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TILAPIA AQUACULTURE IN MEXICO: ASSESSMENT WITH A FOCUS ON SOCIAL AND ECONOMIC PERFORMANCE

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TILAPIA AQUACULTURE IN MEXICO: ASSESSMENT WITH A FOCUS ON SOCIAL AND ECONOMIC PERFORMANCE

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PREPARATION OF THIS DOCUMENT

This document is a technical report under the FAO Fisheries and Aquaculture Department's World Aquaculture Performance Indicators (WAPI). The goal of the report is to provide a comprehensive and balanced assessment of the technical, economic and social dimensions of tilapia farming in Mexico with a focus on its socio-economic impacts. The document is based on local data and information (including field data) provided by government agencies and aquaculture experts in Mexico and incorporates the latest FAO statistics on global aquaculture production, fisheries commodities trade and apparent fish consumption. The document follows the structure of two previous FAO publications: one on tilapia farming in five African countries (i.e. FAO Fisheries and Aquaculture Circular No. 1130) and the other on tilapia farming in Brazil (i.e. FAO Fisheries and Aquaculture Circular No. 1181).

The report was prepared by three aquaculture experts in Mexico (Francisco Javier Martínez-Cordero, Soledad Delgadillo Tiburcio and Edgar Sanchez-Zazueta) and an FAO Aquaculture Officer (Junning Cai). Pablo Rivera and Edmundo Urcelay are acknowledged for their contribution to some contents of the document. Javier Albores Peralta, Gerardo Vírgen, and Jorge Peláez are acknowledged for providing important data and information to the document. Food distributors of the company VIMIFOS are acknowledged for sharing information through different surveys. The Technical Committee on the FAO Special Programme for Food Security (PESA) in Central America is acknowledged for supporting the work with resource-limited fish farmers in the states of Chiapas, Oaxaca and Puebla. Giovanni Fiore-Amaral, Antonio Garza de Yta, Weimin Miao and Xinhua Yuan are acknowledged for their highly valuable review of the document. Maria Giannini and Marianne Guyonnet are acknowledged for their assistance in editing and formatting.

ABSTRACT

The world tilapia aquaculture production grew from 380 000 tonnes in 1990 to 6 million tonnes in 2018, making it the fourth-largest species group in global aquaculture. Tilapias are the second-largest species group in Mexico's aquaculture with its 53 000 tonnes of production contributing to around 20 percent of the 247 000 tonnes of total aquaculture production in 2018. Mexico is the second-largest tilapia capture fisheries country, and its 116 000 tonnes of tilapia capture fisheries production in 2018 was primarily contributed by culture-based fisheries. Mexico is the second-largest international market for tilapia products, and the 228 000 tonnes live weight equivalent of its tilapia import in 2018 was higher than its domestic production. The average per capita apparent tilapia consumption in Mexico was 3.08 kg (around one fifth of its total fish consumption) in 2018, which was much higher than the 0.9 kg world average. This document assesses tilapia farming and the value chain in Mexico by examining tilapia farming systems and practices, dissecting the tilapia value chain, evaluating the sector's social and economic performance, discussing the impacts of proper governance and institutions on the sector development, and highlighting potentials, issues, constraints and challenges in the development of tilapia farming or aquaculture in general. The document ends with a brief discussion of the impacts of the ongoing coronavirus disease (COVID-19) pandemic on the tilapia industry in the country.

CONTENTS

ABBREVIATIONS AND ACRONYMS

AHC	Aquaculture Health Committee
AREL	resource-limited aquaculture
CEIEGT	Research center for research, extension and teaching of tropical livestock
CETMX	Entrepreneurial Council of the Mexican Tilapia
CONACYT	National Council of Science and Technology
CONAFAB	National Council of Balanced Feed Manufacturers and Animal Nutrition A.C.
CONAGUA	National Water Commission
CONAPESCA	National Commission of Aquaculture and Fisheries
COVID-19	coronavirus disease 2019
CP	crude protein
EIA	environmental impact assessment
FAO	Food and Agriculture Organization of the United Nations
FCR	feed conversion ratio
FIRA	Agriculture-related Trust Fund
FMVZ	Faculty of veterinary medicine and zootechnics (UNAM)
GIFT	genetically improved farmed tilapia
HS	Harmonized Commodity Description and Coding Systems
IAS	invasive alien species
INAPESCA	National Institute of Fisheries and Aquaculture
LGPAS	General Law of Sustainable Fisheries and Aquaculture
LNV	La Nueva Viga
MIPYME	micro, small and medium enterprises
NDP	national development plan
nei	not elsewhere included
PESA	Special Programme for Food Security – FAO Mexico
RTM	Tilapia Mexico Network
SADER	Secretary of Agriculture and Rural Development
SEMARNAT	Secretariat of Environment and Natural Resources
SENASICA	National Agro-Alimentary Health, Safety and Quality Service
SPC	System Product Committee
STI	science, technology and innovation
UNAM	National Autonomous University of Mexico
UPA	aquaculture production unit
WAPI	World Aquaculture Performance Indicators

1. INTRODUCTION

The world production of farmed and wild tilapias and other cichlids (tilapias in short) [1] increased 7.6 percent a year, from less than 900 000 tonnes in 1990 to nearly 7 million tonnes in 2018 (FAO, 2020a, p. 6). Aquaculture was the main driving force behind the impressive growth, with the share of aquaculture in the total world tilapia production increasing from 43 percent to 88 percent between 1990 and 2018 (FAO, 2020a, p. 7).

According to FAO statistics, the world tilapia aquaculture production grew 10.4 percent a year, from around 380 000 tonnes in 1990 to 6 million tonnes in 2018 (FAO, 2020b). Tilapias, the fourth-largest species group in the world aquaculture production in 2018, have been widely farmed in over 120 countries or territories worldwide (FAO, 2020c; 2020d). Asia is the largest tilapia farming region, accounting for 68.8 percent of the 6 million tonnes of the world tilapia aquaculture production in 2018, followed by Africa (21.8 percent) and the Americas (9.3 percent) (FAO, 2020a, p.11).

While the 6 million tonnes of the world tilapia aquaculture production in 2018 was contributed by 17 tilapia species items, Nile tilapia (*Oreochromis niloticus*) has been the dominant species in tilapia aquaculture.[2]

Mexico is the fourth-largest aquaculture country (following Ecuador, Brazil and Chile) in Latin America and the Caribbean (FAO, 2020e). Its 0.22 percent share of the world aquaculture production in 2017 (0.14 percent and 0.28 percent for inland and marine/coastal aquaculture, respectively) was less than its 1.46 percent share of world land area; 0.46 percent share of world inland water surface area; 1.16 percent share of world coastline length; 0.84 percent share of world total renewable water resources; and 1.65 percent share of world population (FAO, 2019, p.78).

Mexico's 247 000 tonnes of aquaculture production in 2018 comprised 22 ASFIS – Aquatic Sciences and Fisheries Information System – species items,[3] with whiteleg shrimp (*Penaneus vannamei*) and tilapias being the two largest species items accounting for, respectively, 64 percent and 21 percent of the total production (Table 1). Other major species or species groups included rainbow trout, Pacific bluefin tuna (nearly 20 percent of the world production), oysters, common carp, catfishes, clams, largemouth black bass, and Jacks, crevalles nei (Table 1).

According to the national statistics, Mexico produced around 168 000 tonnes of tilapias, most of which came from capture fisheries. Indeed, the 116 000 tonnes of capture fisheries (including wild and culture-based fisheries) tilapia production in 2018 was the second largest in the world next only to Egypt, which reflects Mexico's conducive natural environment for tilapia growth. It is worth noting that Nile tilapia (the main tilapia species in both countries) is native in Egypt yet an introduced species in Mexico.

Mexico's 53 000 tonnes of tilapia aquaculture production in 2018 was the thirteenth highest in the world accounting for 0.87 percent of the 6 million tonnes of world production. Yet the 26 percent annual growth of its tilapia aquaculture production between 2010 and 2018 was one of the highest among the top 20 tilapia farming countries/territories, and the share of tilapias in its total aquaculture production tonnage increased from 6.5 percent to 21.3 percent during the period (FAO, 2020a, p.12).

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[1] Unless specified otherwise, in this document tilapias broadly cover all cichlids from the family Cichlidae.

[2] According to FAO statistics (FAO, 2020b), Nile tilapia contributed to 75 percent of the world tilapia aquaculture production in 2018. Yet the actual ratio could be much higher because the species item "Tilapia nei" (17 percent of the world production) was primarily Nile tilapia.

[3] ASFIS species items could refer to either individual species, hybrids or groups of related species, such as families (when identification to species is impossible). More information about the ASFIS list of aquatic species can be found at www.fao.org/fishery/collection/asfis/en

Table 1. Top 10 species or species groups in Mexico's aquaculture, 2018

Species or species groups	Aquaculture production (tonnes)	Share of Mexico's aquaculture production of all species (%)	Share of world production of the same species or species group (%)
1. Whiteleg shrimp (*Litopenaeus vannamei*)	157 934	63.88	2.63
2. Tilapias	52 748	21.34	0.87
3. Rainbow trout (*Oncorhynchus mykiss*)	10 440	4.22	0.29
4. Pacific bluefin tuna (*Thunnus orientalis*)	9 352	3.78	19.96
5. Oysters[a]	8 340	3.37	0.14
6. Common carp (*Cyprinus carpio*)	4 272	1.73	0.01
7. Catfishes[b]	1 848	0.75	0.03
8. Clams, etc. nei[c]	990	0.40	0.02
9. Largemouth black bass (*Micropterus salmoides*)	597	0.24	0.08
10. Jacks, crevalles nei (*Caranx* spp.)	240	0.10	0.08
Others (10 species)	*463*	*0.19*	*n.a.*
All (22 species)	**247 222**	**100.00**	**0.22**

Source: FAO (2020d, p. 114) with minor modification.
Notes: [a]Including two species: Pacific cupped oyster (*Crassostrea gigas*) and Cortez oyster (*C. corteziensis*). [b]Including two species items: channel catfish (*Ictalurus punctatus*) and catfishes nei (*I.* spp.). [c]A species item under the ISSCAAP – International Standard Statistical Classification of Aquatic Animals and Plants – group "clams, cockles, arkshells". nei = not elsewhere included.

Mexico has great domestic and foreign market potential for tilapia aquaculture. Mexico is one of the most populated countries with a growing population expected to increase from 129 million in 2020 to 141 million in 2030 and to 155 million in 2050 (United Nations, 2019). Its per capita fish consumption (14.7 kg in 2017) was lower than the world average of 20.3 kg (FAO, 2020f). Mexico imported around 86 000 tonnes of tilapia products in 2018 (FAO, 2020g). Composed primarily of tilapia fillets, the live weight equivalent of the import was 228 000 tonnes,[4] which was greater than the country's 168 000 tonnes of tilapia production in 2018. Mexico is next to the United States of America, which is the largest international tilapia market, importing nearly 200 000 tonnes of tilapia products (nearly half million tonnes live weight equivalent) in 2018 (FAO, 2020g). However, Mexico exported only around 3 000 tonnes (7 000 tonnes live weight equivalent) of tilapia products in 2018 (FAO, 2020g).

The tropical climate in Mexico is suitable for tilapia farming. Brackish-water lagoons along Mexico's long coastline also provide suitable sites for tilapia farming. With great demand- and supply-side potential, tilapia aquaculture in Mexico has ample room to expand. This paper attempts to examine the status and trends of tilapia aquaculture in Mexico, assess its social and economic performance, and discern a road map for future development. Section 2 provides an overview of tilapia production and value chain in Mexico, followed by a detailed examination of the technical aspects in section 3, the economic and social performance in section 4, and the governance and institutional aspects in section 5. The last section (section 6) concludes the paper with an estimation of the growth potential of tilapia aquaculture in Mexico, highlights of challenges and the way forward, and discussion of the impacts of the ongoing coronavirus disease 2019 (COVID-19) pandemic on the tilapia industry in the country.

[4] The method used to estimate the live weight equivalent of tilapia products is explained in section 2.4.

2. OVERVIEW OF TILAPIA PRODUCTION AND VALUE CHAIN IN MEXICO

2.1 Capture fisheries tilapia production

The construction of large dams and reservoirs in Mexico for flooding control, irrigation and hydroelectric power in the 1930s has motivated the introduction of tilapias as a potential fisheries resource to address the shortage of land for crops and livestock production.

In the mid-1960s, three tilapia species (*Oreochromis aureus*, *O. mossambicus* and *Tilapia melanopleura*[5]) were introduced from Auburn University (United States of America) and stocked in the President Miguel Aleman dam in Temascal Oaxaca, one of the largest reservoirs in Mexico (Morales, 1976). Compared to carnivorous native cichlids called "mojarras" (e.g. *Petenia splendida,* aka "Tenhuayaca", and *Cichlasoma urophthalmus,* aka "Castarrica"; Plate 1), the introduced tilapia species have the advantage of being opportunistic omnivorous, with an extremely versatile diet that includes planktons, and reproduce at a faster rate.

Plate 1
A native cichlid species in Mexico: *Petenia splendida*, aka "Tenhuayaca"

© S. Delgadillo

With efforts in governance, research and extension from multiple government organizations, such as the Papaloapan River Commission (CP) (1947–1985), the National Fisheries Consultant Commission (Comisión Nacional Consultiva de Pesca; CNCP), the National Biofisheries Research Institute (Instituto de Investigaciones Biológico Pesqueras, 1962-1970; Guzmán del Proo, 2012), SEPESCA (Ministry of Fisheries; currently the National Commission of Aquaculture and Fisheries– CONAPESCA) and Tropical Aquaculture Station (EAT; Plate 2), tilapias have become the largest fisheries resource in Mexico's inland waters since the 1970s.

According to the estimation of the National Water Commission (CONAGUA), nearly 200 dams with the maximum capacity of around 130 billion m³ are able to stock tilapias for commercial and recreational fishing to provide high-quality protein to the Mexican people (CONAGUA, 2017). However, proper studies of carrying capacity are needed to determine the feasibility and extent of cultured-based tilapia fisheries.

Although tilapia capture fisheries production in Mexico declined from 93 000 tonnes to 72 000 tonnes between 1990 and 2005, it rebounded and increased to 116 000 tonnes in 2018. Most of the production was contributed by culture-based fisheries (i.e. harvesting tilapias artificially stocked in waterbodies) with a relatively small amount of wild tilapia production (Figure 1).[6]

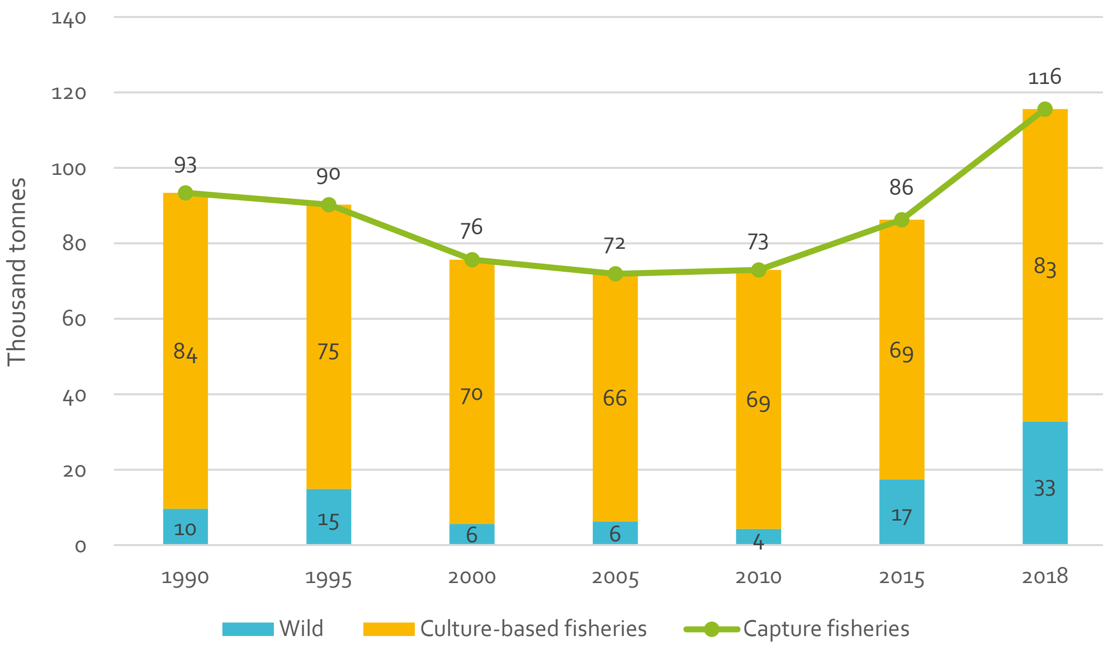
[5] More recent scientific name of this species (i.e. redbelly tilapia) is *Tilapia zillii* or *Coptodon zillii*.

[6] The Mexican national statistics (CONAPESCA, 2020) are used here to distinguish between culture-based fisheries and wild tilapia production. While culture-based tilapia fisheries production is categorized under aquaculture in the Mexican national statistics, the document here follows the categorization used in the FAO statistics (FAO, 2020b) to categorize it under capture fisheries.

Plate 2

Tropical Aquaculture Station (EAT) established in 1972 not only for tilapia aquaculture but also for the farming of native species such as turtles, bull frogs, crocodile and prawn in Mexico

Figure 1: Tilapia capture fisheries production in Mexico, 1990–2018



Source: CONAPESCA (2020).
Note: See footnote 6.

Overfishing was one factor behind the decline in the tilapia capture fisheries production in Mexico. With three fisheries cooperatives legally established and fishing rules (e.g. the minimum mesh size of 14 cm for gillnets used for tilapia fishing) stipulated notwithstanding, the population of large-size tilapias in Mexico's inland waters was gradually depleted, which led to the reduction of mesh size from 14 cm to 12 cm to 9 cm and the drop of average catching size from 800 g to 300 g.

Besides human factors, the lack of knowledge and understanding of the carrying capacity of the waterbodies has been a technical factor that has contributed to the overfishing problem. The situation has also been aggravated by other technical factors, such as (i) hybridization among tilapias (e.g. *Oreochromis aureus* × *O. mossambicus* or *O. niloticus* × *O. aureus*), which tends to hinder tilapia reproduction (Delgadillo and Morales, 1975; Asiain Hoyos, 2009); (ii) bird predation (Chávez, 1981; Cruz Beltrán, 1981); (iii) diseases caused by parasites such as leeches and worms; and (iv) fish predators, including local mojarras such as *Petenia splendida*, aka "Tenhuayaca" and *Cichlasoma urophthalmus,* aka "castarrica", which may be initially brought in to control the population of introduced tilapia species.[7]

The problem of overfishing was mitigated by the Official Mexican Norm NOM-060-SAG/PESC-2014 on fisheries, which regulates the characteristics of nets allowed to be used in tilapia fisheries (including native cichlids "mojarras") in all lakes and dams/reservoirs, i.e. they must be gillnets made of 0.3 mm twine or nylon and with a minimum mesh opening of 101.6 mm (4 inches), maximum length of 50 m and maximum high of 5 m (DOF, 2016a).

The public effort in restocking has been the main driving force of capture fisheries tilapia production in Mexico. In 1980, tilapia was included in the national programme on the Mexican Feeding System "SAM" (Sistema Alimentario Mexicano), together with other freshwater species, such as carps (*Ctenopharyngodon idella*, *Hypophthalmichthys molitrix*, *H. nobilis* and *Cyprinus carpio*) in the central Mexican states; catfish (*Ictalurus punctatus*) in the northern states; and trout (*Oncorhynchus mykiss* and *Salvelinus fontinalis)* in the highlands. The programme helped establish a number of government-run hatcheries to supply fingerlings for restocking, which has sustained the culture-based tilapia fisheries. Yet the resulting low market prices of wild tilapias (often viewed as an unfair competitive advantage thanks to government support in restocking) has been a key factor hindering investments in commercial tilapia farming.

[7] Native mojarras (e.g. *C. urophthalmus,* aka "castarrica", and *C. phenestratum,* aka "paleta") coexist with non-native tilapias in natural and artificial waterbodies and contribute to the tilapia production recorded in the national statistics.

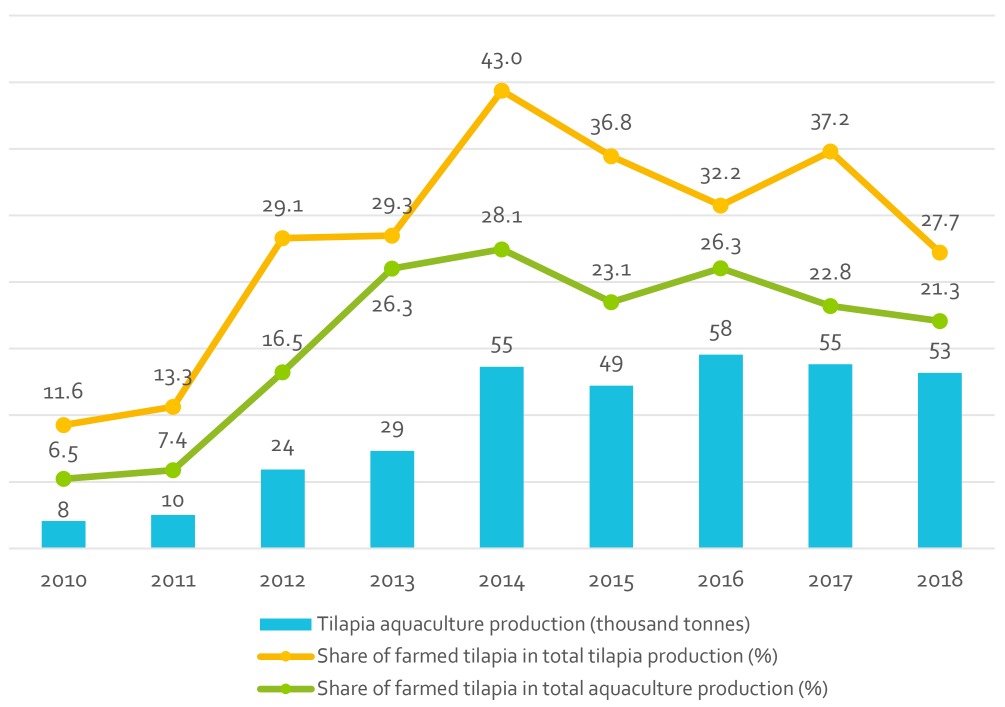
2.2 Tilapia aquaculture production

Tilapia aquaculture production in Mexico was under 10 000 tonnes in most years before 2010. Production rapidly increased in the first half of the decade, from around 8 000 tonnes in 2010 to around 55 000 tonnes in 2014; the share of aquaculture in the country's total tilapia production increased from 11.6 percent to 43 percent; and the tilapia share in its total aquaculture production increased from 6.5 percent to 28.1 percent (Figure 2).

One key driving force behind the surge was big investment in cage tilapia farming by a large commercial farm (i.e. Regal Springs Acuagranjas Dos Lagos SA de CV). The collapse of shrimp farming because of disease outbreaks in the early 2010s also motivated shrimp farmers to farm tilapias as an alternative species and as a means to improve water quality and enhance the resistance of shrimps against viral diseases through the beneficial effect on the ecology of polyculture (Hernández-Barraza *et al*., 2012). A similar experience occurred in Ecuador, where export-oriented tilapia aquaculture expanded significantly following the collapse of shrimp farming in 1995 due to disease outbreaks (FAO, 2005).

Tilapia aquaculture production in Mexico remained stagnant in the second half of the 2010s with a decline in the share of aquaculture in the country's total tilapia production as well as the share of tilapia in its total aquaculture production (Figure 2).

Figure 2: Tilapia aquaculture production in Mexico, 2010–2018



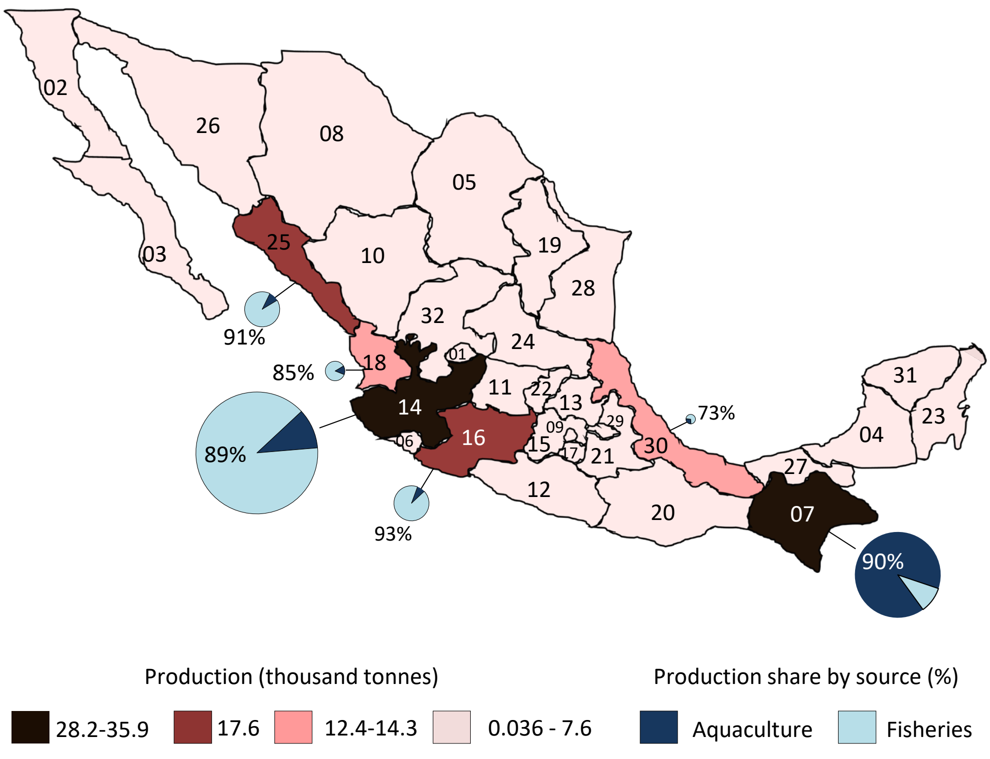
Source: FAO Global Fishery and Aquaculture Production Statistics v2020.1.0, published through FishStatJ (March 2020). www.fao.org/fishery/statistics/software/fishstatj/en
Note: FAO statistics on tilapia aquaculture production in Mexico are consistent with the national statistics, yet there are discrepancies on tilapia capture fisheries production. Thus, the shares may differ from those calculated based on the national statistics.

Tilapias are produced in all the 31 states of Mexico and Mexico City. The top six states with the largest tilapia production accounted for three quarters of Mexico's 168 000 tonnes of total tilapia production in 2018, including (the states of) Nayarit (#18) and Sinaloa (#25) in the northwestern region, Jalisco (#14) and Michoacán de Ocampo (#16) in the central-western region, and Veracruz de la Llave (#30) and Chiapas (#07) in the southeastern region (Figure 3; Table 2). Tilapia production in five of the six states primarily came from capture fisheries, whereas Chiapas (#07) was the only exception with 90 percent of its tilapia production in 2018 coming from aquaculture.

Chiapas (#07) is the largest tilapia farming state with around 25 000 tonnes of production, accounting for nearly half of Mexico's tilapia aquaculture production in 2018 (Table 2; Figure 3). Most of the tilapia aquaculture production in Chiapas (#07) is contributed by Regal Springs (Acuagranjas Dos Lagos SA de CV).

According to the national statistics, aquaculture accounted for only 31 percent of Mexico's total tilapia production in 2018,[8] it was the main source (i.e. over 50 percent) of tilapia production in eight states (Table 2).

Figure 3: Subnational distribution of tilapia production in Mexico, 2018



Source: CONAPESCA (2020).
Notes: See Table 2 for detailed information. Pie charts illustrate the aquaculture share of tilapia production in the top six states with the largest total tilapia production.

[8] The share is slightly different from that shown in Figure 2, which was calculated from FAO statistics.

Table 2: Subnational distribution of tilapia aquaculture and fisheries production in Mexico, 2018

ID #	State (ranked by tilapia aquaculture production)	Tilapia aquaculture production			Tilapia aquaculture and capture fisheries production	
		Tonnes	Share in Mexico's total (%)	Share in the state's total tilapia production (%)	Tonnes	Share in Mexico's total (%)
7	Chiapas	25 455	48.26	90.17	28 230	16.77
14	Jalisco	3 811	7.23	10.62	35 887	21.32
30	Veracruz de Ignacio de la Llave	3 402	6.45	27.46	12 386	7.36
27	Tabasco	2 899	5.50	38.05	7 620	4.53
4	Campeche	2 668	5.06	91.32	2 922	1.74
18	Nayarit	2 091	3.97	14.63	14 292	8.49
26	Sonora	1 655	3.14	85.69	1 931	1.15
25	Sinaloa	1 606	3.04	9.15	17 553	10.43
15	México	1 540	2.92	31.13	4 948	2.94
16	Michoacán de Ocampo	1 312	2.49	7.45	17 615	10.46
21	Puebla	1 173	2.22	99.53	1 179	0.70
12	Guerrero	1 026	1.94	18.08	5 674	3.37
31	Yucatán	847	1.61	89.70	944	0.56
24	San Luis Potosí	723	1.37	44.38	1 628	0.97
28	Tamaulipas	579	1.10	15.95	3 633	2.16
20	Oaxaca	414	0.79	37.90	1 093	0.65
6	Colima	329	0.62	34.70	947	0.56
17	Morelos	241	0.46	66.08	365	0.22
23	Quintana Roo	162	0.31	75.44	215	0.13
22	Querétaro	161	0.30	33.54	479	0.28
13	Hidalgo	150	0.28	3.37	4 457	2.65
19	Nuevo León	106	0.20	48.84	217	0.13
10	Durango	88	0.17	22.38	392	0.23
32	Zacatecas	77	0.15	4.06	1 900	1.13
11	Guanajuato	68	0.13	11.06	616	0.37
8	Chihuahua	55	0.11	28.34	196	0.12
29	Tlaxcala	53	0.10	100.00	53	0.03
1	Aguascalientes	38	0.07	31.70	119	0.07
5	Coahuila de Zaragoza	16	0.03	9.43	166	0.10
3	Baja California Sur	3	0.01	0.50	668	0.40
2	Baja California	-	-	-	36	0.02
	Mexico	**52 748**	**100.00**	**31.33**	**168 359**	**100.00**

Source: CONAPESCA (2020).
Notes: See the geographic location of each state in Figure 3. Tilapia production from culture-based fisheries is categorized as capture fisheries production. The 31.33 percent share of aquaculture in Mexico's total tilapia production is slightly different from that shown in Figure 2, which is calculated from FAO statistics.

2.3 Tilapia trade

Import

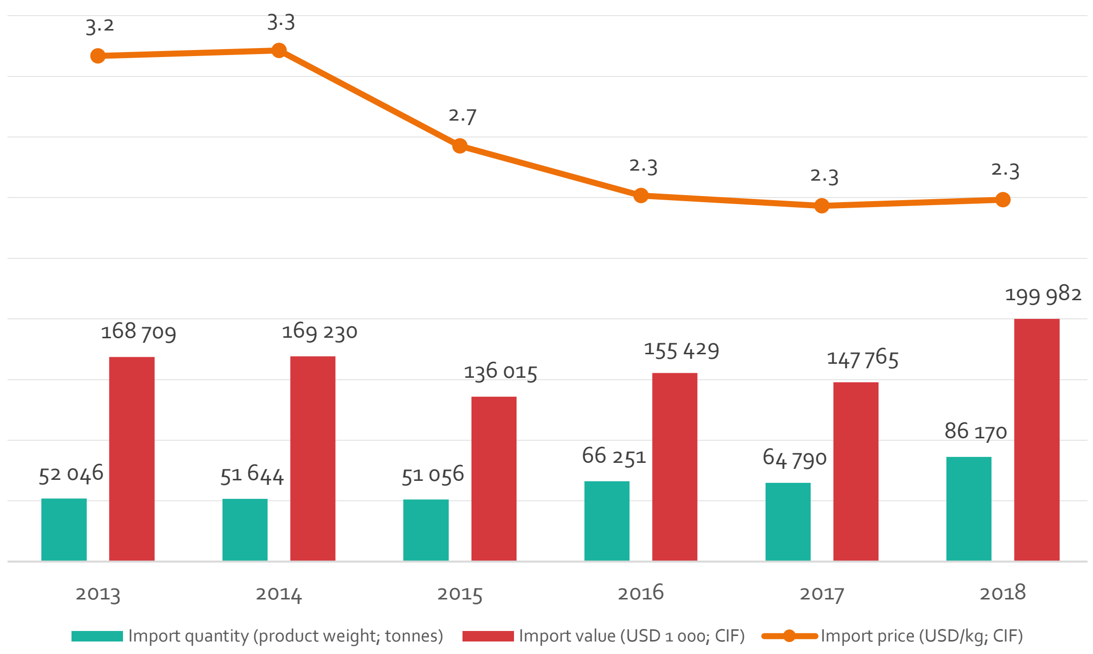
According to FAO statistics (FAO, 2020g), tilapia import in Mexico increased from 52 046 tonnes (USD 169 million) in the early 2010s to 86 170 tonnes (USD 200 million) in 2018 (Figure 4), which accounted for 14 percent of the country's nearly USD 1 billion total import of aquatic products in 2018.

Mexico was the second-largest tilapia importer (following the United States of America), accounting for 16 percent of the world tilapia imports tonnage and 13 percent of the value in 2018. Nearly all of Mexico's tilapia imports came from China (FAO, 2020a, p.79).

Tilapia imports in Mexico were primarily composed of frozen tilapia fillets (HS030461) and frozen whole tilapia (HS030323), which accounted for, respectively, 92 percent and 8 percent of the country's USD 200 million tilapia import in 2018 (FAO, 2020g).

The average price of Mexico's tilapia import declined from USD 3.2/kg in 2013 to USD 2.3/kg in 2018 (Figure 4), reflecting the decline in the price of its frozen tilapia fillets imports from USD 3.8/kg to USD 2.4/kg and that of its frozen whole tilapia imports from USD 2/kg to USD 1.6/kg. The price of Mexico's imports of frozen tilapia fillets in 2018 (USD 2.4/kg) was much lower than the world average of USD 3.4/kg, which reflects the relatively small size and/or thick glaze of tilapia fillets imported in Mexico.

Figure 4: Import of tilapia products in Mexico, 2013–2018

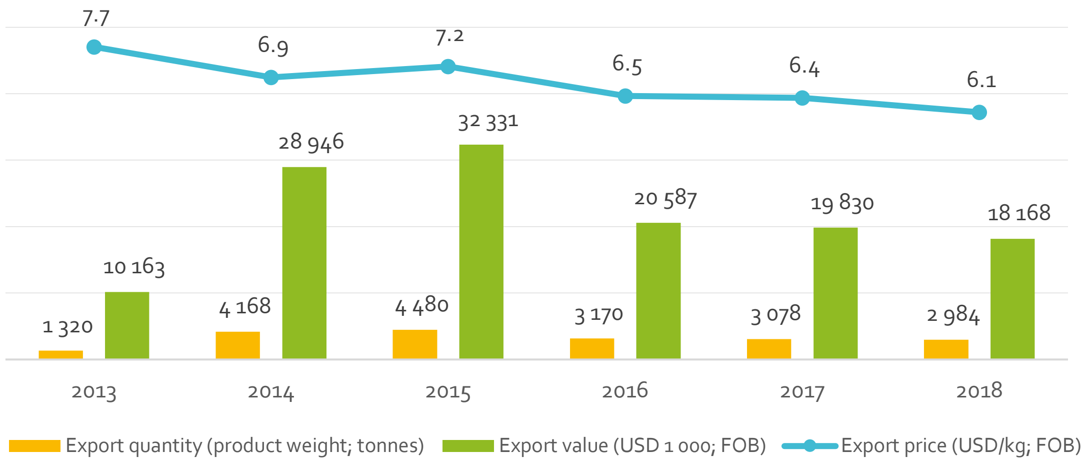


Source: Fishery and Aquaculture Statistics. Global fisheries commodities production and trade 1976–2018 (FishStatJ). www.fao.org/fishery/statistics/software/FishStatJ/en
Note: CIF = cost, insurance and freight.

Export

According to FAO statistics (FAO, 2020g), Mexico's tilapia export increased from 1 320 tonnes (USD 10 million) in 2013 to 4 480 tonnes (USD 32 million) in 2015, yet declined to 2 984 tonnes (USD 18 million) in 2018 (Figure 5). The USD 18 million of tilapia export accounted for 1 percent of the country's export of all aquatic products and 1.2 percent of the world tilapia export in 2018.

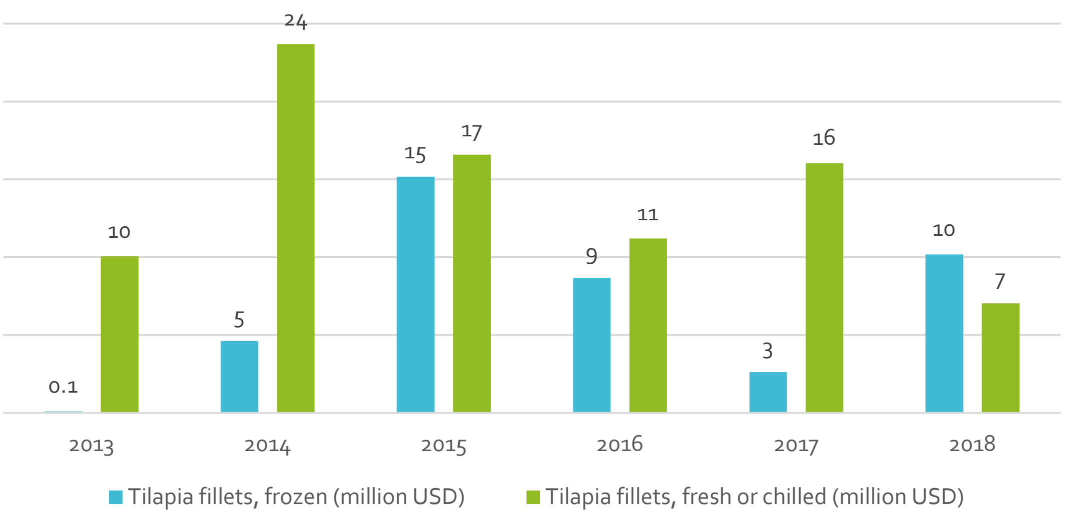
Figure 5: Export of tilapia products from Mexico, 2013–2018



Source: FAO Fishery and Aquaculture Statistics. Global fisheries commodities production and trade 1976–2018 (FishStatJ). www.fao.org/fishery/statistics/software/FishStatJ/en
Note: FOB = free on board.

Composed of primarily tilapia fillets, nearly all of Mexico's tilapia export went to the United States of America. While the country's export of frozen tilapia fillets doubled from USD 5 million in 2014 to USD 10 million in 2018, its export of fresh/chilled tilapia fillets declined from USD 24 million to USD 7 million (Figure 6).

Figure 6: Mexico's export of tilapia fillets, 2013–2018



Source: Fishery and Aquaculture Statistics. Global fisheries commodities production and trade 1976–2018 (FishStatJ). www.fao.org/fishery/statistics/software/FishStatJ/en

The average price of tilapia export from Mexico declined from USD 7.7/kg in 2013 to USD 6.1/kg in 2018 (Figure 5), which primarily reflected the decline in the price of its export of fresh/chilled tilapia fillet (from USD 7.7/kg to USD 6.7/kg) and the decline of the share of this relatively high-value tilapia product in its total tilapia export (from 99 percent to 39 percent).

2.4 Tilapia consumption

According to FAO statistics (FAO, 2020f), Mexico's per capita (apparent) fish consumption[9] was 14.7 kg/year in 2017, which was lower than the world average of 20.3 kg yet higher than the average of 10.5 kg in Latin America and the Caribbean.

According to the estimation in Table 3, Mexico's per capita tilapia consumption was 3.08 kg (live weight equivalent) in 2018, which was 21 percent of its 14.7 kg overall fish consumption.[10] Indeed, tilapia consumption in Mexico increased from 1.04 kg to 3.08 kg between 2012 and 2018, with the tilapia share in its overall fish consumption more than doubling from 8.8 percent to 21 percent (Figure 7). In 2018, Mexico's 3.08 kg of per capita tilapia consumption was more than three times the world average of 0.9 kg (Figure 7).

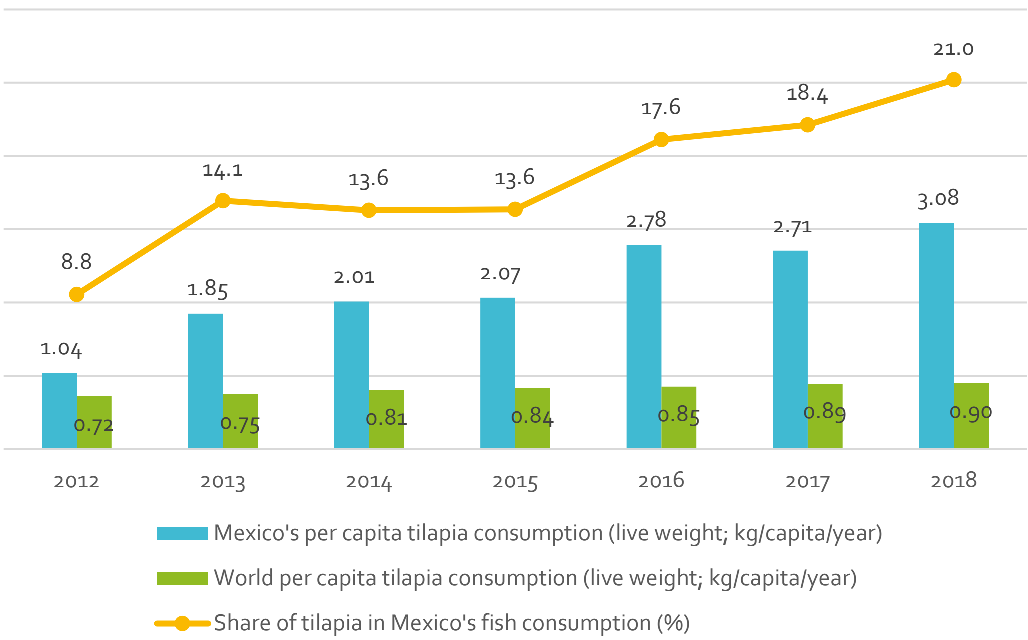
Table 3: Estimation of per capita tilapia consumption in Mexico, 2018

Items in food balance sheet	Product weight	Conversion factor	Live weight or equivalent
Production (tonnes)			**168 359**
Import (tonnes)	**86 170**	**n.a.**	**228 144**
Tilapias, fresh or chilled (HS030271)	5	1.00	5
Tilapias, frozen (HS030323)	10 513	1.12	11 775
Tilapia fillets, fresh or chilled (HS030431)	0	2.48	0
Tilapia fillets, frozen (HS030461)	75 652	2.86	216 365
Export (tonnes)	**2 984**	**n.a.**	**7 394**
Tilapias, fresh or chilled (HS030271)	275	1.00	275
Tilapias, frozen (HS030323)	132	1.12	148
Tilapia fillets, fresh or chilled (HS030431)	1 050	2.48	2 604
Tilapia fillets, frozen (HS030461)	1 527	2.86	4 367
Consumption (tonnes; equal to production + import – export)			**389 109**
Population (million)			126
Per capita consumption (kg/capita/year)			**3.08**

Source: Production data from CONAPESCA (2020); trade data from FAO (2020f); conversion factors from EUFOMA (2019); and population data from United Nations (2019).

[9] Apparent fish consumption is estimated by the food balance approach, i.e. consumption = production + import – export.
[10] Per capita fish consumption in 2018 is assumed to remain the same as that in 2017, the latest year in the FAO statistics (FAO, 2020f).

Figure 7: Tilapia consumption in Mexico

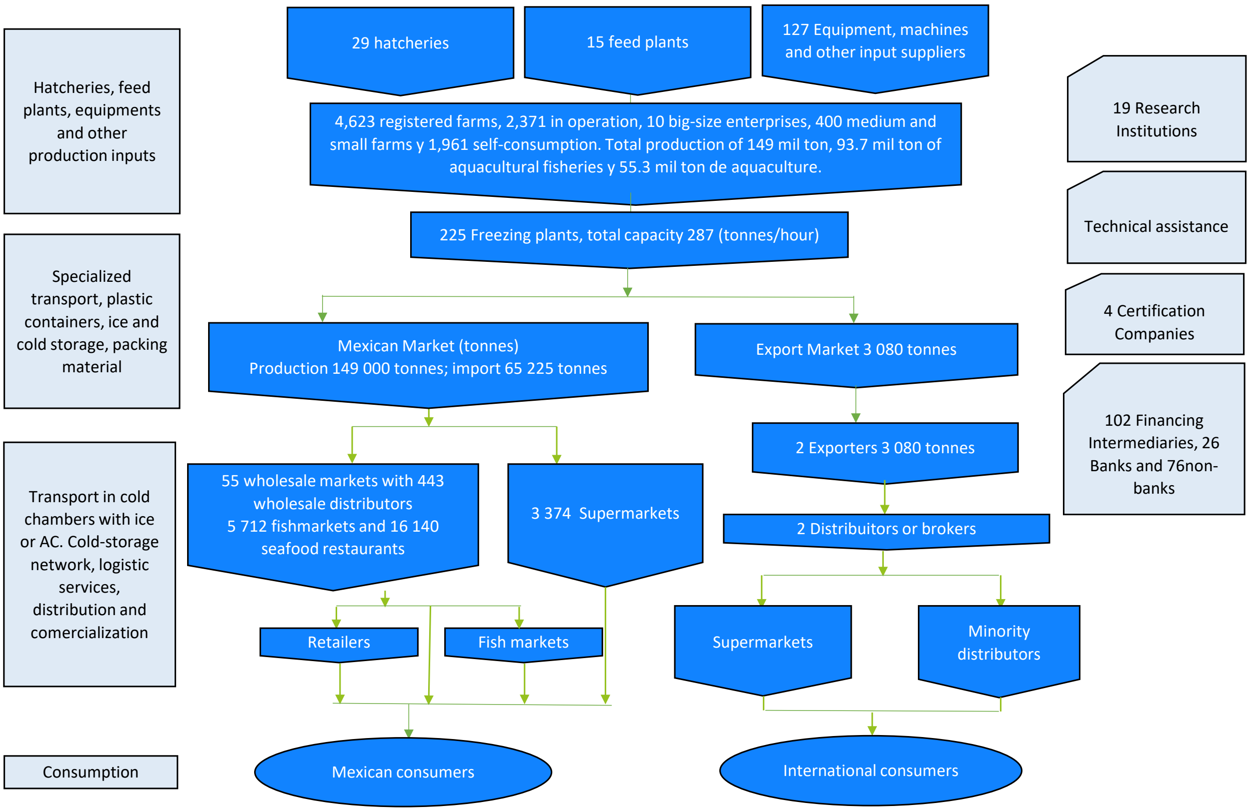


Sources: Per capita fish consumption from 2012 to 2017 calculated from total fish consumption from FAO (2020f) divided by population from United Nations (2019), and the 2018 per capita fish consumption assumed to be equal to that in 2017. World average per capita tilapia consumption equal to world tilapia production divided by world population. Mexico's per capita tilapia consumption estimated based on the food balance approach shown in Table 3.

2.5 Tilapia value chain

Developing a full tilapia value chain map for Mexico is difficult because many stakeholders/participants along the chain are in the informal sector that is not reflected in official records. According to the value chain map developed by the Mexican's Government Institution Fideicomisos Instituídos en Relación con la Agricultura – Agriculture-related Trust Fund, known as FIRA – (FIRA, forthcoming), in 2017 there were 2 371 registered tilapia farms operating in Mexico's tilapia value chain, including 10 large-scale enterprises, 400 small and medium-scale farms, and 1 961 subsistence farms (Figure 8). These tilapia farms were supported by (i) 29 hatcheries (including nine public hatcheries), 15 feed plants and 127 suppliers of equipment, machinery and other inputs on the upstream; (ii) 225 processing/freezing plants and two exporters downstream; and (iii) various service and support agents, including 19 research institutes, four certification companies, and 102 banks and other financial institutes. The domestic fish and seafood market included 55 wholesale markets (hosting 443 wholesale distributors), 5 712 fish vendors, 16 140 seafood restaurants, and 3 374 supermarkets.

Figure 8: Tilapia value chain in Mexico, 2017



Source: Adapted from FIRA (forthcoming) with minor modification.

Tilapia value chain in Veracruz

Veracruz de Ignacio de la Llave (Veracruz in short, ID #30) was the third-largest tilapia farming state, with 3 402 tonnes of production accounting for 6.5 percent of Mexico's total tilapia aquaculture production in 2018; it was one of the six states whose wild and farmed tilapia production exceeded 10 000 tonnes in 2018 (Table 2).

According to a study on the tilapia value chain in Veracruz conducted by Hernández Arzaba *et al.* (2019):

- Local tilapia hatcheries in Veracruz were available yet unable to satisfy the demand of local tilapia farmers who also purchased tilapia seed from other states. It has been recognized that a tilapia genetic improvement programme is critical for supporting the competitiveness and sustainable development of tilapia aquaculture in Mexico (Mojica-Sastoque *et al.*, 2010).
- More than half (54 percent to be exact) of tilapia operations in the state were subsistence farmers (with less than 720 kg production per year), and 41 percent were semi-commercial farmers (with annual production between 720 kg and 10 tonnes). Only 5 percent of Veracruz tilapia operations were commercial farmers (with more than 10 tonnes of annual production), yet they accounted for more than half (51 percent to be exact) of the state's tilapia aquaculture production.
- Most tilapia farmers in Veracruz (irrespective of the scale of operation) sold their produce at farmgate (89 percent) or in local markets (5.7 percent). The lack of cold-chain facilities

(freezers, cold storage, etc.) was a limiting factor for the farmers to sell their produce to other states. The main markets within the state were in urban areas, and 91 percent of the farmers surveyed by the study reported little to no problem with selling tilapia produce, indicating the popularity of fresh tilapias for local consumers.

- The strategy of large commercial farmers was to focus on local and regional markets in the short term and compete in foreign markets (e.g. United States of America, the largest tilapia international market) through quality and freshness in the medium and long term. Yet commercial farmers may need to form an alliance with semi-commercial farmers to maintain a stable supply of a substantial amount of tilapia products, which tends to be a precondition to establish business relationships with tilapia importers. Nearly 80 percent of the surveyed farmers showed interest in being integrated along the value chain in order to better market their produce to consumers.
- For subsistence farmers, the main development priority was to increase production through improving technical know-how and skills in tilapia farming and, eventually, to become a semi-commercial farmer.

Tilapia value chain in Yucatán

Yucatán (ID #31) is one of the six states where aquaculture contributed to over 80 percent of tilapia production in 2018 (Figure 3), yet its 847 tonnes of farmed tilapia production accounted for only 1.6 percent of the country total (Table 2).

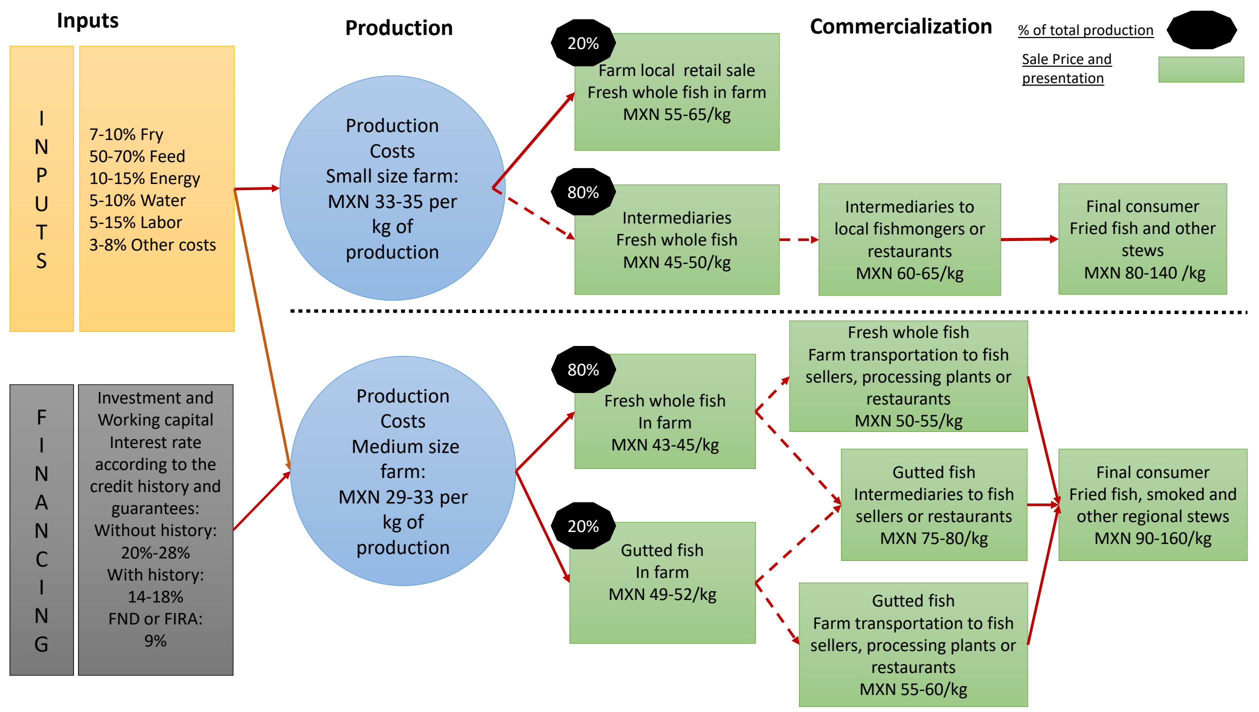
According to a recent study on tilapia supply chain in Yucatán (Suárez-Puerto and Martínez-Cordero, forthcoming), the tilapia aquaculture sector in Yucatán is composed primarily of small farmers with limited financial resources and a few medium producers. In order to avoid vicious competition and increase profit margins, farmers under the state's tilapia System Product Committee (SPC)[11] have agreed to follow a common marketing strategy to set the minimum selling price at MXN 43/kg (around USD 2.2/kg) and the minimum size of 400 g (Figure 9). Most of the production is sold to fishmongers and intermediaries in the nearby state Quintana Roo (ID #23 in Figure 3), specifically in tourist areas such as Playa del Carmen and Cancún.

Small and medium tilapia farmers in Yucatán have a similar cost structure, with feed accounting for 50–70 percent of the total production cost, followed by energy (10–15 percent), labour (5–15 percent), seed (7–10 percent) and water (5–10 percent). The share of energy cost is relatively low compared to other states thanks to subsidies provided by the state government. The water cost can be lowered for farms with a concession for aquaculture water use. Other costs, such as taxes (including payroll tax for social security), transportation and harvesting, account for 3–8 percent of the total cost. Yet not all the farmers incur such expenses.

Financing is critical for the development of aquaculture in Yucatán. Tilapia farmers in the state generally need credits to pay for feed and electricity so that they can spare their own funds for marketing and value-added strategies, which are crucial to their profit margins. However, banks and other financial institutions in the state (which does not have a long history of aquaculture) generally have limited knowledge and understanding of tilapia aquaculture. Bank loans to new farmers, if available, are usually subject to 20–28 percent annual interest, whereas those with several years in operation tend to face more favourable interest rates (14–18 percent). A financing house may charge a lower interest rate (e.g. 9 percent), yet the availability of such cheaper credits is usually limited for tilapia farmers.

[11] SPCs are similar to state's tilapia farmers committees, but the original name as used in Spanish is being kept here.

Figure 9: Tilapia value chain in Yucatán, 2019



Source: Adapted from Suárez-Puerto and Martínez-Cordero (forthcoming) with minor modification.
Note: 1 MXN = USD 0.05.

Most farmers in Yucatán use circular tanks for tilapia outgrowing. A small farmer usually has 1–8 tanks operating at an extensive or semi-intensive level with the use of formulated feed (sometimes supplemented with natural feed) and perhaps a simple aeration system when necessary; the resulting production cost is MXN 33–35/kg (USD 1.65–1.75/kg). A medium-size farmer usually has more than eight tanks operating intensively with formulated feed and intensive aeration; the resulting production cost of MXN 29–33/kg (USD 1.45–1.65/kg) is nevertheless lower than that of smaller farmers (Figure 9) because of the economies of scale.

A small farmer usually sells 20 percent of the tilapia harvest fresh whole at farmgate or to small fish traders in cities such as the state capital Mérida at MXN 55–65/kg (USD 2.75–3.25/kg); the remaining 80 percent is sold to fish traders at a lower price of MXN 45–50/kg (USD 2.25–2.5/kg), which gives the farmer an average of MXN 13.5/kg (USD 0.68/kg) gross profit. The fish traders transport live tilapias in 1 000-litre plastic containers with aeration, preserving the condition of fish in good quality until reaching fishmongers for a selling price of MXN 60–65/kg (USD 3–3.25/kg) for average MXN 15/kg (USD 0.75/kg) markup. The fishmongers in turn cook the tilapias (mostly fried or stewed) and sell them at MXN 80–140/kg (USD 4–7/kg) for average MXN 47.5/kg (USD 2.38/kg) markup.

Medium-size farmers sell 80 percent of their fish fresh whole and 20 percent fresh gutted. The MXN 49–52/kg (USD 2.45–2.6/kg) farmgate price of fresh gutted tilapia is higher than that of fresh whole tilapia (MXN 43–45/kg; USD 2.15–2.25/kg). The fish is usually transported by vehicles with fibreglass containers and ice. Transportation costs are in the range of MXN 4 000 (USD 200) to MXN 7 000 (USD 350) for 500–5 000 kg. Special cold transportation in Thermo King trucks is usually not required for tilapia farmers in Yucatán because the distance to market is not far, and the quality standard of final consumers is usually not as strict as that of hotels and supermarkets. Fish traders who sell fish in wholesale markets in central Mexico or other major regional markets come to Yucatán for a variety of fish products with tilapias being only one of them.

While there are large price markups along the tilapia value chain (Figure 9), this does not necessarily mean that fish traders or fishmongers earn more profit than fish farmers because the price markups do not represent the gross profits of fish traders or fishmongers who incur extra business costs (transportation, labour, etc.) other than the cost of tilapias. Indeed, farmers can transport the fish by themselves to fishmongers, fish traders or processing plants charging MXN 50–55/kg (USD 2.5–2.75/kg) for fresh whole and MXN 55–65/kg (USD 2.75–3.25/kg) for fresh gutted, which are around MXN 7–10/kg (USD 0.35–0.5/kg) higher than the farmgate price. However, the markup may not be sufficient to cover the increased risk involved in transportation.

Micro, small and medium enterprises

While tilapia value chains for micro, small and medium enterprises (MIPYME)[12] in Mexico are loosely organized, formal relationships are occasionally present when the MIPYME producers establish an agreement with larger firms or input suppliers or supermarkets. However, similar to other places in the world (Bjorndal, Child and Lem, 2014), MIPYME farmers generally have the least bargaining power in the tilapia value chain that tends to be dominated by retailers, big wholesalers or supermarkets.

Many of these large buyers are credit purchasers who are given one to two months for payment without interest. Reaching the main seafood wholesale market of the country (i.e. the La Nueva Viga, LNV market in Mexico City) is a case of controlled access by fish traders. Not only does the LNV market buy only large amounts of fish, many times not achievable by MIPYME, but in many cases undifferentiating their origin, mixing good quality products with bad ones. Fish traders who sell to the LNV market can go to provinces and determine the buying-selling conditions, frequently not respecting the selling price agreed upon in advance by telephone. MIPYME farmers, ready to harvest, usually have no choice but to sell at the unfavourable prices set by fish traders.

One option for MIPYME farmers to obtain a better sale price is to focus on local or regional markets and establish own-sale points with containers or vehicles to sell high-quality live tilapias. This strategy has proven successful in Central and South Mexico. Similar to many other cases in the world (Bjorndal, Child and Lem, 2014), such shortened fish supply/value chains can not only increase the income of fish farmers but also help good quality fish reach many households in rural areas.

Another important measure is to keep the tilapia value chain transparent and maintain a consistent pricing mechanism to mitigate MIPYME farmers' disadvantages in bargaining power. Governments at different levels need to play a major role in this respect. The government State of Tamaulipas, for example, through its Ministry of Fisheries and Aquaculture, is already working in this area.

[12] There is an official classification of MIPYME enterprises in Mexico, set by the Ministry of Economy based on number of employees and income level (DOF, 2009).

3. TECHNICAL ASPECTS OF TILAPIA FARMING IN MEXICO

3.1 Categorization of tilapia operations in Mexico

Tilapia farmers in Mexico can be grouped into five categories according to their production capacity (Table 4). While different from other categorization criteria (e.g. extensive, semi-intensive and intensive tilapia farming; or MIPYME producers mentioned above), the categorization in Table 4 is based on field experiences and consultations in many studies and scientific papers and can facilitate assessment of the technical and economic performance of diverse tilapia farming operations in Mexico; see Table 5 for a summary.

Table 4: Categorization of tilapia farmers in Mexico

Scale	Production capacity (tonnes/year)	Notes
AREL/micro farm	≤ 0.5	Mostly subsistence farms
Small farm	(0.5, 50]	Commercial farms
Medium farm	(50, 500]	
Large farm	(500, 10 000]	
Mega farm	> 10 000	

Note: AREL = resource-limited aquaculture.

Resource-limited aquaculture (AREL)/micro operations (less than 500 kg a year) may represent up to 50 percent of tilapia farmers in Mexican rural areas; many of them are unregistered, hence, strictly speaking, unauthorized operations that are usually not captured by official statistics. There are also a minority of AREL/micro farms in suburban areas and big cities. According to FAO (2012), the features of AREL/micro aquaculture include (i) self-employment, full time in aquaculture or complemented with other jobs; (ii) limited access to key production inputs; and (iii) low household income that may not be sufficient to maintain food security. A usual tilapia AREL/micro farm is a family operation with the mother and children taking care of daily management (feeding, pond maintenance, etc.) and sales. The father usually works at the agriculture field or in the construction business, yet he is still the head of the fish farming business. Earthen ponds or concrete ponds/tanks are the most common farming system for AREL/micro farmers in Mexico because they are self-built, sometimes with government aid. AREL/micro farms based on plastic tanks have become increasingly popular in recent years. Around 30 percent of tilapia production of an AREL/micro farm is for self-consumption, and the remaining production is traded among neighbours and/or local consumers.

Small farmers (0.5–50 tonnes a year), which may represent around 30 percent of tilapia farms in Mexico, have more production capacity, technical expertise and experience in tilapia farming than AREL/micro farmers. Similar to AREL/micro farmers, small farmers are usually conducting family operations, yet some of them seriously consider hiring well-trained professionals as managers, but demand for well-trained and experienced technicians is high and not met by the human capacity supply. Small farmers are usually located in suburban areas near large, populated towns and cities. Many of them use floating LVHD (low volume high density) cages of different materials and sizes. Plastic tanks have become the most popular production system for small farmers because they are less constrained by topographic and soil conditions. Some small farmers cultivate tilapia in bigger earthen ponds than those used by AREL/micro farmers. Small tilapia farmers normally sell live or gutted tilapias at the farmgate and/or supply them to their own restaurants. Some have their own delivery trucks, or they have long-term customers who pick up the fish, bringing ice to the farm.

Table 5: Characteristics of tilapia farms in Mexico

Parameters	AREL/micro farms	Small farms	Medium farms	Large farms*
Annual production (tonnes/year)	Less than 0.5	0.5–50	50–500	500–10 000
Number of aquaculture production units (UPAs) and % of the total number	2 766 (59.5%)	1 160 (25%)	700 (15%)	20 (0.5%)
Legal status	Mostly unregistered	Mostly unregistered	Mostly registered	Registered
Farming systems	Earth ponds, circular plastic tanks, floating cages	Earth ponds, circular plastic tanks, floating cages	Earth ponds, circular plastic tanks, floating cages	Earth ponds, circular plastic tanks, floating cages
Water sources	Rain water, creeks, springs, well	Creeks, rivers, lagoons, dams, wells	Creeks, rivers, lagoons, dams, wells	Wells and dams
Fingerling supply	From a dealer	From a dealer	Mostly own production	Mostly own production
Fingerling size (g)	0.7–1	0.7–1	1.0–10	1.0–10
Price of 1-g fingerling (USD/fish)	0.04–0.06	0.04–0.06	0.04–0.06	0.04–0.06
Carrying capacity (kg/m³)	2–3	7–15	15–20	15–30
Survival rate (%)	80	70	70	70
Growing period (months)	4	6	6	6
Harvest size (g)	150–250	300–500	500–1 000	500–1 000
Production cycle (number of crops a year)	3	2	2	2
Feed conversion ratio	1.4	1.5	1.5	1.5
Average feed price (32% CP content; USD/kg)	0.77	0.75	0.67 plus credit on payments	0.67 plus credit on payments
Supplemental feed	Local herbs, grains, molasses, etc.	Rare	None	None
Electricity price (USD/kWh)	n.a.	0.044**	0.044	0.044
Labour	Unpaid family labour	Unpaid family labour and unskilled labour paid minimum salary	Professional crews	Professional crews
Education of owner	3rd to 6th grade	6th to 12th grade	12th grade to college	College graduate
Health risks	High	High	Very high	Very high
Financial sources***	Mostly own savings and family loans; some government support from special programmes like Rural Aquaculture	Own savings, government development funds and bank loans	Own savings, government development funds and bank loans	A few with own investment; government and bank loans

Source: CONAPESCA (2017) and team field research.

Notes: *This kind of aquaculture production unit (UPA) may produce 60 percent of the national production. **This is the electricity price before subsidy from the government, and small cage farmers usually do not use electricity in their operations. ***Government support in past years included development banks and different “fideicomisos”. Now support is significantly reduced, and most of the support programmes from CONAPESCA have been cancelled. AREL = resource-limited aquaculture.

Medium (50–500 tonnes), large (500–10 000 tonnes) and mega (over 10 000 tonnes) farmers maintain tilapia farming as their sole or primary businesses. Representing around 20 percent of tilapia farmers in Mexico, notwithstanding, these farmers account for most of the farmed tilapia production in Mexico – the nearly 40 000 tonnes of the production capacity of major operations listed in Table 6 accounted for 70 percent of Mexico's 55 000 tilapia aquaculture production in 2017. Farmers feel secure or "in business" when they produce over 10 tonnes tilapia per week; farms with 20 tonnes/week are increasing, thanks to the good market demand and the vision of private investors as well as aid from the federal government to support the development of commercial tilapia aquaculture in Mexico. Since 2019, however, aid from the federal government has been drastically reduced.

Table 6: Examples of major tilapia aquaculture operations in Mexico

Farm name	Scale	Location	Farming system	Production capacity (tonnes/year)
Pond				
Tupez	Large	Veracruz #30	Earthen ponds	1 000
La Granja	Medium	Campeche #4	Earthen ponds and in-pond raceway system	240
Central Acuícola	Medium	Campeche #4	Lined earthen ponds	160
Rancho Viejo	Medium	Veracruz #30	Earthen ponds	160
Acuícola Galilea	Medium	Veracruz #30	Earthen ponds	112
Subtotal for pond operations				**1 672**
Cage				
Regal Springs (Acuagranjas Dos Lagos SA de CV)	Mega	Chiapas #7	Floating cages	26 500
Gemso Group	Large	Sonora #26	Floating cages	8 000
Acuícola Campo Viejo	Large	Chiapas #7	Floating cages	780
Tilapia de las Minas	Medium	Chiapas #7	Floating cages	500
La Jolla	Large	Tamaulipas #28	Floating cages	600
Grupo Virgen	Medium	Oaxaca #20	Floating cages	400
Subtotal for cage operations				**36 780**
Tank				
Bubul Ha	Medium	Yucatan #31	Circular geomembrane tanks	240
Santa Rita	Medium	Tabasco #27	Concrete circular tanks	240
Tilapia Azul	Medium	Tabasco #27	Geomembrane circular tanks, concrete tanks, earthen ponds	240
Bio World	Medium	Chiapas #7	Circular, geomembrane tanks	160
Subtotal for tank operations				**880**
Total capacity for all operations				**39 332**

Source: Estimation by Soledad Delgadillo based on farm surveys.
Note: Production capacities presented here may not be consistent with the official statistics.

Medium/large/mega farmers use a variety of farming systems (cages, tanks, ponds or a combination of them) and aeration systems to sustain intensive farming. Some farmers have their own hatcheries to satisfy own demand and sell the surplus. These farmers are usually more organized and have niche markets in neighbouring cities through retail stores. Some have brokers who deliver to the LNV market in Mexico City. Part of the tilapia harvest is sold live, another part head-on, and clean gutted to fish trucks that routinely bring the fish to the market; some of the farmers have their own delivery trucks. The common tilapia weight ranges between 500 g and 800 g, except in the rural areas of some states (e.g. Chiapas, Oaxaca, Veracruz, Puebla, Tlaxcala and Hidalgo) where smaller fish (e.g. 350 g) are wanted for a lower price.

Regal Springs (Acuagranjas Dos Lagos SA de CV), in Chiapas, is the largest tilapia farm, accounting for nearly half of the tilapia aquaculture production capacity in Mexico (Table 6). It is a foreign investment and has been in operation for over ten years. Similar to most aquaculture companies in Mexico with foreign ownership, Regal Springs primarily targets international markets.

The international company has tilapia cage farming operations in two reservoirs in Chiapas (i.e. Peñitas and Mal Paso) and plans to expand the operation to another dam (La Angostura). The company's business benefits nearby villages through generating employment and strengthening the supply chain. However, local farmers are concerned about the impact of the company's large supply on tilapia prices in local markets and the impact of large cage farming operations on water quality in the reservoirs.

Regal Springs (Acuagranjas Dos Lagos SA de CV) follows production standards and has a permanent water quality lab, monitoring the water quality and adjusting the feeding practice accordingly. In addition, Regal Springs has a hatchery for its own supply, and it occasionally gives away free fingerlings to nearby producers. The company employs local labour, except in the case of key positions, which are usually held by Mexican experts trained in other countries. The company primarily exports tilapia fillets to the United States of America (mostly to Miami) and also sells gutted and scaled fresh tilapias to the local markets. In order to practise sustainable use of tilapia by-product wastes, the company processes them into biodiesel, collagen and fishmeal.

3.2 Farming systems and technologies

Catfish and tilapia farming technologies in the United States of America have influenced pioneer tilapia farmers in Mexico, who imported farm equipment and adapted the technologies to local conditions. The localized technology then gradually spread to more farmers – see Table 7 for a summary of tilapia farming technologies adopted by Mexican farmers. Tilapia farmers and experts in Mexico have also been exposed to information and knowledge about global tilapia aquaculture through various meetings and conferences on tilapia farming or aquaculture in general.

Table 7. Examples of technologies adopted by tilapia farmers in Mexico

Technology	Used by	Main impacts
Aerators	Medium, large and mega farms (tanks, ponds and cages)	Increase in carrying capacity, stocking density and fish survival
Oxygen meters	Medium, large and mega farms	Improvement in water quality leading to less disease and higher survival rate
Circular geomembrane plastic tanks	Resource-limited aquaculture (AREL)/micro, small, medium and large farms	Easy to establish (compared to cage and pond); low requirements for soil and terrain conditions; low environmental impacts
Grading cages and grading machines	Small, medium, large and mega farms	Labour saving; more evenly fish growth; more uniform harvest size
Hatchery equipment (incubators, filters, pumps, etc.)	Medium, large and mega farms	More stable and secure seed supply
Hoist and other loading machinery	Large and mega farms	Labour and time saving
National and imported nets, seines and harvest gear	Medium, large and mega farms	Increase in harvest rate; less fish damage during harvest; higher durability
Water-quality management and lab equipment	Small, medium, large and mega large farms	Monitoring and improved water quality, fish health, animal welfare and best production
Greenhouses or individual tank house protection	Small, medium, large and mega large farms	Better temperature control; better fish health, growth and biosecurity
Tilapia best management practices (BMP)	Most of the farms in states where an Aquaculture State Health Committee exists	Improvement of animal welfare by integrating safety practices, farmers and workers' responsibilities about the fish, water, and fish drugs and their disposals and spills
Biofloc technology (BFT), aquaponics	Small, medium and large farms	Savings of money and water, nitrogen toxicity control, more efficient water use and higher productivity
Feed enhancement by probiotics or enzymes	Small, medium and large farms	Natural improvement of fish metabolism, fish welfare, disease control

Earthen pond

While earthen pond culture is the primary tilapia farming system contributing to most of the global production, it represents only a small portion of tilapia aquaculture production in Mexico. Southern states like Veracruz and Tabasco have plenty of water and flat terrains suitable for pond aquaculture, yet they are subject to a relatively high flooding risk.

Earthen ponds used by Mexican tilapia farmers may be built with concrete banks or covered with liners. An AREL/micro or small tilapia farm with one or two earthen ponds can be found everywhere in the country: hills, flat land, coastal land, forest, suburban areas and other places with relatively easy access to water sources (rivers, lakes or springs). A prototype of a low-cost AREL/micro farm (USD 300 investment) includes one 8 m × 4 m earthen pond (1.2 m deep), 800 sex-reversed tilapia fingerlings (1 g), four 20-kg sacs of pelleted feed, and 25 m of chicken wire to protect the pond from predators (Plate 3).

Most of these farmers culture tilapia extensively or semi-intensively, relying mostly on natural foods (e.g. plankton, water lentils *Lemna* sp., or water spinach *Ipomoea aquatica*) and harvesting small size fish (200–250 g) that allow a piece of fish for each family member. Some of the farmers in warmer areas (i.e. no winter) with ample water supply and the use of formulated feed could harvest three crops a year with a total annual production of 2–3 kg per m^2.

Plate 3

Top left: 8 m × 4 m × 1 m earthen pond with soil bottom and stone/cement banks, La Trinitaria, Chiapas

Top right: Earthen pond used to grow water lentils (*Lemna* sp.) for supplementary feeding

Bottom left: Earthen pond with thin plastic liner, Puebla

Bottom right: Backyard earthen pond harvesting three crops of 250 g tilapia a year, Cabo Verde, Veracruz

Intensive pond culture is also conducted by small to large tilapia farmers (Plate 4). These farms use formulated feed and areation equipment to sustain high stocking densities. Novel pond systems, such as in-pond raceway system (IPRS), have also been attempted by some farmers to improve water quality, reduce the cost of electricity and increase fish performance (Plate 4). Farmers at this level are enthusiastic entrepreneurs, eager to innovate and have the confidence of knowing the market and their competitive advantages.

Plate 4

Left: Earthen pond with paddle-wheel aerators (yielding an average of 16 tonnes/year), Minatitlan, Veracruz
Center: Intensive earthen pond in a medium farm (160 tonnes/year), Isla, Veracruz
Right: In-pond raceway system, Chetumal, Quintana Roo

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Cage

Compared to the traditional pond culture, cage culture is a relatively new tilapia farming system that has become increasingly popular in many countries (e.g. Brazil and Egypt) and the primary farming system in some newly developed tilapia farming countries (e.g. Ghana) (FAO, 2017a; Barroso, Muñoz and Cai, 2019).

Most of the micro and small-scale cage tilapia farmers in Mexico have been fishers in the same inland waters for years. Back in the mid-1970s, cage culture was an important programme in the Department of Fisheries, under the Aquaculture Division, as an innovative production system for large reservoirs. Although the programme was envisioned to generate self-sufficient social groups, problems arose in the initial years, such as internal conflicts, deficient training schemes, geographically isolated producers who were difficult to assist, and a lack of responsibility of farmers to take care of production assets that were obtained for free. However, as wild catches declined, fishers again turned towards aquaculture and specifically cage culture.

Mexico has plenty of large inland waterbodies suitable for cage tilapia culture, including 180 dams with total capacity of 127 372 hm^3 (CONAGUA, 2017).[13] The establishment of a cage tilapia farming operation entails water concession for aquaculture through a permit, which is usually granted as long as the operation is considered sustainable and comes with no negative environmental impacts.

Besides dams and reservoirs, tilapias are also farmed in brackish lagoons using cages of various size (e.g. 4 m × 4 m; 5 m × 5 m; 8 m × 8 m). Mexico is endowed with around 1.25 million ha of coastal lagoons. The Mexican Government is keen to utilize coastal lagoons for sustainable aquaculture development, yet one concern is the potential environmental impacts of escapees. Cage tilapia farming in lagoons faces the challenge of having shallow water in some places (only 1 m), lack of water flow, high water temperature and varied climate conditions, among others. Farmers have tried various measures (e.g. lowering density) to overcome mortality in the high temperature season with no complete success.

[13] $1\ hm^3 = 1\ 000\ 000\ m^3$

Cage culture (Plate 5) contributes to most of the tilapia aquaculture production in Mexico. Five major tilapia cage culture operations have a total of around 36 000 tonnes of annual production capacity (Table 6). The rapid growth in the country's tilapia aquaculture production since the early 2010s was primarily caused by large tilapia cage culture operations in dams and reservoirs, particularly the mega farm Regal Springs (Acuagranjas Dos Lagos SA de CV). Group GEMSO (Grupo empresarial de Sonora) transformed its tilapia operation from pond culture to cage farming in the "El Novillo" reservoir and has become the second-largest tilapia farm in Mexico.

Plate 5

Top left: Circular floating cage at San Julian Lake, Veracruz
Top right: Square cages at Ixcatlán, Oaxaca
Bottom left: Square cages in the Dam La Angostura, Chiapas
Bottom right: Circular cages at Peñitas Lake, Chiapas

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Tanks

A typical tank tilapia farming system used in Mexico is a circular geomembrane tank from 9 m to 15 m diameter and 1.2 m depth. Large tanks (e.g. 20–25 m diameter) have also been used in medium-size farms, whereas small farms usually use smaller tanks (6–12 m diameter, 1.2 m depth). Some farms use concrete tanks/ponds, and the combination of tanks and lined ponds is also common among medium-size farms (Plate 6).

Tank tilapia farms tend to be more expensive to establish and operate than pond or cage systems because of the need of aeration and water pumping – most of the equipment or machinery are imported and consume a large amount of electricity. Yet, the relatively low requirement for soil and terrain conditions of a tank system makes it ideal for niche markets that can pay relatively high prices for good quality, fresh/live tilapias. Some tank farms supply their tilapia harvest to associated restaurants and retail stores.

Plate 6

Top left:	Circular concrete tank (3 m diameter)
Top right:	Circular tanks in a greenhouse
Bottom left:	Circular geomembrane tanks with gravity water flow
Bottom right:	Combination of rectangular concrete tanks and circular geomembrane tanks

Aeration

Except for farmers who have access to ample water resources that allow frequent water exchanges, pond or tank farmers often use aeration equipment (e.g. paddlewheel or air injector) to maintain high densities (above 2 kg fish/m^3). Large cage operations may use aeration to maintain water quality, and small cage farmers in shallow lagoons also consider using aeration equipment to help fish survive high temperatures. Yet imported aeration equipment (primarily from China, the Taiwan Province of China, or the United States of America) tends to be expensive and was formerly difficult to acquire because the suppliers are mostly located in the northwest of the country where shrimp farmers are clustered. However, the internet has helped mitigate the logistic problem.

Inadequate or unstable electricity supply and high repairing or maintenance cost are two factors that hinder the effective use of aeration in tilapia farming. Even with functioning aeration equipment, farmers who lack experience and/or equipment (e.g. oxymeters) for water quality control may suffer from fish mortality from inadequate aeration or may incur unnecessary energy cost from overaeration. Therefore, aeration is an important topic in outreach and training activities.

3.3 Seed

In the period 1975–1985, the federal government and state governments established tilapia hatcheries in almost all the states, especially in areas with warm water temperature that is conducive to tilapia growth. As mentioned above, these hatcheries were in charge of the reproduction and stocking of public waters and for supplying fry or fingerlings to farmers, especially to low-income farmers. At their peak, up to 30 government-run hatcheries were operating in the country. Most of them were shut down for multiple reasons (a lack of budget or water supply, inefficient operations, union disagreements, etc.). Ten of them are still in operation today; four of which have been transferred to state governments; one was leased to a private owner for 30 years (CONAPESCA, 2014). In the past eight years, budget cuts have negatively impacted production in public hatcheries with declining facilities and personnel. Currently, most tilapia farmers prefer fingerling supply from private hatcheries.

Since the mid-1990s, new technologies such as artificially breeding tilapias in incubators and sex reversal have resulted in faster tilapia growth and higher yield, which has turned tilapia farming into an attractive investment in Mexico, especially with the declined supply of wild tilapia from capture fisheries. Investments in private hatcheries flourished as the seed supply from government hatcheries was reduced. During 2014–2018, government financial support of between 50 and 80 percent of the capital investment allowed for the development of private hatcheries under special conditions, norms and rules.

While a variety of tilapia species have been introduced in Mexico over the years (Table 8), the genetically improved farmed tilapia (GIFT) strains of *Oreochromis niloticus* are currently the most popular lineages cultured by Mexican farmers under different local names (Plate 7). In 2007, a GIFT strain was imported from the Norwegian company AKVAFORSK based in Viet Nam. The faster growth of this strain immediately attracted the attention of farmers and hatcheries. At present, GIFT is the baseline genetic lineage in virtually all private hatcheries with different strain names, and GIFT is a register brand in Mexico for Tecnopez, SPR de RL.

The technology of sex reversal through 17α-methyltestosterone, which was introduced to Mexico from the United States of America in 1997, has significantly improved the productivity of tilapia farming in Mexico. The monosex seed (above 95 percent male tilapias) has helped reduce the growth period of 500 g fish from 8–9 months to 5–6 months. While the access to 17α-methyltestosterone was relatively easy at the beginning, it is currently under government control, and only one feed company in Mexico has the official permit to sell special feed with 17α-methyltestosterone.

Plate 7

Left: Genetically improved farmed tilapia (GIFT)
Right: Pargo UNAM, a red tilapia strain with *Oreochromis niloticus* genome

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The Aquaculture Tropical Station attempted to crossbreed *O. aureus* × *O. mossambicus* in 1974 and achieved 85 percent males F1. In 1981, crossbreeding between *O. niloticus* × *O. aureus* not only gave a similar male rate but also resulted in a better fish (i.e. more desirable shape, faster growth and hardier). In 1981, a national programme focused on red tilapia (*O. mossambicus* × *O. hornorum*), which is supposed to produce all male offspring with pure breeders. There were also efforts in the research communities to improve tilapia strains, including (i) Mexican postgraduate students at the University of Stirling conducting research under the Tilapia Genetic Improvement Programme at WorldFish; (ii) the establishment of the Tilapia Genome Bank by the State University of Guadalajara and Colima; and (iii) the development of the strain PARGO UNAM (a hybrid from Florida red tilapia crossed with Tilapia Stirling and Rocky Mountain tilapia) (Table 8; Plate 7) developed by the National Autonomous University of Mexico (UNAM) (Muñoz-Córdoba and Garduño-Lugo, 2003).

Table 8: Farmed tilapia species or strains in Mexico

Year	Species	Local name	Source	Site of arrival
1964	*Oreochromis aureus*	Tilapia	United States of America, Alabama (Auburn University)	Temascal, Oaxaca
	O. mossambicus			
	T. melanopleura (sin. *T. zillii*; *Coptodon zillii*)			
1981	*O. mossambicus* × *O. hornorum*	Florida red tilapia	United States of America, Florida	El Rodeo, Morelos
1981	*O. niloticus*	Tilapia Nilótica	Panama	Temascal, Oaxaca and diverse national hatcheries
1990	*O. aureus* (white)	Rocky Mountain tilapia plateada	United States of America, Colorado	Soto La Marina, Tamaulipas
1996	*O. niloticus*	Tilapia Stirling	United Kingdom, Scotland (University of Stirling)	La Antigua, Veracruz
2000	*O. niloticus* × Florida red tilapia × Rocky Mountain tilapia	Pargo UNAM	Mexico, Veracruz	CEIEGT, FMVZ, UNAM, Mexican strain
2000	*O. mossambicus* × *O. hornorum*	Tilapia dorada or golden tilapia	United States of America, California	Coquimatlán, Colima
2001	*O. mossambicus* × *O. hornorum*	Tilapia dorada or golden tilapia	United States of America, California	Jala, Colima
2007	*O. niloticus*	Tilapia GIFT	Viet Nam	Tecnopez Hatchery (Plate 8), Medellin, Veracruz
2009	*O. niloticus* × *O. mossambicus* × *O. aurea*	Tilapia Spring	Viet Nam	Tecnopez Hatchery (Plate 8), Medellin, Veracruz
2011	*O. mossambicus* × *O. hornorum*	Tilapia Roja Cubana	Cuba	Zacatepec, Morelos and Culiacán, Sinaloa

Source: Soledad Delgadillo, personal research for Tilapia México Network conducted in 2020.
Note: GIFT = genetically improved farmed tilapia.

For four decades, from the 1970s up to 2010, tilapia fingerlings were provided by federal or state hatcheries to farmers free of charge, especially to low-income farmers. With the establishment of private hatcheries responding to the shortage of good quality tilapia seed supply, free seeds are now obsolete, and farmers usually need to pay for fingerlings from public hatcheries.

Currently, the price of tilapia fingerlings varies between MXN 0.70 (USD 0.035) and the usual price of MXN 1 per 1-g fingerling (USD 0.05), depending on the seasonality, size and location. The transportation freight, which is usually paid by the client, is primarily determined by the distance, regardless of the amount of tilapia fingerlings sold.

Tilapia seed production in Mexico is a lucrative business, attractive to private investments that help establish state-of-the-art hatchery operations (Plate 8). It is estimated that 41 large private hatcheries had a production capacity of 327 million tilapia fingerlings as compared to 40 million fingerlings in 27 large public hatcheries (Table 9).

While AREL/micro and small tilapia farms usually rely on purchased seed, many medium and large farms produce their own fingerlings. The recent suspected tilapia lake virus (TiLV) situation has made large farms more apt to produce their own fingerlings in order to have more control over the seed quality. There is no official report by the National Agro-Alimentary Health, Safety and Quality Service (SENASICA) about the TiLV impact on hatcheries. The current major concern for tilapia fingerling diseases is bacterial infections from *Flexibacter columnaris*. For the juveniles and adults, more damage is caused by *Streptococcus* sp., *Aeromonas* sp. and *Pseudomonas* sp.

Plate 8
Tecnopez tilapia hatchery (Potrerillos, Medellín, State of Veracruz de la Llave)

Table 9: Tilapia seed production capacity by major hatcheries in Mexico

ID #	State	Tilapia seed production capacity (number of fish)		
		Public hatcheries	Private hatcheries	Total
7	Chiapas	788 644	142 600 000	143 388 644
27	Tabasco	1 040 000	62 400 000	63 440 000
14	Jalisco	7 000 000	50 600 000	57 600 000
30	Veracruz	1 550 000	18 830 000	20 380 000
4	Campeche		18 000 000	18 000 000
25	Sinaloa	5 378 800	8 000 000	13 378 800
26	Sonora	5 000 000	6 000 000	11 000 000
13	Hidalgo		10 200 000	10 200 000
31	Yucatán		6 000 000	6 000 000
6	Colima	2 142 360	2 500 000	4 642 360
28	Tamaulipas	3 869 200		3 869 200
16	Michoacán de Ocampo	3 600 000		3 600 000
1	Aguascalientes	2 454 500		2 454 500
20	Oaxaca	1 069 170	960 000	2 029 170
17	Morelos	1 908 980		1 908 980
32	Zacatecas	1 731 000		1 731 000
21	Puebla	600 000		600 000
23	Quintana Roo		600 000	600 000
18	Nayarit	500 000		500 000
22	Querétaro	386 700		386 700
10	Durango	331 360		331 360
5	Coahuila de Zaragoza	315 000		315 000
15	México	240 000		240 000
8	Chihuahua	234 700		234 700
11	Guanajuato	158 675		158 675
Total		**40 299 089**	**326 690 000**	**366 989 089**
Number of hatcheries		**27**	**41**	**68**
Share of total production (%)		**11**	**89**	**100**

Source: Estimation by Soledad Delgadillo and Edmundo Urcelay based on CONAPESCA (2020) and personal communication with farmers. The production capacity of public hatcheries reflects the situation in 2018, whereas that of private hatcheries reflects the situation in 2019.
Notes: See Figure 3 for the location of each state. The 27 public hatcheries include 16 federal hatcheries (CONAPESCA), 8 state hatcheries and 3 university hatcheries. There are many more small-scale hatcheries with irregular or occasional production and uncertain quality.

3.4 Feed

According to an industry report prepared by the National Council of Balanced Feed Manufacturers and Animal Nutrition A.C. (CONAFAB, 2019), the production of aquafeed in Mexico was 0.38 million tonnes in 2018, which was only 1.1 percent of the country's total formulated feed production for various purposes (fish farming, livestock farming, etc.).

Aquafeed manufacturing is one of the fastest growing industries in Mexico largely thanks to the demand from tilapia aquaculture. Tilapia feed production in Mexico increased from 28 000 tonnes in 2009 to 121 600 tonnes in 2018, which accounted for nearly one-third of the country's aquafeed production.

Tilapia feed supply is generally good in Mexico, yet places that are far from major feed plants (mostly located in Central Mexico) may have difficulties in accessing feed supply. In rural areas, tilapia feeds are usually sold in small stores, many of which may not be specialized feed stores (e.g. aquafeed sold in a veterinary pharmacy store). Some large tilapia farmers buy a large volume of aquafeed not only for their own use but also to resell the feed to smaller farmers to recover transportation costs or even to earn some profit. AREL/micro farmers usually do not have their own vehicles and use public transportation (e.g. bus or smaller vans) to transport a few bags of feed to their farms. Sometimes feed sellers deliver feed to an AREL/micro farm that purchases more than MXN 5 000 (USD 250). The practices are diverse and informal, depending on local conditions and personal arrangements and even the friendship between farmers and feed suppliers.

3.5 Water

Under the laws and regulations established by the National Commission of Water (CONAGUA) – see the discussion in section 5.1 – water use in Mexico's aquaculture has been treated as a relatively more expensive industrial use until recently. However, while the removal of aquaculture from the category of industrial use helps alleviate its economic burden, aquaculture has yet to be treated as an agricultural activity subject to a more favourable water use charge. CONAGUA also regulates the cost of the water outflows from tilapia farms and other aquacultural activities, and the quality of the outflows must be checked out twice a year by a certified laboratory at a high cost. Severe penalties are in place for unpaid fees.

Fish farmers in Mexico have often argued that water use in aquaculture is not consumptive and hence should not be charged against the entire quantity that flows in the farming systems. The quality of aquaculture effluents is another cost factor. Although discharge costs are generally high, sometimes they can be reduced by proving the good quality of the effluents. Water quality tests may detect traces of heavy metals and other pollutants that are clearly not introduced by fish farming operations, which means that fish farms may need to pay for the pollution in water inflows. The water quality tests per se represent an extra cost that could be burdensome for fish farmers, especially for AREL/micro or small farmers.

With increasing water scarcity due to climate change and population growth, aquaculture tends to face an increasing shortage of water supply. On the other hand, farmers would need more water to compensate for the increasing evaporation losses due to the warmer climate. The conflict means that tilapia farmers are expected to have less water available for their operations and at a higher cost, which tends to lead to lower profitability in tilapia farming (Loaiza Vega, 2013). Water-saving technologies and farming systems (e.g. recirculating aquaculture systems [RAS], biofloc and in-pond raceway system [IPRS], among others) can help improve water efficiency in tilapia farming. Yet their relatively high technical and financial requirements currently make them less profitable means of tilapia production in Mexico (Verdugo Mora, 2009).

Cage culture, which has been the main contributor to the tilapia aquaculture growth in Mexico in recent years, is considered not a consumptive use of water. However, dams and reservoirs in Mexico were not built for aquaculture; hence, the management authorities of these waterbodies usually do not give priorities to cage farming. Oftentimes water is extracted without properly considering the impacts on cage operations established in the waterbodies. In some places (e.g. Sinaloa and Chiapas), there have been incidences in which the opening of the dam gate, decided by the water management authority, caused huge mortalities in tilapia cages operating onsite due to the resuspension of organic matter underneath the cages, originated from feeding practices.

Water quality in dams and lakes are highly susceptible to the feeding practices of cage farms. When assigning farming permits, the decision maker should follow the environmental impact assessment and an ecosystem approach, where a critical element is the carrying capacity study of the waterbody, including its dynamics. Unfortunately, in many cases, such studies have not been readily available, and cage farming permits were granted without a clear understanding of the carrying capacity of the farming environment. This tends to affect not only the water quality in the waterbody but also the technical and economic performance of the operation. For example, eutrophication could cause the proliferation of water hyacinth (Plate 9), which tends to lower the dissolved oxygen level in the water and results in disease outbreaks and fish mortalities.

Plate 9
Invasion of water hyacinth in Peñitas Lake, Chiapas

© J. Albores

3.6 Electricity

In Mexico, electricity is supplied by the Comisión Federal de Electricidad (CFE), a state-owned enterprise. The fee varies across different types of usage (domestic, industrial, agricultural or mining) and depends on the working hours (more expensive for daytime than nighttime). Semi-intensive and intensive aquaculture usually uses a large amount of electricity. Expensive electricty often makes it the third largest operating cost after feed and salaries.

In Mexico, electricity is, in general, expensive for aquaculture (around USD 0.044/kWh). After many years of efforts, however, a 50 percent discount for aquaculture farmers has been obtained. However, the subsidy is applicable only to registered farmers for up to a certain amount of electricity consumption. Some farmers have installed solar panels and photovoltaic devices to lower electricity expenses. However, doing so would disqualify them for the electricity subsidy because there are already subsidies on the acquisition of photovoltaic panels in agriculture/aquaculture.

4. SOCIAL AND ECONOMIC DIMENSIONS OF TILAPIA FARMING IN MEXICO

Table 5 in section 3.1 provides a glimpse of diverse tilapia farms in Mexico. A more in-depth assessment is conducted in this chapter based on field data from a three-year project funded by the National Council of Science and Technology (CONACYT), which allowed extensive fieldwork in the states of Guerrero, Oaxaca and Chiapas. Detailed information generated by the project is also used for an analysis on the role of tilapia farming on poverty and vulnerability of micro and small farmers discussed in the last chapter.

4.1 Technical and economic performance of tilapia farming in Mexico

The technical and economic performance of 64 small tilapia farms in 2018 (including 36 cage farms, 25 tank farms and three earth-pond farms) in the states of Chiapas, Guerrero and Oaxaca is summarized in Table 10.

All these farms earned positive gross profits, although for slightly different reasons. While the cage farms faced relatively low farmgate prices because of competition among fellow cage farmers, as well as from capture fisheries tilapia production, they earned money by maintaining relatively low operating costs. In contrast, while tank farms generally had a higher operating cost, their operations were also profitable through targeting niche markets that offer premium prices for high-quality, fresh/live tilapias. The three pond farms had relatively low operating costs similar to the cage farms, and their relatively high sales prices are similar to the tank farms. But the relatively small number of pond farms in the sample may not be representative.

Table 10: Technical and economic performance of AREL/micro and small tilapia farms in Southwest Mexico

Technical or economic indicators	All (64 cases)		Cage (36 cases)		Earthen pond (3 cases)		Tank (25 cases)	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Production								
Harvest size (g)	494	[250, 1 000]	594	[300, 1 000]	292	[250, 375]	375	[250, 700]
Production (kg)	2 509	[80, 12 000]	3 863	[667, 12 000]	1 428	[800, 2 000]	690	[80, 1 500]
Seed								
Fingerling size (g)	1.2	[0.3, 10]	1.0	[0.3, 2]	1.0	[1, 1]	1.5	[0.6, 10]
Fingerling price (USD/fish)	0.05	[0.02, 0.13]	0.05	[0.04, 0.06]	0.02	[0.02, 0.02]	0.07	[0.02, 0.13]
Survival rate (%)	62	[18, 94]	63	[18, 90]	83	[80, 88]	59	[27, 94]
Fingerling cost (USD/kg of production)	0.26	[0.05, 1.09]	0.17	[0.05, 0.51]	0.07	[0.05, 0.08]	0.41	[0.05, 1.09]
Fingerling share in operating cost (%)	15	[2, 47]	12	[4, 33]	7	[4, 9]	20	[2, 47]
Feed								
Feed price	0.71	[0.51, 1.22]	0.66	[0.54, 0.79]	0.82	[0.6, 1.22]	0.76	[0.51, 1.11]
Feed conversion ratio	1.5	[0.9, 3.4]	1.5	[1, 2.1]	1.2	[1, 1.4]	1.5	[0.9, 3.4]
Feed cost (USD/kg of production)	1.07	[0.63, 2.13]	1.02	[0.63, 1.34]	0.96	[0.76, 1.22]	1.15	[0.69, 2.13]
Feed share in operating cost (%)	72.4	[36, 96]	76.7	[46, 96]	91.9	[90, 94]	63.8	[36, 92]
Energy								
Energy cost (USD/kg of production)	0.19	[0.03, 0.71]	0.14	[0.03, 0.34]	n.a.	n.a	0.25	[0.03, 0.71]
Energy share in operating cost (%)	11	[2, 32]	11	[2, 21]	n.a.	n.a.	12	[3, 32]
Profit								
Operating cost (USD/kg of production)	1.55	[0.75, 3.22]	1.34	[0.75, 2.1]	1.04	[0.84, 1.3]	1.93	[0.83, 3.22]
Farmgate price (USD/kg)	2.72	[1.54, 5.66]	2.03	[1.54, 3.09]	2.92	[2.32, 3.35]	3.70	[2.32, 5.66]
Gross profit (USD/kg of production)	1.17	[0.22, 3.59]	0.69	[0.22, 1.82]	1.88	[1.48, 2.12]	1.77	[0.38, 3.59]
Gross profit margin (%)	40	[9, 71]	33	[9, 71]	65	[61, 69]	47	[11, 69]
Gross profit (USD/crop)	2 164	[42, 12 164]	2 713	[232, 12 164]	2 562	[1 700, 3 032]	1 325	[42, 4 791]

Source: Based on the survey of 64 farms in Mexico, including 21 farms in Chiapas (12 cage farms, 3 earthen pond farms and 6 tank farms), 14 farms in Guerrero (all cage farms), and 29 farms in Oaxaca (10 cage farms, and 19 tank farms that include 4 AREL/micro tank farms).

Note: AREL = resource-limited aquaculture.

Capital costs

AREL/micro earthen pond system (150 kg production per year)

An AREL/micro farm with a small earthen pond costs USD 137 to establish (Table 11), including USD 51 for constructing an 8 m × 4 m × 1 m pond and USD 86 for auxiliary facilities (mostly a protecting fence). The unit investment cost and annual depreciation of the small pond system is, respectively, USD 4.28/m^3 and USD 19.6/year.

Table 11: Investment and capital cost of AREL/micro pond farm

Investment item	AREL/micro pond farm (1 pond; 8 m × 4 m × 1 m = 32 m^3; 1.56 kg/m^3 carrying capacity, three crops; 150 kg production per year)				
	Initial investment		Depreciation		
	Total investment (USD)	Unit cost (USD/m^3)	Depreciation period (years)	Annual depreciation (USD/year)	Depreciation per unit of production (USD/kg)
Culture system	**137**	**4.28**	**n.a.**	**19.6**	**0.131**
Pond excavation	51	1.59	20	2.6	0.017
Protecting fence	67	2.09	5	13.4	0.089
Wooden poles	12	0.38	5	2.4	0.016
Wire	6	0.19	5	1.2	0.008

Note: AREL = resource-limited aquaculture.

With frequent water exchange for aeration, the small earthen pond system can be used to culture tilapias semi-intensively with 1.56 kg/m^2 carrying capacity, which could yield 150 kg per year through three crops of operation. This implies the annual fixed cost of USD 0.131 per kilogram of production (Table 11).

Without sufficient water supply or other economic aeration mechanisms, such a small earthen pond system may be suitable only for extensive tilapia farming with lower density because of technical constraints such as difficulties in controlling water quality. The resulting lower yield would tend to make the annual capital cost higher.

AREL/micro tank system (255 kg per year)

An AREL/micro circular plastic tank farm with one circular tank (6 m diameter and 1 m deep resulting in 28 m^3 capacity) needs USD 467 initial investment, mostly for purchase/construction of the tank (Table 12). The unit cost and annual depreciation are, respectively, USD 16.5/m^3 and USD 52/year, which are much higher than those of the AREL/micro pond system (Table 11). Even the 255 kg annual production of the AREL/micro tank system is 1.7 times that of the AREL/micro pond system; its capital cost per unit of production (USD 0.204/kg) is still higher than the AREL/micro pond system (USD 0.131/kg).

Table 12: Investment and capital cost of AREL/micro tank farm

Investment item	AREL/micro tank farm (1 tank; 6 m diameter; 1 m depth = 28.3 m^3; 2.96 kg/m^3 carrying capacity; 255 kg production a year)				
	Initial investment		Depreciation		
	Total investment (USD)	Unit cost (USD/m^3)	Depreciation period (years)	Annual depreciation (USD/year)	Depreciation per unit of production (USD/kg)
Culture system	**467**	**16.5**	**n.a.**	**52.0**	**0.204**
Tank	412	14.6	10	41.2	0.162
Protecting fence	33	1.2	5	6.6	0.026
Wooden poles	15	0.5	5	3.0	0.012
Wire	6	0.2	5	1.2	0.005

Note: AREL = resource-limited aquaculture.

AREL/micro cage system (500 kg per year)

An AREL/micro cage system that yields 500 kg production a year needs only USD 52 initial investment (Table 13), which is much lower than the AREL/micro tank system (Table 12) and the AREL/micro pond system (Table 11). Although the cage system is less durable than the tank system and the pond system, its unit investment cost and annual depreciation (USD 5.2/m^3 and USD 0.02 per year) are much lower. This reflects the conducive farming environment of cage culture in large waterbodies (dams, reservoirs, lagoons, etc.).

Table 13: Investment and capital cost of AREL/micro cage farm

Investment item	AREL/micro cage farm (10 cages; 1 m × 1 m × 1 m each = 10 m^3; 25 kg/m^3 carrying capacity; two crops; 500 kg production a year)				
	Initial investment		Depreciation		
	Total investment (USD)	Unit cost (USD/m^3)	Depreciation period (years)	Annual depreciation (USD/year)	Depreciation per unit of production (USD/kg)
Culture system	**52**	**5.2**	**n.a.**	**12.3**	**0.02**
Cage	38	3.8	5	7.6	0.02
Protecting net cover	5	0.5	3	1.7	0.00
Food control fence	9	0.9	3	3.0	0.01

Note: AREL = resource-limited aquaculture.

Small pond farm (50 tonnes per year)

Establishing a small pond farm specified in Table 14 costs around USD 100 000, producing 50 tonnes of farmed tilapia with a 9 000 m^3 pond facility. The cost of pond construction accounts for only 15.2 percent of the total investment, which is smaller than the cost of land (18.2 percent) and building (26.5 percent) and similar to that of a backup power plant (15.2 percent).

The small pond farm's annual depreciation cost of pond construction (USD 0.015 per kilogram of production; Table 14) is lower than the USD 0.17/kg for the AREL/micro pond farm (Table 11), which reflects the higher productivity of intensive pond culture.

However, the small pond farm's annual depreciation cost of all fixed assets is USD 0.182 per kilogram of production, over 70 percent of which comes from the depreciation of equipment and machinery that generally have a shorter lifespan than ponds and other facilities (Table 14).

Table 14: Investment and capital cost of small pond farm

Investment component	Small pond farm (6 earthen ponds; 50 m × 20 m; 1.5 m depth; total 9 000 m^3; 50 tonnes production a year)					
	Initial investment		Annual capital cost			
	USD	Share of total investment (%)	Depreciation period (years)	Annual depreciation (USD/year)	Share of total annual depreciation (%)	Capital cost per unit of production (USD/kg)
Total investment or capital cost	**101 723**	**100.0**	n.a.	**9 124**	**100.0**	**0.182**
Pond construction	**15 443**	**15.2**	20	**772**	**8.5**	**0.015**
Other facilities	**53 180**	**52.3**	n.a.	**1 732**	**19.0**	**0.035**
Land	18 532	18.2	n.a.	-	-	-
Deep water well	7 722	7.6	20	386	4.2	0.008
Building	26 927	26.5	20	1 346	14.8	0.027
Equipment and machinery	**33 100**	**32.5**	5	**6 620**	**72.6**	**0.132**
Office furniture	1 287	1.3	5	257	2.8	0.005
Backup power plant	15 443	15.2	5	3 089	33.8	0.062
Aerators	6 074	6.0	5	1 215	13.3	0.024
Pumping system	6 177	6.1	5	1 235	13.5	0.025
Water quality and monitoring equipment	1 544	1.5	5	309	3.4	0.006
Tools: electric and mechanic	1 544	1.5	5	309	3.4	0.006
Harvest equipment	1 030	1.0	5	206	2.3	0.004

Small tank farm (50 tonnes per year)
The initial investment needed for a 50-tonne tank farm is around USD 140 000 (Table 15), which is higher than the investment needed for the 50-tonne pond farm (Table 14). The annual depreciation cost for the tank farm (USD 0.268 per kilogram of production) is also higher than that of the small pond farm (USD 0.182/kg).

While aerators and backup power plants account for, respectively, 12.4 percent and 10.9 percent of the initial investment, they account for, respectively 26.6 percent and 23.5 percent of the annual depreciation because of their relatively shorter depreciation period compared to tanks and other facilities. Tanks accounted for 43.4 percent of the initial investment and 23.3 percent of annual depreciation, and its annual depreciation is USD 0.061 per kilogram of production.

Table 15: Investment and capital cost of small tank farm

Investment component	Small tank farm (34 geomembrane circular tanks; 12 m diameter, 1 m depth; total 3 845 m^3; 50 tonnes production a year)					
	Initial investment		Annual capital cost			
	USD	Share of total investment (%)	Depreciation period (years)	Annual depreciation (USD/year)	Share of total annual depreciation (%)	Capital cost per unit of production (USD/kg)
Total investment or capital cost	**142,450**	**100.0**	n.a.	**13 412**	**100.0**	**0.268**
Tanks	**61 257**	**43.4**	20	**3 063**	**23.3**	**0.061**
Other facilities	**36 691**	**26.0**	n.a.	**1 448**	**11.0**	**0.029**
Land	**7 722**	**5.5**	n.a.	**-**	**-**	**-**
Deep water well	7 722	5.5	20	386	2.9	0.008
Building	21 248	15.1	20	1 062	8.1	0.021
Equipment and machinery	**44 502**	**30.6**	5	**8 900**	**65.7**	**0.178**
Office furniture	1 287	0.9	5	257	2.0	0.005
Backup power plant	15 443	10.9	5	3 089	23.5	0.062
Aerators	17 476	12.4	5	3 495	26.6	0.070
Pumping system	6 177	4.4	5	1 235	9.4	0.025
Water quality and monitoring equipment	1 544	1.1	5	309	2.3	0.006
Tools: electric and mechanic	1 544	1.1	5	309	2.3	0.006
Harvest equipment	1 030	0.7	5	206	1.6	0.004

Small cage farm (50 tonnes per year)

The initial investment cost (around USD 53 000) and annual depreciation (USD 0.126 per kilogram of production) of the 50-tonne cage farm (Table 16) are both smaller than those of the 50-tonne pond farm (Table 14) and tank farm (Table 15). Similar to the tank farm, equipment and machinery account for most of the annual depreciation cost.

Table 16: Investment and capital cost of a small cage farm

Investment component	Small cage farm (60 cages; 4 m × 4 m; 1.5 m depth; 50 tonnes production a year)					
	Initial investment		Annual capital cost			
	USD	Share of total investment (%)	Depreciation period (years)	Annual depreciation (USD/year)	Share of total annual depreciation (%)	Capital cost per unit of production (USD/kg)
Total investment or capital cost	**52 635**	**100.0**	n.a.	**6 287**	**100.0**	**0.126**
Culture system (cage)	**14 992**	**28.5**	10	**1 499**	**23.8**	**0.030**
Other facilities	**18 273**	**34.7**	n.a.	**914**	**14.5**	**0.018**
Building	13 099	24.9	20	655	10.42	0.013
Primary process facilities	5 173	9.8	20	259	4.1	0.005
Equipment and machinery	**19 371**	**36.8**	5	**3 874**	**61.6**	**0.077**
Boat and canoes	9 441	17.9	5	1 888	30.0	0.038
Outboard motors	8 000	15.2	5	1 600	25.4	0.032
Ice machine	1 416	2.7	5	283	4.5	0.006
Miscellaneous	515	1	5	103	1.6	0.002

Large cage farm (1 000 tonnes per year)

It costs around USD 300 000 to construct a large cage farm with 1 000 tonnes of annual production (Table 17). However, its annual depreciation (USD 0.0364) is much lower than the small cage farm (Table 16), reflecting significant economies of scale.

Table 17: Investment and capital cost of a large cage farm

Investment component	Large cage farm (75 cages; 12 m × 12 m; 5 m depth; 1 000 tonnes production a year)					
	Initial investment		Annual depreciation			
	USD	Share of total investment (%)	Depreciation period (years)	Capital cost (USD/year)	Share of total annual depreciation (%)	Capital cost per unit of production (USD/kg)
Total investment or capital cost	**321 063**	**100.0**	n.a.	**36 356**	**100.0**	**0.0364**
Culture system (cage)	**236 479**	**73.7**	10	**23 648**	**65.0**	**0.0236**
Other facilities	**28 055**	**8.7**	n.a.	**1 403**	**3.9**	**0.0014**
Building	24 452	7.6	20	1 223	3.36	0.0012
Primary process facilities	3 603	1.1	20	180	0.5	0.0002
Equipment and machinery	**56 529**	**18.0**	5	**11 306**	**31.1**	**0.0113**
Boat and canoes	32 678	10.2	5	6 536	18.0	0.0065
Outboard motors	21 921	6.8	5	4 384	12.1	0.0044
Ice machine	1 416	0.4	5	283	0.8	0.0003
Miscellaneous	515	0.2	5	103	0.3	0.0001

Operating costs

Feed

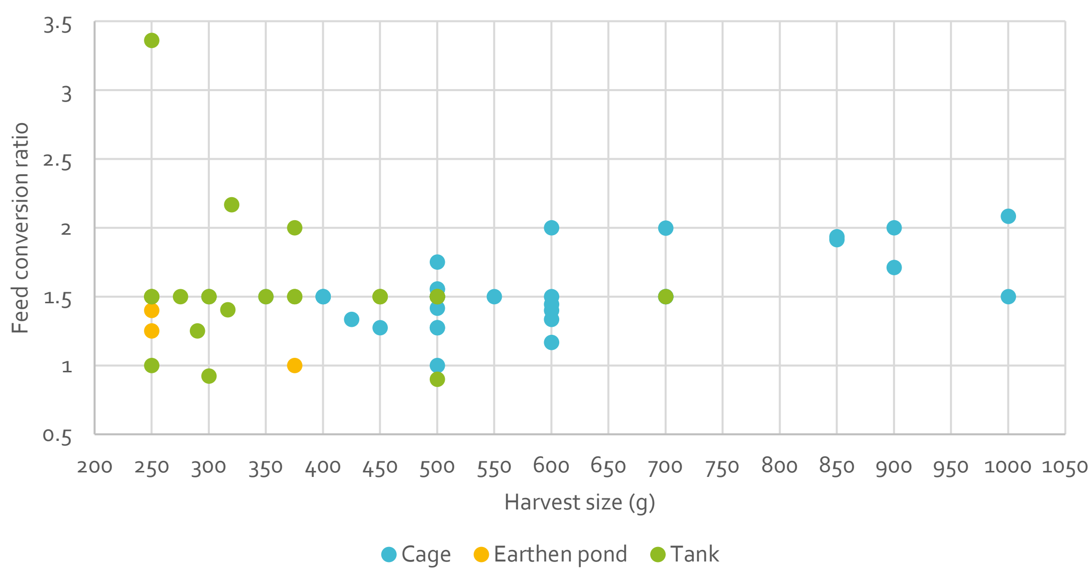
Tilapia farmers in Mexico follow the common practice of nursing tilapia fingerlings with high protein feed and using relatively low protein feed for outgrowing. The 30–32 percent crude protein (CP) content in the outgrowing feed is similar to the practice in Brazil (Barroso, Muñoz and Cai, 2019) yet higher than the 28 percent CP tilapia feed used in China (Cai *et al.*, 2018) and the 25 percent CP tilapia feed used in Egypt (El-Sayed, 2017).

In Mexico, the price of 32 percent CP tilapia feed is between USD 0.67/kg and USD 0.77/kg, depending mostly on the scale of operation. While an AREL/micro farm that purchases a small amount of feed needs to pay USD 0.77/kg, a medium or large farm not only enjoys the low price (USD 0.67/kg) but also may be able to purchase the feed on credit.

Feed price varies according to different CP contents. For example, the price of 30 percent CP feed is USD 0.62/kg (MXN 12/kg),[14] whereas the 45 percent CP feed for fingerlings is USD 1.45/kg. The USD 0.62/kg feed price (30 percent CP) is lower than the price level in China (around USD 0.67/kg; Cai *et al.*, 2018) yet higher than that in Brazil (around USD 0.55/kg for 32 percent CP feed; Barroso, Muñoz and Cai, 2019).

The feed conversion ratio (FCR) of the 64 farms in Table 10 was on average 1.5, ranging from 0.9 to 3.4. The highest FCR (3.4) appears to be an extraordinary case caused by poor farm management, whereas most of the high FCR is around 2. The FCR of the 36 cage farms was mostly between 1 and 1.5 for harvesting less than 600-g fish and between 1.5 and 2 for a larger harvest size between 700 g and 1 000 g (Figure 10). The FCR for earthen pond culture is relatively low (between 1 and 1.4).

Figure 10: Feed conversion ratio versus harvest size

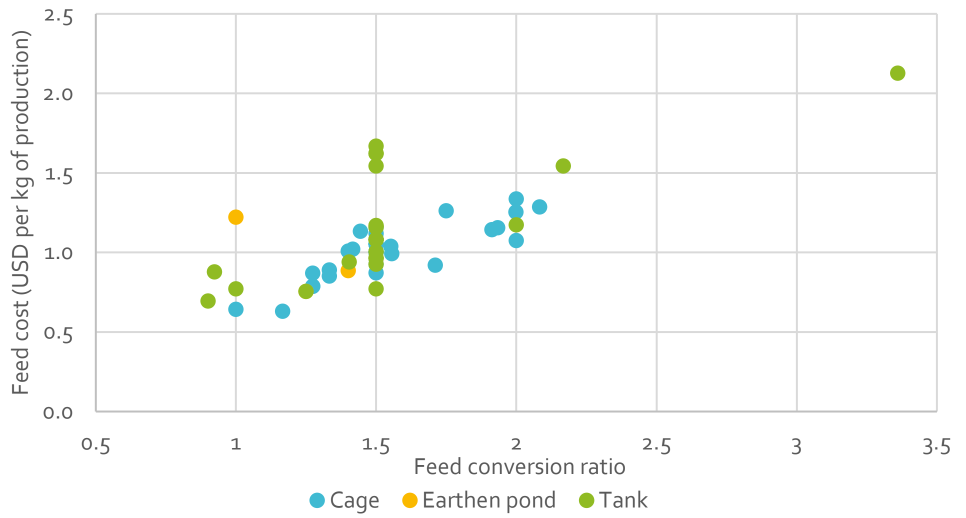


Source: Table 10.

[14] 1 MXN = USD 0.051.

The feed cost of the 64 farms was on average USD 1.07 per kilogram of production with nevertheless a wide range, from USD 0.63 to USD 2.13 (Table 10). FCR is a major factor affecting the feed cost – the feed cost was mostly below USD 1/kg of production for FCR ≤ 1.5, whereas it was above USD 1/kg for the farms with FCR ≥ 2 (Figure 11). However, the feed cost for the farms with FCR equal to 1.5 varied, from USD 0.77/kg of production to USD 1.68/kg of production, which primarily reflects the influence of feed price on the feed cost.

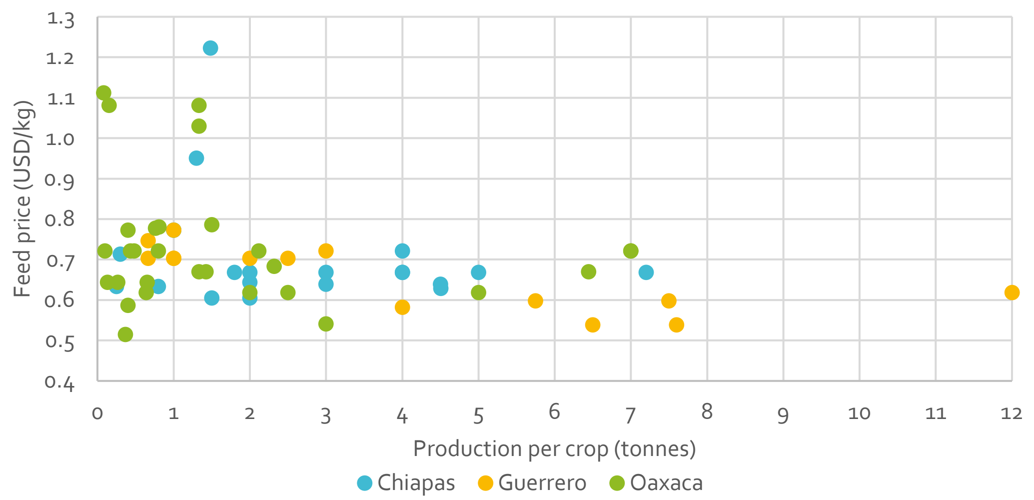
Figure 11: Feed cost versus feed conversion ratio



Source: Table 10.

The average feed price for the 64 farms in Table 10 was USD 0.71/kg, ranging from USD 0.51/kg to USD 1.22/kg. For the 14 farms in Guerrero, there was an obvious pattern of lower feed price with a larger operation (Figure 12). The feed price for the 21 farms in Oaxaca with no more than 2 000 kg production a crop varied from USD 0.51/kg to USD 1.11/kg (Figure 12), which reflects the influence of logistics on feed price.

Figure 12: Feed price versus production scale

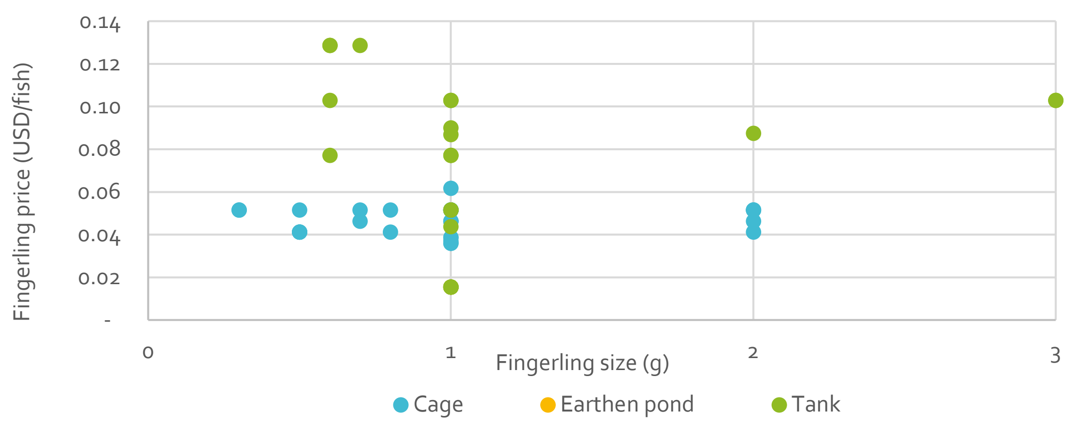


Source: Table 10.

Seed

As a common practice in Mexico, 39 farmers out of the 64 cases in Table 10 stocked 1-g fingerlings, and the fingerling price ranged from USD 0.015 to USD 0.102 per fish (average USD 0.047). Eight cases (including three pond farms that are not visible in Figure 13) bought fingerlings at the lowest price with local government support at the time of the survey (Figure 13). The USD 0.047 average price is higher than the USD 0.015 price for 1-g GIFT tilapia fingerlings in China (Cai *et al*., 2018). While the fingerling price was below USD 0.06/fish for most of the cage farms, it was above USD 0.08 for several tank farms (Figure 13).

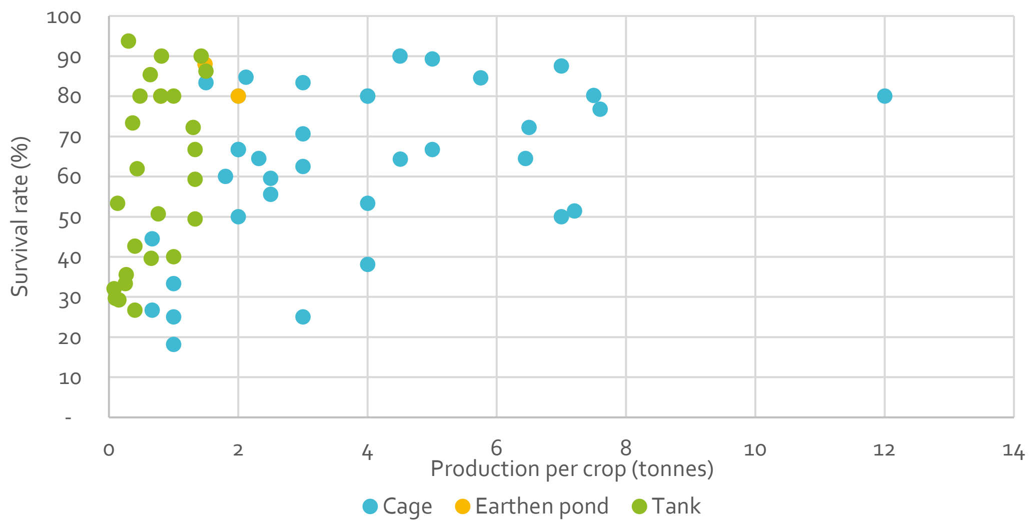
Figure 13: Fingerling price versus fingerling size



Source: Table 10.
Note: Three pond farms that are not visible in the chart used 1-g fingerlings at USD 0.015/fish.

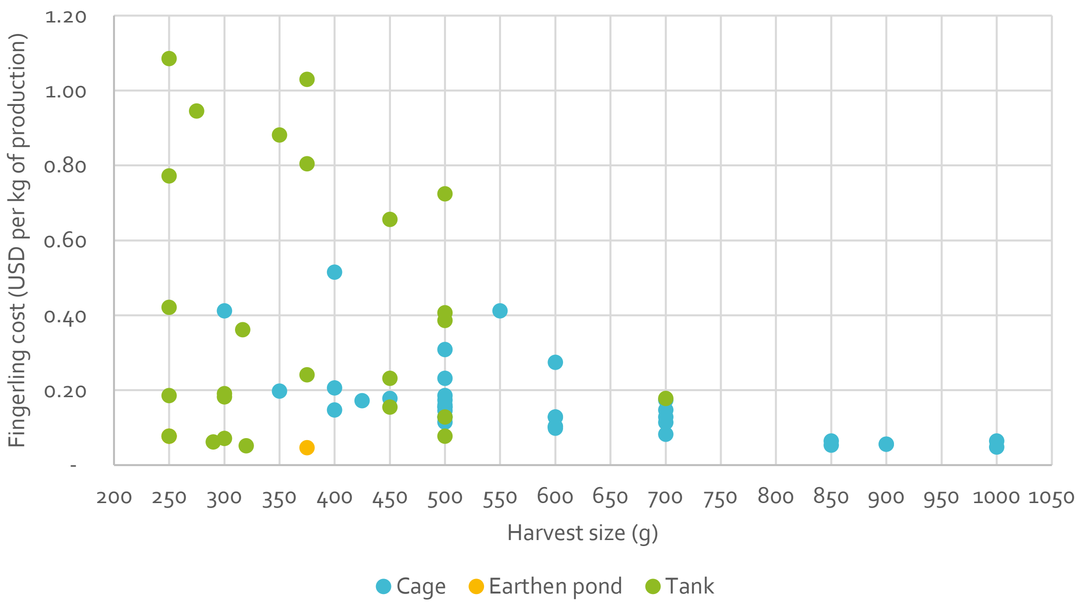
For the 64 cases, the survival rate was 62 percent on average with a wide range from 18 percent to 94 percent (Table 10; Figure 14). The fingerling cost per unit of production was USD 0.26 per kilogram of production on average, mostly less than USD 0.4/kg, and negatively correlated with harvest size (Table 10; Figure 15). While the fingerling cost was lower than USD 0.4 per kilogram of production for most of the cage farms, it was above USD 0.6/kg for some tank farms (Figure 15), which had a below average survival rate (Figure 16).

Figure 14: Survival rate versus production scale



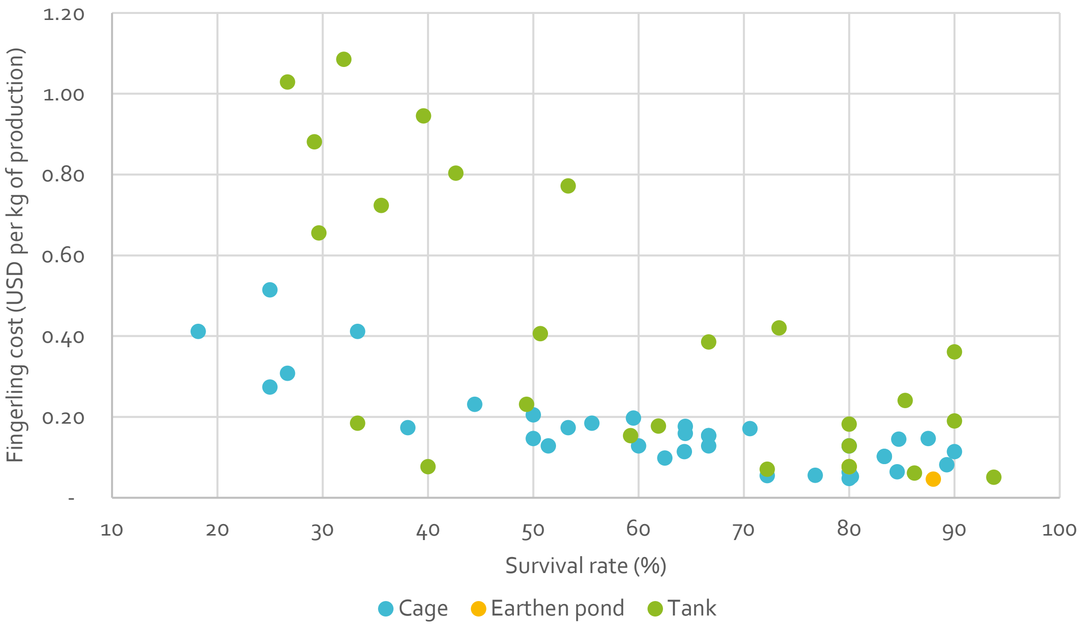
Source: Table 10.

Figure 15: Fingerling cost versus harvest size



Source: Table 10.

Figure 16: Fingerling cost versus survival rate

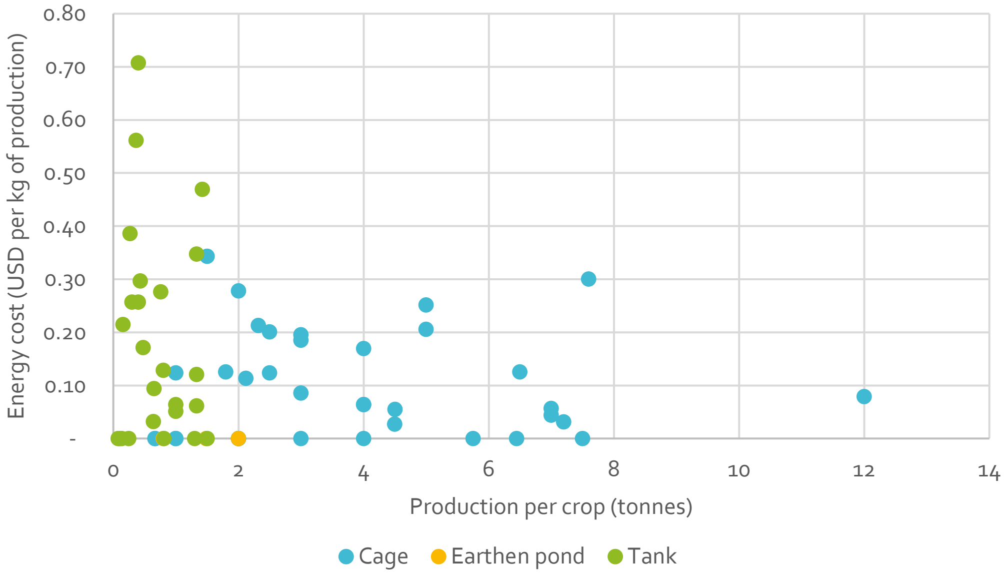


Source: Table 10.

Energy
Tilapia farmers who use electricity in pond or tank systems normally pay USD 0.044/kWh. Registered farmers can apply for a subsidy that can reduce the price by half. For a tank operation that needs to pump underground water and constant aeration, the cost of energy (electricity and/or fuel) could be over half of the operating cost.

The energy cost for the 64 farms ranged from USD 0.03 to USD 0.71 per kilogram of production with average USD 0.19/kg of production (Table 10). While the energy cost for most of the cage farms – from fuel consumption – was less than USD 0.2 per kilogram of production, that for some tank farms was higher than USD 0.3/kg of production (Figure 17).

Figure 17: Energy cost versus production scale



Source: Table 10.

Total operating cost

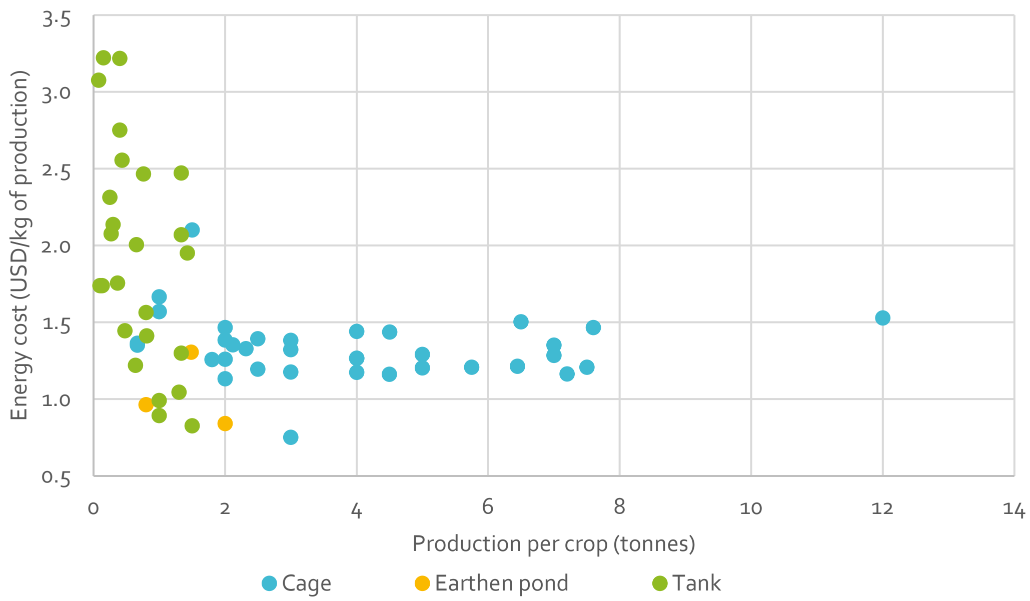
The operating cost of the 64 farms in Table 10 was USD 1.55 per kilogram of production on average and ranged from USD 0.75 to USD 3.22 per kilogram of production.

The average operating cost for the 36 cage farms (USD 1.34 per kilogram of production) was lower than that of the 25 tank farms (USD 1.93/kg of production), whereas that of the three pond farms (USD 1.04 per kilogram of production) was the lowest (Table 10).

While the operating cost of most of the cage farms was between USD 1 and USD 1.5 per kilogram of production, that of the tank farms varied significantly, from less than USD 1 to more than USD 3 per kilogram of production (Figure 18).

Feed was the largest cost item, accounting for on average 72.4 percent of the operating cost, followed by seed (average 15 percent) and energy (average 11 percent) (Table 10). The 64 farms primarily relied on unpaid family labour and hence had a minimal labour cost.

Figure 18: Operating cost per unit of production versus production scale



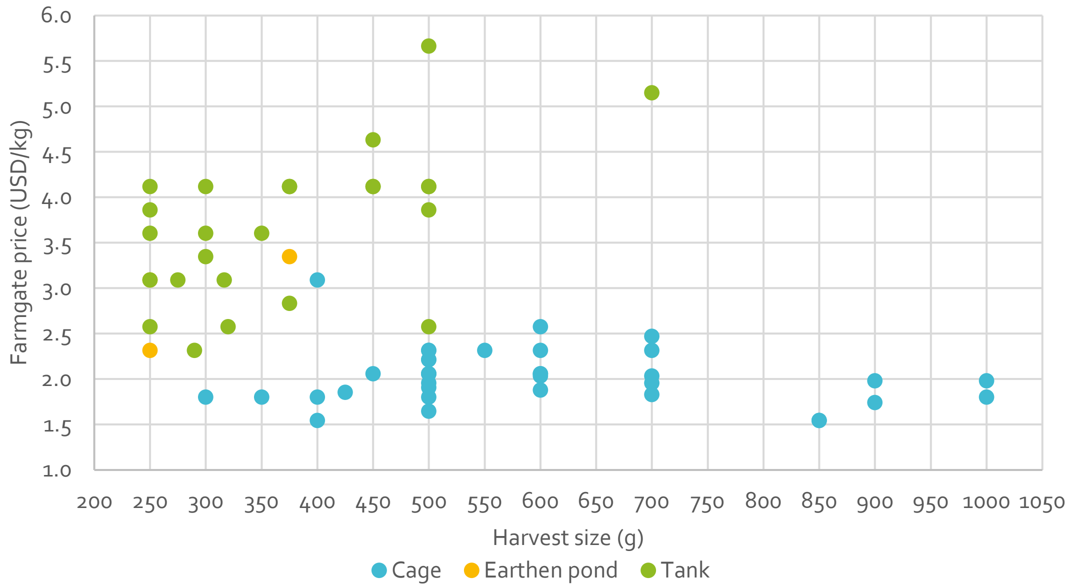
Source: Table 10.

Farmgate price

The farmgate price of the 64 farms was on average USD 2.72/kg, ranging from USD 1.54/kg to USD 5.66/kg (Table 10). While the farmgate price of most of the cage farms was between USD 1.5/kg and USD 2.5/kg, that of most of the tank farms was above USD 2.5/kg (Figure 19). The high farmgate price of these small suburban tank farms reflect their targeting niche markets in nearby cities that are willing to pay a premium price for high-quality, live tilapias, especially for special occasions (e.g. Easter and Christmas). Cage farmers, on the other hand, need to compete with each other as well as with wild tilapias supplied by fishers, and hence tend to be sold at relatively low prices.

While it tends to be more costly to produce large-size tilapias for which consumers are usually willing to pay a relative high price, large-size tilapias (above 800 g) produced by five cage farms did not appear to enjoy such price premiums (Figure 19).

Figure 19: Farmgate price versus harvest size



Source: Table 10.

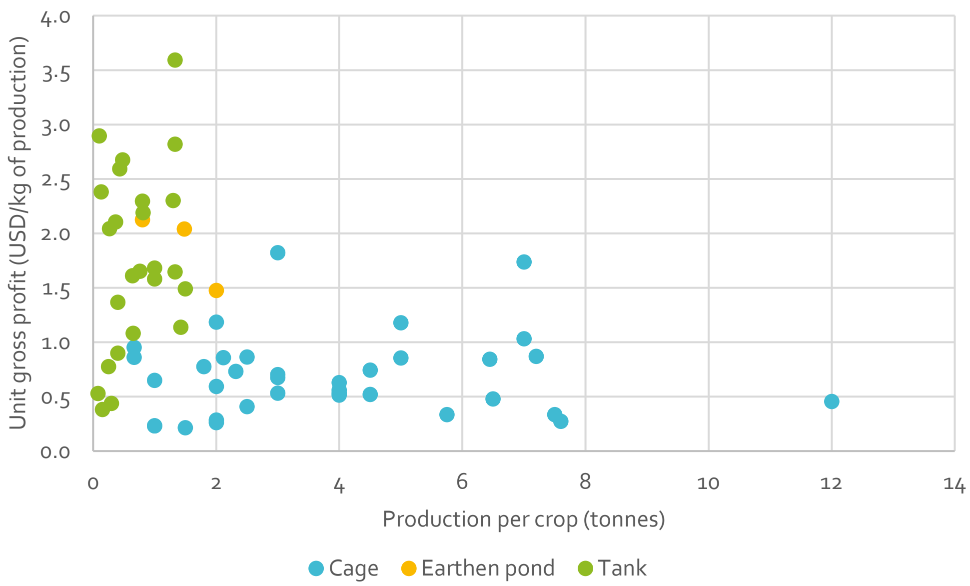
Gross profit

Gross profit is equal to sales revenue minus total operating cost, and gross profit per kilogram of production (unit gross profit in short) is equal to farmgate price minus operating cost per kilogram of production (unit operating cost in short).

The unit gross profit of the 64 farms was on average USD 1.17 per kilogram of production and ranged from USD 0.22 to USD 3.59 per kilogram of production (Table 10). The unit gross profit of most of the cage farms was below USD 1/kg of production, whereas that of most of the tank farms was above (Figure 20). Because of their relatively high farmgate prices (Figure 19), the tank farms had a relatively high unit gross profit (Figure 20) despite their relatively high operating cost (Figure 18).

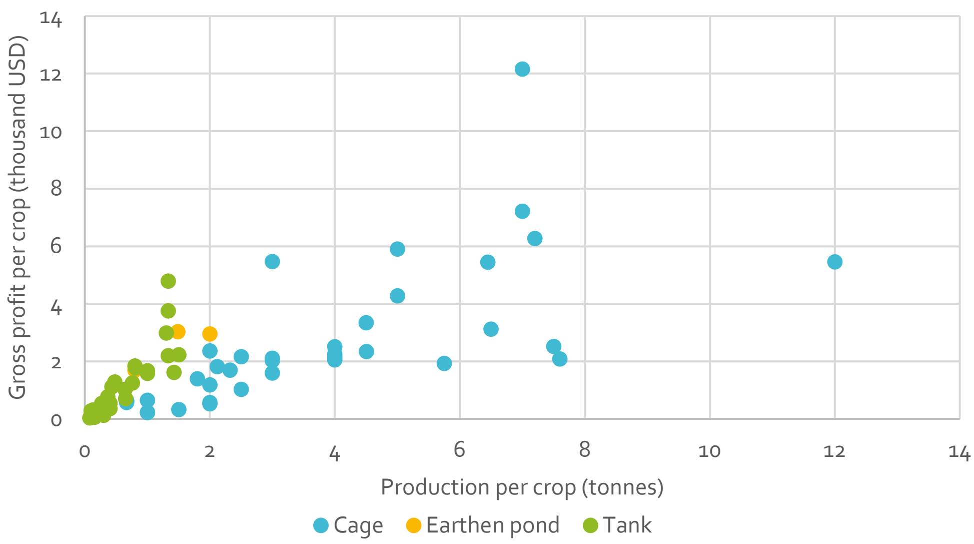
However, while most of the tank farms had less than USD 2 000 operating profits per crop because of their relatively small production scale (Figure 21), most of the cage farms had more than USD 2 000/crop operating profits (Figure 21) despite their relatively low unit operating profit (Figure 20).

Figure 20: Unit gross profit versus production scale



Source: Table 10.

Figure 21: Gross profit per crop versus production scale



Source: Table 10.

The annual depreciation of the small cage farm in Table 16 is USD 0.126/kg of production, which can be covered by the USD 0.69/kg of production average operating profit of the 36 cage farms in Table 10. Similarly, the USD 0.182/kg depreciation cost of the small pond farm in Table 14 can be covered by the average USD 1.88/kg of production average operating profit of the three pond farms in Table 10; the USD 0.268 depreciation cost of the small tank farm in Table 15 can be covered by the USD 1.77/kg of production average operating profit of the 25 tank farms (Table 10).

Therefore, the 64 operations with an average USD 2 164 operating profit a crop (Table 10) were generally profitable. However, as their operating profit ranging from USD 42/crop to USD 12 164/crop, the farms at the low end of operating profit tended to have insufficient operating profits to cover their fixed cost and the opportunity costs of their family labour input.

The above economic assessment is focused on small tilapia farms, yet the finding that tilapia farming operations are generally profitable tends to apply to medium, large or mega farms. Unfortunately, there is a general lack of detailed data to assess the performance of these farms, and more efforts are needed to fill the gap.

4.2 Social performance of tilapia farming in Mexico

Although AREL/micro and small-scale tilapia farming accounts for a small percentage of tilapia aquaculture production in Mexico, it has a significant contribution to the food security and livelihood of numerous households and has become an important node in the socio-economic fabric of rural and suburban areas in the country. Evidence from field surveys indicates that AREL/micro and small-scale tilapia farming in Mexico contributes to improving family nutrition, generating extra income, keeping family intact, discouraging emigration, and empowering women within the family. Family tilapia farming represents another production asset that generates employment. Therefore, the role and contribution of micro and small-scale tilapia farmers to the economy and social equity need to be reinforced and extended beyond production to processing and marketing through product differetiation (e.g labelling) and other measures to increase their competitiveness.

Contribution to food and nutrition

While Mexico’s 3.7 percent of prevalence of undernourishment in the total population in the mid-2010s was much lower than the world average of 10.7 percent, the country’s 8.9 percent of prevalence of severe food insecurity in the total population was slightly higher than the world average of 8.2 percent, and its 28.4 percent of prevalence of obesity in the adult population was more than twice the world average of 13.2 percent (FAO, 2019).

Fish contributed 7.6 percent of Mexico’s animal protein intake in 2013, which was less than half of the world average of 16.3 percent and lower than the country’s 9.2 percent fish share in animal protein intake in 1993 (FAO, 2019). The evidence indicates a great need and potential for increasing the contribution of fish to food security and nutrition in Mexico.

Tilapia aquaculture contributes to food and nutrition in Mexico not only through directly supplying high-quality animal protein but also through its income effect. According to the study of Martínez-Cordero and Sanchez-Zazueta (forthcoming), rural tilapia farmer households of micro, small and medium enterprises in the southern states of Chiapas, Guerrero and Oaxaca increased their fish and meat consumption from an average of 2.35 days a week to 2.96 days a week and increased the variety of animal protein diets.

Contribution to poverty alleviation

According to the National Council for the Evaluation of Social Development Policy, 52.4 million of the Mexican population (41.9 percent of total population) lived in multidimensional poverty in 2018, and 9.3 million (7.4 percent of total population) lived in extreme poverty.

A study of 133 tilapia farmers in the southwestern region of Mexico (Chiapas, Guerrero and Oaxaca where there is the highest percentage of total population in poverty) has revealed significant impacts of tilapia farming on poverty alleviation (Martínez-Cordero and Sanchez-Zazueta, forthcoming). The study indicates that (i) most tilapia farming households in the studied area are below the minimum well-being line – only 7 percent of the surveyed farmers are in no poverty or vulnerability situations; (ii) the surveyed tilapia farmers tend to be self-employed individuals with no access to government programmes and have a much higher vulnerability in multiple social factors (including food, housing conditions, basic residential services, health services, social security and education) than the municipal, state and national averages; (iii) the share of surveyed farmers in extreme or moderate poverty conditions is lower than the average levels in the municipalities and states where they are located; and (iv) cage tilapia farming, which usually occurs in isolated rural areas near dams or lakes, tends to have a more significant impact on farmers' income than earthen pond or tank farming which tends to occur in suburban areas.

Gender

Mexican women actively participate in tilapia aquaculture (Plate 10), especially on AREL/micro farms. Often considered the core of an AREL/micro tilapia farm, women are in charge of feeding and other daily farm management activities with the help of male family members (e.g. husbands who usually spend most of their time in agricultural fields) and other family members (e.g. children). In addition to feeding the family with tilapias weekly, women are also good salespersons and sometimes diversify the sales by offering fried tilapias or other on-farm food catering businesses.

Commercial tilapia farms usually hire women for primary processing, such as cleaning, scaling, gutting and packing (Plate 11). These women are efficient and dedicated, and they usually receive fair pay. Women also contribute as technicians and administrators in the tilapia sector (Plate 11). There are many women conducting research and outreach activities related to tilapia farming in the field. These women speak local dialects, know how to read and do calculations, and they are very patient and keen in following instructions in training processes and deemed more responsible than men in most of the cases. In Mexico, it is common that women hold high positions in administration of aquaculture farms.

Plate 10

Top left: Female farmer in Soyaltepec, Oaxaca, feeding tilapias in a cage farm co-managed with her two sisters, one of whom used the income to fund her university studies

Bottom left: Farmer in Caracol tending tilapias in a farm with 10 cages (1 m^3 each producing 50 kg of fish)

Right: Tilapia cage farmers in San Julian lagoon, Veracruz, showing their harvest

© S. Delgadillo

Plate 11

Mexican women participation in the tilapia sector

© S. Delgadillo

5. GOVERNANCE AND INSTITUTIONS

5.1 Institutional, legal and regulatory framework

National Commission of Aquaculture and Fisheries (CONAPESCA)

The National Commission of Aquaculture and Fisheries (CONAPESCA), a subsidiary of the Secretary of Agriculture and Rural Development (SADER), was created in 2001 and is responsible for the design and operation of the federal government's public policies related to aquaculture and fisheries. The main functions of CONAPESCA are to manage and promote aquaculture and fisheries and to enforce laws and regulations related to the sector.

National Institute of Fisheries and Aquaculture (INAPESCA)

The National Institute of Fisheries and Aquaculture (INAPESCA) was originally established in 2001 as the National Fisheries Institute and had its name changed to the present one in 2017 to recognize the importance of aquaculture. INAPESCA and CONAPESCA, through coordinated work, conduct the decision-making processes related to fisheries and aquaculture through scientific and technological research. INAPESCA publishes the National Fisheries Chart and the National Aquaculture Fisheries Chart, which are an inventory and summary of all aquaculture and fisheries resources in federal waterbodies, and has along the years established them as key instruments for the management of fisheries and aquaculture. Mandated by the General Law of Sustainable Fisheries and Aquaculture (LGPAS), INAPESCA is also responsible for coordinating scientific and technological research on aquaculture and fisheries at the national level.

General Law of Sustainable Fisheries and Aquaculture (LGPAS)

The first law on fisheries and aquaculture (i.e. the Federal Fisheries Law) was issued in 1986. The current law (i.e. LGPAS) was issued in 2007, with the critical inclusion of the sustainability perspective in its objective of integral and sustainable management of fisheries and aquaculture, taking into consideration the social, technological, productive, biological and environmental aspects. Another key aspect of the LGPAS is the recognition of fisheries and aquaculture as activities that fortify food and territorial sovereignty and hence matter to national security.

Most of the 31 states and Mexico City have already published their own state fisheries and aquaculture laws that apply to tilapia farmers, including Baja California, Oaxaca, Jalisco, Hidalgo, Sinaloa, Nayarit, Tamaulipas, Veracruz, Michoacán, Baja California Sur, Sonora, Colima, Yucatán, Puebla, Tabasco, Campeche and Chiapas.

Some of the states have established more detailed regulations based on the LGPAS. While the state laws and regulations are similar to the national ones, enforcement (e.g. inspection and health management) is carried out by state employees or local civil associations, supported by the federal government, with operations based on the current legal framework. There is a general lack of personnel in most states to enforce the state fisheries and aquaculture laws. However, in the northwest of the country, there are gateways on the main roads for inspection of live organisms in transit.

The legal framework for aquaculture activities in Mexico needs to be improved in order to satisfy the needs of the fast growing sector. Notwithstanding the issuance of LGPAS as the general law, its procedures have yet to be established, and the procedures in place are those from the previous law – see Cuéllar-Lugo *et al.* (2018) for a review of the evolution of aquaculture-related legislation in Mexico. This is a factor that hinders the development of aquaculture in Mexico. Also, faster technological evolution relative to that of the legal framework makes it difficult to establish tilapia farming operations, especially for small and medium-size farmers.

Environmental impact assessment

A major regulatory challenge to tilapia farmers and aquaculture operations in general is the requirement of the environmental impact assessment (EIA), which is regulated by the General Law of Ecological Balance and Environmental Protection (LGEEPA) issued in 1988. The EIA tends to be costly for small tilapia farmers and oftentimes hinders the establishment of new operations.

While the EIA is mandatory for all operations that may cause harm to an ecosystem or endanger one or several species, there are some exemptions that apply to most small operations. For example, the EIA may be exempted for a fish farm established on previously transformed land (e.g. for crop or livestock farming activities), yet the final decision is dependent on the judgement of the evaluator (i.e. the Secretariat of Environment and Natural Resources, or SEMARNAT). A better solution could be to issue a special norm to help micro and small-size farmers reduce the EIA cost.

Invasive alien species

In Mexico, introduced tilapias are considered as invasive alien species (IAS) by the National Commission of Biodiversity (CONABIO), which makes them subject to a particular legal framework that may not be conducive to the development of tilapia aquaculture in the country. Considering that introduced tilapia species have been established in the local waters, the tilapia industry has frequently tried to get them out of the IAS category, with the support of legal authorities at the federal level. The latest attempt in 2019 with the support of expert opinions from the National Tilapia Network has not achieved the intended outcome. However, the classification of IAS has not prevented the establishment of programmes or projects at the three government levels (federal, state and municipal) to promote new tilapia farms, and research projects on tilapia aquaculture are funded by CONACYT. The public supports reflect the important socio-economic impacts of tilapia farming in the country, including its critical role to improve food security and nutrition and alleviate poverty and vulnerability.

Water use

The use of water for aquaculture is regulated by laws, notably the National Waters Law. An aquaculture farm requires a passage permit, described as “the national water passage for exploitation set of activities aimed at the reproduction, control, culture and fattening of the aquatic flora and fauna, performed in facilities in national waters, through breeding and cultivation techniques, susceptible to ornamental and recreational commercial exploitation” (DOF, 2016b). The requirement for a passage permit applies to activities carried out in both surface and underground water, except for those practiced as water-holding systems, as long as it does not deviate the water from its channel and does not affect the water quality, navigation or other permitted uses and exerts no damage to third parties (DOF, 2016b).

Most of tilapia farms in Mexico are established in agricultural lands and therefore assigned concessions of water use for agriculture, since there are usually no specific concessions of water use for aquaculture. In practice, it is usually complicated to modify the category of water use once the concession is granted. An important progress for aquacultural farms is that the water fee for aquaculture, instead of being considered as intended for relatively more expensive industrial use, has been reduced towards the relatively low level for agricultural use. In the long run, it is important to establish clear regulations on water use in aquaculture by updating relevant laws and regulations and taking into account international documents and standards generated by recognized organizations, for example, the Tilapia Aquaculture Dialog (TAD) that has issued the International Standards for Responsible Tilapia Aquaculture (ISRTA).

Obtaining and maintaining a water discharge permit for aquaculture is often subject to a cumbersome process of application, interpretation and compliance, which entails routine analysis of aquaculture discharges. Farms would need to obtain a discharge permit, install a water metre, establish a contract with a laboratory for water analyis and pay a monthly fee at a fixed rate for cubic metre of effluents. The lack of certified laboratories that can offer affordable water analysis poses a major constraint to small and medium operations. In addition, there are usually no studies of the water quality in inland waterbodies prior to the establishment of fish farming operations, which makes it difficult to assess the impact of aquaculture on the water quality in the surrounding environment.

National Agro-Alimentary Health, Safety and Quality Service (SENASICA)

The National Agro-Alimentary Health, Safety and Quality Service (SENASICA) is the national service that protects plant and animal health and addresses issues related to food safety and feed quality. The LGPAS recognizes SENASICA's faculty of designing and operating health campaigns. Generally speaking, the responsibilities of certification, animal health, quality and competitiveness prior to processing belong to SENASICA, whereas the certification, quality, labelling and competitiveness on and after processing are the responsibilities of the Federal Commission for Protection against Sanitary Risks (COFEPRIS), under the Federal Health Secretary.

Through the State Aquaculture Health Committees (AHCs), SENASICA operates inspection and surveillance programmes for animal diseases. Through the System of Information on Diagnosis Results of the Network of Laboratories (SIRED), SENASICA provides information on the occurrence of high-risk diseases in aquaculture. Through AHCs as auxiliary entities established by states, SENASICA engages in the prevention, diagnosis and control of aquaculture diseases, including the promotion of sanitation campaigns. AHCs, in coordination with the federal and state governments, coordinate sanitary programmes and campaigns and promote good practices of aquaculture production. At present, 22 AHCs operate in the country, and in many of them, there is a specialized subsection related to tilapia aquaculture (or fish in general). Many of the AHCs were originally farmer organizations that were seeking a better way to cope with diseases in aquaculture. Currently, AHCs are financially supported, at least partially, by SENASICA. While established to address fish health in aquaculture, AHCs also carry out activities related to food safety in aquaculture.

Science, technology and innovation (STI) institutions

The sustainable development of Mexican aquaculture in general, and tilapia farming and value chain in particular, requires strong support from science, technology and innovation (STI) institutions. Fisheries public policy analysis in Organisation for Economic Co-operation and Development countries (OECD, 2018) shows that for the sake of sustainability, the government's support to key areas (e.g. fish health and STI) could be more effective than direct subsidies to reduce input costs and/or increase sales prices.

The National Council of Science and Technology (CONACYT) represents 26 public research centres in the country. Eight of them are grouped into the node with main subjects, including environment, health and food, carry out research at different levels related to aquaculture in general and tilapia farming in particular, and offer postgraduate degrees.

There are over 5 000 higher education institutions (including public and private universities) in Mexico (SEP, 2017), many of which develop aquaculture-related STIs in addition to offering undergraduate and postgraduate studies on aquaculture. STI support is also offered by the National Autonomous University of Mexico (UNAM) and the National Polytechnic Institute, the two largest public STI institutions in the country.

Aquaculture research in the private sector has been carried out by some large tilapia enterprises in Mexico. Most of the research was conducted in collaboration with research centres or universities, including undergraduate and postgraduate theses or dissertations on various subjects, such as fish nutrition, genetics, economics, health and management.

The LGPAS establishes that INAPESCA coordinates and runs the National Network of Research and Information on Fisheries and Aquaculture (RNIIPA). Working in the country by region, RNIIPA can become an important tool for achieving sustainable aquaculture development by species, such as tilapia.

5.2 Farmer organizations

In Mexico, a family tilapia farm is usually more successful than farms co-managed by non-family members, which are more likely to fail because of different opinions and disagreements. Family members usually do not receive wages for working on the family farm. They consider their activities in the farm part of their responsibilities to the family, and their efforts are rewarded through personal consumption of tilapias and income from tilapia sales. Most of the proceeds from tilapia sales go back to the family farming business for purchasing materials (e.g. seed and feed) and/or investment in another pond, tank or cage.

Mexico has several tilapia farmer organizations. Some of them are independent organizations, while others are promoted and supported by the government. The three main organizations are the following.

- System Product Committee (SPC). For more than fifteen years, the Ministry of Agriculture (under the different official names it has had in recent history, currently SADER) has set the public policy of promoting agrifood value chains. SPC is an organization that congregates all the agents (farmers/producers, processors, traders, representatives from the academic community, etc.) along the value chain of a particular species or food product (shrimps/prawns, tilapias, pelagic fish, etc.) to facilitate the development of the value chain. SPCs can be established at the state, regional or national level. At present, there are 84 aquaculture and fisheries SPCs registered under CONAPESCA, including 23 tilapia SPCs at the state level and one at the national level.
- Entrepreneurial Council of the Mexican Tilapia (CETMX). CETMX is composed of the largest private tilapia hatcheries and outgrowing farms in Mexico: Regal Springs Acuagranjas Dos Lagos SA de C; Acuícola Campo Viejo SPR de RL; GEMSO, Acuícola; Tilapia Azul Acuacultura SPR de RL; Tilapia La Granja; Aquamol Tilapia; La Jolla; Tilapia San Vicente and La Noria. The outgrowing farms carry out tilapia production in cage, tanks and/or ponds. Some of them include not only hatcheries but also build alliances with players along the tilapia value chain (e.g. processing, packaging and trading). These high-volume tilapia producers/suppliers are well recognized by the government and have a large influence over sector development as innovators and state-of-the-art fish farms.
- Tilapia Mexico Network (RTM). Founded in 2014 with WorldFish as one of the founding members, RTM works for the sustainable development of micro, small and medium enterprises (MIPYME) along the Mexican tilapia chain value. RTM follows the triple-helix model (industry, government and academia), and includes as a fourth element external experts and organizations. In addition to WorldFish, founding members include the National Tilapia SPC, government institutions (CONAPESCA, INAPESCA and FIRA), 11 universities and research centres in the country, and more than 50 researchers in nine different disciplines. RTM develops annual strategic planning exercises to identify key projects and actions for MIPYME according to industry and government priorities and the demands related to the Mexican tilapia value chain. RTM's members are actively engaged in research projects, human capacity development and outreach, consultancies, policy and planning, among others.[15] RTM has signed a collaboration agreement with CETMX to facilitate sustainable development of the tilapia value chain in Mexico based on domestically produced tilapias and has a long-term goal of substituting the large volume of tilapia imports.

There are several general aquaculture organizations in the country where tilapia farmers can enroll at will. Notably, AVAC (Acuacultores Veracruzanos, Veracruz Aquaculturers, Civil Association) is one of the oldest aquaculture organizations in Mexico with more than 20 years of experience in advocating aquaculture in public policy (e.g. rate reduction of water and electricity used in aquaculture), providing training and consultations to government at the federal, state and municipal levels, and organizing meetings and conferences, such as the Seventh International Symposium of Tilapia Aquaculture (ISTA 7) held in Boca del Río, Veracruz, in 2006.

[15] More information about RTM can be found on their webpage (www.redtilapiamexico.com).

5.3 Policy and planning

Planning is mandated by the Mexican Constitution at the three government levels: federal, state and municipality. Also, the Planning Law is the normative framework that regulates the exercise of the national planning for development, including the National System of Democratic Planning that includes the federation, states and municipalities.

The federal government develops a national development plan (NDP) for each presidential period (six years). The new government has already issued the NDP 2019–2024, in which food self-sufficiency and restoration of agricultural fields are two priority areas.

SADER has published in the *Official Federal Gazette* the sectoral development programme on agriculture based on the NDP 2019–2024 (SADER, 2019; DOF, 2020a). In turn, CONAPESCA has recently published the National Program of Aquaculture and Fisheries 2020–2024 (DOF, 2020b).

With three primary operational objectives (Box 1), the programme proposes policies to be developed at the territorial level with four major national projects: (i) units of aquaculture logistics to promote aquaculture and food sovereignty; (ii) strategic programme of aquaculture; (iii) integral programme of surveillance and inspection in fisheries and aquaculture to combat illegal operations; and (iv) programme of sport fishing as an alternative, sustainable production activity.

Before the establishment of the National Program of Aquaculture and Fisheries 2020–2024, CONAPESCA launched two national planning exercises: one prepared together with a research institution (Research Center for Biological Research in the Northwestern A.C., or CIBNOR) in 2010 and the other being the National Strategic Plan for Aquaculture and Fisheries developed in 2016 under FAO guidance. Neither plan was officially published in the *Official Federal Gazette* and therefore received no budget for the implementation.

The state and municipality governments, which stay in office for, respectively, six and three years, also develop their own strategic plans that cover aquaculture. The planning process is coordinated by the Committee for State Development Planning (COPLADE) at the state level and the Committee for Municipality Development Planning (COPLADEM) at the municipal level. Generally speaking, the reference to tilapia in plans and programmes varies nationwide, depending on the level of importance given to tilapias and aquaculture in general by specific planning agencies. However, on several occasions, the Secretariat of Environment and Natural Resources (SEMARNAT) through its state offices has changed its local policies because introduced tilapias are considered IAS.

When established and recognized by CONAPESCA, each of the tilapia SPCs at the state level must develop and issue strategic plans, called "plan rector" or master plan. Each of the 23 state-level tilapia SPCs has its own master plan. However, an analysis of the existing aquacultural SPCs master plans (including those on tilapias) shows that the methodology used in their development was not uniform, and in many cases a list of actions and projects were listed without an articulated planning strategy and practical implementation tactics (Hernández-Echeagaray *et al*., forthcoming).

In 2010, the National Tilapia SPC – including all the state-level tilapia SPCs – engaged in a 10-year strategic foresight planning exercise that resulted in a planning document named Tilapia 2020 (Mojica-Sastoque *et al*., 2010; Box 2). The document provides guidance to the operation of the national tilapia SPC during 2010–2020. It is necessary at this time to update this planning document.

Box 1: National Program of Aquaculture and Fisheries 2020–2024

Objective 1: To contribute, as fisheries and aquaculture activities, to food security, mainly for populations located in rural areas.

- To increase Mexico's total fisheries and aquaculture production from 2 201 590 tonnes in 2020 to 2 494 830 in 2024.
- To increase the number of people who consume fish and fish products from 6 175 913 in 2017 to 8 648 273 in 2024.
- To increase the number of projects approved for implementation of technology for traceability of fisheries and aquaculture products from zero in 2018 to 25 in 2024.

Objective 2: To improve income and reduce poverty of fisher and aquaculture communities.

- To increase the average annual income (total value of national production less the total operation cost) from MXN 209 per fisher/day or fish farmer/day in 2018 to MXN 368 in 2024.
- To increase the number of storage, processing and distribution units of fisheries and aquaculture products at the national level from 26 in 2018 to 230 in 2024.
- To increase the number of supports to small fishers for higher efficiency (e.g. upgrading the motors of their boats) from 800 in 2018 to 5 600 in 2024.

Objective 3: To guarantee the sustainable development of fisheries and aquaculture resources of commercial interest.

- To increase the number of fisheries exploited at the biological sustainable level from 26 in 2017 to 68 by 2024.
- To increase the number of fishers operating under the Fisheries Ordering Program from 238 783 in 2018 to 313 783 by 2024.
- To increase the number of fisheries that are ordered and regulated from 18 in 2018 to 38 in 2024.

Box 2: Tilapia 2020 – Foresight strategic planning of the National Tilapia System Product Committee (SPC)

Recognizing the importance of strategic planning to sustainable development of tilapia aquaculture in Mexico, the National Tilapia SPC organized five expert workshops (funded by CONAPESCA) in 2010 to prepare the "Tilapia 2020" as a strategic document to guide the development of tilapia aquaculture in Mexico between 2010 and 2020. The document set the development goal of strengthening national production of tilapia in Mexico through high-quality standards along the value chain. Production growth and technological change are two key strategic vectors that define the sustainable horizon for 2020 for the National Tilapia SPC, and the decisive role of the educational and research communities in advancing technical innovations has been recognized.

Key actions proposed include (i) promoting tilapia consumption; (ii) enhancing technical training and outreach; (iii) advancing best management practices; (iv) improving the genetic stock of tilapias in Mexico; (v) establishing a Mexican brand for quality certification; (vi) introducing new schemes for financing micro and small producers; and (vii) promoting technology advancements in current production systems. After publication, Tilapia 2020 has often been consulted in subsequent policy and planning exercises on aquaculture development in Mexico.

The lack of coordination among stakeholders in the fisheries and aquaculture sector has been a major constraint hindering the development of tilapia farming and other aquaculture activities. CONAPESCA coordinates the National Council of Fisheries and Aquaculture comprised of public and private institutions, academia and the representatives of a variety of subsectors. The council intends to serve as a governance mechanism to ensure widespread stakeholder participation in the decision-making process over public policies and government actions. While the council has yet to be fully functional, it can potentially become a mechanism to facilitate coordination in the fisheries and aquaculture sector.

5.4 Financing mechanisms

Along the tilapia value chain, there are three financing schemes (FIRA, forthcoming), including (i) credits provided by input suppliers (e.g. commercial feed companies financing outgrowing operations and sometimes even providing credits to hatcheries); (ii) credits provided by wholesalers or retailers to outgrowing farms; and (iii) credits from financing intermediaries. Supermarkets also receive informal financing from the producers, since they can procure tilapias with a delay payment for 30 to 90 days. Tilapia farmers are also beneficiaries of such trade credits from feed producers/suppliers that sell feed at 30-, 60- or 90-day credit depending on the historic feed purchase record of each outgrowing farm.

Bank credits can be provided by commercial banks or development banks. The fisheries and aquaculture sector accounted for 2.5 percent of the country’s total MXN 4.6 billion commercial bank loans in 2017. Most of the credits given to aquaculture were directed to shrimp farming.

Government financing through development banks has channelled MXN 174 million of credits to the tilapia value chain in 2018 through direct FIRA financing or through financial intermediaries. Around 60 percent of the credits were formal bank loans. Short-term operational loans are usually payable in 6 to 12 months, whereas long-term investment loans have a duration of four to seven years.

Medium and large-size enterprises have a relatively easy access to FIRA credits, usually at competitive costs and with favourable conditions. However, micro and small tilapia farmers, especially those not integrated in a supply chain, have more difficulties in getting access to sufficient and affordable credits. FIRA (forthcoming) presents a description of credits in the tilapia value chain, which heavily financed large private cage operations in Chiapas with mostly long-term credits for capital investments (e.g. equipment and machinery) and also short-term credits for operation costs. Chiapas has received 35 percent of total formal credits to tilapia farming during 2013–2018, followed by Campeche (22 percent), and Tabasco and Veracruz (11 percent each).

A stronger financing of aquaculture in general and tilapia farming in particular is needed to support the growth of the activity in the country. Prioritizing aquaculture development is urgent and must be reflected in the budget to support its growth, both through federal programmes (CONAPESCA) and financing through development banks.

6. UNLOCKING THE GROWTH POTENTIAL OF TILAPIA FARMING IN MEXICO

6.1 Growth potential of tilapia farming in Mexico from a demand-side perspective

In 2018, Mexico produced 168 359 tonnes of tilapias (115 611 tonnes of capture fisheries production and 52 748 tonnes of aquaculture production), imported 228 144 tonnes (live weight equivalent) and exported 7 394 tonnes (live weight equivalent); the resulting 389 109 tonnes of total (apparent) tilapia consumption gave the 126 million Mexican population an average of 3.08 kg per capita tilapia consumption (Table 18) – see section 2.4 for more discussion.

The Mexican population is expected to increase by 12 percent, from 126 million in 2018 to 141 million in 2030. Given the baseline of 3.08 kg per capita tilapia consumption in 2018, the 12 percent population growth will drive up domestic tilapia demand in Mexico by 45 281 tonnes, which needs to be satisfied by domestic production and/or imports. Three scenarios are considered (Table 18).

Scenario I (demand growth satisfied proportionally by domestic production and imports)
Suppose that the 45 281 tonnes demand growth driven by the 12 percent population growth between 2018 and 2030 is partly satisfied by 12 percent growth in imports (i.e. 26 549 tonnes), and the rest is satisfied by the expansion of domestic tilapia aquaculture. In this scenario, tilapia aquaculture production in Mexico will increase by 18 732 tonnes (36 percent), from 52 748 tonnes in 2018 to 71 480 tonnes in 2030.

Scenario II (demand growth satisfied entirely by aquaculture)
Suppose that the 45 281 tonnes population-driven demand growth is entirely satisfied by aquaculture production, then tilapia aquaculture production in Mexico will increase by 45 281 tonnes (86 percent), from 52 748 tonnes in 2018 to 98 029 tonnes in 2030.

Scenario III (demand growth satisfied entirely by aquaculture and 100 percent import substitution)
Suppose that aquaculture expansion not only covers the 45 281 tonnes population-driven demand growth but also entirely substitutes the 228 144 tonnes import in 2018, then tilapia aquaculture production in Mexico will increase by 273 425 tonnes (518 percent), from 52 748 tonnes in 2018 to 326 174 tonnes in 2030.

These scenarios are not meant to predict Mexico's tilapia aquaculture production in the future but to provide some reference points to estimate the growth potential of tilapia farming in Mexico. Three general assumptions apply to all the three scenarios.

First, it is assumed that Mexico's per capita tilapia consumption in 2030 will remain at the 2018 level (i.e. 3.08 kg). As Mexico's per capita fish consumption (14.7 kg in 2017) is higher than the Latin America and the Caribbean average (10.5 kg) but lower than the world average (20.3 kg), it may have some room to rise along with the growth of the Mexican economy. While the room for growth in tilapia consumption may not be large since the 3.08 kg per capita tilapia consumption in Mexico is already quite high compared to the world average (0.9 kg), lowering tilapia price would tend to drive up per capita tilapia demand in Mexico.

Second, it is assumed that wild tilapia production from capture fisheries in Mexico will remain the same, which is a convenient assumption often used in the projection of aquaculture production. If the upward trend of wild tilapia production in Mexico (Figure 1) continues, then its farmed tilapia production would need to compete with wild production for the domestic market expansion; hence, the estimations in the three scenarios would need to be adjusted downward.

Third, it is assumed that export remains the same. As a small tilapia exporting country accounting for only 1 percent of world tilapia export in 2018, the growth potential of tilapia aquaculture in

Mexico through the expansion of export tends to be limited unless the country can increase its market share in the United States of America, which is the largest international market for tilapia products and the primary destination of Mexico's tilapia export. The close vicinity to the United States of America tends to give Mexico a long-term competitive advantage in exporting tilapias to the market. Yet Mexico would need to compete not only with large tilapia exporters in Asia (e.g. China and Indonesia) but also with large exporters in the Americas (Honduras, Colombia and Costa Rica) in order to increase its market share (1.7 percent in 2018) in the market (FAO, 2020a, p. 78). In light of its large tilapia import, in the short term it may be easier for Mexico to expand its tilapia aquaculture through import substitution than through export expansion.

In terms of live weight equivalent, Mexico's tilapia import was greater than its domestic production (Table 18). Thus, its tilapia import tends to increase with the population-driven demand growth, as described in scenario I, which is the most likely scenario under the status quo (compared to the other two scenarios in Table 18).

Mexico's tilapia production, which is sold to the domestic market primarily as whole fish, may not be directly substitutable to the imports, which are mostly tilapia fillets. However, if Mexican tilapia farmers can reduce their production cost and supply more affordable raw materials, domestically produced tilapia fillets can potentially compete with imported fillets, as described in scenarios II and III. Indeed, domestic tilapia production can not only substitute imported tilapia products but also other products such as catfish fillets (primarily pangasius), which was Mexico's largest fish import product (FAO, 2019, p. 47).

Table 18: Estimation of tilapia aquaculture growth potential from demand-side perspective

Tilapia production, trade and consumption in Mexico (measured in live weight or equivalent)	Baseline 2018	**Scenario I:** Demand growth proportionally satisfied by aquaculture and import			**Scenario II:** Demand growth entirely satisfied by aquaculture			**Scenario III:** Demand growth entirely satisfied by aquaculture and 100 percent import substitution		
		2030	Absolute change	Percentage change (%)	2030	Absolute change	Percentage change (%)	2030	Absolute change	Percentage change (%)
Population (million)	126	141	15	12	141	15	12	141	15	12
Production (tonnes)	168 359	187 091	18 732	11	213 640	45 281	27	441 785	273 425	162
Capture fisheries	115 611	115 611	-	-	115 611	-	-	115 611	-	-
Aquaculture	**52 748**	**71 480**	**18 732**	**36**	**98 029**	**45 281**	**86**	**326 174**	**273 425**	**518**
Import (tonnes)	228 144	254 694	26 549	12	228 144	-	-	0	- 228 144	- 100
Export (tonnes)	7 394	7 394	-	-	7 394	-	-	7 394	-	-
Total consumption (tonnes)	389 109	434 391	45 281	12	434 391	45 281	12	434 391	45 281	12
Per capita consumption (kg/capita/year)	3.08	3.08	-	-	3.08	-	-	3.08	-	-

Sources: Production data from CONAPESCA (2020); trade data from FAO (2020g); population data from United Nations World Population Prospects (2019 revision); and conversion factors between production weight and live weight of export and import can be found in Table 2.

Notes: Apparent consumption = production + import – export. A general assumption is no change in per capita consumption, export or wild tilapia production. For Scenario I, it is assumed that import grows 12 percent following the 12 percent population growth, and the rest demand growth is satisfied by aquaculure expansion. For Scenario II, it is assumed that the population-driven demand growth is entirely satisfied by aquaculture expansion. For Scenario III, it is assumed that aquaculture expansion not only covers the population-driven demand growth but also entirely substitutes the baseline import.

6.2 Challenges and the way forward

In light of the experiences of other major tilapia farming countries such as Egypt, which produced over 1 million tonnes of farmed tilapia with limited land, water, feed and other resources (El-Sayed, 2017), Mexico has enough resources to increase its tilapia aquaculture production to over 300 000 tonnes in 2030 (scenario III in Table 18). However, the country needs to overcome some major constraints and challenges in order to unlock its growth potential.

Improving technical and economic performance

The average operating cost of the 64 cases of small tilapia farming operations in Table 10 was USD 1.55/kg of production. Medium or large operations tend to have a lower operating cost thanks to economies of scale. However, with capital and labour cost accounted for, the total cost of a medium or large operation may not be lower than the price of imported whole tilapia (around USD 1.5/kg during 2016–2018). This indicates that, generally speaking, tilapia farmers in Mexico would need to reduce the production cost in order to compete with tilapia products from other countries.

Earthen pond

Farming tilapias in earthen ponds, which can benefit from natural foods and dissolved oxygen generated through proper fertilization and other water management mechanisms, can have a relatively low production cost compared to cage and tank systems. The production cost of earthen pond tilapia culture in Western Paraná, Brazil, was USD 0.82/kg of production (Barroso, Muñoz and Cai, 2019). The current farmgate price of 300 g to 500 g pond-cultured tilapia in some places of China is USD 0.85/kg.

Earthen pond culture has only a small contribution to tilapia aquaculture production in Mexico. While in the domestic market Mexican tilapia farmers may overcome high production cost through better quality products and more efficient logistics, in international markets it tends to be difficult for cage cultured tilapias from Mexico to be competitive with earthen pond cultured tilapias from other countries.

The lack of tradition and experience in earthen pond culture of tilapias or freshwater fishes in general tends to be a key constraint over the development of earthen pond tilapia culture in Mexico. Land tenure is another issue. The focus of the current NDP 2019–2024 on the restoration of agriculture fields may make the government unwilling to allocate land resources for earthen pond culture. Last, but not least, with the impacts of climate change, the cost advantage of earthen pond culture is not guaranteed in the long run. Therefore, in the short term, the government can create an enabling environment to facilitate private investments in earthen pond culture in suitable sites with ample land resources and sustainable water supply and at the same time conduct an in-depth, thorough assessment of the potential for pond tilapia culture in Mexico before making a strategic commitment to the promotion of earthen pond tilapia culture in the country.

Cage

Cage culture contributes most of the tilapia aquaculture production in Mexico and is expected to continue this role for the near future. Mexico has plenty of inland waterbodies and coastal lagoons suitable for tilapia cage farming. Yet the experience of cage aquaculture in other countries (either in inland waters or in marine areas) indicates that proper planning and management are crucial to the long-term sustainability of cage aquaculture. In Ghana, disease outbreaks have recently caused large mortalities in cage tilapia farming in Lake Volta. In China, many cages have recently been removed from inland waterbodies that are used as water sources for residential use. The global salmon farming industry has faced increasing resistance against cage salmon farming in marine areas because of concerns over its negative environmental impacts.

Therefore, it is essential for the Mexican government to properly plan and manage cage tilapia farming (e.g. zoning based on the carrying capacity of each waterbody, promotion of best aquaculture practices to mitigate negative environmental impacts) at the early stage before it becomes unsustainable. Indeed, eutrophication has lately become a serious problem in some dams in Chiapas where cage tilapia farming is operated (see Plate 9).

Tank

Tank culture is generally a more expensive farming system than pond or cage farming. While tank culture is commonly used in tilapia hatcheries, its widespread use in growout seems to be a unique feature of tilapia aquaculture in Mexico. Despite its relatively high cost (both capital cost and operating cost), tank tilapia culture in Mexico is generally profitable because of price premiums in niche markets for locally produced, high-quality, live/fresh tilapias. However, such niche markets tend to have a limited growth potential, and the price premiums may not be sustainable in the long term. Therefore, it is crucial for tank tilapia farmers to find ways to reduce the production cost. For example, tank farmers may reduce production cost by stocking large-size fingerlings and hence shortening the production cycle. Obviously, adopting this measure depends upon the availability and cost of large-size fingerlings. More economic energy sources (e.g. solar panels) may also be helpful.

Seed

The lack of a stable supply of good quality tilapia seed is one of the main constraints for the development of commercial tilapia farming in Mexico, especially for AREL/micro, small and medium farms. Farmers are often forced to stock fingerlings according to their availability but not at the most opportune time according to climate and market conditions, which tends to result in suboptimal performance. In 2019, a large private hatchery based in Mazatlán, Sinaloa, with distribution plants in Nayarit and Veracruz suddently shut down its operations, causing a big shortage of tilapia seed supply.

As good quality seed is important to many aspects of aquaculture (high growth, low mortality, low FCR, high disease resistance, etc.), the establishment of a solid national programme for tilapia genetic improvement is deemed necessary in the long run.

The government should also facilitate the establishment of specialized hatcheries and nurseries in strategic locations to help reduce transportation cost and deliver more healthy fingerlings to small farmers vastly distributed all over the country. As mentioned above, tank farmers may be able to reduce production cost by stocking large-size fingerlings supplied by specialized nurseries. The experiences of some farmers in China indicate that properly managed earthen ponds tend to be a better nursing system than hapas or tanks.

Feed

Mexico's large animal feed manufacturing industry lays a solid foundation for aquafeed production, which also benefits from its rich resources of key feed ingredients – Mexico exported 85 000 tonnes of fishmeal in 2017 (FAO, 2019). While the average tilapia feed price in Mexico is generally comparable to other large tilapia producers (e.g. Brazil and China), many small tilapia farmers are subject to high feed cost (Figure 12) because of expensive delivery cost.

Major feed ingredient mills are located in Sonora in the north of Mexico, whereas aquafeed plants are mainly located in central Mexico, and many large tilapia farming states (e.g. Campeche, Chiapas, Tabasco and Veracruz) are located in the south (Table 1; Figure 3). The geographical mismatch has led to high delivery cost, which is aggravated by logistic issues, such as losses due to theft in transit from feed ingredient mills and aquafeed plants. The promising prospects of tilapia aquaculture tend to motivate the private sector to improve efficiency in the feed production and distribution system; for example, a large feed plant has been recently established in Tabasco.

The public sector can create an enabling environment (e.g. capacity building on feed handling and waste reduction, establishment of aquaculture parks or hubs in strategic areas and promoting consolidated feed purchasing, among others) to facilitate more efficient aquafeed production and deliveries in Mexico.

Climate change vulnerability

It is a general consensus that poor, rural aquaculturists tend to be the most affected by climate change, risking individual and communal resilience (FAO, 2015; Barange *et al.*, 2018). High temperatures, extreme and/or irregular weather conditions, and other climate-change issues pose increasing challenges to the performance and sustainability of tilapia farming in Mexico. Coordinated efforts are called for to help farmers better adapt to and prepare for climate change. The long-term impacts of climate change and adaptation strategies (e.g. development of more resilient strains through genetic selection) should be an essential factor to be considered in strategic planning of tilapia aquaculture development in Mexico. Climate change has already been addressed by the Aquaculture Ordinance from the Federal Government in collaboration with the National Institute of Ecology and Climate Change (INECC).

Appreciating the socio-economic contribution of small-scale tilapia farming

While a general perception is that isolated, AREL/micro and small-scale tilapia farming operations have only limited contribution to local markets, it has to be understood that they have much to offer to the private sector and to the customer, starting with a sustainable supply of high-quality tilapia to local communities. Successful AREL/micro and small tilapia farms can contribute to a vibrant rural economy through not only their own production but also other activities along the value chain (feed manufacturing, processing, marketing, etc.). Tilapias produced by local farmers are favoured by customers, and there is an ongoing trend for tilapia farmers in suburban areas setting up small restaurants near the farm where they can cater to customers who live in nearby cities with live, high-quality tilapias.

It can be successful for regional aquaculture development to develop or strengthen rural clusters that can take advantage of scale economies and connectivity to be more profitable. The diverse experience of small tilapia farmers (Table 10) indicates that more efforts are needed to improve performance through capacity building and logistic support. In addition, the public sector should help AREL/micro and small farmers better integrate in the tilapia value chain in Mexico. For example, FAO has developed several documents and guidelines on public purchases from family farmers and the development of markets of producers (FAO, 2017b; 2017c). Under the FAO Special Programme for Food Security (PESA), AREL/micro and small tilapia farmers in Oaxaca and Puebla were trained not only in technical aspects but also in their incipient experiences in the value chains. Nationally, the current public policy in Mexico from the federal government favours inclusion of AREL/micro and small farmers in the value chains and national markets.

Strenthening institutions to facilitate sustainable development of tilapia farming

Aquaculture is a means of fish production intrinsically different from capture fisheries. It is important to distinctly recognize aquaculture (instead of subordinating it under the fisheries sector) in public policy and planning. Aquaculture should be specifically recognized in legal and regulatory frameworks, in terms of its right to access to land, water and other natural resources.

For many years, the Mexican government had supported aquaculture through input subsidies, such as fuel, seed/fingerlings and even maintenance of the facilities, and the efforts should continue. Favourable public policies (such as low electricity price for aquaculture operations, tariff reduction for imported aquaculture equipment) can help the young industry develop its competitive advantage in the long run. While continuingly committed to environmental sustainability, the government should help fish farmers reduce the financial cost and time spent in complying with environmental regulations.

Transparency and traceability need to be improved along tilapia supply chains at both the national and local levels. The existence of many unregistered tilapia farmers has not only affected the accuracy of official statistics but also may hinder the implementation of supportive policy or regulatory measures (e.g. tax reductions). Public and private sectors (including all stakeholders on tilapia supply chains) ought to work closely together to address the issue.

Legislation is a critical issue and for many years the aquaculture sector has not had a full normative framework in place that sustains its development. There is a General Law, but the particular rules (*reglamento*) of its application are missing. Strengthening or streamlining the legal and regulatory framework and measures is an important way to address salient issues, such as farmers' request for reclassification of non-native yet well-established tilapia species out of the IAS category and their concerns over unfair competition from imported tilapia products.

The full development of aquaculture must be addressed through differentiated public policy that oversees from different perspectives the individual problems of the value chains and of producers of different scales and with different necessities. The critical role of aquaculture development in Mexico and tilapia aquaculture is not only an issue of food and nutrition security but also of sustainability and social inclusion. Technology and innovation must reach not only big projects but also small ones in rural areas.

Established institutional food procurements can take advantage of the expected aquaculture growth in the coming years. Government purchases of fish, and inserting them into programmes for school breakfasts or meals for programmes targeting vulnerable populations, are also worth noting. If properly designed, this would allow small farmers to be linked to final consumers, bringing about a better distribution of the economic margins along the value chain. These programmes, however, require strong multisectoral coordination and adaptation of institutional policies and procedures, and even legislation.

Last, but not least, the establishment and effective implementation of a national programme on tilapia development is crucial to coordinating the efforts in the public and private sectors for sustainable tilapia aquaculture development. Past and ongoing efforts in policy and planning (see discussion in section 5.3) have laid a substantial foundation for further efforts in this regard, and there are many planning tools – see, for example, Aguilar-Manjarrez, Soto and Brummett (2017) for aquaculture zoning under the ecosystem approach to aquaculture to facilitate the process.

Research, development, innovation, extension and outreach

The role of research, development and innovation, supporting the desired sustainable growth of tilapia farming in the country, in order to achieve the Sustainable Development Goals by 2030, must be reinforced. The research community must conduct critical and key projects to solve specific problems of the tilapia farming sector at all levels. Research must be determined by the demands of the main users – tilapia farmers – and results oriented. The tilapia industry may learn from the experiences of the shrimp farming industry, where academia has been intensively involved in the development of sustainable shrimp farming in the country, and shrimp farming organizations funded research on priority issues (e.g. genetics and diseases).

There is also much room to improve in extension and capacity building, which should be planned with a long-term perspective and at local (municipality or region) levels. Extension and capacity building should focus not only on technical aspects but also pay attention to economic and marketing skills as well as legal and administrative aspects. Contributing to the formation of human and institutional capital, outreach activities tend to be well-worth investments that have magnifying returns.

6.3 Impacts of the COVID-19 pandemic on the tilapia industry

The ongoing COVID-19 pandemic has had profound impacts on global agrifood chains (FAO, 2020h) and aquaculture and fisheries in Latin America and the Caribbean (FAO and CEPAL, 2020; FAO, 2020i). In Mexico, the pandemic has also caused a significant disruption on the aquaculture value chain (Arosemena, 2020; Garza de Yta, 2020; Martínez-Cordero, 2020), especially since the pandemic coincided with the high season of fish and seafood consumption in the Holy Week and Easter.

According to a survey of 100 medium-size tilapia farmers in late April 2020 (Martínez-Cordero *et al*., 2020a), 46 percent of the farmers have reduced their sales volume by half; 35 percent planned to reduce their production capacity by half; and 20 percent indicated that without the government's financial support, they may have to terminate their operations. According to a survey of 29 tilapia farmers conducted in early May in the rural area of Guerrero (Martínez-Cordero *et al*., 2020b), 86 percent of the farmers have been negatively affected by the pandemic, with 41 percent suffering lowered sales volume and 38 percent facing a complete cancellation of purchasing orders. Similar market disruptions were found in another two surveys, one conducted in Oaxaca by Oaxaca's State Aquaculture Health Committee and the other by Red Tilapia México.

The decline in tilapia sales has a ripple effect on input suppliers in the upstream. For example, tilapia hatcheries reported that a decline in fingerling sales forced them to hold tilapia fingerlings for a longer period, hence incurring a higher feed cost.

Despite the negative impacts it has inflicted, the COVID-19 pandemic has not led to a collapse of the tilapia industry in Mexico. Several factors have contributed to the resilience of the tilapia industry to the pandemic. The domestic market orientation has helped shield the industry from more severe disruptions in international trade due to travel restrictions. Being a relatively low-value fish, tilapias have been subject to a less severe decline in prices (FAO and CEPAL, 2020); e.g. the respondents to the 100-farmer survey mentioned above indicated a fall in tilapia sales price in the order of 15–17 percent. The relatively short tilapia supply chains, especially the fresh tilapia supply chains in central and south Mexico, are more resilient to travel restrictions under the pandemic. However, the pandemic has increased the appreciation of the importance of cold-chain capacities to the resilience of the tilapia industry to market disruptions.

By shortening the supply chain, e-commerce is a business model that tends to be more resilient to travel restrictions under the pandemic. However, only 9 percent of the respondents in the 100-farmer survey mentioned above indicated that they used e-commerce to market tilapia products. This reflects the shortage of human capital, digital capacity and governance framework to facilitate e-commerce in Mexico. While there is still a long way to go before e-commerce becomes a mainstream marketing channel for the tilapia industry in Mexico, the pandemic may create opportunities and momentum to move in that direction.

REFERENCES

Aguilar-Manjarrez, J., Soto, D. & Brummett, R. 2017. *Aquaculture zoning, site selection and area management under the ecosystem approach to aquaculture. A handbook*. Report ACS18071. Rome, FAO, and World Bank Group, Washington, DC. 62 pp. Includes a USB card containing the full document (395 pp.).

Arosemena, V.R. 2020. La acuicultura en tiempos de pandemia. *Panorama Acuícola Magazine*, Vol. 25, No. 4, May/Jun 2020, pp. 88–90. https://issuu.com/designpublications/docs/panorama_acuicola_25-4_mayo_junio_2020

Asiain Hoyos, A. 2009. *Technology transfer for commercial aquaculture development in Veracruz, Mexico*. Ph.D dissertation. Institute of Aquaculture. University of Stirling, Scotland. 288 pp.

Barange, M., Bahri, T., Beveridge, M.C.M., Cochrane, K.L., Funge-Smith, S. & Poulain, F., eds. 2018. *Impacts of climate change on fisheries and aquaculture: synthesis of current knowledge, adaptation and mitigation options*. FAO Fisheries and Aquaculture Technical Paper No. 627. Rome, FAO. 628 pp.

Barroso, R.M., Muñoz, A.E.P. & Cai, J. 2019. *Social and economic performance of tilapia farming in Brazil*. FAO Fisheries and Aquaculture Circular No. 1181. Rome, FAO. Licence: CC BY-NC-SA 3.0 IGO.

Bjorndal, T., Child, A. & Lem, A. eds. 2014. *Value chain dynamics and the small-scale sector: policy recommendations for small-scale fisheries and aquaculture trade*. FAO Fisheries and Aquaculture Technical Paper No. 581. Rome, FAO. 112 pp.

Cai, J.N., Leung, P.S., Luo, Y.J., Yuan, X.H. & Yuan, Y.M. 2018. *Improving the performance of tilapia farming under climate variation: perspective from bioeconomic modelling*. FAO Fisheries and Aquaculture Technical Paper No. 608. Rome, FAO.

Chávez, G.R. 1981. Aspectos demográficos *Phalacrocorax olivaceus* (Aves Phalacrocoracidae). En la presa Presidente Miguel Alemán, Temascal, Oaxaca. México. Tesis. Escuela nacional de Estudios profesionales Zaragoza. U.N.A.M. 61pp.

CONAFAB. 2019. *La Industria Alimentaria Animal de México 2019*. CONAFAB, A.C. 96 pp.

CONAGUA. 2017. *Estadísticas del Agua en México*. Ed. Nov. 2017. pp. 112–115. http://sina.conagua.gob.mx/publicaciones/EAM_2017.pdf

CONAPESCA. 2014. *Ubicación de Centros Acuícolas*. https://www.gob.mx/conapesca/documentos/ubicacion-de-centros-acuicolas

CONAPESCA. 2017. *Comisión nacional de acuacultura y pesca – Anuario estadístico de acuacultura y pesca 2017 – Database*. Consulted online 17 July 2019. www.gob.mx/conapesca/documentos/anuario-estadistico-de-acuacultura-y-pesca

CONAPESCA. 2020. *Comisión nacional de acuacultura y pesca – Anuario estadístico de acuacultura y pesca 2018 – Database*. Consulted online 3 April 2020. www.gob.mx/conapesca/documentos/anuario-estadistico-de-acuacultura-y-pesca

Cruz Beltrán, M.E. 1981. *Hábitos Alimenticios de Phalacrocorax olivaceus en la Presa Presidente Miguel Alemán, Temascal, Oaxaca. México*. Escuela Nacional de Estudios Profesionales Zaragoza. UNAM. 68 pp.

Cuéllar-Lugo, M.B., Asiáin-Hoyos, A., Juárez-Sánchez, J.P., Reta-Mendiola, J.L. & Gallardo López, F. 2018. Normative and institutional evolution of aquaculture in Mexico. *Agricultura, Sociedad y Desarrollo*, 15, 4: 541–564.

Delgadillo, T.M.S. & Morales, D.A. 1975. *Hibridación de O. mossambicus × O. aureus para la obtención de machos en la Estación de Acuacultura Tropical, Temascal, Oax*. Memorias del Primer Congreso nacional de pesquerías en Aguas Continentales. INP. Tomo II, pp. 183–187.

DOF. 2009. *Acuerdo por el que se establece la estratificación de las micro, pequeñas y medianas empresas*. Secretaría de Economía. México. http://dof.gob.mx/index.php?year=2009&month=06&day=30

DOF. 2016a. *Pesca responsable en cuerpos de agua continentales dulceacuícolas de jurisdicción federal de los Estados Unidos Mexicanos. Especificaciones para el aprovechamiento de los recursos pesqueros.* Norma oficial Mexicana NOM-060-SAG/PESC-2016. www.dof.gob.mx/nota_detalle.php?codigo=5452927&fecha=19/09/2016

DOF. 2016b. *Decreto por el que se reforman y adicionan diversas disposiciones de la Ley de Aguas Nacionales*. www.dof.gob.mx/nota_detalle.php?codigo=5430933&fecha=24/03/2016

DOF. 2020a. *Decreto por el que se aprueba el Programa Sectorial de Agricultura y Desarrollo Rural 2020–2024*. https://dof.gob.mx/nota_detalle.php?codigo=5595548&fecha=25/06/2020

DOF. 2020b. *Programa Nacional de Acuacultura y Pesca 2020–2024*. www.dof.gob.mx/nota_detalle.php?codigo=5609194&fecha=30/12/2020

El-Sayed, A.-F.M. 2017. Social and economic performance of tilapia farming in Egypt. In J. Cai, K.K. Quagrainie & N. Hishamunda, eds. *Social and economic performance of tilapia farming in Africa*, pp. 1–48. FAO Fisheries and Aquaculture Circular No. 1130. Rome, Italy.

EUFOMA. European Market Observatory for Fisheries and Aquaculture Products. 2019. *Conversion factors by CN-8 codes from 2001 to 2019.* Metadata 2 – Data management (Annex 7). www.eumofa.eu/documents/20178/24415/Metadata+2+-+DM+-+Annex+7+CF+per+CN8_%252707-%252714.pdf/7e98ac0c-a8cc-4223-9114-af64ab670532

FAO. 2005. *National Aquaculture Sector Overview*. Visión general del sector acuícola nacional – Ecuador. National Aquaculture Sector Overview Fact Sheets. Texto de Schwarz, L. In: *Departamento de Pesca y Acuicultura de la FAO* [en línea]. Roma. Actualizado 1 February 2005. [Citado 4 December 2020].

FAO. 2012. *Diagnóstico de la Acuicultura de Recursos Limitados (AREL) y de la acuicultura de la micro y pequeña empresa (AMYPE) en América Latina*. Serie Acuicultura en Latinoamérica, No. 7, Diciembre 2012. Santiago de Chile. 26 pp.

FAO. 2015. *Assessing climate change vulnerability in fisheries and aquaculture: available methodologies and their relevance for the sector*, by C. Brugere and C. De Young. FAO Fisheries and Aquaculture Technical Paper No. 497. Rome. 98 pp.

FAO. 2017a. *Social and economic performance of tilapia farming in Africa*, edited by J. Cai, K.K. Quagrainie and N. Hishamunda. FAO Fisheries and Aquaculture Circular No. 1130. Rome.

FAO. 2017b. *Guide for the development of producers markets*. (In spanish) 87 pp.

FAO. 2017c. *Guide for the implementation of local strategies for public purchases to the family agriculture*. (In spanish) 20 pp.

FAO. 2019. *WAPI factsheet on aquaculture growth potential in Mexico.* World Aquaculture Performance Indicators (WAPI). Rome. 85 pp.

FAO. 2020a. *Tilapia production and trade with a focus on India.* World Aquaculture Performance Indicators (WAPI). Rome. 100 pp. www.fao.org/3/ca9224en/ca9224en.pdf

FAO. 2020b. *FAO Global Fishery and Aquaculture Production Statistics v2020.1.0*, published through FishStatJ (March 2020). www.fao.org/fishery/statistics/software/fishstatj/en

FAO. 2020c. *Top 10 species groups in global aquaculture 2018.* World Aquaculture Performance Indicators (WAPI). Rome. 4 pp. www.fao.org/3/ca9383en/ca9383en.pdf

FAO. 2020d. *Top 10 species groups in global, regional and national aquaculture 2018. Supplementary materials to the World Aquaculture Performance Indicators (WAPI) factsheet on top 10 species groups in global aquaculture*. World Aquaculture Performance Indicators (WAPI). Rome. 316 pp. www.fao.org/3/ca9383en/ca9383en.pdf

FAO. 2020e. *WAPI factsheet on aquaculture growth potential in Latin America and the Caribbean (LAC).* World Aquaculture Performance Indicators (WAPI). Rome. 83 pp. www.fao.org/3/ca8180en/ca8180en.pdf

FAO. 2020f. FAO. 2020. *Fishery and Aquaculture Statistics. Food balance sheets of fish and fishery products 1961–2017* (FishStatJ. www.fao.org/fishery/statistics/software/fishstatj/en

FAO. 2020g. *Fishery and Aquaculture Statistics. Global fisheries commodities production and trade 1976–2018* (FishStatJ). www.fao.org/fishery/statistics/software/FishStatJ/en

FAO. 2020h. *COVID-19 and the risk to food supply chains: how to respond?* Rome. https://doi.org/10.4060/ca8388en

FAO. 2020i. *Coronavirus disease 2019 (COVID-19) and family farming*. Rome. https://doi.org/10.4060/cb0417en

FAO and CEPAL. 2020. *Sistemas alimentarios y COVID-19 en América Latina y el Caribe: Hacia una pesca y acuicultura inclusiva, responsable y sostenible*. *Boletín N.°15*. Santiago, FAO. https://doi.org/10.4060/cb1197es

FIRA. (Forthcoming). *Mapeo de Redes de Valor. Red Tilapia*. Fideicomisos Instituídos en Relación con la Agricultura. 95 pp.

Garza de Yta, A. 2020. Lecciones del COVID-19 para el sector acuícola. *Panorama Acuícola Magazine*, Vol. 25, No. 4, May/Jun 2020, pp. 80–83. https://issuu.com/designpublications/docs/panorama_acuicola_25-4_mayo_junio_2020

Guzmán del Proo, S.A. 2012. Ciencia Pesquera, 20, 2: 3–7. www.inapesca.gob.mx/portal/documentos/publicaciones/REVISTA/Nov12/Prologo.pdf

Hernández Arzaba, J.C., Platas-Rosado, D.E., Asiain Hoyos, A., Vásquez, A.P., Avalos de la Cruz, D.A. & Avila Serrano, N.Y. 2019. Mapeo de la cadena de valor de la tilapia en el estado de Veracruz (Tilapia value chain map in the State of Veracruz. In Spanish). *Revista Mexicana de Ciencias Agrícolas*, 10, 5: 1167–1176.

Hernández-Barraza, C., Loredo, J., Adame, J. & Fitzsimmons, K. 2012. Effect of Nile tilapia (*Oreochromis niloticus*) on the growth performance of Pacific white shrimp (*Litopenaeus vannamei*) in a sequential polyculture system. *Latin American Journal of Aquatic Research*, 40, 4: 936-942.

Hernández-Echeagaray, L., Martínez-Cordero, F.J., Taddei-Bringas, C. & Sanchez-Zazueta, E. (forthcoming). Evolving the strategic planning of aquaculture to meet sustainable development: analysis of aquaculture programs in Mexico under the Ecosystem Approach to Aquaculture (EAA). *Reviews in Aquaculture* (forthcoming).

Loaiza Vega, P.O. 2013. *Efectos económicos del cambio climático en la acuicultura comercial en México: análisis de rentabilidad y riesgo de los impactos por uso de agua en la piscicultura* (Economic effects of climate change on commercial aquaculture in Mexico: risk and feasibility analysis of impacts by freshwater use in fish aquaculture). M.Sc. dissertation CIAD, A.C. (in Spanish). 89 pp.

Martínez-Cordero, F.J. 2020. La agenda urgente y de corto plazo en tiempos de emergencia. *Panorama Acuícola Magazine*, Vol. 25, No. 4, May/Jun 2020. pp. 84–88. https://issuu.com/designpublications/docs/panorama_acuicola_25-4_mayo_junio_2020

Martínez-Cordero, F.J. & Sanchez-Zazueta, E. (forthcoming). Poverty analysis of tilapia farmers in the States of Oaxaca, Guerrero and Chiapas in Mexico. *Aquaculture Economics and Management* (forthcoming).

Martínez-Cordero, F.J., Campos, A., Borrego, P., Monroy, S. & Meza, S. 2020a. Efectos del COVID-19 en la acuicultura de tilapia en México. *Panorama Acuícola Magazine*, Vol. 25, No. 4, May/Jun 2020, pp. 50–56. https://issuu.com/designpublications/docs/panorama_acuicola_25-4_mayo_junio_2020/s/10579371

Martínez-Cordero, F.J., Eguibar, V.O., Ortiz, L.R. & Sanchez-Zazueta, E. 2020b. *Estimaciones generales del impacto de COVID-19 en productores micro y pequeños de tilapia y camarón en Guerrero y Oaxaca.* (in Spanish). Unpublished manuscript.

Mojica-Sastoque, F.J., Vivanco-Aranda, M., Martínez-Cordero, F.J. & Trujillo Cabezas, R. 2010. *Tilapia 2020: Foresight of the Tilapia National CSP.* (in Spanish). 285 pp. https://www.scribd.com/document/360100896/Tilapia-2020-Prospectiva-Sistema-producto-Nacional-de-Tilapia-en-Mexico

Morales, D.A. 1976. Estadísticas pesqueras de 7 embalses mexicanos. Memorias del Simposio sobre Pesquerías en Aguas Continentales, Instituto Nacional de Pesca. México. Vol. II. pp. 203–237.

Muñoz-Córdoba, G. & Garduño-Lugo, M. 2003. *Mejoramiento Genético en Tilapia. Sistemas de cruzamiento y mecanismos genéticos en la determinación del color*. Facultad de Medicina Veterinaria y Zootecnia de la UNAM y Sistema de Investigación del Golfo de México del CONACYT.

OECD. 2018. *OECD Science, Technology and Innovation Outlook 2018: adapting to technological and societal disruption*. OECD Publishing, Paris.

SADER. 2019. *Programa Sectorial de Agricultura y Desarrollo Rural 2019–2024*. México City. 74 pp.

SEP. 2017. *Sistema Nacional de Información de Estadística Educativa*.

Suárez-Puerto, B.Z. & Martínez-Cordero, F.J. (forthcoming) Supply chain analysis of tilapia produced by aquaculture in Yucatan, Mexico. *Estudios Sociales* (forthcoming).

United Nations. 2019. *United Nations World Population Prospects (2019 revision).* https://esa.un.org/unpd/wpp/Download/Standard/Population

Verdugo Mora, L. 2009. *Análisis bioeconómico para determinar la rentabilidad y economías de escala en el cultivo intensivo de tilapia en sistemas de recirculación, bajo escenarios de riesgo (Bioeconomic analysis for determination of feasibility, scale economies and risk in intensive culture of tilapia incorporating recirculation systems).* M.Sc. dissertation CIAD, A.C. (in Spanish). 77 pp.

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9 789251 339541

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