

Scientific research on exotic and native fish farming in Mexico: a scientometric view

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ABSTRACT

Objective: To analyze through a scientometric study, the research effort in Mexico on the study of native and exotic fish species with aquaculture production technology, indexed in Scopus.

Design/methodology/approach: Fish species were selected based on a previous study and communications with researchers. Scientific articles from 1990 to 2023 were collected from the Scopus database, focusing on studies conducted by Mexican institutions. Data were transferred to Excel[®] sheets for analysis, including number of publications, topics, institutions, funding sources and open access documents.

Results: The species that shows the greatest number of articles published is *Oreochromis niloticus*, although there is a clear interest in addressing studies on native species. In general, scientific production is led by institutions such as UNAM, IPN, UABC, CIAD and CIBNOR. The dominant topics are aquaculture, ecology, biochemistry, immunology, and parasitology. CONAHCYT is the main source of funding. About half of the publications were open access.

Limitations on study/implications: The study is limited to the Scopus database, which is the one that includes the largest number of journals worldwide. However, by not including other databases the results could have a slight bias, although we do not consider that the trends changed significantly.

Findings/conclusions: Fish research in Mexico shows a positive outlook, with great interest in several species. However, it faces challenges such as the concentration of effort on exotic species, and the impact of the pandemic on research. A balanced approach is needed to encourage research on native species and facilitate open access to scientific information. This will strengthen fish research in Mexico and enhance its impact on the development of the country.

Keywords: Bibliometrics, native fish, open access, aquaculture, tilapia

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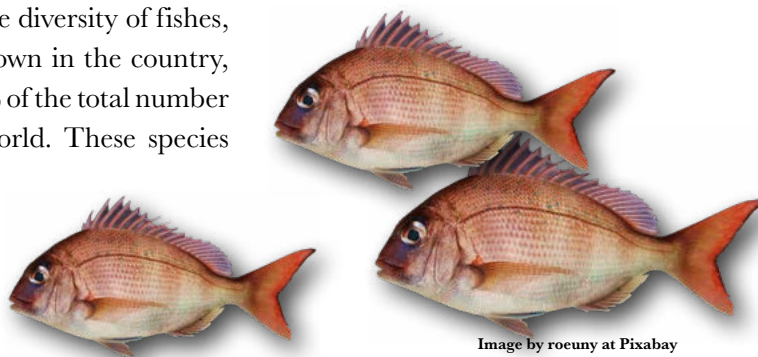
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INTRODUCTION

Mexico stands out for its wide diversity of fishes, with a total of 2,763 species known in the country, representing approximately 9.8% of the total number of fish species known in the world. These species are comprised in 53 orders, 265 families and 967 genera (Espinosa-Pérez, 2014).



Although the diversity of fish in Mexico is one of the highest in the world, only a few native species have been studied for the development of technologies to consider their cultivation. According to Chong-Carrillo *et al.* (2023), research directed to these purposes by the Public Research Centers (CIP) of the National Council of Science, Humanities and Technology (CONAHCYT), studies with native species have focused, for the most part, on marine fish with high added value, while freshwater species have been poorly attended. This is even though the country's major fish production is based on farmed fish in inland systems and waters, with introduced species such as tilapia, carp and catfish (SADER, 2022).

According to Dávila-Camacho (2019), success in the cultivation of native species is based on selecting those with commercial potential due to their rapid growth, high market demand and tolerance to environmental parameters. In mariculture in Mexico, the cultivation of totoaba (*Totoaba macdonaldi*) stands out with complete technological mastery. Other species with advances are the red snapper (*Lutjanus guttatus*), the red snapper (*Lutjanus peru*), and the bullseye puffer (*Sphoeroides annulatus*). In freshwater, the cultivation of the pejelagarto (*Atractosteus tropicus*) for restocking, ornamental and commercial purposes, with complete technology, stands out. Native mojarras such as the castarrica (*Cichlasoma uroptalmus*) and tenguayaca (*Petenia splendida*) are also cultivated.

Although, as mentioned above, research has been carried out with native fish species and there are successful cases of development of finished technologies for their cultivation, the largest production for consumption is based on carp of the *Cyprinus* genus, tilapia (*Oreochromis niloticus*, *O. aureus*, *O. mossambicus* and *Tilapia melanopleura*), commonly known as mojarras and channel catfish (*Ictalurus punctatus*) have also been recorded with important productions (Ortega-Mejía *et al.*, 2023). The first two species are exotic and introduced in most of the country's inland water bodies and both can be considered invasive species due to their high reproductive and adaptive capacity. Although, rainbow trout and channel catfish are native species to specific areas in northern Mexico, their cultivation has also spread to locations outside their natural range, so that, despite being native, they can also be considered invasive species (Mendoza-Alfaro *et al.*, 2021).

The objective of this article is to evaluate the research effort developed by Mexican institutions in relation to the study of native and exotic fish species with aquaculture production technology developed, under development or with potential, based on articles published in international and regional journals deposited in Scopus. This will make it possible to know the scenario in which this type of research is carried out and what its real social impacts are for the country.

MATERIALS AND METHODS

The fish species were selected based on Dávila-Camacho *et al.* (2019), and through personal communication with researchers related to the topic. All scientific papers published between 1990 and 2023 that included the species name in the title, abstract and keywords were selected from the Scopus[®] database (Elsevier, Netherlands). The database

obtained was subjected to a filtering process that focused on studies carried out by Mexican institutions. Subsequently, we proceeded to eliminate those papers that did not comply with the parameters established for the genus and species of the fish under study. The complete records were transferred to datasheets of Excel[®] (Microsoft, USA) for later analysis. The database was organized to obtain, by species and in general, the number of publications, publication timelines, topics addressed, type of access to publications, institutions that have addressed the study, sponsors and type of access (open or paid). The results were graphed using Excel[®].

RESULTS AND DISCUSION

The SCOPUS search yielded a total of 1,316 articles published by Mexican institutions on native and exotic fishes that are subject to study in Mexico for farming purposes. The study focused on 27 species, which are mentioned individually below.

Atractosteus spatula (catán)

The catán is a fish of the ‘pejelagartos’ group, it is the largest species within this group (Ríos-Espino, 2012), however, it barely reaches a total of seven published studies (Table 1). This species is in the status of foster aquaculture by the Mexican government, and its level of biotechnology mastery is reported as complete larval reproduction and culture and in fattening and experimental production (IMIPAS, 2018). The first study appears in 2002, with records ending in 2015. The Universidad Autónoma de Nuevo León is the institution that contributes to the totality of the studies published on this species (Figure 2), and the thematic axis cover areas of biochemistry, physiology and nutrition. The Consejo Nacional de Ciencia y Tecnología (now Consejo Nacional de Humanidades, Ciencias y Tecnologías-CONAHCYT) is the main source of funding mentioned and one document appears as open access (Figure 3).

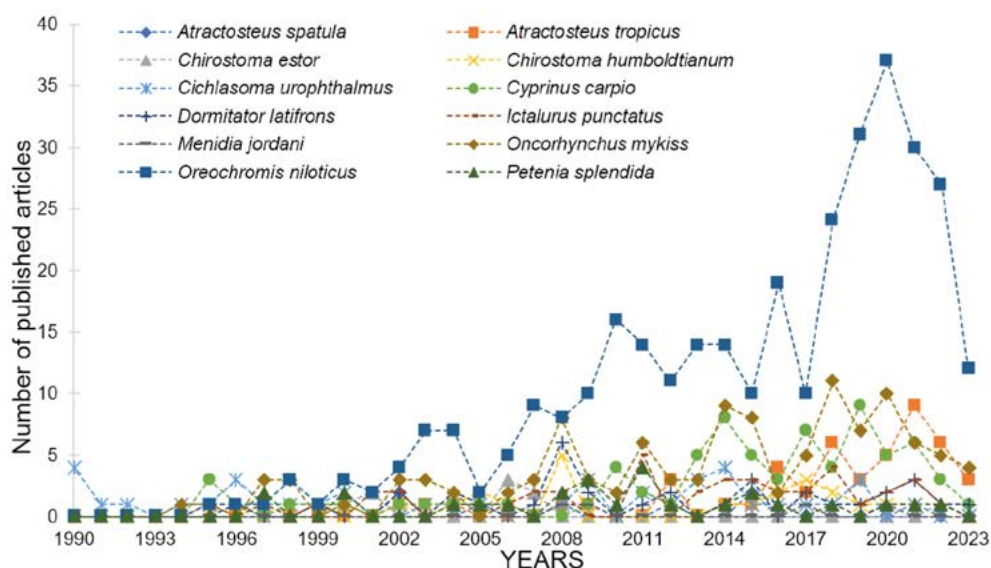


Figure 1. Timeline of studies of freshwater fish with developed, under development or potential production technology in Mexico according to Scopus.

Table 1. Fish species studied with developed, under development or potential production technology in Mexico. Scientific name, common name, status (exotic/native) and the number of publications found in Scopus are shown.

Scientific name	Common name	Common name (spanish)	Status	Number of published articles
<i>Atractosteus spatula</i>	Alligator gar	Catán	Native	7
<i>Atractosteus tropicus</i>	Tropical gar	Pejelagarto	Native	49
<i>Centropomus undecimalis</i>	Common snook	Róbalo común	Native	20
<i>Chirostoma humboldtianum</i>	Shortfin silverside	Charal plateado	Native	23
<i>Chirostoma estor</i>	Whitefish	Pescado blanco	Native	9
<i>Cichlasoma urophthalmus</i>	Mayan cichlid	Mojarra Castarrica	Native	47
<i>Cynoscion othonopterus</i>	Gulf corvina	Curvina golfina	Native	22
<i>Cyprinus carpio</i>	Common carp	Carpa común	Exotic	78
<i>Dormitator latifrons</i>	Pacific fat sleeper	Chame, chopopo, puyequé	Native	35
<i>Ictalurus punctatus</i>	Channel catfish	Bagre de canal	Native	40
<i>Lutjanus guttatus</i>	Spotted rose snapper	Pargo lunarejo	Native	106
<i>Lutjanus peru</i>	Pacific red snapper	Huachinango del Pacífico	Native	74
<i>Menidia jordani</i>	Silverside	Charal	Native	4
<i>Mycteroperca rosacea</i>	Leopard grouper	Mero leopardo	Native	32
<i>Ocyurus chrysurus</i>	Yellowtail snapper	Pargo canané rabirrubia	Exotic	19
<i>Oncorhynchus mykiss</i>	Rainbow trout	Trucha arcoíris	Native	114
<i>Oreochromis niloticus</i>	Tilapia	Tilapia del Nilo	Exotic	333
<i>Paralabrax maculatofasciatus</i>	Spotted sand bass	Lubina manchada	Native	31
<i>Paralichthys californicus</i>	California halibut	Lenguado de California	Native	22
<i>Petenia splendida</i>	Bay snook	Tenguayaca	Native	26
<i>Rachycentron canadum</i>	Cobia	Cobia o esmedregal	Native	9
<i>Sciaenops ocellatus</i>	Red drum	Corvina ocelada o roja	Native	22
<i>Seriola lalandi</i>	Yellowtail kingfish	Jurel, jurel de castilla	Native	22
<i>Seriola rivoliana</i>	Longfin yellowtail	Medregal limón	Native	28
<i>Sphoeroides annulatus</i>	Bullseye puffer	Botete diana	Native	46
<i>Thunnus orientalis</i>	Pacific bluefin tuna	Atún aleta azul	Native	13
<i>Totoaba macdonaldi</i>	Totoaba	Totoaba	Native	85

***Atractosteus tropicus* (tropical gar)**

The tropical gar or pejelagarto (*A. tropicus*) is the species of this group of fishes (Lepisosteidae) best studied by Mexican institutions. This species is not only economically, but also socially and culturally important for the communities within its distribution area (Márquez-Couturier and Vázquez-Navarrete, 2015). A total of 49 documents were registered (Table 1), the first publication appeared in 1995, and it was not until 2002 that the number of publications began to increase (Figure 1). The leading research institution for this species is the Universidad Juárez Autónoma de Tabasco (UJAT), which registers 44 documents deposited in the Scopus database. The Centro

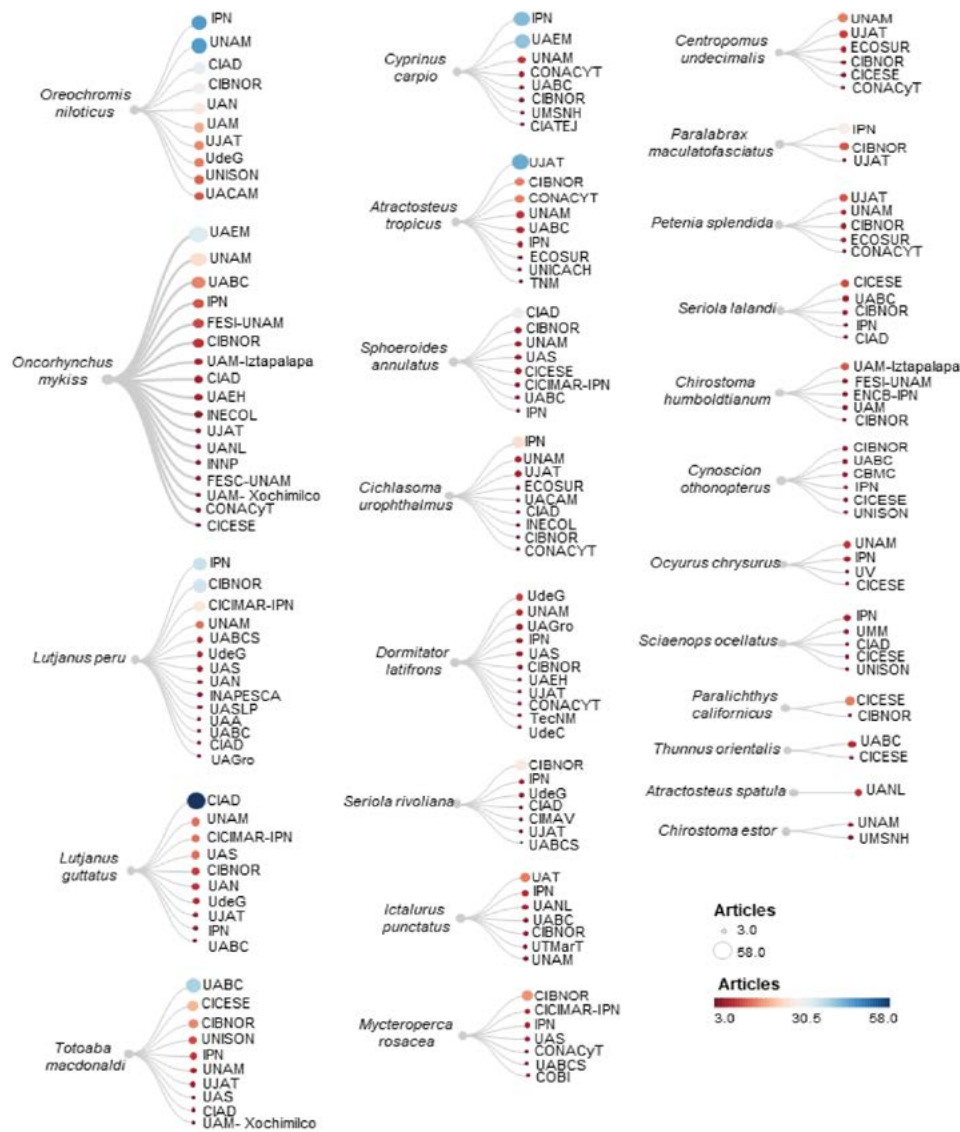


Figure 2. Mexican institutions that undertake studies of fish with developed, under development or potential production technology in Mexico, detected through Scopus. The size and color of the circle indicates the number of articles by institution. Nomenclature of institutions in alphabetical order: CBMC=Centro para la Biodiversidad Marina y la Conservación A.C., CIAD=Centro de Investigación en Alimentación y Desarrollo, CIATEJ=Centro de Investigación y Asistencia en Tecnología del Estado de Jalisco, CIBNOR=Centro de Investigaciones Biológicas del Noroeste, CICESE=Centro de Investigación Científica y de Educación Superior de Ensenada, CICIMAR/IPN=Centro Interdisciplinario de Ciencias del Mar del Instituto Politécnico Nacional, CIMAV=Centro de investigación en Materiales Avanzados SC., COBI=Comunidad y Biodiversidad AC., CONAHCYT=Consejo Nacional de Humanidades, Ciencia y Tecnología, ECOSUR=El Colegio de la Frontera Sur, ENCB-IPN=Escuela Nacional de Ciencias Biológicas-Instituto Politécnico Nacional, FESC-UNAM=Facultad de Estudios Superiores Iztacala, UNAM, FESI-UNAM=Facultad de Estudios Superiores Iztacala, UNAM, INAPESCA=Instituto Nacional de Pesca y Acuicultura, IPN=Instituto Politécnico Nacional, ITNM=Instituto Tecnológico Nacional de México, UAA=Universidad Autónoma de Aguascalientes, UABC=Universidad Autónoma de Baja California, UABCS=Universidad Autónoma de Baja California Sur, UACAM=Universidad Autónoma de Campeche, UAEH=Universidad Autónoma del Estado de Hidalgo, UAEM=Universidad Autónoma del Estado de México, UAGro=Universidad Autónoma de Guerrero, UAM=Universidad Autónoma Metropolitana, UAMIZt=Universidad Autónoma Metropolitana Iztapalapa, UAMXoch=Universidad Autónoma Metropolitana Xochimilco, UAN=Universidad Autónoma de Nayarit, UANL=Universidad Autónoma de Nuevo León, UAS=Universidad Autónoma de Sinaloa, UASLP=Universidad Autónoma de San Luis Potosí, UAT=Universidad Autónoma de Tamaulipas, UdeC=Universidad de Colima, UdeG=Universidad de Guadalajara, UJAT=Universidad Juárez Autónoma de Tabasco, UMM=Universidad Marista de Mérida, UMSNH=Universidad Michoacana de San Nicolás de Hidalgo, UNAM=Universidad Nacional Autónoma de México, UNICACH=Universidad de Ciencias y Artes de Chiapas, UNISON=Universidad de Sonora, UTMarT=Universidad Tecnológica del Mar Tamaulipas Bicentenario, UV=Universidad Veracruzana.

de Investigaciones Biológicas Del Noroeste (CIBNOR) is the second most productive institution and in third and fourth place are CONAHCYT and the Universidad Nacional Autónoma de México (Figure 2). The dominant thematic areas for this species are aquaculture, such as diet design, enzymatic biochemistry and expression of genes involved in metabolism.

CONAHCYT is the main funding source mentioned in documents and fifty-two percent of them are open access (Figure 3).

Centropomus undecimalis (common snook)

The common snook *Centropomus undecimalis* is distributed throughout the tropical and subtropical western Atlantic Ocean from the United States of America to Brazil (Arenas *et al.*, 2021). The scientific production for this species by Mexican institutions records a total of 20 papers deposited in the Scopus database (Table 1). The first document was registered in 2006, and its behavior does not show any trend over the years (Figure 4). The Universidad Nacional Autónoma de Mexico (UNAM) is the institution that devotes the most effort to this species followed by the UJAT and El Colegio de la Frontera Sur (Figure 2). The predominant themes for the study of *C. undecimalis* are ecology and aquaculture, with a wide variety of topics such as fisheries, enzymatic biochemistry and reproduction.

CONAHCYT is the main funding source followed by UNAM and El Colegio de la Frontera Sur. Nine documents are registered as open access (Figure 3).

Chirostoma humboldtianum (silver charal) and Chirostoma estor (white fish)

The silver charal is a native species found in shallow waters of the Lerma system of the Mexican highlands (Betancourt-Resendes, 2018). Despite being a species with fishery

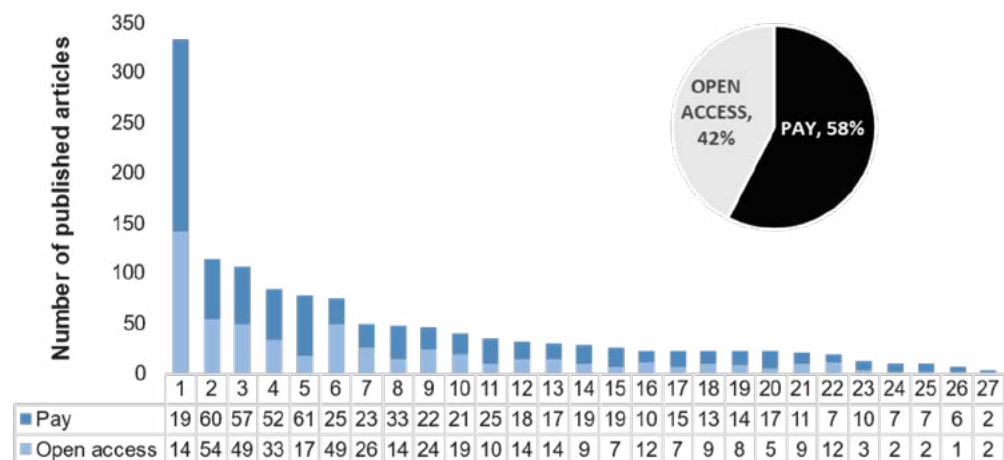


Figure 3. Number of publications by fish species with developed, under development or potential production technology in Mexico detected in the Scopus database, and divided by their access (open access and paid). Legends on the x axis: 1 *Oreochromis niloticus*. 2 *Oncorhynchus mykiss*. 3 *Lutjanus guttatus*. 4 *Totoaba macdonaldi*. 5 *Cyprinus carpio*. 6 *Lutjanus peru*. 7 *Atractosteus tropicus*. 8 *Cichlasoma urophthalmus*. 9 *Sphaeroides annulatus*. 10 *Ictalurus punctatus*. 11 *Dormitator latifrons*. 12 *Mycteroperca rosacea*. 13 *Paralabrax maculatofasciatus*. 14 *Seriola rivoliana*. 15 *Petenia splendida*. 16 *Paralichthys californicus*. 17 *Sciaenops ocellatus*. 18 *Cynoscion othonopterus*. 19 *Seriola lalandi*. 20 *Centropomus undecimalis*. 21 *Ocyurus chrysurus*. 22 *Thunnus orientalis*. 23 *Rachycentron canadum*. 24 *Chirostoma estor*. 25 *Atractosteus spatula*. 26 *Menidia jordanii*. 27 *Chirostoma humboldtianum*.

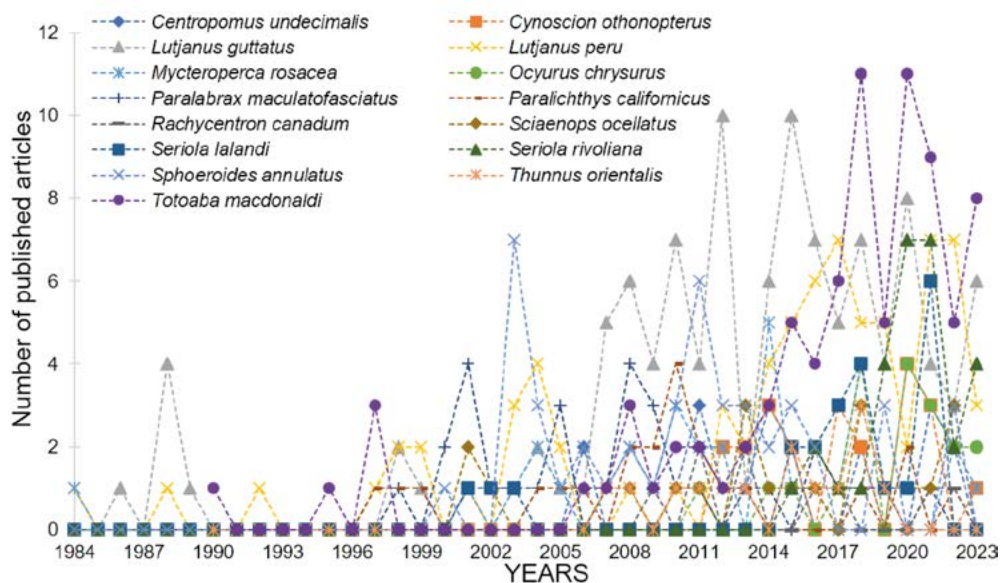


Figure 4. Timeline of studies of marine fish with developed, under development or potential production technology in Mexico according to Scopus.

importance for human food, it barely reaches a total of 23 papers registered in the Scopus database (Table 1). The first production records appear in 2006, and it has remained without any trend over the years (Figure 1). The Universidad Autónoma Metropolitana (UAM) is the main institution that dedicates research to this species followed by UNAM and in third place is the Instituto Politécnico Nacional (IPN) (Figure 2). The main topics treated for the species are ecology and fisheries, genetics and aquaculture, with works such as population genetics, karyotypes and aquaculture nutrition.

CONAHCYT is the main funding source mentioned in the documents on six occasions, followed by UAM with two, the rest of the funding sources barely appear with a single mention. Five documents were published with the open access category (Figure 3).

The whitefish, *C. estor*, is a species endemic to the lakes of Pátzcuaro and Zirahuén and shares many characteristics, both biological and commercially important, with *C. humboldtianum* (Rojas-Carrillo, 2005); however, its scientific productivity is only nine papers registered in the Scopus database (Table 1). UNAM and the Universidad Michoacana de San Nicolás de Hidalgo are the institutions that pay most attention to this species (Figure 2). The topics published are on ecology, parasitology and aquaculture. Only two papers were published under the open access category (Figure 3).

***Cichlasoma urophthalmus* (mojarra castarrica, mojarra colorada, mojarra criolla)**

This native freshwater fish is in the top 5 of the most studied species, with 47 papers registered in the Scopus database (Table 1). The first record has been kept since 1986, and its production has been between 1 and 3 articles per year (Figure 1). The main institutions that dedicate research to this species is the IPN, which leads the research on this species, the second place is occupied by the UJAT and the third by El Colegio de la Frontera Sur

(Figure 2). There is interest in developing its production technology, with some pilot farming programs (Ramírez-Abarca *et al.*, 2011), although parasitology is the main thematic area, followed by aquaculture and ecology.

CONAHCYT dominates as the main funding source, followed the Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO) and UNAM. Of the 47 documents, 14 appear in the open access category (Figure 3).

***Cynoscion othonopterus* (Gulf corvina)**

The Gulf corvina is distributed throughout the tropical and subtropical western Atlantic Ocean from the United States of America to Brazil (Arenas *et al.*, 2021). It is a native marine species that only records a total of 22 papers deposited in the Scopus database (Table 1). 2020 was the year with the most records (four), and the behavior through the years is very variable, with highs and lows (Figure 4), with an average of approximately two articles per year, starting in 2012. The institutions that stand out are, in first place, CIBNOR and the Universidad Autónoma de Baja California (UABC), followed by the IPN, the Centro de Investigación Científica y Educación Superior (CICESE) and the Universidad de Sonora (Figure 2). The main line of research directed at this species is ecology with and aquaculture, population genetics and fisheries.

CONAHCYT is the main funding source, followed by a foreign foundations, the David and Lucile Packard Foundation, the Walton Family Foundation and the Universidad de Sonora. Nine published documents appear in the open access category (Figure 3).

***Cyprinus carpio* (Common carp)**

The common carp is the second most studied exotic species by Mexican institutions, with 78 publications registered in the Scopus database (Table 1). The first study in Mexico for this species was recorded in 1984, while 2013 has the highest number of publications, with nine. There is no pattern in the number of publications over time, but there is an increase that falls during the pandemic (Figure 1). The IPN tops the list of institutions with the most studies for this species, the UNAM is positioned as the second, and UNAM as third (Figure 2). The studies with the highest proportion for *C. carpio* are those on toxicity, dealing with topics such as bioaccumulation, heavy metals, among others. The next most important thematic area is immunology, oxidative stress and hematology.

Among the main funding sources for studies focused on *C. carpio*, CONAHCYT obtained the most mentions, followed by the IPN. Of the 78 documents published, 17 appear in the open access category (Figure 3).

***Dormitator latifrons* (chame, chopopo, Pacific fat sleeper, puyequé)**

D. latifrons (Richardson, 1844), commonly known as the Pacific fat sleeper, inhabits continental waters from California (USA) to Ecuador (Aréchiga-Palomera *et al.*, 2022). There is a record of 35 documents published in the Scopus database (Table 1). The first document appeared in 1996 and productivity has ranged from 1 to 3 documents per year (Figure 1). The Universidad de Guadalajara (UdeG) is the leader in research for this

species, followed by UNAM and the third place is occupied by the Universidad Autónoma de Guerrero (UAG), with (Figure 2). The main areas addressed for this species are, in first place, parasitology, followed by ecology and aquaculture.

Only seven documents mention that funding is granted by CONAHCYT, one for the UdeG and another for the Universidad Autónoma de Sinaloa (UAS). Ten documents appear with the category of open access (Figure 3).

***Ictalurus punctatus* (Channel catfish, American catfish)**

Channel catfish is a native freshwater species that is cultivated in various areas of the country (Lara-Rivera *et al.*, 2015). A total of 40 documents deposited in the Scopus database are registered (Table 1). The first record is from 1984, and its productivity ranges from one article to five over the years (Figure 1). The Universidad Autónoma de Tamaulipas (UAT) is the leader in research for this species, followed by the IPN and the Universidad Autónoma de Nuevo León (UANL) (Figure 2). The main thematic area is aquaculture, followed by genetics and biochemistry and parasitology.

CONAHCYT is the main funding source followed by IPN and the Secretaría de Educación Pública (SEP). There were 19 documents under the open access category, almost 50% of all the documents registered (Figure 3).

***Lutjanus guttatus* (spotted rose snapper)**

The snapper, *L. guttatus*, is a marine native species of the tropical and subtropical eastern Pacific, its distribution extends from the southwestern coast of Baja California Sur and the Gulf of California, Mexico, to Peru. Low-scale, wild juvenile grow-out farms are reported in Baja California Sur, Sinaloa and Jalisco (IMIPAS, 2018). It is the most studied native species by Mexican institutions, with a total of 106 papers deposited in the Scopus database (Table 1). The Centro de Investigación en Alimentación y Desarrollo (CIAD) is the leader in research for this species followed by UNAM, the Centro Interdisciplinario de Ciencias Marinas del IPN, CIBNOR and the UAS (Figure 2). This species is one of those for which the greatest effort has been given to promote its cultivation, with some precedents of aquaculture activity led by CIAD and INAPESCA (IMIPAS, 2018). Aquaculture is the main thematic axis of study for this species with topics from larval stages to juveniles, search for diets according to their nutritional requirements, among others, and topics of reproduction. Ecology is the second thematic area for the species, and in third place is Parasitology.

CONAHCYT is the main source of funding for studies in this organization, followed by the Secretaría de Agricultura y Desarrollo Rural (SADER), and the Comisión Nacional del Pesca y Acuicultura (CONAPESCA). 46% of the documents were published under the open access category (Figure 3).

***Lutjanus peru* (Pacific red snapper)**

The red snapper, *L. peru*, is a species with similar characteristics to *L. guttatus*; they are well accepted species in the regional market and their capture is persistent throughout the year (Chiappa-Carrara *et al.*, 2004). It is also a species that has generated a high scientific

production by Mexican institutions, with a total of 74 papers deposited in the Scopus database (Table 1). The years 2017, 2021 and 2022 have the most published papers, with seven (Figure 4) with a dramatic decrease in 2023. The leading institutions in research for this species are led by the IPN, followed by CIBNOR and UNAM (Figure 2). The main thematic area is ecology, which include fisheries and deal with topics such as assemblages, connectivity and population characteristics. The next area is immunology, dealing with topics such as immune response, use of glucans, use of probiotics, among others, and in third place appears aquaculture which is combined with immunology to deal with topics such as use of ingredients like probiotics or immunostimulators added to the diet of these organisms; the third most important topic is reproduction.

CONAHCYT is mentioned as the main source of project funding, followed by the IPN and SEP. A total of 27 documents were published under the open access category (Figure 3).

***Menidia jordani* (river charal)**

The river charal, *M. jordani*, is distributed in the Mexico Basin, in the Lerma River Basin and its associated lake systems (Cuitzeo and Chapala), as well as in the Pánuco, Cazones and Tecolutla Rivers and their tributaries, with Lake Metztlán as the eastern limit of its distribution in lentic environments (Ibáñez *et al.*, 2008; Abeja-Cruz *et al.*, 2013). The scientific information for this species, at least that reported for the Scopus database is very poor, with only four documents (Table 1). It is almost probable that the information generated on this species is available in gray literature (such as thesis, newspaper notes, and low print run books and manuals), and mostly on its ecology and fisheries.

***Mycteroperca rosacea* (leopard grouper)**

This endemic, marine species is distributed from the southeastern coast of the Baja California peninsula, throughout the Gulf of California to the coasts of Jalisco, Mexico. It has strong importance in commercial fisheries and is a candidate for cultivation (Romo-Mendoza, 2019). A total of 32 papers deposited in the Scopus database were counted (Table 1). CIBNOR leads the research on this species followed by IPN with and UAS (Figure 2). The main thematic areas addressed for this species are, in first place, reproduction followed by Ecology and Immunology.

CONAHCYT dominates as the main source of project funding, followed by Sistema de Investigación del Mar de Cortés (SIMAC). There were 14 documents published under the open access category (Figure 3).

***Ocyurus chrysurus* (canané snapper, yellowtail snapper)**

This organism has a wide distribution range that goes from Massachusetts, USA, to Brazil, including Bermuda, the Gulf of Mexico, the West Indies and the Antilles, and since it is considered a high-quality food, studies have been developed that involve its cultivation in controlled systems (Gutiérrez-Benítez, 2012). A total of 19 documents deposited in the Scopus database were recorded (Table 1), starting in 2011 (Figure 4). The institutions with the highest number of publications on this species are UNAM, IPN, Universidad

Veracruzana (UV) and CICESE (Figure 2). The main topic addressed in this species is Ecology, with nine documents, followed by Aquaculture with four.

CONAHCYT and UNAM are the main contributors of funding for the study of this species. Twelve documents were published under the open access category (Figure 3).

***Oncorhynchus mykiss* (rainbow trout)**

Rainbow trout, *O. mykiss*, (Walbaum, 1792) is a salmonid distributed from southern Alaska to northwestern Mexico (Hernández and Carrillo, 2018). According to the SADER (2021), trout production in 2020 was 3,898 tons. Although 18 states are reported as the producers, the main ones are (in order of production volume): Tamaulipas, Veracruz, Puebla, Michoacán and Chihuahua. The Scopus search yielded a total of 114 articles generated by Mexican institutions, the most important being the Universidad Autónoma del Estado de México (UAEM), UNAM, the Universidad Autónoma de Baja California (UABC), IPN, CIBNOR and the Universidad Autónoma Metropolitana (UAM) – Unidad Iztapalapa (Figure 2). With almost 50% of the articles detected, Agriculture and Biological Sciences is the most frequently addressed topic, followed by Veterinary Science, Environmental Science and Biochemistry, Genetics and Molecular Biology (the four topics account for almost 90% of the articles published). CONAHCYT is the institution that has provided the most funding for research on this species, followed by UNAM and the Universidad Autónoma del Estado de México, a total of 54 articles are available as open access (Figure 3).

***Oreochromis niloticus* (tilapia, Nile tilapia)**

These fish of African origin were introduced into many regions of the world during the second half of the 20th century for the purpose of providing a sustainable, inexpensive, high-quality source of protein. They have become widely popular because they tolerate high densities, are fast growing, disease resistant, easily adaptable to captivity, accept balanced feeding diets, the meat is of good quality and affordable price (Jácome *et al.*, 2019). In Mexico, the research directed to this species is the one that has made the greatest effort. A total of 333 documents deposited in Scopus are registered, from the year 1994 the first article is registered, while the year 2020 is positioned as the most productive, with 37 publications. Although there is no constant growth, there is an increase in the number of publications over the years (Figure 1). The institutions that direct most effort to the study of this species, in decreasing order, are the IPN and UNAM, CIAD and CIBNOR (Figure 2).

Despite being a species of commercial importance for human consumption, most of the studies are focused on the area of ecology, followed by genetic and immunological studies and microbiology and biochemistry. Although these studies are considered aquaculture topics, these areas are strongly related to aquaculture, as they address information on the metabolism and physiology of this species that is important for human consumption. CONAHCYT is the institution as the main source of funding, followed by IPN and UNAM. Of the 333 documents registered, 142 have open access status (Figure 3).

***Paralabrax maculatofasciatus* (spotted sand bass)**

The cabrilla arenera is a marine fish native to the Eastern Central Pacific. It is exploited throughout the year, mainly in local fisheries where it is marketed as one of the most important products in the northwestern region of Mexico (De la Re-Vega *et al.*, 2020). A total of 31 papers registered in the Scopus database were counted (Table 1). The IPN is the institution with the highest number of publications, followed by CIBNOR (Figure 2). Aquaculture and biochemistry were the main areas that dominate the study of this species.

CONAHCYT is the organization that provides the most funding to projects, followed by the IPN. A total of 14 documents were published under the open access category (Figure 3).

***Paralichthys californicus* (California halibut)**

The California sole (*Paralichthys californicus*) is a flatfish that inhabits the waters of the west coast of northern Mexico and the USA. It is considered a species with high aquaculture potential in both countries (Badillo-Zapata *et al.*, 2010). A total of 22 papers deposited in the Scopus database were registered (Table 1). CICESE is the institution with the most research on the species, followed by CIBNOR (Figure 2). Aquaculture is the main thematic axis for the study of this species, followed by Biochemistry, but this last area is related to aquaculture.

CONAHCYT is the source of funding for projects for the study of this species, followed by CICESE. Of the 22 published papers, 12 were published under the open access category (Figure 3).

***Petenia splendida* (tenguayaca, bay snook)**

Bay snook (*Petenia splendida* Günther, 1862), locally known as “tenguayaca” is a highly valued native cichlid for human consumption, inhabiting freshwater bodies from southeast of Mexico. It represents significant ecological importance and economic value (locally and regionally) for aquaculture (Rodríguez-Estrada *et al.*, 2020). A total of 26 papers were registered in the Scopus database (Table 1). UJAT leads in scientific production for this species, followed by UNAM, CIBNOR and El Colegio de la Frontera Sur (Figure 2). Ecology is the main dominant area, followed by aquaculture and parasitology.

CONAHCYT received only three mentions as a source of funding for projects aimed at the study of this species, and other institutions and foundations received only one mention. Seven documents were published with the category of open access (Figure 3).

***Rachycentron canadum* (cobia)**

This marine fish is a cosmopolitan organism from the Atlantic, has commercial importance and in Mexico is under the category of Aquaculture of promotion (IMIPAS, 2018). Studies in Mexico regarding this species are poor, with only a total of nine records deposited in the Scopus database (Table 1). UABC, CIAD and IPN are the institutions with the highest publication records, but with just two for each institution (Figure 2). Most of the topics related to this species are related to ecology and fisheries. There is no funding

source that stands out, all with one mention, including CONAHCYT and the institutions mentioned above.

***Sciaenops ocellatus* (Corvina ocelada or red drum)**

This native marine species is distributed in the northern Atlantic Ocean and the Gulf of Mexico. The level of mastery of its culture technology is complete and it already has a history of aquaculture production (IMIPAS 2018). Despite having the technological development for its cultivation, research directed in Mexico towards this species barely reaches 22 publications deposited in the Scopus database (Table 1). Institutions such as IPN, Universidad Marista de Mérida and CIAD stand out (Figure 2). Aquaculture is the main thematic focus for the study of this species, with ecology in second place.

CONAHCYT is the main source of funding for projects aimed at the study of this species, while the IPN and the Universidad Marista de Mérida occupy the second position. Seven papers were published under the open access category (Figure 3).

***Seriola lalandi* (California horse mackerel, yellowtail jack mackerel)**

This native marine species has in Mexico a partial culture domain limited to fattening and there are antecedents of its culture based on the collection of juveniles (IMIPAS, 2018). Research directed at this species is concentrated in institutions in the north of the country, and its productivity accounts for 22 papers registered in the Scopus database (Table 1). The institutions that stand out are CICESE, UABC and CIBNOR (Figure 2). Aquaculture dominates as the thematic axis in the study of this species.

CONAHCYT is the main source of funding for projects aimed at the study of this species. Eight papers were published under the open access category (Figure 3).

***Seriola rivoliana* (Bojala, lemon medregal)**

The lemon sole, *S. rivoliana*, is a native pelagic fish that is distributed circumtropically in the Pacific, Atlantic and Indian Oceans. It has been identified as having high aquaculture potential due to its rapid development, good meat quality and market value (Mendoza-Portillo, 2022). The scientific production of this species registers a total of 28 papers deposited in the Scopus database (Table 1). CIBNOR is the leader in research for this species, followed by IPN and the UdeG (Figure 2). Immunology, aquaculture and biochemistry are the main axes for the study of this species. CONAHCYT and CIBNOR are the main funding sources for projects. Nine published documents appear with the category of open access (Figure 3).

***Sphoeroides annulatus* (bullseye puffer, botete)**

This native marine species, the botete or *S. annulatus*, is a species found in the Mexican Pacific with distribution from the Coast of San Diego, California (USA) to Peru (Abdo-De la Parra *et al.*, 2022). Forty-six papers are registered in the Scopus database (Table 1). CIAD leads the research for this species, followed by CIBNOR (Figure 2). The main thematic areas are reproduction, aquaculture and parasitology.

The topics addressed are hatchery, aquaculture nutrition and parasites associated with fisheries. CONAHCYT is the main source of funding for projects aimed at the study of this species, followed by SAGARPA. There were 24 documents published under the open access category (Figure 3).

***Thunnus orientalis* (bluefin tuna)**

The bluefin tuna *T. orientalis*, a marine fish distributed from Japan to the Baja California peninsula in Mexico. It is of undoubted importance in commercial and sport fishing. The domain of its biotechnology is partial and limited to fattening culture through the collection of wild organisms (IMIPAS, 2018). Despite its importance, in Mexico it barely reaches 13 publications registered in the Scopus database (Table 1). UABC and CICESE are the institutions with the highest numbers of publications with aquaculture as main topic.

CONAHCYT and UABC are the main entities that offer financial support for projects aimed to study of this species. Three papers were published under the open access category (Figure 3).

***Totoaba macdonaldi* (Totoaba)**

The totoaba is one of the most prized marine fish species in the upper gulf area. It is currently included in the list of endangered species and is permanently banned. The decline of its populations due to illegal fishing has forced institutions to redouble their efforts in the study to develop aquaculture technology (Cáceres-Martínez *et al.*, 2023). In fact, it is the second best studied native species by Mexican institutions, with a total of 85 published papers registered in the Scopus database (Table 1). An increase in the number of publications over the years can be observed (Figure 4). UABC is the leader in research, followed by CICESE and CIBNOR (Figure 2). Aquaculture is the main thematic axis in the study of this species, representing 35% of the published papers.

The topics covered include the use of additives, ingredient replacements to evaluate larval and juvenile growth, among others. Ecology and fisheries represent the second thematic axis treated in this species, fundamental for the evaluation and management of this species that is catalogued as vulnerable due to illegal fishing. CONAHCYT is the main entity with the highest number of mentions in funding, followed by UABC and CICESE. There were 33 documents published under the open access category (Figure 3).

General scenario

The results show that Mexican academic and research institutions have a clear interest in approaching the study of native species in a basic way and in the development of technologies for their cultivation. Applied research, based on basic studies of physiology, nutrition and reproduction, among others, have resulted, in some cases, in efficient cultivation technologies. However, the species that has shown the greatest growth, with the greatest number of articles published, is *O. niloticus*, a freshwater and exotic species. The common carp, *C. carpio*, also accumulates a good number of

published articles, despite being another of the exotic species most widely distributed in dams and reservoirs in Mexico (Table 1). These two species alone account for 31% of all the articles published on fishes of commercial or social interest despite constituting only two of the 27 species covered in this work, or 7% of these. Most of the research has been directed towards marine species with high added value (Table 1). This has already been commented by Chong-Carrillo *et al.* (2023), who mention that the research conducted by the Public Research Centers (CIP) of the National Council for Science, Humanities and Technology (CONAHCYT) has focused, for the most part, on marine fish with high added value, while native freshwater species have received less attention.

The native fishes that show a growth in the number of publications are the rainbow trout *O. mykiss*, which after tilapia, is the fish with the most total published studies, followed by the tropical gar *A. tropicus*, the castarrica mojarra *C. urophthalmus*, and the channel catfish *I. punctatus*, species whose biological cycle has been closed and whose culture technology is very advanced. Of the total number of species included in this study, the 12 freshwater species, native or exotic, represent 44%, but in the total number of articles they have generated, they account for 58%.

Of the marine fishes recorded in the present study –15 in total– the lunar snapper *L. guttatus*, accumulated the most publications, followed by the totaba *T. macdonaldi*, the Pacific red snapper *L. peru*, and the botete *S. annulatus* (Table 1). These four species accumulate 311 published articles, which represents 24% of the total number of articles of the species covered in this study. Research with the remaining marine species (11) yielded 18% of the total publications. The cumulative number of articles published with marine species is 42%.

As it is possible to observe, and as mentioned before, native species have received great attention from the country's scientific community, and this complies with the concern expressed by FAO (2010, 2014, 2016, 2020, 2022) in relation to avoiding the introduction of exotic species with potential or known invasive capacity, and the need to research and develop technologies of regional, native or endemic species.

Figures 1 and 2 show the timeline of publications generated with freshwater species (Figure 1) and marine species (Figure 2). In both graphs it can be observed that there are species that show a profuse production of scientific articles, the least, and a majority that maintain a modest production over time. This may indicate that the knowledge generated about them is not yet sufficient to derive efficient cultivation technologies. This is more evident for native freshwater species. For the latter, the interest in tilapia in research development is clear, with an upward trend until 2020, for a dramatic decline to date. This decline is probably one related to the effects of the COVID-19 pandemic that forced much of the country's scientific community into a work stoppage. This same phenomenon, although on a much smaller scale, can be observed in other freshwater species that were experiencing greater growth in research translated into published articles, such as rainbow trout, common carp and the common red snapper. This decrease does not show an increase in the last recorded year. In the case of marine species, the phenomenon is apparently repeated.

Species that showed a growth trend, despite significant variations in the timeline, are noted with significant declines from the year 2020 to increase again in the post-pandemic stage, which is not observed in freshwater species. This is the case of *L. guttatus*, *S. rivoliana* and *T. macdonaldi*. The consequences of the isolation forced by the pandemic suggest a negative effect on the continuation of research centers and universities. This phenomenon has been mentioned by Jamali *et al.* (2023), who comment that the closure of laboratories and the impossibility of carrying out field work had a severe impact on the development of young scientists in training and on their productivity, an important sector in the scientific population since it is the main work force of research groups.

Regarding the thematic areas, classified by Scopus, the articles published address aquaculture in more than 30% of the total, followed by Ecology and Immunology/Microbiology. These areas alone represent more than 50% of the publications (Figure 5). Most of the remaining publications deal, directly or indirectly, with aspects also related to aquaculture, such as Genetics, Biochemistry, Reproduction, Parasitology and Physiology (Figure 5).

The above shows that both basic and applied research have been directed to fill gaps in knowledge related to the capacity to carry out the culture of the species of interest and, in the case of Ecology, to determine population and environmental aspects (particularly of native species) that, although in *sensu stricto* do not follow the previous path, do allow contemplating a more complete scenario on the status of the species' populations, their interactions with the environment and the possibility of sustainable use.

Figure 3 shows the publications by species considering the access to them, either open access or paid access. Of the total number of articles published, 58% could only be accessed through the pay access system of the respective journals, while only 42% had open access. This may reflect the need for authors to use journals known as “mainstream”, generally published by transnational publishers that only offer the opportunity for articles to be

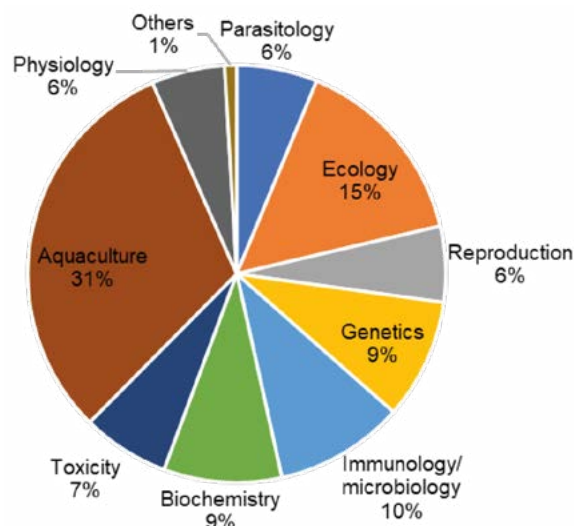


Figure 5. Thematic areas in studies of fish with developed, under development or potential production technology in Mexico and detected through Scopus.

freely read by charging very high fees. In addition, Mexican scientific policies, through CONAHCYT, promote publication in journals of “recognized prestige” included in indexes, also transnational, such as the Journal Citation Rank (JCR) and in databases such as Clarivate, Scimago Journal & Country Ranks and Scopus. In the case of open access journals, these are generally sponsored by academic institutions, public or private, whose publication costs are generally low. Many of these are also included in international indexes and databases. However, our study indicates that researchers prefer to publish in more prestigious journals with the idea that their work will be better located and cited (Figure 3).

With the popularization of the Internet and easy access to free databases, this justification has weakened as open access articles can be easily detected and consulted. Open access advocates argue that scholarly communities should organize against the current system in which scholars donate articles for free but then must buy them at high prices from commercial publishers (Wellen, 2004). Undoubtedly, the payment of high publication fees represents a deterrent for many researchers, especially those attached to public universities with limited economic resources. In addition, another negative factor is the loss of copyright, with the obligatory assignment to the journal. In such a way, the authors themselves do not have the legal right to disseminate their published work, although this is *de facto* done. Of the species addressed in this study, only four demonstrate open access publications superior to paid publications: *A. tropicus*, *S. annulatus*, *P. californicus* and *T. orientalis*. In the remaining, the vast majority, the ratio of open access: paid access is always higher than the latter. It is worth mentioning that in many cases this ratio is close, indicating an interest or need to publish in open access journals.

Reaching a scenario of only “open access” is not real; transnational commercial publishers are companies with great power, not only economic but even political, and they will continue to occupy a preponderant place in the dissemination of science. Promoting the development of open access publications, with rigorous editorial standards and mechanisms to deal with possible biases and inequities, emerges as a promising strategy to reform scholarly communication practices. The two models, paid and open access, should not be mutually exclusive; it is necessary to find ways for them to coexist and collaborate to broaden access and dissemination of scientific knowledge.

In relation to the institutions that have addressed the study of marine and freshwater fishes, Figure 2 shows their preponderance in the number of published articles on a scale from 3 (at least three published articles), deep red, to 58 (up to 58 published articles) deep blue. The identifying circle is directly proportional, in size, to the number of publications. The institutions that have studied the most species are (in order from highest to lowest) IPN>CIBNOR>UNAM>UABC>UJAT>CICESE>CIAD (Figure 6). This reflects the capacity of these institutions not only to have human resources but also financial resources, which allow them to demonstrate a clear superiority over the rest. The Public Research Centers (CPIs) of CONAHCYT are represented by CIBNOR, CICESE and CIAD, centers that have proverbially been spearheads in many of the studies carried out, mainly with marine species (Chong-Carrillo *et al.*, 2023). It is worth noting that four universities show a profuse publication, such is the case of the IPN (all its centers and

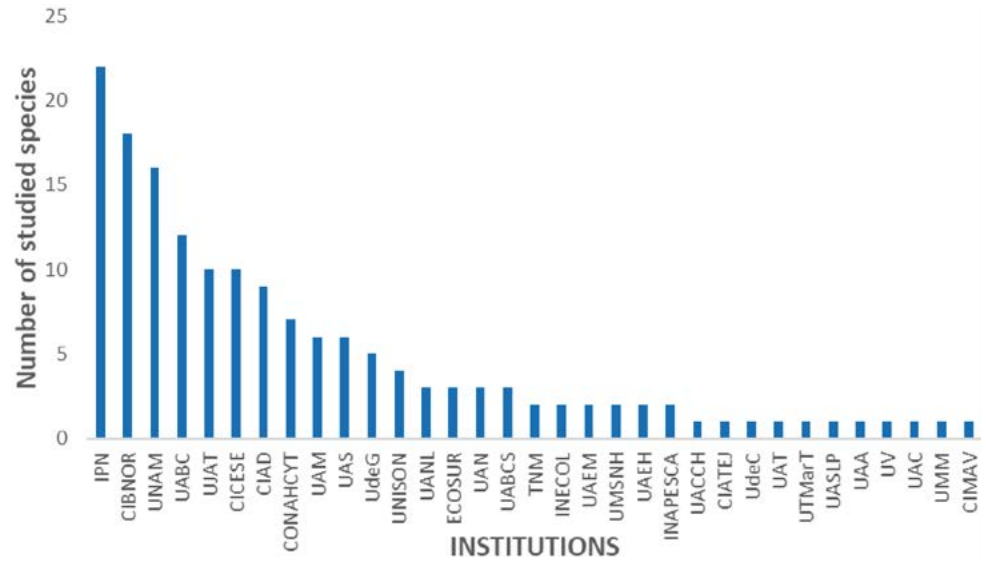


Figure 6. Number of fish species addressed by Mexican institutions detected in the Scopus database

units were included), which stands as the institution that has been involved in the study of the greatest number of species, followed by UNAM, UABC and UJAT.

Although tilapia is the species with the most articles published in the period analyzed, according to Scopus, the species that has received the most attention from the total number of institutions is the rainbow trout, *O. mykiss*, with 17 institutions, followed by red snapper, *L. peru* (14), puyequé, *D. latifrons* (11), tilapia, *O. niloticus* (10), snapper, *L. guttatus* (10) and totoaba, *T. macdonaldi* (10) (Figure 7).

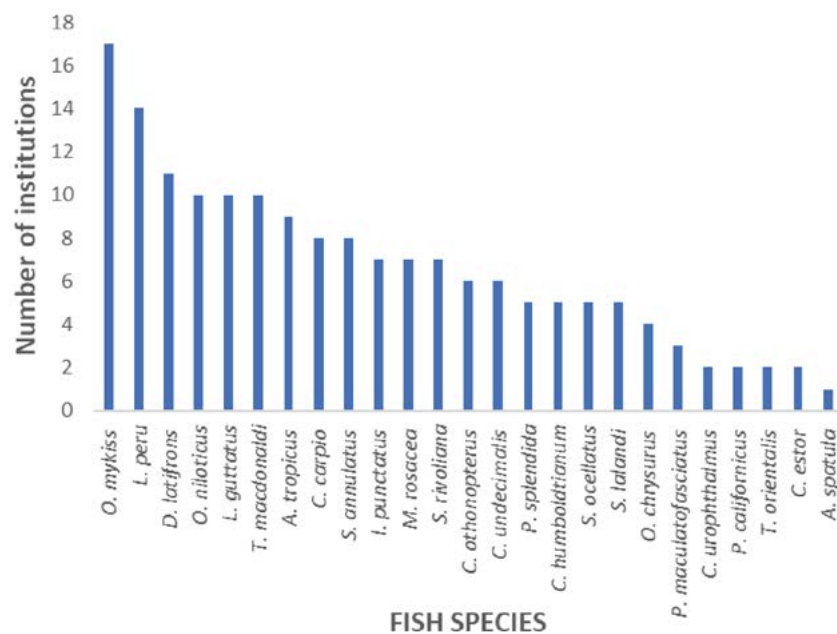


Figure 7. Number of Mexican Institutions that undertake fish studies with developed, under development or potential production technology in Mexico and detected through Scopus.

There does not seem to be a direct relationship between the number of institutions that study a fish and the number of articles published. The Pacific fat sleeper *D. latifrons*, stands out, despite being the third species that has received the most attention from various institutions, with only 35 registered publications (Table 1, Figure 1). A study should be carried out to determine the causes of this phenomenon, with this and other species.

In relation to the social impact that research could have on the species addressed (translated into technologies), the results suggest that although most species, both marine and freshwater, are native (and even some endemic), the institutions involved in their study, have not given them balanced and similar importance. Most of the species carried out for research are considered to have “high added value”, rather than social, interest of Mexican institutions. This phenomenon was already addressed by Chong-Carrillo *et al.* (2023) who, based on projects developed by public research centers, demonstrate that few projects are aimed at solving priority needs (food, nutrition) of the population in general and focus on species considered of interest. for marketing in international markets. Native species with social and cultural value are little attended to, although there are relevant examples that suggest that research groups do dedicate efforts to them. Such is the case of the alligator gar, *A. tropicus*, which has been widely studied and has great social and cultural value in the southeastern Mexican region. Another example could be the castarrica mojarra, *C. urophthalmus*, which is already cultivated and is a fish that can be acquired by a large part of the population, also in the Mexican southeast. Even so, the appearance of tilapia (*O. niloticus*) as the most studied species, with the greatest number of publications, is evidence of the need for institutions to provide new information that allows its more efficient cultivation based on a spirit of social benefit. The above has also been mentioned by Chong-Carrillo *et al.* (2023) who show that some public research centers allocate significant funding to the study of this exotic species. This study showed that CONAHCYT is the main entity that allocates the most funding to fish research. However, it is evident that, although there are efforts for the study of certain native species with a view to their technological development, most Mexican institutions do not seem to have sufficient interest in directing their studies to regional needs, and food security of vulnerable groups. However, CONAHCYT itself has redirected its objectives in relation to the social impact of research as a fundamental aspect in the development of the country.

CONCLUSIONS

There is a clear interest of Mexican institutions in addressing the study of native fishes with publications in national and international journals, however, the publication trends suggest a significant focus on exotic species of commercial or social interest. *Oreochromis niloticus* and *Ciprinus carpio* are the species with the highest number of published articles, representing 31% of the total. On the native fishes in Mexico, *Oncorhynchus mykiss* is the species that has received the most attention, followed by *Lutjanus guttatus*, *Totoaba macdonaldi* and *Atractosteus tropicus*.

A decline in publications is observed from 2020 onwards, possibly related to the effects of the COVID-19 pandemic. Laboratory closures and difficulties in carrying out field work have had a negative impact on the productivity of the scientific community.

The research addresses aspects related to physiology, nutrition, reproduction, genetics, biochemistry, parasitology and physiology, evidencing an integrated approach to the development of culture technologies. More than 50% of published articles focus on aquaculture, ecology and immunology/microbiology. Approximately 58% of the articles are only available through paid systems, reflecting the researchers' preference for "mainstream" journals. Open access represents 42% and highlights the need to find a balance between both models to broaden access and dissemination of knowledge. Institutions such as IPN, CIBNOR, UNAM, UABC, UJAT, CICESE and CIAD lead in number of articles published. There is no direct relationship between the number of institutions and the number of articles published for each species. Research aimed at solving priority needs related to food is few, and most are focused on the study of tilapia, even though it is an exotic species and considered invasive.

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