Colegio de Postgraduados

Scientific research on exotic and native mollusk farming in Mexico according to SCOPUS

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ABSTRACT
Objective: The objective of this study was to evaluate scientific productivity in this field through the database deposited in SCOPUS for Mexico.
Design/methodology/approach: The genera and species of mollusks, currently cultivated or with cultivation potential, marine and freshwater, native and exotic, that have been studied are identified. The SCOPUS search was performed using the scientific name of the corresponding species in the publication title. The number of publications, the institutions that generated them, the SCOPUS theme of the study and the research funders were obtained.
Results: There is an uneven growth, with a greater focus on abalone and octopus, while the genus *Crassostrea*, particularly the species *C. gigas*, leads the production of scientific articles. CIBNOR and IPN are the most relevant institutions in scientific production in molluscan aquaculture in Mexico.
Limitations on study/implications: Despite the interest, advances in areas such as physiology, nutrition and reproduction have not been translated into efficient culture technologies in most cases.
Findings/conclusions: These findings highlight the need to promote research and technological development in the aquaculture of native mollusks in Mexico, as well as to promote collaboration between academic research institutions and the production sector to overcome the challenges in the culture of these species.

Key words: *Crassostrea*, *Magallana gigas*, cultivation, scientometry, production.

INTRODUCTION

Aquaculture plays an important role in food security, as it increases food availability by providing a reliable source of protein and other essential nutrients for human consumption (Hosomi *et al.*, 2012, Garlok *et al.*, 2020, FAO 2022). In Mexico, aquaculture has presented

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a remarkable growth in recent decades, this practice has generated a significant impact on various social aspects of the country, opening a wide range of opportunities and challenges (Sosa-Villalobos *et al.*, 2016, SAGARPA 2017).

Mollusk production is a sector of great importance for Mexico, as it is part of the economic development of the communities that are dedicated to their exploitation, either through cultivation or artisanal fishing, positioning this group of species as potential candidates for technological development (Sarkis, 2008; CONAPESCA, 2012; FAO, 2022). Research in mollusc farming is essential in Mexico to ensure food security, boost sustainable economic development, conserve the marine environment and promote adaptation to climate change (Maeda-Martínez, 2008, Cáceres-Martínez and Vásquez-Yeomans, 2014). In addition, by investing in research and development in this field, the country can strengthen its position in aquaculture nationally and internationally.

Mollusks are a good source of nutrients, such as high biological value proteins, amino acids, essential minerals, and vitamins (Astorga-Espana *et al.*, 2007; Kehinde *et al.*, 2015; Cheong *et al.*, 2017). Bivalve mollusks are considered as a food low in saturated fat and high in essential amino acids and fatty acids, such as omega-3, EPA and DHA (Valenzuela *et al.*, 2011; Joy and Chakraborty, 2017). Consuming mollusks regularly can improve immune response and help avoid some physical ailments, this because of their content of vital nutrients and active secondary metabolites (Benkendorff, 2010). Another importance of mollusk production is the development of other markets such as pearl and nacre shell production (Serna-Gallo *et al.*, 2014); and the potential in environmental services, due to their ability to regulate marine nutrient flows, filter pollutants in the water and their function as marine indicators (Galimany *et al.*, 2017; Smaal *et al.*, 2019).

Globally, the group of mollusks (phylum: Mollusca, Linnaeus 1758) represents 10% of the total marine capture fisheries; Mexico is among the main fishery producers (FAO, 2022). In terms of world production of mollusks by aquaculture, despite the COVID health contingency, a total of 17.7 million tons was recorded, which in monetary terms represents US$29.8 billion; however, Mexico is not among the main producers of these resources (FAO, 2022). Despite this, more than 54 species of mollusks are exploited in the Mexican Pacific alone (Baqueiro, 1984; Maeda-Martínez, 2008).

The universities and public research centers of CONAHCYT have dedicated a great effort in economic and human resources to carry out research and technological development on mollusks with economic importance, with the objective of laying the foundations for their cultivation in Mexican coastlines (Chong-Carrillo *et al.* 2023). Much of the research carried out focuses on native species; however, there are exotic species whose cultivation has spread rapidly by adapting imported technologies (Chong-Carrillo *et al.*, 2023). Even so, there have been no studies that address the scientific production, understood as articles published in specialized journals, generated with native or exotic mollusks in Mexico. In the present work, the mollusk species currently under cultivation were identified, as well as those with potential for cultivation, with the objective of evaluating the behavior of scientific productivity in Mexico deposited in the SCOPUS database.

MATERIALS AND METHODS

To develop the study, the genera, and species of mollusks, currently cultivated or with potential for cultivation, marine and freshwater, native and exotic, of which studies have been carried out that have resulted in scientific publications, were identified. The SCOPUS database was used to obtain this information. The SCOPUS search was performed using only the scientific name of the corresponding species in the title of the publication. This variable alone was used to obtain the number of publications, the institutions that generated them, the SCOPUS subject of the study and the funders of the research. Only Mexican institutions were included, both in the institutions of affiliation and in those that financed the projects that generated the published articles. The data obtained were captured in Excel® spreadsheets for their management and creation of graphs. Likewise, a review of the lines of research involved was made based on the titles of the publications. In the general analysis, the results obtained for all the species previously identified were included. The data on the number of publications over the years were subjected to simple linear regression analysis to evaluate if there is a pattern of increase or decrease, this included the genera *Haliotis*, *Octopus*, *Panopea*, *Nodipecten*, *Argopecten*, *Mytilus*, *Atrina*, *Pomacea* and *Anadara*. Data were analyzed with SigmaPlot 11.0 software.

RESULTS AND DISCUSSION

The mollusk species already cultivated or with potential for cultivation were identified based on research projects developed by several public research centers and from direct information provided by researchers and academics from academic and scientific institutions. All species considered in this study are native except *Crassostrea gigas*, *Crassostrea sikamea* and *Mytilus galloprovincialis*.

Anadara tuberculosa (mangrove cockle)

Anadara tuberculosa is distributed in the mudflats of the mangrove areas of the Pacific coast of tropical America between Baja California and the northern coast of Peru (Lucero-Rincón *et al.*, 2021). Despite being a very popular clam for consumption in Mexico, the research that has been carried out, with a view to its cultivation, is poor. Only twelve articles were detected in SCOPUS, involving Mexican institutions. Figure 1 shows that the interest in developing studies with this species, mainly covers the period from 2008 to 2019, to later disappear.

The Mexican institutions that are most mentioned in the articles are shown in Figure 2. The Centro de Investigaciones Biológicas del Noroeste (CIBNOR), the Instituto Nacional de la Pesca (INAPESCA) and the Centro Interdisciplinario de Ciencias Marinas (CICIMAR) are the research institutions with the highest number of mentions. In relation to the topics covered by the publications, although it is a clam with potential for cultivation in Mexico, most of these are on aspects of population ecology, potential of its filtering capacity to remove effluents and obtaining probiotics. There are no studies on aspects of captive breeding or culture. The only entity that has financed the projects

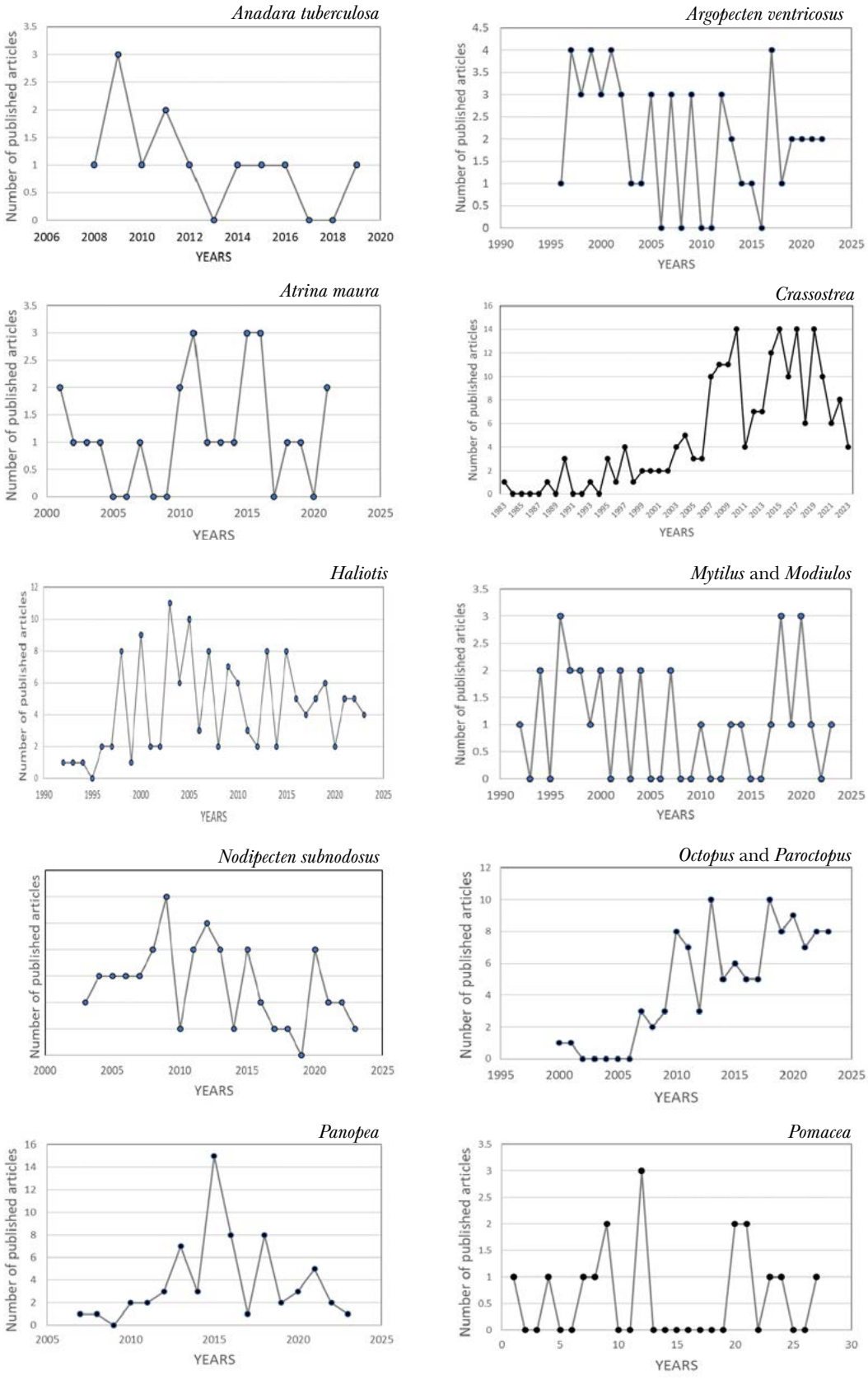

Figure 1. Timelines of the publication of articles on mollusks by Mexican institutions according to SCOPUS.

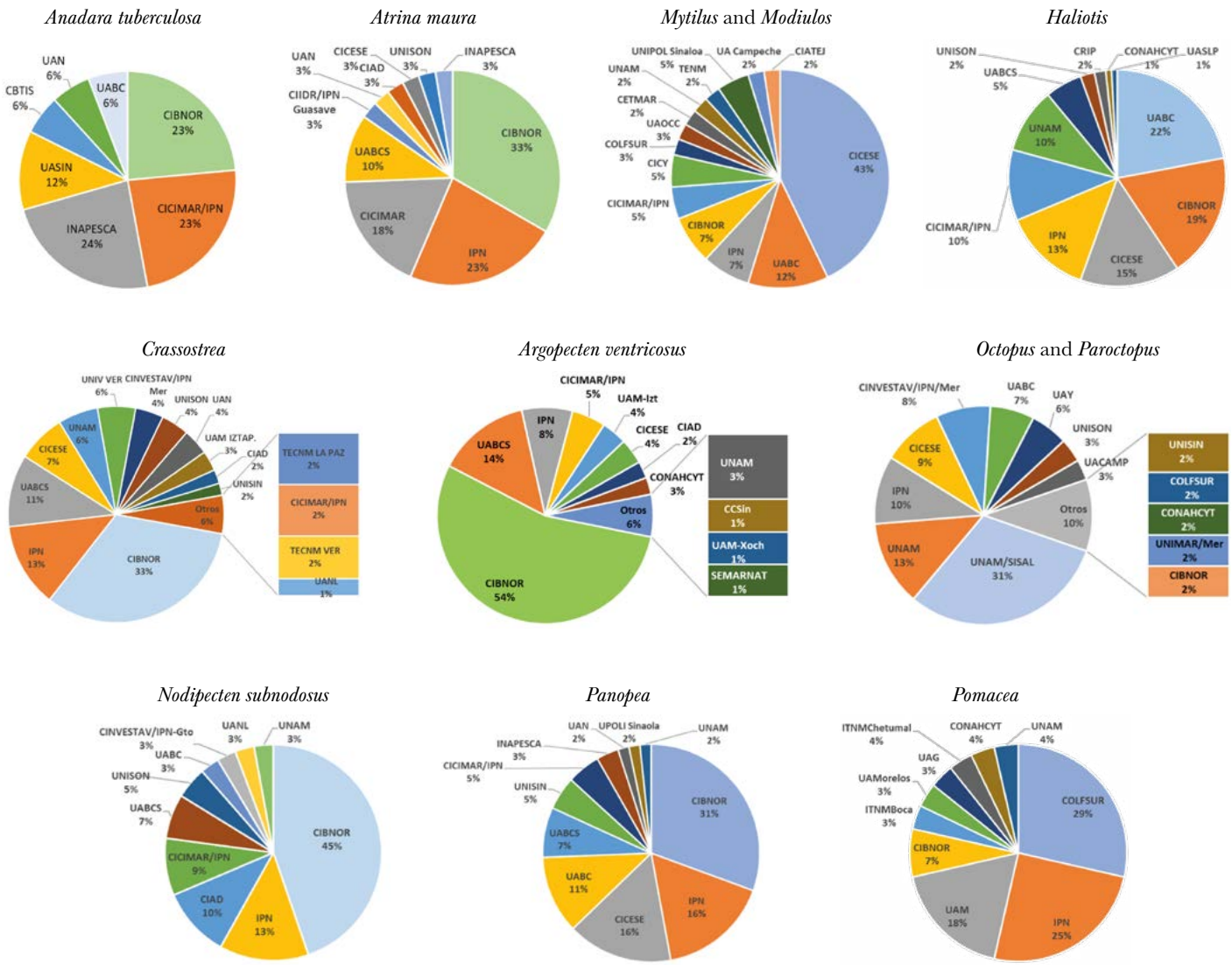

Figure 2. Mexican institutions generating articles on mollusks (in percentage). Nomenclature of institutions in alphabetical order: CBTIS=Bachillerato Tecnológico Industrial y de Servicios, CETMAR=Centro de Estudios Tecnológicos del Mar, CIAD=Centro de Investigación en Alimentación y Desarrollo, CIATEJ=Centro de Investigación y Asistencia en Tecnología del Estado de Jalisco, CIBNOR =Centro de Investigaciones Biológicas del Noroeste, CCSin=Centro de Ciencias de Sinaloa, CICESE=Centro de Investigación Científica y de Educación Superior de Ensenada, CICIMAR/IPN=Centro Interdisciplinario de Ciencias del Mar del Instituto Politécnico Nacional, CICY=Centro de Investigación Científica de Yucatán, CIIDIR/IPN Guasave=Centro Interdisciplinario de Investigación para el Desarrollo Integral Regional unidad Guasave, CINVESTAV/IPN=Centro de Investigación y de Estudios Avanzados del IPN, COLFSUR=Colegio de la Frontera Sur, CONAHCYT=Consejo Nacional de Humanidades, Ciencia y Tecnología, CRIP=Centro Regional de Investigación Pesquera, INAPESCA=Instituto Nacional de Pesca y Acuicultura, IPN=Instituto Politécnico Nacional, ITNMBoca=Instituto Tecnológico Nacional de México Boca del Río, ITNM Chetumal=Instituto Tecnológico Nacional de México campus Chetumal, TECNM=Tecnológico Nacional de México, TECNM La Paz=Tecnológico Nacional de México La Paz, TECNM VER=Tecnológico Nacional de México Veracruz, UANL=Universidad Autónoma de Nuevo León, UABC=Universidad Autónoma de Baja California, UABCS=Universidad Autónoma de Baja California Sur, UA Campeche=Universidad Autónoma de Campeche, UAG=Universidad Autónoma de Guadalajara, UAM Izt=Universidad Autónoma Metropolitana Iztapalapa, UAM Xoch=Universidad Autónoma Metropolitana Xochimilco, UAMorelos=Universidad Autónoma de Morelos, UAN=Universidad Autónoma de Nayarit, UANL=Universidad Autónoma de Nuevo León, UAOCC=Universidad Autónoma de Occidente, UASIN=Universidad Autónoma de Sinaloa, UASLP=Universidad Autónoma de San Luis Potosí, UAY=Universidad Autónoma de Yucatán, UNIMAR=Universidad del Mar, UNAM=Universidad Nacional Autónoma de México, UNAM/SISAL=Universidad Nacional Autónoma de México unidad SISAL, UNIPOL Sinaloa=Universidad Politécnica de Sinaloa, UNISON=Universidad de Sonora, UNIV VER=Universidad Veracruzana, SEMARNAT=Secretaria de medio ambiente y recursos naturales.

that resulted in these publications was the National Council of Humanities, Science and Technology of Mexico (CONAHCYT).

***Argopecten ventricosus* (Catarina scallop)**

Argopecten ventricosus (Waller, 1995) commonly known as the Pacific scallop or catarina scallop, is a species of bivalve of the family Pectinidae, whose habitat is distributed in the eastern Pacific Ocean, from the west coast of North America to Central and South America, including regions such as the Gulf of Baja California, Mexico, to Peru (Bertsch and Aguilar-Rosas, 2016). It has been collected in both brackish marine environments and fully marine areas. In SCOPUS 53 articles were detected, involving Mexican institutions, covering a period from 1996 to 2022. Between 1996 and 2002 there is a higher production than in the rest of the period, although this has been maintained with only a slight decrease in recent years (Figure 1). The institutions that have contributed most to the accumulation of published information are CIBNOR with more than 50% of the total, followed by UABCS and IPN, these three institutions accumulate more than 75% of all the articles registered in SCOPUS (Figure 2).

The topics that produce the most articles cover diverse lines of research: abundance, genetics/genomics, growth, reproduction in captivity, immunomodulation, bioactive compounds, pathology, nutrition, probiotics, fisheries, exposure, and accumulation of heavy metals/biotoxins, ecology, environmental conditions, settlement and morphology, among others. The funding entity that has supported the most projects resulting in publications is CONAHCYT with almost 75% of the funding, followed by CIBNOR with 17% and IPN with 9%.

***Atrina maura* (maura pen shell)**

Atrina maura (Sowerby 1835) is a bivalve commonly known in Mexico as "callo de hacha". This species is distributed from the Baja California peninsula to Peru and is found in protected bays with sandy, silty, or clayey soils (Góngora-Gómez *et al.*, 2016). For this species, 24 articles were identified, involving Mexican institutions. Figure 1 shows the 20-year period that records published articles, from 2001 to 2021. Just a little more than one article per year, at least in the journals included in SCOPUS. This shows that, although it is a species of interest, its scientific approach is poor compared to others. The Mexican institutions that are most mentioned in the articles are shown in Figure 2. CIBNOR is the one that has contributed the most research, followed by IPN, CICIMAR and UABCS. The four of them account for almost 80% of all the publications generated. The topics covered by the publications include studies on reproductive aspects and culture and development both in nature and under laboratory conditions, fisheries, nutrition, environmental conditions, presence of heavy metals and ecology, among others. CONAHCYT and IPN are the entities that have financed most of the projects that resulted in these publications (39% and 23%, respectively), although the Comisión Nacional de Áreas Naturales Protegidas, the Instituto Nacional de Pesca y Acuicultura and CIBNOR are also included.

Crassostrea **(oysters)**

Crassostrea is a genus of bivalve mollusks, known as oysters, belonging to the family Ostreidae. They are used as food because of their high nutritional value and the ease with which they are obtained.

This section includes the four species of *Crassostrea* that have been studied in Mexico and have resulted in publications in SCOPUS. In order of importance by number of articles published are *C. gigas*, *C. corteziensis*, *C. virginica* and *C. sikamea*. *C. gigas* has been the species of greatest interest to Mexican institutions. Less attention has been paid to the native species (*C. corteziensis* and *C. virginica*), although both account for 50% of the published studies (Figure 1). The other exotic species, *C. sikamea*, is of more recent interest and has generated the least number of articles.

In relation to the Mexican institutions that have conducted the studies and published the results, we found that there are a good number of them. CIBNOR leads the production of articles with 32% of the total, followed by IPN with 12% and UABCS with 9%. These three institutions alone exceed 50% of the articles published according to SCOPUS (Figure 2). The lines of research addressed are practically all those related to aquaculture research: reproduction, genetics, pathology, culture, development, environmental conditions, nutrition, accumulation of contaminants and biotoxins, and ecology, among others. However, *C. gigas* has been the most extensively studied in all of the above aspects. The native species *C. corteziensis* has also been the subject of studies in many of the aforementioned lines. However, in the case of *C. virginica*, also native, there are still few studies that involve its management in the laboratory; however, it is included because it is a species of high economic interest and, in fact, it is already in extensive cultivation in some regions of Mexico. The financing entities have been mainly CONAHCYT with 64%, the rest include CIBNOR, IPN and CICESE as the most important.

Haliotis **(abalones)**

Abalone is a gastropod mollusk of the family Haliotidae that inhabits rocky areas associated with mats of *Macrocystis pyrifera* and other algae and is widely distributed in temperate and tropical oceans (Gluyas-Millán and Talavera-Maya, 2003). Of this genus, articles produced by Mexican institutions and housed in SCOPUS were identified with the species *H. fulgens*, *H. corrugata* and *H. rufescens*. *Haliotis fulgens* is the species that has generated the most articles with almost 60% of the total. The publication of articles, the sum of the three species, over the period 1992 to 2023, demonstrates a production with ups and downs but which has remained constant for 40 years (Figure 1).

Regarding the Mexican institutions that have carried out the studies and published the results, UABC, CIBNOR and CICESE are the most mentioned and represent more than 50% of the total (Figure 2). The lines of research identified in the articles are diverse and address practically all areas related to aquaculture biology and management: nutrition, fisheries, management and culture, environmental preferences, pathology, genetics/genomics, reproduction, ecology, and morphology, among others. The funding entity has been mainly CONAHCYT with more than 60% of the total number of projects supported, and with CICESE and CIBNOR they account for almost 80% of contributions.

Mytilus **and** ***Modiulos*** **(mussels)**

Mitylids (Mytilidae), commonly known as mussels or choros (in some parts of South America), are a family of bivalve mollusks of great economic and gastronomic interest. Like other bivalves, they are filter-feeding animals that live attached to the substrate. They are mainly marine and live in both intertidal and submerged areas of coasts around the world, although there are species that live in freshwater and mixed or brackish bodies of water (a mixture of freshwater and seawater) (NaturalisEc, 2023).

This study brought together the two species identified with publications in the SCOPUS database: *Mytilus galloprivincialis* (Mediterranean mussel) and *Modiulos capax*, the former is an introduced species, and the latter is native. Paradoxically, although *M. galloprivincialis* is an exotic species, it has generated the most articles (66%) while *M. capax* only 34%. Research on these species has been carried out from 1991 to the present year, with little but constant production of articles (Figure 1). The institutions that are most mentioned as generators of publications are CICESE with a wide advantage over the others, followed in importance by UABC (Figure 2). The lines of research addressed are mostly nutrition, accumulation of heavy metals and biotoxins, reproduction, distribution, larval production, environmental conditions, pathology and culture. Regarding the entities that have provided funding for projects that have resulted in publications, CICESE is the most relevant with almost half of the support granted, followed by CONAHCYT.

Nodipecten subnodosus **(giant lion's paw)**

Bivalve distributed from Laguna Ojo de Liebre in Baja California Sur to the coasts of Peru (Rombouts *et al.*, 1991), large size (up to 175 mm), with symmetrical valves characterized by two auricles and in the center is the hinge. Their coloration varies from opaque purple or white with purple lines, to bright orange and magenta (INAPESCA 2021). Its exploitation is relatively recent, in 1995, its capture was introduced as a replacement for the catarina scallop (*Argopecten ventricosus*) because the latter had suffered overfishing that led to its depletion in the late 1980s (González-Ortíz and Hernández-Alcántara, 2021).

The SCOPUS database identified articles published by Mexican institutions in the period from 2003 to 2023 (Figure 1). During this period there are ups and downs, although the production of articles has remained constant. CIBNOR, like most of the species treated in this study, is the institution that is mentioned most often as the institution generating the publications, with 45% of the total, followed by IPN, CIAD and CICIMAR. However, the sum of the four institutions exceeds 75% of the total number of publications (Figure 2). The lines of research addressed in the publications correspond to reproduction, larval production, nutrition, developmental biology, pathology, development under diverse environmental conditions, among others. The funding entities are CONAHCYT with more than 50% of support for projects that resulted in publications, followed by CIBNOR (33%) and the IPN the rest.

Octopus **and** ***Paroctopus*** **(octopuses)**

For this analysis we combined the publications identified in SCOPUS of four species of octopus, all native to Mexico: *Octopus maya*, *O. vulgaris. O. bimaculoides* and *Paroctopus digueti*.

The largest number of articles was concentrated in *O. maya* with 74% of the total, followed by *O. vulgaris* with 19% and the rest, with similar numbers, for the other two species. Regarding the period of publication of articles, these were dissimilar among the species. *Octopus maya* shows publications from 2000 to the present, *O. vulgaris* records publications in a period of 13 years (2010 to present), *O. bimaculoides* a period of nine years, starting in 2009 and ending in 2018 and finally P. digueti, with the shortest period of only four years, from 2020 to 2023. Figure 1 shows the sum of all publications of the four species as a function of time. Publications with *O. maya*, are the ones that contribute the most published research of the total, with 81 articles hosted in SCOPUS, developed by Mexican institutions, out of a total of 109.

The institution that has contributed most to the knowledge of these species is UNAM, mainly in its SISAL Unit, which alone accounts for 31% of the mentions in articles. CICESE registers 9% and IPN also stands out, mainly through CINVESTAV-Mérida (8%) (Figure 2). The most common lines addressed in the study of octopuses have been nutrition, environmental conditions, reproduction, physiology, embryology, exposure to contaminants, abundance, distribution, climate change, fisheries, immunology, pathology, ecology, genetics/genomics, and culture, among others. Of the sponsoring institutions, CONAHCyT has made the greatest contribution, as in all previous cases, with 60% support for projects that have resulted in publications. UNAM also stands out with 35%.

Panopea **(geoducks)**

In the present analysis we included the two species present in Mexico and for which research has been carried out leading to publications: *Panopea generosa* and *P. globosa*. The clam *P. globosa* is distributed in the Gulf of California and Magdalena Bay, while the clam *P. generosa* is distributed from Alaska, United States of America to Baja California, Mexico (Arambula-Pujol *et al.*, 2008; DOF, 2013).

Between 2013 and 2018 there has been a constant publication of articles, however, it is from 2013 to 2018 that there was a significant upturn and then a decline until the present (Figure 1). CIBNOR is the most represented institution in the publications followed by IPN, CICESE and UABC (Figure 2), which account for almost 75% of the published articles. The topics most addressed are ecology, distribution, genetics/genomics, larval production, reproduction, and nutrition, among others. Regarding the entities that have financed the projects that have resulted in the identified publications, CONAHCYT accounts for more than 50%, followed by CICESE and INAPESCA.

Pomacea **(snails)**

Apple snails or Pomaceous snails are a group of aquatic mollusks belonging to the family Ampullariidae. They inhabit muddy and shallow waters of lakes and rivers, are found in tropical and humid subtropical areas of southeastern Mexico, Central America, South America and the Caribbean Islands, inhabiting rivers, lakes, canals, swamps, and wetlands, preferably in places with abundant vegetation (Castillo-Capitán *et al.*, 2020).

This analysis considered the two species with articles in the SCOPUS database: *Pomacea patula* and *P. flagellata*. Only 16 articles were identified, of which 10 correspond to *P.*

patula (63%) and six to *P. flagellata* (37%). These articles have been published from 1995 to 2023. Figure 1 shows that, although the production of articles has been maintained during the period, there is a valley of seven years in which none were published. The Colegio de la Frontera Sur and the IPN are the two institutions that have contributed the most articles to the knowledge of these species, followed by UAM and CIBNOR. These four institutions account for a little less than 75% of all that has been published (Figure 2). The topics covered include cultivation, environmental conditions, bioeconomics, ecology, distribution, exposure to contaminants, physiology, reproduction, cultivation, nutrition, genetics, and morphology, among others. There is no record of financing entities.

The results show that Mexican academic and research institutions have a clear interest in addressing the study of native species, however, technologies derived from basic studies of physiology, nutrition, and reproduction, among others, have only rarely resulted in efficient culture technologies. In fact, there is apparently an impasse in the study of most native species, with few articles published over time, although there are two groups, abalone, and octopus, that demonstrate statistically confirmed growth. However, the genus demonstrating the most growth, with the highest number of published articles is *Crassostrea*. Although the native species (*C. virginica* and *C. corteziensis*) have received attention, *C. gigas* accumulates 46% of the publications and if *C. sikamea* (also exotic) is added, it reaches 50%.

Table 1 shows the total number of articles published and hosted in the SCOPUS platform. The number of publications through the years 1983-2023 records the species of the genus *Crassostrea* as the most studied (with 200 publications), followed by *Haliotis* (141), *Octopus* (109), *Panopea* (64), *Nodipecten* (56), *Argopecten* (53), *Mytilus* (30), *Atrina* (24), *Pomacea* (16) and *Anadara* (9). Of all the groups of mollusks analyzed, only three show a linear growth pattern through the years: *Octopus* (0.838, $P<0.001$), *Crassostrea* ($R=0.772$; $P<0.001$) and *Haliotis* ($R=0.556$, $P<0.001$), the rest of the genera, although they register an increase in the number of publications through the years, these appear with variations without a defined or significant predictive pattern.

Crassostrea gigas, with 92 articles, is the most studied, even more than the native species of the same genus. Twenty-eight percent of the articles generated correspond to *Crassotrea*, 20% to *Haliotis* and 15% to *Octopus*. The latter has shown the greatest increase in recent years (Figure 3). In Figure 4, the production of articles can be observed in a timeline. It is evident that there are three that have maintained almost constant growth (*Crassostrea*, *Haliotis*, *Octopus*) or with dramatic but short increases over time (*Panopea*), while the others have barely maintained a discrete pro production despite the fact that they are all native species (with the exception of the introduced mussel, *M. galloprovincialis*). With respect to one of the most socioeconomically and ecologically important native species in the Yucatan Peninsula and the southern Gulf of Mexico, *O. maya*, UNAM generates almost all the research on the cultivation of the species, while the IPN collaborates to an equal extent with research on exploitation and governance in the use of the species (Santamaria *et al.*, 2023). Since 2007 to date, research on the cultivation of *O. maya* has been generated from the Multidisciplinary Unit of UNAM in Sisal, Yucatan, covering many aspects that are determinant for mastering the technology of the species (*e.g.* Rosas *et al.*, 2014).

Of the institutions that have generated the total number of articles on mollusks,

CIBNOR (including all its regional and local units) is positioned as the most relevant with 31.3% of all the mentions that refer to the authors' affiliation. IPN, including all its units (CICIMAR, CIIDIR, CINVESTAV), is in second place with 22.8% and CICESE in third place with 10.3%. Only CIBNOR and IPN exceed 50% of all mentions. Of the latter, of the ten mentioned, eight are universities (including UNAM, also including all its units) (Table 2).

The results show that, in general, bivalve aquaculture in Mexico has focused on the Pacific oyster *C. gigas* (now *Magallana gigas*), which was introduced in the 1970s (Chavéz-Villalba, 2014). It is important to note that not all exotic mollusks have negative effects, some introduced bivalves can even generate welfare to ecosystems by increasing water filtration capacity and decreasing the effects of eutrophication (Burlakova *et al.*, 2023), as well as antiviral medicinal and commercial uses (Khan and Liu, 2019). There is equal

Table 1. Number of publications by mollusk genus.

Gender	Publications
Crassostrea	200
Haliotis	141
Octopus/Paroctopus	109
Panopea	64
Nodipecten	56
Argopecten	53
Mytilus/Modiulos	31
Pomacea	16
Atrina	24
Anadara	9
TOTAL	703

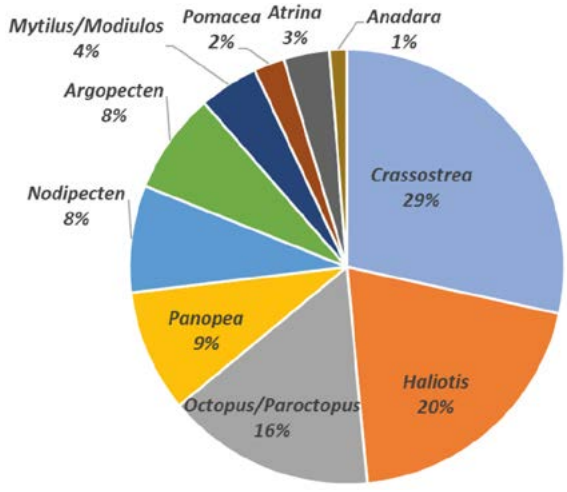

Figure 3. Percentage of publications by mollusk genus produced by Mexican institutions according to SCOPUS.

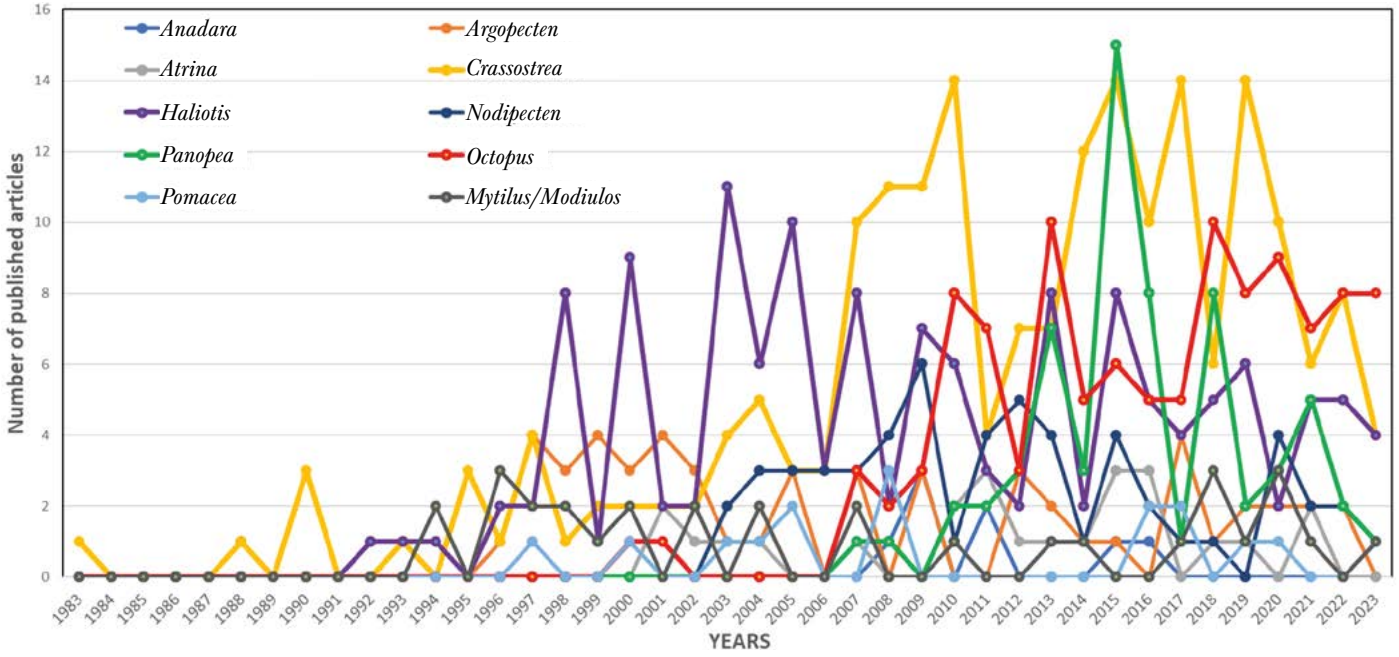

Figure 4. Timeline of publication of articles on mollusks by Mexican institutions according to SCOPUS.

Table 2. Institutions most mentioned in articles on mollusks published by Mexican institutions and hosted in SCOPUS (as a percentage of total articles).

Institutions	%
CIBNOR	31.3
IPN	21.8
CICESE	10.3
UNAM	7.7
UABCS	6.9
UABC	6.2
COLFSUR	3.8
UAM	3.1
UNISIN	2.3
CIAD	1.9
UNISON	1.5
UAN	1.5
TecNM	1.2
UANL	0.4

information on successful cases of introduced mollusc cultures, such as red or Californian abalone (*H. rufescens*) in Chile, which, when carried out in a responsible and sustainable manner, has allowed technological consolidation and increased the production of other marine crops such as macroalgae (mainly *Macrocystis* spp.) so as not to exploit natural

populations (Mardones *et al.*, 2013); such algae generate opportunities to meet other needs because the alginates produced in the processing of algae have nutraceutical properties and important industrial uses (Hernández-Carmona *et al.*, 2012). However, the introduction of exotic species into new habitats should always be carefully evaluated and regulated to minimize potential negative impacts on local ecosystems and species (Gubiani *et al.*, 2018).

In contrast to exotic species, Mexico has native species of bivalve mollusks that are cultivated, including the American oyster *Crassotrea virginica* and the pearl oyster *Pinctada mazatlanica*; in addition, there are a large number of species with cultivation potential (Cáceres-Martínez and Vásquez-Yeomans, 2008), as may be the case of the rock oyster (*Striostrea prismatica*) that requires incentivizing scientific research to realize its technological development, since it is a commercial fishery resource destined for human consumption (Ríos-González *et al.*, 2018).

It is important to recognize that the production of farmed mollusks in Mexico is low compared to world statistics (FAO, 2022). Maeda-Martínez, (2008), comments that this problem can be explained by the lack of trained technicians, the lack of organization and a business culture in the production sector, and the lack of interest of the scientific sector in solving the problems they pose. In this perspective, the analysis of bibliometric indicators of scientometric type on scientific productivity (such as the number of publications, the institutions that generate them, the subject of the study and the funders of the research) constitutes a fundamental tool for developing political and social strategies that contribute to a better diagnosis of scientific productivity in the country (Quintanilla, 2007; Jiménez-Borges *et al.*, 2020). As a sample derived from this type of analysis, we can cite the works of Mohd Noor *et al.*, (2021), Chong-Carrillo *et al.*, (2015), and Kumaresan *et al.*, (2014), whose objectives share that of highlighting trends in research on aquaculture-related species, as well as identifying more developed areas of research and pointing out possible gaps in scientific knowledge on target species.

CONCLUSIONS

The results of this study reveal important trends in mollusk aquaculture research in Mexico. There is a clear interest on the part of academic and research institutions in addressing the study of native mollusks and integrating them into aquaculture production systems. Despite this interest, technologies derived from basic studies in areas such as physiology, nutrition and reproduction have not been translated into efficient culture technologies in most cases. There was uneven growth in aquaculture research on native species, with few publications on aquaculture during the period evaluated, with a greater effort in two groups: abalone and octopus.

With respect to the overall production of scientific articles, the genus *Crassostrea* leads the publication efforts in SCOPUS, with *C. gigas* being the most studied species. And there is a recent trend towards growth in research on the genus *Octopus*, especially on the species *O. maya*. Regarding the role of academic institutions in Mexico, CIBNOR and IPN are the most relevant institutions in scientific production in mollusk aquaculture, generating most of the publications in this field.

Despite having an important diversity of native mollusks with culture potential in Mexico, aquaculture production of these organisms is low when compared to global statistics; this can probably be attributed to the lack of trained technicians, lack of adequate organization in the production sector, and limited interest on the part of the scientific community with respect to consolidating technological processes in mollusk culture. These findings highlight the need to foster research and technological development in native mollusk aquaculture in Mexico, as well as to promote collaboration between academic research institutions and the production sector to overcome challenges in the culture of these species.

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