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Review

Fish Farming Techniques: Current Situation and Trends

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Abstract: World aquaculture is increasingly diversified and intensive, due to the use of new technologies, having grown a lot in recent decades and contributed significantly to improving food security and reducing poverty in the world, with fish farming being a promising activity for the production of protein with high nutritional value. The large aquaculture companies that recognize the potential of this important modality have invested in the study and production of various productive segments of the most diverse species of fish. This review article aims to provide information on the world panorama of marine fish farming, with the main systems and production stages of the most important organisms with commercial potential, aiming to achieve a highly sustainable production, with high nutritional content and benefits for human health. The production of live feed in the larval stage should be highlighted, in order to optimize survival and weight gain. In addition, trends in the cultivation of estuarine and saltwater fish will be detailed in this review, such as the use of biotechnology and technological innovations, cultivations integration, and biosecurity. Thus, innovative methods to optimize the farming system need to be more ecosustainable, reducing the negative impacts on the environmental level.

Keywords: aquaculture; culture; fish farm; production; innovations

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1. Introduction

Aquaculture is the cultivation of aquatic organisms, with human intervention in the breeding process to increase production in operations, such as reproduction, storage, feeding, and protection against predators, among others [1].

According to the FAO data, in 2020, the world fish production (fishing and aquaculture) was approximately 177.8 million tonnes, with 90.3 million tonness coming from fisheries and 87.5 million tons coming from aquaculture. World exports of aquatic products in 2020, excluding algae, totaled about 60 million tonnes of live weight, worth 151 billion USD. Only in relation to aquaculture was the largest amount produced in fresh water (54.4 million tons, 62.2% of the world total), when compared to brackish and salt water (33.1 million tons, 37.8% of the world total). Global aquaculture production retained its growth trend in 2020 amid the worldwide spread of the COVID-19 pandemic, albeit with differences among the regions and among the producing countries within each region. Finfish farming remained steady, with minimal fluctuation around 66 percent, and accounted for the largest share of world aquaculture for decades. In 2020, farmed finfish reached 57.5 million tonnes (146.1 billion USD), including 49.1 million tonnes (109.8 billion USD) from inland aquaculture and 8.3 million tonnes (36.2 billion USD) from mariculture in the sea and coastal aquaculture on the shore [2].

Additionally, according to FAO [2], in 2020, the group of organisms that presented the greatest prominence in aquaculture was freshwater fish, followed by seaweed, showing the great importance of fish farming in food production worldwide. According to the data, aquaculture development has exhibited different fluctuating patterns in growth among regions. In the largest producing region, Asia, the growth in the 1990–2020 period was relatively steady in the major aquaculture countries, although with decreasing growth rates. Other regions had had relatively fluctuating growth in the same period, while experiencing negative growth in some years. Asia has overwhelmingly dominated world aquaculture for decades, producing 91.6 percent of global aquatic animals and algae in 2020. However, there are huge differences in the level of aquaculture development between countries within Asia. Countries such as Mongolia and Timor-Leste, as well as some countries in Central and West Asia, are in need of accelerated aquaculture development to exploit their aquaculture potential [2].

The proportion of fisheries and the aquaculture production of the aquatic animals used for direct human consumption increased significantly from 67 percent in the 1960s to about 89 percent in 2020 (that is over 157 million tonnes of the 178 million tonnes of total fisheries and aquaculture production, excluding algae). The remaining 11 percent (over 20 million tonnes) was used for non-food purposes; of this, 81 percent (over 16 million tonnes) was reduced to fishmeal and fish oil, while the rest (about 4 million tonnes) was largely utilized as ornamental fish, for culture (e.g., fry, fingerlings, or small adults for on growing), as bait, in pharmaceutical uses, for pet food, as raw material for direct feeding in aquaculture, and for the raising of livestock and fur animals [2]. Fish farming is a modern agricultural production system. To obtain the planned results, modern methods must be used, based on scientific, ecological, technological, and economic principles [3]. For the sustainability and competitiveness of fish farming, it is not enough just to fit it into the current environmental legislation, but it is necessary to define the good management practices (GMPs) that establish adequate procedures, regarding the ideal stocking density, the intensity of the cultivations, and the maximum amount to be used for both feed and chemical and organic fertilizers, among others, so that it can operate with zero effluent and harvesting techniques that minimize the contribution of both solids and nutrients to the environment. For this, it is necessary that the ponds be built properly, and the existing ones adapted, so that fish farming can develop in a responsible and competitive way [4].

Aquatic animal farming systems are very diverse, in terms of culture methods, practices, facilities, and integration with other agricultural activities. Land ponds remain the most common type of facility used for freshwater aquaculture. However, in recent years, rapid and significant advances in improving freshwater aquaculture farming systems, integrated with agricultural systems, have resulted not only in higher productivity and better efficiency in the use of resources, but also in an impact on the environment [5].

According to the institution, in freshwater aquaculture, the dominant position of fish has been gradually reducing, from 97.2% in 2000 to 91.5% in 2018, reflecting the strong growth of other groups of species, particularly the creation of crustaceans in freshwater in Asia, including prawns, crayfish, and crabs. Thus, fish farming, the most diversified subsector of aquaculture, contains 27 species and groups of species, which represented more than 90% of the total fish produced in 2018, where the twenty most important species represented 83.6% of the total fish production. Compared with fish, fewer species of crustaceans, mollusks, and other aquatic animals are farmed [5].

According to the institution, in the global production of aquaculture in brackish and salt water in 2018, the biggest highlights were mollusks, with 17.3 million tons, followed by fishes (7.32 million tons) and crustaceans (5.73 million tons); fish, that is, marine fish, farming ranked second in the segment, in relation to the volume produced in the world in 2018 [5].

In this review, we will address some of the main fish currently cultivated, highlighting marine aquaculture. It is worth noting that the production of live food in the larval stage will be highlighted, aiming to optimize survival and weight gain. In addition, trends in the cultivation of freshwater, estuarine, and saltwater fish will be detailed, such as the use of biotechnology and genetics, nutrition, technological innovations, cultivations integration, health, and biosecurity.

2. Considerations about World Fish Farming

In marine and coastal aquaculture, production is currently concentrated mainly on crustaceans and mollusks, with Atlantic salmon (*Salmo salar*) being the species whose production has expanded the most in recent years. Other species that also had a significant increase in production were European sea bass (*Dicentrarchus labrax*) and gilthead (*Sparus aurata*). In some European countries, technological developments have made the sea bass and snapper industries grow remarkably in the past decade [6].

There are few species produced on a large scale and at costs that satisfy the items established by the market, such as some mollusks and Atlantic salmon. The distinction made, in relation to these two market segments, is relevant, due to the high expectations that aquaculture raises at a global level [7].

The success of salmon farming in Norway and Chile is known worldwide. The governments of these countries have stimulated the production of Atlantic salmon, *S. salar*, with the feasibility of spaces for aquaculture in coastal waters. There are thousands of kilometers of practically intact coastline and hundreds of sheltered areas, where marine farms find ideal conditions for their implementation and development. Countries whose coastlines do not have natural shelters have the option of farms in the open sea ("off shore") [8]. Still, according to the author of [8], the great challenge is to develop structures capable of withstanding the severe disturbances caused by bad weather. Thus, large aquaculture companies that recognize the potential of this new modality, with advantages in the environmental component, as well, have invested in researching more resistant and functional models. Its installation in deeper oceanic areas, far from the coast, aims to take advantage of the best water quality, as it is far from riverside pollution. On the other hand, it does not suffer from the competition resulting from the great real estate speculation and the use of these spaces for water sports and recreation.

Preliminary studies with "Pacific threadfin" (Moi) in Hawaii, sea bass and pompano in the Mediterranean, salmon in the United States and Norway, "yellowtail" in Japan, "milkfish" in the Philippines, and "cobia" in Taiwan have provided promising results. The question that arises is: which countries will have the financial capacity to adopt this technology [7]?

In developing countries, with the exception of marine shrimp, aquaculture production was mainly omnivorous, herbivorous, or filterer fishes [9].

3. Recirculation System in Fish Farming

The water recirculation system in aquaculture has aroused great interest worldwide. However, its production in a commercial scale has not yet been achieved, even with the advances that research has provided in the past few decades [10]. Energy costs, associated with intensive fish production, are the main obstacles to expanding investments in this technology. Biological filtration, aeration, water circulation, and temperature control are necessary for obtaining good results. Therefore, the use of motors, pumps, heaters, and ventilation devices make energy a fundamental element in the entire process [11]. Although, in parts, it is not yet possible to confirm the economic viability of this system, as it largely depends on the balance between the high capital to be invested and operating costs [12].

If the water recirculation system intends to compete directly with other forms of production, such as excavated ponds and cages, the need to reduce costs cannot interfere with the quality of the water that must be supplied for long periods, because the fattening process only becomes profitable if repeated constantly [13]. At high densities, the possibility of reusing water is an important alternative to conventional systems that normally impose environmental restrictions and generate conflicts over the availability of land and water [14]. According to Blancheton [15], this system allows for the rapid growth of fish and the adequate use of natural resources, advantages that can undoubtedly favor its economic viability.

Feeding fish in captivity is processed differently from what happens in a natural environment, where decisive factors, such as the nutritional contribution of natural aquatic organisms in the farming ponds, as well as the effect of food on water quality and loss of nutrients, if the food is not consumed immediately, interfere with the zootechnical performance. The adoption of more effective cultivation technologies, which allow for good growth rates, reaching industrial production is only possible with food that meets the nutritional requirements of the species. Thus, in highly modified environments, such as floating cages, "raceways", or ponds stocked with high densities, successful fish farming depends on nutritionally balanced foods [16].

The deficiency of a single nutrient in the diet, combined with stressors agents inherent to confinement, can compromise growth, feed conversion, handling tolerance, and disease resistance, causing inadequate productive performance and high mortality [17].

Almost all commercially cultivated marine species have carnivorous feeding habits; therefore, their dietary protein requirements are relatively high. Thus, feeding is one of the most important aspects in the cultivation of aquatic organisms, as the costs can become rather high, depending on the feeding strategy adopted [18].

Araujo et al. [19] evaluated the zootechnical performance of Nile tilapia, *Oreochromis niloticus*, varying the amount of daily feeding in the masonry tanks for 154 days, and observed that this species, being fed in daily amounts of 20 and 30% of food (morning) and 20 and 30% of food (afternoon), showed a better zootechnical performance at the end of the experiment, when compared to the control, mainly noticed in biomass, final average weight, and feed conversion.

4. Importance of Live Food in Aquaculture

The supply of live food optimizes the growth and weight gain in the first days of the lives of the cultivated species, with several technological strategies aiming to reduce costs and increasing production, without losing essential nutritional characteristics [20].

The larval stage of cultivated aquatic organisms demonstrates a certain need for care, regarding food and nutrition, as this stage is where high mortalities occur, due to inappropriate use and choice of food to be offered [21]. During this phase, in the first days of life, many larvae of different species are not able to consume inert food, and the individuals still do not have the complete digestive tract, making it difficult to digest and absorb the nutrients present in the food. As an alternative, the use of live food enables production in larvicultures, with increased feed efficiency [22].

Live food constitutes a large part of the diet of cultivated species, due to its excellent nutritional potential, as it has a high-value biochemical composition, mobility, and variable sizes and formats, important characteristics to be offered as food for a vast number of species of cultivable aquatic organisms. Other essential factors required for safe production are ease of cultivation, resistance to contamination, and rapid growth [23].

Several organisms are used as live food, highlighting microalgae, rotifers, copepods, cladocerans, and brine shrimp as the most produced. Other species are also offered, such as polychaetes, micro-worms, beetles, and insect and mosquito larvae, mainly in ornamental aquaculture [24].

Microalgae are the most used live food, being the basis of the modified food chain in aquaculture, as they serve as food for both cultivated species and live food. They have a high content of protein and polyunsaturated fatty acids, as well as essential pigments, vitamins, and minerals. The strains used in aquaculture, in this context, have dimensions from 0.2 to 500 μm and are cultivated in fresh or saltwater environments, enriched with nutrients, according to the microalgal species cultivated. The most used are those of the genera *Arthrospira* (Cyanobacteria), *Chaetoceros*, *Thalassiosira* (Bacillariophyta), *Chlorella*, *Dunaliella*, *Tetraselmis* (Chlorophyta), *Nannochloropsi*s (Ochrophyta, Eustigmatophyceae), *Isochrysis* (Haptophyta, Coccolithophyceae), and *Schizochytrium* (Labyrinthulea) [25]. Table 1 shows the classes, genera, and main species of the microalgae currently cultivated as live food in aquaculture and their utilization. Table 2 shows the zooplankton and micro-worms most used as live food in aquaculture.

Table 1. Classes, genera, and species of major currently named microalgae grown for food in aquaculture and their main utilization. FFL: food for fish larvae; FBML: food for bivalve mollusc larvae; FSL: food for shrimp larvae. Source: modified and updated from Silva et al, [25] and Muller-Feuga [26].

Class	Genus	Species	Main Utilization
Cyanophyceae (blue-green algae)	*Arthrospira* (*Spirulina*)	*platensis*, *maxima*	FFL
Bacillariophyceae (diatoms)	*Skeletonema*	*costatum*, *pseudocostatum*	FBML, FSL
	Phaeodactylum	*tricornutum*	FBML, FSL
	Chaetoceros	*calcitrans*, *gracilis*, *punilum*	FBML, FSL
	Thalassiosira	*pseudonana*	FBML
Chlorophyceae (green algae)	*Chlorella*	*minutissima*, *virginica*, *grossii*	FFL
	Dunaliella	*tertiolecta*, *salina*	FFL, FSL
	Nannochloris	*atomus*	FBML
	Haematococcus	*pluvialis*	FFL
Prasinophyceae (scaled green algae)	*Tetraselmis* (*Platymonas*)	*suecica*, *striata*, *chuii*	FFL, FBML, FSL
	Pyramimonas	*virginica*	FBML
Cryptophyceae	*Rhodomonas*	*salina*, *baltica*, *reticulata*	FBML, FSL
Eustigmatophyceae	*Nannochloropsis*	*oculata*	FFL, FSL
Prymnesiophyceae (Haptophyceae)	*Isochrysis* *Pavlova* (*Monochrysis*)	*galbana*, aff. *Galbana*, *'Tahiti'* (***T-iso***) *lutheri*, *salina*	FBML, FSL
Dinophyceae (dinoflagellates)	*Crypthecodinium*	*cohnii*	FFL
Thraustochytriidae	*Schizochytrium*	sp.	FFL

Rotifers range in size from 50 to 2000 μm, acting as a nutritional capsule, transferring nutrients required by larvae of the cultivated aquatic organisms. Its reproduction is by parthenogenesis, making cultivation easier and faster. The two most used species as live food are *Brachionus rotundiformis* and *B. plicatilis* [27].

Copepods are more numerous and diversified in the marine environment, with sizes of 0.3 to 3.2 mm. They have sexual reproduction and present sexual dimorphism. Its cultivation alternates from the selected individuals to the wild ones collected in natural environments. In the feeding of fish and shrimp, copepods act as bio-capsules, transferring energy from microalgae and enriched foods. Copepods have a high reproductive capacity, resulting in high population densities. The most used groups are *Cyclopoida*, *Calanoida*, and *Harpacticoida* and are offered as food at different stages of life (nauplius, copepodite, and adults) [28].

The cladocerans are predominantly from freshwater, with few marine species, ranging from 0.2 to 3 mm. In addition to having good nutritional characteristics, they are also used as bio-capsules for transferring enriched foods to cultivated organisms. They have a life cycle of 1 to 2 weeks, with reproduction by parthenogenesis or sexual means. Its cultivation is practical, being able to offer microalgae and biological yeast for food maintenance. The most used are *Daphnia* and *Moinas* [29].

Artemia have excellent nutritional value, which can be influenced by their diet and can be enriched with microalgae and nutritional additives, characterizing brine shrimp as bio-capsules, as they transfer these compounds to the larvae of cultivated aquatic organisms. Its cultivation is easy, as they are marketed as dehydrated cysts, easy to hatch and maintain, and can be offered as live food in their various stages of life, from cysts to the nauplius, meta-nauplius, pre-adult, and adult stages. The most commercialized and used species as live food is *Artemia franciscana* [30].

Polychaetes, micro-worms, beetle larvae, insects, and mosquitoes are most used in ornamental aquaculture, being offered from the larval to adult stages to fish and shrimp

(Table 2). They are organisms that are easy to grow and of great economic importance, as they contribute up to 80% of the diet of some species of ornamental fish. They can be offered directly or mixed with foods, increasing the palatability of the inert food [31].

Table 2. Zooplankton and micro-worms most used as live food in aquaculture. FFL: food for fish larvae; FSL: food for shrimp larvae. Source: modified from Silva et al. [22].

Organism	Genus	Species	Main Utilization
Rotifer	*Brachionus*	*rotundiformis, plicatilis*	FFL, FSL
Cladocera	*Daphnia*	*carinata, magna*	FFL, FSL
	Ceriodaphnia	*carnuta*	
	Moina	*macrocopa, micrura*	
Copepod	*Tigriopus*	*californicus, brevicornis, japonicus*	FFL, FSL
	Tisbe	*biminiensis, holothuriae*	
	Acartia	*tonsa, clausi, hudsonica, omorii*	
	Paracalanus	*parvus*	
	Cyclops	*bicuspidatus, strenuus*	
	Thermocyclops	*parahastatus, parvus, thailandensis*	
Artemia	*Artemia*	*franciscana, salina*	FFL, FSL
Micro-worms and Protozoan	*Enchytraeus*	*albidus*	FFL
	Paramecium	*caudatum*	
	Anguillula	*silusiae*	
	Limnodrilus	*hoffmeisteri*	

The main obstacle to the use of live food is the high cost, compared to inert foods, as maintenance requires a small-scale trophic strategy, sometimes requiring the cultivation of several basis organisms of the trophic chain to maintain the organisms that will be used as live food, as an example of the use of zooplankton, which need microalgae in their diet. One of the alternatives is the cultivation of low trophic level organisms, as it reduces the diversity of species used as food, in addition to facilitating the gradual weaning for feeding with inert food, without causing undesirable results in the zootechnical indexes of the cultivated organisms. Another way is to work with the species of high commercial value, which can cover the costs of production and maintenance of live food [32,33].

5. Biology and Cultivation of the Main Species Cultivated in Marine and Coastal Fish Farming

Coastal aquaculture and mariculture play an important role in the livelihoods, employment, and local economy for communities' development in many developing countries. They are practiced in fully or partially artificial structures, in areas adjacent to the sea, such as land ponds along the coast and closed lagoons. Although land ponds, modern or traditional, are found in almost all regions of the world, they are much more concentrated in South, Southeast, and East Asia and in Latin America, Europe, and North America for the creation of crustaceans, fish, mollusks, and, to a lesser extent, marine algae [5]. Thus, to obtain the highest potential of fish cultivation, there is need to understand the species cultivated.

Table 3 shows the fifteen species (including the species group) most cultivated in marine and coastal aquaculture in the year 2020, with the percentage of the total produced worldwide in the same year [2]. Among the species described in the table, in this article, we highlight three of them (*Salmo salar*, *Chanos chanos*, and *Lates calcarifer*), with two of them being the most produced (*S. salar* and *C. chanos*, respectively), in addition to a species of pompano of the genus *Trachinotus* (*T. blochii*), of which the annual production is 110,194 tons, with an increasing trend [34]. Its annual production has increased from 25,000 tons to more than 168,000 tons in a decade [35], and cobia *Rachycentron canadum* produced almost 50,000 tonnes in 2019 [36]. These five chosen species have their peculiarities of great relevance to aquaculture, such as the growth in the volume produced in recent years and consequent economic impact, being, therefore, trends in marine and coastal aquaculture, as also shown in Table 4.

Table 3. Fifteen species (including the species group) most cultivated in marine and coastal aquaculture in the year 2020, with the percentage of the total produced worldwide, in the same year. Source: FAO [2].

Species (including Species Groups)	Production in 2020 (Thousand Tonnes, Live Weight)	Percentage of Total, 2020
Atlantic salmon, *Salmo salar*	2719.6	32.6
Milkfish, *Chanos chanos*	1167.8	14.0
Mullets nei, Mugilidae	291.2	3.5
Gilthead seabream, *Sparus aurata*	282.1	3.4
Large yellow croaker, *Larimichthys croceus*	254.1	3.0
European seabass, *Dicentrarchus labrax*	243.9	2.9
Groupers nei, *Epinephelus* spp.	226.2	2.7
Coho (=Silver) salmon, *Oncorhynchus kisutch*	221.8	2.7
Rainbow trout, *Oncorhynchus mykiss*	220.1	2.6
Japanese seabass, *Lateolabrax japonicus*	196.9	2.4
Pompano, *Trachinotus ovatus*	160.0	1.9
Japanese amberjack, *Seriola quinqueradiata*	137.1	1.6
Nile tilapia, *Oreochromis niloticus*	107.4	1.3
Barramundi (Giant seaperch), *Lates calcarifer*	105.8	1.3
Red drum, *Sciaenops ocellatus*	84.3	1.0
Subtotal of 15 major species	6418.2	77.0

In this section, we will address some of the main fish currently cultivated, highlighting: in marine aquaculture, the cobia *Rachycentron canadum*, which has a high volume of production in China, with a promising future; the Asian bass, *Lates calcarifer*, highlighting the cultivation in Taiwan, Malaysia, Thailand, Indonesia, and Australia, with its growth and resistance to diseases being improved; the milkfish, *Chanos chanos*, which can be cultivated in ponds, in-fenced, or cages; the pompano species, of great worldwide importance; the Atlantic salmon, *Salmo salar*, the species whose production has had the greatest expansion in recent years, where Norway and Chile are the main producers; the golden pompano *Trachinotus blochiis*, which has a fast growth rate, good meat quality, and high market demand. Table 4 shows the species of marine or coastal fish, highlighting their main characteristics, as covered in this article. It is worth noting that the production of live food in the larval stage will be highlighted, aiming to optimize survival and weight gain. In addition, trends in the cultivation of freshwater, estuarine, and saltwater fish will be detailed, such as the use of biotechnology and genetics, nutrition, technological innovations, cultivations integration, health, and biosecurity.

Table 4. The species of marine or coastal fish, highlighting their main characteristics, as covered in this article.

Common Name	Scientific Name	Main Feature	Source
Cobia	*Rachycentron canadum*	Rapid growth, high market value, good meat quality	Liao et al. [37]
Barramundi	*Lates calcarifer*	Tolerate wide ecological conditions and a wide range of salinity	Venkatachalam et al. [38], Sorphea et al. [39]
Milkfish	*Chanos chanos*	Marine and brackish water fish, as well as fresh water	Riede [40]
Atlantic salmon	*Salmo salar*	Spawns in fresh water and growth in sea water	Bigelow [41]
Golden pompano	*Trachinotus blochii*	Rapid growth rate, good meat quality and high market demand	McMaster and Gopakumar [34]

5.1. Cobia, Rachycentron canadum

This fish belongs to the family Rachycentridae, order Perciformes, class Actinopterygii, genus Rachycentron, scientific name *Rachycentron canadum* (Linnaeus, 1766), and its common name is cobia. For this species found in the natural environment, its maximum size was 200 cm, with a maximum weight of 68 kg. The maximum age recorded was 15 years. It is associated with coral reefs. They are oceanodromes (migrate within the marine environment), estuarine, and marine. Their depth range goes from 0 to 1200 m, and they live in subtropical climate. They occur in a variety of habitats, including mud, sand, boulder bottoms, coral reefs, estuaries, etc. They feed on crabs, fish, and squids. In the warmer months, this species spawns, and its eggs and larvae are planktonic. In addition, they exhibit solitary behavior [42].

5.1.1. Cobia Economic Impact

The global aquaculture production of Cobia increased rapidly since 2002, reaching 41,774 tonnes in 2012 [1]. In 2015, the global Cobia production was approximately 40,000 tons [43]. China is the highest producer, with 43,000 tonnes, followed by Taiwan (2000 tonnes), Panama (1800 tonnes), Viet Nam (1700 tonnes), and Ecuador (400 tonnes) [23]. The aquacultural production of cobia in 2019 was almost 50,000 tonnes [36].

5.1.2. Cobia Farming

Currently, recirculation systems are being used, due to the availability of water. These systems have been developed and improved in recent years. They are currently common in North American aquaculture stations, due to the limitation of water catchment. In the recirculation systems used in cobia hatcheries, generally the tanks are of small volume (about 300 L). They are efficient in terms of control and precision and inefficient in terms of large-scale production, as they are quite expensive and occupy a relatively small area, providing low to medium productivity. In recirculation, the water must pass through a filtering process, where a 5 ppm chlorine treatment is carried out for sterilization. Due to the use of chlorine, which is harmful to the cultivation, one must make sure that this compound has been completely volatilized, using water aeration for a certain period, between 24 to 72 h [44].

In Taiwan, cobia remains the most popular species for cage cultivation in the open sea, due to its rapid growth, high market value, good meat quality, technology in mass production of larvae, cultivation in intensive and super-intensive ponds, and formulated species-specific foods [37].

According to the Carvalho [44], some observations must be followed during the management of cobia cultivation, such as the constant monitoring and control of the physical and chemical parameters of the water, with the limiting factors being the dissolved oxygen, temperature, pH, salinity, alkalinity, and nitrogen compounds, such as ammonia and nitrite. Debris deposited on the bottom must be siphoned daily, which compromises the quality of the water and the good performance of the animals. From the larval to juvenile stages, the food must meet their dietary needs, with the greatest care being the first feeding (3rd and 4th day after hatching), where the larvae have 4 mm of total length. In this first feeding, visual changes are observed in the digestive tract of the fish.

During the fattening phase, the fish grow very quickly, reaching 6 to 8 kg in a year, twice as high as when growing salmon [44]. In Taiwan, cultivation is carried out in two phases: fingerling hatchery, where nursery cages are used, and fattening, carried out in larger cages. Additionally, in this phase, an adjustment in the density occurs: 1000 fish per cage (2.7 fish m^{-3}), until the end of cultivation and feeding twice a day (10 and 16 h). Thus, the cultivation cycle lasts 17 to 18 months. The individuals are harvested when they reach an average weight of 6 to 8 kg, when they are exported, or 8 to 10 kg, destined for local markets. Fish can also be processed in specialized industries and implemented with the HACCP (Hazard Analysis and Critical Control Points) system [45].

Wang et al. [46] investigated four isonitrogenic and isolipidic diets, regarding the effects of carbohydrate level (CBH) in the diet of cobia *R. canadum* with an initial weight of 22.2 ± 0.27 g for 8 weeks. The authors found that CBH promoted the growth and food utilization of fish, although it also had negative effects, such as greater lipid deposition and higher body indexes.

Cobia Feed

Cobia is a marine fish with a carnivorous feeding habit that reaches close to 60 kg in nature. Under cultivation conditions, this fish can reach 4 to 5 kg in 12 to 15 months. The fast growth, efficient feed conversion, and high quality of the meat make the cobia a fish of great interest for marine cultivations. Several successful commercial cultivations are already established in Asia, the United States, and the Caribbean, stimulating the development of research and the improvement of production technology [47].

According to the Carvalho [44], for cobia larviculture, it is necessary to produce phytoplankton (microalgae) and zooplankton (rotifers and brine shrimp), which are important in the early stages of the animals' lives. Several species of microalgae can be used in the hatchery of cobia. The cultivation of these microalgae has two purposes: the cultivation of rotifers (food) and the larviculture of fish. Cobia larviculture is usually carried out using the "green water" technique, containing, for example, the microalgae *Nannochloropsis oculata* (Ochrophyta, Eustigmatophyceae) at a density of 120,000 cells.mL^{-1}. Other microalgae can also be used, such as *Isochrysis galbana* (Haptophyta, Coccolithophyceae) and *Tetraselmis* sp. (Chlorophyta). Microalgae can be cultured in the farm's own laboratory or obtained from other locations.

Two species of rotifers can be used in cobia larviculture, *Brachionus rotundiformis* and *B. plicatilis*, related to different larval sizes. Rotifers can be cultivated in two systems: continuous and non-continuous. In the continuous system, the tank is emptied daily, removing about 40% of the volume, with the density maintained at 400 to 500 rotifers.mL^{-1}. In the non-continuous system, which is carried out over four days, about 70 % of the volume is harvested, and 30% remain for the inoculum (new cultivation). This system enables greater biological control and animal health [44].

Artemia are microcrustaceans, also known as brine shrimp. *Artemia nauplii* are used to feed marine fish, obtained through a process of decapsulation of the cysts. The decapsulated cysts can be used as a rich source of energy in food. The decapsulation process involves the hydration of the cysts, removal of the shell with a sodium hypochlorite solution, washing in running water, and maintenance in salt water with constant aeration [48]. In cobia larviculture, two different types of nauplii are used: reduced size and high amount of lipids (430 × 162 μm) and larger size with low amount of lipids (630 × 185 μm). For larger nauplii, enrichment must be carried out before use. For fish, the smaller size nauplii should be offered in the first three days of the transition phase from rotifer to brine shrimp feeding. Then, larger nauplii, until the complete exclusion of live food [49].

In nauplii enrichment, also called bioencapsulation, important nutrients for the development of larvae are added, using numerous products, such as algae, yeasts, protein, and lipid concentrates, etc., separately or together [50]. Products containing high concentrations of docosapentaenoic (DHA) and eicosapentaenoic (EPA) acids are highly recommended. Marine fish generally lack the enzymes needed to synthesize these acids. Protein, algae, and yeast-based products are also used [44].

5.1.3. Cobia Reproduction

When studying sperm cryopreservation and oocyte induction, Caylor et al. [51] found that sperm motility decreases after about 60 min at room temperature, but approximately 100% can be restored by adding a few drops of theophylline 5 mM. Mature and wild females were kept in recirculating water systems, and ovulation was induced by injection of chorionic gonadotropin (HCG) at a concentration of 275 IU.kg^{-1} of body weight.

The maturation tanks are the first step in the production of juveniles. In them, females and males are kept in highly controlled facilities, such as photoperiod, temperature, salinity, etc. Females can produce between 300,000 and 1.9 million oocytes [52].

Zhang et al. [53] studied the initial stages of development of the cobia, *R. canadum*, aiming for the large-scale production of larvae and juveniles. The authors observed that, after three days after hatching (DAH), the larvae began to feed, and the feeding incidence was 70%. The incidence was 100% in the case of juveniles. Food consumption of larvae and juveniles increases with increasing body mass. Cobia larvae and juveniles were satiated in one hour. The digestion time of larvae for rotifers and copepods was between 0.5 and 1.5 h and 0.5 to 2 h, respectively, while that of juveniles was 1 to 3 h.

5.1.4. Cobia Farming Problems

Some diseases/pathological agents can affect the animals, causing damage during cultivation, such as *Cryptocaryon irritans* and *Amyloodinium ocellatum* (parasites), *Streptococcus* spp. and *Photobacterium* spp. (bacteria), and *Lymphocystis* (virus) [54]. Nguyen et al. [55] observed that two surface proteins, namely phosphoenolpyruvate protein phosphotransferase (PtsA) and glyceraldehyde-3-phosphate dehydrogenase (GAPDH), showed strong reactions with cobia antisera against severe infection by the bacterium *Streptococcus dysgalactiae*, being promising for the development of vaccines against this pathogen.

5.1.5. Technological Obstacles in the Cultivation of Cobia

Technological obstacles that prevent the activity from expanding significantly are: food limitation, since fishing waste is increasingly limited; water quality and excess of nutrients during cultivation, due to the expansion of the cultures; the environmental danger, caused by the escape of individuals to the natural environment, where it is cultivated and diseases, which are related to the increase in density and improper management and global supply of fish (competition with other cultivated species) [54]. The lack of regulation in open sea aquaculture in some parts of the world, such as Taiwan, results in the uncontrolled proliferation of marine farms. Disease outbreaks remain the greatest threat to cobia cultivation in Taiwan, causing a significant drop in production [37].

5.2. The Asian Sea Bass, Lates calcarifer

This fish belongs to the family Latidae, order Perciformes, class Actinopterygii, genus *Lates*, scientific name *Lates calcarifer* (Block, 1790), and its common name is barramundi. For this species, found in the natural environment, its maximum size was 200 cm, with a maximum weight of 60 kg. They are catadromous (migrate from fresh water to the sea). Their depth range goes from 0 to 40 m, and they live in tropical climates [42].

According to the authors, these fish are found in coastal waters, estuaries, and lakes. Larvae and juveniles inhabit swamps and estuaries temporarily. Older individuals inhabit the seas. This fish has a preference for stems and submerged vegetation. They feed on fish and crustaceans. Juveniles also feed on insects. They have high economic importance.

5.2.1. Asian Sea Bass Economic Impact

Asian sea perch, widely known as Asian seabass or barramundi (common name in the commonwealth countries, mainly Australia) (*Lates calcarifer*), is the second highest cultured marine fish in Malaysia [56]. The production of farmed seabass of five countries, including Taiwan, Malaysia, Thailand, Indonesia, and Australia, has increased from 10,000 tonnes (70,720,000 USD) in 1991 to 30,970 tonnes (79,034,000 USD) produced in 2005 and about 95,000 tonnes in 2018, with a growth rate of 170.6% from 2006 to 2016 [57]. In 2019, the global output of *L. calcarifer* rose to about 76,842 tonnes [58]. However, its economic value after 2005 was not yet calculated.

5.2.2. Asian Sea Bass Farming

Sea basses are estuarine fish with opportunistic carnivorous habits. In addition to aquaculture, they are of great importance in commercial and sport fishing, in addition to their high market value [59]. These fish tolerate wide ecological conditions and a wide range of salinity, from 0 to 56 ppt, depending on the cultivation conditions, whether in fresh, brackish, or saline waters [38,39]. Mozanzadeh et al. [60] found that intermediate salinities (brackish water) between 6 and 12 ppt are recommended for the cultivation of this species. These fish can be cultivated in different production systems, including cages, land ponds, and in recirculation systems [61].

In some parts of Asia, juveniles are still collected in the wild, but the most come from larviculture, which is now well-established. Breeders are kept in floating cages or tanks in salt water (28 to 35 ppt). This species does not have secondary sexual characters, requiring cannulation to detect its sex and reproductive status. Breeders feed on fishing waste or small fish (baitfish). This diet should be supplemented with a vitamin [54].

Nhan et al. [62] evaluated the impacts of high stocking densities on the growth performance, survival rate, and economic efficiency of the Asian sea bass *L. calcarifer* farmed intensively in land ponds. The fish had initial average weights of 22.1 ± 1.3 g and were stored in ponds with an area of 1000 m^2 and a water depth of 2.0 m, being fed with pelleted food containing 43 to 44% of crude protein, with densities of 6, 8, and 10 fish.m^{-2}. The authors found that the growth in weight and daily weight gain of fish at a density of 6 fish.m^{-2} was significantly higher, compared to the density of 10 fish.m^{-2}. In addition, the highest capital efficiency was also recorded in the treatment with 6 fish.m^{-2}.

In Australia, sea basses are stored in cages in fresh or brackish water environments, in marine waters, or in terrestrial recirculation systems [63].

The fishing technique in the cage system is relatively simple. In the pond's cultivation system it is more difficult, requiring the use of nets or mechanisms for water drainage [54].

To optimize the efficiency of barramundi farms, Nor et al. [64] mention that it is necessary to increase the production cycle to 1.73 times.$year^{-1}$, in order to reduce production costs. Government should give more priority to the research and development of cheaper feed alternatives, probiotics, and vaccines. Farmers should be aware of the costs and make better decisions, for example, improving the feed conversion ratio (FCR) and biosecurity to improve profitability.

Asian Sea Bass Feed Needs

Most barramundi cultivations use pelleted food, although "trashfish" is still used, as it has a lower cost, compared to pelleted food. The feed conversion in this system generally ranges from 4:1 to 8:1, in relation to feeding with pelleted food. Fish are also fed with "trashfish" twice a day, in 8 to 10% of the total biomass, up to 100 g, and decreasing to 3 to 5% up to 600 g. It is also necessary to add a vitamin premix in the proportion of 2%. The feed conversion in this system generally varies from 1.0 to 1.2:1 experimentally and 1.6 to 1.8:1 in commercial cultivation [54].

Hassan et al. [65] tested the cultivation, for 70 days, of juveniles of the Asian bass, *L. calcarifer*, with an average weight of 0.2 g, varying the feeding frequency (one, two, three, and four times a day) in the zootechnical performance of the animals and found that the feeding frequency of three times a day had a positive effect on weight gain, survival rate, and food utilization, while animals fed only once a day had the lowest zootechnical indexes.

Chaklader et al. [66] found that the combination of a diet replacing fishmeal (FM) by a whole meal of *Hermetia illucens* larvae (HI) with a poultry by-product meal (PBM) for barramundi allowed for the complete replacement of the meal of fish, without negative effects on growth, also improving the gut health of fish, and may be a protein alternative for the production of commercial food for the species.

5.2.3. Asian Sea Bass Reproduction

The reproductive physiology of the species is reasonably well-understood, with the life cycle fully closed and hatchery production of juveniles routinely achieved [67].

Research has shown that there is usually hormonal induction for spawning. Currently, its spawning uses luteinizing hormones and synthetics. The mating ritual is characterized when the male rubs its dorsal surface against the female genital papilla and fertilization occurs, which is external. Spawning occurs 34 to 38 h after hormone injection, at dusk, lasting for five consecutive nights. The eggs are 0.74 to 0.80 mm in diameter, and they are collected with a mesh of 300 μm. Reproduction of this species in cages is possible, but only if it has a very fine mesh, preventing the eggs from passing through the meshes [54].

According to the institution, the hatching occurs 12 to 17 h after fertilization, at 27 to 30 °C. The yolk sac is absorbed during the first 24 h. The mouth and digestive tract (organs between the esophagus and the rectum) are developed in two days. Therefore, the beginning of feeding occurs 45 to 50 h after hatching. Barramundi larviculture is carried out using the "green water" technique, using circular or rectangular tanks with a capacity of 26 m^3. The microalgae *Tetraselmis* sp. or *Nannochloropsis oculata* can be used in this system. Barramundi is intensively fed with rotifers of the species *B. plicatilis* from the 2nd to the 15th day after exclusion and with *Artemia* sp. from the 8th day after exclusion and onwards. Freshwater cladocerans (*Daphnia* and *Moina*) are used to supplement or replace the brine shrimp.

Fraser et al. [68], when studying the existing deformities in larvae of barramundi *L. calcarifer*, recorded three types of spinal deformities, with the most common being light malformations of the centers. One case of lordotic/scoliotic/kyphotic (LSK) syndrome and one gross vertebral malformation were also documented. The first spinal deformities were observed at 20 days after hatching (DAH). The frequency of deformities increased to a maximum of 7.7% of sampled fish at the completion of the study, at 38 DAH. The deformities were recorded 6 days after ossification of the spine (20 DAH), implying dysfunctions in bone metabolism.

The survival of juveniles with a total length of 10 mm is 10 to 50%. They can also be produced extensively in ponds of 0.05 to 1 ha, lined with plastic tarpaulin. In this system, some factors occur relatively frequently, including stratification, fertilization, and plankton growth. The larval density is 400,000 to 900,000 larvae.ha^{-1}. In this system, harvesting takes place when the fish reach 25 mm in total length (about three weeks after storage). Then, the larvae are transferred to nursery tanks. Survival is 20%, but it is highly variable (ranging from 0 to 90%) [54].

According to the institution, the juveniles, with total lengths of 1.0 to 2.5 cm, can be stored in floating or fixed cages in rivers, ponds, or coastal areas or directly in fresh water. Feed is chopped "trashfish" (4 to 6 mm) or in small pellets. In this food, vitamin premix can be added in the proportion of 2%. This phase lasts from 30 to 45 days, when the juveniles reach 5 to 10 cm in total length. Cannibalism among larvae is the main problem during the nursery phase, occurring most frequently in fish up to 150 mm in total length. In order to reduce this problem, fish should be selected by size [54].

5.2.4. Asian Sea Bass Farming Problems

Some diseases/pathological agents can affect animals, causing damage during cultivation, such as nervous necrosis virus (NNV) and lymphocysts (virus), vibriosis, bacterial hemorrhagic septicemia, integumentary bacteriosis and *Streptococcus* spp. (bacteria), white spot, chilodonelliasis and trichodyniasis (protozoa), integumentary mycoses and branchiomycosis (fungi), and *Argulus* sp. and *Lernaea* sp. (copepods) [54].

Jitrakorn et al. [69] report an unexpected finding of dual infections of both Megalocytivirus ISKNV and nervous ncrosis virus (NNV) in a single Asian bass, *Lates calcarifer*, farm, causing approximately 50% mortality in the animals. According to the authors, these viruses are the two main viral pathogens that affect marine fish on farms in the Asia–Pacific region.

Yu et al. [70] demonstrated that astragalus polysaccharides (APS) supplementation at a dosage of 0.1% is the optimal level to promote the growth performance, health, and resistance of barramundi against *Vibrio harveyi*, while the dosage of 0.2% exerts adverse effects on fish.

Siddik et al. [71] observed a significant improvement in the expression of the immune response genes found in *L. calcarifer* fed with symbiotic (*Lactobacillus casei* and garlic *Allium sativum*), when compared to the control, without the inclusion of them. Overall, the results indicate that dietary symbiotic supplementation has the potential to improve the antioxidant response and health welfare of barramundi.

5.2.5. Technological Obstacles in the Cultivation of Asian Bass, *L. calcarifer*

The technological obstacles that prevent the activity from expanding significantly are the environmental impacts, due to excess nutrients and residues during cultivation, especially in cage fattening, resulting in diseases [54].

5.3. The Milkfish, Chanos chanos

This fish belongs to the family Chanidae, order Gonorynchiformes, class Actinopterygii, genus *Chanos*, scientific name *Chanos chanos* (Forsskal, 1775), and its common name is milkfish. They are marine and brackish water fish, as well as fresh water, being benthopelagic and amphidromic [40]. Their depth ranges from 1 to 30 m [72], and they are from tropical waters, with temperatures between 15 and 43 °C [73].

The milkfish *C. chanos* is a tropical species known for being less tolerant of cold and being suitable for cultivation in hot seasons of the year, since the highest mortality usually occurs in the winter period, when cold fronts predominate, causing catastrophic damage for the aquaculture industry of this species [74].

These fish are found in marine and coastal waters, but can also occur in estuaries and penetrate rivers [75,76]. They occur in small to large shoals close to the coast or around islands, such as coral reefs. Eggs and larvae are pelagic up to 2 to 3 weeks. The most developed larvae migrate to the coast and settle in brackish coastal wetlands (mangroves or estuaries) during the juvenile stage or occasionally enter freshwater environments. The most developed juveniles return to the sea, where they mature sexually. Mature adults spawn only in seawater. The larvae feed on zooplankton; juveniles and adults have cyanobacteria, small benthic invertebrates, and even larvae and fish eggs in their diet. The larvae can be collected in rivers, as well as in laboratories aiming for their development (aquaculture) [77].

5.3.1. The Milkfish Economic Impact

More milkfish is being processed into value-added forms, such as smoked, dried, marinated (brined, sweetened), fermented with rice, and canned or bottled in a variety of styles (salmon style, sardine style, Spanish style, smoked in oil, etc.). Some Philippine enterprises now make frozen prime slices of milkfish bellies and backs, as well as heads and tails. Milkfish is exported in a variety of forms, including quick-frozen, dried, tinned, smoked, and marinated. In 2002, the Philippines exported about 17.040 tonnes of milkfish products to the EU, valued at 58,000 USD. While China's Taiwan Province focuses on processed and value-added goods for sale to the United States, Indonesia has increased its export of hatchery-reared seedstock to the rest of the Asia–Pacific area [43].

5.3.2. The Milkfish Farming

In the Philippines, this species is of great importance for aquaculture, where they were traditionally cultivated in ponds with brackish water, but eventually expanded to fenced-in and marine cages [78]. The total annual production of this fish has exceeded 300,000 tonnes, since 1981 [79]. In the year 2015, the annual global production reached more than 1.1 million tons, highlighting the Philippines, Indonesia, and Taiwan as the main producers [80,81]. In 2016, the species contributed 1.188 million tonnes, representing 2% of the total fish produced globally in aquaculture [23].

In addition to the characteristics described, this species has rapid growth, efficient use of natural foods, herbivorous feeding habits, resistance to diseases, and tolerance to a range of ecological factors [82].

According to the FAO [54], the fenced-in system was first introduced in the Philippines in 1969. Due to its good acceptance, its use increased a lot from 1973 to 1983. In the beginning, where there were few milkfish farms, the amount of natural food was high. Currently, where there is an expansion of cultivations, the amount of natural food is low. Therefore, the demand for this food is high. To meet this demand, commercial foods are used, supplying the nutritional needs of fish. The stocking density of juveniles in this system ranges from 30,000 to 35,000 specimens.ha^{-1}. The biggest problem in the fattening of this species in fenced-in is the spread of diseases, causing high mortalities.

Another form of cultivation frequently used is carried out in cages, where smaller and more restricted areas are used. They can occur in shallow water (fixed) or in deep water (floating cages). It is commonly performed in coastal marine waters. In this type of culture, very high stocking densities are used, from 5 to 30 fish.m^3. Densities are higher in this system, due to the flow of water inside the cages, renewing it frequently, with a high amount of dissolved oxygen [54].

Lee et al. [79], when comparing the operational procedures, as well as production costs in the intensive and semi-intensive systems in the milkfish cultivation in Taiwan, concluded that the semi-intensive or outdoor environments are profitable operations for the production of juveniles, when compared to the intensive one.

Fishing is usually carried out when the fish reach 20 to 40 cm and around 250 to 500 g. It can be carried out through three different methods: partial, selective harvesting only in commercial size (average weight of individuals greater than 250 g); total, complete harvesting, carried out, for example, by completely draining the water from the pond (in this type of harvesting, the average weight can vary from 250 to 500 g); forced, it is the emergency fishing, regardless the size of the fish. It occurs when there is an imbalance in the cultivation, for example, the occurrence of red tide or depletion of dissolved oxygen in the water. The commercial food used in fenced-in and cages are of floating and semi-floating forms, which give a visual response to the consumption of this food by the fish. In pond cultivation, the food is pelleted, sinking in water. Due to the extensive research related to the nutritional requirements of *C. chanos*, food is currently offered depending on the animal life stage [54].

The Milkfish Feed Needs

For the production of natural food in ponds, it is necessary to make a fertilizers, carried out through the use of organic fertilizers, such as ammonium fertilizers $(NH_4)_2SO_4$, nitrate $Ca(NO_3)_2$, starch 46% N, urea, superphosphate $Ca(H_2PO_4)_2.H_2O$ and dicalcium phosphate $CaHPO_3.H_2O$, or inorganic substances, such as cattle, pig, or goat manure. Cottonseed, rice bran, and other agricultural residues are also used. Thus, the algae growth rate must exceed the fish pasture rate. Otherwise, it is necessary to make a food supplementation with the associated microorganisms. The average depth of the ponds is 30 to 40 cm, and the water supply is independent. The productivity can reach 800 kg.ha^{-1}, in a total of three annual harvests, and can be increased to 2000 kg.ha^{-1} [54].

Hussain et al. [83] verified the effects of different levels of protein in the diet of *C. chanos*, in relation to growth and survival during 90 days in soil ponds. The presented results showed that fishes fed 30% of the protein-containing feed have the highest weight gain (WG), specific growth rate (SGR), average daily weight gain (ADWG), survival, and the best feed conversion ratio (FCR), compared to the other treatments.

Sandeep et al. [84] studied the potential of fish waste hydrolysate (FWH) in the production of phytoplankton and reduction of formulated foods in the cultivation of *C. chanos*. The authors found that FWH supplementation at 40 ppm saved 50% of the food required by the animals, without affecting growth and survival.

5.3.3. The Milkfish Reproduction

Breeding facilities demand pumping of salt water and integration with 15arvicultures. The sexual maturity of this species stored in floating cages is 5 years and in tanks or fishponds, 8 to 10 years. The production of oocytes from a given breeder of about 8 years and an average weight of 6 kg is about 3 to 4 million. The mass production of juveniles, as practiced in Taiwan, Indonesia, and the Philippines, occurs through natural spawning, featuring high survival rates. Artificial induction of reproduction is not normally used. Spawning usually takes place around midnight, but can occur during the day. The collection of wild juveniles, directly from nature, occurs through the use of a fine mesh net, called a "sweeper", commonly occurring in the Philippines and Taiwan [54].

According to the FAO [54], for the larviculture of this species, the following facilities are necessary: tanks for raising the larvae, tanks for growing rotifers (genus *Brachionus*) and green microalgae (for example, algae of the genus *Chlorella*), and tanks for hatching brine shrimp. After larviculture, the nursery phase begins, which varies depending on the cultural practices of each place. Suspended nylon hapas are also used and installed in fresh or salt water. Due to the high density of fish in this system, natural food is practically extinct. To satisfy their high food demand, artificial foods can be used, such as rice bran, corn, etc. For storage in the fattening phase (finishing), it is ideal to have juveniles with 5 to 8 cm, achieved when the time in the nursery phase is about 4 to 6 weeks. The fattening phase (finishing) can be carried out in ponds, cages, or in-fenced.

In a typical production cycle, juveniles are captured in the wild or obtained in laboratories, measuring 2 to 3 cm, being cultivated in nursery tanks until the size of 5 to 8 cm, with an average weight of 30 to 40 g; after that, they will be transported to fattening ponds, fenced-in, or cages until harvesting, thus having 20 to 40 cm in length and 400 to 700 g in weight, depending on the market [77,80].

5.3.4. The Milkfish Farming Problems

Some diseases/pathological agents can affect animals, causing damage during cultivation, such as nematode infestation (nematode), anchor worm disease and *Caligus* infestation (copepods), trichodynosis and *Cryptobia* infestation (protozoa), and scolex infestation (helminths) [54]. In the Philippines, Estante-Superio et al. [85] observed that the bacterium *V. harveyi* is an opportunistic pathogen capable of instigating disease epizootics in milkfish juveniles stocked at high densities. Another consequence of using high densities is the increase in cortisol levels, which, together with other management characteristics, such as feeding strategy and location, increase the stress of farmed animals, as observed in milkfish mariculture by Hanke et al. [86], and require more sustainable practices in the aquaculture of this species.

5.3.5. Technological Obstacles in the Cultivation of Milkfish, *C. chanos*

The technological obstacles that prevent the activity from expanding significantly are: the low reliability of the breeders of this species, the uncontrolled supply of juveniles, and the low market acceptance, due to the high amount of spines in the meat, being necessary to use a technique to debone the same, and due to the expansion of aquaculture by other species of greater commercial value, thus minimizing the production of milkfish [54].

5.4. The Atlantic Salmon, Salmo salar

This fish belongs to the family Salmonidae, subfamily Salmoninae, order Salmoniformes, class Actinopterygii, genus *Salmo*, scientific name *Salmo salar* (Linnaeus, 1758), and its common name is Atlantic salmon. For this species, found in the natural environment, its maximum size was 150 cm, with a maximum weight of 46.8 kg. They are benthopelagic (they live close to the bottom and move away from it at night), anadromous, and from brackish or marine water. Their depth range goes from 0 to 210 m, and they live in temperate climates [42].

In the natural environment, this fish spawns in fresh water and the larvae, by absorbing the natural reserves of the yolk sac, are ready to accept exogenous food. At this stage, these fish remain in fresh water for 2 to 5 years, depending on the water temperature and food supply. Before migration, juveniles undergo physiological and behavioral changes, which prepare them for life at sea. After spending 1 to 2 years at sea, they return to their rivers, freshwater environments, to spawn. At sea, Atlantic salmon prefer temperatures of 4 to 12 °C, but can withstand short periods of time at lethal temperatures below −7 °C or above 27.8 °C, respectively [41]. On the market, they can be sold fresh, salted, smoked, or frozen, and the fillet can also be used for sushi and sashimi.

In streams, they mainly feed on aquatic insects, including chironomid larvae and nymphs, for example; in the marine environment, they mainly feed on a variety of organisms, including crustaceans, amphipods, decapods, and fish [87].

5.4.1. Atlantic Salmon Economic Impact

The Atlantic salmon (*Salmo salar*) represents, by volume, approximately 90% of the total salmonid farming, with a world production of approximately 1,000,000 tonnes [88]. In Norway, salmon production in 2019 reached 845,000 tonnes and a value of 5 billion euros [89]. In Chile, in 2020, salmonid production reached 1.468 million tonnes [90]. Thus, the species has achieved the greatest expansion in recent years, with these two countries being the main world producers.

Aquaculture of Atlantic salmon (*S. salar*) has become an important industry for several countries globally and in the North Atlantic, in particular [91]. In Norway, the production of farmed salmon started in the 1970s. The industry has since grown rapidly, resulting in the country having the highest per capita aquaculture production in 2016 [92].

In addition to the great importance of the Atlantic salmon industry in Norway and Chile, it is worth mentioning Canada and the United Kingdom [93].

Salmon farming has been hailed as one of the great success stories in modern Norway. The industry started in the late 1960s and, within 50 years, it became the most important export industry, next to oil and gas [94]. This success can be attributed to factors such as favourable natural conditions, increasing seafood demand, and a steady investment, accompanied by technological development. However, after an expansive growth period that lasted until around 2013, there has been a stagnation in the production volumes [95].

Norway exports >95% of its salmon production, with firms tending to focus on a few markets or regions [96]. On top of that, salmon farming takes place mainly in remote coastal communities, offering valuable employment in municipalities hard hit by the rationalization of the traditional fisheries and processing industry [97].

5.4.2. Atlantic Salmon Farming

Cross et al. [98] found that a lower water temperature (12 °C) reduced the prevalence of *S. salar* maturation in recirculation systems (RAS), keeping production performance similar to the higher temperature (14 °C). However, more than 20% of salmon cultured at 12 °C matured, indicating that an even lower temperature, additional manipulations to the RAS environment, or the use of all-female stocks are needed to optimize Atlantic salmon growth in RAS for reduced maturation.

According to the FAO [54], fish with an average weight of 40 to 120 g are transferred to specific structures and already acclimatized to the sea (smolt). Transfers are normally carried out in specialized transport tanks, using specific boats for this purpose. The cages come in a variety of shapes, being square or circular and have different sizes, up to 24 m^2 or 100 m in diameter, and depths from 15 to 18 m. Salmon grow best in water temperatures between 6 to 16 °C and salinities of 33 to 34 $mg.L^{-1}$ of salt. The water flows must be sufficient to eliminate waste and for oxygenation. The maximum density can be up to 20 $kg.m^{-3}$. The cultivation time in these structures can be up to 2 years, and harvesting takes place when the salmon reach an average weight of more than 2 kg.

According to the institution, salmon fishing techniques vary greatly, depending on the location and structures used. Usually, the fish stay three days without feeding (depuration). The entire process must occur with minimal stress, so that a higher quality of the product occurs. When harvesting from the cages, a net can be used, or the fish can be pumped alive and transported to the processing plant in the shortest possible time and at low temperatures [54].

Atlantic Salmon Feed

Wei et al. [93] used the flour of the microalgae *Pavlova* sp. cultivated in photobioreactors in the diet of *S. salar*, with an average weight of 170.1 ± 23.9 g during 12 weeks, and verified that the flour of this microalga could be a good source of protein and n-3 LC-PUFA in the performance of this species cultivated in commercial farms.

The basis of the salmon diet consists of fishmeal and oil. Due to the high price reached by these two compounds, it is necessary to carry out research, in order to replace these elements, for example, using vegetable protein or other sources of oil. The diet contains high levels of fish oil, with a feed conversion ratio close to 1:1, which is excellent for cultivation. Many marine farms use computerized systems to conduct feeding, with mechanisms to detect when the fish has finished feeding [54].

Hansen et al. [99], when using yeast to optimize the nutrient digestibility of Atlantic salmon (*S. salar*), found that Saccharomyces cerevisiae increased the solubility of protein and β-glucan. In addition, different yeast processing triggered different immunostimulatory effects in this fish species.

The salmon market demands a reddish-colored meat, requiring the addition of carotenoid pigments, which comprise a family of natural compounds, of which, more than 600 structural variants are reported and characterized, from bacteria, algae, fungi, and higher plants, thus raising the cost of production [54].

5.4.3. Atlantic Salmon Reproduction

In commercial cultivation, the breeders are selected from the breeding stock. These fish are transferred to freshwater cages or tanks. The collected oocytes are cleaned, fertilized with extruded semen (extrusion process), and disinfected, before going to the tray system, where they hatch in this system [54].

After a certain period, the unfertilized eggs are removed, and the hatched ones are transferred to tanks or incubators. For juveniles, carpets, mats, or stones are needed as a "substrate", imitating natural gravel. For the incubation of eggs and the development of juveniles, the ideal water temperature is below 10 °C. After the absorption of the yolk sac, the juveniles go upwards in the water column, indicating the beginning of the first feeding, which can be carried out initially in incubators, through inert (non-live) foods. Juveniles can be grown in tanks with continuous flow or in a recirculation system. Fish can be kept at room temperature and in a light regime. Production densities vary, depending on the system, for example, in a super intensive cultivation, densities are high and can be greater than 50 kg.m^{-3} [54].

5.4.4. Atlantic Salmon Farming Problems

Some diseases/pathological agents can affect the animals, causing damage during cultivation, such as infectious salmon anemia, viral hemorrhagic septicemia and infectious pancreatic necrosis (virus), bacterial kidney disease and salmon rickettsial disease (bacteria), saprolegniasis (fungi), and amoeba in gills and freshwater protozoa (endoparasites) [54].

Hevrøy et al. [100], in a study on the depth of the infestation of the ectoparasite *Lepeophtheirus salmonis* in Atlantic salmon (*S. salar*), concluded that this species, kept at 0 to 4 m depth in cages, developed greater infestation than at greater depths (4 to 8 and 8 to 12 m). A strategy to minimize the effects of the ectoparasite in question is to insert the golden wrasse (*Ctenolabrus rupestris*) into the cultivation cages, a species that will do the complementary delousing, but studies must be done, so that they do not escape through the meshes of the cultivation cage net, causing, for example, genetic pollution [101].

5.4.5. Technological Obstacles in the Cultivation of Atlantic Salmon, *S. salar*

The technological obstacles that prevent the activity from expanding significantly are: the drop in the sales price, due to the high expansion of the activity, causing high production, culminating in high supply, and consequent low market prices. Another bottleneck would be the low availability of suitable places for cultivation, with good quantity and quality of water, for example. In Europe, the production costs are quite high. Finally, the use of food during cultivation has an impact on world fisheries, due to the need for raw materials for its manufacture (flour and fish oil), in addition to the high prices of the inputs currently [54].

5.5. The Golden Pompano, Trachinotus blochii

This fish belongs to the family Carangidae, order Carangiformes, class Actinopterygii, genus Trachinotus, scientific name *Trachinotus blochii* (Lacépède 1801), and its common name is Florida pompano, or golden pompano. The genus *Trachinotus* is composed of about 20 species. Most are shoal fish and occur mainly in coastal environments and brackish waters (especially juveniles), although others are oceanic. They occur abundantly in shallow waters up to 60 m deep [34].

5.5.1. The Golden Pompano Economic Impact

This fish species has high demand in local and international markets, especially in Singapore, Taiwan, Hong Kong, and China. The market value and growing demand are the main factors that contribute to the interest in the aquaculture of this fish [102]. Furthermore, juvenile production techniques have been widely performed in Southeast Asia, along with other high-value marine fish species [103]. According to McMaster and Gopakumar [34]., among the many tropical marine fish of high commercial value that can be farmed, the golden pompano *Trachinotus blochii* is one of the most outstanding, mainly due to its rapid growth rate, good meat quality, and high market demand. Aquaculture of this species has been successfully established in many Asia–Pacific countries, including Taiwan and Indonesia. They can be successfully grown in ponds, tanks, and floating cages at sea. The species is pelagic, very active, and able to acclimate to lower salinities. Presenting strong growth, even at 10 ppt, this species is suitable for cultivation in low salinity coastal waters, as well as in sea cages. In addition, basic hybridization efforts were tested, selecting individuals primarily for rapid growth and early fertility. These findings strongly demonstrate that selective crossbreeding can result in an improved variety more adapted to agricultural environments than the wild stock.

5.5.2. The Golden Pompano Farming

The mariculture of this fish is carried out in open sea cages, brackish water cages, and in ponds in China, India, Indonesia, Philippines, Taiwan, Thailand, and Vietnam. The methods for cultivation cages in open sea have been well-established in Vietnam, and commercial cultivation is being carried out by smallholder farmers and private companies [34].

Juveniles inhabit sandy shores and shallow sandy or muddy bays close to the river mouths, while juveniles move along coral reefs and rocks towards the sea, in small shoals. Adults are generally solitary, feeding mainly on sand mollusks and other invertebrates. Concerning aquaculture, they can be weaned to inert food, such as floating or sinking pellets and catch residue. They can tolerate a wide range of salinities, from 0 to 65 ppt. The species prefers warm tropical waters, with a tolerance of 25 to 29 °C. This species is widely distributed in the Indian, Western, and central Pacific Oceans, with a wide and elongated range from the east-central United States of America to southern Brazil. It is a coastal species, rarely found in waters deeper than 33 m. This species inhabits both coastal areas with oceanic salinities and coastal bays and lagoons (estuaries) with low salinities. The cultivation temperature range is 24 to 28 °C, with an ideal temperature of 27 °C. In addition, their primary diet consists of small shrimp, crabs, and bivalves.

The golden pompano, *T. blochii*, is characterized by its rapid growth and tolerates a wide range of temperatures. Because of its delicate meat and high nutritional value, it is widely accepted for consumption, where this species is becoming increasingly popular with consumers in China, the United States, and Canada, and its annual production has increased from 25,000 tons to over 150,000 tonnes within a decade [104]. Globally, snubnose pompano production reached about 0.11 million tonnes during 2014, with a major chunk from China through net cage farming, low saline pond culture, and re-circulatory aquaculture systems [23].

The golden pompano, *T. blochii*, needs to swim continuously and, therefore, needs an energy-rich diet to support an active metabolism. Growth diets contain an approximate analysis of 40 to 50% protein and 7 to 10% fat. The pompano spawns naturally in offshore waters between early spring and mid-autumn, mostly from April to June. Pelagic eggs are approximately 1mm in diameter and hatch within 24 h. The larvae feed on zooplankton and undergo metamorphosis after 15 days. Juveniles are common in coastal waters during the early summer [34].

The culture of this species is being widely spread in various parts of India, in cages or in ponds close to the coast, using low-cost fish and pelleted food as the main diet [105].

This species can be grown in cages, ponds, and fenced-in. Among all methods, cultivation in low salinity brackish water ponds yielded good harvest after 240 days of cultivation, when the fish reached an average weight of 450 to 500 g and a survival of 94%. In these systems, for fishing, the preferred method is to use gillnets (entanglement nets) with selective meshes. Mesh size targets specific-sized fish, allowing smaller fish to escape, to be captured once they reach market size [34].

The Golden Pompano Feed Needs

Ebenezar et al. [105] cultivated the golden pompano *T. blochii* fed with diets containing the amino acid lysine at different concentrations and observed a high survival rate (95–100%). Maximum weight gain (WG), specific growth rate (SGR), and protein efficiency ratio (PER) occurred at 2.21% dietary lysine. For Stites et al. [106], the minimum lysine requirement is 1.67% of dry weight in food formulations, and it is recommended to meet the nutritional needs for the growth of this species.

5.5.3. The Golden Pompano Reproduction

The reproduction of this species occurs artificially, with the administration of the hormone human chorionic gonadotropin (HCG), at a dosage of 350 IU per kg of body weight in males and females, in a single dose, and the release of oocytes in females can be via a natural way or by extrusion, which is the most effective way. Spawning will usually occur within 36 to 48 h after hormone injection. Spawning normally occurs between the late evening and early morning hours [34].

5.5.4. The Golden Pompano Farming Problems

Maintaining adequate levels of dissolved oxygen is important for the feeding, growth, disease resistance, and reproduction of the golden pompano *T. blochii*, as this species requires large amounts of oxygen. Thus, increasing the stocking density is an effective way to improve the production volume, requiring, for this, a greater supply of this gas [107].

Some diseases/pathological agents can affect animals, causing damage during cultivation, such as ectoparasite (white spot, marine ich) and white spot disease (protozoa), ectoparasite (gill bacterium) and vibriosis (bacteria), ectoparasite (marine velvet) (dinoflagellates), ectoparasite (flukes) and ectoparasite (monogenean worms), cardiac myxosporidiosis (myxosporidian protozoan), and parasitic dermatitis (sea lice) [34].

Ransangan et al. [102] reported the first molecular detection of *Betanodavirus* in *T. blochii* juveniles grown in cages offshore in Langkawi, Malaysia. The virus caused the fish fingerlings to exhibit abnormal swimming behavior, dark skin coloration, and loss of appetite, prior to mass mortality. Histopathological examination revealed acute cell vacuolation in both the brain and retina tissues of the affected fingerlings.

5.5.5. Technological Obstacles and Future Perspectives in the Cultivation of Golden Pompano, *T. blochii*

Temperature tolerance is probably the main environmental constraint for the natural range of this species. The lowest temperature tolerance is 12 °C, at which fish are inactive and are at risk of mortality. The upper temperature tolerance is 33 °C, and if left at that temperature for more than a few days, mortalities will occur. In addition, the supply of energy-rich diets can be a factor that raises the cost of production, especially nowadays. Another obstacle is the possibility of the interruption of public electricity, which is a serious risk in some places, because high-density ponds require constant supplemental aeration, usually provided by electric pumps. Finally, artificial chemicals, especially the pesticides used to control mosquitoes, can have direct and indirect negative effects on the success of a cultivation business of this species [34].

5.6. Other Important Species

While various species are cultured in inland waters using various methods, freshwater finfish aquaculture and shrimp aquaculture, based on brackish water, are two major forms of fish farming in Asian countries. Various types of carp, tilapia, and catfish are the major species produced in the former, whereas whiteleg shrimp (*Penaeus vannamei*) are becoming the second-most dominant in the world, after the black tiger prawn [108].

Due to the importance of the cultivation of these fish in Asia, including the imposing China, we will briefly address these three species (tilapia, catfish, and carp), which are of relevant importance for aquaculture in this region, as described below.

5.6.1. Tilapia Culture

Tilapia are omnivorous, rustic fish that easily adapt to confinement in intensive farming systems, tolerating low levels of oxygen and high concentrations of ammonia [109]. Such characteristics also led them to be commercially cultivated in brackish or salty waters [110–112], bringing economic, social, and environmental earnings. Among the tilapia species, the Nile tilapia, the Thai variety, is the most cultivated strain in Brazil [112].

Native from several African countries, the Nile tilapia or Nilotic tilapia is the most cultivated species of tilapia worldwide. This species stands out from the others for its faster growth and later reproduction, allowing it to reach a bigger size before the first sexual maturation. In addition, it has a high prolificity, which makes it possible to produce large amounts of fingerlings. The Nile tilapia *Oreochromis niloticus* seems to have a great ability to filter plankton particles, and, when cultivated in green water fishponds, this species generally outperforms other tilapia species in growth and feed conversion [113].

Araujo et al. [114] evaluated the effect of stocking density on the zootechnical performance of Nile tilapia *O. niloticus* cultivated in circular and quadrangular cages and found a better performance in the treatment in which circular cages were used at a density of 100 fish.m^{-3}. In addition, the net revenue per kilo of produced fish was also higher in the circular cages at the lowest studied density.

Tilapia tolerate low concentrations of dissolved oxygen in water. Despite the tremendous ability of tilapia to survive a few hours under anoxia, when they are often exposed to low concentrations of dissolved oxygen, they are more susceptible to disease and have reduced growth. Many species of tilapia are euryhaline, that is, they are able to adapt to different salinity conditions. Among the main cultivated species, Mozambique tilapia (*O. mossambicus*) and Zanzibar tilapia (*O. eurolepus hornorum*) are the ones with the highest tolerance to salinity. Both *O. mossambicus* and *O. eurolepus hornorum* are able to reproduce at a salinity of 32 ppt. *O. mossambicus* breeds, even in waters with 49 ppt. However, the maximum production of post-larvae occurs at 9 ppt, which is three times higher than the production of post-larvae in fresh water, that is, in low salinity. Although not as euryhaline as *O. mossambicus* and *O. eurolepus hornorum*, the blue tilapia (*O. aureus*) and Nile tilapia (*O. niloticus*) can be acclimatized in salt water. Nile tilapia breeds normally in salinity up to 15 ppt, and its growth in water with salinity of 16 to 18 ppt is compatible with that observed in fresh water [113]

Figure 1 shows a female red tilapia, *Oreochomis* sp., protecting the offspring (fertilized eggs incubated in the mouth) during reproduction in masonry tanks at the Fish Farming Station of the Federal Institute of Education, Science, and Technology of Ceará–IFCE, Campus Aracati, east coast of Ceará State, Brazil, which has excellent environmental conditions for cultivation, mainly due to the hot climate, practically throughout the year. The red tilapia (*Oreochromis* sp.) is highly in demand, due to many factors, such as its high flesh quality, main source of protein, and its attractive color, which makes the fish worth the high price [115].

Figure 1. Female red tilapia, *Oreochomis* sp., protecting the offspring (fertilized eggs incubated in the mouth) during reproduction in masonry tanks at the Fish Farming Station of the Federal Institute of Education, Science and Technology of Ceará–IFCE, Campus Aracati, East coast of Ceará State, Brazil.

5.6.2. Catfish Culture

The channel catfish (*Ictalurus punctatus*) was introduced into China in 1984 and has become an important species farmed in nearly 20 provinces in China. According to production estimates, the annual output of farmed channel catfish in China was about 220,000 tonnes in 2009 [116]. The channel catfish are the most widely cultured catfish in China, and they are important food sources for the Chinese people [117]. The consumption of channel catfish has expanded several times, too, especially southwest of China, where eating scaleless fish was a traditional consumption habits [118].

In recent years, channel catfish have played an essential role in specialty freshwater fish aquaculture in China, due to the wide range of suitable farming areas, fast growth, large harvest size, and high quality [119]. With the development of biology, ecology, breeding, and farming technology, channel catfish have been cultured on a large scale, becoming one of the top aquatic products. The rapid growth of channel catfish aquaculture has prompted a complete industrial chain, including seed supply, table fish production, processing, and export [120]. Due to its wide adaptability, miscellaneous food habits, strong disease resistance, fast growth, high yield, and tender meat, the scale of aquaculture has expanded rapidly, and the degree of intensification has been continuously improved [121].

African catfish, *Clarias gariepinus*, is a freshwater fish that widely cultivated in Indonesia. The average production increased by 15.84% during the 2015–2019 period. In 2019, Indonesian catfish production reached 1.2 million tonnes from the production targeted at 1.7 tons. Catfish production in 2030 is projected to increase by 100% [122].

5.6.3. Carp Culture

Cyprinidae is a major source of animal protein in many Asian and eastern Europe countries and plays an important role in aquaculture and recreational fishery [123]. Common carp (*Cyprinus carpio*) is one of the most important Cyprinidae fish in the world [124], it is one of the most farmed fish in pond aquaculture in Asian and eastern Europe, and it is the third-most farmed fish of aquaculture production, with the seventh largest market value [123,125]. In addition to the broadly distributed wild populations, dozens of distinctive domestic strains were developed worldwide during its lengthy aquaculture history. Those variants, such as the Songpu carp, Jian carp, Purse Red Carp, German mirror carp, Majalayan, Yamoto, Galician, Dor-70, etc., exhibit obvious morphological variability and/or particular adaptability within this species [126].

Common carp (*C. carpio*) is an omnivorous species that feeds on aquatic insects, oligochaetes, mollusks, detritus, seeds, and phytoplankton [127]. Phytoplankton and zooplankton are important components of the digestive system contents [128].

In 2020, crucian carp production in China was 2.75 million tons, accounting for 8.9% of the total freshwater aquaculture production in China. Grass carp are a commonly cultured fish distributed in more than 40 countries worldwide [129]. Grass carp (*Ctenopharyngodon idella*) is one of the most frequently farmed warm-water species in China, due to its ease of domestication and acceptance in the marketplace [130]. Grass carp is one of the main cultured freshwater species in China, with an annual production of over 5.8 million tons, which is also the largest production of fish in the world's aquaculture [131].

6. Sustainability in Marine and Coastal Fish Farming

To increase the production of aquatic organisms, it is necessary to raise the stocking density in the cultivation facilities. Cultivation at high densities can cause negative environmental repercussions, such as chemical and biological pollution, disease outbreaks, unsustainable feeding, and competition for coastal area. [107], and may also compromise the environment, to a certain extent.

Jiang et al. [132] developed a food-energy-water-carbon (FEWC) sustainability index, from 0 to 100, to assess the global sustainability of aquaculture among countries. The results indicate that the overall sustainability of global aquaculture is low (average score = 26), with none achieving a high sustainability score (75–100) and almost all practicing aquaculture in a relatively low, sustainable way (0–50). Considering the sub-sustainability at a sector level, 80% of countries had at least two sectors among the FEWC falling into the low sustainable zone (score less than 25). China led all countries by contributing to more than half of global aquaculture water consumption and greenhouse gas emissions, followed by India and Indonesia.

6.1. Classical Methods to Have Fish Farming More Sustainable

Among the most sustainable practices in fish farming, we can highlight the use of moderate densities, feeding strategy, and location, as verified through the level of cortisol in the fish, an indicative factor of stress in farmed animals, observed, for example, by Hanke et al. [86].

Kumaran et al. [133] observed favorable technical indicators (fish survival, feed conversion, growth rate, and productivity), economic parameters (cost-benefit ratio, payback period, and internal rate of return), and indicators of livelihood security in the cultivation of barramudi *L. calcarifer*, when cultivated in the three-phase system in India, comprising larviculture, pre-growing, and final grow-out in cages, thus showing that this system is technically and economically viable, socially acceptable, and, therefore, sustainable.

Calleja et al. [134] found a high potential for marine aquaculture, specifically for large and medium-sized enterprises. Three out of each five species studied showed high suitability in most study sites (central and northern Pacific coasts of Costa Rica), and the other two species showed promising results in the Gulf of Nicoya. At a regional scale, the Pacific coast of Costa Rica presents a high potential for fish aquaculture, being a promising development medium for coastal communities, as long as it is environmentally sustainable and compatible with other coastal activities, such as tourism.

IMTA

Another point to comment on is the discharge of effluents from aquaculture, mostly obtained through the foods used in cultivations, which can greatly affect the environment, if not treated correctly. Based on this notion, the IMTA (integrated multi-trophic aquaculture) concept was developed, which applies a simplified food web structure to a farming system of fed species, such as fish and shrimp, in conjunction with extractive organisms, such as mollusks and seaweed, which suck up particles and nutrients from the environment [135]. On this point, when designing an effluent treatment unit, such as a recirculation system (RAS) and the use of macrophytes or adsorbents, fish farmers must consider a variety of factors. Through appropriate treatment methods, the objective is to reduce environmental pollution [136]. A greater input, mainly of nitrogen and phosphorus, in aquatic ecosystems will be evidenced in eutrophic environments, which means an increase in primary production in water bodies [136].

Current RAS knowledge and technology make these systems viable and economical only for the production of high-value species at the moment, but other aquatic species may become sustainable with alternative choices, such as aquaponics. Many present and future advancements in renewable energy production will lower RAS operating costs. To lower RAS costs, aquaculture producers, scientists, and engineers must collaborate to properly design and constantly improve every component of RAS. Through research and field tests, greater information about RAS technology is gathered, as well as a better understanding of the interplay between its numerous components. RAS technology will continue to alter and modernize the aquaculture sector, including the local production in or near metropolitan areas, as well as in locations and nations with limited water resources, where more traditional aquaculture systems will be implemented [137].

The wastewater from the cultivation tanks of the most diverse cultivated marine species, rich in nutrients, can be used, for example, for the cultivation of marine macroalgae, which shows the cultivation of the red macroalgae *Calliblepharis jubata* in an external environment (outdoor) (Figure 2), using a prototype cultivation tank developed by the company Lusalgae Ltd., located in Figueira da Foz, Coimbra, Portugal. This macroalgae, in addition to the environmental quality, due to the consumption of excess nutrients from fish farming, with the increase in biomass, can be used for the extraction of carrageenan (phycocolloid), of great importance for the world food industry. In that figure, the culture medium was estuarine seawater (29 to 34 ppt) obtained from the Mondego River estuary, in the same locality, without addition of nutrients. The culture tank had a capacity of 1000 L, containing 800 L of mechanically-filtered estuary water.

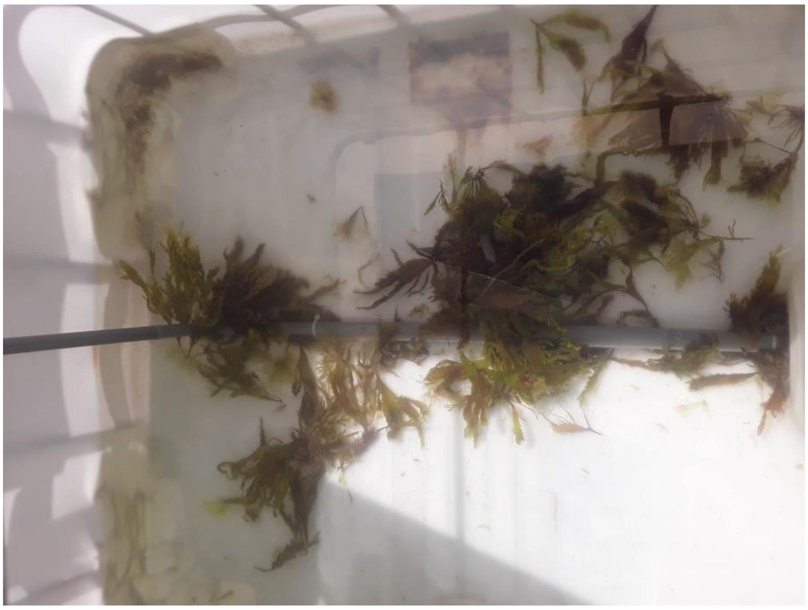

Figure 2. Cultivation of the marine macroalgae *Calliblepharis jubata* in an external environment (outdoor).

6.2. Technological Evolution in Fish Farming

Industry 4.0 is associated with engineering and computer science knowledge, coupled with multisensory schemes for aquaculture systems associated with online servers and/or workstations with the most appropriate software to manage and control the system, thereby contributing to improved aquaculture productivity and efficiency, while lowering the overall costs [138]. Aquaculture 4.0 technologies are a long-term solution for increasing production (quantity and quality), while decreasing expenses and pollution in aquaculture [139]. Because aquaculture can be offshore or onshore, abiotic and biotic factors influence the aquaculture system, which has a high influence on aquaculture productivity. The 4.0 technologies and methods must be developed to deal with the environmental demand from the aquaculture location and species cultivated [140].

Numerous technologies are now being used in different domains that can be included in aquaculture 4.0: recirculation aquaculture systems (RAS), smart aquacultures (offshore and onshore), and real-time water quality [138].

Aquaculture 4.0 programs provide farmers with real-time monitoring of water quality and aquaculture conditions. These systems can provide a large amount of information at intervals of seconds or minutes, allowing for the more accurate planning of aquaculture activities and the possibility of prompting alarms, in case of unsafe water conditions/quality or weather alerts (e.g., allowing the offshore systems to descend the fish cages to deep sea weight, reducing the negative effects of sea waves and bad weather in the aquaculture system). Additionally, the creation of a comprehensive database will aid in precise and specialised research to improve the efficiency of aquaculture over the medium- and long-term, minimising risks and elevating fish farming productivity.

One of the key benefits of aquaculture 4.0 is the remote control and viewing of the RTD on a cloud-based platform, particularly in marine farms, where cages cannot always be entered quickly and at the desired moment. Onshore fish farmers applaud the cloud-based system of onshore aquaculture characteristics, which can be accessible from anywhere [138]. Thus, the evolution of the fish farm passes for an adaptation to IMTA protocol to reduce wastes in the aquatic systems.

Offshore aquaculture is still a new business that needs to include additional technology, such as artificial intelligence and augmented reality, that can improve and automate numerous activities remotely, such as feeding, sampling, monitoring, and surveillance.

More study on the implications and repercussions of offshore aquaculture on seafood security and marine habitats, as well as the social dimensions and effects of offshore aquaculture, is required.

6.3. Feed and Nutrition in Fish Farming

Rising fish feed prices, as well as the environmental consequences of over-harvesting forage fish for feed and fish oil, have led to a rise in the rearing of herbivorous fish (carp and tilapia) and omnivorous fish (barramundi), which use significantly less fishmeal to generate protein. Furthermore, antibiotics or pesticides used on farmed fish can have an impact on other marine species or human health. These nutrients and pollutants fall to the ocean floor, where they may have an influence on the biodiversity. Meanwhile, research to discover alternatives to fishmeal feed or methods to make it more sustainable is continuing. Thus, finding the finest fish feed formulae also includes attempting to attain the lowest feed conversion ratio—the amount of feed supplied, in relation to the weight acquired by the fish [141].

The production of feed based on new ingredients is important, due to the fact that raw materials for feed increase the price and sustainability; therefore, there is an increased demand to exploit more sustainable and economic raw source for feeds. At this moment, vegetable- (non-competing vegetables for animal feed or human food) and insect-based feeds can be an economic and efficient alternatives to the traditional feeds [142]. Thus, the exploitation of microalgae, macroalgae, bacteria, yeast, and insects can substitute for the actual forage fish, particularly in high-value species, such as salmonids, which will be critical for fed aquaculture sustainability [142]. Furthermore, nutrition is a vital player in fish farming economy, since feed accounts for almost half of the variable production cost. In recent years, fish nutrition has evolved substantially with the development of new, balanced commercial diets that support optimal fish growth and health. The creation of novel species-specific diet formulas helps the aquaculture sector expand to meet the rising demand for economical, safe, high-quality fish and seafood [143].

Other aquaculture problem is overfeeding, which wastes valuable feed. Water contamination, low dissolved oxygen levels, higher biological oxygen demand, and increased bacterial loads are other consequences. Fish should typically be fed simply the quantity of feed that they can ingest fast (in less than 5 to 10 min). A decent general rule of thumb is to give the fish around 80% of what they want to consume (satiation). In this method, you feed, for one day, as much as the fish will ingest on a regular basis, possibly twice a month [143]. Thus, the new feed needs to have higher nutritional values.

Due to the antibiotics and pharmaceuticals restriction used in the fish cultivation. The industry's future development is heavily reliant on the sustainable use of natural resources. Nutraceuticals are being used in aquaculture to improve disease resistance, growth performance, food conversion, and product safety for human consumption. Probiotics boost growth and feed conversion, enhance health, promote disease resistance, reduce stress sensitivity, and boost overall vigor. Currently, the majority of nutraceuticals come from terrestrial sources, rather than fish. Host-associated (autochthonous) nutraceuticals, on the other hand, are expected to be more durable in the gastrointestinal system of fish and, as a result, may have longer-lasting benefits on the host. Nutraceuticals candidates are often evaluated in vitro; however, the transition to in vivo testing is frequently difficult [144]

Although the administration of adequate doses of immunostimulants or immunomodulatory agents promotes an increase in resistance to different diseases and improves the animals' health statuses, some studies demonstrate that the administration of an optimal dose of an immunostimulant is extremely important to obtain an effective response. These effects were proven in the cultivation of Asia seabass (*Lates calcarifer*), and the *Kappaphycus alvarezii* (Rhodophyta) addition showed excellent immunostimulatory activity, constituting a good immunostimulant/immunomodulating agent in the fish aquaculture field, although more trials are needed [145].

The use of natural substances capable of immunomodulating the fish reaction to stress factors, combined with good management of cultivation, emerges as a promising tool for aquaculture, as it promotes action against the negative effects, reducing mortality during the production process of these organisms.

6.4. Biosecurity in Fish Farming

According to FAO, biosecurity is a comprehensive and integrated strategy that encompasses both the policy and regulatory frameworks aimed at analysing and managing relevant hazards to human, animal, and plant life and health, as well as the associated environmental problems. It is a comprehensive concept that addresses food safety, zoonoses, the introduction and management of animal and plant illnesses, and invasive alien species. It also addresses the introduction and dissemination of live modified organisms and their by-products [146]. Failure to apply biosecurity can result in disease outbreaks, which, as previously said, can reduce farm output, pose hazards to human health, give fish a terrible flavour and look, and obstruct farm access to markets. All of this, of course, reduces a farmer's cash return. Globalization, for example, has increased the risk of disease spread, due to the increased volume, diversity, and social-economical relevance of aquatic animal trafficking. Several stages must be performed, in order to build a successful biosecurity plan. These processes are as follows: hazard identification and prioritisation; risk-impact assessment; identification, mitigation, management, and remediation of critical the control points through which diseases may enter or leave the epidemiological unit; development of a contingency plan if a disease is discovered in the unit through disease surveillance, monitoring, and determination of disease status or freedom in the epidemiological unit; and periodic audition of procedures. Veterinarians test these procedures, and government veterinary authorities should evaluate and approve them [147].

Aquaculture has been demonstrated to have the potential to contribute to socially beneficial global food production. However, in order to address the expanding global food security issues, the aquaculture blue revolution must be accelerated, but corrective techniques to mitigate its negative repercussions must also be developed. While contributing to global food production and boosting per capita animal protein intake, aquaculture has depleted resources that sustain regional and global food security in some circumstances. Indeed, certain aquaculture methods are viewed as a danger to food security [148].

Most aquaculture laws and certification programs are geared toward individual farms. Even if everyone follows the rules, having a large number of producers in the same location might have a cumulative environmental impact, such as water pollution or fish infections. Spatial planning and zoning can help to guarantee that aquaculture activities stay within the carrying capacity of the surrounding environment, while also reducing disputes over resource usage. For example, Norway's zoning restrictions guarantee that salmon farmers are not unduly concentrated in one location, thus decreasing disease risk and helping to manage environmental repercussions.

Many fishponds in China, Thailand, and Vietnam have been converted from rice fields, a practice that China has since prohibited, owing to national food security concerns. More crucially, it represents a change from producing a main food crop for local populations to producing a commodity for the export market, and so food security is a major concern for some small farmers, who have converted good rice fields into fish farms [149].

According to Beveridge et al. [150], the contribution of aquaculture to food security is dependent not only on where it happens, but also on culture species, product price, and fish size—all of which impact availability and usage by poor customers. Farmers can be incentivized to conduct more sustainable aquaculture through a range of governmental and commercial programs. Thailand's government, for example, has offered free training, water supply, and wastewater treatment to shrimp farmers working lawfully in aquaculture zones. The government has also offered low-interest loans and tax breaks to small-scale farmers, assisting them in adopting superior technology that has enhanced production and decreased the need to clear additional land [151]. Thus, to inspire farmworkers to execute biosecurity measures, they should be instructed on biosecurity by reputable and credible sources, such as veterinarians, so that they understand the benefits of implementing biosecurity measures, as well as the costs of not implementing them.

A biosecurity strategy must be evaluated and updated on a regular basis to reflect the changes in internal infrastructure, production, and external exposure, as well as regulations. The most effective strategy to establish robust biosecurity at an aquaculture plant is to create a documented biosecurity plan, based on risk assessment, and utilise audits to determine how well the plan meets the risks and hazards present. The grading method will be critical in determining the relative relevance of the many elements and activities included in the plan, both individually and as part of a biosecurity farm programs. A biosecurity strategy will not be effective unless it is adequately taught and adopted by farm employees, as a routine operating procedure. Biosecurity cannot be cost-effective unless farmers collaborate transparently at the regional, national, and international levels. Transparent reporting of critical data and information exchange on the area health status, particularly the prevalence of infectious illnesses and increasing mortality occurrences, is critical. Transparent collaboration among stakeholders is the only way for the industry to effectively prevent and control disease outbreaks [152].

6.5. Fish Genetics on Farming

Appearance factors in fish, or those exterior body qualities that impact consumer acceptability at the moment of sale, have risen to prominence in commercial fish farming, as culture success is strongly tied to control of these traits. Body form and skin pigmentation are the two most important physical characteristics. An examination of the genetic basis of these qualities in various fish finds considerable genetic diversity among populations, indicating the possibility of genetic improvement. Work on determining the minor or main genes driving commercial fish aesthetic attributes is growing, with significant success in model fish, in terms of discovering genes that regulate body form and skin colors [153].

As a result, in order to meet the current market expectations and maximize profitability, manufacturers are being obliged to regulate outward features, particularly body form and skin color, more intensely on an industrial scale. In commercial fish, such as common carp, tilapia, sea bream, and salmonids, this genetic strategy is supplemented with previous progress, based solely on the breeding values estimated with phenotypic and genealogical information or classical genetics, which has enabled the development of new strains, for example [153,154].

This is not a simple operation, however, because body form and skin color in fish are complicated features influenced by a variety of hereditary and environmental variables. Thus, development in this subject will be dependent, in part, on unravelling the underlying genetics of these traits, in order to use current selection procedures, such as marker-assisted selection, based on molecular data, in the future [153].

This type of selection approach has resulted in new fish populations with greater market involvement, contributing to the better profitability of fish cultures. Because of the sophistication of the market in many parts of the world, this tendency is projected to continue in the coming years. As a result, there is interest in fish selection to ensure visually pleasing species, such as tilapia, rainbow trout, common carp, gilthead sea bream, and sea bass [153].

To address this challenge, however, fish producers must adapt and connect their selective breeding objectives with market expectations. One older and antique approach that might be used to attain this goal is the finding of quantitative trait loci (QTLs) or genes that underpin body form and skin color, where continuous variation of the various qualities that comprise these traits is typically found. This knowledge might be utilized to conduct marker-assisted selection, which is based on molecular markers that are strongly related to QTLs that affect several appearance features of economic relevance. This technique still is widely applied in various countries for the rainbow trout, common carp, gilthead sea bream, and sea bass farming [153].

However, nowadays, the trend is in selective breeding using genomic selection, which has an enormous potential to increase aquaculture efficiency and minimize its environmental footprint [155]. This genomic selection is based on enhanced genomic tools during the last decade. Thus, these genomic tools are extremely useful for sustainable genetic improvement. Nowadays, these tools have low cost and ease of use, meaning that they can now be used at all stages of the domestication and genetic improvement processes, from informing the selection of base populations to advanced genomic selection in closed commercial breeding nuclei [155,156]. With the high interest in this genetic technology, equipment companies are interested in developing equipment for the fish farming. Thus, R&D and fishery-related laboratories can sequence a target fish species' genome, thus eliminating the need for the coordinated effort and financing that resulted in the first farmed animal species' reference genome assemblies (for example, the QTLs method) [155]. In this case, the most advanced fish farming species is the *S. salar* (Atlantic Salmon) [157].

Furthermore, genomics technologies are useful for addressing the species-specific breeding and production difficulties associated with the very diversified biology of aquaculture species. The introduction of well-managed selective breeding programs for aquaculture, based on pedigree recording and routine trait assessments, has resulted in the increased output of various species (QTLs method). This previous work, which can be upgraded with these new genomics technologies, can drive fish farming to a new a level of aquaculture on the safety, economic, and efficiency levels [155].

In conclusion, biotechnological developments have the potential to overcome productivity constraints in aquaculture if the all the work done is coupled with new technologies and not started from ground zero. These advancements include the use of genome editing technologies to make targeted changes to aquaculture species' genomes, thus resulting in improved health and performance, the use of reproductive biotechnologies, such as surrogate broodstock, to accelerate genetic gain, and combinations of both approaches [155].

6.6. Dangers Nowadays in Fish Farming

Finally, Mahamud et al. [158], in their review article, discussed the factors associated with the introduction of macro and microplastics (MPs) in aquaculture via fishmeal obtained from animals caught in natural environment that can accumulate these materials. There are great consequences of MPs on cultivation ponds, fish physiology, and consumer health. The authors recommend taking the necessary care to improve the PM screening process during fish food production and focusing on further studies to elucidate the impacts of MPs on sustainable aquaculture production.

Because there are several international and national aquaculture certification systems, the FAO created technical criteria for aquaculture certification, as well as an evaluation methodology. However, although many big fish farms are obliged to do environmental impact studies and obtain certifications, small farms, many of which are unsustainable, are not. Many nations have lax regulations managing responsible aquaculture development [141].

7. Conclusions and Future Perspectives on the Main Species Cultivated in Marine and Coastal Fish Farming

Breeding technology advancements, disease management, feeds and nutrition, and low-impact production techniques are all interconnected areas where science may supplement traditional wisdom to increase efficiency.

7.1. Cobia

Future perspectives for expanding the cultivation of the cobia *R. canadum* are: the improvement of the nursery stage and adaptation of juveniles to lower salinities, thus allowing for the cultivation of this species in various environments. Thus, the future of the cultivation is bright, as it has a good growth rate and excellent meat quality [54]. At present, research on the development of vaccines against major bacterial pathogens (*Photobacterium damsel*a subsp. *piscicida*, *Vibrio alginolyticus*, and *Streptococcus* sp.) are undergoing. Another alternative approach to this problem is the use of immunostimulants (e.g., h-glucan, levamisole, etc.) to enhance the nonspecific immunity of fish to various diseases [37]. Still, according to the authors, the use of automation, in terms of the feeding, sorting, harvesting, and washing of the cultivation structures, still needs to be developed, as these activities are highly necessary for the use of manpower, especially in the fattening cages in the open sea.

7.2. Asian Sea Bass

For Asian sea bass, *L. calcarifers*, the future prospects for expanding the activity are: the implementation of genetic improvement programs, mainly related to growth (higher growth rate) and disease resistance. Studies of environmental impacts are also necessary, mainly in cage cultivation and the improvement in the commercialization of this product, with greater emphasis on by-products (added value) [54]. Given the wide range of production environments under which they can be cultivated, it is important to adopt selective breeding programs to optimize growth rates, considering the impact of the genotypic interactions (GxE) in these environments [61].

7.3. Milkfish

The future perspectives for the expansion of the cultivation of milkfish *C. chanos* are: the use of new production technologies, through the implementation of more efficient systems, aiming to increase the productivity and the supply of juveniles. It is also necessary to use by-products (added value) and to open new markets for the commercialization of this species [54].

7.4. Atlantic Salmon

Still, according to FAO, for Atlantic salmon, *S. salar*, the future perspectives for the expansion of the activity are: carrying out research related to the reduction of environmental pollution caused by activity, due to the excess of nutrients and use of chemical products, in addition to the danger caused by the escape of specimens to the environment, as well as in the resistance to several diseases that occurs during cultivation [54].

Regarding the densities in cultivations, there is a concern, for example, in super-intensive storage in the cultivation of Atlantic salmon, *S. salar*, regarding the need to feed the animals and obtain food, with the tons of fish caught destined for fishmeal, the main source of protein in the food, being an environmental challenge that this industry faces globally [159]. Under these conditions, alternative sources of protein should be sought, as described in some works in the previous topics.

7.5. The Golden Pompano

The future perspectives for the expansion of the cultivation of the golden pompano *T. blochii* are: the optimization of the cultivation stages and increasing productivity and production, given the increase in market demand, in addition to discovering new specific demands and processing, in order to maintain a constant supply of the product, respecting its short shelf life (very perishable food) [34].

7.6. Conclusions

Thus, this review demonstrates that fish farming is evolving to be more neutral to the surrounding environment; it is also a hypothesis for being a good food source for humanity, due to being used aquatic systems and not arable land.

The increase of coastal aquaculture can contribute to the production of much-needed extra food for the world's rising population. Increasing fish output, through the growth of coastal aquaculture, using ecologically friendly techniques and suitable adaption measures for the physical cultivation methods used nowadays, is important.

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