0.2–2) are lower than broilers (HePCRe 5.2) and industrially produced pigs (HePCRe 4.5).

FEED CONVERSION RATIO (FCR) IN FISH FARMING

The primary finfish species contributing 91% of total European finfish production—Atlantic salmon, Rainbow trout, European seabass, Gilthead seabream, and Common carp—require 0.94 to 2.4 kg of formulated feed to produce 1 kg of fish (harvested weight), based on the sector's **economic Feed Conversion Ratio** (eFCR) values. The eFCR measures the amount of feed needed to produce a unit of fish or shrimp, taking into account feed wastage as well as production losses, such as mortalities.

Economic FCR = Total feed consumed (kg) / Total weight gain of the cultured species (kg)

Table 7. Species group eFCR values with median values of aquaculture literature data and wide range of referenced FCR data of other livestock animals

Species group	Min	Max
Salmonids	0.94	1.44
Marine fish	1.7	2.4
Carps	1.16	2
Fish (median range)	1.19	2.05
Chicken	1.7	2.1
Pig	2.7	5
Beef	5.18	15.8

Some studies also use the **biological FCR** data (bFCR) which is a more theoretical metric used to define the biological efficiency of the feed (and/or animal). It removes any non-consumed feed and production losses from the calculation to allow for that focus on the biological efficiency. The bFCR is always lower than the eFCR.For each species, both FCR value can be very different because it is affected by:

- Age class: fingerlings and juveniles usually have lower FCR.
- Feed Quality: High-quality feed typically results in better growth and lower FCR.
- Health and Genetics: Healthier and genetically superior stock generally have better FCRs.
- Environmental Conditions: Optimal water quality, temperature, and other environmental factors can enhance feed conversion efficiency.
- Feeding Practices: Proper feeding techniques, such as appropriate feeding times and quantities, can improve FCR.
- Management Practices: Controlled production technology, optimal stocking density, proper health management, stress minimalisation etc. can improve the FCR.

In other animal husbandry sectors, FCR values vary even more widely due to significant differences in species, breeds, feed types, feeding technologies, and husbandry practices.

Table 8.FCR data of the main aquaculture species and terrestrial animals from studies and industry documents

Species	FCR	Note	Reference
Atlantic salmon	1.3	eFCR, company data	("MOWI Salmon Farming Industry Handbook 2023," 2023)
	1.28	eFCR, traded feed basis, industry level data	(Aas et al., 2022a)
	1.12	bFCR data from PEF study	(Technical Secretariat, 2024)
	1.3	FCRs are average values based on Tacon and Metian (2008)	(Fry et al., 2018)
European Seabass	1.7-2.2	Data from Turkey	("Improvement Feed Conversion Ratios (FCR's) of seabream for a private fish farming company, Turkey," n.d.)
	2.4	Italian farm data	(Zoli et al., 2023b)
Gilthead Seabream	1.9	Italian farm data	(Zoli et al., 2023a)

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	1.8-2.2	Mediterranean industry data	("JUL | AUG 2016 - International Aquafeed magazine by Perendale Publishers Ltd - Issuu," 2016)
Rainbow trout	1.44	eFCR, traded feed basis, Norway	(Aas et al., 2022b)
	1.061	eFCR, genetically improved fish from Finnish breeding program	(Kause et al., 2022)
	1.1-1.2	eFCR farm data from Italy, 60-300t farmas	(Maiolo et al., 2021)
	0.94 – 1.1	eFCR data from Germany, Denmark and Turkey	(Lasner et al., 2017)
	1.3	FCRs are average values based on Tacon and Metian (2008)	(Fry et al., 2018)
Common carp	4-5	Wheat and corn supplemental feeding	(Kiss, 2023) Not reliable data, rejected
	1.16-1.2	Pellet feeding in RAS	AllerAqua facebook posts
	1-3.5	Pellet feeding in pond	(Woynárovich et al., 2023) not reliable data, rejected
	1.7	FCRs are average values based on Tacon and Metian (2008)	(Fry et al., 2018)
	2	FCR of 2 kg feed per kg of total weight gain per pond including losses was used in the baseline scenarios, as suggested by literature	(Biermann and Geist, 2019)

Species	FCR	Comment	Reference
Chicken	2-2.1	kg DM/ kg live weight	(Mekonnen et al., 2019)
Pig	3.3	kg DM/ kg live weight	
Beef	12.4-15.8	kg DM/ kg live weight	
Turkeys	3.0	kg DM/ kg live weight	
Beef	5.18 – 9.33	Table 3.	(Davison et al., 2023)
Chicken	1.7-2.0	Smil (2013) (livestock species) Shike (2013) (cattle) Zuidhof et al (2014) (chicken) Rabobank Research (2015) (pigs)	(Fry et al., 2018)
Pig	2.7-5.0		
Beef	6.0-10		

CARBON FOOTPRINT OF FISH FARMING

The tool commonly used to assess the environmental sustainability of food production systems is life cycle assessment (LCA). LCA is an ISO-standardized methodology, which quantifies the impacts on ecosystems, human health and natural resources stemming from products and systems throughout their entire life cycle, i.e. from the extraction of the raw materials through their production and use or operation up to their final decommissioning and disposal. (Bohnes et al., 2019)

In the **Impact Assessment** (Life Cycle Impact Assessment - LCIA) the most relevant Environmental Impact Categories must be selected and the emissions from the LCI are allocated to each selected impact category. For example in fish farming the most relevant impact categories can be:

- Global warming potential (GWP): GWP expresses the impact of each Green House Gas - GHG (CO_2, CH_4, N_2O) in terms of the equivalent amount of CO_2 (called CO_2-equivalents or CO_2e) over a specific time frame (commonly 100 years).
- Land use: Transformation and use of land for fish production, feed production, roads, housing, mining or other purposes. The impact can include loss of species, organic matter, soil, filtration capacity, permeability. In LCA studies it is expressed as "m^2a" stands for square meter per year.
- Water use and consumption: Analyze water use efficiency and consumption rates in aquaculture systems.

Table 9. Summary of GWP data from various studies (in CO2e/kg live weight)

Species group	Min	Max
Salmonids	3.8	5.4
Marine fish	2.6	3.6
Carps	3.02	6.9
Fish (median range)	3.1	4.96
Chicken	3.7	8.9
Pig	3.9	10
Beef	14	82

The outcomes of the LCA studies depend very much on the defined **system boundaries** and **functional unit**. For example, the average CO2 emission per life cycle phase for farmgate salmon is 3.8 kg CO2e/kg LW salmon, while including the primary processing and transport in the system boundaries, head-on gutted products that are shipped by road or sea have a carbon footprint between 5-6 kg CO2e/kg edible product (Functional Unit) deliver to the wholesaler. (Johansen et al., 2022) Generally, airfreighted salmon aquaculture products from Europe to Asia or USA have a carbon footprint in the range from 16-28 kg CO2e/kg edible product delivered to wholesaler. For these finfish aquaculture product supply chains, airfreight is accounting for 68-82% of the carbon footprint. (Johansen et al., 2022)

For feed based aquaculture, feed production is the main impact driver and up to the farmgate contributes 75% of total farmgate CO2 emissions in case of salmon and it is between 60%-93% for Mediterranean production of sea bass and sea bream. (Johansen et al., 2022, Zoli et al., 2023a, Zoli et al., 2023b)

Table 10. CO2 emissions of main European aquaculture species and livestocks, calculated for 1 kg for farm gate product and primary processed, transported products

Species	Functional Unit (FU)	CO2 equivalent emission / FU (kg)	Reference
Atlantic salmon	1 kg Live weight	3.8	(Johansen et al., 2022)
Atlantic salmon	1 kg fresh head-on gutted to Paris by Truck	5.0	(Johansen et al., 2022)
Atlantic salmon	1 kg fresh head-on gutted to USA by Air	20.3	(Johansen et al., 2022)

Atlantic salmon	GHG emissions ($kgCO_2e\ kg^{-1}$) Median values from Fig. 1: Stressor posterior distributions., Values represent kg of edible weight and use mass allocation.	5.1	(Gephart et al., 2021)
Rainbow trout from extensive farm	1 kg of live rainbow trout at farm gate RAS data rejected	2.2	(Samuel-Fitwi et al., 2013)
Rainbow trout from intensive flow-through		3.5	
Rainbow trout from RAS		13.6	
Rainbow trout (flow through, Italy)	1 kg of live rainbow trout at farm gate	2.8	(Maiolo et al., 2021)
Trout	GHG emissions ($kgCO_2e\ kg^{-1}$) Median values from Fig. 1: Stressor posterior distributions., Values represent kg of edible weight and use mass allocation.	5.4	(Gephart et al., 2021)
European seabass	1 kg of fish biomass (whole body) at the harvest size, farm gate	3.1	(Zoli et al., 2023a)
		3.6	(Aubin et al., 2009)
Gilthead Seabream	1 kg of fish biomass (whole body) at the harvest size, farm gate	3.6	(Abdou et al., 2017)
		2.6	(Zoli et al., 2023b)
Common carp	1 kg of fish biomass (whole body) at the harvest size, farm gate	5.98	(Biermann and Geist, 2019)
		3.02	(Bürgés et al., 2020)
Misc. carps	GHG emissions ($kgCO_2e\ kg^{-1}$) Median values from Fig. 1: Stressor posterior distributions., Values represent kg of edible weight and use mass allocation.	6.9	(Gephart et al., 2021)
Silver/Bighead carp		3.5	
Chicken		7.8-8.9	
Beef	Mean GWP (kg CO_2/kg Edible Yield)	27	(C. A. Roberts, 2015)
Pork		6	
Chicken		4	
Beef	No reference indicated	39	MOWI Industry Handbook Not reliable data, rejected
Pork		12.2	
Chicken		8.4	
Beef (herd)	Greenhouse gas emissions are measured in kilograms of carbon	82.1	Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through
Beef (dairy herd)		26.7	

Pig meat	dioxide-equivalents (CO_2eq) per kilogram of food Land use change+Farm+Feed	9.0	producers and consumers. Science, 360(6392), 987-992. – processed by Our World in Data (https://ourworldindata.org/grapher/food-emissions-supply-chain)
Poultry		6.9	
Chicken	Recalculated results of each study to a FU of 1 kg of Live Weight (LW) Global warming potential (GWP) for livestock products in CO2-equivalents (CO2-e) per kg of product.	3.7-6.9	(de Vries and de Boer, 2010)
Beef		14-32	
Pork		3.9-10	

FRESHWATER USE OF FISH FARMING

Freshwater use in marine aquaculture and freshwater aquaculture differs significantly due to the very different production systems and technologies. In marine aquaculture, consumptive freshwater use is minimal, with most water use tied to the production of fish feed. Feed production involves processes such as crop irrigation, which indirectly require large volumes of freshwater. However, the aquaculture operation itself relies on seawater for rearing, thus requiring limited freshwater resources on-site.

In contrast, freshwater aquaculture is directly dependent on freshwater systems for both ecosystem services and production needs. In freshwater aquaculture distinction must be made between freshwater consumption and water withdrawal or degradative use (Gephart et al., 2017). The portion of water that is not returned to the source is considered consumed water. This includes water lost through evaporation, incorporated into products and organisms, or lost through infiltration. On-farm evaporative losses may account for over 60% of water consumption for freshwater pond aquaculture (Gephart et al., 2021), but fish pond evaporation also contributes to microclimate regulation by cooling the air, increasing humidity, interacting with wind patterns, and supporting local ecosystems. Conversely, water returned to the environment includes the exchange of water from aquaculture systems, which may contribute to the replenishment of water flows.

The importance of water use in aquaculture has been highlighted by researchers like Samuel-Fitwi et al. (2013), who stressed the need for standardized methodologies to evaluate water use in aquaculture systems. Various studies have used unique approaches to assess water use, but a unified framework remains elusive. For instance, one study analyzed water use across production systems by simply comparing the volume of water required annually to produce one ton of trout. Such comparisons can provide valuable insights but also underline the methodological challenges in defining water use in aquaculture.

Table 11. Summary of data on freshwater use (m3/kg) of edible yield or live weight of various fish cultures and terrestrial animal production

	Species group	Min	Max
Data analysis	Atlantic salmon	0.156	2.35
	Marine fish	0.4	4
	Trout	0.113	4.38
	Carps	3.1	9.2
Infographic data	Marine fish	1.3	2.2

	Freshwater fish	2.2	6.2
	Chicken	0.4	9
	Pig	1.7	17
	Beef	1.4	150

Table 12. Detailed data about freshwater use of main finfish aquaculture species and other animals

Species	**Freshwater use m³/kg of edible yield or live weight**	**Note**	**Reference**
Atlantic salmon	2 – 2.35	Multiple studies for (EY)	(C. A. Roberts, 2015)
Atlantic salmon	0.156	Median data from several studies, calculated for edible weight	(Gephart et al., 2021)
Rainbow trout	0.113		
Misc. marine species	0.4		
Salmoniformes	2.8	Water per kg production. Feed-associated water use in aquaculture for major species groups.	(Verdegem et al., 2006)
R. trout extensive (Exteme high)	473	water use among the different production systems by simply comparing the amount of water used per year for producing 1 kg (recalculated from tonne production) of trout	(Samuel-Fitwi et al., 2013)
R. trout intensive (most common system)	4.38		
R. trout RAS (extreme low)	0.01		
European seabass and Gilthead seabream	4	Mean Freshwater Water Use (m³/kg Edible Yield)	(C. A. Roberts, 2015)
Common carp	3.1	Estimation of feed associated water use in inland and brackish water aquaculture	(Verdegem et al., 2006)
Misc. carp sp.	3.5	Median data from several studies, calculated for edible weight	(Gephart et al., 2021)
Silver and bighead carp	9.2		
Beef	150	Various, pasture and feed lot plus national averages. Ireland, Sweden, EU, Australia, US FU mainly live weight or carcass weight Allocation mass, gross energy, system expansion	(C. A. Roberts, 2015) Mean Freshwater Water Use (m³/kg Edible Yield)

Pork	17	Conventional, traditional, organic, certification scheme. Denmark, Germany, France Spain Netherlands, US. FU mainly live weight Allocation economic, system expansion, gross energy	
Chicken	9	Various, pasture and feed lot plus national averages. Ireland, Sweden, EU, Australia, US FU mainly live weight or carcass weight Allocation mass, gross energy, system expansion	
Beef (dairy herd)	2.7	Freshwater withdrawals per kilogram of food product Freshwater withdrawals are measured in liters per kilogram of food product.	https://ourworldindata.org/water-use-stress Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. Science. – processed by Our World in Data
Beef (beef herd)	1.4		
Pig Meat	1.7		
Poultry Meat	0.66		
Chicken	0.425-0.505	industrial chicken produced in the USA and Europe, estimated chicken minimum to maximum range expressed in terms of live weight	(Gephart et al., 2021)

LAND USE OF FISH FARMING

Land use in aquaculture involves the physical footprint of operations and the broader ecological impacts of farming activities. Generally, most land use in aquaculture is associated with feed production for fed systems. Expanding aquaculture production, and reducing the share of fishmeal used in fish feed, can lead to increased oilseed crop production and trade (Heimann and Delzeit, 2024). Innovations such as integrated systems, urban aquaculture, and technological advancements are helping to reduce the land footprint of aquaculture while meeting growing global demand for seafood.

Land use, especially conversion of natural areas, results in a range of context-dependent biodiversity impacts and GHG emissions and creates potential trade-offs with alternate uses, including production of other foods. On-farm land use is low (<1,000 m^2 annual terrestrial land occupation per tonne, m^2a/t; <10%) for most intensive aquaculture systems and highest (3,737–8,689 $m^2a\ t^{-1}$) for extensive ponds (for example, milkfish, shrimp and silver and bighead carp). (Gephart et al., 2021)

Table 13. Calculation of land use of pond aquaculture production in Europe

Pond production surface use	Semi-intensive pond production	Extensive pond production

Production/ha	1200	kg	600	kg
Area for 1 kg production	**8.33**	**m²**	**16.67**	**m²**
Average production yield of cereals used as feed in pond production (2018 Hungary data)			5418	Kg/ha
FCR	2		1	
Feed production area required	**3.692**	**m²**	**1.846**	**m²**
Total production area	***12.03***	***m²***	***18.51***	***m²***

In Europe the main species produced in extensive ponds is Common carp where annual land use calculations include the required pond surface use and land use for supplementary grain production. In our calculation the typical semi-intensive production yield was 1200 kg/ha market size fish, while in extensive systems the average yield is 600 kg/ha. We calculated with supplementary grain feeding in both systems, but the FCR is much lower in an extensive system because of the higher relative yield from natural production. The average grain production yield (including wheat, maize, barely, rye) was calculated according to the Hungarian 2023 statistical data as 5418 kg/ha. Based on this assumptions, the land use per year of semi-intensive and extensive carp ponds is calculated in Table 13

Table 14. Total land use of finfish production and other animals including feed production areas

Species	Mean Land Use (m²/kg Farm gate (FG) or Edible Yield (EY)	Note	References
Atlantic salmon	4.86	Median data for EY, recalculated from annual terrestrial land occupation per tonne m2a/t	(Gephart et al., 2021)
Rainbow trout	3.81		
Rainbow trout extensive	1.2	Comprehensive LCA on different systems FG, Land competition (LC) m2a	(Samuel-Fitwi et al., 2013)
Rainbow trout intensive	1.0		
Rainbow trout RAS	1.4		
European seabass and Gilthead seabream	1.3 – 1.4	Comprehensive LCA on different sites FG.	(Abdou et al., 2017)
Misc. carps	11.4	Median data for EY, recalculated from annual terrestrial land occupation per tonne m2a t−1 For extensive ponds	(Gephart et al., 2021)
Silver/Bighead carp	8.22		
Beef	81		(C. A. Roberts, 2015)
Pork	14		

Chicken	6	Mean values calculated for Edible Yield	
Beef (beef herd)	326.21		https://ourworldindata.org/grapher/land-use-per-kg-poore Land use is measured in meters squared (m²) per kilogram of a given food product. Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. Science. – processed by Our World in Data
Beef (dairy herd)	43.24		
Pig Meat	17.36		
Poultry Meat	12.22		
Beef	27-49	Recalculated results of each study to a FU of 1 kg of Live Weight (LW) required m2 land	(de Vries and de Boer, 2010)
Pork	8.9-12.1		
Chicken	8.1-9.9		

CIRCULARITY IN FISH FARMING

By utilizing by-products and improving resource efficiency in aquaculture can play a crucial role in meeting the growing global demand for fish while also make the finfish aquaculture production mor sustainable.Replacing food-competing feedstuffs—such as cereals, whole fish, vegetable oils, and pulses—with food system by-products could boost the global food supply by up to 13% in terms of calories and 15% in protein content. This approach promotes a more circular food system, enhancing resource efficiency and reducing environmental pressures.(Sandström et al., 2022)

New fish feeds (Aquafeed 3.0) will use ingredients produced through the circular bioeconomy, which can improve aquaculture's sustainability by reducing its environmental footprint in terms of water and land use, CO2 conversion, GHG emissions, nutrient recycling and wastewater remediation. Aquafeed 3.0 will be based on raw materials that are nutritionally superior and closer to the natural diet of many carnivorous aquatic species than the terrestrial plant and animal by-products currently being used. There are already several examples of new aquafeed ingredients that are produced through circular bioeconomy frameworks, such as insects, microbial single-celled organisms, seaweeds and fishery and aquaculture processing byproducts. (Colombo and Turchini, 2021) (Table 15, Table 16)

Chary et al.(2023) identify six priorities for achieving a more circular aquaculture system:

1. Increasing production and demand for essential species: Focusing on species that require fewer resources and have lower environmental impacts.
2. Enhancing feed efficiency and resource utilization: Improving feed conversion ratios and utilizing alternative feed ingredients to reduce reliance on wild fish stocks and agricultural crops.
3. Reducing waste and promoting recycling within the system: Implementing waste management practices that allow for the reuse and recycling of nutrients and materials.
4. Integrating aquaculture with other food production systems: Developing integrated multi-trophic aquaculture (IMTA) systems and combining aquaculture with agriculture to create synergistic effects.
5. Encouraging the use of renewable energy sources: Transitioning to renewable energy to power aquaculture operations, thereby reducing greenhouse gas emissions.
6. Implementing effective governance and policy frameworks: Establishing policies that support circular practices and promote collaboration among stakeholders.

Table 15. List of traditional used ingredient for formulation of aquafeeds and its possible replacement alternatives (Conceição et al., 2020)

Traditional ingredient	Alternatives
Fish meal (FM)	Fish Protein Hydrolysate, Processed Animal Proteins, Yeast meal, Vegetable meals / protein concentrates of European origin (pea, rapeseed, sunflower), Insect meal
Commodity Vegetable Meals (Includes soybean meal, Soy Protein Concentrate, Faba meal, Lupins meal, Wheat meal, Corn meal,Pea meal, Sunflower meal, Rapeseed meal)	
Fish oil (FO), soybean oil	FO from trimmings, Single cell oil, vegetable oils (linseed, rapeseed, sunflower), Poultry fat, Insect oil
Premixes and additives	Microalgae, macroalgae and yeast products

Table 16. List of emerging ingredients including source, major benefits and target inclusion for experimental aquafeed formulations (Conceição et al., 2020)

Emerging commercial ingredients	Source	Major "benefits"	Alternatives to	Target inclusion levels in projects
Insect meals	Tenebrio, Hermetia	Protein	FM, VPC	5-10%
Insect oil	Tenebrio Hermetia	Lipids, Lauric acid (antimicrobial)	FO	0-1%
Heterotrophic microalgae	Schizochytrium	Protein, HUFA	FO	1-4%
	Chlorella	Protein	FM, Antioxidants	1-10%
Autotrophic microalgae	Nannochloropsis	Protein, HUFA´s, antioxidants	FM, FO, Antioxidants	1-3%
	Chlorella	Protein, antioxidants	FM, Antioxidants	1-3%
Single cell protein/meals	Bacteria	Protein, nucleotides	FM, nucleotides	5-10%
	Yeast	Protein, nucleotides	FM, nucleotides	2-5%
Vegetable meals	Faba, Lupins, Wheat, corn, Sunflower, Rapeseed	Protein	Non European Soya meal	Depends on the species
European Vegetable Protein Concentrate (VPC)	Pea, potato, wheat gluten, corn gluten, Sunflower, lupin, rapeseed	Protein	FM, non European VPC	Depends on the species
Macroalgae		Binders, minerals	Starch rich producs, premixes	1-4%

ECOSYSTEM SERVICES OF FISH FARMING

Aquaculture, particularly freshwater and marine extensive farming systems, provides a multitude of ecosystem services that are crucial for both environmental sustainability and human well-being (Figure 1). These services can be categorized into provisioning, regulating, cultural, and supporting services, each contributing to the overall functionality and health of ecosystems (Bardócz, 2024).

Provisioning services are perhaps the most recognized benefits of aquaculture, primarily through the production of fish and other aquatic organisms for human consumption. Carp pond aquaculture, for instance, has been highlighted for its role in food production while simultaneously supporting local economies through diversification strategies that enhance market reach (Turkowski, 2021). Moreover, aquaculture systems can also provide raw materials such as reeds, which are essential for various ecological functions and have been shown to correlate with nutrient cycling and habitat provision for wildlife (Sharma et al., 2023).

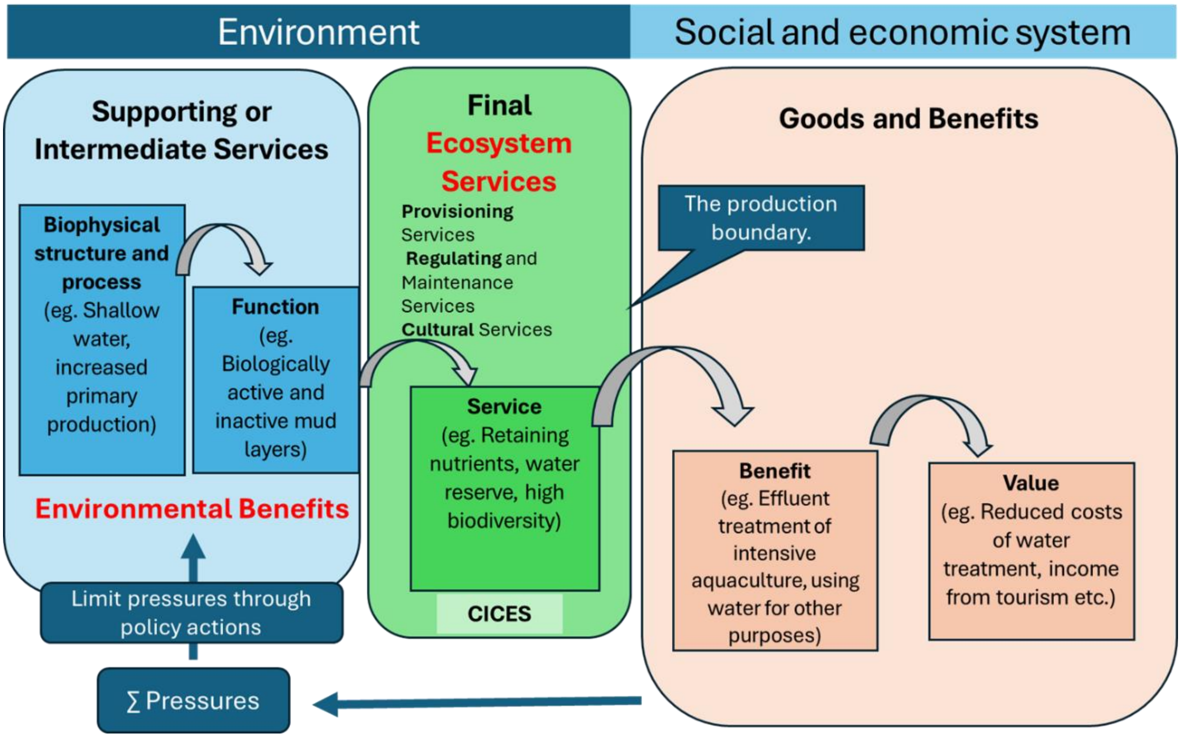

Figure 1. The cascade model of ecosystem services and the scope of this study after Haines-Young and Potschin (2018) (Bardócz, 2024)

Regulating services are also significant in aquaculture systems. These include water purification, nutrient cycling, and habitat provision, which collectively enhance biodiversity and ecosystem resilience. For example, the establishment of multi-purpose fishpond systems can mitigate the impacts of climate change by maintaining water quality and supporting diverse biological communities (Palásti et al., 2022). Additionally, the integration of ecosystem services into aquaculture management practices can lead to improved ecological outcomes, as highlighted by the ecosystem service framework that supports an ecosystem approach to aquaculture (EAA) (Willot et al., 2019).

Cultural services, which encompass recreational, educational, and aesthetic benefits, are increasingly recognized in aquaculture. Fish ponds not only serve as sites for fish production but also provide spaces for recreational activities such as angling and nature tourism, thereby contributing to the cultural heritage and community well-being (Popp et al., 2019). The multifunctionality of these systems underscores their value beyond mere food production, promoting a holistic view of aquaculture that includes social and economic dimensions (Landuyt et al., 2014).

Supporting services, which underpin the other categories, include processes such as soil formation, nutrient cycling, and primary production. The health of aquaculture ecosystems is vital for sustaining these processes, as they ensure the long-term viability of fish farming practices. Research has shown that effective management of fishpond systems can enhance these supporting services, thereby fostering a more sustainable aquaculture industry (Palásti et al., 2020).

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