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Review Article

Aquaculture and Fisheries as a Food Source in the Amazon Region - A Review

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Abstract

This is a review of the importance of inland water fisheries and fish farming as a food source in the Amazon basin. Small-scale fisheries resources have been depleted and climate change poses a growing threat, failure to address the issues confronting the sector places the food safety and livelihoods of millions of people at risk. The governments should form partnerships with the communities for them to assist in managing the resources. The fishers would gain in this co-management but also have to assume responsibility for their decisions and actions. Co-management is always far better than no-management. From the landings, trade, and consumption of fish, it has been estimated that the total fish catch in the Amazon basin is above half a million tonnes/year in live weight. However, this figure is very rough given that 75 per cent of represented landings come from Brazil with no updated official statistics after 2010 on commercial landings. Aquaculture offers the largest potential to increase fish supplies in the long term but the rapid growth is unevenly distributed among countries. Three major aquaculture producers are Ecuador, Brazil and Colombia but Amazon basin aquaculture has some importance also in Peru. Aquaculture development in the region is facing many challenges including to combat against diseases and epizootics, the need for better hatchery and grow-out technology, brood stock improvement, appropriate and most economic feed production and water-quality management. This paper pays also attention to the unwanted spread of alien fish species often as escapees from aquaculture. Annual per capita fish consumption in kg/capita in the Amazon basin countries varies between 2.6-25.3 kg/year, the three leading countries being Guyana, Peru and Suriname. The consumption is fairly low compared to the European Union and the global averages which are around 27 and 22 kg/capita/year, respectively. However, in all Amazonian countries, 50 up to almost 100 per cent of artisanal freshwater fishing takes place for personal consumption, implying that it may not be fully recorded in official consumption statistics. Ornamental fish culture and trade have had an important role in the Amazon basin countries, the three biggest producers and exporters of aquarium fish being Brazil, Colombia and Peru. In 2008 economic crisis hit Brazil and started the decline of the ornamental fish trade. One reason for the decrease in the trade was the competition with neighbouring Colombia and Peru with less bureaucratic systems and fewer restrictions on which species can be exported. International pressure to stop the commerce of wild-caught fish intensified and the increase of husbandry practices and reproduction in Southeast Asia caused the downturn of the Brazilian Amazonian market. Thousands of families lost their livelihoods and many fishermen were forced to start working in sport fishing and commercial fisheries. Sport fishing is a hobby for those to whom money or fish food is not the main object but more important is to get a good photo together with a big fish. Sport fishers are all practising the catch and release system so fish is not away from nature and the activity is an important income source in tourism and benefits the local fishers often in remote rural areas. Free-time fishing may not be so significant for the national economy but it has high value in social and recreational terms for many people from all walks of life.

Keywords: Artisanal Fishery; Aquaculture; Indigenous and Non-Native Fish Species; Demand of Fish; Consumption; Fisheries Economy; Ornamental Fish Trade; Sport Fishing

Introduction

In 1978 Bolivia, Brazil, Colombia, Ecuador, Guyana, Peru, Suriname and Venezuela signed the Amazon Cooperation Treaty (TCA). The aim of the Treaty is the harmonious development promotion of the Amazon basin, including an equitable benefit distribution, improving the quality of living of its peoples and achieving the full incorporation of their Amazon territories into the respective domestic economies. In 1995, the TCA member countries created the Amazon Cooperation Treaty Organization to strengthen the implementation of the Treaty [1].

Raising awareness of the importance of small-scale fisheries and fish farming in the Amazon basin is particularly relevant, not only because these livelihoods depend on sustainable use of the natural resource base, but also because these activities provide vital local nutritious food and a safety net for many poor households in rural communities. At a time when fisheries resources are increasingly depleted and climate change poses a growing threat, failure to effectively address the issues confronting aquaculture and fisheries places the livelihoods of millions of people at risk [2]. By quantifying the regional economic and social footprint of fish farming and small-scale fisheries, this paper calls for increased attention to issues facing food- and fish-related activities in the Amazon area.

Worldwide, fish is the main source of animal protein and is most easily accessible because it is often available year-round when other sources of protein are at a seasonal low. In many rural communities, it is the cheapest and most easily accessible source of animal protein, particularly for food-deficient and poor people [2]. Fish is also an important source of essential fatty acids and micronutrients, especially when eaten whole. These micronutrients are an important complement to the predominantly carbohydrate-based diets of many people including also vitamins A, B and D as well as iodine, iron, zinc and calcium [3]. Luckily fairly good information exists on the importance of fish consumption in diets in indigenous and rural communities in the Amazon region.

The information is compiled from case studies and FAO country and Globefish market profiles [3-12] and the paper draws on a wide range of published information to provide a regional picture of aquaculture and fisheries mainly from a social and economic perspective. It presents an estimate of the contribution of the fisheries sector to the gross domestic product, including recreational fishing and postharvest activities, and highlights the importance of subsistence fishing in the Amazon basin.

A major review of the potential for the production of selected South American native fish species in aquaculture was done three decades ago [13]. Butterfly peacock bass *Cichla ocellaris*, sabaleta or matrinchã *Brycon* spp. Characidae, black banded leporinus *Leporinus fasciatus* and boquichico *Prochilodus nigricans* have advanced slowly, but others, such as tambaqui *Colossoma macropomum* and arapaima *Arapaima gigas*, have been developing with a promising market, especially in the Amazon region. Other fish (tiger catfish species *Pseudoplatystoma* spp. and silver catfishes *Rhamdia* spp., beyond the Characiformes *Piaractus* (e.g. pirapitingas) and *Astyanax* (e.g. tetras) have gained prominence as shown later [14,15].

The ornamental fish trade started during the 1950s [16], becoming in 2014 a global industry of ten billion USD, while the entire industry (including plants, accessories, aquariums, feed, and drugs) is estimated to be worth 18–20 billion USD annually in 125 countries [17]. It was calculated that two billion live ornamental fish were exported annually worldwide in 2010 and that same year estimated 7.2 million homes in the United States and 3.2 million in the European Union had aquariums [18]. In South America, the majority of species traded are wild-caught fish from the Amazon [19,20].

In this context, sport fishing and recreational fishing are used as synonyms, although for some people only fishing with a rod and real is sport fishing. Recreational fishing techniques include also hand gathering, bow fishing, spearfishing and trapping [21].

Geography of the area

The Amazon River is the widest and deepest river in the world and has by far the largest flow of water and drainage area. The Amazon and the Tocantins-Araguaia basins in the north account for 55 per cent of Brazil's total drainage area. Some studies consider the Amazon to be the longest river in the world with a length of 6990 km and the Nile the second longest with 6850 km. The Amazon River is navigable by ocean steamers as far as Iquitos in Peru [22]

Three of the largest tributaries of the Amazon basin are born in Colombia: the Putumayo River (1700 km), the Negro or Guainía River (2000 km), and the Caquetá River (2200 km) [1].

The total incoming water is 2985.5 km^3/year, of which 29.5 per cent (880 km^3/year) comes from Colombia (Japura, Negro, and Putumayo), 1495.5 km^3/year from Peru (Amazon, Jurua and Purús), 550 km^3/year from Plurinational State of Bolivia (Madeira), 60 km^3/year from Bolivarian Republic of Venezuela (Casiquiare) [1].

Casiquaire River forms a unique natural canal between the Orinoco and Amazon river systems. It is the waterway of the world linking together two major river systems. This phenomenon is called bifurcation. The area forms a water divide, more dramatically at the regional flood stage [22].

Amazon basin has an area of 2.7 million square miles belonging to nine countries as follows:

Bolivia 7.7%, Brazil 58.4%, Colombia 7.1%, Ecuador 1%, French Guiana 1.4%, Guyana 3.2%, Peru 12.8%, Surinam 12.5% and Venezuela 6.1% [23].

Bolivia

General

As a land-locked country of 1.1 million km^2, it has no marine resources but extensive freshwater resources with a great diversity of fish species. There are some 145 important rivers, 37 lakes and 202 permanent lagoons in Bolivia's 7.7 per cent of the Amazon basin. The country has also a large area (100 000 - 150 000 km^2) that is regularly flooded during February and August. Fishing activities take place nationwide, involving both capture fisheries in rivers and open waterbodies, and fish farming [4,12]. In the Amazon basin, the usual fishing techniques include nets of several sizes and long lines with 10 fishhooks. Three types of fishing boats are used: canoes, boats and potons, which are largish, motorized, wooden vessels about 10 m x 1.60 m [4,12].

Inland fisheries

Bolivia is one of those countries in the region not able to provide FAO with fish statistics since 2015 [12]. The fishery resources in the Amazon basin are estimated to yield 12 000 – 14 000 tons/year, although the size of the potential fishing resources is believed to be much higher [12]. In 2019, the national catch was estimated to be 7900 tons [12]. The Bolivian fisheries are not well developed because of communication difficulties due to long distances between the fisheries and the commercial centres. This increases the costs of fishing and distribution of the products but there is great potential for increasing the commercial catch, as well as for extending and diversifying the fish farming production of native species. The Amazon basin in Bolivia has 790 native fish species and 12 alien species [12]. Many more species could still be identified, although only some 40 species have commercial value. Fish like the surubi *Pseudoplatystoma fasciatum* (Figure 1), the chuncuina *P. tigrinum,* the pacú *Piaractus mesopotamicus* and the tambaqui (the last two belonging to the Serrasalmidae family) are the most prominent species, forming about 45% and 39% of the catch, respectively [4,24].

Figure 1: Surubi *Pseudoplatystoma fasciatum*. Photo courtesy of Matthieu Sontag.

There are two types of commercially exploited fishery resources: fish species that migrate long distances for spawning (f.i. surubí and sábalo jetón *Prochilodus lineatus*), and those that travel laterally to the adjacent flood-prone plains to feed and spawn (f.i. the pacú). The migrating fish are caught mainly during the dry season migrations in the river channel. The fish of the flooded lands are caught all year round, especially during the later part of the dry season. The size of the lagoons is reduced in September and October, thus facilitating fish capture. These lagoon areas are important for fish breeding and feeding as well as productive fishing zones [4].

Aquaculture

Bolivian aquaculture activities started with the introduction of many non-native species of freshwater salmonids during the 1930s. Rainbow trout *Oncorhynchus mykiss* adapted well to extensive fish farming in the Altiplano basin. In 1955, the Argentinian silverside *Odontesthes bonariensis* – known in Spanish as *pejerrey* – was introduced into the valleys' region, and later accidentally introduced to the Altiplano, where it competes with the local fish fauna. Attempts to repopulate rivers with subtropical and tropical species started in 1962 with the introduction of the common carp *Cyprinus carpio*. The programme was operated by Universidad Mayor de San Simón, the local state university in the Department of Cochabamba. Around 1964, evangelical missions were responsible for the introduction of the Nile tilapia *Oreochromis niloticus* and the Mozambique tilapia *O. mossambicus* into the Yungas region. The latter species was introduced again by USAID in 1990 to promote semi-intensive fish culture [4].

Thus far, aquaculture is not very important in the Bolivian economy. In 2020 the annual aquaculture production was 3720 metric tons, and next year 133 tonnes more (Table 1.). Even though there have been numerous efforts to develop aquaculture projects, only trout breeding in the Altiplano has reached a commercial level, operated by small enterprises that have access to the necessary inputs like eggs, alevins and balanced feed. These enterprises have been successful to a certain extent mainly because they receive support from the Bolivian Aquaculture Centre for Research and Development. It is the national entity in charge of research and development in the field. However, the majority of the communities involved in fish farming are not yet self-sufficient.

Country/Year	2020	2021	Difference +/–
Bolivia	3720	3853	+ 133
Brazil	630 200	650 356	+ 20 156
Colombia	179 351	192 521	+ 13 170
Ecuador	774 569	896 435	+ 121 866
Guyana	138	142	+ 4

Peru	143 830	150 818	+ 6 988
Suriname	37	40	+ 3
Venezuela	53 609	53 601	– 8
Latin America & Caribbean	3 780 917	3 848 605	+ 67 688

Table 1: Aquaculture production in metric tons in the Amazon basin countries. Source of information [14].

In the Amazon basin fish farming has had minimal importance, despite having ideal conditions. Mainly native species are cultivated (like the pacú and tambaqui), with some exotic species (tilapia) cultivated in extensive systems. The two regional fish culture stations are producing small quantities of alevins of tilapia; these stations are also importing tambaqui and pacú alevins. The two stations have brood parents but have not yet managed to artificially stimulate the spawning process of these two species. There is potential for the introduction of freshwater shrimp production, either alone or in conjunction with other fish production projects. The development of fish farming in the Del Plata basin is based on the common carp. The governmental sector, through the San Jacinto Fishculture station, has implemented a programme for populating the hydroelectric dam. The introduction of the common carp for subsistence fisheries has been successful because of the reduced sábalo population; moreover, because carp has a national demand, there is the possibility of further development based on this species [4].

There is a new outcome story that reports on fish farming research in Bolivia supported by the Canadian International Food Security Research Fund, a program of Canada's International Development Research Centre, undertaken with financial support from the Government of Canada [25].

Based on a study carried out by experts from Canada, Brazil and Bolivia, the Fish for Life project was set out to increase family fish farming profitability, sustainability and gender sensitivity. Before the project, fish farming in the Yapacani area was carried out by 40 vulnerable rural families. Now there are 130 families engaged in fish farming, each with three fish ponds. This has increased the supply of fish from 50 to 400 tons per year, of which 70 per cent is consumed locally and the remaining 30 per cent is consumed elsewhere in the country.

Fish availability in Yapacani has grown dramatically, increasing per capita fish consumption from 3.8 kg per year (2008) to 5.6 kg per year (2014). Fish farming families, previously among the most vulnerable, now consume more fish: nearly 42 kg per year [25]. Fish sales generate an additional income of 15 000 USD a year per rural family, compared to an average of 3000 USD previously generated annually. For this reason, fish farming is the main income source for a growing number of families.

Fish farming families had previously raised only the tambaqui for single fish production (monoculture). The project introduced technology for polyculture (integrated, multispecies fish farming) by adding another species of smaller size, the boquichico or black prochilodus which is also native to the region. Polyculture yields more than monoculture and improves the quality of pond water. The black prochilodus feed on algae and decaying material, including uneaten feed used for the other fish that would otherwise decompose on the bottom [26]. This polyculture offers higher yields since tambaqui production remains the same, the black prochilodus are produced with no additional feed costs, and pond conditions are improved.

The project improved the skills of 435 people (145 women and 290 men, including producers, technicians, students and business people) in appropriate water management, efficient feeding and polyculture technologies. Now 56 per cent of fish farmers report having solved their problems with their knowledge, without the external technical support that they previously required.

Maybe most importantly fish farming in the region has become a female-led activity. Before the fish farming project, women were generally not recognized in economic organizations in Yapacani. Now they are formal partners and co-owners of productive assets, with the same rights and obligations as men. The female members benefit from the credit for purchasing fish feed and have access to the same technical assistance as men [25].

Family unity has improved through increasing support from husbands. Initially, 70 per cent of husbands had doubts about this productive activity and in some cases, they did not respect female entrepreneurs. Now the situation has completely changed: 100 per cent of the 50 project families have seen the males diversify their agricultural livelihoods to support their wives in family-based fish farming [25].

There is an emphasis on leadership by women, who have tripled their families' incomes. Women increasingly occupy executive positions in their communities and are taken into account at events at the municipal level. A project study shows that they have greater financial responsibilities in the family, with 31 women now controlling family finances. Previously, their productive role was not recognized [25].

Economy

In 2003, national fishery and aquaculture contributed 7.5 million USD to the national GDP, representing 10% of the forestry, hunting and fishing sector. Continental capture fishery accounted for 6.98 million USD (93%), and the aquaculture subsector for 533 268 USD (7%). Very few Bolivian fishery products are exported. Some fish from the Amazon region, in the northern part of Beni, are exported to Brazil. These exports represent, most probably,

less than 40 tonnes/year [4].

Fish consumption

In 2019, the annual per capita consumption of fish in Bolivia was 2.6 kg which is one of the lowest in the region (Table 2). Household expenditure on fish products is very low, approximately 0.8 per cent of total food expenditure. Studies of meat consumption preferences in Bolivia show that in the three main cities (La Paz, Cochabamba and Santa Cruz), the population prefers beef and poultry, and fish comes in a very distant third. Among the reasons given for the low consumption of fish were inadequate hygiene during the selling procedure, limited supply and elevated prices [4].

Indigenous people in the Amazon basin have much higher fish consumption varying between 15 and 80 kg/person/year, so for them, fish is an important component of food security [12].

Country	Consumption	Year
Bolivia	2.6	2019
Brazil	9.5	2020
Colombia	7.1	2020
Ecuador	8.6	2020
Guyana	25.3	2019
Peru	25.1	2018
Suriname	17.0	2020
Venezuela	9.8	2005
European Union	27.0	2006
The World	21.9	2020

Table 2: Annual average fish consumption of the Amazon basin countries in kg/capita. Sources of information [4, 5,9].

Ornamental Fish Trade

There used to be an aquarium fish export activity based in Trinidad, East Bolivia, but it is not known if this still operates. The country appears to be a good candidate for further developing the ornamental fish trade in poor and/or remote communities, but there is a need to satisfy several conditions [27]. It must be able to compete on price with neighbouring countries offering similar species, especially Peru and Brazil, both of which have a more developed ornamental fish trade. The trade would also be dependent on good airline connections, at least to the US and EU as well. To be competitive airfreight charges would need to be comparable with those of neighbouring countries. Bolivia has a good range of species suitable for export, ranging from the common species to the rarest ones which would appeal only to the specialist [27].

In Bolivia, the peak time for collecting fish is in June/July when flood waters recede to leave standing pools. There are good opportunities for harvesting the fish for the ornamental trade before the pools dry up and/or the fish are eaten by birds and caimans. Given that these fish would die anyway, the impact on populations is negligible. Bolivia has good prospects for further developing its ornamental fish export, but the scope for this and how it could be achieved need to be verified [27].

In the experimental harvest in an indigenous territory where there is interest in starting the sustainable use of ornamental fish, the mortality rate was measured and reached 47 per cent. The highest mortality occurred during boat transportation of fish and the lowest during air transportation. Many species survived the entire process from the wild to the aquarium but some do not pass even the first stage, i.e. trawl capture. These problems should be taken into account in the regulations and planning of the operations [28].

Sport fishing

Recreational fishing is minimal attracting mainly Brazilian fishers [12]. There are some specific initiatives in Beni, Santa Cruz and La Paz, where tourist services are offered associated with hunting and fishing in lakes and rivers. It is expected that such activities will increase in the future. The wild arapaima is a noble fish described as rustic and originating from the Jurassic period [29]. This ”Amazon giant” is reaching 200 kg body weight and can be up to 3 meters long and is therefore very high on the wish list of many foreign fishers. And one should not forget the jau or long-whiskered catfish *Zungaro zungaro* which can reach over 80 kg and is often named the rottweiler of the river. Travel brochures tell that no other destination offers a more visceral immersion into the jungle than fly fishing in Bolivia for golden dorado *Salminus brasiliensis* . Fishers are promised super-remote locations where jungles are still completely wild [29]. One particular river, the Casare River, is mentioned as it is located in an indigenous territory at the point where the Bolivian Amazon and the Eastern Slopes of the Andes Mountains meet. The structure of the river allows for it to be fished by wading or drifting, and even offers opportunities to do sight casting [29].

Brazil

General

The total area of Brazil is just over 8.5 million km^2 making it the fifth largest country in the world, after the Russian Federation, Canada, the United States of America and China. It has one of the largest amounts of surface freshwater in the world and the Amazon basin accounts for 73.6 percent of the internal surface water resources. The long-term average internal renewable surface water resources are estimated at 5661.2 km^3/year and the highest average annual precipitation (2205 mm) is observed in the Amazon region [1].

Brazilian coastal fishery resources are fully exploited or over-exploited, generally by industrial fishing. Some inland fish stocks are also overexploited, but given appropriate management plans it is still possible to increase capture fisheries production from inland waters. In 2019, the fishing fleet was estimated at 21732 vessels, with the large majority under 12 meters in length and about one-third without motors. Small canoes are often very old, up to 40 years, creating a safety risk for the fishers [5].

Inland fisheries

More than 30 per cent of capture fisheries production comes from inland fisheries. Almost all the available water is in rivers, which have the greatest diversity of freshwater fish of any country on Earth [30]. There are at least 2481 known freshwater fish species and still more can be found [31]. Many species of this megadiverse freshwater fishes are migratory and these species migrate during all life stages along their river using habitats essential to their life cycle. These movements, however, have been severely blocked by hundreds of hydroelectric dams and reservoirs and they will be even more obstructed due to hundreds of new developments. River dams provide 95% of all the electrical power consumed in the country [32]. The Brazilian hydropower potential is 260 GW, but only 23% of this potential has been developed. By the early 2000s, 433 hydropower dams had been built in Brazil [32]. Thus, hundreds of new plants are yet to be constructed. Fishway construction is also booming in Brazil. Some misbeliefs are that fishways are only needed to facilitate upstream spawning migrations or that upstream passage is not useful if there is no large free-flowing stretch upstream of an impoundment containing a large natural floodplain for spawning and nursery habitat. However, providing passage for pre-spawning migrants, upstream fishways also provide passage for other fish migrations and foraging trips. Therefore an upstream fishway is important even if the upstream reach does not have spawning or nursery habitats. There is also a need for the protection of downstream migrant fish [33].

Most migratory fishes are potamodromous (migratory in freshwater), locally known as 'piracema' fishes, and only some are diadromous (migratory between salt water and fresh water). Piracema fishes normally grow to a large size, are more abundant in undammed rivers, and are the most important commercial and recreational fishes in Brazil. The large aggressive dourados *Salminus* spp., the abundant curimbata´s *Prochilodus* spp., and the highly prized food catfishes spotted sorubim or pintado (in Brazil) and spotted shovelnose *Pseudoplatystoma corruscans* and gilded catfish or zungaro dorado *Brachyplatystoma rousseauxii* are few examples from the large group of piracema fishes [33].

Aquaculture

Aquaculture offers the largest potential to increase fish supplies in the long term, in addition to having a high economic return. It is an efficient way to produce food, with low investment, when compared to other production systems, such as beef. When compared to other agribusiness sectors, fish farming has the greatest capacity to increase world food production [34,35]. Brazil is the second largest aquaculture producer in the region after Ecuador (Table 1), and the production level has had a steady increase as shown in Table 3.

Year	Production in metric tons
1997	87 879
2000	172 500
2007	290 000
2017	595 000
2020	630 200
2021	650 356

Table 3: Total aquaculture production in Brazil from freshwater aquaculture (tilapia, carps and some indigenous Amazonian fish species)(Sources: [2,14]).

In Brazil, the most cultivated species are the Nile tilapia, common carp and the tambaqui; however, carp aquaculture has declined since 2010. The production of tambaqui and its hybrids has grown considerably, namely the tampaqui and pacú hybrids (tambaqui x pacú, red pacú *Piaractus brachypomus* x pacú *P. mesopotamicus*), and catfish of the genus *Pseudoplatystoma* and its hybrids are also worth mentioning [15,36]. The largest scale fish in the world, the arapaima (in Brazil also pirarucu = redfish due to the colour of its scales) is one of the most important species to the development of intensive aquaculture in the Amazonian Region [37]. It is the unique fish in the world which can fatten in captivity over 1 kg per month and this fish is ready for slaughter when weighing between 14-15 kg [26].

The contribution of aquaculture to total fish production in 2017 was 46 per cent and the share of marine shrimp culture was only 14% of the total. There is no official information available regarding the number of people engaged in aquaculture but it is estimated that the sector involves over 40 000 people [5].

The production of fish of Amazon origin appears as the most promising market nationally and internationally [38, 39]. It is noteworthy that in the Amazon region, round fish and their hybrids play an important role in food production and in the local economy, among which the tambaqui stand out, followed by pirapitinga, and the hybrid named tambatinga (*Colossoma macropomum* female x male *Piaractus brachypomus*)[15]. In addition to the round species, the hybrid pintado da Amazônia (sorubim *Pseudoplatystoma* sp. female x male sailfin pim or Achara catfish *Leiarius marmoratus*) is highly appreciated because of the absence of thorns in the fillet and excellent quality meat, due to its firm texture and light colour [15,40].

Economy

Although fisheries play an important role in the local Amazon basin economy, it has not had a significant role in the national economy making only 0.5% of Brazil's Gross Domestic Product (GDP). However, it is estimated that 3.5 million people are directly or indirectly involved in fisheries and aquaculture. Total capture fisheries production was estimated at 704 100 tonnes in 2017 and 708 640 in 2020 [5,10]. More than 60 per cent of the total fish landings originate from artisanal fisheries, which represent more than 90 per cent of the employment in the capture sector. These proportions are higher if only the inland fisheries are considered. The latest estimates included a total of 1.1 million full-time fishers in 2017, half of which were reported to be women [5]. Still, a substantial amount of fish are imported, legally from Argentina, Chile, Norway and Uruguay and illegally from Bolivia and Peru. In 2019 value of imports was 1292 million USD while exports earned 411 million USD, the trade deficit being 881 million USD [5].

The commercialization of fish in the Amazon region is usually sold fresh, cooled with ice. The Rules of Industrial and Sanitation Inspection of Animal-based Products considers fresh fish to be that which has not been subjected to any conservation process, except for the action of ice [41].

Fish consumption

The average annual fish consumption per capita has increased steadily from 6.9 kg in 2007 to 9.5 kg in 2020 (Table 2) but it is still very low compared to annual consumption worldwide (close to 22 kg/person/year in 2020). The government encourages the production and consumption of fish and the aim is to have the average Brazilian consume 14 kg of fish per year. The actual per capita consumption varies greatly among regions and states, both in terms of quantity and type of fish consumed [5]. However, fish consumption is constantly increasing but the product price plays a relevant role in this increase since lower prices contribute to the decision to choose fish against other sources of protein of animal origin [42]. In the northern region of the country, for example, due to the constant supply and attractive prices of fish, people tend to consume more fish, especially in riverside communities [43]. For example, in the Brazilian part of the Amazon region, fish consumption varies between 30 and 150 kg/person/year, in rural areas average being 95 kg/year and in cities only 40 kg, respectively [12]. Food security of rural people depends on fish availability which has been widely disturbed by the present El Niño drought [22].

Ornamental Fish Trade

Ornamental fish have been commercialized in the Brazilian Amazon since the 1950s [44]. Ornamental fish can be a sustainable resource if they are taken from rivers in the region without causing damage to the environment. As a result, these fisheries can bring income to fishers and benefit the entire production chain [44].

The Amazonas State is quantitatively the biggest producer of tropical wild-caught ornamental fishes in Brazil. Between 2002 and 2005, approximately 100 million specimens were exported to 35 countries, the year 2005 being the record in sales reaching 36 million specimens representing 169 species and exports generating 2.4 million USD. The Manaus Area housed 16 ornamental fish export companies, but three of them controlled 82 per cent of the market until 2005 [20].

Most ornamental fishes were from the middle Negro River Region, supplying 90 per cent of the exports and generating income for the municipalities of the area. Wild-caught fish generated 10 000 indirect and direct jobs benefitting around 1600 families in the region [44, 45], although that number has declined in recent years [46, 47].

The market is organized in a way that the main players are the fisherman (”piabeiros”), usually older, who capture only what the export companies request via the middleman (”patrones”). The middleman is the communication channel between the piabeiros and the export companies that buy the fish and resell it with a 20 per cent profit [45]. The cardinal tetra *Paracheirodon axelrodi* was the number one export species, representing 70 per cent of total exports. Other exported species include firehead tetra *Hemigrammus bleheri*, golden oto *Otocinclus affinis,* sucker catfish *O. flexilis,* marbled hatchet fish *Carnegiella strigata,* lesser breeding heart tetra *Hyphessobrycon socolofi,* reticulated cory *Corydoras reticulatus,* spotted cory *C. agassizii,* Schwartz's cory *C. schwartz,* leopard cory *C. julii,* Loricariidae catfish *Peckoltia vittata* and Heckel or red discus *Symphysodon discus* [20].

According to the Department of External Commerce SECEX, the 2008 economic crisis hit Brazil and the number of commercialized fish started to decline drastically at that time [48]. The sharp drop in sales resulted in the closure of the biggest ornamental fish export company which was responsible for over half of Brasilian sales [20,48]. In addition to the economic crisis, other factors such as extremely high freight prices (the highest in the world from Manaus to beyond), a volatile exchange rate, and extremely bureaucratic Brazilian customs contributed to this decline [48]. According to ornamental fishermen, the middlemen were paying very little for the fish they caught, the fishermen thought that the trade came to a halt because the middlemen did not want to pay them [49]. More likely the reason for the downturn of the Brazilian Amazonian market was the competition with neighbouring Peru and Colombia with less bureaucratic systems and fewer restrictions on which species can be exported [19,49]. Finally, international pressure to stop the commerce of wild-

caught fish intensified and the increase of husbandry practices and reproduction in Southeast Asia decreased the trade in Brazil. That left thousands of families without their livelihoods and forced many fishermen to start working in sport fishing and commercial fisheries [48].

Unfortunately, there exists also a parallel illegal market that is always looking for new varieties that may have great export potential. International ornamental fish importers, with little or no legislation in their countries, are constantly searching for new fish species with the potential to generate more sales. This encourages illegal fishers from some remote regions like the Amazon to catch species that are endangered or vulnerable [45,50].

The black market for ornamental fish has existed in Brazil for many years and is growing every year in the Brazilian Amazon [51]. This represents a serious threat to the biodiversity of the region. Illegal trade is quite intense in the northern region [52]. Earlier it has been reported that indigenous peoples of the Javari River located on the northern Brazil-Peru border were enticed by smugglers to catch ornamental fish, and many ornamental fishers have also been involved in this practice [52,53]. The recent data from the Federal Police and Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) show that in 98 seizures made between January 2003 and January 2020 a total of 170,849 specimens of at least 73 species of 10 families, and 5 orders were recovered. Most of the illegally trafficked species are from the Loricariidae family (31 species, 8.5%). Due to their high-value zebra pleco *Hypancistrus zebra*, pearl stingray or jabuti *Potamotrygon jabuti*, white-blotched stingray or polka dot stingray *P. leopoldi*, silver arowana *Osteoglossum bicirrhosum* and black arowana *O. ferreirai* (Osteoglossidae) are the most targeted by the traffickers. At least 12 species are undescribed new species and were registered in this study [54]. The fish followed different routes to reach the border that Brazil, Colombia, and Peru share. To fight this illegal trade, tougher laws against smugglers, agreements with neighbouring countries to combat trafficking, formal environmental education programs for riverine populations, and further scientific studies of smuggled species are necessary [54].

Sport fishing

Recreational fishing activity in Brazil has grown tremendously in recent years. About 200 000 fishers have amateur angling permits. Already in 2007, it was estimated that there were an additional one million unregistered recreational fishers in the country. Sport fishing is growing fast at a rate of up to 30 per cent annually. It generates millions of dollars per year as it draws thousands of foreign visitors every year [5].

Practically the entire of Brazil has good prospects for the development of recreational fishing as the waters are home to more than 400 fish species considered of interest to sport fishers. The Ministry of Fisheries and Aquaculture (MPA) is promoting a national policy for the sustainable development of fisheries, which includes angling by amateur/sport fishers. A strategy for sustained recreational fisheries has been developed and the MPA has established a mechanism that monitors and coordinates the management of recreational fisheries throughout the country and recreational fishing in the Amazonas is strictly catch-and-release [5].

Travel brochures tell that the giant and wild arapaima is high on the wish list of many foreign fishers. These mighty ancient fish are the Holy Grail of all fish species in the Amazon for every angler. But there are other freshwater fish from the Amazon region, such as apapa *Pellona castelnaena*, Brazilian tucunare or peacock bass, golden dorado or dourado, pacú, pintado *Pseudoplatystoma corruscans* and piranjuba *Brycon orbignyanus*, that are considered trophies in the fishing world [55]. Xingu Lodge is highlighting the impressive numbers of large payara or vampire fish *Hydrolycus scombiroides* as one of the hardest-hitting and strongest fighting fish in the Amazon [56].

Colombia

General

Colombia is a large country of 1 142 000 km^2 with exclusive economic zones in the Pacific and the Caribbean Sea that cover over 3000 km of coastline and an area of over 800 000 km^2. In addition, it has over 700 000 micro basins and more than 20 million hectares of lakes, ponds, reservoirs and channels. The main watersheds used for inland fisheries and aquaculture include the basins of the Magdalena, Amazonia, Orinoquia and Sinú rivers [57,58]. This richness of aquatic ecosystems results in one of the highest biodiversity indices and one of the greatest diversity of fish on the planet [59]. Such a high level of biodiversity implies a relatively low abundance of each species. Fish harvests are thus relatively modest (compared to neighbouring countries like Peru, for example) and ecosystems are particularly fragile.

The Amazon basin (34.2 million ha) is extremely important for the development of the country since it constitutes 29 per cent of its surface and three of the largest tributaries of the Amazon River are born in Colombia: Putumayo (1700 km), Negro or Guainía (2000 km), and the Caquetá River (2200 km) [1]. Already in 1972, it was written that fishing in the Amazon region was a resource that was then beginning to develop [60]. Appreciable amounts of fresh, dried or salted fish are transported daily to the interior of the country from Leticia. It was also mentioned that within all the Amazonian fauna, the use of fishing resources is the one that presents the greatest development possibilities, especially for fish farming [60].

Despite the efforts made by numerous scientists, freshwater fish species (especially those of the Eastern Plains and the Amazon) were long imperfectly known in terms of their taxonomy, distribution, ecology and possibilities for aquaculture. Regarding the Orinoquia, the ichthyofauna of the upper Meta River was better studied already in old times [60], but the Colombian Amazon was long time largely unexplored. The earliest of the existing records for the region appear in the Catalog of Freshwater Fishes of Brazil [60].

There is no doubt that the Colombian Amazon today represents a pantry for the future in terms of fishing. However, to ensure its intense and continuous use, it is necessary to carry out the necessary studies on the biology of the species, taking into account limnological and distribution aspects to use them in the future for the development of intensive aquaculture. Perhaps the most important Amazonian species for Colombia has been the arapaima existing in the lower Caquetá, Putumayo and Amazonas basins proper. Other predominant fish belong to the orders Cypriniformes and Siluriformes and also some elements of marine origin representing interesting endemism of the Amazon basin [60].

Inland fisheries

Inland fisheries in Colombia take place mainly in the rivers of the Magdalena, Orinoco and Amazon catchment areas. A total of 173 species were caught in inland waters for the consumption of riverine communities in 2010; 17% of these (31 species) faced some degree of threat [61]. This situation of stock status is worrying, both from a conservation and economic perspective.

Until 1978 freshwater fishing was an important source of income, food security and local development but then the inland fisheries began to collapse due to the contamination of the rivers [62, 63] and rampant deforestation [64], especially in the Magdalena river basin. Freshwater fishing has continued to decline since then, but now at a slower pace, due to the effects of medium and long-term management measures being implemented more recently. Production from capture fisheries has decreased significantly over the last ten years, mainly due to overexploitation of the main harvested species. In 2013, about 70 000 tonnes of fish were captured, down almost by half from the peak levels of the 1990s [65]. Over half of all marine species for which information was reported are estimated to be overfished. Overexploitation is also believed to be a serious concern in continental waters, although the status of the resources on which inland fishing relies remains largely unknown [57]. Amazon region's annual catch in Colombia has recently been estimated to be at least 15 000 tonnes which seems to be considerably higher than previously thought [66].

Most fishermen alternate fishing with other jobs, e.g. in agriculture, trade and building construction. This ensures that the household economy is diversified, as formal job opportunities are few and far between. Prices in inland fisheries are affected by the number of middlemen involved in the marketing chain. One of the factors responsible for this is the fishermen's isolation from the marketing and service centres, especially in the Orinoco and Amazon basins [6].

Aquaculture

The aquaculture sector, however, is growing rapidly, reflecting global trends. Since 2008, aquaculture has produced more than capture fisheries, with about 88 000 tonnes of fish products farmed, an almost three-fold increase from the mid-1990s [65]. Again twofold increase has taken place between 2008 and 2020 (Table 1). In 2011 the value of aquaculture production was estimated at 222 million USD [67] while in 2021 it was approximately 414 million USD [57].

Future growth in fish production is likely to come primarily from aquaculture. However, overall growth hides intersectoral variations. Marine aquaculture, which was essentially devoted to shrimp production, almost collapsed in the mid-2000s because of a disease outbreak. Colombia has since built reliable diagnostic laboratories for aquaculture diseases and scientific research has developed technical packages to increase productivity. Transfer of technologies and good practices could be scaled up, but the transport and storage infrastructure that could support production expansion is lacking and the sector remains largely small-scale and informal.

Colombia has had a good rate of growth in the aquaculture industry with the white shrimp *Litopenaeus vannamei*, Nile tilapia, red pacú and rainbow trout being the most important species for this country [15]. Red pacú (or cachama white in Colombia) enjoys consumer preference and so a good market due to its good quality flesh. It suits well to aquaculture with a constant water supply and can reach 500 g in six months when stocked at a density of four fish/m^2 [68]. Commercial inland water productions from the tambaqui and barred surubim *Pseudoplatystoma reticulatum* have been carried out since the early 2000s in Columbia [69]. In 2013, the red pacú was the second most produced fish in Columbia, with the red and white tilapias *Oreochromis spp.* representing the majority of production and, on a smaller scale, bocachico *Prochilodus magdalenae*, common carp and yamu *Brycon spp.* Interestingly, Miocene tambaqui fossils are known from the Magdalena River, but modern occurrence in this river is due to introductions by humans [70]. Research into the culture of native species such as bagre rayado or surubi and capaz *Pimelodus grosskopffi* has progressed in the past years [6,7]. An interesting project exists in the Caquata province where 300 fish farming families are raising arapaima which will be as food for the Colombian domestic market [71].

The aquaculture's share of total fishery production stood at three per cent in the mid-eighties but rose to 20 per cent in 2001. Fish products are mainly intended for the domestic market and are produced on both a commercial and a small scale [6]. Freshwater fish farming is carried out throughout the country because Colombia has various relatively constant temperature zones, climates and microclimates throughout the year. The high cost of feed concentrate and the presence of rebel groups has hindered aquaculture development. The Government and the Revolutionary Armed Forces of Colombia leaders signed a historic ceasefire on 23 June 2016, bringing them a little closer to ending this fifty years-long conflict [72].

The Colombian government wishes to promote the further growth of aquaculture and a review was undertaken and led to the adoption of a National Plan for Sustainable Aquaculture (PlaNDAS) [58]. The review concluded that the aquaculture has potential to grow and create employment, notably due to an entrepreneurial momentum for investing in the sector. The PlaNDAS mapped the areas that are most suitable for aquaculture development in the country. Good aquaculture and fish processing practices were listed and it was noted that Colombia also has reliable diagnostic laboratories for diseases [58].

A national program of vigilance, prevention, control and eradication of diseases and calls for improving the knowledge base for ecosystem protection regulation has been created. Low economic productivity was identified as a key challenge for aquaculture because it affects competitiveness and reduces profitability. Low-cost imports of fishery products are competing with domestic production and lead to a lower level of domestic consumption [57,58].

Economy

The contribution of fisheries and aquaculture to GDP in Colombia is relatively small. The sector represented 0.19% of GDP in 2020 [10]. The most valuable sub-sectors are those targeting products for export, which usually account for at least three-quarters of the ex-vessel value of fisheries output. The tuna fishery was valued at USD 120 million in 2012, and the shallow and deep water shrimp catch accounted for another USD 13.5 million. Aquaculture production in Colombia was 179 351 metric tons in 2020 and 192 521 metric tons in 2021 (Table 1). In 2013, the inland ornamental fish catch was estimated to be USD 12.5 million [65] already two times that of 2005 (see below).

Colombia does not have a history of providing high levels of support to the fisheries and aquaculture sector but this situation is common to many OECD countries [57]. Support to aquaculture development has increased between 2012 and 2014 from 13% to about a third of the support to the sector, mainly in the form of grants. Direct payments have also increased over the same period from about 15% to over 40%, while fuel tax concessions have decreased from about 55% to about 40% of the total. The minimal share of support allocated to general services reflects a lack of data on the budgets allocated to different management, research, enforcement and infrastructure services [57].

Colombia has between 67 000 and 150 000 artisanal fishers, of which about a third would operate on the coasts and two-thirds in inland waters [67]. Ministry for Trade, Industry and Tourism believes that the aquaculture sub-sector generates about 1.2 jobs per tonne of production, and therefore estimates employment in the sub-sector to be almost 120 000 jobs, a third of which are on small-scale farms [67].

It is estimated, however, that over 1.5 million people work in the sector and associated services [57]. Therefore the sector plays an important role in the local economy of poor rural and coastal regions and has the potential if managed appropriately, to contribute to the government's goal to promote sustainable and inclusive growth in all parts of the country. Several challenges currently prevent it from contributing fully [57].

Fish consumption

About 7 kg of fish is consumed annually per capita, meaning that fish is a relatively small contributor to average food consumption [Table 2]. According to the FAO balance sheet for 2013, fish accounted for only 3% of total protein consumption on average, slightly more than 5% of total animal protein consumed and less than 1% of average calorie intake. However, these averages hide strong regional and household-level variations. In Colombian Amazonia, the average fish consumption was in 2015 above 26 kg/person/year which is well above the world average [12].

Ornamental Fish Trade

Although Colombia is among the three biggest producers and exporters of ornamental fish in the region, there is no exact information on the number of ornamental fishes captured or produced in the country [74]. The current stock status of the dominant ornamental species harvested has seldom been studied [75]. In the Colombian Amazon, 52 % of the regional production of fish is based on small-scale artisanal fishing [76]. On the one hand, 335 captured species are considered ornamental, and represent 50 % of this commodity exported from Colombia [77].

In Colombia, the trade of ornamental fish is mainly the extraction of individual species of fresh water, which has generated imbalances in the natural populations and has deteriorated aquatic ecosystems in the country [74]. The exports made during 2004 were of 26.6 million units of individuals alive representing an entrance of foreign currencies of 7.3 million USD, and in 2005 were of 29.5 million units of individuals alive but valued at only 6.3 million USD. So this practice faces a progressive decrease

due to overfishing among other causes [78], although users' perception recognizes no such decrease [74]. Moreover, according to local inhabitants and researchers in the zone, the prices of this commodity have remained constant over the past 10 years due to the bargaining power of local buyers [79].

In Colombia, the main exported species are the cardinal tetra, the neon tetra *Paracheirodon innesi* , 22 species of the freshwater catfish *Corydoras* sp., 32 species of the armoured catfish (cuchas), otocinclo or the planet catfish *Otocinclus* sp., the brilliant or Armstrongs tetra *Hemigrammus armstrongi* and the rummy-nose tetra *H. rhodostomus,* which together represented more than 70 per cent of the exports of 2002 [80].

Aquaculture Association of Caqueta (ACUICA) promotes research, development and transfer of technology for small and medium aquaculture producers and works with female-led households and ex-coca growers and displaced families who have aquaculture as an economically, socially and environmentally sustainable alternative [81]. ACUICA focuses on the production of alevins of native Amazonian species intended for ornamental fish export. It is driving to steer the local economy away from illegal coca farming toward filling Asia's growing demand for expensive ornamental fish [81]. Fish farming in Florencia focuses on the silver arowana a highly wanted species in China where it is called a dragonfish and nine of them in the aquarium are seen as a sign of good luck for the owner. Each dragonfish costs pennies to raise in Colombia but sells at retail for up to 40 USD in Hong Kong. Amazon International Trade company expects to ship 20 000 silver arowana to wholesalers in China, Singapore and Japan. The market has no limits so sales could reach 100 000 units. Unfortunately, the silver arowana is fast disappearing from the Amazon and the Colombian government has banned the wild capturing of that fish during the five months of each year. In China, the dragonfish aquarium is a status symbol because the fish resembles mythical dragons that bring good luck and protection against evil spirits [71].

In Colombia, coca farming was the region's number one economic activity but now the governor aims to use some state funds to subsidize the export of up to one million arowana fish to Asia. Even the Ministry of Agriculture experts agree that fish deserve a lot more attention than they get in Colombia [71].

Sport fishing

During my time in Colombia in the FAO project from 1974 to 1976, no recreational fishing activities were witnessed in the major river systems [82]. Nowadays, sport fishing is practised in almost the entire national territory (80%) and popular fishing events take place also in Amazon flowing rivers [83]. Special permits are needed from the National Fishery Administration for the competitions held in the country [6].

Travel brochures are advertising Colombia Amazon Adventures promising comfortable camps with the Puinave Indians and giant peacock bass fishing [84]. The highest number of species of interest for sport fishing can be found in the Amazon and Orinoco tributaries with 42 and 43 species respectively, followed by the Magdalena-Cauca rivers with 28 species [83]. A guidebook is formulated for the most wanted species with biological details and fishing methods including the conservation status [83].

Ecuador

General

Ecuador has an area of 276 840 km^2 when including the Galapagos Islands [5]. The coastline is 2237 km making the fishery sector very important. The fishing fleet operates mainly along the coastal areas of the Pacific Ocean and in the Galapagos waters. The sector employed some 218 000 people in 2017 and only 3.3 per cent of those were women [5]. The industrial fleet includes 184 vessels over 24 meters in length mainly catching tunas (400 845 tonnes in 2017). Three species of tuna are either fished from the high seas or directly from Ecuador's waters: skipjack *Katsuwonus pelamis*, yellowfin *Thunnus albacares* and bigeye *T. obesus* [85].

Inland fisheries

The total area of inland waters is more than 30 per cent of the country's water area, so a significant potential exists for the enhancement of freshwater fisheries in Ecuador. However, it seems that fisheries statistics may not always cover the entire sector and are therefore incomplete [5]. The latest report concludes that inland fisheries have little importance and that the total catch is only 2500 tonnes, including both the Amazon area and other continental waters [85]. From the Amazon area, the report mentions Napo, Aguarico, Pastaza, Morona and Santiago as fishing rivers. In these waters, only small wooden canoes are used.

Ichthyological studies within the Ecuadorian Amazon have described that fish communities in the lagoons, rivers and forest streams are highly diverse and variable, including common species occurring within several habitats, characteristic species found throughout the year, and seasonally migrating species [86]. The current number of species in the Napo River basin is approximately 562 out of which 193 have commercial value. Characteristic lagoon species are mainly the boquiche *Curimata vittata*, chio chio *Psectrogaster amazonica*, sardinón *Potamorhina altamazonica*, yahuarachi *P. latior* and sabaru *Cyphocharax plumbeus*. The sardinita *Hyphessobrycon copelandi* and sardina *Hemigrammus* cf. *lunatus* and the pirillo *Nemadoras humeralis*, pimelodella *Pimelodella* sp. and unidentified shovelnose catfish *Sorubim* sp. are characteristic river species. Typical forest stream species include trahira *Hoplias malabaricus*, sardinita, pimelodella and longtail knifefish *Sternopygus macrurus*. During the dry season, lagoon and river habitats have the highest species

richness and abundance of individuals and species, as fishes are concentrated in decreasing habitat areas. In contrast, stream habitats have the highest species and individual fish numbers during the rising water and falling water seasons. Species include vital food fishes and seasonal migrants. The migratory catfishes like the laulao *Brachyplatystoma vaillantii*, porthole shovelnose catfish *Hemisorubim platyrhynchos*, coroatá *Platynematichthys notatus*, bagre or zorro catfish *Platystomatichthys sturio* and duckbill catfish *Sorubim lima* are common during the falling water season, suggesting that these species begin migrating much earlier than expected. The findings of the study highlight the importance of seasonality for both aquatic biodiversity assessment and for research and conservation program development covering whole river ecosystems [86]. There is a new report anticipating that Amazon basin fish landings in Ecuador could be considerably higher than previously thought although the recent official statistics are not available [87,88]. On the other hand, aquatic ecosystems in the country are under serious threat and conditions are deteriorating. The government was sponsoring in 2018–19 a series of workshops to examine the conservation status of Ecuador's freshwater fish. Concerns were identified for 35 species, most of which are native to the Amazon region, and overfishing of Amazonian pimelodid catfishes emerged as a major issue [89]. Besides overfishing other important reasons affecting freshwater fishes in Ecuador are the physical alteration of rivers, deforestation, wetland and floodplain degradation, agricultural and urban water pollution, mining, oil extraction, dams, introduced species and climate change [89].

Aquaculture

Aquaculture production was 2020 the highest in the region, the total being 774 569 metric tons and the next year it was already 896 435 metric tons (Table 1). In Ecuador, aquaculture represents 55 per cent or more of the total fisheries production [14]. More than 95 per cent of the country's aquaculture corresponds to shrimp farming but tilapia farming has had considerable growth over the last twenty years. Pacific white shrimp dominates but also blue shrimps *Penaeus stylirostris* are cultivated. Most tilapias are red tilapia which is a tetrahybrid from the interbreeding of Mozambique tilapia, Nile tilapia, wami tilapia *Oreochromis hornorum* and blue tilapia *O. aureus*. The culture of the channel catfish *Ictalurus punctatus* has made some progress at the coast and rainbow trout is farmed in the inter-Andean region [8]. There are only a few indigenous species that are farmed successfully. These species are: cachama blanca or red pacú, cachama negra or tampaqui, sabalo or sabaleta and bocachico or boquichico. Farms, which cultivate these species, use earthen ponds of various sizes depending on the fish stage: 15m x 17m, 35m x 17m, and 70m x 17m. The polyculture systems are employed as most of the above species utilize different niches of the same earthen pond. Daily water renewal ranges from 5% to 40% of the water volume. Acidification and eutrophication occur seasonally so more efforts are needed for the improvement of the present production techniques. No specialized dietary formulas exist for the indigenous species but feed supplements are administered in the form of intact agricultural grains or flours. Fish farmers cannot guarantee a stable supply of fish at the commercial size all year round [90].

Economy

It is estimated that the primary sector of fisheries contributed to 1.1 per cent of the total GDP in 2020 [10].

Fish consumption

Ecuador's per capita fish consumption is still low, around 8.6 kg/year compared to the world average which is around 22 kg/capita/year (Table 2). However, in the Amazon basin fish is a staple food for the local populations and the amount of fish eaten is far more than the fish production statistics would indicate, 4478 vs. 2500 tonnes [88].

Ornamental Fish Trade

Often the ornamental fish trade goes unreported, with potential conservation implications. Therefore it is relevant to have a better understanding of the scale of this trade. According to the LEMIS dataset, over 13.2 million ornamental fish were exported from Ecuador to the United States between 2005 and 2014 [91]. However, the trade has declined over time, from approximately 1.6 million live fish in 2005 to roughly one million in 2014. Of the live exports, 79 per cent were tropical freshwater species, with a further 20 per cent reported as ray-finned species (class *Actinopterygii*). Detailed analysis into the most commonly traded species was not possible due to a lack of taxonomic specificity in the database entries. Trends over time for the taxonomic breakdown indicate that the number of tropical freshwater fish imported by the United States declined by nearly 50% between 2005 and 2014 while the ray-finned fish numbers increased over the years 2005–2014, peaking in 2013 [91].

The absence of detailed information on the species or their origin (either being farm-raised or wild-caught) makes it impossible to conclude the conservation significance of this trade. However, the relatively high volumes of imports reported by the United States suggest that a more detailed assessment may be warranted [91]. Other studies have shown that the majority of species traded from South America are wild-sourced fish from the Amazon [19,20].

Sport fishing

Ecuador is selling Amazon Jungle fishing with the same species as the previous countries, i.e. tucunare or peacock bass and its close relatives which are not bass at all. These species are Cichlid family members and reach up to nine kg weight. Other sought-after exotics are various large catfish species, not

forgetting aruaña, pacu, payara and many more. The brochure text says: ”Getting Ecuador to chase the arapaima, one of the largest and craziest fish in the jungle that breaths air and has bulletproof scales.” [92-94].

French Guiana

General

French Guiana is a French overseas territory in South America with an area of 83 846 km^2 of which over 90 per cent is covered by forest. The continental shelf of French Guiana is a tropical ecosystem under the influence of the Amazon estuary, as is the entire North Brazil Shelf Large Marine Ecosystem, which has a high level of biodiversity [95]. With a 350 km coastline, French Guiana benefits from a 130 000 km² exclusive economic zone including 50 000 km² of continental shelf, bordered in the west by Suriname and in the east by Brazil. The coastal fishery operates in a 16 km offshore zone with depths from 0 to 20 m; fishing areas are close to the landing points. The eight main landing points are spread out along the coastline. Some 30 species are commonly exploited by the small-scale coastal fishery. The principal types are acoupa weakfish *Cynoscion acoupa,* green weakfish *C. virescens,* South American silver croaker *Plagioscion squamosissimus,* hammerhead sharks *Sphyrna* spp., requiem sharks *Carcharhinus* spp., crucifix sea catfish *Sciades proops,* gillbacker sea catfish *S. parkeri*, tripletail *Lobotes surinamensis,* snooks *Centropomus* spp., tarpon or palika *Megalops atlanticus*, mullets or milé *Mugil* spp., crevalle jack or karang *Caranx hippos,* longnose stingray *Hypanus guttatus*, and Atlantic goliath grouper or vièy *Epinephelus itajara* [96].

The French Guiana coastal fishery has been neglected although it supplies exclusively to local food demand. Various landing sites and numerous species exploited make this fishery quite complex as it is partially informal. The great potential of this fishery has been revealed after the decline of the shrimp fishery. The second significant continental shelf fishery is that of the red snapper *Lutjanus purpureus*. Other species like the vermillion snapper *Rhomboplites aurorubens* and lane snapper *Lutjanus synagris* are also found but less commercially exploited. This fishery is mainly practised by Venezuelan long-line trawlers [96]. The coastal fishery has yielded more than the shrimp and red snapper fisheries since 2008. The coastal fishery has been monitored for 6 years, but no stock assessment has been carried out so far [96].

Inland fisheries

French Guiana covers only 1.4% of the Amazon basin area [22] and not much is known about its continental fisheries. Only one time the inland water fish catch has been reported to FAO being 44 tonnes in 2009 [12]. After that, FAO estimated the catch to vary between 30 and 62 tonnes from 2010–2019. However, the fish fauna of French Guiana is among the best-known in South America. Various fieldwork campaigns have been conducted, particularly in poorly surveyed areas, leading to the discovery of new taxa. An updated checklist contains 416 species, 367 of which are strictly freshwater. Around a quarter of the ichthyofauna, 87 species, are endemic, but a rather strict definition of endemism was used, so this could be an underestimate [97]. The rate of endemism is strongly correlated with catchment size, with some families showing higher than average rates. Fish diversity is, on average, higher in French Guiana than in Suriname. The Characiformes (41%), Siluriformes (33%) and Perciformes (13%) are the largest groups. The relative abundance of taxonomic groups differs between catchments, probably reflecting the ecological character of the rivers. A comparison of the number of species shared by the different catchments suggests a highly complex pattern of dispersal as a function of the catchment size, topography, and species. Some rivers, like Oiapoque, seem to belong to a relatively distinct biogeographic zone influenced by the Amazon basin [97].

Subsistence fishing and conservation issues have been studied in the Maroni River which is 610 km long and flows between Suriname and French Guiana. The watershed hosts 264 strictly freshwater fish species, of which 17 per cent are endemic [97]. A total of 754 boat landings were surveyed in seven villages. Between November 2013 and September 2014, some 6300 fish were investigated. Yields were consistently low and some highly targeted species showed typical signs of a prolonged period of exploitation, especially a decrease in the average body weight. There is a need to conserve the river’s remarkable biodiversity [98].

Aquaculture

In French Guiana, the population has long been more interested in fishing than in aquaculture [99]. According to FAO statistics aquaculture started in 1984 with two metric tons of production and the peak year was 1989 with 89 tons with a heavy decrease after that. The last figure is from 2006 when the production was 37 tons [100]. However, in a strategic assessment of the potential for freshwater fish farming in Latin America French Guiana scored highest both for Nile tilapia and common carp small-scale farming [101]. Despite slow development in aquaculture or maybe partly because of that reason, it is seen as a source of non-native freshwater fish introductions in French Guiana [102]. Eleven non-native species have been reported in 2021, four of which are well established, namely kounanni or tucunare *Cichla monoculus*, paya *Herox efasciatus*, *Mesonauta guyanae* (no common name) and guppy *Poecilia reticulata*. The paya is rapidly increasing its spatial range. Five well-known fish farming species, namely arapaima, common carp, Mozambique tilapia, silver arowana and tambaqui, have not been established so well outside the farms as only a few specimens were observed in the wild. Two

alien species, jewel tetra *Hyphessobrycon eques* and freshwater angelfish *Pterophyllum scalare*, have not been retrieved recently and could be extinct from French Guiana [102]. The country has one well-documented case when introduced and cultivated species from aquaculture are now present in natural conditions in several river basins. The introduction of the giant freshwater prawn *Macrobrachium rosenbergii* from Hawaii in 1979–1980 led to production which fairly soon exceeded the consuming capacity of the local market estimated to be at 30 tonnes per year. Despite the export market success in 1989, commercialization was facing problems due to unreliable production fluctuation, and concurrent Asian production. The State of French Guiana decided to stop its financial support in 1990, and that led to the closure of the hatchery ultimately ending the giant prawn aquaculture in the country [103]. Although the cultivation of prawns stopped more than 30 years ago, some escaped populations have persisted in the wild until the present. Now there are new populations in the areas where the species was never cultivated proving that this alien species can colonize new locations. This highlights the potentially invasive nature of the giant freshwater prawns [103]. And brings again an example in which the introduction of a species, voluntarily or not, in a region where it is not native and where its proliferation causes ecological damages threatening natural biodiversity [104].

Economy

In 1987 French Guiana imported fish and shellfish products of 1957 tonnes valued at 10.5 million USD and exported 3777 tonnes which had a value of 33.5 million [105]. In 2018 the fishing industry focusing on shrimps is one of the most important economic sectors in the country but no GDP value was given [106].

Fish consumption

FAO estimated in 1989 that the consumption of fish and shellfish in French Guiana was 37.0 kg/annum per caput [105] which is the highest in the region (cf. Table 2) if it has been maintained at that level despite the water contamination. Indigenous people used to eat mercury-contaminated fish up to 115 kg/person/year beginning of the century [12].

Ornamental Fish Trade

The ornamental fish trade exists but no good statistics have been found. Instead, the aquarium fish trade development is seen as a source of non-native freshwater introductions in French Guiana [102]. All invasive fish species are seen as an early warning for both researchers and environmental managers.

Sport fishing

Guiane Amazonie Peche company sells adventure journeys to the Amazon for wolf fish *Hoplias malabaricus* fishing (Figure 2). The dog-like teeth have given the fish its name. The maximum size is officially 15 kg but fishermen talk about fish of 27 kg. French Guiana is much less explored by sports fishers than the rest of the Amazon. Little to no lodge operations exist in the interior [107].

Figure 2. The trahira or wolf fish *Hoplias malabaricus*. Photo by courtesy of Commons.wikimedia.org

Guyana

General

Guyana has an area of approximately 215 000 km² and is bordered by the Atlantic Ocean on the north, Venezuela on the west, Suriname on the east and Brazil on the south. The coastline of the country is 432 km and the size of the continental shelf of 48 665 km². The average width of the continental shelf is 112.6 km while the area of the exclusive economic zone is 138 240 km² [108]. Most of Guyana's fishing effort occurs in the relatively shallow waters of the continental shelf. After a peak in 2012, when capture production reached 53 800 tonnes, the following years showed a declining trend. In 2016 that trend was interrupted thanks to good catches of shrimps which are the major fishery resource [9].

In 2017 the fishery sector employed an estimated 8386 people, of which 7141 in marine coastal fishing, 1125 in inland water fishing and 120 in aquaculture. Many more people benefited indirectly from fishing-related occupations, such as boat building, supply and repair. In Guyana, capture fisheries are undertaken by artisanal fishers and by an industrial fishing fleet composed of trawlers and hand-liners, including some foreign-flagged, licensed vessels. In 2017 the estimated fleet was composed of some 1500 vessels ranging in size from 6 to 24 m, of which the great majority (83 per cent) were gill netters [9].

In the artisanal fishery access to the resources is constrained by licenses granted by the government, but it has, however, failed to implement fisheries management plans effectively due to inadequate financial and personnel resources. Monitoring, control and surveillance activities have taken a back seat to other activities such as narcotics trade and fuel smuggling which the government is trying to eradicate. Also, over the years fishing has been viewed as a last resort activity. However, currently, the government has been working on revised management plans for the fisheries sector. So now it is awaited that the recommendations from this report can be used in developing the new management plans. Previously there have been no management measures in place for inland fisheries [109].

Inland fisheries

Freshwater fishing involves the catching of fish in rivers, creeks, lakes and reservoirs, canals, and in savannah area flood plains when the seasonal increase in rainfall gives rise to large expanses of flooded lands. The activity tends to be influenced by the season often being the down period in agriculture and other activities. For example, in the sugar estate areas, the intensity of fishing varies with the sowing and harvesting of sugar cane and rice. The activity is carried out with small, flat-bottomed, dory-type vessels using cast nets, seine or handlines [9]. This fishery is important to the well-being of the hinterland population which is about 10% of the population of Guyana. The limited data available indicate that most inland subsistence fishing is carried out by Amerindians who usually get their main source of protein from the rivers and creeks in their communities. They also depend on the fish for their livelihood [109].

Fish is caught and dried and sold to miners and foresters in their area and other communities. Other groups exploit the freshwater resources near the coast and in the vicinity of logging and mining communities situated in the interior of the country. At present, the effort is largely directed at subsistence fishing, although a few fishermen participate in small-scale commercial fisheries. The main species caught are peacock bass, catfish and tambaqui. Production figures for Amazon basin rivers are not known, but the total inland fisheries production was reported in 2019 to be 700 tonnes [9]. Based on small changes in the boat numbers FAO has modified the catch data to vary between 625–875 tonnes [12].

Over the years a lot of harvesting of a particular species, arapaima, has caused the stock to be depleted. The government made it illegal in its 1973 regulations for anyone to harvest the arapaima. However, with the opening of the hinterland for mining and other activities the ban was completely ignored and a cross-border trade developed between Guyana and Brazil. This depletion was caused by a demand for the product in neighbouring Brazil since their stocks were also depleted. With the help of Iwokrama [110] and local authorities, sixteen communities formed the North Rupununi District Development Board, to develop the Arapaima management plan in 2001. After several consultations and reviews the plan was finally presented to the cabinet by the minister responsible for fisheries in 2006. Next year the Management Plan for the Arapaima in North Rupununi, Guyana was approved for implementation. By using the community management approach organised fishermen were aiming to recover the arapaima population by regulating and sharing the number of fish harvested. Their goal was to use both scientific data and traditional knowledge. It is not known what was the outcome of the arapaima management plan because not much monitoring has been done by the authorities [109].

Aquaculture

Aquaculture in Guyana is a relatively new concept; however, people on the Corentyne Coast have practised a form of fisheries enhancement that is similar to aquaculture for over 100 years. Several attempts have been made over the years to develop freshwater and brackishwater aquaculture especially since local consumer demand for freshwater fish is high [9]. Aquaculture has been practised for many years using mostly low-input culture methods in brackishwater and freshwater ponds employing cachama, tilapia, and whiteleg shrimp as the major target species. Giant freshwater prawns, armoured catfish or atipa *Hoplosternum littorale* and the salmon shrimp *Mesopenaeus tropicalis* have been cultivated in Guyana. Aquaculture production was almost 700 tonnes in 2017, consisting of three alien species (namely Mozambique tilapia, Nile tilapia, and Jamaican red tilapia) plus a few native species [9]. To develop further the farming of native species Guyana was selected as a host country for a promising FAO project: ”Promotion of Small Scale Aquaculture in Guyana for Food Security and Rural Development” The project was carried out in the period 2014–2017, and the main objective was to reduce poverty and food insecurity, both of which are still prevalent in large parts of Guyana, particularly in some hinterland and coastal areas. FAO technical assistance was provided with a view to building capacity among small-scale farming households through simple production methods, and introducing new technology for fish reproduction. Farmers were trained in simple applicable hatchery, nursery, and feeding techniques for tambaqui which originates from the Amazon and Orinoco river basins in South America [24].

The project focused on tambaqui because it is an ideal species for producing cheap animal protein to improve food security. This omnivore fish is relatively easy to grow because it requires a comparatively low protein content in its feed. In farming, it is possible to make use of low-cost feed and feed ingredients such as forest fruits, the seeds of leguminous plants, cassava, etc. As tambaqui not only tolerates well both soft- and acid waters, and grows in water with relatively high salinity, up to about 10 ppt. This species is hardy reaching quickly a large size, which means that even seasonal waters are suitable for producing them. First, the aquaculture production of tambaqui continued to increase – from 13 thousand tonnes in 2000 to 142 thousand tonnes in 2016 – and there was huge potential for its cultivation on both a large and small scale [24].

After the project, a drastic decline in aquaculture started in Guyana same time when tambaqui farming was successfully spreading to many new countries. From Puerto Rico, this species is now spreading likely due to deliberate releases by aquarists to a wide range of US states but can survive only the warmest regions. In Thailand tambaqui has a local name ’pla khu dam’ and it has

escaped from fish farming projects in the wild waters [24].

Guyana seeks to rebuild the aquaculture sector by doubling the country's production by 2025 [111]. In 2019 the production was still 246 tonnes but in the following year, it went down to 138 tonnes [14]. In 2021 year, it was 142 tonnes, i.e. the same as tambaqui production alone during the FAO project in 2016.

Economy

The fishery sector is of critical importance to the economy and social well-being of the country. It is estimated that the primary sector of fisheries contributed to 1.9 per cent of the total GDP in 2012 but only 1.04 per cent in 2019. In 2017, reported capture production was about 43 000 tonnes, mostly marine, and in 2019 less, than 39 331 tonnes [9,10].

In 2017, exports of fish and fishery products were valued at 111.2 million USD (with a significant share of crustaceans), while imports were worth 2.9 million USD. In 2019 corresponding figures were 96 million and 4.8 million, respectively [9,10].

Fish consumption

Fish is an important food item and the major source of animal protein in the country and it is well-liked by consumers. Estimated per capita annual fish consumption rose from 9 to 27 kilograms between 1980 and 1988, being 45 kg in 1991 and jumped to 59.8 kg in 1998 which was four times more than that time world average (14 kg) consumption [108]. However, declines in production in recent years have led to a reduction in the average consumption which was still 40 kg in 2003 but went down in ten years to 29.5 kg in 2013 and seems to continue to go downwards to 25.3 kg in 2019 (Table 2). Local populations still eat a lot of fish, for instance at Rupununi River, where in 2019 the average fish consumption was almost 51 kg making 60% of the diet of 787 families in 20 villages [12].

Ornamental Fish Trade

The only commercial exploitation in the small-scale commercial fisheries sector is for ornamental fish in the inland waters of Guyana. Although the country's ornamental fish industry is small, it is relatively active. Live fish are caught in the upper reaches of the rivers by licensed collectors. They use craft powered by outboard engines, and varying types of fishing gear like dip- and dragnets/seines and pinseines. Typically, the catch is sold on the coast to six exporters of ornamental fish. The fish are exported mainly to the United States as well as Canada and Europe. The ornamental fishery is not managed by the Fisheries Department [9].

The District Development Board in North Rupununi has also been involved with the harvesting of aquarium fish and has been assisted by the Netherlands Committee for the IUCN [110]. Although people started as a donor-funded project they are moving towards self-sufficiency through community management. Now the fishers are focusing on the sustainable utilisation of wild-caught aquarium fishes harvested with minimal ecological and environmental impact [110]. The business concentrates mainly on Loricariid catfish to enable low-volume harvesting of high-value fish. Presently, only three species are targeted: the lemon fin *Hemiancistrus* spp., the bushy nose *Ancistrus* spp. and the red tail pleco *Pseudacanthicus leopardus*. Especially the last mentioned fish is one of the high-value species currently harvested by the Rupununi people [110].

Sport fishing

Sport fishing in Guyana mainly concentrates on river fisheries, for the arapaima, which attracted many fly sport fishers every year until it was made illegal in 1973 to harvest that fish. Travel brochures still claim that, unlike other parts of the world, arapaima population in Guyana is healthy,due largely to an aggressive Protective Management Plan [112]. Luckily the country indeed has hundreds of other fish species to attract the sport fishers. Marine recreational fisheries are relatively underdeveloped [9].

Peru

General

Peru is a large country with an area of 1 285 000 km^2 and long coastline of 3362 km and a huge exclusive economic zone of 746 525 km^2 [9]. It covers almost 13 per cent of the Amazon basin [22] which contains a large part of the headwaters of the Amazon River. The Pacific Ocean along the Peruvian coast is one of the most productive fishing areas in the world. Peruvian anchoveta *Engraulis ringens* account for 86% of the catch but mackerel *Scomber japonicus*, horse mackerel *Trachurus murphyi* and jumbo flying squid *Dosidicus gigas* are also fished [113]. Pota as Peruvians call that squid is the largest artisanal fishery in the country and has the highest socioeconomic importance due to the number of fishers involved. More than 30 per cent of the squids are exported to the US and EU volume being (2020) 441 750 metric tonnes [114].

Inland fisheries

The most important inland fishery in Peru is in Amazonia covering 778 449 km^2 and having some 900 fish species to be harvested [12]. It is typically artisanal and mainly for subsistence consumption by the local population. Fishers use a variety of gears, including gill nets, hooks, and cast nets, and species composition in urban markets depends on the use of these different techniques. It is alarming that in 1975 FAO report [115] wrote Amazon basin was one of the few remaining areas of the world having an abundance of unpolluted fresh water with a wide variety of fish species native to eastern Peru. Now it is reported that fish diversity is

increasingly threatened by hydropower development and ongoing fish exploitation. Also, climate change is predicted to cause a large challenge to the river's biodiversity [116]. Simulated biodiversity changes indicate that pimelodid catfish and arapaima have the highest extinction risk. Following the anticipated extinction of the large migratory catfish come medium-sized characiforms, such as boquichico, which has a 50% chance of remaining in the communities at 50% of species loss. Smaller characiformes, such as julilla *Anodus* spp., have lower extinction probabilities and often compensate for the decline in the larger species, as noted also in the analysis of Amazon fisheries time series. While the future of fish biodiversity in the Amazon is difficult to predict, with overfishing and dam development, these declining trends are likely to continue [116].

Peru is well aware of the problems the alien fish species may cause in the natural ecosystems. The introductions of the 20 alien fish species and transfers of the seven native species have impacted each of the river basins sampled [117]. Alien fishes being pearl gurami *Trichogaster leerii*, Argentinian silverside or pejerrey argentino, convict cichlid *Cichlasoma nigrofasciatum* , blue tilapia or tilapia dorada, wami tilapia, Mozambique tilapia, Nile tilapia, Rufigi tilapia *Oreochromis urolepis*, Congo tilapia or redbreast tilapia *Tilapia rendalli*, big-head carp *Aristichythys nobilis*, goldfish or pez dorado *Carassius auratus*, grass carp *Ctenopharyngodon idella*, common carp or carpa comun, silver carp *Hypophthalmichthys molitrix*, mosquitofish or gubi *Gambusia cf. affinis*, guppy, sailfin molly or moli *Poecilia velifera*, green swordtail *Xiphophorus helleri* , southern platyfish *X. maculatus*, and rainbow trout. Lowland forest native fishes being arapaima (paiche in Peru), oskar or acarahuasú *Astronotus ocellatus*, sábalo cola roja *Brycon cephalus*, tucunare, tambaqui (gamitana in Peru), paco or pacú and boquichico [117]. Peru's freshwater environments have faced threats due to pollution and habitat destruction due to human activities such as deforestation, mining, oil extraction, and drug trafficking [118]. Aquaculture and urban development have also taken a toll on Peruvian aquatic ecosystems. All of these alterations and other modifications to natural water bodies like watering, energy generation and food consumption can generate environmental conditions that can favor exotic species. For example, pearl gurami has adapted to the small, blackwater, almost polluted Moronacocha Lagoon in the Amazonian plain. Tilapias have already escaped or even been released from fish farms into warm-water bodies of the high Amazon River system. However, all alien species have not only negative impacts as since the 1940s, various forms of aquaculture including aquarium fish culture, ''ranching'' of fish species in natural environments, intensive aquaculture have increased in importance as sources of food production and given continuously economic benefits in Peru [117].

Aquaculture

Aquaculture started in Peru in already 1920s when the rainbow trout was introduced from the US [9]. A new Aquaculture Act has been recently adopted to promote this sector, given its importance in terms of food security as the captured fish supply falls short of demand which aquaculture seeks to fill up [113]. In Peru, the bivalve mollusc *Argopecten purpuratus* and Pacific whiteleg shrimp are the most important farmed species. After Ecuador, Brazil and Colombia, Peru has the fourth-highest aquaculture production in the region, 143 830 metric tonnes in 2020 and nearly 7000 more in 2021 (Table 1). Freshwater fish production is represented by the species: rainbow trout, red tilapia, red pacú, tambaqui and arapaima [113]. However, the production of native fish in Peru is less developed when compared to the other South American countries while the production of the rainbow trout continues to rise [15]. The genetic diversity of arapaima (paiche in Peru) within and between the Peruvian populations resembles the results obtained in other studies in the Amazon basin. Sustainable fish farming could offer a solution to maintaining the genetic diversity of the species [119].

Economy

World's most productive seas give Peru 0.55 per cent of the GDP from the fisheries sector (2018) while exports of fish and fish products amounted to 3281 million USD and imports to 319 million [10].

Fish consumption

Some riverine communities of the Peruvian Amazon are known for high rates of fish consumption, ranging from 51.6 to more than 169 kg per year per person [116] although the average consumption in the country was in 2018 only 25.1 kg (Table 2).

While declining fish catches will undoubtedly have detrimental impacts on human nutrition [120], the degree to which fish biomass is declining, steady, or increasing is a matter of debate. It is also obvious that fish landing statistics and household consumption and expenditure surveys can give very different results. In the Peruvian Amazon, the given values were 84 000 and 154 000, respectively [120].To improve such estimates, it has been proposed that local case studies should be used to calibrate household consumption and expenditure (HCES) data, thus combining the high precision of local case studies with the wide coverage of HCES data, and market surveys, as all have their benefits and drawbacks. Some minor modifications of HCES procedures could considerably improve their usefulness for estimating fish landings in the Amazon Basin [88,120].

Ornamental Fish Trade

Ornamental fishes are exported in large numbers from Peru

and among nine countries of the Amazon region, Peru is the second largest exporter of ornamental fish [19]. In 2007 it was estimated that 14 000 people were depending directly on the aquarium trade which was centralized in the city of Iquitos in the Department of Loreto. Some 28 established aquarium fish exporter firms market

ornamental fish to 24 countries [19]. Virtually all fishes in the trade are taken from a variety of wild aquatic habitats such as main river channels, small tributaries, floodplain oxbow lakes, swamps, flooded moriche palm forests, and remote upland streams [19]. In the Amazon basin, there are some 730 fish species and out of those 420 have been utilized in the ornamental trade [9]. Several concerns have been raised about the sustainability of the aquarium trade. Already in 2004 a study in two lakes of the Nanay River, a tributary of the Amazon River in Peruvian Amazonia indicated that two ornamental fish species angelfish *Pterophyllum scalare* and brown discus *Symphysodon aequifasciatus* were endangered in their natural habitats because of overfishing and destructive fishing methods [121]. This study provided an understanding of sustainable management of a resource through communal management plans; guidelines and criteria for management; evaluation of the feasibility of certification practices; and promotion of sustainable ornamental fishery [121]. Two years later another study concluded that fishing grounds are showing a decrease in the abundance and diversity of species of tropical fish at the Peruvian Amazon [122], and international pressure to stop the commerce of wild-caught fish intensified. Silver arowana trade from the Peruvian Amazon is still large and growing, as the rural poor are attracted to that fish not only for its economic value but also for the ease with which buyers can be found and the convenient timing of the fishery concerning other livelihood activities. However, the local practice of killing the reproductive adults and taking all their juveniles for the aquarium trade may threaten the fishery's long-term sustainability [123]. The arowanas' life-history characteristics including unusually low fecundity make them unsuited to heavy exploitation. Two osteoglossid species with similar biological traits are already listed on CITES to protect wild populations from the collection for the aquarium and food fish trades, i.e. the Asian arowana and the arapaima of Amazonia. No similar international trade restrictions are in place for the silver arowana, and little information is available on the status of wild populations in Peru or elsewhere in South America. Arapaima is categorized as Data Deficient on the IUCN Red List [124], but silver arowana has yet to be evaluated [123].

Sport fishing

Peru has a large share of the Amazon basin and sport fishing in the jungle is an exciting adventure. Popular fish species are arapaima, pacú, tucunare, huasaco or trahira and silver dollars *Metynnis* spp [125].

Suriname

General

Suriname has a land area of 163 820 km^2 with a coastline of 380 km and a continental shelf area of 54 550 km^2. Fishing vessels operating in Surinamese waters are multi-species and multi-gear, with trawlers, snapper boats, open or decked wooden vessels and canoes. The various fishing fleets are defined as combinations of boats and gear, and the artisanal fleet is divided into coastal and inland fleets. The total number of vessels reported in 2016 was 1502. Overall, the sector is divided into deep sea, coastal, brackish water and freshwater fisheries [9]. In 2017 the production of capture fisheries was around 47 000 tonnes, with small Atlantic seabob shrimp *Xiphopenaeus kroyeri* accounting for about 7650 tonnes. Three-quarters of the fish catch is caught by the artisanal fleet although other fisheries are developing as tuna catches began to be reported in 2012 and reached 4700 tonnes in 2015, but decreasing to 3400 in 2016 and 2017 [9].

Inland fisheries

The resource situation of inland fish is unknown but there are some indications of average fish sizes getting smaller, which point out some problems with the sustainability of the use of fish resources. The overall importance of inland fisheries is low and the last report to FAO in 2016 stated the freshwater catch of 865 tonnes [12]. The catch statistics do not identify inland water species but the main species caught are peacock bass, catfish, and tampaqui [9].

The main inland landing sites are along the rivers and in the estuaries where flat-bottom boats and round-bottom boats are mostly used (Figure 3).

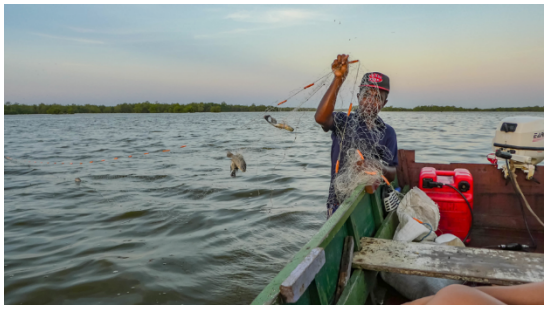

Figure 3: Typical artisanal fishing with a nylon net and outboard engine-powered wooden boat in Suriname. Photo courtesy of Global Forces.

Small and medium-level gold mining started in Suriname at the end of the 18th century but the real gold rush year was 1907 when 1200 kg of gold was produced. Pollution caused by this mining affects still nature as indicated by the mercury levels in sediments and fish in the county. Measurements for 53 localities

proved that 41 per cent of the predatory fish studied had a mercury level higher than the EU standards for human consumption of 0.5 μgg^{-1} [126]. Piscivorous species formed 79 per cent of all studied fish, the most common species being redeyed piranha *Serrasalmus rhombeus* forming 34 per cent of all specimens. The aimara *Hoplias aimara* was the second most common comprising 18 per cent. Neither of these species is known to be migratory. A similar pollution problem in gold mining has impacted aquatic ecosystems also in other Amazon basin countries. The Suriname study mentioned Brazil and French Guiana with larger or comparable mercury problems [126].

Aquaculture

The Mozambique tilapia was introduced to Suriname in 1955 for aquaculture and for stocking natural waterbodies. Soon afterwards people started to complain that this alien fish was outcompeting their favourite food fish soke kwi-kwi, the indigenous armoured catfish *Hoplosternum littorale*. In 1995 a detailed study proved that there was only a moderate or low overlap in the diet and that they used largely different habitats even if living in the same geographical range. No predation was proven between the species and the study concluded that the disappearance of catfish was due to overfishing rather than interactions between tilapia and catfish [127].

The total aquaculture production in 2017 was estimated at 110 tonnes. One company produced cultured shrimp, but outputs have been going down in recent years, and in 2020 the World Bank estimated Suriname's aquaculture production to be 37 tonnes [9,14]. Aquaculture, especially small-scale freshwater aquaculture and rice-fish culture is seen to have a good potential for improving the livelihoods of poor rural households by generating income, increasing fish consumption and improving family nutrition. However, no significant progress has been made in this respect so far. On the other hand, some cachama or tambaqui production has emerged in recent years. This indigenous freshwater species may bring up the country's production numbers [9,24].

Economy

The fishing industry is an important economic sector in Suriname, although, over the last decade, the sector has become less important. In 2017 exports of fish and fishery products were estimated at USD 107 million, while imports were at USD 5.7 million but went down to 56.6 million and 5.0 million in 2020 respectively [9,10]. However, the role of the fisheries sector in the economy of the country is important in assuring a reasonable animal protein supply for the local population; providing jobs (aquaculture and fisheries employed an estimated 4876 people in 2017); assisting the balance of payment through the export of fish and shrimp products; contributing 2.34 per cent to national GDP in 2020; and contributing to the national budget through fees and income taxes [9,10].

Fish consumption

In 2013 estimated per capita consumption amounted to 17.7 kg but went a little down to 17.0 in 2020. Even with that average consumption, Suriname is third highest in the Amazon region after Guyana and Peru [Table 2].

Ornamental Fish Trade

Suriname has started an ornamental fish trade and in 2019 a modest 6 377 kg was exported mainly to China, Hong Kong, Japan, Singapore and the US. Trade was valued at 16.47 K USD [128].

Sport fishing

Recreational fisheries are underdeveloped compared to other places in the Caribbean but the country is now selling Amazon Surinam Super jungle fishing trips with the same favourite fly fishing species as the previous countries [129].

Venezuela

General

Venezuela has a land area of 916 445 km^2 with a coastline of 6762 km and an exclusive economic zone of 385 674 km^2 [10]. Its share of the Amazon basin is 6.1 per cent [22]. Both industrial and artisanal fisheries are important and marine fisheries take place in coastal waters, estuaries, offshore areas and in the vicinity of the country's islands. Among the important commercial species are sardines, shrimps, tunas and various demersal finfish. In Venezuela, mariculture started in 1960 with brown mussel *Perna perna* and mangrove oyster *Crassostrea rhizophorae* cultivation in Eastern Venezuela. Prominent coastal aquaculture development has occurred mainly due to the production of shrimp after the introduction of *Penaeus* spp shrimp in 1984 [130]. Eight thousand hectares were used for shrimp farming; although since late 2004 a 50 per cent reduction of the total surface was registered due to the epizootic generated by the Taura Syndrome viral disease. The introduction of the Specific Pathogen Free *Penaeus vannamei* , resisting the virus was approved solely for reproductive purposes in 2005 [11].

Inland fisheries

Venezuelan freshwater fisheries are conducted in inland waters but despite Amazon and Orinoco Rivers and Lake Maracaibo, it remains far behind the marine fisheries in the development [131]. Until 2004 the inland water catch was up to 50 000 tonnes annually but after that started to go down, some 10 per cent in some years like 2016. Freshwater capture was in 2004 two kilograms per habitant but only one kg in 2016 [132]. Overfishing and the political system are mentioned as possible reasons for this downturn [142]. In general, the harvest of wood,

wildlife and fish increased sharply after 1983 when Venezuela's economic crises started [131]. The contraction of the economy led to massive unemployment and the workforce shifted to natural resource harvesting as an alternative source of food and income. Unsustainable biodiversity use was reaching previously unrecorded levels lowering the catch per unit value of many popular fish species and declining the fish availability in local markets [133].

Aquaculture

Venezuela's lake "ranching" type of aquaculture is known already from 1830 when "marine" fish was stocked in Lake Valencia [130]. Rainbow trout farming started in 1937 and provided the first stimulus to the development of fish farming in the Andean regions of the country [130]. In 1940 common carp and in 1959 the Mozambique tilapia were stocked in natural waters in Venezuela [11]. In 1980 red tilapia was introduced as a commercial crop and in 1982 large-scale commercial fish farms were built for the cultivation of native species. The warm-water inland fish culture was promoted especially from 1974 through 1977 by FAO/UNDP, notably through the development of induced reproductive technology (hypophysation) of coporo *Prochilodus mariae*, pirapitinga, tambaqui and their hybrids [11]. Since the late 1990s, the tambaqui has been the most cultivated fish as it seems to have the greatest potential to compete economically with tilapia production in South America [15]. Tambaqui cultivation is being developed in the country's rural areas and is usually integrated into other agricultural activities. Its contribution to the national aquatic production was eight per cent in 2004 [134]. However, the future perspectives for its growth present some limitations, such as the deficient promotion; incipient commercialization of the product; the lack of sources of financing for the development and yet non-availability of low-cost concentrated fish feed [11].

The total surface area (530 hectares) of fish farming production includes 503.5 ha for extensive and semi-intensive and 26.5 ha for intensive farming [11]. At the semi-intensive level, some 14 000 tambaqui individuals are harvested per hectare per year (8-month cycle), at a stocking rate of one fish per square metre [135]. Bocachico is mostly cultivated extensively and also under polyculture with red tilapia and tambaqui, in densities ranging between 0.2 and 1 fish per square metre, which generates an annual production of between 2000 and 10 000 fish with an average weight of 450 grams, for production in 9-month cycles, between 900 and 4500 kg [136]. Red tilapia production has 100 000 fish per hectare per year; 50 000 fish/6-month cycle, which provides 35 tonnes annually.

The estimated aquaculture production in 2013 was 15 712 tonnes the value being 51.1 million USD [11] In 2020 the production was already 53 609 tonnes but went down 8 tonnes the next year (Table 1) but still being 5th highest in the Amazon basin countries [14].

Economy

The GDP value from fisheries and aquaculture is not available in the Bolivarian Republic of Venezuela but in 2020 total fisheries production in Venezuela was 307 532 tonnes out of which 84 per cent came from capture fisheries and 16 per cent from aquaculture. The country exported fish in 2020 with 124 million USD and imported 30 million USD [10].

Fish consumptionThe fish consumption was already 19 kg/year/capita before 2000 but went down to 13.5 kg in 2004 and was only 9.8 kg/capita in 2005 (Table 2). A special nutrition study shows that this downward trend has continued and in 2016 the per capita consumption was not more than 5.1 kg [132]. For indigenous people in the Amazon basin fish is a very important protein source but there are no data on fish catch after 2016 [12].

Ornamental Fish Trade

Venezuela together with Brazil, Colombia and Peru, is one of the main exporters of ornamental fish in the region and together these countries possess the highest diversity of fish species (up to 5000 species) per unit area in the world [137]. Five to six per cent of the ornamental fish could originate from Venezuela meaning that the country has a good share of this global trade. The political system makes it easy to regulate the trade but socialistic statistics are not so easily available. INAPESCA and subsequently INSOPESCA have accepted the recommendations adopted by CITES. "Any natural or legal person engaged in the activities of production and trade in ornamental fish must be registered with the Institute. Persons engaged in the export of ornamental fish will be required to obtain a permit issued by the Institute and must present a quarterly report indicating the common and the scientific name of the species, quantities, areas where caught and the destination of the specimens" [134]. From 1973 to 1978 Venezuela was the leading country to prevent and control diseases in ornamental fish. During shipment and at holding facilities ornamental fish were affected by bacterial and mycotic infections, as well as parasitic infestations associated with protozoans and metazoans. Several groups of bacteria were responsible for the diseases and the onset of bacterial diseases often occurred when the fish were in the exporter's establishments. Studies evaluated various treatments and substances and all of them had a good but variable rate of success in diminishing mortalities [138–140].

Sport fishing

A few places can beat Venezuela when it comes to fishing diversity. From freshwater fish, the peacock bass and its snaggletoothed cousin, the payara, are mentioned [141].

Discussion and conclusions

Because of their dispersion, social complexity and variety, small-scale fisheries are often poorly documented, and due to lack of regulations and control many of the complex management issues remain largely unresolved [2]. The Amazon Basin is a good example of such situation even though for many of its inhabitants fishing is a crucially important source of food and income. Unfortunately, the benefits derived from mostly informal, part-time, seasonal, and subsistence-based activities such as fishing are largely invisible to policy-makers [88]. Any government intervention in fisheries management is to prevent the overuse of resources and seek economic benefits from the fisheries. To achieve this goal the government ought to have an effective management system in place that will ensure that all decisions have the desired effects [109]. Fishers are not normally involved in the management process. The decisions are made without consulting them explaining why fishers often ignore the decisions. They are fully aware that the government is unable to manage the local resources from the central level. This situation leads to the decline of the resources and decreasing profits from the fisheries [109]. So it is important to get the fishers involved in the management of the resources through empowerment. Since the government is in most cases incapable of enforcing its decisions it is necessary to decentralise power so that some of the management can be given to the fishers [109,142]. The government needs to form partnerships with communities for them to assist in managing the resources. The fishers gain from this co-management but also have to assume responsibility for their decisions and actions [109,142].

It can be estimated from the landings, trade, and consumption of fish that the total fish catch in the Amazon basin is far beyond half a million tonnes/year in live weight [12,87,88]. However, there is a very large margin of uncertainty given that almost 75 per cent of represented landings come from the Brazilian part of the basin, and that, there are no recent official statistics on inland water fish catches from most of the region countries. It is known that local fish consumption in the Amazon area can be up to 150 kg/capita [131] so not much will be recorded in official trade. In all Amazonian countries, 50 up to almost 100 per cent of the fishing takes place for personal consumption, implying that it is not recorded in official landing statistics [88]. Available time series data indicate that fish consumption in Brazil, as well as commercial fish landings in Peru and Colombia, have declined in recent years. Local case studies should be used to calibrate household consumption and expenditure surveys, and market survey data [88].

Damming of rivers negatively impacts the aquatic biota in many ways and is one of the main causes of the reduction of fish abundance and species diversity worldwide [132]. Blocking the movements of migratory fish species is one of the most obvious impacts of dams. Therefore, fishways have been used in many countries to pass fish around dams and are part of the technical arsenal for fisheries restoration in dammed rivers [144]. Fishway construction is booming in Brazil, but a poor understanding of migrations by Brazilian fish has led legislators, scientists, and the public to several misconceptions about the rules of fishways in fisheries conservation [144]. However, addressing the threats to aquatic habitats, ecosystem functioning, and fisheries is frequently given low priority in national development agendas [88].

Aquaculture offers the largest potential to increase fish supplies in the long-term but the rapid growth of global aquaculture is unevenly distributed among countries [15]. Rightly so South American scientists have criticized the international funding and technical assistance organizations for being part of the introduction of alien species in new environments through the aquaculture development. These alien species contribute to an irreversible and devastating impact on natural ecosystems [145]. Instead, it is essential to encourage the production of native fish in the Amazon basin since several species of zootechnical interest can contribute to meeting the internal demand for fish [15]. For this, it is necessary to know the species since its acquisition, production, processing, and marketing. Luckily, the production of native fish is currently overtaking the production of exotic species in some countries, which is considered a milestone for South American aquaculture. In Bolivia, the Fish for Life project has effectively contributed to the development of farming of native fish species as an alternative means for rural families to improve their quality of life. Its focus on strengthening local stakeholders as well as key alliances has allowed the enhancement of technical skills and the creation of opportunities for collaboration between those involved. Fish farming has opened up a greater role for women and has improved family diets with the addition of an affordable, high-quality protein source [25].

Ornamental fish culture and trade have still some importance in the Amazon basin countries. However, nowadays South Asian countries are the main providers of aquarium fish with 85 per cent of the global market share, whereas the remaining 15 per cent is distributed between Brazil, Colombia and Peru [146]. In Colombia, the project turning ex-coca farmers into ornamental fish breeders is a positive social development [71]. The ornamental trade in many species of live aquatic animals, freshwater and marine fish, and shellfish can be even more lucrative than the trade in food fish. However, a valid concern has been raised, mainly in developed countries, that this trade risks spreading diseases worldwide when millions of ornamental fish cross borders and continents every day [147].

Sport fishing is a hobby for people with money and benefits the local fishers often in remote rural areas. Sport fishers are not fishing for food but just want to have a good photo with the largest possible fish. Then the catch is normally released. This catch-and-release system is seen as a great conservation strategy, although simply letting a fish go does not guarantee it will live. Luckily many keen sport fishers follow the best actions in using the right gear and effective release techniques to keep fish populations healthy [148]. Free-time fishery may not be significant for the national economy but it is important in social and recreational terms for folks from all walks of life. Catches are small, so hardly any fisheries management plans have been drawn for this fishery.

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