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Evolution and Prospects of Freshwater Fish Species and Aquaculture in Colombia: A Historical Perspective

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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Review Article

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ABSTRACT

Since the 1970s Colombia has been aware of the importance of aquaculture and inland fisheries in the future of its economy due to the constant increase of a population that is increasingly in need of protein of animal origin. In 1972, a joint project between the Government of Colombia and the Food and Agriculture Organization of the United Nations was approved and aimed at studying inland fishing and developing aquaculture in the country. The work of the project is described, as are the fish culture and fisheries research activities starting with the situation in the 1970s but comparing it with recent findings. A list of the main capture and culture fish species is given. Colombian fishing production has had great variations, but first inland water fishing was more important than marine. For instance, in 1972 total fish catch was 104,390 tons and 79% of that originated from inland waters. After the continental fisheries went down, the marine fisheries accounted in 2019 already 78 per cent of the total catch of the country. Mean standing fish crop estimates in 1975–76 from the bay, open water and vegetation habitats in four floodplain lakes were 118, 12 and 251 kg/ha indicating clearly that the fish productivity on the Magdalena floodplain was relatively low. The

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aquaculture sector has been growing rapidly, reflecting global trends, and producing more than capture fisheries. Aquaculture produced 88,000 tons in 2013, which was a three-fold increase from the mid-1990s. Again twofold increase took place before 2020 when the production was almost 180,000 tons. Future development prospects of inland fisheries and aquaculture are discussed and a mention is made of the present situation of ornamental fish cultivation and trade in Colombia.

Keywords: Inland fisheries; colombian fish species; fishery limnology; aquaculture development; native and alien species in aquaculture; ornamental fish trade.

1. INTRODUCTION

Due to its geographical position, Colombia was an important dispersal route for the first settlers who, through Central America, arrived in South America. These first peoples based their diet on fishing, hunting and the collection of some plant products. Significantly, rivers have not only constituted dispersion and communication routes but have favoured the appearance of population centres, due to the availability of a permanent source of protein [1]. The high number of freshwater and marine species in the country offers great possibilities for fishing and intensive farming, especially considering that just after Brazil Colombia's freshwater fish fauna is perhaps the most varied in the neotropical region [2]. The Colombian government wishes to promote the further growth of aquaculture and a National Plan for Sustainable Aquaculture (PlaNDAS) has been adopted [3]. The aquaculture has potential to grow and create employment, notably due to an entrepreneurial momentum for investing in the sector. The PlaNDAS mapped the most suitable areas for aquaculture development in the country. Good aquaculture and fish processing practices were listed and it was noted that the country also has reliable diagnostic laboratories for fish and shrimp diseases [3,4]. Colombia does not have a history of providing high levels of support to the fisheries and aquaculture sector but a similar situation is common in many OECD countries [5,6]. It is estimated, however, that over one million people work in the sector and associated services [5]. 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 [5]. Despite its existing production possibilities Colombia imported 114,950 tonnes of fish and derivate in 2021, namely, Atlantic salmon *Salmon salar* (whole and fillets) 20%, shrimps and prawns accounting for 17%, tunas *Thunnus* sp. 10%, catfish *Bagre* sp. 8%, Basa fish *Pangasius bocourti* 8%, tilapias *Oreochromis* sp. 7%, molluscs species 6%, Coho salmon *Oncorhynchus kisutch* 5%, Nile perch *Lates niloticus* 3% and other frozen fish species 16% [7].

Before 1969, fishing in the country was governed by the Natural Resources Division of the Ministry of Agriculture. This activity was considered in conjunction with the fauna and wildlife and only staff included a boss and some assistants and field assistants [2]. Starting in 1969, with the creation of the Institute for the Development of Renewable Natural Resources, hereafter INDERENA, the fishing sub-sector took a very important step in its development. There was a department in charge of establishing an appropriate policy for the rational use of fishing resources. This department had more than 70 professionals and was divided into three large branches: the Division of Maritime Fisheries, the Division of Inland Fisheries, and the Project for the Development of Inland Fisheries. Under the responsibility of the latter were 12 field stations and 37 professionals. The Inland Fisheries Division was made up of two sections: Research and Promotion. The tasks corresponding to the first were covered by the Project for the Development of Inland Fisheries, while those corresponding to the second were taken care of both by the personnel of the same project and by a specialized group for that purpose [2, 8-10].

The FAO/INDERENA project for the Development of Inland Fisheries started in 1972 and lasted until mid-1979. The author was assigned to that project for two years in 1974 as Pollution Biologist and Fishery Limnologist. The work between 1974 and 1976 included stock and catch assessment surveys with FAO and Colombian personnel. Data presented and all personal statements in this chapter are from that period but the chapter intends to review also the past and present situation in Colombian fisheries.

2. INLAND FISHERIES RESOURCE BASE

Inland fishing is carried out mainly in the Magdalena River basin, which covers 256,622 km^2, or 22.5 per cent of the country's surface. The River basin includes, apart from the Magdalena River, countless tributaries, the most important being: Cauca, Sogamoso, César, San Jorge, Saldaña and Bogotá. The fishing activity is carried out mainly during the two annual reproductive seasons: The Subienda in the first half of the year and the Mitaca in the second. Both upstream fish migrations are one month to one and a half months long. During the migration fishes spawn when winter begins with the onset of the rainy season and resident individuals remain in the river. The downstream movement is called the Bajanza during which the fish return to the Magdalena floodplain lakes to grow and fatten [2,11,12]. During the rest of the year, the fish consumed in the country comes, in part, from the complex of floodplains that this basin has. The floodplain lakes (hereafter Ciénagas) have an approximate area of 500,000 ha and represent also considerable space for developing both extensive and intensive aquaculture [2]. Among the main ciénagas one can mention: La Ciénaga Grande de Santa Marta (44,000 ha), Zapatosa (34,000 ha), Ayapel (12,800 ha), Ciénaga Grande del Sinú (11,900 ha), Guájaro (16,000 ha), Zárate o Plato (8,060 ha), San Antonio (4,030 ha), La Raya (3,780 ha), and Sapayán (3,780 ha) [2,13].

Three large tributaries of the Amazon basin are born in Colombia: the Putumayo River (1,700 km), the Negro or Guainía River (2,000 km), and the Caquetá or Japurá River (2,200 km). Colombian tributaries (Caquetá, Negro, and Putumayo) contribute 29.5% (880 km^3/year) of the total incoming water of the Amazon basin (2,985.5 km^3/year) [2,14].

The Arauca River starts high in the Colombian Andes, and then runs east across the Llanos Orientales. Initially, a swift mountain stream called Chitagá receives inflows from the Carabo and the Cacota Rivers. After twisting its flow towards the east it is joining with the Culaga and Bochaga Rivers. Then the name changes to the Margua. Numerous new tributaries are flowing into that river which serves as the border line between Colombia and Venezuela for 296 km. Finally, the waters reach the Orinoco River in Venezuela. Up to 80 per cent of the 1,050 km long river is navigable in small boats [14]. The Guaviare River is another tributary of the Orinoco in Colombia (basin 140,000 km^2) and it is the longest Orinoco tributary (1,497 km) and navigable for 630 kilometres. It is sizewise and hydrologically the mainstream of the Orinoco system and it is also seen as the border between the Llanos and the Amazon Rainforest [15]. The Inirida River is 1,300 km long and its basin size is 53,795 km^2 thus being the main tributary of the Guaviare (the Orinoco River basin). It has a dark water colour due to the abundance of plant residues [16]. The Meta River is 1,100 km long with a 103,000 km^2 basin making it the major left-side tributary of the Orinoco River in western Colombia. It originates in the Eastern Ranges of the Andes and flows through the Meta Department dividing the Colombian Llanos into two different parts with a clear climate difference. The west side is more humid and nutrient-rich but the east portion has a longer dry season and surface waters are oligotrophic [17]. One more Orinoco tributaries is the Vichada River which has 580 km length and 26,212 km^2 basin. Like Inirida it is a typical blackwater river in the country [18].

3. INLAND FISH IDENTIFICATION HISTORY

Knowledge of the country's ichthyofauna began with several works written by chroniclers and travellers from the 16th and 17th centuries. The first review of marine and freshwater fish was done in 1746 by Canon Nicolás de la Rosa [19]. However, scientific knowledge of Colombian ichthyofauna began with the South American trip of Baron Alexander von Humboldt (1769–1859), and the French botanist Aimée Jacques Alexandre Bonpland (1773–1858). The results of their 1799–1804 trip were published between 1806 and 1833 by Baron von Humboldt [20–23]. Subsequently, between 1875 and 1915, the study of fish from the Magdalena basin gained momentum with the work carried out by Franz Steindachner [24–29]. In these publications, he described new species belonging to the Magdalena and lower Cauca Rivers.

Colombian medical doctor Andrés Posada Arango also described 1909 some new fish species in his Scientific Studies [30]. Under the auspices of Indiana University, Carl H. Eigenmann, together with Arthur J. Bierhaus, ascended the Magdalena River, visited the surroundings of Bogotá, and then went on to Valle del Cauca and the Department of Chocó. Carl H. Eigenmann's lifelong Colombia investigations have been published between 1912 and 1922 [31–45]. The collections obtained

Fig. 1. *Pterigolichthys* sp catfish which I named as 'Walking and Talking Catfish [81] Photo: Juha Laaksonen

are largely in the California Academy of Sciences in San Francisco, CA. Reverend brothers Apolinar and Nicéforo María contributed material that was sent to Carl H. Eigenmann, George S Myers and Henry W Fowler for further classification. The last two mentioned published their reports between 1919 and 1950 [46–52]. Swedish G Dahl made collections in the Hoya del Magdalena (1942, 1963 and 1971) and the Sinú River (1955, 1958 and 1964), which resulted in the publication of some new species [53–60]. In addition to previous authors AW Henn [61, 62], C Miles [63–68], and C Regan [69] have to be mentioned in the context of old fish species investigations in Colombia.

Modern-day scientists have continued fish taxonomy studies covering the Colombian species, just to mention a few like Mejía [70], Diaz [71], Ospina & Restrepo [72], Ardila-Rodriquez[73], Galvis et al. [74], Mantilla-Adlana [75], Mojica et al. [76], Reis et al. [77], Ortega-Lara [78], Maldonado-Ocambo et al. [79] and Lasso et al. [80]. It is also interesting that the aquatic macroinvertebrates have been the best studied in Colombia and the guide for their identification and study in the Department of Antioquia has served as a reference for the establishment of similar keys in most Latin American countries [81].

Despite all the taxonomic work with fish species, [82] it is still difficult to identify some species even from a good photo (Fig. 1).

4. AQUACULTURE HISTORY

The Colombian history in aquaculture is longer than one would expect. Like many other nations, the early mistake was made by only considering alien species for aquaculture [83, 84]. Even though before 1939 some experiments were made on the culture of fish in closed environments, it was in this year that practical fish farming began in Colombia, through the importation of 100,000 embryonated Rainbow trout *Oncorhynchus mykiss* eggs [2]. At the beginning of 1942, some 30,000 fingerlings were planted in Lake Tota, from where came all the specimens that were distributed throughout the cold regions of the country. There are, however, clear indications of the dominance of the trout over the native species, and today we can assume that this species has been practically responsible for the disappearance of the Capitán or Chimbe *Eremophylus mutisii*, of the Guapucha *Grundulus bogotensis*, and the Runcho *Rhizosomichthys totae* [2].

The trend from 1940 onwards was to promote the translocation of local species, repopulations (= introduction or release of individuals from a taxonomically identical population into an area where they previously existed), and introductions of exotic species from abroad in the main basins of the country. A few years ago a controversy arose around the advisability of carrying out translocations and introductions of some freshwater species from the Amazon basin or other continents to the Magdalena River basin and other regions. Although this aspect has not been fully elucidated, the country has introduced species such as the Rainbow trout, the Brown trout *Salmo trutta*, the Common carp *Cyprinus carpio*, the Goldfish *Carassius auratus*, the Tilapia species *Oreochromis mossambica* and *Coptodon rendalli*, the Guppy or Rainbowfish *Poecilia reticulata*, the Amazon molly *Poecilia formosa*, the Black bass *Micropterus salmoides*, etc. In the majority of these cases, empirical criteria lacking any technical basis were used, and many times without the legal provisions established in the country on the subject [2]. On the other hand, translocation from one basin to another within Colombian territory has been quite common. As examples, we have the case of the Butterfly peacock bass or tucunaré *Cichla ocellaris* carried from the Amazon basin to the Cauca River basin in a hasty manner, as so often has happened with the ornamental fish species that have been caught in the Llanos Orientales and Amazonia region and then disseminated throughout the national territory [2].

Introducing species into an environment where they do not naturally occur can result in ecological imbalances which have rapid and dramatic consequences. Introduced species may have no natural predators to control their population growth. They may out-compete any indigenous species for space, breeding sites or food, or decimate local flora and/or fauna which may not have time to acquire any resistance to the new pressure. As indigenous species have not co-evolved with the introduced species, they are susceptible to factors such as predation or competition by the alien species [85]. It should be noted that the translocation of local species presents the same problems and dangers as introductions of exotic species [83] since in both cases they are adventitious elements that are introduced into ecosystems where there is no evidence of such items. Due to the profound ecological differences that the country presents, any transplant can have the same ecological significance as the introduction of non-native species within the country, and there are many cases of the harmful influence that the introduction of exotic species can have and how their eradication or control can be expensive or impossible [86]. Since 1972, The Colombian Government has been interested in favouring aquaculture based on native species that offer good possibilities for their intensive culture, taking into account their wide acceptance in the domestic market. They have also been working with some species that may represent an important source of export, in the future [2].

5. INLAND FISHERIES CATCH

Inland fisheries in Colombia take place mainly in the catchment areas of the rivers of the Magdalena, Orinoco and Amazon catchment. 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 [87]. The most valuable species is the Bocachico *Prochilodus reticulatus magdalenae*, whose catch corresponds to 60% of the total catches in the Magdalena basin. Next in importance is the Barbudo blanco or Nicuro *Pimelodus clarias* with 13%, the Barred sorybim or Bagre pintado *Pseudoplatystoma fasciatum* (Fig. 2.) with 12% and the Capaz *Pimelodus grosskopfii* with 4%. In the Ciénaga Grande de Santa Marta, the Mullets *Mugil* sp. head the list, in order of economic importance and the Mojarras *Caquetaia* sp. of the Gerridae family.

The fishing fleet consists of dugout and plank canoes, larger of which serve for seine fishing and smaller ones for cast net, hand-line, trap and spear fisheries. In the floodplain, fishermen were using the cast net more than any other gear [87]. Most fishermen are only part-time fishers alternating the activity with other jobs like agriculture, trade and building construction. This is diversifying the household economy, as formal work opportunities are few and far between. Before 1972, Colombian fishing production had some variations, but in any case, inland water fishing was in the old times always higher than marine. In 1972, 79% of the national fishing production (104,390 tons) corresponded to that obtained in the main rivers, especially those from the Magdalena basin [87].

Fig. 2. Bagre pintado *Pseudoplatystoma fasciatum* was the second most common fish captured (17 kg/ha). It can can grow up to 25 kg Photo: Matthieu Sontag/Wikimedia

Until the mid-eighties inland fishing was an important income source, supporting food security and local development. Serious contamination of the water sources [88, 89] and rampant deforestation [90] caused the decline in fisheries, especially in the Magdalena River basin. The decline of the freshwater fisheries has since continued but at a slower pace. Prices in inland fisheries are affected by the number of middlemen involved in the marketing chain [91, 92].

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 [9]. 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 [9]. The bottom of the inland water catch went just below 20,000 tonnes in 2006, after that a slow recovery started and in 2019 the catch was 22.495 tonnes which was 22% of the country's total marine catch now being 78 per cent of the total [87].

6. FISH CONSUMPTION

In many coastal and rural areas fish is the cheapest and most easily accessible source of protein, often available year-round including when other sources of protein are at a seasonal low. Worldwide, it is the main source of animal protein, especially for poor and food-deficient people [93]. Fish, especially when eaten whole, is also an important source of essential fatty acids and micronutrients, which are an important complement to the predominantly carbohydrate-based diets of many poor people. These micronutrients include vitamins A, B and D as well as iodine, iron, zinc and calcium [94].

In mid 70 only 3.6 kg of fish was consumed annually per capita, market study showed that only every second inhabitant ate fish at least once a month [91]. 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. Since that time the average fish consumption in the country has slowly increased nearing now 8.9 kg/capita, meaning that fish is still a relatively small contributor to average food consumption. However, these averages hide strong regional and household-level variations. For instance, in Colombian Amazonia, the average fish consumption was in 2015 above 26 kg/person/year which is well above the world average (22 kg/capita) [95].

7. FISHERIES LIMNOLOGY

The study of limnology in Colombia begins with the works carried out by Joaquin Molano Cambuzano in the 1950s [96, 97].

The FAO/INDERENA project with international Limnologists did not change a lot but we introduced the term Fishery Limnology in Colombia [98–100].

7.1 Water Quality

Limnological analysis included Temperature º C; Dissolved Oxygen (O_2) and Oxygen Saturation; Carbon dioxide (CO_2); Conductivity; pH; Ammonium (NH_3); Alkalinity; Hardness ($CaCO_2$); Hardness total; Nitrates (NO_3); Phosphates (PO_4); Sulphates (SO_4); Silica (SiO_2) non-filtered; Iron total (Fe); Copper undissolved (Cu); Manganium (Mn); Turbidity JTU (= Jackson Turbidity Unit); Color; Secchi reading; Chloride, Cyanide and Detergents LAS/ABS. Biological parameters included aquatic vegetation, benthos, phyto- and zooplankton and primary production [13].

The water quality and pollution were studied first in Chicamocha River [88] and a particular study [89] was made on the impact of polluted Bogota River water on the clean Magdalena River (Table 1). Detailed measurements are given here in hopes that some young scientists would repeat that kind of study 50 years later. The first-year water pollution study in Chicamocha River revealed lethal levels of cyanide and that alerted the authors. The United Nations got a note from the highest level in Colombia that there is no reason to continue any pollution studies in the Chicamocha River. The topmost authorities owned the most polluting steel plants in the Chicamocha River basin. A typical UN solution was to respect the corrupted authorities and therefore it was decided to move the entire research team from Bogotá to Cartagena and to continue only the fishery limnology programme instead of the water pollution studies. After pollution studies fishery limnologist work started in clean waters of the seven floodplain lakes

(Ciénagas) near San Cristóbal [13]. Later studies continued in Canal del Dique and 10 connected Ciénagas: namely Carabalí (300 ha), Guájaro (16,000 ha), Jobo (1,600 ha), Luisa (400 ha), Maria La Baja (2,300 ha), Matuya (500 ha), Palenque (380 ha), Palotal (720 ha), Quintanilla (3,800 ha), Zarzal (300 ha)[13].

Turbidity in these shallow floodplain lakes was very high (up to 210 JTU in Palotal and 250 in Canal del Dique) and therefore the primary production was very low, the highest value measured was 0.24 g/C/m^3/hour in Carabali. Dissolved oxygen concentrations were measured day and night from the surface to the bottom. They were high in all studied ciénagas because strong winds blow often during the afternoon and night and that oxygenate the water from top to bottom [13]. An interesting aspect was to find out how the full moon affected the oxygen content (Table 2). It was clear that full moon nights allowed the oxygen content to remain high and stable until the bottom in the shallow ciénagas. Unfortunately, calm and clear nights with a full moon were not many, so it was not possible to finalize this particular study more profoundly.

7.2 Stock Assessment

Two methods were used for fish stock assessment: a toxicant applied in an area of known volume and an area enclosed by a block net, and a fleet of multi-mesh gillnets [100, 101]. A block net of 175 m x 4.5 m of 2.5 cm stretched mesh was used and set from two small boats running in reverse. It took 3 to 5 minutes to close the block net and then 5% powdered rotenone was spread in the blocked area of 1,850 m2. Moribund fishes began to surface within 15 minutes after the application of rotenone and dead fishes were collected for up to 24 hours [102]. To recover some hard-to-kill species multi mesh gill nets were used within the block net area. Gill net stock assessment was undertaken near the block net activity by using 5 panels

Table 1. The impact of Bogota River on the chemical composition of the Magdalena River Mean values and standard deviation for 12 months between January 1974 and April 1975

Water Quality Measurements	Magdalena above Confluence with Bogota River	Bogota River near the Mouth at Girardot	Magdalena 2 km below Confluence	Change in the Percentages; + or –
Temperature ºC	25.3 ± 3.4	24.7 ± 2.4	24.9 ± 3.1	– 1.54
pH (in pH units)	7.5 ± 0.3	7.1 ± 0.4	7.3 ± 0.3	– 2.14
Conductivity (µmho/cm)	119.8 ± 21.6	586.6 ± 88.4	148.0 ± 42.4	+ 23.58
Turbidity (in JTU)	228.1 ± 169.3	410.2 ± 617.9	194.8 ± 151	– 14.60
Colour	588.5 ± 511.3	1225.4 ± 2155.5	668.9 ± 977	+ 15.34
Silica (mg SiO_2/l)	9.5 ± 4.1	5.7 ± 3.0	10.4 ± 6.2	+ 9.51
Alkalinity (mg $CaCO_3$/l)	49.5 ± 8.8	104.6 ± 44.8	52.6 ± 12.2	+ 6.22
Dissolved Oxygen (mg O_2 / l)	6.8 ± 0.6	1.9 ± 0.8	6.7 ± 0.7	– 2.20
Oxygen % saturation	83.9 ± 9.5	23.5 ± 10.6	81.0 ± 8.7	- 3.40
Carbon dioxide (mg CO_2/l)	8.9 ± 6.1	16.0 ± 10.6	5.3 ± 4.3	- 40.34
Hardness, Calcium (mg $CaCO_3$/ l)	39.1 ± 11.7	143.4 ± 22.3	43.0 ± 11.6	+ 9.97
Hardness, total mg/1	50.6 ± 13.5	172.3 ± 29.0	56.5 ± 13.9	+ 11.54
Orthophosphate (mg PO_4 / l)	0.56 ± 0.2	1.4 ± 0.4	0.56 ± 0.1	± 0
Nitrogen, Ammonia (N x 1.22 = NH_3 mg/1)	0.70 ± 0.5	3.9 ± 4.5	0.94 ± 0.5	+ 34.29
Nitrogen, Nitrate (N x 4.4 = NO_3 mg/l)	12.2 ± 21.0	25.5 ± 44.1	14.3 ± 24.0	+ 17.52
Sulfate (mg SO_4 / l)	8.3 ± 7.8	81.7 ± 28.0	13.6 ± 6.3	+ 63.94
Iron total (mg Fe/ l)	1.6 ± 2.8	2.1 ± 3.5	1.5 ± 2.9	– 1.94
Copper undissolved (mg Cu/l)	0.11 ± 0.2	0.15 ± 0.17	0.07 ± 0.11	– 36.36
Manganese (mg Mn/ l)	0.31 ± 0.91	0.2 ± 0.5	0.01 ± 0.03	– 96.77
Chloride (mg Cl^-/ l)	11.0 ± 10.8	83.5 ± 56.8	15.0 ± 7.7	+ 36.36
Detergents LAS/ABS	0.04 ± 0.04	0.9 ± 0.3	0.09 ± 0.08	+ 125.0

Table 2. Dissolved Oxygen (O_2 mg/l) measurements and water temperature (ºC) (in the brackets) in two shallow Cienagas (Palotal and Carabali): full moon values 20–21.2.1975 at 21.30 and 02.00 o'clock and 18–19.2.1976 at 21.00 and 02.00 o'clock; and no moon values 16–17.08. at 24.00 and 17–18.08. 1975 at 21.00 and 02.00 o'clock

Water Depth	Full Moon (Average)	No Moon (Average)	Full Moon & No Moon Diference
Surface	7.2 (27.9)	5.3 (28.6)	– 1.9 (+ 0.7)
30 cm	7.1 (28.0)	5.2 (28.8)	– 1.9 (+ 0.8)
60 cm	7.0 (28.0)	5.2 (28.8)	– 1.8 (+ 0.8)
90 cm	7.3 (28.0)	5.0 (28.8)	– 2.3 (+ 0.8)
120 cm	6.9 (28.0)	4.8 (28.8)	– 2.1 (+ 0.8)
150 cm	7.0 (27.9)	2.9 (28.7)	– 2.9 (+ 0.8)
180 cm	6.7 (27.8)	1.4 (28.6)	– 5.3 (+ 0.8)
210 cm (bottom)	6.3 (27.8)	0.7 (28.5)	– 5.6 (+ 0.7)
Average	6.9 (27.9)	3.8 (28.7)	– 3.1 (+ 0.8)

of 50 m long and 1.83 m high monofilament nets with varying mesh sizes from 7.62 to 17.78 cm in 2.54 cm increments. Mean standing fish crop estimates from the bay, open water and vegetation habitats were 118 (49-232), 12 (0.2 - 28), and 251 (201-302) kg/ha respectively, with min and max values in the brackets. Preliminary data was in 1976 available only from Ciénagas Carabali, Jobo, Luisa, Maria La Baja and Palotal [103]. It might be good to add that 99% of the fish captured were donated to local populations after advising them to remove the gills carefully as the rotenone concentrates on those. Otherwise, the rotenone did not spoil the fish. This was also a way to calm down the agitated villagers who thought that heavily disliked Americans had arrived with their superior boats and nets to steal their meagre fish resources.

7.3 Fish Species

In the bay areas, 21 species with an average of 1700 individuals per hectare were captured, Raya *Potamotrygon magdalenae* being most abundant (mean 53 kg/ha), followed by Bagre pintado (17 kg/ha), Pácora or Burra *Plagioscion surinamensis magdalenensis* (16 kg/ha) and Bocachico (mean 10 kg/ha). Of the total 21 species only 12 could be classified as of commercial importance and they counted for 51% of the mean standing crop in the bay habitat [103].

Open water habitat had 16 species with an average of 941 individuals per hectare. The most common in weight terms was Pácora (mean 5 kg/ha), followed by Raya (1 kg/ha), Robalo *Centropomus undecimalis* (1 kg/ha) and Barbudo blanco or Nicuro (0.9 kg/ha). Eight species were classified as marketable among the 16 species and these accounted for 77% of the mean standing crop.

Habitats with vegetation had 22 species in block net samples. The density of Mojarra amarilla *Caquetaia kraussii* (Previously *Petenia kraussii*) was very high (144 kg/ha), the next common species being Moncholo or Perraloca *Hoplias malabaricus* (20 kg/ha) (Fig. 3.), Doncella or Vieja *Trachycorystes insignis* (17 kg/ha) and Barbudo blanco (16 kg/ha). Eleven species were classified as marketable of those total 22 species and these commercial species accounted for 80% of the mean standing crop in this ecological zone [103].

Fig. 3. Perra loca *Hoplias malabaricus* was often captured in the habitats with vegetation (20 kg/ha)
Photo: Wikimedia Commons

It was noted that block net quadrats and gill net captures gave different results: in the bay habitat two new species were captured in the gill nets against the quadrat determinations; in the open water eight new species were found with the gill nets and lastly in the vegetation habitat gill nets captured three species which were not recovered from the quadrats. So, gill nets sample different populations of fish that are present in the same habitats at the same time [103].

7.4 Limnology versus Fish crops

We studied also the relationships between standing fish crop estimates, gill net catches, and the limnological characteristics of ciénaga waters [13, 103]. Only open-water habitat results are presented because too few replications were available in the bay and vegetative habitats. Simple linear regressions were calculated, and it was assumed that apparent linear relationships, with coefficients of less than 0.25 (linear correlation coefficient, r = 0.50) were due to chance alone.

Of the six physical variables tested, three had coefficients higher than 0.25, these being watercolour (0.85) and turbidity (0.72). The daytime temperature was inversely related to standing crop estimates (r^2 = 0.38). Physical variables had no apparent relationship with gill net captures [13, 103].

Of the 17 chemical variables measured six had more than 25% of the variation in the standing crop estimates. Iron content was directly related to the standing crop estimates accounting for the highest proportion of variation (r^2 = 0.93). The remaining influencing chemicals were nitrate, chloride, ortho-phosphate, free carbon dioxide and sulfate but all accounted only for a lesser amount by being inversely related to the standing crop estimates [13, 103].

Five chemical variables accounted for more than 25% of the variation in the gill net catches. Ammonia explained the largest proportion of variation with r^2= 0.77. Chloride, daytime oxygen, free carbon dioxide and ortho-phosphate were other variables which accounted for more than 25% of the variation in gill net catches and also in the previous standing crop estimates. However, chloride was inversely related to standing crop estimates and directly related to gill net catches. Daytime oxygen concentration was not an important variable in the standing crop estimates but was directly related to the gill net catches[13, 103].

From biological variables only three were ready for the comparison: combined weight of phyto- and zooplankton, numbers of phytoplankton and numbers of zooplankton per 0.01 ml. Combined plankton weight was inversely related to both standing crop estimates and gill net captures, against what we had expected. Phytoplankton numbers were positively correlated with the standing crop estimates but accounted only for five per cent of the variation. In the gill net catches phytoplankton numbers were inversely related, again differing from the expectations. Similarly, zooplankton numbers were inversely related to standing crop estimates against the expectations. In the case of gill net catches zooplankton numbers were directly related and accounted for 54% of the variation [13, 103].

It was concluded that even though the setting of the block net lasted less than five minutes, some of the larger fish species were frightened out of the area. So, large fish like Bocachico, Sabalo *Tarpon atlanticus*, Bagre pintado and Dorada *Brycon moorei* were often found only in the gill nets. Limnological variables made us believe that the unavailability of carbon could be one of the most important factors directly influencing fish production in this floodplain system. Support for this conclusion comes from the low concentration of bicarbonate in ciénaga water and that free carbon dioxide concentrations had an inverse relationship both with standing crop estimates (r = – 0.62) and gill net catches (r = – 0.52). Other chemical factors limiting biological production are phosphorus and nitrates, both of which played an expected inverse relationship with the standing crop estimates, r = – 0.65 and – 0.71 respectively. The phosphate relation with gill net catch was r = – 0.51. In addition, chloride could be mentioned among those substances indirectly affecting fish production. In this study r values were – 0.73 for gill net catches and – 0.66 for standing crop estimates [13, 103].

Standing fish stock estimates of the ciénagas of the Canal del Dique indicated clearly that the productivity appears to be relatively low. In the habitats of the Kafue River floodplain in Africa comparable to those investigated in Colombia much higher-standing crops were found [101, 104]. For example, in the vegetation habitat of the Kafue River floodplain in Zambia, the mean standing crop at low water was 879 kg/ha and at the high water 2682 kg/ha, as compared with 251 kg/ha from the ciénagas of the Canal del Dique during the rising water phase in August. In open waters, the Kafue had a high-water mean standing crop of 337 kg/ha and at the low water the fish mass was 575 kg/ha, whereas in the Canal del Dique, with water levels rising, the open water average standing crop was only 12 kg/ha [101,103,104].

8. UNIVERSITY LEVEL COOPERATION

The teaching and training of personnel at a professional level in the field of marine biology, fisheries biology and related sciences was in charge of "Jorge Tadeo Lozano" University of Bogotá. The Faculty of Marine Sciences was founded in 1962, and before 1973 it had produced more than 50 professionals in the different branches of fisheries sciences. Despite the boost given to aquaculture in the country, in 1973 there were no specific courses to prepare personnel in this field and therefore some of the biologists dedicated to this activity have had to specialize abroad. The University planned, however, to open after 1973 the specializations in limnology, inland fishing and aquaculture.

The University of Bogotá and the Government had an agreement to finance the degree theses for final-year students of the Faculty of Fisheries Sciences of the University, as long as the topics were of interest to the Government and had to do with the immediate development of inland fisheries and aquaculture. During the project, more than twenty theses have been financed. As part of the FAO/INDERENA cooperation, the author participated in the supervision and some field work four of these Master level theses the project counterparts presented between 1975 and 1977 [105-107].

8.1 First Colombian Trials to find New Native Species for Aquaculture

In 1972 when the FAO project was initiated aquaculture was practically a new and unexplored discipline. This phenomenon had been due to the discontinuity of the tasks that were being undertaken, the lack of coordination between the different national and international organizations that in one way or another carried out fish farming investigations, the limitations of human and financial resources necessary to carry out basic studies to develop the industry, and the lack of incentives to attract investors to the sub-sector. Since 1973, obstacles have been overcome and it was expected that in the future a decisive boost will be given to aquaculture development. Below are some native species which in 1973 were seen as possible candidates in aquaculture [2]:

Bocachico: *Prochilodus reticulatus magdalenae* is distributed in the basin of the Atrato, Magdalena and Sinú rivers, up to a height of 1,000 m above sea level (Fig. 4). This fish participates in migrations known as Subienda. During this period it enters the small tributaries of the aforementioned rivers, where they spawn when winter begins. The number of eggs per female is approximately 100,000. Fish farming development with the Bocachico especially in private farms has allowed acquiring information on its growth in closed environments without supplementary feeding. Under these conditions, production of 1,300 kg/ha/year has been achieved. Particularly Regional Autonomous Corporation of Valle de Cauca (CVC) has done experiments in Bocachico farming [108].

Fig. 4. Bocachico *Prochilodus reticulatus magdalenae*
Photo: A Zuluaga-Gómez/Wikimedia Commons

Because this species does not reproduce indoors, its induced reproduction – hypophysation – has been successfully experimented. Extracts of pituitary glands are injected into fishes that enable them to breed. Hormones such as gonadotrophins are employed in the process. Bocachico reaches sexual maturity at approximately 25 cm in size. Due to its abundance in times of Subienda migration, the practice of collecting them for lake ranching in controlled artificial or natural lagoons is spreading, to later capture them in periods of little fishing activity and sell them at a better price in the main markets.

Nicuro: *Pimelodus clarias* and Capaz *P. grosskopfii*, are species also known as Barbados. They are mainly distributed in the Magdalena River basin but also occur in the Eastern Plains, where they have been exploited and exported as ornamental fish. These species also participate in the Subienda upstream fish migration. As equivalent to the Channel catfish *Ictalurus punctatus* of the United States they represent a magnificent possibility to use them in intensive fish farming. Before 1973, some experiences were carried out on Barbados cultivation, mainly at the Research Station of the University of Córdoba. Reproduction in closed environments was not easy, but work is being done with hypophysitis. Ripe fish brooders are induced to breed in captivity by using pituitary gland extract to trigger spawning. Sexual maturity is reached at approximately 18 cm; they can likely be cultured in cages, using artificial feed pellets.

Capitán or Chimbe: *Eremophylas mutisii* is distributed in the cold climate regions of the country, especially in the Sabana de Bogotá. This species has been able to successfully resist the Rainbow trout competition. Capitán reaches up to 50 cm in length and its meat is truly excellent. Before 1973, attempts had been made to intensively cultivate this species, using natural and complementary feeding, at the Las Cintas biological fishing station, in the Department of Boyacá.

Pataló or Moreno: *Ichthyoelephas longirostris* is endemic to the Magdalena basin and reaches more than 50 cm in length. It is distributed in many tributaries of the Magdalena River, except the upper Cauca, where it has been practically exterminated. Its meat is excellent and comparable to that of Atlantic Salmon *Salmo salar*. In 1972, the basic information on its biology had been completed, to start experiments on its cultivation in controlled environments.

Mojarra amarilla: *Caquetaia kraussii* and **Mojarra negra** *C. umbrifera* are present in most of the lentic waters of Colombia, their meat is very fine and desirable. Although they sometimes reach considerable sizes (30 cm for the yellow mojarra and 50 cm for the black mojarra), their normal length is 20 cm. Being cichlids, they lend themselves to pond culture, but as in the case of Tilapia, their numbers need to be limited and their population controlled as they are very prolific. Promotion campaigns have been carried out for some time, especially in the northern parts of the country.

Sabaleta: *Brycon henni* is found mainly in the upper and lower Cauca and certain tributaries of it, and the San Jorge River. It reaches lengths of 35 cm and due to the quality of its meat and its eating habits, experiments have been carried out for its cultivation. Its distribution is limited to areas with a medium climate.

Dorada: *Brycon moorei* is distributed throughout the Magdalena system. It reaches sizes of 50 cm and weighs between 5 and 6 kg and the meat is highly prized. In 1973, its biological study was completed and the development of experiments has been scheduled to establish its potential as a species for intensive culture, especially in cages and using different diets.

Barbudo negro: *Rhamdia sebae* is abundant species in warm climates, widely accepted for the good flavour of its meat and the few amount of thorns. It can reach about 35 cm in length and its appearance is very similar to that of the Nicuro. It inhabits the Magdalena and Sinú Rivers and participates in the Subienda. The Black barbudo is omnivorous but with a carnivorous tendency. In 1973, the University of Caldas carried out some research on the possibilities for fish farming [109].

Guapucha: *Grundulus bogotensis* is distributed in the highlands of the eastern Cordillera, from the vicinity of Bogotá to the Department of Santander. It reaches a length of 8 cm and the way to use this species as a forage fish for trout has been studied.

Mullets: *Mugil* sp. are secondary freshwater species widely cultivated in several countries around the world. On the Caribbean coast, it occurs in large quantities, and therefore it has

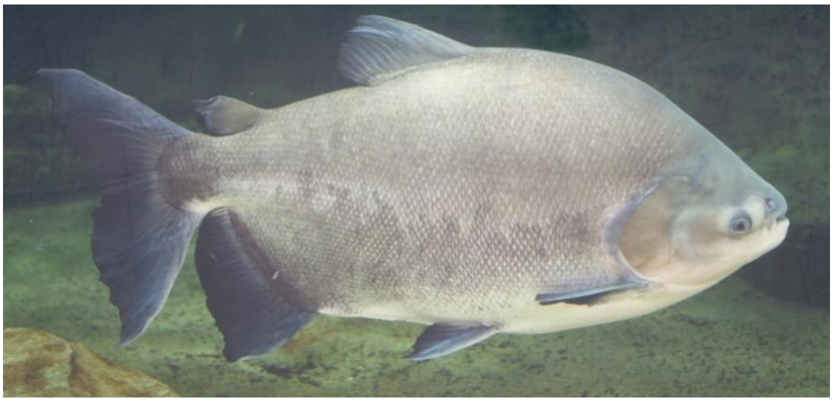

Fig. 5. Tambaqui *Colossoma macropomum*

Photo: Kinori/Wikimedia Commons

been the object of replanting, with considerable success. Sampling is currently being carried out in the Totumo pilot ciénaga to determine its growth, mortality, etc.

Freshwater shrimp: *Macrobrachium* sp. Due to its economic importance, a project tending to industrially produce freshwater shrimp is developed, based on the experiences that exist in several countries in this regard. Up to now, the investigations carried out are encouraging and therefore it is believed that this crop will represent, soon, a new source of protein and foreign currency for the Colombian people.

Pirarucú or Paiche: *Arapaima gigas* is a species present in the lower Caquetá, Putumayo and Amazonas basins proper. Perhaps it is the most important Amazonian species for Colombia and research on its cultivation started already in the 1970s with the initiation of aquaculture activities in the Leticia region. A long time before fish was produced by Peru, Ecuador and Brazil [2]. A new project exists in the Caquetá province where 300 fish farming families are raising pirarucú to be used as food fish for the Colombian domestic market [110].

Tambaqui: *Colossoma macropomum* is another species originating from the Amazon and Orinoco River basin (Fig. 5). It is a hardy fish that quickly grows to a large size meaning that even seasonal floodplain waters can be suitable for producing them and there is a huge potential for its cultivation on both a large and small scale. This species is now farmed across South and Central America, as well as in some countries in Asia. Aquaculture production has continued to increase – from 13,000 tons in 2000 to 142,000 tons in 2016 [111].

9. HISTORY OF THE ALIEN SPECIES IN COLOMBIAN AQUACULTURE

Rainbow trout: *Onchorhynchus mykiss* was introduced into the country in 1939 (100,000 embryonated eggs from California, USA) and were initially adapted successfully. Currently, the trout is distributed in the main lakes and streams with cold water (around 13°C). This species is of significant importance for sport fishing, as well as for the production of embryonated eggs, which are used for restocking in lakes and rivers, for export, and to supply private fish farms. The reproduction of this species occurs throughout the year, obtaining an approximate production of 5 million embryonated eggs in this period. The main problem the country had with intensive trout farming was the lack of adequate concentrated feed. However, currently (=1972), this stage has been passed and it is estimated that the volume of production will increase considerably shortly. There are clear indications of the dominance of trout over native cold-water species [2].

Tilapia: *Oreochromis mossambica* is a cichlid that was introduced into the country in 1959. Until now, fish farming carried out with these species has been called "agricultural" because its development is carried out at the level of smallholder farmers, especially in the Departments of Caldas, Risaralda and Valle. Their habitat is lentic and they can live without major problems between 14 and 30°C. They can survive for several hours at dissolved oxygen levels below 1 ppm. It is also known that tilapia species are euryhaline since they are capable of living and reproducing in both fresh and brackish waters of estuaries.

Professor Aníbal Patiño, together with biology students, has carried out some studies with *Coptodon rendalli* and with some native species in the University of Valley [2]. *Oreochromis mossambica* has restricted the promotion of *rendalli* to the areas where it currently exists, while its competitive capacity with the native species is not known in detail. One of the main problems of tilapia fish farming is represented by the lack of training of the farmers to handle it properly.

Despite the controversy in the advisability of carrying out alien introductions from other continents to the Magdalena River basin and other regions, INDERENA introduced Nile tilapia *Oreochromis nilotica* in 1979 to Colombia. This fish originates from Egypt, Israel and Syria [72]. Naturally, it was meant only for aquaculture but spread rapidly to many Ciénagas in the Departmento del Atlantico. It is almost a rule that introduced species will escape the confines of a facility, and therefore the introduction of aquatic organisms for aquaculture should be considered a purposeful introduction into the wild, even though the quarantine or hatchery facility may be a closed system [83].

Tucunaré: *Cichla ocellaris* is distributed in the Orinoco and Amazon River basins (Fig. 6). This species is known to spawn twice per year and prefers calm waters, with temperatures between 24 and 27°C. There are clear indications of its ability to vary those ecological systems where it is introduced. Its cultivation and promotion as a fish for fish farming are prohibited in the country [2]. Sport fishers have been accused that they have introduced this fish in the Magdalena basin [87].

Common carp: *Cyprinus carpio* is seen as harmful to Colombian ichthyofauna (Fig. 7). It is very little accepted species for consumption and its cultivation is prohibited in the country. However, some experiments have been carried out with selected monoculture and polyculture trials to determine the most advisable system for its use, since it is widespread in some regions of the country [2].

Brown trout: *Salmo trutta* has had only little success in Colombian waters, and it seems that it is only found in some lagoons in the centre of the country.

Black bass: *Micropterus salmoides* introduction into Colombian waters was not successful. A few years ago some specimens were reported in the Department of Caldas, but their existence in the region could not be confirmed [2].

Goldfish: *Carassius auratus* is of Asian origin **(**Fig. 8). Of its twelve varieties, five have been cultivated in the country. So far there is no inventory of its presence in natural environments. The reproduction of these individuals can be induced by temperature changes.

Mollienesias, pipones: *Mollienesias* spp. are originally from Asia. They are characterized by their eurythermy; they prefer alkaline waters with high hardness. Although they are omnivorous, their diet is preferably herbivorous. They are viviparous fish and have clear sexual dimorphism [2].

Guppy: *Poecilia reticulata* has been introduced into the country as an ornamental species and many varieties are being cultivated commercially. It has spread in many natural environments due to its insectivorous habits. The different varieties are identified in the male in terms of the shape of the tail, and receive names such as: "bandera", "espada", "lira", etc. They prefer temperatures between 22 and 23°C, although for their reproduction a temperature of 26°C with a slightly alkaline pH is advisable. At present, this species occupies a large part of the warm climate areas in the Hoya del Magdalena and the Departments of Cauca and Valle [2].

Green Swordtail: *Xiphophorus hellerii* and closely related southern platyfish or 'platy' *X. maculatus* are two exotic species of great acceptance in the national market. They have omnivorous eating habits and viviparous reproduction [2]. In several countries, swordtails and platys have caused ecological damage because of their ability to crossbreed and rapidly reproduce in high numbers (Fig. 9).

9.1 New Risky Alien

Since 2011 the farming of Basa fish *Pancasius bocourti* was initiated in Colombia in Cauca, Huila, Meta and Santander areas but soon invasive fish were reported also from natural waters like Carare River and Cienaga Guarinocito. There is a risk that this species will spread like fire in the Magdalena basin which resembles very much its original living conditions in the Mekong River [87].

Fig. 6. Tucunaré or peacock bass *Cichla ocellaris*

Photo: Karelj/Wikimedia Commons

Fig. 7. Common carp *Cyprinus carpio*

Photo: Bi-Jun Li/Wikimedia Commons

Fig. 8. Goldfish *Carassius auratus*

Photo: Dat Doris/Wikimedia Commons

Fig. 9. Green swordtail Xiphophorus hellerii. Red form of a male fish

Photo: Francesco Loda/Wikimedia Commons

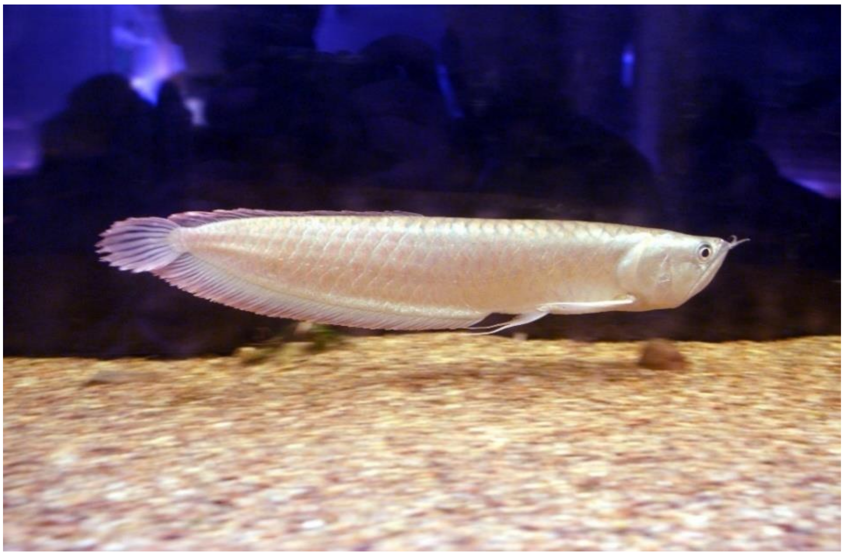

Fig. 10. Silver arowana *Osteoglossum bicirrhosum*

Photo: Homelka/Wikimedia Commons

9.2 Future of the Aquaculture Sector with new cooperation partners

Today, aquaculture production comes mainly from ponds and floating cage aquaculture systems, supplying more than 90% of the freshwater and saltwater organisms consumed in the country, where the production is based on tilapia (*O. niloticus and Oreochromis sp.*), trout (*Oncorhynchus mykiss*), cachama (*Colossoma macropomum*) and shrimp (*Penaeus vannamei*). The fresh review concluded that Colombia has all the potential to develop tropical aquaculture, which should focus on native fish breeding, genetic improvement, high-tech aquaculture systems, agro-industrial and fish biomass development valorisation [4].

9.3 Colombian Aquaculture Research Centre (CENIAQUA)

Nowadays more than before scientific research is essential to lead the country in the field of aquaculture development. Therefore, fish farms must collaborate with local universities and research institutes like the Colombian Aquaculture Research Centre (CENIAQUA) and, the Institute of Marine and Coastal Research

(INVEMAR) to explore the reproductive biology of potential high-value aquaculture species. The government has invested in the genetic improvement of *P. vannamei* shrimp and tilapia. After the introduction of more diverse germplasm, breeding programmes must progress faster. There are two production technologies with a promising future for aquaculture such as complete recirculation systems (RAS) and open sea culture. Despite Colombia being the first Latin American country to adopt a circular economy strategy, the productive sector with the guidance of the academic and governmental actors should make efforts to translate the strategy and research into operational plans [4].

Aquaculture production increased almost three-fold between the mid-1990s and 2013, reflecting global trends. In 2013 aquaculture produced almost 88,000 tonnes of fish for local consumption and export and in 2014 already 100,000 tonnes [112]. The same trend seems to continue as in 2020 total aquaculture production in Colombia was already 179,351 tonnes and in the next year 192,521 tonnes, the annual growth rate being 7.3 per cent [113]. The sector is largely dominated by inland freshwater pisciculture and small-scale farmers produce about a third of the total volume. Three species account for the bulk of production: Silver and Red tilapia contribute around two-thirds of the total volume, while Rainbow trout and Pirapitinga and Tambaqui each account for around 13% [87, 94].

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 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 [2].

The contribution of fisheries and aquaculture to GDP in Colombia is relatively small. The sector represented less than 0.25% of GDP in 2012 [94]. 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. In 2013, the inland ornamental fish catch was estimated to be USD 12.5 million [112]. The value of aquaculture production was approximately USD 222 million in 2011, while in 2021 it was already 414 USD million, in both years tilapia accounted for more than 60% [5,114].

9.4 Ornamental Fish Farming and Trade

The ornamental fish trade started during the 1950s [115]. First, the trade of ornamental fish was mainly the extraction of individual species of fresh water, which generated imbalances in the natural populations and deteriorated aquatic ecosystems. International pressure to stop the commerce of wild-caught fish intensified but ornamental fish culture and trade have still some importance in the Amazon basin countries. The three biggest producers and exporters of ornamental fish are Brazil, Colombia and Peru and the majority of species traded are wild-caught fish from the Amazon [116-118].
Bacterial diseases have been a persistent problem in the ornamental fish industry in South America and a valid concern was raised, mainly in developed countries, that this trade risks spreading diseases worldwide when millions of ornamental fish cross borders and continents every day [119]. During shipment and at holding facilities ornamental fish are affected by bacterial and mycotic infections, as well as parasitic infestations associated with protozoans and metazoans. several groups of bacteria are responsible for the diseases and the onset of bacterial diseases often occurs when the fish are in the exporter’s establishments. A pioneer of ornamental fish diseases in South America is Dr. David Conroy who from 1973 to 1978 led a project to characterise, prevent and control diseases in ornamental fish, involving the cooperation of Colombia, Peru and Venezuela. He was also shortly the FAO Project Manager in our Colombia project [120], making Colombia one of the leading countries to prevent and control diseases in ornamental fish. During this work, several treatments and substances were evaluated and all of them were reported to have a good but variable rate of success in diminishing mortalities [120-124].

There is not much information on the recent numbers of ornamental fishes captured or produced in Colombia but the work of NJ Mancera-Rodríguez and R Álvarez-León [117] offers an investigated view on the trade of ornamental fish in the country. It is approaching the topic from the development that has had its productive activity and extractive use, as well as the dynamics of its legal and illegal trade in Colombia. According to the Incoder exports made during 2004 were 26.6 million units of individuals alive which represented an entrance of foreign currencies of 7.3 million US$, and in 2.005 were of 29.5 million units of individuals alive which brought an entrance of foreign currencies of 6.3 million US$. The main exported species are the cardinal tetra *Paracheirodon axelrodi*, the neon tetra *P. innesi*, 22 species of the freshwater catfish *Corydoras* sp., 32 species of the armoured catfish (cuchas), the planet catfish (otocinclo) *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 [112]. In 2013, the inland ornamental fish catch was estimated to be USD 12.5 million [112] already two times that of 2005 (see above). 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 [125].

Still, 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. Colombia has proven this by turning ex-coca farmers into ornamental fish breeders [110]. This is a positive social development in a country, where coca farming was the region's number one economic activity. Fish farming in Florencia, the Capital of Caqueta province, is focusing on the silver arowana *Osteoglossum bicirrhosum* a highly wanted species in China where it is called a dragonfish and nine of them in the aquarium is seen as a sign of good luck for the owner (Fig. 10). 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 [110]. Even the Ministry of Agriculture experts agree that fish deserve a lot more attention than they get in Colombia and now the governor aims to use some 2.4 million USD of state funds to subsidize the export of up to one million arowana fish to Asia [110]. Local NGO, 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 (many due to 50 years of armed conflict!) who have aquaculture as an economically, socially and environmentally sustainable alternative [126]. 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 [126].

9.5 New Fisheries Administration

The potential for sustainable and inclusive growth of the sector has been recognised by the Colombian government, which has put fisheries and aquaculture high on its political agenda and worked to improve the institutional and legal framework in which the sector operates. The Directorate of Fisheries and Aquaculture (DPA) was created within MADR with Decree 4909 of 2007, as the highest entity responsible for formulating fisheries and aquaculture policies; promoting sustainable resource use; and concluding cooperation agreements with public or private, national or foreign agencies for the strengthening of the sector. In 2011, a new executive agency was created, the National Authority for Fisheries and Aquaculture (*Autoridad Nacional de Acuicultura y Pesca*), and currently two laws are being drafted that will improve institutional mandates to regulate fisheries sustainably, and strengthen the judicial and administrative penal procedures related to illegal fishing. These two priorities were identified through a comprehensive process of stakeholder consultation. In 2018, Colombia established the National Committee in charge of incidental catches [5].

National Statistics Agency (DANE) certifies now the operation of the Colombian Fisheries Statistical Service (SEPEC) of which the National Aquaculture and Fisheries Authority (AUNAP) is in charge as a part of the national statistical system and including "the estimation of artisan volumes landed in fishing sites" within the framework of the standard [5].

Other new research institutions are the Colombian Corporation for Agricultural Research (CORPOICA), a mixed private-public scientific and technological research organisation related to MADR, the Research Institute of Biological Resources "Alexander von Humboldt" (IAvH), the Institute of the Pacific Environmental Research "John von Newman" (IIAP), the Amazonia Institute of Scientific Research (SINCHI) and the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM). The Colombian Institute of Farming (ICA) is in charge of the surveillance and control of health, biological and chemical risks to animal and plant species. It also issues sanitary and phytosanitary regulatory measures.

In 1977 I wrote that Colombia would benefit from Fisheries Cooperatives [91]. Nowadays the country counts about 1200 cooperatives and associations of which about a third of Colombian fishers are members [87,112]. For aquaculture, there are several regional and two national private organisations (FEDEACUA, which brings farmers together, and ACUANAL, which brings shrimp producers together).

10. DISCUSSION AND CONCLUSIONS

In the Magdalena floodplain from the bay and vegetation habitats in four floodplain lakes the average standing crops were 118 and 251 kg/ha while the open water average was only 12 kg/ha, which is very low production in global terms [104]. Since 2008 aquaculture has produced more than capture fisheries and the Amazon region's annual catch has recently been estimated to be considerably higher than previously thought, at least 15,000 tons annually [95].

It is important to note that there is a population of approximately 200,000 fishermen in the country, that is, close to 0.8 per cent of the current population and 7.5 per cent of that employed by the agricultural sector. On the other hand, about 1 million people live directly or indirectly from fishing. There is currently a growing interest in increasing the export of red meat, but to achieve this successfully, the development of fishing as a source of supplementary animal protein has been thought of.

Because of their variety, dispersion, and social complexity, small-scale fisheries are often poorly documented and poorly regulated, and many of the complex management issues remain largely unresolved [127]. For instance, the statistical volume Colombia, Fishing in Numbers 2014 [94], which was meant to be a reference document for policymakers, did not contain information on the contribution of different sub-sectors (artisanal vs. industrial, aquaculture vs. fishing and different species) to employment and income generation, and little was known about their profitability and competitiveness [128]. Nor was there any information on the status of resources. Improving access to information on fish stocks and ecosystems that are collected by different research centres and not directly by the AUNAP is needed in particular. Such information is difficult to find, scattered in a large number of technical documents accessible from different sources [9].

Already in 1972, the fishing productivity of the Magdalena and Sinú systems had decreased sharply due to meteorological variations, the use of irrational capture methods [for example, the use of barbasco (=a plant *Deguelia rufescens ururu* used as a fish poison for fishing), dynamite or inadequate gear], the environmental deterioration caused by erosion, water pollution and large fluctuations in the level of our main rivers favoured by deforestation. All of the above obliged the Government to think about proper management of the main basins and orderly development of aquaculture that allowed the restoration of the prevailing conditions until a few years ago and increased the protein sources of the Colombian people [2].

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. However, recent Government and NGO projects turning ex-coca farmers into ornamental fish breeders is a positive social development [126].

The Colombian government has put fisheries and aquaculture high on its political agenda to increase the growth of the sector, and it has worked to improve the institutional and legal framework in which the sector operates. Within MADR a new Directorate of Fisheries and Aquaculture (DPA) was created in 2007 and in 2011 a new executive agency was created, the National Authority for Fisheries and Aquaculture (*Autoridad Nacional de Acuicultura y Pesca*). The end of the 50 years' civil war should help the new entities in formulating better fisheries and aquaculture policies; promoting sustainable resource use; and concluding cooperation agreements with public or private, national or foreign agencies for the strengthening of the sector.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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