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Review

Recent Trends and Economic Aspects in the Rainbow Trout (*Oncorhynchus mykiss*) Sector

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Abstract: In recent decades, the global aquaculture sector has become more complex and dynamic due to several factors, such as strong demand at the retail level, diversification of farmed species, outsourcing of product processing, and synergies among producers, processors, and retailers. Globally, the fish food sector has become very important to meet the growing human demand for food. In 2020, 89% of fish production was used for direct human consumption (17% of the total protein consumed). Global fish consumption has increased (excluding algae) at an annual rate of 3% since 1960. In 2030, the total fish production is expected to reach 202 million tons (MT) and the aquaculture production 106 MT. The United Nations has estimated that, between now and 2030, the global demand for fish products will increase by at least 40 MT each year. This need cannot be satisfied by fishing alone, given that fishing practices have reached an intensity that is unsustainable, and that climate change and pollution are worsening the problems of marine ecosystems. European and Italian aquaculture is characterised by a diversification scenario in terms of production systems, technologies adopted, and species bred. According to an EU report, Italian aquaculture production has grown by 4% in the last five years (fourth place in Europe). In Italy, rainbow trout is the most widely farmed species. The production of rainbow trout contributes approximately 25.5% of the total value and 69.9% of the volume of farmed fish. Over the past ten years, trout production has increased by 8.5% overall with an average annual growth rate of 2.5%. The purpose of this review is to provide an overview of the economic situation of the rainbow trout production and consumption sectors in Italy using a supply chain approach. In particular, in this brief excursus, the main production trends and the economic and organisational relationships between the various companies and associations in the aquaculture sector are analysed.

Keywords: aquaculture; rainbow trout; production; economic analysis

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1. Aquaculture Production

1.1. Global Aquaculture Production

According to the FAO [1], global aquaculture production nearly tripled from 34 MT in 1997 to 82 MT in 2020 (Table 1). Freshwater fish production accounts for 62% of total production. Globally, total fish production, compared to 1997, increased by 40%. However, the majority of global fish production remains limited to only 22 of the 425 farmed species (Table 1) [2].

Table 1. Inland world aquaculture production of major species.

Species	Production (×1000 t) 2020	% of Total
Grass carp, *Ctenopharyngodon idellus*	5791.5	11.8
Silver carp, *Hypophthalmi-chthys molitrix*	4896.6	10
Nile tilapia, *Oreochromis niloticus*	4407.2	9
Common carp, *Cyprinus carpio*	4236.3	8.6
Catla, *Catla catla*	3540.3	7.2
Bighead carp, *Hypophthalmichthys nobilis*	3187.2	6.5
Carassius spp.	2748.6	5.6
Striped catfish, *Pangasianodon hypophthalmus*	2520.4	5.1
Roho labeo, *Labeo rohita*	2484.8	5.1
Clarias catfishes, *Clarias* spp.	1249.0	2.5
Tilapias nei, *Oreochromis* spp.	1069.9	2.2
Wuchang bream, *Megalobrama amblycephala*	781.7	1.6
Rainbow trout, *Oncorhynchus mykiss*	739.5	1.5
Black carp, *Mylopharyngodon piceus*	695.5	1.4
Largemouth black bass, *Micropterus salmoides*	621.3	1.3

Source: FAO, 2022 [1].

The main producers of salmonids (excluding Asia) are Norway and Chile, which account for approximately 2% of global production (primarily Atlantic salmon (*Salmo salar*)). In 2019, global trout production stood at 940,000 tonnes [1]. The main farmed species is rainbow trout, which accounted for 97% of the total volume. In 2019, trout production increased by 21% in volume compared to 2015.

Over the past decade, total annual fish catches have shown wide variations, while aquaculture production has increased steadily [1] (Table 2). Over the period 2001–2020, aquaculture production grew by an average of 5.3% per year. According to a recent study, global investments in the aquaculture sector are expected to significantly increase in the coming years [3]. In Western countries, fish farming is mainly based on one or two species using a single production system. In recent decades, the fish farming sector has taken advantage of significant improvements in the genetic and nutrition fields. Aquaculture growth has been stimulated by the strong expansion of global trade, fish availability in freshwater streams and lakes, competitive product prices, rising personal incomes, and increased urbanisation. Asia remains the largest producer of fish products, accounting for 92% of the total production by volume. The largest producers of Atlantic salmon are Norway, Chile, and Scotland, and those of rainbow trout are Norway, Chile, and Turkey (Figure 1).

Table 2. World fisheries and aquaculture production (×1000 t).

	Fisheries			Aquaculture			
Year	**Marine**	**Inland**	**Total**	**Marine**	**Inland**	**Total**	**Total**
2010	77,820	11,271	89,099	22,310	36,790	59,100	148,200
2011	82,623	11,124	93,747	23,366	38,698	62,065	155,813
2012	79,179	11,630	91,350	24,707	41,948	66,655	158,025
2013	80,899	11,687	92,586	35,536	44,686	70,223	162,810
2014	81,564	11,895	93,460	26,727	47,104	73,832	167,292
2015	81,179	12,525	93,704	27,879	48,761	76,641	170,345
2016	79,288	11,635	90,923	28,703	51,360	80,071	170,395
2017	81,200	11,900	93,100	30,000	49,000	79,603	172,700
2018	84,400	12,000	96,400	30,800	51,300	82,100	178,500

Source: FAO, 2022 [1].

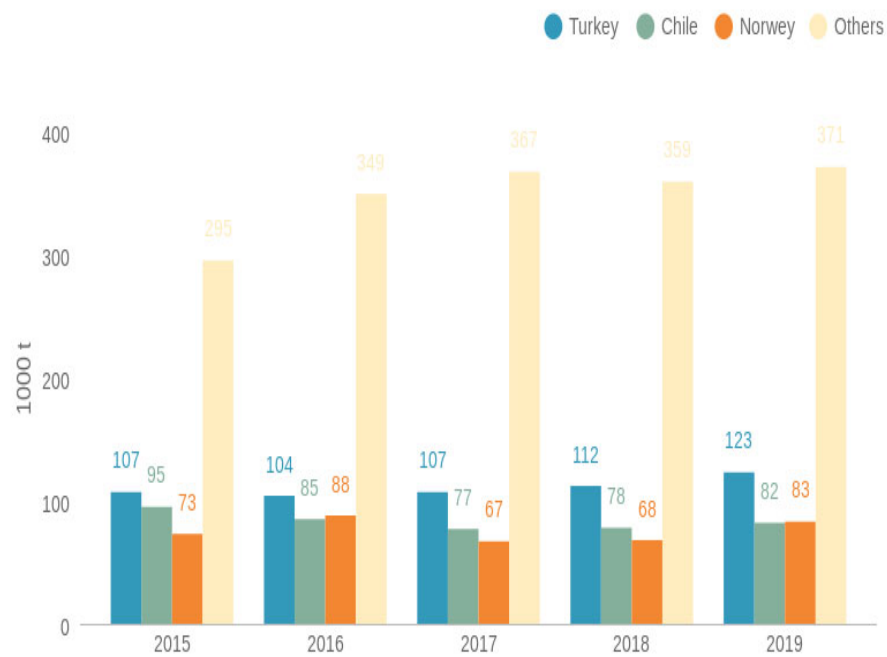

Figure 1. Major producers of rainbow trout worldwide (×1000 t). Source: FAO, 2022 [1].

In Asia, the recent increase in freshwater aquaculture production is due to the higher demand for fish in urban areas and a reduction in inland and rural fishing activities. The process of globalisation has been very rapid, with widespread increases in household incomes and the expansion of markets, especially in developing countries (which have grown more rapidly than developed countries). According to the FAO, global fish production in 2020 was 178 MT [1]. However, aquaculture production is unevenly distributed. China leads in both fisheries and aquaculture, with a total production of 66.8 MT, followed by Indonesia, India, Vietnam, and the United States [1]. China is the world's largest exporter, followed by Norway, Vietnam, the United States, Thailand, and Turkey (Table 3).

Table 3. Main exporting and importing nations of aquaculture products in 2020.

Country	Export	Country	Import
China	14.1	USA	14.0
Norway	7.6	Japan	9.3
Vietnam	5.1	China	5.9
Thailand	4.1	Spain	5.0
USA	4.1	France	4.6
Chile	4.0	Italy	4.0
Holland	4.0	Germany	4.0

Source: FAO, 2022 [1].

Developed countries account for 75% of total imports. The United States is in first place for imports of aquaculture products (15.2% of the total), while Japan is in second place at 10.3%. The growth of domestic markets, particularly in Asia, has led to a reduction in the trade of fish products in international markets.

1.2. Aquaculture Production in the European Union

In 2018, the aquaculture sector of the European Union (EU) achieved a production of EUR 5.1 billion, with EUR 1.7 MT of traded fish. In the EU, fish production is mostly concentrated in five countries: Spain (21%), France (15%), Italy (14%), the United Kingdom (14%), and Greece (10%) [4]. Table 4 shows the aquaculture production and fishery sectors at the global level, in the EU, and in Italy.

Table 4. Production of farmed fish in the world, in the EU and Italy (×1000 t).

	World	EU	Italy	% World	%EU
Fisheries	93,204	5253	192	21	4
Aquaculture	111,966	1372	156	14	11
Total	205,170	6625	348	17	5

Source: FAO, 2020 [1].

Table 5 shows the main salmonid species farmed globally. In the EU, the recent increase in aquaculture production is due to the increase in marine fish products, while freshwater fish production has remained constant. In Europe, between 2002 and 2015, marine aquaculture production increased by 60% (mainly driven by Atlantic salmon production in Norway) [5], while in the EU, it increased by only 4%.

Table 5. World production of the main salmonid species (×1000 t).

	2010	2012	2014	2016	2018	% Total
Atlantic salmon	1437	2074	2348	2247	2435	4.5
Rainbow trout	752	882	794	832	848	1.6

Source: FAO, 2022 [1].

In 2020, there were 12,500 active enterprises with 75,300 employees in the aquaculture sector in the EU. Note that approximately 90% of these firms are micro-enterprises with constant turnover over the last ten years. The primary farmed species are Atlantic salmon (mainly produced in Norway and the UK) and rainbow trout. From a production standpoint, the most important freshwater species is rainbow trout, which accounts for 69% of total production volume and 64% of total production value. In 2020, the EU-28 was the world's second-largest producer of trout (183,000 tons or 20% of global production). The main producers are Italy (19%), Denmark (17%), and France (14%) (Table 6).

Table 6. Main rainbow trout producing nations in Europe (×100 t).

Nation	2000	2005	2010	2015	2018
EU	1402	1272	1263	1270	1318
Italy	330	350	310	350	350
Denmark	330	310	310	310	330
France	350	310	290	260	260
Spain	170	160	150	170	170
Norway	491	661	1019	1380	1354
Others	158	203	243	304	363
Total	2052	2137	2527	2948	3082

Source: FAO, 2022 [1].

During the period 2010–2030, the overall production of salmonids is expected to increase by 2–10% and the price to decrease by 2%. Table 7 shows the main importing nations in the EU.

Table 7. Main exporting and importing countries of rainbow trout in the European Union (×1000 t).

Country	Import		Export	
	Fresh	Frozen	Fresh	Frozen
Italy	1128	968	4273	119
Poland	9957	2021	1021	87
Germany	4610	6627	770	744
France	2191	793	158	721
Denmark	1565	383	5877	7526
United Kingdom	388	176	2626	89
Spain	2168	286	3472	713

Source: FAO, 2022 [1].

1.3. Aquaculture Production in Italy: An Evolving Scenario

In the last decade, the Italian aquaculture sector has been dynamic from an economic point of view, as well as profitable [6]. In 2020, national fish production was 180,000 t, and the turnover was EUR 500 million. The production of rainbow trout was 36,000 t. Fifteen percent of the best companies realised fifty-four percent of the total turnover of the sector. The family business is the most common enterprise form (66% of the total). Most of the farms are concentrated in the northeast regions (50% of the total) and the islands (19% of the total). In recent years, there has been a slight increase in the number of employees per company, which has reached 7.7 units. Italian companies represent 7.8% of the EU, accounting for 16% of production by volume and 13% by value.

Rainbow trout is the most widely farmed species in Italy [7]. The production of rainbow trout contributes approximately 25.5% of the total value and 69.9% of the volume of farmed fish production. Over the past ten years, trout production has increased by 8.5% with an average annual growth rate of 2.5%. Rainbow trout production is mainly carried out in 360 farms located in the northern part of Italy (70% of total production and EUR 120 million in turnover). The organic production system is a growing sector in the aquaculture supply chain. According to data published by the National Information System on Organic Agriculture (SINAB), there were 45 organic fish farms in Italy in 2020 across 11 regions [8]. Almost 75% of them are concentrated in two regions (Emilia-Romagna and Veneto).

2. New Trends in Aquaculture Feed Production

Fish plays a crucial role in global human nutrition as a source of essential nutrients [1,9]. Marine-derived ingredients (fishmeal and fish oil) are of critical importance in fish feed production [10]. Fishmeal primarily provides protein for fish growth but is also a valuable source of micro-nutrients such as vitamins, minerals, and lipids. In addition, fishmeal contributes to improved feed digestibility and palatability, particularly in weaning diets for many species [11]. Fish oil is used in fish feed to meet the requirements of the long-chain omega-3 series essential fatty acids (HUFAs, highly unsaturated fatty acids) [12] DHA (docosa-hexaenoic acid) and EPA (eicosapentaenoic acid) [13]. In recent decades, fish oil has been partially replaced with several vegetable oils, such as canola and flax oil [14]. The use of marine-derived ingredients (meal and oil) is higher in species of high commercial value, such as rainbow trout and Atlantic salmon [1,15]. In 2020, 15 MT of harvested fish was used for fishmeal and fish oil production [1]. Fishmeal and fish oil are obtained from small pelagic species (e.g., anchovies (*Engraulis encrasicolus*) and blue whiting (*Micromesistius poutassou*)). The fisheries are primarily concentrated in certain countries, notably, Peru, Chile, Norway, and Thailand [16]. The amount of fish oil recovered for anchovies is approximately 5% of the total weight, while that for herring (*Clupea* *harengus*) and capelin (*Mallotus villosus*), the most commonly used fish for fish oil production in Europe, is approximately 10%. Up to 33% of fishmeal and fish oils are obtained by means of by-products. Fishmeal and fish oil are obtained through the same production process [17]. On average, processing one tonne of caught fish yields 225 kg of fishmeal and 50 kg of fish oil [18]. The processing coefficient varies according to the different fish species, sizes, and seasons of capture [19]. From 2000 to 2020, global fishmeal production decreased from 6.6 to 4.8 MT and fish oil production from approximately 1.5 to 1.0 MT. Over the past decade, fishmeal and fish oil prices have been higher than those of vegetable meals and oils (Table 8).

Table 8. Soybean meal and fishmeal prices over the past decade (USD/t).

Year	Soybean Meal	Fishmeal
2010	400	1600
2012	410	1250
2014	450	1610
2016	390	1590
2018	400	1600
2020	380	1550

Source: FAO, 2022 [1].

From 2000 to 2020, in fish feed manufacturing, the fishmeal percentage increased from 33% to 69%. During the same period, the fish oil percentage increased from 55% to 75%. Recently, the increasing amounts of fish products used in fish feeds have raised global public concern regarding the sustainability of the marine system [1,20]. Indeed, excessive fishing activity could result in a global reduction in the valuable ecosystem benefits of fish [10]. Moreover, a portion of the caught fish could be used for direct human consumption [5,19,21].

Although marine-derived resources continue to play an important role in fish feed production, the use of plant-derived ingredients is steadily increasing [22]. Some feed ingredients, such as grains and legumes used in pet food, present some critical issues for fish. In fact, fish are more sensitive to some substances, such as antinutritional factors and toxins. For this reason, additional processing steps are used in the production of fish feed to increase their nutritional value. There are several factors to consider when using new feed ingredients to replace fishmeal, including: nutritional value, availability and price, customer acceptability, and effects on growth and health [3]. Different types of plant-based ingredients have been studied. Soybean products are the most widely used plant-based protein source in trout feeds, used alone or in combination with other plant-based ingredients. There are several limitations in using plant sources in rainbow trout diets, including: antinutritional factors (ANF), amino acid, fatty acid, and mineral contents, and palatability. Some additives can be used to reduce the negative effects of plant proteins. Alternative oil sources, including canola, palm oil, and chicken fat, are commonly used to replace fish oil. Replacing fish oil with alternative oils reduces the omega-3 content of trout fillets. The use of finishing diets, rich in fish oil, reduces the level of HUFAs (highly unsaturated fatty acids), fatty acids that are accumulated during the growing phase [3].

Some alternative ingredients, such as canola oil, palm oil, and chicken fat, are used to replace fish oil. In fish feed, oil extracted from algae, which has high omega-3 content, can partially replace fish oil [23]. Replacement of fishmeal and fish oil in feeds with plant-based products may affect the health of rainbow trout through changes in gut morphology, immune function, and interferences with the normal endocrine system function. In the future, more research is needed on the effects of new protein sources on trout growth and health. The use of plant-derived ingredients in diets may also change the microbial populations living in the fish gut [24]. Metagenomic analysis, which is performed by next-generation sequencing (NGS) techniques, allows the identification of the main bacterial species of the fish gut microbiome [25]. In France, rainbow trout populations have been selected to efficiently digest diets containing some plant-based ingredients [26].

The environmental impact of raw materials throughout the production chain and feeds used during the production phase is determined by life cycle assessment (LCA) methods [27]. In fish farming, the nutrition phase accounts for more than 90% of carbon dioxide equivalent emissions [28]. The substitution of fishmeal with plant-based ingredients (e.g., soy) results in increased pollution [29] and ecotoxicity related to the use of fertilisers and pesticides during the plant production phase, reduction in natural resources, and loss of biodiversity, especially due to deforestation (particularly in Brazil) [30]. Between 2000 and 2020, the amount of marine-derived product used in salmonid feed manufacturing decreased from 33.5% to 14.5%, while lipids decreased from 31.1% to 10.4% [31]. Despite success in replacing fishmeal and fish oil with plant-based products, the feed industry is looking for new ingredients to reduce environmental impacts. Proteins obtained from insect and microalgae meal can be used to partially replace fishmeal and fish oil in fish feed [32].

Boissy et al. [33] studied the replacement of fishmeal and fish oil with plant-based ingredients. The results of the experiment showed that the environmental impact of rainbow trout feeds varied with respect to the geographic origin of the fishmeal and fish oil (e.g., Peru or Norway) and the type of plant used (e.g., canola or palm oil). Feeds are the most important contributors to the environmental impact in fish farming [33,34]. In LCA, the allocation method used strongly influences the environmental impact results [35]. The allocation of resources and the calculation of the environmental impact of coproducts (e.g., fishmeal and fish oil) are two very important activities in LCA [36–38]. Economic allocation has been frequently used in LCA studies applied to the aquaculture sector [39,40]. According to Guinée et al. [41], economic product allocation allows a more accurate estimation of the environmental impact. This method is also suggested in the European Commission's guidelines for the animal feed sector [42].

2.1. Extraction of Active Ingredients from Molluscs and Algae

The extraction of active ingredients from plant and animal products is a rapidly evolving research area [43]. From 2000 to 2020, the production of algae and molluscs doubled. In 2020, the production of algae and bivalve molluscs represented 43% of the total aquaculture sector by volume and 7.6% by edible weight [1]. Since 2000, the cultivation of algae (especially macroalgae) has increased steadily [44]. Global aquatic plant production tripled from 10 MT of wet biomass in 2000 to over 32 MT in 2020. A total of 31–38% of 32 MT of algae production is used by humans (99% in Asia) [1]. In 2020, macroalgae production was 4.6 MT. Many algae are used in the food industry as an additive for the production of nutraceuticals (source of polysaccharides), pharmaceuticals, cosmetics (source of hydrocolloids), and fertilisers and feed ingredients. Recently, fucoxanthin, a potent anti-inflammatory, has been extracted from some brown algae [45]. The production of microalgae such as *Spirulina* spp., *Chlorella* spp., *Haematococcus pluvialis*, and *Nannochloropsis* spp. is highly developed in some countries [46]. In 2020, the world production of microalgae amounted to 130,000 t. In 2020, the demand for dried microalgae in Italy was 200 t. Meal obtained from algae can be used in fish diets [46]. Generally, the nutritive value of brown algae is lower than that of red and green algae due to the lower protein content. The algae production process can be improved by means of a "biorefinery" approach. In this method, active ingredients from the algae are produced using large photobioreactors and are then extracted sequentially, thereby reducing waste, energy inputs, and environmental damage. New technological advances allow algae to be grown on a large scale in coastal and offshore locations. Disease prevention and management and optimisation of environmental parameters during the cultivation phase (nutrients, light, and temperature) are some of the aspects that are still under development. In intensive plants, bacterial and viral diseases are particularly frequent, and disease management costs can represent up to 50% of variable costs. New varieties are needed to improve production and profitability to improve yield, disease resistance, and nutritional characteristics. Microalgae can replace fishmeal and fish oil in fish feeds. However, some technical, biological, and economic difficulties related to the production of high-quality microalgal biomass limits its practical use. According to some recent studies, a level of macroalgae inclusion with rates >10% results in adverse effects on trout growth. Some bacteria and yeasts have a high potential as alternative sources of protein. However, their use is still limited due to high production costs.

Shellfish production includes approximately 65 species, mainly bivalves (clams (*Venerupis decussata*), oysters (*Ostrea Edulis*), scallops (*Pecten jacobaeus*), abalone (*Haliotis Linnaeus*), and mussels (*Mytilus galloprovincialis*). Bivalve mollusc farming does not require the use of feed. The active ingredients extracted from molluscs are used in various sectors, such as the production of fertilisers, building materials, pharmaceuticals, and nutraceuticals [47].

2.2. Use of Insects in Fish Feed

Insects represent a potential alternative source of animal protein in the production of fish feed [48,49]. The growth cycle of insects is very rapid, and several breeding cycles can be implemented throughout the year [49]. The protein, fat, and vitamin contents in insects vary according to different factors, such as species, sex, developmental stage, and growth environment. Insect meal is a good source of protein (40–75 g/100 g DM) and minerals [48]. Protein digestibility (77–98%) varies in relation to several factors, such as the presence of the exoskeleton and the content of essential amino acids [50]. The average lipid content varies from 13 to 33% of DM depending on species, sex, and developmental stage [50]. The average omega-3 and omega-6 fatty acid compositions of yellow mealworms (Tenebrio molitor) are similar to those of several fish species. Insects contain some bioactive compounds, such as antimicrobial peptides (e.g., amino-rich peptides), fatty acids (e.g., lauric acid), and polysaccharides (e.g., chitosan and chitin) [51]. The most interesting insect meals for the fish feed industry are those obtained from yellow mealworms, black soldier flies (*Hermetia illucens*), common house flies (*Musca domestica*), crickets (*Acheta domesticus*), and grasshoppers (*Tettigonia viridissima*) [49,52]. House crickets (*Acheta domesticus*), mealworms, and migratory locusts (*Locusta migratoria*) were recently authorised as food ingredients in the EU.

Insect larvae (black soldier fly, common house fly, and yellow mealworms) can be reared in large plants. The larval reproduction systems are similar among the different species. Recent studies have shown that mealworms and soldier flies can be used in the formulation of fish diets because of their excellent palatability and composition in amino acids, lipids, and calcium [53]. Insects can also play a fundamental role in the biodegradation/recovery of several wastes, reducing contamination, and contributing to the sustainability of animal production systems [54]. In fact, insects can be fed agricultural wastes, transforming them into a valuable nutritional resource. Insects can be raised with a reduction of 50–90% in land use compared to conventional livestock farming and with a decrease of approximately 100 times in greenhouse gas emissions. It has been reported in some studies that insect meal may affect the sensory profile of rainbow trout fillets. For some insect species, further investigation and careful economic analysis are needed. The use of insect meal can pose some risks, such as the presence of allergens, chemical contaminants, parasites, and microbiological threats [55]. Currently, there are still limited data available for a thorough risk analysis. In Table 9 are reported the effects of alternative diets (plant, insect, algae, etc.) on growth and quality parameters in rainbow trout.

Table 9. Effects of alternative diets on growth and quality parameters in rainbow trout.

Protein Ingredient	Inclusion Level (%)	Effects	Reference
Mixed plant meals	46, 70, 100	FBW (reduction) PUFA n-3 (reduction)	[56]
Schizochytrium limacinum	5	FBW (no difference)	[57]
Hermetia illucens	10, 20, 30	FBW, SGR, FCR (no difference)	[58]
Tenebio molitor	50	FBW (no difference)	[59]
Saccaromyces cerevisiae and *wickerhamomyces anomalus*	10, 20, 30	FBW, FCR (no difference)	[60]

FBW = Final Body Weight. SGR = Specific Growth Rate. FCR = Feed Conversion Ratio. PUFA n-3 = Polyunsaturated Fatty Acids n-3.

2.3. Recent and Future Trends of the Sector

The life cycle of rainbow trout begins with brood stock breeding and egg fertilization and continues through the growing phase. Achieving high-quality standards at the first stage (selection of breeding stock and egg production) of the cycle is critical to the entire production process. Recently, in the rainbow trout sector, there has been evidence of a high degree of vertical integration among farms [1]. In particular, several production farms have integrated their activities with brood stock breeding and egg production activities. Female reproductive characteristics (egg diameter, fecundity rate, and number of viable eggs) vary with rearing conditions (temperature, feeding, light cycle, etc.) and genetic selection. Egg quality characteristics vary according to the number of eggs laid and the ability to develop a viable embryo [1]. Recently, automated phenotyping systems, using image analysis technologies (and wireless data transfer), have been developed to determine the presence of dead eggs and/or any embryonic malformations [3]. At the first stage of the production chain, water reuse methods (Recirculating Aquaculture Systems, RASs) allow the farmer a greater degree of control (over production), to reduce water consumption and the release of effluent into the environment. Due to high costs and high energy use, RASs are used only at certain stages of the cycle (particularly in hatcheries where control over environmental conditions is more critical and unit values higher).

In the following growing phase, feed conversion ratio (FCR) is the most important parameter for improving the production indices and reducing the environmental impact [42]. Reducing FCR by 10% also results in a 9.5% reduction in the carbon footprint [34]. Recently, several companies have used underwater cameras and sonars to reduce feed waste. The feed industry is continuously working on developing new feed ingredients and improving formulations with higher energy content. While in the 1990s fishmeal and fish oil made up more than 80% of trout feeds, today, conventional marine-derived ingredients make up only 25–30%. As a result, in farmed trout, the content of long-chain omega-3 fatty acids has decreased. Genetic selection and marker-assisted selection have also been used to improve fish growth and health [25]. For example, selected trout show 10–15% weight gain per generation with feeds based on plant ingredients. In addition, supplementing feed with nutraceuticals, prebiotics and probiotics, and plant extracts is used to improve fish growth and immunity and reduce the use of antibiotics. In recent years, researchers have conducted extensive studies to develop new vaccines to control diseases caused by bacteria or viruses. To date, two effective vaccines for IPNV (Infectious Pancreatic Necrosis Virus) and ERM (Enteric Red Mouth) are used in rainbow trout farming.

3. Analysis of the Rainbow Trout Sector Using the Value Chain and Multi-Market Equilibrium Method

The development of large-scale distribution and retail activities has brought about some structural and organisational changes in the salmonid production chain. For many companies, this situation has led to a higher level of integration and the adoption of some solutions, such as hierarchical governance and centralised control of strategic decisions and management [61]. This coordination of different activities has a positive effect on the market equilibrium and allows pricing at different levels of the supply chain and the distribution of profits among partners [62,63]. Relationships among partners of the supply chain are the result of vertical integration [64]. In recent years, large companies have become vertically integrated, and direct production activities have increased, including hatcheries, fish processing, and export and distribution points. In Norway, large producers also own slaughtering facilities, including boats for fish transport and primary processing, while small producers do not have slaughtering and primary processing facilities. Small-scale farmers often use/rent or purchase slaughter services from other companies. Companies operating upstream in the supply chain can integrate with the acquisition of companies operating downstream, while the opposite rarely happens. Final consumer demand is exercised in two main channels: large-scale distribution and in hotels, restaurants, and catering (HoReCa).

The five forces of Porter's model indicate the factors responsible for competitiveness and value creation in the fish supply chain. This model is derived from industrial economic organisation and indicates the competitive activity and attractiveness (or lack thereof) of a sector in terms of profitability [65]. In an "unattractive" industry, the combined result of these five forces reduces the overall profitability. Firms operating in an unattractive industry have little competitive advantage because they operate in an environment where profits tend to be close to zero. Porter's Five Forces include three forces of "horizontal" competition: (1) threat of substitute products or services, (2) threat of established rivals, and (3) threat of new competitors.

The production cycle of rainbow trout consists of the following phases:

(1) One month for incubation and hatching of eggs;
(2) Three months for weaning of fry;
(3) Ten to twelve months for the growing phase (commercial weight of 300–350 g) [66].

In Italy, 54% of total production is carried out by corporations and cooperatives. Family-owned and single proprietorships, which are the most common, account for 22% and 23% of total turnover, respectively. In Italy, the structure of the rainbow trout sector has changed over time, transitioning from a situation in which companies were managed directly by owners to a more integrated industry with a reduced number of large companies. This new situation has changed the organisation of the company (e.g., number of companies, size, type of product, productivity, etc.), organisation (e.g., competitive, oligopolistic), and economic results. In the rainbow trout production sector, there are different organisations characterised by six widespread models (T1–T6):

T1: Closed-cycle farming with breeding animals;
T2: Production for the restocking of recreational fishing;
T3: Breeding with well water;
T4: Breeding with derived water;
T5: Multiple reproduction sites;
T6: Integrated supply chain.

Rainbow trout farms T1–T4 share some common characteristics:

- Family-owned;
- Small size;
- Fish are mainly sold live or fresh. Product processing is only a small part of the total production. Raw materials are the only products purchased outside the farm;
- Fish are sold in local markets and less frequently nationally.

Rainbow trout farms T5 and T6 are characterised by a leading position at the national level:

- Companies with professional management;
- One-third of the trout farms in Italy (approximately 20 farms with 60% of the total annual production);

- Products are sold regionally, nationally, and abroad;
- T5 companies sell live trout to both commercial operators and processing companies;
- T6 farms are integrated with the different stages of the supply chain.

The average production costs vary according to the different farming systems. The estimated production cost is approximately 2.8 EUR/kg [67]. The gross revenue is approximately 3.3 EUR/kg, with a margin of 0.5 EUR/Kg realised by the most efficient farms [67]. The main factors in production costs are feed, followed by labour, energy, and oxygen supply. Food and labour costs can be reduced through economies of scale and represent an obstacle to the competitiveness of small companies. The most common sale channels are fresh and processed products. The most common processed products are fillets (precooked, marinated, or smoked), pâtés, and fish burgers. In 2020, fish consumption by Italian households consisted primarily of fresh and frozen products, followed by packaged, frozen, and semi-preserved products. Among the various distribution channels, consumers prefer new types of distribution (81% in volume and 82% in value) over traditional channels (local markets or specialised fish mongers). Within the new distribution channels, hypermarkets and supermarkets play a central role and represent approximately two-thirds of the market in volume compared to discounted stores. The diversification of the product into fresh and processed (smoked, marinated, fillet, pâté) products has favoured the spread and sale of fish products. Companies are expanding into new demand segments (for example, the Halal certification for trout slaughtering requested by the Islamic countries). Demand for fish products is changing from "commodity" to "service food product", where brand image, quality, safety, and sustainability have become increasingly important, especially for urban consumers. The beneficial health effects of fish foods for humans are a key factor in the increasing popularity of fish products. The Eat-Lancet Commission recommends fish consumption as a source of protein [63]. Salmon and trout are rich in micro-nutrients, minerals, omega-3 fatty acids, high-quality protein, and numerous vitamins. The FAO emphasises that "fish is a food of excellent nutritional value, providing high-quality protein and a wide variety of vitamins and minerals, including vitamins A and D, phosphorus, magnesium, selenium, and iodine in marine fish" [1]. In Table 10 are reported the structural indicators of the aquaculture industry in the EU and the ratio analysis.

Table 10. Structural indicators of the aquaculture industry in the EU and ratio analysis.

Country	N° Enterprises	Total Production	Total Sales	Employment	FTE [1]	Ratio 1	Ratio 2	Ratio 3	Ratio 4	
	N°	(t × 1000)	Millions EUR	N°	N°					% Sales
	(1)	(2)	(3)	(4)	(5)	(2)/(1)	(3)/(1)	(4)/(1)	(3)/(4)	
United Kingdom	473	195	1023	3285	2802	412	2.16	6.95	0.31	20.65
France	2700	220	765	15,064	8837	81	0.28	5.58	0.05	15.44
Spain	2990	295	627	17,811	6534	98	0.21	5.96	0.04	12.66
Greece	328	135	584	3986	3482	411	1.78	12.15	0.15	11.79
Sum 1 *	6491	845	2999	40,146	21,655	251	1.11	7.66	0.14	60.53
%	51.94	59.40	61.30	53.20	49.58					
Italy	711	201	557	5460	3289	282	0.78	7.68	0.10	11.24
Germany	293	41	129	1638	983	139	0.44	5.59	0.08	2.60
Denmark	107	48	185	549	366	448	1.73	5.13	0.34	3.73
Ireland	289	44	168	1948	1027	152	0.58	6.74	0.09	3,39
Sum 2 **	7942	1238	4099	49,794	27,369	254	0.93	6.56	0.15	81.50
%	63.30	83.62	82.75	65.94	62.59					
Malta	6	14	164	301	256	2333	27.33	50.17	0.54	3.31

Poland	1242	38	110	8759	5256	30	0.09	7.05	0.01	2.22
Others	3357	191	581	16,665	10,848	56	0.17	4.96	0.03	11.73
Total	12,547	1481	4954	75,519	43,729	118	394	6.02	394	100
Average	1136	129	444	6860	39,700	404	3.23	10.72	0.16	
Standard Deviation	1200	91	294	6354	3379	627	7.65	12.62	0.16	

* Sum 1 = United Kingdom + France + Spain + Greece. ** Sum 2 = United Kingdom + France + Spain + Greece + Italy + Germany + Denmark + Ireland. [1] Full-time equivalent labour.

3.1. Competitiveness Indicators

The main indicators of competitiveness in the aquaculture sector are the number and size of companies, turnover, added value, operating income before interest, taxes and depreciation (EBITDA), return on investment (ROI), and employment (Table 11).

Table 11. Economic indicators of the aquaculture industry country's structure in the EU and ratio analysis.

Country	VAL	EBIT	ROI	Mean Wage	Labour Productivity	Capital Productivity	Future Expect Index
	Million EUR	Million EUR	%	Thousand EUR	Thousand EUR	Thousand EUR	
	(1)	(2)	(3)	(4)	(5)	(2)/(1)	(4)/(1)
United Kingdom	286	127	14.6	36.6	101.8	33.00	3.70
France	421	130	12.7	25.1	47.7	40.80	−1.40
Spain	238	74	10.8	22.4	36.6	34.70	−0.60
Greece	209	145	13.4	16.2	60.3	19.30	0.10
Italy	185	103	24.1	37.2	97.7	42.90	28.20
Denmark	44	12	5.9	65.7	127.7	21.90	0.40
Ireland	71	40	21.1	28.5	69.2	37.20	0.80
Malta	18	13	50.5	17.1	82.6	70.10	0.80
Others	225	120	13.76	26.41	69.99	29.61	0.73
Total	1701	767	14.5	24.6	57.3	32.20	3.10
First 8							
Average	184	80	19.14	31.10	77.95	37.49	4.00
Other nations *							
Average	30	15	13.76	26.41	69.99	29.61	0.73
Standard deviation	26	18	18.27	19.53	49.00	25.89	7.11

* includes Bulgaria, Croatia, Finland, Latvia, Holland, Portugal, Slovenia, Sweden. Source: MIPAAF, 2021 [66].

In recent years, the aquaculture production sector has been characterised by a reduction in the number of companies and an increase in production per employee. In 2020, within the EU, the profitability of the aquaculture sector was positive. From 2000 to 2020, Gross Value Added (GVA = final value of production minus the value of capital and labour) increased by 29%, operating income before return on capital (EBIT) almost doubled, and labour productivity increased by 20%. Table 9 shows the four indicators that measure the economic capacity of the most important EU countries. Labour productivity is the sum of wages and the value of unpaid labour divided by the total number of those with full-time equivalent work (FTEs). The last column shows production as a percentage of total sales, which measures the ability of the EU countries to process fish products.

In 2020, the European aquaculture sector produced EUR 1.7 billion in terms of GVA. This index calculates the increase in value of a given sector due to manufacturing activity. The ROI allows for comparison between the different manufacturing activities. This index increased from 14.5% in 2015 to 15% in 2020. In the last ten years, the manufacturing trend has increased with a compound average annual rate (CAGR) of 2.5%. The formula for the calculation is as follows: Cn = C° (1 + r) n, where Cn is the end value, C° is the initial value, r is the growth rate, and n is the number of years of the growth phase. This index is used to calculate the growth rate of different production sectors assuming a constant annual r rate. The labour productivity of aquaculture in the EU was EUR 57,300 in 2020. Italy's value was 70% higher than the average of the best countries (Denmark, UK, Ireland) [66]. Capital productivity is calculated as the ratio between the value of the capital (total value of aquaculture sector assets) and GVA. In 2020, the capital productivity of the aquaculture sector within the EU was 32%, which was a significant increase compared to the previous period [66]. In Italy, productivity was 34%, showing a higher value compared to the eight best-performing countries of the EU. The weak structure of the sector in Italy, which mostly consists of small companies, is compensated by international perceptions of a high-quality product.

3.2. Price Trend Analysis

At the three market levels, rainbow trout prices change over a wide range from EUR 3.3 (production level) to EUR 6.57 (processing level) and EUR 9.9 (distribution level) (Figure 2) [67].

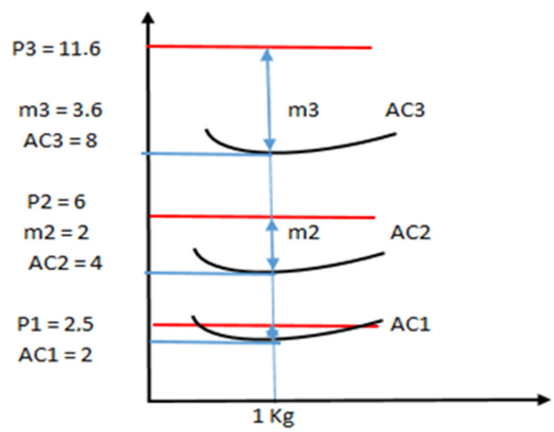

Figure 2. Trout supply chain: the multi-market equilibrium model: price, cost, and margin per 1 kg of product.

Rainbow trout prices vary according to market conditions and final consumer demand [68]. In Figure 2, the m_2 and m_3 price levels indicate the added values obtained after the processing phase. Profit margins vary according to the market efficiency conditions. Services and products offered by suppliers vary in relation to the technology and logistical costs. Product demand is influenced by consumer preferences, import–export dynamics, and the degree of product differentiation. Product demand is important in the price-setting phase, as its responsiveness increases in relation to the price variation (elasticity) as production moves from the basic product to the final product. Economic margins increase moving from the growing phase to the processing and distribution phases.

3.3. New Consumption Trends

Globally, consumption of fish as food has increased by approximately 70% since the 1960s–70s. The most important nations in terms of fish consumption are Japan, the United States, and Europe (Table 12) [1].

Table 12. Total per capita fish consumption (kg/year) and product types traded (live weight MT) in developed countries in 2018.

World	**20.3**
Europe	21.6
North America	22.4
South America	10.5
Asia	24.1
Africa	9.9
Fresh	2
Frozen	14
Transformed	5
Cured fish	4
Others	5

Source: FAO, 2022 [1].

The globalisation of fish product trade has fostered the development and expansion of new distribution chains. The ways in which fish products are purchased and prepared have changed in recent years. In 2020, 88% of fish products were directly consumed (156 MT of 179 MT). In 2020, in several developed countries, frozen products represented the most popular product type (Table 13).

Table 13. Price paid by consumers in different geographical areas of Italy.

Different Trout Cuts	**Area 1**	**Area 2**	**Area 3**	**Area 4**	**Area 5**	**Area 6**
Trout fillet	12.73	13.06	12.28	13.50	11.90	10.90
Whole white trout	6.50	6.70	5.95	6.81	7.41	5.94
Whole salmon trout	9.93	10.40	9.97	9.10	7.60	7.62
Gutted salmon trout	7.51	7.77	6.90	6.95	7.10	6.99

Area 1: regions include Lombardia, Piemonte, Liguria, and Val D'Aosta; Area 2: regions include Veneto, Trentino, Friuli, and Emilia-Romagna; Area 3: regions include Toscana, Marche, Umbria, and Lazio; Area 4: regions include Campania, Abruzzo, Molise, Puglia, Basilicata, and Sicilia; Area 5: region includes Sardegna; Area 6: region includes Calabria.
Source: ISMEA, 2021 [7].

Table 13 shows the prices of different rainbow trout products in six geographic zones of Italy. The highest prices are paid in Zone 2, in which there are regions with a greater tradition in trout farming and a high quality of products. Zone 3 includes the regions of central Italy, whereas Zone 4 includes the southern regions. Zones 5 and 6 refer to single regions. In these cases, the lower price is due to the high availability of fish and the preference for fresh products. The diffusion of these products is determined by various factors, such as the possibility of preservation for long periods, the absence of limitations due to seasons, the preservation of the nutritional value, and the ease of use. The wide flexibility of frozen products determines an increase in the elasticity of offers and, therefore, in the income of producers. The frozen food segment is an interesting sector for the fishing industry in relation to its high added value and the possibility of exporting the product. Consumer preferences vary in relation to ease of use, quality, freshness, taste, safety, and price of the product. Consumer preferences also vary in relation to household income and demographic and lifestyle changes. Technological developments in processing and distribution and the expansion of large-scale distribution (GDO) have contributed to the rapid change in the fish sales system. Consumption of organic aquaculture products grew at the European level by 20% in the five-year period 2015–2019, and in some nations, such as France, consumption even increased by 48% [67].

The portion size is generally a whole rainbow trout, which is less than 500 g with white or pink flesh. Medium-sized trout are between 500 g and 1.2 kg and are generally used for filleting. Large trout are over 1.2 kg and are generally used for smoking. In 2020, approximately two-thirds of EU-28 production was in portion-sized and medium-sized trout (64%) (Italy: 88%), while approximately one-third was large-sized trout (36%). The share of portion-sized trout decreased in 2020 compared to 2014. In 2020, 50% of intra-EU trout trades were of smoked rainbow trout, while portion-sized trout accounted for 15% [62]. The main intra-EU suppliers of portion-sized trout are Denmark, Spain, and Poland. The main intra-EU destinations are Germany, Poland, and France. Rainbow trout produced within the EU accounted for 83% of total supply, while the remaining 17% are imported trout mainly from Turkey and Norway. Germany, France, Italy, Spain, Poland, and Finland are the main EU markets for trout. In Germany, the main consumption is of smoked rainbow trout, while in Italy and Poland, consumption is primarily of portion-sized trout [62]. In Italy, for the portion-sized trout, the market shares can be divided as follows:

- HoReCa: 25–30%;
- Large-scale retailers: 20–25%;
- Sport fishing: 25%;
- Exports (mainly to Austria, Poland, Germany, and Romania): 25% [67].

Among the factors that have influenced and changed the organisation of fish sale markets are the control of product quality, the availability of new "private labels", and the development of specific market channels for the protection of consumer health [69]. Some factors, such as the price of fish, type of products available, and average educational level of the population, can greatly influence consumer choices. These changes have stimulated new trends, such as food safety, sustainability, animal welfare, and employee welfare. The need to differentiate domestic products from that of low-cost foreign competitors highlights the opportunities that must be seized to open up the processed/processed product market, thereby investing in quality production and high added value. The growing demand for processed products should induce national producers to shift in this direction to satisfy market needs.

4. Quality and Food Safety

Hazard analysis and critical control points (HACCP), good manufacturing practice (GMP), and post-mortem microbiological analysis are some of the product control activities that ensure product safety during production, storage, and sale activities [70]. Food safety is based on the respect of the healthy characteristics of the product and the use of good practices. The application of these principles within the seafood supply chain is of paramount importance in terms of customer satisfaction and health. The main quality certificates in the agri-food sector are the Global Good Agricultural Practice G.A.P., Aquaculture Stewardship Council (ASC), Best Aquaculture Practices (BAP), Friends of the Sea, British Retail Consortium (BRC), UNI EN ISO (9001), and International Featured Standards (IFS). Fish farms are evaluated based on various characteristics, such as fish health, product safety, farm sustainability, environmental impact, responsibility, and social rights of the workers. The Global G.A.P. standard requires the same certificates from farmers and suppliers of feed and raw materials. BRC and IFS certificates are based on product safety [4,71]. These certificates guarantee that the products are safe from the growing phase to the table and that the production process meets quality and safety requirements. Quality certificate standards are updated annually, and a time period is allotted for the new standards to be implemented. In 2020, within the EU, there were 53 quality certificates. These relate to Geographical Indications (GIs), Protected Designations of Origin (PDOs), Protected Geographical Indications (PGIs), and Traditional Specialities Guaranteed (TSG) [72]. Two-thirds of the designations (36) are PGIs, approximately one-quarter (14) are PDO, and 6% (3) are TSG. The number of GIs and TSGs has increased significantly in the last decade, from 21 in 2010 to 53 in 2020 [67]. Of the 53 registered names, 36 (68%) are registered in EU member states, and 32% come from third countries. Germany, France, Italy, and Spain are the countries with the highest registrations [67]. Green aquaculture certifications, adopted by approximately 60% of fish processing companies, are gaining increasing attention in Italy. In 2022, in Italy, the Aquaculture Stewardship Council and the Friends of Sea expect to produce more than 50,000 tons of certified products.

5. Animal Welfare

Animal behaviour can be used as an indicator of welfare and health status [73–75]. Certain physical characteristics of fish, such as growth rate, fattening level, and reproductive status, can provide useful information on their welfare [76]. Monitoring fish behaviour is important in welfare assessment [74]. Some behavioural indicators of welfare can be irregular swimming, loss of appetite, and natural signs of distress, such as erratic swimming and reacting of certain actions [77]. Computer image analysis can be used as a non-invasive and accurate indicator of welfare. Fish are monitored using a variety of methods, including manual analysis (coding) of video recordings, direct analysis by an operator, and the use of automated methods (e.g., computer vision) [78,79]. Fish monitoring and analysis are based on observations of the movement of groups and not on individuals [80]. Gesto et al. [81] used specific behavioural indicators to measure the welfare of rainbow trout, while Bui et al. [82] used general behavioural indicators that can be used for all fish. Modern fish slaughter techniques may involve the use of electric stunning methods. By means of these techniques, fish are killed quickly (less than two seconds) with minimal suffering and/or changes in quality characteristics [83]. This is a prerequisite for many fish chains in Europe (particularly in England). Examples of ethical and quality certificates used in the aquaculture industry are shown in Table 14.

Table 14. Certification methods used in the aquaculture sector.

Ethical Certification		Quality Certification
Social	Environmental	
Community rights	Land use	Food safety
Wages of workers	Pollution	Quality of food
Working conditions	Protection of biodiversity	Traceability
Work safety	Use of resources	

6. Conclusions

Sustainable farming systems can increase the overall economic efficiency of the system and minimise negative environmental impacts. In social terms, increased production in the aquaculture sector can create new job opportunities for farmers and increase wages (particularly in the processing sector). The efficiency of the fish chain system could be further increased if the fish product demand is coordinated across different nations. Reducing the amount of fishmeal and fish oil used in fish feed is a priority for the aquaculture sector (stimulated by lower prices for plant-based raw materials). In recent decades, significant progress has been made in identifying alternative ingredients to fishmeal to be used in fish feeds (e.g., algae and insects).

In Italy, rainbow trout is the main freshwater species. The production supply chain of the rainbow trout sector is a "consumer driven" system, characterised from an organisational point of view by the vertical relationships existing among the main producers of the sector. The retail sector still maintains leadership and price control (due to its proximity to demand) and is able to influence consumer preferences. The structure of the supply chain determines the price levels and margin distributions, which are less favourable to producers. The largest companies, vertically connected (producers/processors) with the main distribution companies (retail/supermarkets), are able to achieve a certain control of the market. To improve market efficiency, these companies use some specific contracts, such as fixed-price, adjustable, and partially adjustable contracts. The decisional power between producers/processors and retailers, therefore, generally remains in the hands of the head company (retail/supermarkets). The transparency of activities and interactions is limited. With this weak industry structure, prices move according to the decisions of the strongest player (large industry companies and distributors). Reorganising the supply chain with a system approach would allow for greater competitiveness and the redistribution of added value among partners according to the principles of equity and risk shares. The governance of the rainbow trout supply chain must be carefully evaluated to manage the complexity of inter-factory relationships. Some useful tools to implement this strategy could be the establishment of an observatory to monitor fish prices and market threats, the improvement of farming methods (more sustainable and environmentally friendly), and an increased use of quality certificates. Quality certification by third-party companies can help improve the company's image. The role of certification remains, however, limited by the low (but increasing) compliance levels of fish producers. The two main certification companies, the Aquaculture Stewardship Council and the Global Standard (GAA-BAP) of the Aquaculture Alliance, represent only 3% of global aquaculture production. Globally, low levels of adherence to certification processes are determined by several factors, such as low demand for certified products for certain species and limited literacy and administrative skills of farms in the monitoring and reporting phases. At the European level, 57% of salmon and trout farms are certified (with high levels of conformity).

The differentiation of fish products is a very important aspect in market development. In the near future, consumer preferences regarding fish quality and health characteristics must be analysed in detail.

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