



Bacterial diseases and bacteria identified in farmed fish from Mexico

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Received: May 2021; Accepted: September 2021; Published: May 2022.

ABSTRACT

This study concentrates information from the publications that have described the occurrence of bacterial diseases and the isolation and identification of bacteria from Mexican fish. The research consisted of the systematic search of scientific papers in Pubmed, Scopus and other search engines using the key words: diseases, bacteria, fish, Mexico- in English and Spanish, without date restrictions; information from official institutions was also included. The analysis shows records of isolation and identification of several bacterial genera obtained from both clinically diseased and subclinical fish, with high frequency of opportunistic bacteria and that in the last decade the occurrence of septicemic diseases caused by emerging bacteria has been confirmed. In freshwater environment *Flavobacterium psychrophilum*, *Yersinia* spp., *Weissella ceti* and *Lactococcus garviae* have caused septicemic disease in rainbow trout (*Oncorhynchus mykiss*), while *Francisella orientalis*, *Streptococcus iniae* and *Mycobacterium* spp. have affected tilapia (*Oreochromis* spp.). In the saline environment, *Nocardia seriolae* is reported as a cause of systemic disease in red croaker (*Sciaenops ocellatus*). It should be noted that, despite having this information, diseases that affect or have affected fish in the country are not officially reported. To promote the development of fish farming, it is necessary to know and report its health status, in this way risks and opportunities can be identified, and control actions established.

Keywords: Bacteria; diagnosis; emergent; diseases; fish; health (*source AGROVOC*).

RESUMEN

Este trabajo concentra información de las publicaciones que han descrito la ocurrencia de enfermedades bacterianas y el aislamiento e identificación de bacterias a partir de peces de México. La investigación consistió en la búsqueda sistemática de artículos científicos en Pubmed, Scopus y otros buscadores utilizando las palabras clave: *enfermedades, bacterias, peces, México-* en inglés y español, sin restricción de fecha; también se incluyó información de instituciones oficiales. El análisis muestra registros de aislamiento e identificación de varios géneros bacterianos obtenidos tanto de peces clínicamente enfermos como subclínicos, con alta frecuencia de bacterias oportunistas y que en la última década se ha confirmado la ocurrencia de enfermedades septicémicas causadas por bacterias emergentes. En ambiente de agua dulce *Flavobacterium psychrophilum*, *Yersinia* spp., *Weissella ceti* y *Lactococcus garviae* han causado enfermedad septicémica en trucha arcoíris

How to cite (Vancouver).

Alcántara-Jauregui FM, Valladares-Carranza B, Ortega SC. Bacterial diseases and their etiological agents identified in fish from Mexico. Rev MVZ Córdoba. 2022; 27(2):e2387. <https://doi.org/10.21897/rmvz.2387>



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(*Oncorhynchus mykiss*), mientras que *Francisella orientalis*, *Streptococcus iniae* y *Mycobacterium* spp. han afectado a tilapia (*Oreochromis* spp.); en ambiente salino, *Nocardia seriolae* se reporta como causa de enfermedad sistémica en corvina roja (*Sciaenops ocellatus*). Cabe resaltar que, pese a contar con esta información, oficialmente no se comunican las enfermedades que afectan o han afectado a peces del país. Para favorecer el desarrollo de la piscicultura es necesario conocer y difundir su condición sanitaria, con ello se pueden identificar riesgos y oportunidades, y establecer acciones de control.

Palabras clave: Bacterias; diagnóstico; emergentes; enfermedades; peces; sanidad (Fuente AGROVOC).

INTRODUCTION

Advances in the knowledge regarding nutritional characteristics and environment requirements and fish management have favored the development and expansion of fish culture. However, increases in fish production have favored the occurrence of infectious diseases, their epizootic propagation and the expression of emergent diseases are becoming more frequent (1).

In 2018, the main species cultured in Mexico was tilapia (*Oreochromis* spp.) with 168 359 MT worth \$ 163 168 USD (1 USD = 20.0546 MXN; values at April 29th, 2021); Carp (*Cyprinus* spp.), 48 126 MT worth \$23 635 USD; rainbow trout (*Oncorhynchus mykiss*), 13454 MT worth \$40 391 USD; and, catfish (*Ictalurus* spp.) with 6 589 MT worth \$9 335 USD (3). Although these values are far from those of the main producing countries, Mexico has potential to stand out in fishing activities, either increasing production in established areas with known species (tilapia, rainbow trout, carp and catfish) and harnessing underused or unused facilities, strengthening thus the culture of other freshwater and marine species (2,3). In order to reach the expectations of development for the country's pisciculture, it is necessary to strengthen all the processes in the production chain, with an emphasis on health (4,5).

Disseminating the health status of livestock activities in a region is very important, as the information regarding outbreaks and / or surveillance is useful to identify risks and / or establish control actions (5). In this sense, some independent studies on the health status of pisciculture in Mexico have described the isolation of opportunistic bacteria (5,6,7), and there were cases for which it was verified that bacteria provoked clinical disease, even by emergent bacteria (3,8,9,10,11). For their part, the country's health care authorities carry out surveillance activities related to fish health via State committees (4,5), nevertheless the health status of fish culture in Mexico is not known. Despite official documents indicate exotic and endemic species for aquatic animals in the country (4), there are no known studies

to support them, what is more, they do not include various emergent diseases which have been verified. The this present paper is an overall review of bacterial diseases and causal agents that have been identified and reported to affect fish in Mexico, both clinically and sub-clinically.

Bacterial diseases reported for fish in Mexico

Infections by *Aeromonas* spp. Genus *Aeromonas* comprises 31 gram -negative bacterial species (12) naturally distributed in freshwater and marine environments, where they behave as opportunistic agents of fish and other aquatic organisms (13,14). *Aeromonas* spp. are able to colonize and infect a number of hosts by means of different virulence factors that facilitate their adhesion, colonization and invasion of cells; no factor is determinant in the infectious process (15). By and large, infections in human beings occur in immunocompromised individuals associated to *A. hydrophila*, *A. veronni* and *A. schubertii* (16). Infections in fish are predisposed by stress conditions.

In Mexico, *Aeromonas* spp. have been isolated and identified from clinically diseased and healthy fish. Though, considering that the phenotypical and biochemical identification has limitations, it is possible to imply that some descriptions before molecular identification could have been inaccurate. Molecular assays based on the amplification of gene 16S rRNA and RFLPs classification allow discriminating bacteria that belong to this and other genera (1,13).

An early record of bacterial diseases in Mexico reported infectious ascites in common carp, attributed to *Aeromona* spp. and *Pseudomona* spp. in 1987. A decade later (1997), *A. hydrophila* was isolated from rainbow trout and tilapias affected by septicemia; whereas a year after that, *A. hydrophila* was isolated from trout infected by hemorrhagic disease that caused 51.2% mortality (5). In these cases, no

identification process was described and the bacteria were not molecularly characterized (5). However, the research work shows that these are the only cases associated to *Aeromonas* spp. that have expressed septicemia signs.

Another studio reported the isolation of *A. hydrophila* and *Vibrio* spp. in the liver of *Carassius auratus* with signs and lesions from the disease; however, they described neither the clinical picture nor the pathological lesions associated to the infection (17). For their part, Soto-Rodríguez et al (18) identified 17 bacterial genera isolated from diseased tilapias; bacteria of *Aeromonas* genus were the most frequent, being distinguishable *A. ichthiosmia* isolated from kidneys, *A. dhakensis* from eyes, *A. popoffii* from liver, *A. allosaccharophila* from kidneys, and *A. veronii* from brain; however, it was not stated if they were single or mixed isolations. The work distinguishes the first report of *A. dhakensis* as a fish pathogen.

In their study based on molecular identification, Zepeda-Velázquez et al (14) isolated *A. salmonicida*, *A. hydrophila* and *A. veronii* from external injuries in juvenile trout from three different farms; *A. veronii* was also isolated from liver and kidneys. Despite the fish did not manifest signs or lesions associated to septicemia, histologically the three pathogens produce lesions in kidneys and liver.

Bacteria from *Aeromonas* have been frequently isolated from clinically healthy fish. Eighty-two strains were isolated out of 250 tilapias from public markets in Mexico City; molecular analyses demonstrated that 67.5% corresponded to *A. salmonicida*; 20.9%, *A. bestiarum*; *A. veronii*, 5.2%; *A. encheleia*, 3.9%; and, *A. hydrophila*, 2.6% (19). The study does not describe the isolation of other bacterial genera, however, the sort of sampling is not a referent for the natural bacterial population in fish subjected to manipulation.

Salgado-Miranda et al (6) studied bacterial populations in rainbow trout farms reporting 371 isolations of 8 bacterial genera, of which 181 (48.78%) corresponded to *Aeromonas*; 90, *Aeromona* spp.; 84, *A. hydrophila*; and, 7, *A. salmonicida*. None of the analyzed fish expressed a clinical disease; only 4.79% exhibited some sort of lesion in skin, liver, spleen or intestines. For their part Vega-Sánchez et al (20) obtained 50 isolations from 10 species of *Aeromonas*, begin predominant *A. veronii* biovar *sobria* 22%;

A. hydrophila and *A. bestiarum*, 20% each; and, *A. sobria* 14%. The study shows the importance of *Aeromonas* spp. as opportunistic agents, for only 6 isolations were obtained from fish with skin lesions, while the other 44 were obtained from clinically healthy fish; among these *A. allosaccharophila*, *A. bestiarum*, *A. hydrophila*, *A. popoffii*, *A. salmocida*, *A. sobria* and *A. veronii* bv. *sobria* were obtained from the main internal organs. *Aeromona bestiarum* was isolated from the kidneys of carps that did not display signs or lesions from septicemic disease (7).

Infections by *Pseudomonas* spp. *Pseudomonas* spp. are opportunistic gram-negative bacteria able to develop at low temperature; this way, they are part of the dominant natural microflora in aquatic environments and intestinal flora in healthy fish (21). At temperatures over 10°C, they may be replaced by competing mesophilic microorganisms, including the genus *Aeromonas* (22). *P. fluorescens*, *P. anguilliseptica*, *P. aeuroginosa* and *P. putida* are described as the main *Pseudomonas* spp. that cause septicemic disease in a number of fish species. In spite that *P. putida* and *P. luteola* have also been isolated from internal organs, they are considered accompanying microflora (22).

Pseudomonas are responsible for causing redmouth disease in rainbow trout and tench (*Tinca tinca*). Similar systemic infections have been observed in crucian carp (*Carassius carassius*) and silver Prussian carp (*Carassius gibelio*) (22) and tilapias (23). Regardless of temperature, in rainbow trout infections can lead to sudden mortality that may reach 100% at any season. Clinically, the infection is characterized by skin darkening, with possible hemorrhages, petechiae, and ulcerations that reach fins and tail. In systemic cases, there is separation of scales, ascites, exophthalmos (21); lesions and signs may be similar to those observed in infections by *A. hydrophila* (22).

In Mexico, there are no cases report of clinical diseases associated to bacteria of the genus *Pseudomonas*. In a health analysis of ornamental fish (cichlids, poeciliidae and *cyprinodon*), six species from the pseudomonadaceae family were identified: *Pseudomonas cepaciae*, *P. diminuta*, *P. fluorescens*, *P. putida*, *P. sutzerii* and *P. vesicularis* (24). However, the study does not state if they were single or mixed isolations between bacteria of the same genus or other, neither was the clinical, macroscopic and histologic pathology described.

Out of 371 isolations from rainbow trout carried out by Salgado-Miranda et al (6), 47 were of *Pseudomonas* spp., 8 of *P. aeruginosa* and 5 of *P. fluorescens*. Some of these bacteria were isolated from spleen and liver, but the analyzed fish did not display signs or lesions from diseases. For their part, Soto-Rodríguez et al (18) identified *P. mosselii* and *P. anguilliseptica* as tilapia pathogens; the former was isolated from kidneys of fish with no signs of septicemia, and *P. anguilliseptica* from brains of fish that only expressed loss of scales.

Infections by *Flavobacterium* spp. Genus *Flavobacterium* comprises 241 species (12) of gram-negative non-flagellated immobile bacillus, slightly curved and rounded ends, which do not produce endospores. They are aerobic *chemo-organotrophic* organisms, which when grown in an artificial culture media form yellow-tone pigmented colonies (25); most of them are environmental microorganisms that may be pathogenic for fish, amphibians, reptiles, birds and mammals, including humans (25).

The main agents involved in disease processes in fish are *Flavobacterium columnare*, *F. branchiophilum* and *F. psychrophilum* (26). *Flavobacterium columnare* causes columnar disease, characterized by whitish or necrotic spots that may evolve into skin, fins, gills and caudal peduncle erosion. *Flavobacterium branchiophilum* causes bacterial gill disease (BGD), a condition associated to high morbidity and mortality in any species of fish. The colonization of gill lamella may cause varying degrees of necrosis in the laminar epithelium. For its part, *F. psychrophilum* is associated to a number of pathologies whose names come from the clinical signs of the affected fish. The bacterial cold water disease (BCWD), a pathology of septicemic appearance in recently hatched fish and in their first feeding, was observed in North America in 1941, while a similar disease called rainbow trout fry syndrome (RTFS) has been observed in Europa as of 1980; at present it has a worldwide distribution (25,26).

Even if *F. psychrophilum* does not have a specific host, rainbow trout and coho salmon (*Oncorhynchus kisutch*) are very susceptible to the infection in captivity. This bacterium has also been retrieved from other species that do not manifest clinical disease, which may act as carriers and disseminators (27).

The first antecedent of *Flavobacterium* spp. in fish in Mexico (5) described a case of gill disease

in trout fry and similar conditions to RTFS. Formally, the syndrome was documented for trout fry of 4 ± 0.5 g (27). Septicemic evidence comprises ascites, hemorrhages and spleen liquefaction, adherence of abdominal organs and necrosis in the abdominal wall around the spleen. The isolation of *F. psychrophilum* was molecularly verified and the study of RFLP classified the isolation in genotypes B and R, which indicates that the bacterium comes from the importation of oculated eggs (27). Diagnosis activities (unpublished) have demonstrated that after this notification, RTFS has been observed in rainbow trout fry in several states in the country, killing the fish in first feeding; likewise, cases that suggest columnar disease have been observed. These statements are likely since *Flavobacterium* spp. are common pathogens in pisciculture systems (25,26). However, it is necessary to research and keep a record of the cases.

Infections by *Yersinia* spp. Yersiniosis, also known as enteric redmouth disease (ERM) is one of the diseases with the heaviest economic impact on freshwater salmonid cultures; it affects other species as well. It is caused by *Yersinia ruckeri*, a gram-negative bacterium member of the Enterobacteriaceae family, with neither sporulation nor capsule and varying motility, isolated for the first time in the 1950's from rainbow trout; presently, it produces the disease virtually everywhere salmonids are cultured (28,29). In Latin America, ERM has been recorded to affect Atlantic salmon and rainbow trout in Chile (30) and rainbow trout in Peru (29).

In Mexico, a case of yersiniosis in juvenile rainbow trout was disclosed in 2000 (5), with no further reports. In mid 2018, there was a case in juvenile fish in a fattening farm in the center of the country. In the cases described, the affected fish presented clinical signs reported in the literature for this infection, being distinguishable hemorrhages in eyes, mouth, fin base and spleen as well as enteritis. *Y. ruckeri* was also isolated from rainbow trout without signs of disease (6).

Weissellosis by *Weissella ceti*. Genus *Weissella* comprises 23 species of lactic-acid bacteria (LAB) (12), gram-positive coccobacilli, negative catalase and oxidase, with no sporulation, immobile, facultative anaerobe with fermentative metabolism (31). Members of this genus have been isolated from a wide variety of

habitats, from products and food by-products from animals, fermented foods, urogenital and gastrointestinal tracts of humans and animals. Some species are considered probiotic; *W. cibaria* is used to control periodontal diseases; *W. confusa* and *W. cibaria* have potential as prebiotics and are used in bakery and to prepare fermented beverages (31). *W. cibaria* 110 produces a bacteriocin active against gram-positive bacteria and has possible anti-cancer, anti-inflammatory, antibacterial, antifungal and immunostimulating potential. However, *W. viridescens*, *W. cibaria* and *W. confusa* are related to various infections in humans as opportunistic pathogens (31,32).

In animals, *Weissella ceti* causes "weissellosis", an emerging septicemic disease that causes high mortality in rainbow trout cultures (32,33). Outbreaks usually take place in summer or when temperatures are between 16 – 18°C. The severity of the disease decreases as temperature does (32) and may disappear in winter, though it has been proven to be recurrent (33). In spite of being considered a pathology in fish larger than 100g, Figueiredo et al (33) report that it can infect fish at any production stage.

The first weissellosis report was described in China in 2007 (34), with losses up to 40% for adult trout with septicemic signs. Later on, it was reported in Brazil (33), with septicemic manifestation in adult trout as well; while similar symptoms have been reported in the United States, Japan, Colombia (34,35), Mexico (10), Canada, South Africa and Peru (35).

The only case of weissellosis documented in Mexico caused 60% mortality in trout between 100 and 300 g in a farm in the center-west of the country (10). The diseased fish presented clinical signs and lesions similar to those reported in other countries and typical of hemorrhagic septicemia, consistent in darkening of the body, swimming atop the water column and jumping out of the ponds, anorexia, lethargy and incoordination. Lesions may be branchial paleness, exophthalmos, corneal opacity, peri- and intra-ocular hemorrhage and corneal rupture. Internally, hemorrhagic liver and / or irregular in color, hemorrhages in swim bladder, gonads and at the coelom parietal surface, formation of pseudo-membranes in heart and brain hemorrhages (32). Histopathological lesions encompass corneal edema, retro-orbital inflammation, meningitis, degeneration, necrosis and hepatic vasculitis, epicarditis and

granulomatous myocarditis (32,33). Other cases of this emergent disease are likely, however they have not been reported. A possible explanation for the lack of reports is underreporting, since weissellosis' clinical signs are similar to other infections caused by gram-positive bacteria (32,33).

Infections by *Streptococcus*-type bacteria.

Fish streptococcosis is the clinical manifestation of a set of acute septicemic infections that tend to chronicity, produced by a number of gram-positive bacterium taxa with coccoid aspect, negative catalase and oxidase, which comprises the genera *Streptococcus*, *Lactococcus* and *Vagococcus*. These agents are known to affect terrestrial animals, including humans. In any case, the intensification of fish culture has favored its occurrence as emergent infections in fish species, among which rainbow and yellow tail trout (*Seriola* spp.) and tilapias (36,37) stand out.

The main bacteria implied in the *Streptococcus* complex are *S. iniae*, *S. agalactiae*, *S. dysagalactiae*, *S. parauberis*, *S. feacalis*, *Lactococcus garvieae* and *L. lactis* (38), which are usually present in water, sediments and fish. The appearance of the clinical disease is commonly related to manipulation stress, high density, inadequate nutrition and poor water quality, being distinguishable the increase in temperature to values between 18 and 25°C, according to the diseased species. It is important to point out that conventional phenotypical and biochemical tests are insufficient to differentiate these bacteria, which makes it necessary the use of genetic-molecular procedures such as hybridization and sequencing of gen 16S RNA (37,38).

The first record of streptococcosis in fish was for rainbow trout in 1957, ever since outbreaks have been reported for other species. It is considered one of the main health risks for salmonids, which usually experience yearly events, generally in summer (36). In like manner, *Streptococcus* spp. are the gram-positive bacteria that affect tilapias the most, in which it may produce mortalities of about 90%, mainly associated to *S. iniae* and *S. agalactiae* (9).

The clinical signs of infections caused by bacteria of the *Streptococcus* complex are very similar, oriented to systemic affectations with variations according to the affected species, being difficult to establish actual differences (36,37,38).

Diseased fish exhibit inactivity-lethargy, body darkening, anorexia, and cachexia, erratic swimming, branchial paleness, petechiae or pericocular hemorrhage, uni- or bilateral exophthalmos with or without corneal opacity, scale loss, hemorrhages and/or ulcerated lesions or skin abscesses, anal prolapse and edema, hemorrhages at the fin base (38,39).

The first report of *Streptococcus* in fish in Mexico indicated the presence of *S. iniae* and *S. agalactiae* in farmed tilapias; though, neither the clinical picture nor the bacteria's characteristics were described. The formal identification of *S. iniae* as a cause of Streptococcosis was verified in tilapias between 200 and 450 g (9) which showed clinical signs and lesions previously described for this disease (36,37,39). Internally, the fish presented ascitic fluid of serum-bloody or turbid aspect, main organs increased in size with irregular aspect and hemorrhages, formation of adherences between internal organs and toward the coelom wall, whitish-greyish membranes of purulent aspect in heart, edema and brain hemorrhage. Histologically, the main organs presented degeneration and necrosis areas, and granulomas; purulent exudate in muscle tissue with melanized encapsulation, meningitis, encephalitis or meningoencephalitis, pericarditis and myocarditis (36). After the description by Ortega et al (9), other cases of *S. iniae* in tilapias have been verified, whereas unpublished evidence suggests that other *Streptococci* affect tilapias in the country. No cases of infection by bacteria from the *Streptococcus* spp genus have been reported for other fish species in the country.

Lactococcus garvieae causes septicemic disease in rainbow and yellow tail trout with clinical signs similar for descriptions of Streptococcosis (11,38). In Mexico, in 2016, there were cases of septicemic disease in commercial-size rainbow trout, which in view of the clinical signs and the preliminary identification as gram-positive cocci were thought to be weisselosis (10). Albeit, later studies found out that *L. garvieae* was the causal agent. Presently, cases of lactococcosis have been observed in the main trout producing zones in Mexico, affecting fish in farms with various technological levels, having as a common factor the temperature of the culture water between 16 and 18°C (11).

For tilapias, infections by *L. garvieae* have also become relevant (37) and they are usually graver when water temperature is over 20°C.

Its economic impact is related to mortality, channel deteriorations and growth delay. Up to date, there are no reports for lactococcosis in tilapias in Mexico.

Infections by *Mycobacterium* spp.

Mycobacteria are slow-growth acid-alcohol resistant bacillus, immobile aerobic (40). There are 193 species validly recognized that belong to a single genus of the *Mycobacteriaceae* family (12). Medically, mycobacteria divide into three groups: 1) *Mycobacterium tuberculosis* complex that causes tuberculosis; 2) non-tuberculous mycobacteria (NTM); and, 3) *Mycobacterium leprae*.

Mycobacterial infections in fish or "atypical mycobacteriosis" is caused by NTM, mainly *M. marinum*, *M. chelonae* and *M. fortuitum* (41). They are environmental organisms present in potable water supply points, pools, coastal waters and aquarium facilities. They usually turn into opportunistic pathogens of immunocompromised and immunocompetent hosts. There is no clear evidence of direct transmission; the infection takes place via skin, gills and intestine lesions, consumption or contact with infected animals or protozoans. In viviparous fish, vertical transmission has been demonstrated. Manipulation stress, confinement and transport predispose the infection (42).

Clinically, an atypical mycobacteria infection is a chronic progressive disease with unspecific signs, characterized by formation of granulomas in internal organs and external surfaces in fish. It may occur asymptotically and develop into a chronic course that predisposes to the recurrence of outbreaks, even in wild organisms (42); losses are variable and may cause mortalities over 10%.

The NTM that affect fish with zoonotic potential do not cause the typical lesions observed in cases of tuberculosis (43). Cases related to manipulation of fish usually take place in aged and/or infirm individuals, who present localized nodules or ulcers, or in a "sporotrichosis pattern" by lymphatic dissemination. Histologically, they express granulomatous surface inflammation in limb skin and on rare occasions in deeper tissues. The incubation period is variable and may prolong from weeks to months before the onset of symptoms (43).

In fish in Mexico, in 2013, *M. fortuitum* and *M. marinum* were isolated and verified in the State

of Campeche; however, as of 2007, lesions that suggest infections by mycobacteria in fish have been described and prevalence is considered constant (44). The authors also refer the isolation of *Vibrio* spp. and *Streptococcus* spp. and relate the clinical cases and histologic damage to mycobacteriosis, supported by the positivity of Ziehl-Neelsen stain. However, as it is an important pathogen for freshwater tilapias, the effect and identification of the *Streptococcus* sp. involved remain to be interpreted.

Francisellosis by *Francisella orientalis*.

Bacteria of *Francisella* genus are gram-negative, immobile and aerobic coccobacillus that belong to the group of γ -proteobacteria. They are facultative intracellular organisms difficult to isolate in artificial culture media due to their dependence on cysteine and hemoglobin (Fe). They are capable of replicating in macrophages and various sorts of fish and mammal cells and existing as endosymbionts of amoebas and arthropods (45). The genus comprises 9 species (12), being *F. tularensis* the cause of rabbit fever (i.e., tuleramia, a zoonotic disease) in mammals, the type species.

Fish francisellosis is an emergent disease that causes economic losses in cultures of various freshwater and marine species (45). The two validly described species that affect fish are *Francisella orientalis* and *Francisella noatunensis*. The first, formerly classified as *F. noatunensis* subsp. *orientalis* (Fno) (46), affects warm water fish, including tilapia, striped bass, treeline grunt, and ornamental fish. For its part, *Francisella noatunensis* affects fish such as Atlantic cod and Atlantic salmon, and divides into two subspecies *Francisella noatunensis* subsp. *noatunensis* and *Francisella noatunensis* subsp. *Chilensis*; the former reported in the north of Europe (Ireland, Norway, Sweden and the United Kingdom), while the latter only affects Atlantic salmon in the south of Chile (46).

The earliest antecedents for *Francisella* spp. describe there were high mortalities of tilapias in Taiwan. As a main finding, fish presented whitish-greyish nodules in spleen and kidneys, which histologically corresponded to granulomas with presence of intracellular gram-negative bacteria in macrophages. The cause was attributed to Rickettsia-like organisms (RLO) (47). Between 2006 and 2007, the bacterium was isolated independently from tilapias with nodules by European researchers and called it *Francisella noatunensis* subsp. *Orientalis*, and

Americans, who called it *Francisella asiatica*. Later on, it was demonstrated that it is the same pathogen (47).

Clinically, francisellosis may occur as an acute syndrome with few unspecific signs and high mortality rate, or else subacute to chronic with unspecific signs such as anorexia, anemia, progressive thinning, lethargy, exophthalmia, distended abdomen with hemorrhagic nodules or skin ulcerations and incoordination (48). Distinguishable in necropsy is the presence of whitish-greyish nodules mainly in spleen and kidneys, though they may be found in any organ (8) and present other septicemic lesions (8,47). The most noticeable histological finding is the formation of granulomas in tissues with nodules (occasionally, they are found in fish with subclinical infection). The inside of the granulomas may contain mixed inflammatory liquid and infiltrates with abundance of hypertrophied vacuolated macrophages, fibroblasts and leukocytes. Occasionally, they may be totally or partially covered in necrotic material (47).

Morbidity and mortality are influenced by factors such as population density, sort of production unit and environmental conditions, as well as the presence of mixed infections with other pathogens. The range of mortality may be between 1 and 90% (48). It expresses more acutely and aggressively if temperature increases; at 26°C, the bacterium reaches its maximal pathogenicity (45).

Francisellosis was verified in Mexico by the end of 2012 in tilapias in a farm in the center of the country. A mortality of 40% was recorded in reproducing fish between 200 and 350 g, which displayed a clinical picture similar to that reported in the literature (8); later on, it appeared in other places with varying mortalities. After affecting tilapias, the infection was also verified in the African jewelfish cichlid (*Hemichromis bimaculatus*), which presented multiple nodules in kidney and spleen, which histologically correspond to granulomas (49). This emergent disease is the only that the sanitary authorities recognize as an important disease for the country's fish culture (4).

Infections by *Nocardia* spp. Nocardiosis is a systemic bacterial disease that affects humans and other terrestrial and marine mammals and fish (50). It is caused by bacteria from the *Nocardia* genus which are filamentous

organisms, aerobic, gram-positive, partially acid-resistant which in nature are found as saprophyte in soil (51).

In fish, nocardiosis is an emergent disease that usually mainly affects animals over 300 g in weight. Out of the 115 validly recognized *Nocardia* species (12), only *N. asteroides*, *N. seriolae* and *N. salmonicida* have been isolated from diseased fish. The first case of nocardiosis in fish was attributed to *N. salmonicida* in sockeye salmon (*Oncorhynchus nerka*) in 1949; albeit, *N. seriolae* is the most reported species that causes severe economic losses in several fish, mainly in Asia (51), though not restricted to this continent (50). Mortality can be 35% or higher (3).

Fish affected by nocardiosis present signs of anorexia, emaciation, slow and erratic swimming, abdominal distension, presence of ulcers and / or whitish-ivory nodules in gills, skin and fins, which also appear in serous organs and surfaces. Histologically, nodules correspond to granulomas that consist in necrosis and debris with bacterial aggregates in the center of the lesion (50,51).

In Mexico, by the end of 2013, a 70% accumulated mortality in red drum (*Sciaenops ocellatus*) was reported for a marine farm in Campeche (3). The diseased animals, over 898 g in weight and between 12 and 18 months of age, presented symptoms and lesions typical of granulomatous disease, including multiple white-yellowish nodules from 0,1 to 0,8 cm in diameter in internal organs. The presence *N. seriolae* as causal agent was verified by means of a comprehensive health diagnosis (3). The publication describes a new fish species affected by this pathogen and was the first report of a disease in saltwater fish in the country; the recurrence of the disease made the affected farm suspend its activities.

Final considerations. Actions at academic and official levels are carried out to ascertain the health status of fish culture in Mexico, however, results are poorly disseminated. A reason may be that when the results of diagnoses and/or surveillance aimed at finding out the presence of certain pathogens and/or specific diseases (4) are negative or differ from research goals, these are not published (52, 53). Having these data available, not necessarily as scientific publications nevertheless, is very important as it allows acknowledging the actual health

status of the country, estimating losses and impacts from diseases, learning their behaviors and variants and putting forward actions for prevention and control.

The publications cited in this paper in reference to diseases of fish in Mexico report research works with varying scientific rigor. The most reported bacteria were from the *Aeromonas* genus, which seemingly have had negligible economic impact, with the exception of the earliest reports (5), no other systemic outbreaks are specified. Even *A. salmonicida* considered a primary agent of disease has been isolated from internal and external lesions without causing systemic disease.

Other bacteria considered relevant for pisciculture were detected and/or isolated without causing clinical disease such as *Vibrio* spp. (18, 44). *Plesiomonas shigelloides*, which has been observed to cause septicemia in rainbow trout and other species (54, 55), did not cause clinical disease in trout (6) and in spite of being isolated from clinically diseased tilapias, it is not described if it was a single infection or in combination with other bacteria isolated in the same work (18). Although the isolation of *Edwardsiella* spp. and *Pseudomonas* spp. has been reported, no cases of clinical disease are known.

Following the international sanitary tendency that witnesses an increment in the occurrence of emergent diseases (1), over the last decade Mexico's fish culture has been affected by francisellosis and estreptococcosis in tilapias; weiseellosis and streptococcosis-lactococcosis in rainbow trout; while nocardiosis in red drum. There is no information regarding the isolation or identification of *Renibacterium salmoninarum* (6), a bacterium with severe sanitary implications for trout and considered exotic in the country.

Although the impacts on the economy and production have not been studied, these diseases pose risks for Mexican fish culture. However, with the exception of francisellosis, health care authorities do not consider them important diseases (4).

Acknowledgements

This work was supported by Proyecto de Investigación 4489/2018/CI registered in SIEA - UAEM; Ciencia Básica CONACYT: 287537.

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