Latin American Journal of Aquatic Research, 53(2): 186-208, 2025
DOI: 10.3856/vol53-issue2-fulltext-3302

Review

Trends in bivalve aquaculture research and production in Mexico

Jorge Chávez-Villalba[1] **& Edgar Alcántara-Razo**[1]
[1]Centro de Investigaciones Biológicas del Noroeste, S.C. (CIBNOR)
Unidad Guaymas, Guaymas, Sonora, México
Corresponding author: Jorge Chávez-Villalba (jechavez04@cibnor.mx)

ABSTRACT. A review of the available studies on aquaculture research and its relationship with production was undertaken to update the status of marine bivalves in Mexico. The search included articles and theses and the situation of each species in cultivation or fishery. We found 281 studies (216 articles; 65 theses), including 8 families and 24 bivalve species (3 of them introduced), mainly concentrated in the northwest Pacific (La Paz Bay), and few studies on the Atlantic coast. The Pacific oyster *Crassostrea gigas* is the most studied and most produced, followed by the scallops *Argopecten ventricosus* and *Nodipecten subnodosus*, but without consolidated cultures. Established cultures exist for oysters *Crassostrea corteziensis*, *C. virginica*, and *C. sikamea*, for the mussel *Mytilis galloprovincialis* and the pearl oysters *Pteria sterna* and *Pinctada mazatlanica*. Commercial hatchery-spat production occurs for *C. gigas*, *C. virginica*, *C. sikamea*, *C. corteziensis*, and *Chionista fluctifraga*, and proven spat production protocols for *A. ventricosus*, *N. subnodosus*, *Panopea generosa*, and *P. sterna*. Hatchery protocols are at the R&D level for *Atrina maura*, *Megapitaria squalida*, and *Anadara* spp., with many aspects to improve even for established species, addressing problems such as slow progress in larval development for *A. maura*. Several native species with aquaculture potential should be studied for hatchery spat production. Extensive cultivation works well for native species such as *Atrina tuberculosa*, *C. virginica*, and *C. corteziensis*. Still, it must be optimized, and the official aquaculture and repopulation standards in force for more than 40 years must be respected. More information is provided in the supplementary document "List-articles-thesis-by-species.pdf", available on request. In summary, there are conditions to improve current intensive and extensive cultures. Basic research and its technological and productive applications must be expanded to promote the cultivation of bivalves on both Mexican coasts.

Keywords: bivalves; collection; culture; fishery; hatchery; larvae; spat

INTRODUCTION

Aquaculture is an important source of available nutritious food, a livelihood base, and a key driver of coastal and rural economic development worldwide (Subasinghe et al. 2009). Aquaculture animal production is constantly increasing (~2.7% annually), reaching 94.4 million metric tons (mt) in 2022, of which 18.9 million mt correspond to mollusks, mostly bivalves. Oysters, mainly *Crassostrea* species such as *C. gigas* and *C. virginica*, predominate among bivalve aquaculture production, accounting for around 7.1 million mt (FAO 2009, 2024, Nowland et al. 2019).

Mexico ranks 24th worldwide in aquaculture production, with 247,222 mt in 2018, showing a high average annual growth rate of 10.3% in the past decade (García-Medel 2022). Oyster production also predominates in Mexico, with 55,470 mt in 2018 (SAGARPA 2024), of which the majority is produced through extensive aquatic management of the eastern oyster *C. virginica* in the Gulf of Mexico; production is concentrated in the states of Veracruz (43%) and Tabasco (30.2%) (CONAPESCA 2018). Commercial spat availability of several bivalve species (*C. gigas*, *C. corteziensis*) is much greater on the Pacific coast than the limited and insufficient spat production of *C. virginica*

Associate Editor: César Lodeiros

in the Gulf of Mexico. Consequently, intensive and technologically advanced bivalve aquaculture is practiced almost exclusively in the Mexican Pacific and Gulf of California, particularly in the northwest region, including the states of Baja California (BC), Baja California Sur (BCS), Sonora (SON), Sinaloa (SIN) and Nayarit (NAY) (Ramírez-Ambriz et al. 2023).

Mexico is megadiverse in flora and fauna, and marine mollusks are no exception, with approximately 4,643 species, of which 670 correspond to bivalves from the Pacific coast and 532 to bivalves from the Gulf of Mexico and the Mexican Caribbean (Castillo-Rodríguez 2014). Many bivalve species have historically been used as food, using their shells for utensils, decoration, or manufacturing products (crafts, buttons). Its exploitation has occurred first as collecting organisms in seashores (intertidal zones), then as fisheries using boats and collection artifacts, and more recently through the management of organisms through aquaculture practices (Cariño & Monteforte 2009). According to Baqueiro-Cárdenas & Aldana-Aranda (2003), before the year 2000, more than 80 species of gastropods and bivalves had already been exploited in the country. Mexico is one of the pioneer countries in the cultivation of bivalves worldwide since one of the first cultivation farms (Compañía Criadora de Concha y Perla) operated from 1903 to 1914 in La Paz (BCS) for the production of natural pearls with the pearl oyster *Pinctada mazatlanica* (Chávez-Villalba 2024). The farm served several purposes, such as producing gems for sale, shells to manufacture buttons, and meat (mainly muscle) as food for workers.

The first studies related to bivalve aquaculture in Mexico date back to the early 1900s, reporting the exploitation and cultivation of the pearl oyster *P. mazatlanica* (Estrada 1916, Diguet 1919). Afterward, Sevilla-Hernández (1959) provided biological information for cultivating the native oyster *C. corteziensis* in Guaymas (SON). Nevertheless, it was not until 1975 that aquaculture studies began to develop with the introduction of the Pacific oyster (*C. gigas*) and its evaluation of performance in culture in BC (Islas-Olivares 1975). In the 1980s, Baqueiro-Cárdenas & Castagna (1988) studied the status of bivalves and their cultivation prospects in the Mexican Pacific, highlighting 28 species with aquaculture potential. Subsequently, Baqueiro-Cárdenas (2001) conducted a similar study in the Gulf of Mexico, emphasizing 12 species with culture possibilities. Since then, numerous studies have been carried out to support and develop bivalve cultures, particularly in northwestern Mexico.

The development of cultivation activities in any country requires research on basic biological aspects (reproduction, feeding) as well as field and laboratory experiments that report the cultivation performance of the target species. Therefore, it is important to review and summarize the most accessible published literature on bivalve aquaculture in Mexico to provide a baseline for the research topics addressed and identify gaps, successful actions that can be replicated, and new subjects for future research. All this academic effort, as well as studies and experiments, is analyzed in the context of the current state of bivalve production in Mexico. In addition, researchers and professionals can access the information collected for their studies or work.

Study scope

In general, studies on bivalve aquaculture cover various topics. In the case of this review, the following aspects (field and/or hatchery) were considered: reproduction, larvae and post-larvae culture, spat collection in the wild, spat production and nursery under controlled conditions, initial and intermediate growth, and final growth-out to marketable size in the field. Studies on diseases, genetics, immunology, and other topics were also considered as long as their objective was cultured bivalves or related to their management.

To obtain this information, we conducted a comprehensive and in-depth search of the information available in personal literature collections, Web of Science, Scopus, Google Scholar (using various keywords and their combinations), and repositories of universities and research centers. The criteria for including information in this review take into account the following: 1) those publications coming from scientific journals, book chapters, and books, 2) that these studies are publicly available (at least the abstract), 3) theses were included preferably when the document (pdf) is available on the internet, government, producer websites, and institutional repositories, and 4) the published information is related to the aquaculture aspects mentioned above. The review included studies from 1916 (the first contribution found) to December 2023. For this study, we followed Bayne et al. (2017) recommendations to search for information on the Pacific oyster considering the genus *Crassostrea*. Other species have changed genus or species over time (Table 1); the information searches for these species were done using previous and current scientific names.

A dynamic database was created (Excel) with the information obtained organized as follows: 1) type of

document, article, or thesis, 2) year of the study, 3) species involved, 4) main topics, 4) subtopics, 5) if the study was carried out indoors, outdoors or both, 6) the state or states of the country where the study was conducted, 7) the specific locality or localities, and 8) the institution that conducted the study. Most references and theses show that studies were conducted on the Mexican Pacific. Still, the context of bivalve production on the Mexican Atlantic is presented later.

To relate the studies carried out with the production of bivalves in Mexico, we searched for the species of bivalves that are produced by aquaculture or fishery, looking for the main forms of production, the volumes produced (when available), and the general status of the activity (Chávez-Villalba & Grijalva-Chon 2022). The main information on aquaculture and fisheries' production of bivalves in Mexico was compiled. According to the information collected, a status was assigned to the activity of each species using the following categories: 1) consolidated - when the species is commercially cultivated and production has been maintained over time, 2) in development - when there is progress in both the collection or production of spat and field cultures, but commercial farms have not been established, 3) experimental - when there is progress in some aspect of cultivation but other aspects are missing to study or develop, 4) inactive - when obtaining spat and cultivation are dominated, but the activity is not currently being developed, and 5) restricted - when the activity is exclusively concessioned to a producing group.

Studies on bivalve aquaculture

Our review found 281 documents, of which 216 corresponded to studies published in journals, books, or book chapters and the other 65 to theses. The studies include 8 families and 24 species of bivalves. Of these, 21 are endemic species, while the remaining three are introduced (exotic) (Table 1). The bivalve species with the most studies as a principal topic in Mexico is the Pacific oyster (*C. gigas*), with 55 articles and 17 theses, followed by the Catarina scallop (*Argopecten ventricosus*) with 30 articles and 10 theses, and then by the lion paw scallop (*Nodipecten subnodosus*) with 28 articles and 8 theses (Table 1). Then, in descending order, the number of studies of another 18 species follows until those with only one reported work. In some previous studies, other species of bivalves appear as a secondary topic (Table 1); the number of works as a secondary topic is also indicated. Here, three new species appear as secondary topics which are the rock oyster (*Striostrea prismatica*), the tuberculate pen shell (*Atrina tuberculosa*), and the California mussel (*Mytilus californianus*). Therefore, there are 24 species of bivalves in Mexico having aquacultural studies.

Some authors have addressed the subject of knowing the studies carried out on bivalves in general or on bivalves concerning aquaculture in some countries like Malaysia (Hamli & Al-Asif 2021) and the Philippines (Lebata-Ramos 2023). These studies are relevant because they highlight what has been done and published, the gaps, and where the technology needs improvement or development. In this study, we did a similar exercise to know these aspects of Mexico. What is evident is that bivalve production is difficult to achieve without the support of basic and applied studies, as we confirm in this review.

Topics

Regarding the central topics, as expected, the main one in most of the studies is cultivation (one or several aspects), followed by spat production, then larval culture (one or several characteristics), and the collection of spat; other topics are listed in Table 2. Considering the main sub-topics, the most studied is performance (which includes growth, survival, and some index), followed by bottom culture, spat, and collectors. The sub-topic culture is associated with the reviews, and there are many other sub-topics in descending order; the main ones are shown in Table 2.

Of all the topics, one of the most relevant is the collection of spat in nature since this is the basic requirement to obtain the initial material to develop any aquaculture activity at any level (experimental, pilot, or commercial). In this regard, several studies have been carried out focusing mainly on species such as *A. ventricosus* (Ruiz-Verdugo et al. 1990), *Modiolus capax* (Aguirre-Hinojosa & Bückle-Ramírez 1992), *Mytillus galloprovincialis* (Curiel-Ramírez & Cáceres-Martínez 2010), *P. mazatlanica* (Bervera-León et al. 2022), *Pinna rugosa* (Cendejas et al. 1985, Arizpe 1995), and *Pteria sterna* (Cáceres-Puig et al. 2012). Of all of them, *M. galloprovincialis* and the two pearl oyster species support commercial aquaculture activities with naturally collected spat. However, one company that produces pearls and mabe pearls reports that spat collection has decreased significantly lately (Enrique Arizmendi, manager of "Perlas del Mar de Cortez", *pers. comm*.). Although the other company does not have spat collection problems, it reports abnormal mortalities in cultured pearl oysters (all sizes) since a nearby fish farm came into operation (Javier Cortés, manager of "Perlas de La Paz", *pers. comm*.). In

Table 1. Bivalve species as a main and secondary topic in studies on aquaculture in Mexico. *Introduced (exotic) and families: Os: Ostreidae, Pe: Pectinidae, Pi: Pinnidae, Pt: Pteridae, Ve: Veneridae, My: Mytilidae, Hi: Hiatelidae, and Ar: Arcidae.

Scientific name(s)	Authority	Common name	As the main topic			As secondary topic		
			Articles	Theses	Total	Articles	Theses	Total
*Crassostrea gigas** (Os)	Thunberg 1793	Pacific oyster	55	17	72	1	0	1
Argopecten ventricosus (*circularis*) (Pe)	Sowerby II 1842	Catarina scallop	30	10	40	6	2	8
Nodipecten (*Lyropecten*) *subnodosus* (Pe)	Sowerby I 1835	Lion's paw scallop	28	8	36	2	1	3
Crassostrea corteziensis (Os)	Hertlein 1951	Pleasure oyster	23	5	28	5	3	8
Atrina maura (Pi)	Sowerby I 1835	Maura pen shell	16	7	23	4	0	4
Pteria sterna (Pt)	Gould 1851	Rainbow-lipped pearl oyster	11	7	18	6	0	6
Pinctada mazatlanica (Pt)	Hanley 1856	Pearl oyster	14	3	17	0	2	2
Modiolus capax (My)	Conrad 1837	Fat horsemussel	7	2	9	0	0	0
Chionista (*Chione*) *fluctifraga* (Ve)	Sowerby II 1853	Black venus clam	6	0	6	1	0	1
Pinna rugosa (Pi)	Sowerby I 1835	Rugose pen shell	3	2	5	2	0	2
Crassostrea virginica (Os)	Gmelin, 1791	Eastern oyster	3	2	5	0	0	0
Saccostrea (*Crassostrea*) *palmula* (Os)	Carpenter 1857	Mangrove (palmate) oyster	3	1	4	0	0	0
*Mytilus galloprovincialis** (My)	Lamarck 1819	Mediterranean mussel	4	0	4	3	0	3
*Crassostrea sikamea** (Os)	Amemiya 1928	Kumamoto oyster	4	0	4	1	1	2
Anadara (Larkinia) grandis (Ar)	Broderip & Sowerby I 1829	Ark clam	3	0	3	0	0	0
Euvola (Pecten) vogesi (Pe)	Arnold 1906	Flying clam	2	0	2	4	1	5
Panopea generosa (Hi)	Gould 1850	Geoduck clam	1	0	1	0	0	0
Dosinia ponderosa (Ve)	Gray 1838	Queen conch	1	0	1	0	0	0
Mytella strigata (My)	Hanley, 1843	Charru mussel	1	0	1	0	0	0
Megapitaria squalida (Ve)	Sowerby I, 1835	Chocolate clam	1	0	1			
Anadara tuberculosa (Ar)	Sowerby I, 1833	Mangrove cockle	0	1	1			
Striostrea prismatica (Os)	Gray 1825	Rock oyster	0	0	0	1	0	1
Atrina tuberculosa (Pi)	Sowerby I 1835	Tuberculate pen shell	0	0	0	1	0	1
Mytilus californianus (My)	Conrad 1837	California mussel	0	0	0	1	0	1
Total			**216**	**65**	**281**	**38**	**10**	**48**

the case of pen shell species, wild collection is scarce and intermittent in all regions (Ángel-Dapa et al. 2015).

When the collection of spat in nature is non-existent, not enough for aquatic activities, with many intermittencies, or the species is introduced and does not exist naturally, the option to obtain starting material is to produce spat in hatcheries. Introducing exotic species, particularly *C. gigas* (Islas-Olivares 1975), was the main reason for the launch of hatcheries to produce spat locally and not depend on imports from other countries. From there, studies of various kinds were undertaken to support the production of spat under controlled condi-

Table 2. Main topics and sub-topics in the studies of bivalve aquaculture in Mexico.

Main topic	Number of studies	Main sub-topic	Number of studies
Field culture	139	Performance	59
Spat production	46	Bottom culture	25
Larval culture	28	Spat	22
Spat collection	20	Collectors	14
Review	14	Culture	13
Reproduction	9	Microalgae	10
Diseases	8	Probiotic	10
Conditioning	5	Conditioning	9
Genetics	4	Larvae	8
Hatchery	2	Density	8
Repopulation	1	Suspension culture	8
Morphology	1	Temperature	7

tions for the Pacific oyster (Mazón-Suástegui et al. 1990, Barraza-Guardado et al. 2009) and for other exotic and local species. Currently, there are established production protocols that guarantee the commercial production of spat in hatcheries for *C. corteziensis*, *C. gigas*, *C. sikamea* (Chávez-Villalba et al. 2008, Mazón-Suástegui et al. 2008, 2009, Ojeda-Ramírez et al. 2008, Campa-Córdova et al. 2009), and *Chionista fluctifraga*. The Pacific oyster is routinely produced in several regional hatcheries (Reynaga-Franco et al. 2020), while the other species are produced only by farm demand. There are spat production protocols for other species, such as *A. ventricosus*, *N. subnodosus*, *Panopea generosa*, and *P. sterna*, but they are not at a marketable level. There is a special case for the pen shell *Atrina maura*, given that there is great interest in its spat production due to its high market demand. However, obtaining spat, whether natural or from hatchery, is difficult and intermittent.

Location

Although numerous species of bivalves live along the Pacific and Atlantic coasts of Mexico (Castillo-Rodríguez 2014), practically all aquaculture studies have been developed in the northwest of the country, particularly on the Pacific coast and the Gulf of California. Considering the location, the majority of the studies have been carried out in BCS (161), particularly in the city of La Paz (76 indoor studies) and in the Bay of La Paz (28 outdoor studies). The next locations are SON and SIN, with 33 studies each (5 indoor studies in Bahía Kino and Hermosillo and 1 indoor study in Guasave, respectively). Studies have also been done in BC (29; 11 indoor studies in Ensenada), NAY (4), Jalisco (JAL; 3), Tabasco (TAB; 3), and Guerrero (GRO; 1). Considering reviews where several states are included, these represent 14 of the total (Fig. 1).

Regarding the Gulf of Mexico, there is also the production of bivalves considering two sources: one is a clam fishery that includes several species in a general category (3%), and the second and more important is the production of the eastern oyster *C. virginica* (97%) (AEAP 2021). This species is mainly produced through extensive aquatic management (not considered aquaculture) (FAO 2016), where empty oyster shells are scattered in certain places to settle wild spat. The attached juveniles grow on the shells, forming clusters, and after several months, they are the target of fishing and have recovered using spoon-type shovels. Oysters are rarely separated from the bunches; what is done is to obtain the meat for direct sale or store it in jars (Mora et al. 2011). We only found five studies related to the eastern oyster.

Studies in nature and laboratory

Of the total studies, 154 (54.8%) were carried out essentially in the field, 97 (34.5%) were performed under controlled conditions (laboratory), and 30 (10.7%) of them combined both laboratory and field aspects. The institutions in La Paz (BCS) are characterized by carrying out numerous studies in the field or under controlled conditions of local species but also on species that are not cultivated there or that do not exist locally, such as *C. virginica* that is cultivated in the Gulf of Mexico from on-cultch and cultch-less spat produced in the COTET hatchery (Tabasco, Mexico), a way to develop cultivation and/or production protocols that are used in other regions. For exam-

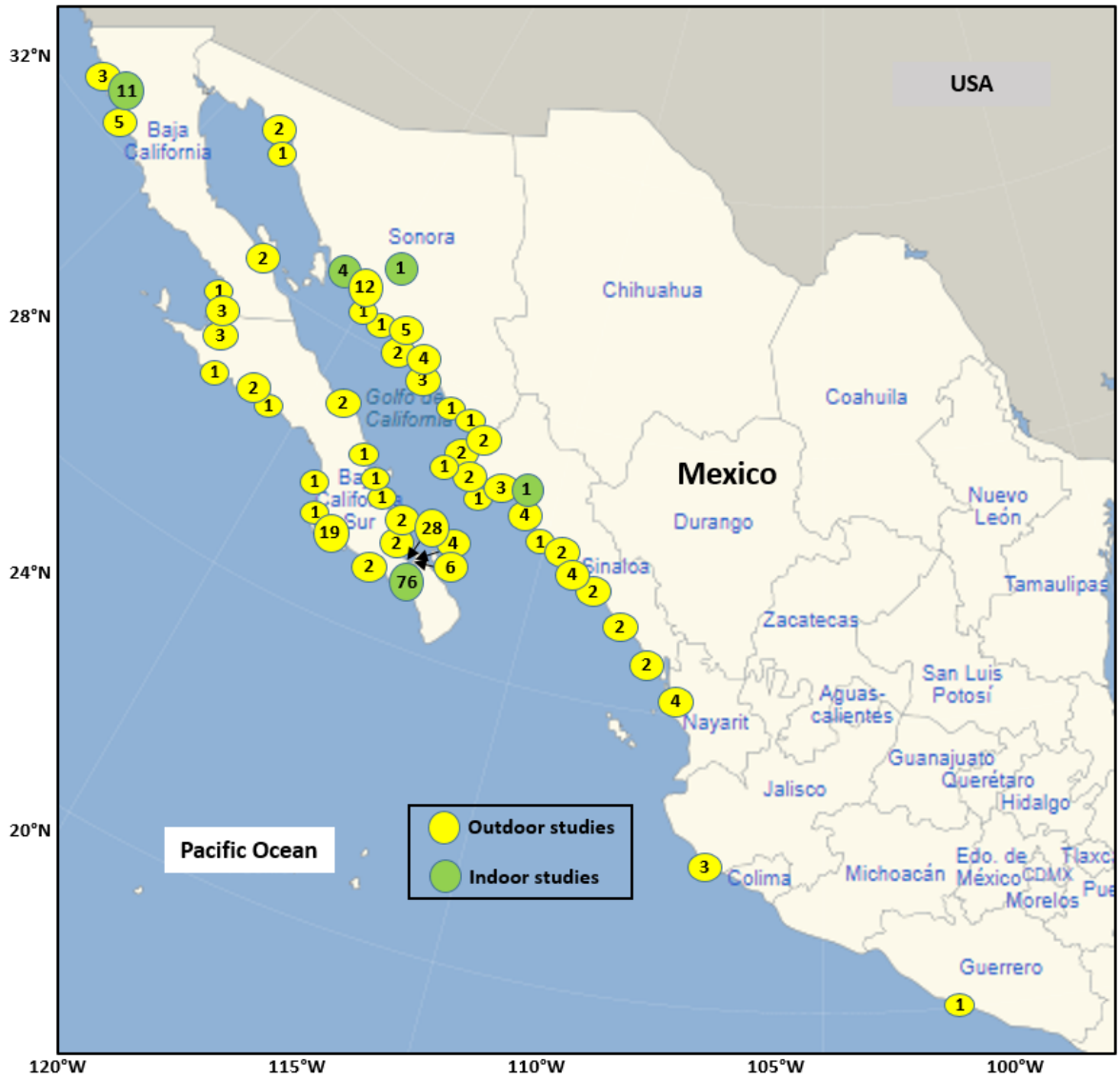

Figure 1. Number and places where most bivalve aquaculture studies have been carried out in Mexico. There are five studies in the Gulf of Mexico (Tabasco), which are not shown here.

ple, some species studied here in the laboratory are *C. corteziensis* produced in NAY and SIN and *C. sikamea* and *M. capax* grown in BC. Regarding field studies, Bahía de La Paz is where the largest number of studies have been carried out, followed by Bahía Magdalena, also in BCS. Although the first area is not characterized by aquaculture production of bivalves, there is a significant increase in the cultivation of Pacific oysters *C. gigas* in estuaries and protected coastal areas of the Santo Domingo-Magdalena Bay lagoon complex.

Institutions studying bivalves

The institutions that have carried out the most studies on bivalve aquaculture are Centro de Investigaciones Biológicas del Noroeste (CIBNOR; 115), including three of its units (La Paz, Guaymas, and Nayarit). The next institution is the Universidad Autónoma de Baja California Sur in La Paz (UABCS; 58), and then by the Centro Interdisciplinario de Investigación para el Desarrollo Integral Regional Unidad Sinaloa (CIIDIR; 26), followed by other institutions with fewer studies (see Table 3).

Table 3. Institutions that carry out studies on bivalve aquaculture in Mexico.

Institution	Articles	Theses	Total
Centro de Investigaciones Biológicas del Noroeste, SC - CIBNOR	103	12	115
Universidad Autónoma de Baja California Sur - UABCS	22	36	58
Centro Interdisciplinario de Investigación para el Desarrollo Integral Regional Unidad Sinaloa - CIIDIR	21	5	26
Centro de Investigación Científica y de Educación Superior de Ensenada - CICESE	17	2	19
Universidad de Sonora - UNISON	11	2	13
Centro Interdisciplinario de Ciencias Marinas La Paz - CICIMAR	6	6	12
Universidad Autónoma de Baja California - UABC	10	1	11
Secretaría de Pesca - SEPESCA	9		9
University of California, Davis	3		3
Universidad Autónoma de Guadalajara - UAG	3		3
Universidad Autónoma de Sinaloa - UAS	1		1
Archivos de la Compañía Criadora de Concha Perla	1		1
Centro de Investigación y Experimentación en Maricultura	1		1
Investigación para la Conservación y el Desarrollo, La Paz	1		1
Instituto Tecnológico de Estudios Superiores de Monterrey, Guaymas	1		1
Leibniz-Zentrum für Marine Tropenökologie	1		1
School for Field Studies, Center for Coastal Studies	1		1
Virginia Institute of Marine Science	1		1
Western Washington University	1		1
Zentrum für Marine Tropenökologie	1		1

Universities and research centers are in practically all the country's coastal states. Still, research on bivalve aquaculture has been concentrated in BC, BCS, SON, and SIN. Numerous studies are carried out in La Paz (BCS) and its bay; it is a region where various institutions converge (CIBNOR, UABCS, Centro Interdisciplinario de Ciencias Marinas-CICIMAR) and have a clear vocation for the study of marine bivalves, not only in aquaculture but also in a wide variety of aspects. Most studies here have been conducted under controlled conditions to study larval culture spat production and determine the effect of various factors (temperature, food, probiotics) on larvae and postlarvae. Those studies have been done on *Anadara grandis* (Reynoso-Granados et al. 2012), *A. ventricosus* (Mazón-Suástegui 2005, Mazón-Suástegui et al. 2022), *A. maura* (Ángel-Dapa et al. 2015), *C. corteziensis* (Mazón-Suástegui et al. 2008, 2009, Ojeda-Ramírez et al. 2008, Campa-Córdova et al. 2009, Maeda-Martínez et al. 2016), *C. gigas* (García-Corona et al. 2019), *C. sikamea* (Flores-Higuera et al. 2020), *Euvola vogdesi* (Monsalvo-Spencer et al. 2015), *M. capax* (López-Carvallo et al. 2017, García-Corona et al. 2024), *N. subnodosus* (Mazón-Suástegui et al. 2011a,b, Saucedo et al. 2013), *P. mazatlanica* (Saucedo et al. 2009), and *P. sterna* (Gómez-Robles et al. 2023). As indicated before, the concentration of studies in certain locations is the same; in the same way, most studies are carried out by only three or four institutions. Therefore, it would be advisable for more centers to get involved in studying these organisms by starting to implement some lines of research.

Research effort and production

The main information on the production of bivalves in Mexico by aquaculture and fisheries is shown (Table 4). Six of the 24 species considered have consolidated cultures, 6 have developed cultures, and 10 are experimental. Likewise, one is inactive, and the other is restricted to a producer group. In addition, the main places on the Mexican coast where the bivalve species are exploited through aquaculture or fishery are indicated (Fig. 2). The most produced species with the most cultivation sites is the Pacific oyster *C. gigas*, while the species with the most fishing sites is *P. generosa*. The rest of the species have fewer production sites, and most are found in specific sites, such as *Atrina tuberculosa*, *P. sterna*, and *P. mazatlanica*.

The work of Chávez-Villalba & Grijalva-Chon (2022) was updated to determine the status of bivalve species produced through aquaculture and fishing in Mexico. Subsequently, all the documents cited in the

Table 4. Production of bivalves in Mexico is either by aquaculture (A), fisheries (F), or both. The aspects of forms of cultivation and production by aquaculture are summarized. Na: not available.

Species	Production forms	Production (mt) (2021)	Status	Reference
Family Ostreidae				
Crassostrea gigas (introduced)	Produced by aquaculture, spat only from hatcheries. Main cultivation systems: long lines with various types of containers, racks, bags, and floating rafts depending on the region	6340 (A)	Consolidated	Chávez-Villalba (2014), AEAP (2021)
C. corteziensis	Aquaculture and some intermittent fishery. Natural spat collection or from a hatchery. Traditional management using shell strings suspended from artisanal racks. Other culture methods: plastic trays in longlines and bottom culture using bags.	4956 (A)	Consolidated	AEAP (2021)
C. sikamea (introduced)	Produced by aquaculture; spat from hatchery. Culture using the same systems as for *C. gigas*	Na	Consolidated	Flores-Higuera et al. (2020)
C. virginica	Aquatic management and fishery. Spat collected from nature, and few produced in hatcheries for field culture (Australian system). Collection on scattered shells supporting artisanal fishery	16000 (F)	In Development	Mazón-Suástegui (2018), AEAP (2021)
Striostrea prismatica	Some hatchery trials	Na	Experimental	Chávez-Villalba et al. (2021)
Saccostrea palmula	Collection and cultivation experiments	Na	Experimental	Chávez-Villalba & Cáceres-Martínez (1994)
Family Pectinidae				
Argopecten ventricosus	Spat can be obtained from the wild or hatchery. Suspension and bottom cultures were developed some time ago. There is occasional fishing for the species	Na	Inactive	Maeda-Martínez et al. (2000)
Nodipecten subnodosus	Fishing is the main form of production Nevertheless, spat can be produced in hatchery or collected from the wild for use in non-permanent suspension cultures.	Na	In development	Koch et al. (2015)
Euvola vogdesi	Some larvae culture trials were conducted in the laboratory and on experimental suspension culture	Na	Experimental	Monsalvo-Spencer et al. (2015)
Family Pteridae				
Pteria sterna	Produced by aquaculture, the spat is collected in the wild or possibly produced in hatchery. Culture is suspended with different types of containers depending on the farm	Na	Consolidated	Cortés-Salazar (2013)

Continuation

Species	Production forms	Production (mt) (2021)	Status	Reference
Pinctada mazatlanica	Similar to *P. sterna* but production to a lesser extent. Spat is only from the wild collection	Na	Consolidated	Cortés-Salazar (2013)
Family Pinnidae				
Atrina maura	Mainly fishery. Spat is difficult to obtain either from the wild or from hatchery. Some sporadic cultures combine suspension and bottom systems	Na	In development	Leal-Soto et al. (2011)
A. tuberculosa	Spat collected from the wild. Indigenous people perform extensive cultivation on the bottom.	Na	Restricted	Chávez-Villalba et al. (2022)
Pinna rugosa	Similar to *A. maura* but to a lesser extent. Bycatch production	Na	In development	Arizpe (1995)
Family Veneridae				
Chionista fluctifraga	Fishery and pilot aquaculture. Spat is produced in hatchery. Pilot culture combines suspension and bottom systems.	4,500 (F)	In development	Chávez-Villalba et al. (2023)
Donisia ponderosa	Some hatchery trials	Na	Experimental	Villanueva-Gutiérrez et al. (2019)
Megapitaria squalida	Field cultivation trials	Na	Experimental	Mazón-Suástegui et al. (1994)
Family Mytilidae				
Mytilus galloprovincialis (introduced)	The spat is collected from the wild and produced by aquaculture. It is cultivated in strings suspended from longlines or racks and a stake system	Na	Consolidated	Curiel-Ramírez & Cáceres-Martínez (2010)
M. californianus	Some experimental trials	Na	Experimental	Cáceres-Martínez (1997)
Modiolus capax	Some spat collection and hatchery trials.	Na	Experimental	López-Carvallo et al. (2017)
Mytella strigata	Field culture trials	Na	Experimental	Diarte-Plata et al. (2013)
Family Hiatelidae				
Panopea generosa	Fishery and aquaculture. Spat can be produced in hatchery and used for bottom culture	2,200 (F)	In development	Aragón-Noriega et al. (2012)
Family Arcidae				
Anadara grandis	Some hatchery trials	Na	Experimental	Reynoso-Granados et al. (2012)
Anadara tuberculosa	Some hatchery trials	Na	Experimental	Sánchez-Ortíz (2015)

complementary file (List-articles-theses-by-species. pdf; available on request) were used to relate studies and production, synthesizing the most relevant aspects for each species. Still, not all documents were cited due to space issues, only some of the most relevant ones. This relationship was made generally because the production data, the cultivation surfaces, and the number of producers are incomplete or do not exist for most species to conduct more robust analyses.

Pacific oyster (*Crassostrea gigas*)

Here, it is possible to observe that the largest number of studies corresponds to the most produced and widespread species in the country's northwest. The interest in this introduced species marked in some way the beginning of the diversification and intensification of studies on native bivalves in Mexico. Various topics have been studied for *C. gigas*. Many are about cultivation (Rodríguez-Quiroz et al. 2016), reproduction,

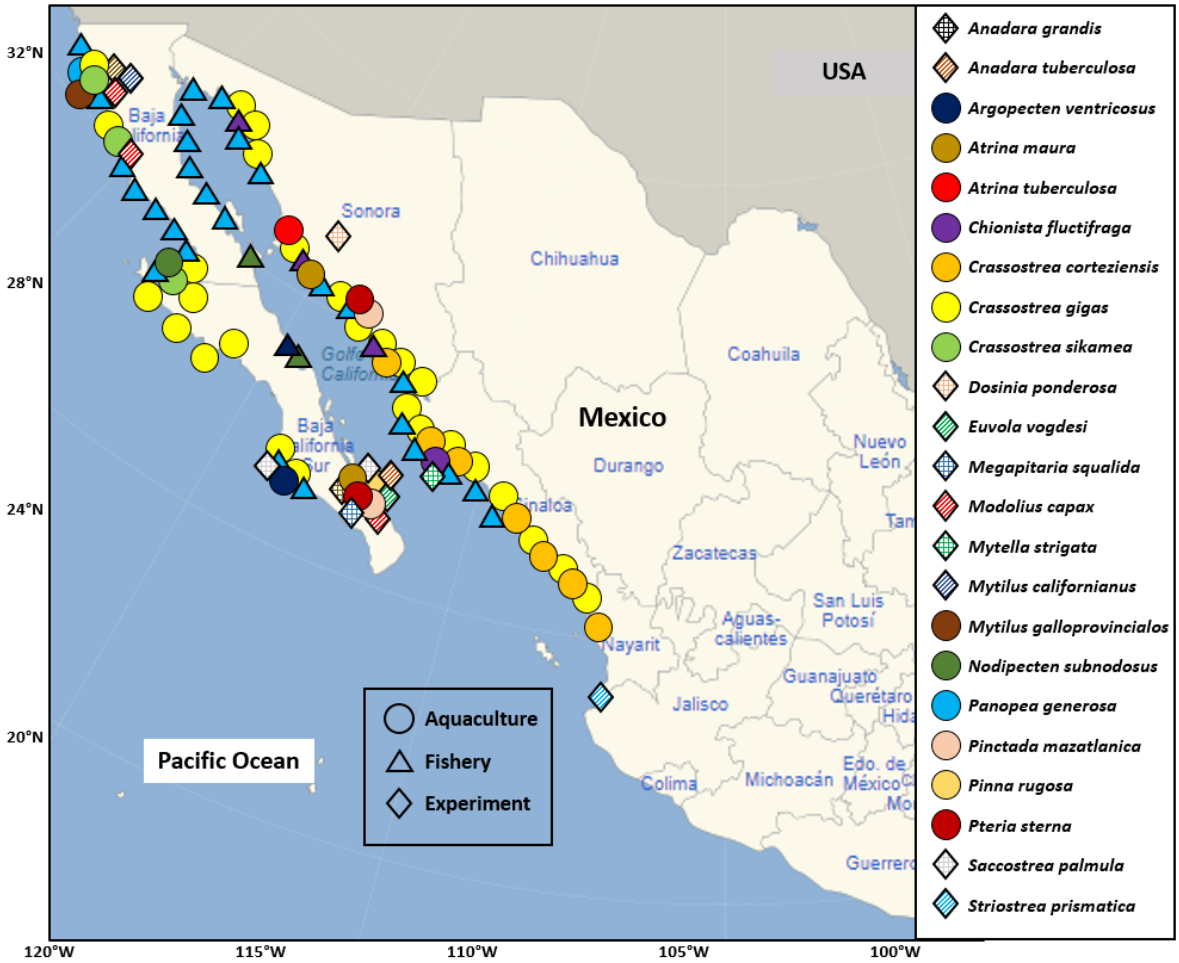

Figure 2. The main places where bivalve production takes place in Mexico through aquaculture and fisheries. Some experimental sites are indicated (diamonds), but those in the Gulf of Mexico with *Crassostrea virginica* are not shown.

diseases, genetics, and immunology (Gallo-García et al. 2004), allowing the Pacific oyster to be the first to establish its cultivation through the use of a wide variety of production systems that have been adapted to the conditions of each region, becoming a consolidated commercial activity since more than 40 years (Chávez-Villlaba 2014). More than 40 years ago, an oyster hatchery dependent on the Federal Fisheries Secretariat (SEPESCA, by its Spanish acronym) was created to produce spat of the species in Estero San Buto (BCS). This hatchery was closed and ceased operations due to changes in government policy, and today, practically all the oyster spat is produced in private hatcheries. The subsequent studies helped establish spat production at the local level. Currently, more than 10 hatcheries are selling spat to meet regional demand. However, several of them are not certified. Some hatcheries sell triploid spat, which is grown in some oyster regions of the country (Villanueva-Fonseca et al. 2017). In 2023, 50 years have passed since the species was introduced into the country, with no evidence of feral populations until 2019, when uncultivated oysters living on rocks and with mature gonads were discovered in the north of the Peninsula (PNUD 2019). It seems that *C. gigas* has had to undergo a long adaptation process to reproduce and produce naturalized oysters, as in the USA and Canada for this species (Ruesink et al. 2005). For some people, feral oysters may represent a threat (Reyes-Bonilla et al. 2024), but for others, an opportunity to increase production (Martínez-García et al. 2021).

Catarina scallop (*Argopecten ventricosus*)

Many studies on aquaculture for endemic species began with this scallop, both in the laboratory and the field (Ruiz-Verdugo et al. 2016). It was one of the first where production protocols for larval and spat culture were

established, which later allowed the production of spat and the study of the effect of other factors under controlled conditions (Mazón-Suástegui 2005, Mazón-Suástegui et al. 2011a,b, 2017, 2020, 2021, 2022, López-Carvallo 2020). Production systems were also established in the field using suspended, bottom, or a combination of both systems. Experience indicates that mass spawning of cultured organisms, collected in the wild or from hatcheries, produces an enormous number of larvae that establish themselves and can sustain, at least temporarily, a commercial fishing operation. Despite being the Catarina scallop the second most studied species, only cultures were established at a pilot level in Bahía Magdalena, BCS (Maeda-Martínez et al. 1997). Nevertheless, successful commercial farms were not created due to their low profitability in the face of competition with the fisheries. Still, these have been intermittent over time, apparently due to overfishing and natural recruitment variability.

Paw's lion scallop (*Nodipecten subnodosus*)

This species is very attractive due to its great demand because of its large abductor muscle but also thanks to its beautiful shells (Lodeiros et al. 2021). Important studies have been carried out that have helped establish production protocols in the laboratory and field, including research articles (Osuna-García et al. 2008, Abasolo-Pacheco et al. 2009, Granados-Amores et al. 2012, Saucedo et al. 2013, Koch et al. 2015), theses (Quintero-Ojeda 2003, Osuna-García 2006, Diarte-Plata 2007, Garzón-Favela 2011), and book chapters (Freites-Valbuena et al. 2011, García-Pámanes et al. 2011, Mazón-Suástegui et al. 2011a). Some suspension culture systems work adequately (Barrios-Ruíz et al. 2003), but the species is very sensitive to environmental changes, particularly high temperatures. Although it is also one of the most studied species, only small-scale cultivations were developed, some operated temporarily in Laguna Manuela BC, and San Ignacio Lagoon and Bahía Tortugas in BCS. The farm "Perlas de La Paz" currently separates and cultivates the spat from the lion's paw scallop that comes to settle on its pearl oyster collectors. It also receives small quantities of hatchery-produced spat; all gathered scallops are cultivated at a low scale at a depth >30 m, and after approximately two years, the organisms are sold individually to gourmet restaurants (Javier Cortés manager of the farm, *pers. comm*.). Nevertheless, almost all production comes from very localized fisheries.

Pleasure oyster (*Crassostrea corteziensis*)

This species was one of the first to be studied to try to implement cultures in SON (Sevilla-Hernández 1959). A hatchery (Centro de Acuacultura - SEPESCA) focused on this native species was created in San Blas, NAY, about 45 years ago. It later reoriented its objectives to *C. gigas* but finally stopped its operations. However, several laboratory contributions helped to establish spat production of *C. corteziensis* in commercial hatcheries and their intensive cultivation in the field (Chávez-Villalba et al. 2008, Mazón-Suástegui et al. 2008, 2009, 2011b, 2014, 2019, 2022, Ojeda-Ramírez et al. 2008, Campa-Córdova et al. 2009, 2011, Trabal-Fernández et al. 2014, Góngora-Gómez et al. 2018, García-Bernal et al. 2019). In parallel, wild spat collection and aquaculture management were implemented into an extensive traditional aquaculture activity, just as with *C. virginica* in the Gulf of Mexico. The production is mainly based on natural collection with shell collectors tied to strategically installed racks; the collectors with attached wild spat are transferred to growing areas where they remain until harvest. At the same time, field works allow this species to be grown using different commercial culture systems in diverse regions (Maeda-Martínez et al. 2023). The fishery is another form of exploitation; it is sporadic in some places of SIN and NAY, but it is so intense in SON that most of the natural populations have disappeared.

Maura pen shell (*Atrina maura*)

As mentioned above, and due to the high price of the adductor muscle, this is one of the species with the most interest in aquaculture production (Góngora-Gómez et al. 2011). Although there are a good number of studies about the species (Robles-Mungaray 2004, Góngora-Gómez et al. 2015), it has not been possible to establish permanent commercial cultures since the collection of natural spat is very scarce and intermittent while it is difficult to obtain hatchery spat due to high larval mortality. Production in hatchery has been studied directly for Hoyos-Chairez & Chávez-Villalba (2023), describing the various problems that have been faced, particularly the most critical phase, which is the transition from D-larvae to umbo larvae. Other studies have shown that when spat is available regardless of the source, the culture systems established in the field allow the organisms to reach commercial size without problems (Góngora-Gómez et al. 2016). Currently, most production comes from fisheries, but natural stocks are at risk of depletion.

Pearl oyster (*Pinctada mazatlanica*)

This pearl oyster is iconic because it was one of the first species to be cultivated in the world, and it is the first species whose cultivation was documented at the

beginning of the 20th century. However, the natural populations were overexploited due to the search for natural pearls, and despite the established ban (since 1939) and the time that had passed, they have not fully recovered. Studies have helped establish cultivation techniques that can be applied to commercial farms (Cortés-Salazar 2013). Still, regardless of studies in the laboratory (Saucedo et al. 2007), the spat supply for the two existing pearl companies continues to be a natural collection (few spat but relatively constant). It is a consolidated activity because the cultivation cycle is mastered from obtaining spat to bead-nucleated pearl production. Still, it should be noted that production is very limited, and companies try to take advantage of the few pearl oysters obtained to produce pearls that are round and cultured profitably.

Rainbow-lipped pearl oyster (*Pteria sterna*)

This species began to be studied in the 90s with works on wild spat collection and testing different artifacts and management systems for their cultivation to adult size for pearl implants or broodstock conditioning to spawn under laboratory conditions (Avilés-Quevedo & Mazón-Suástegui 1988, Monteforte et al. 2005, Gómez-Robles 2013, Gómez-Robles et al. 2013, Granados-Amores et al. 2017, 2018). These and other experimental studies, added to efforts with a profitable business approach, allowed the creation of two commercial farms in SON and BCS, which have been in operation for over 20 years. It is a consolidated activity because the cycle from obtaining spat to producing mabes (hemispherical pearls) and round bead-nucleated pearls have been mastered. Production is small-scale, and one farm in SON has recently reported low spat collection. Hoyos-Chairez et al. (2020) produced spat in the hatchery, which was successfully grown on this farm to confront this challenge. However, there have been problems in continuing spat production under controlled conditions locally.

Rugose pen shell (*Pinna rugosa*)

This species is also very attractive to the market due to the value of its adductor muscle, although its price is lower than that of *A. maura*. However, all pen shell species are threatened by overfishing, and populations are greatly reduced, making natural capture generally scarce. Nevertheless, some work was done in the 90s, during which the feasibility of bottom cultivation was demonstrated (Arizpe 1995), but all remained experimental. To our knowledge, no attempts to produce spat in hatchery have been documented. Normally, this species is obtained for consumption from bycatch.

Palmate oyster (*Saccostrea palmula*)

A little-studied species that sparked interest in the 80s to learn about its cultivation potential. Subsequently, studies of natural spat collection and experimental cultivation were carried out (Chávez-Villalba & Cáceres-Martínez 1994), with good outcomes for spat collection but not cultivation. However, good collection and cultivation results were obtained in a recent study in Colima (Durand-Acosta et al. 2024), and local producer groups are interested in starting pilot ventures.

Kumamoto oyster (*Crassostrea sikamea*)

Although this is a little-studied species, its cultivation technology is consolidated from hatchery spat to adult size in commercial units. There are references to experimental studies (García Bernal et al. 2016, 2019, Flores-Higuera et al. 2020). However, not as much research effort is required because spat production and culture techniques for *C. gigas* are perfectly adapted for this species. Normally, this species is native to temperate waters and is cultivated by some groups on a small scale in the north of the country within the same *C. gigas* culture systems, which means that production units could be limited because most Pacific oyster cultures are in subtropical areas. Nevertheless, according to some oystermen, the Kumamoto oyster has good growth and attained a marketable size in some Mexican subtropical areas, even in less time than normally required in the USA, where the average water temperature is lower. Nevertheless, the production of the species is scarce and merely for export.

Black venus clam (*Chionista fluctifraga*)

A species whose production is mainly based on fisheries, but there are spat production protocols in hatchery for commercial sale. The spat was initially used for repopulation (planting spat in commercial fishery grounds). Still, it has been used to develop field cultivation techniques (Chávez-Villalba et al. 2023), which are applied to the pilot level in SIN (Góngora-Gómez et al. 2021). The populations of this species are suffering from depletion due to fishing pressure. The northwest's largest and most important cooperative that sustainably exploited this species has ceased operations due to conflicts with criminal groups, so productive activity has been minimized.

Mediterranean mussel (*Mytilus galloprovincialis*)

This mussel was introduced and quickly adapted to both environmental conditions and culture systems; for some time now, cultivation has been based on the natural collection of spat from feral populations. The cultivation is consolidated and one of the country's most technical, and most of the production is for export. Not many studies were required to achieve this status.

Tuberculose pen shell (*Atrina tuberculosa*)

Although there are almost no studies, the Seri indigenous people cultivate the species extensively and have an exclusive concession to exploit this species in the Infiernillo channel between Isla Tiburón and the coast of SON. Because of this, it was given a restricted status. Seri people were trained (Basurto 2006) to cultivate the species by placing collectors in certain areas and leaving them until the juveniles reached 5 and 7 cm in shell length. Subsequently, the collectors with the juveniles attached are transported to growth areas where they are detached and planted on sandy bottoms ~10 m deep until they reach market size (>20 cm shell length) and then sold in the local markets (Chávez-Villalba et al. 2022). The Seris are the only ones able to maintain a modest but constant production of pen shells in Mexico.

Geoduck clam (*Panopea generosa*)

Only one study was found for the species (Nava-Gómez et al. 2018), but researchers from the University of Baja California have developed reliable spat production protocols in the laboratory. The spat produced has been used to implement bottom cultures in some areas of BC with encouraging results. Despite these important advances, practically nothing has been published about them in scientific journals.

Eastern oyster *Crassostrea virginica*

As previously stated, extensive aquatic management of *C. virginica* has been insufficient on the coasts of the Gulf of Mexico, and overall production is decreasing over time, from 41,000 mt per year in 2011 to 16,000 mt in 2021 (AEAP 2021). Although official regulations establish the obligation for fisheries to quickly return empty shells to the seabed after opening oysters for their meat, it is common practice for fishermen not to return fresh "green" shells with live larvae and juveniles attached. Oyster shells are used to fill land and buildings, and it is a traditional practice that is difficult to eradicate, which is why the installation of wild spat collectors is promoted. At the same time, government and business hatcheries are trying to produce spat. Derived from the advice and technological design services of CIBNOR, through CONACYT-PROINNOVA projects (2012-2017) awarded to Productora de Especies Acuáticas Company (PEASA), the Centro Ostrícola Tecnológico del Estado de Tabasco (COTET) has been able to produce cultch-less and on-cultch spat of *C. virginica* for more than 13 years (https://datos.gob.mx/busca/dataset/programa-de-estimulos-a-la-innovacion-pei). Some of these spat are grown in Australian and other types of culture containers (Pérez-López 2021). Consequently, private and social oyster farmers currently produce individual pieces of oysters, which are mainly sold in tourist places to obtain the highest economic income. The I+D+I links between PEASA-COTET-CIBNOR and Fundación Produce Tabasco A.C. conducted to prototypes development, technical manuals, workbooks and business plans, technological innovations, and novel research (Mazón-Suástegui et al. 2018, 2022, García-Bernal et al. 2020, Hernández-Villasana 2023). COTET is located in Cárdenas, TAB; its monthly production capacity is at least 8.5 million individual spat and 5 million spat in mother shells (https://tabasco.gob.mx/noticias/impulsa-gobierno-del-estado-proyectos-para-detonar-la-actividad-ostricola; https://www.gob.mx/imipas/acciones-y-programas/acuacultura-ostion-del-este). However, the intensive and technical cultivation of *C. virginica* from cultchless spat continues to advance but slowly (Pérez-López 2021) due to the idiosyncrasy of the regional oystermen accustomed to the cultivation of wild spat, which is less demanding of investment and work, although the product quality is much lower.

Species with cultivation potential

There are several species with aquaculture studies having cultivation potential such as *Modiolus capax*; there are several contributions on this species about its gonad maturation as well as trials for spawning and larval culture under controlled conditions (Mazón-Suástegui 1987, Mazón-Suástegui & Avilés Quevedo 1996, López-Carvallo 2015, López-Carvallo et al. 2017, García-Corona 2018, García-Corona et al. 2018, 2023). Similarly, other works have been focused on *Euvola vogdesi* (Ruiz-Verdugo et al. 1990, Monsalvo-Spencer et al. 2015), *Anadara grandis* (Reynoso-Granados et al. 2012, Robles-Mungaray et al. 2002), *Anadara tuberculosa* (Sánchez-Ortiz 2015), *Dosinia ponderosa* (Villanueva-Gutiérrez et al. 2019), *Megapitaria squalida* (Mazón-Suástegui et al. 1994), and *Mytella strigata* (Diarte-Plata et al. 2013). Other species, such as *Mytilus californianus* and *Striostrea prismatica*, are considered secondary subjects in

similar studies. All these contributions have been made at an experimental level, and there is no evidence that its management has been scaled up to an aquacultural level, for which more studies in the laboratory and field are required.

Perspectives

This review shows that Mexico's potential for using marine bivalves is not being fully exploited. Considering the number of bivalve species reported for both coasts of the country and its great extension, the number of exploited species and production sites could be higher.

The case of the Atlantic coast is surprising since there is only one species exploited through extensive (wild spat) and intensive (hatchery spat) aquaculture (*C. virginica*) despite having several candidates with great potential (Baqueiro & Castagna 1988). On the other hand, the management of the oyster *C. virginica*, the most important species in the region, must be modernized; otherwise, it will continue to decline. Oystermen must be motivated to understand the advantages of technical cultivation, from cultch-less spat, in producing individual pieces in good size and shape for more profitable markets instead of selling small and shucked oysters in bulk in plastic bags. It would be important to implement extensive or intensive cultivation systems based on those carried out in other countries where the cultivation of the species is completely dominated (Campbell & Gray 2024). For species with potential, spat collection experiments should be initiated where natural populations exist to determine the best collecting areas, collection periods, material for settlement, and whether recruitment is sufficient to sustain cultivation projects of different levels. Increasing experimental studies under controlled conditions is also important since they support all species, particularly those with little capture or overexploited.

Having more and better bivalve hatcheries in the Gulf of Mexico that can produce spat of various species would be ideal for developing cultivation projects in various regions. Something similar should be implemented in the central and southern parts of the Pacific littoral (Jalisco, Colima, Michoacán, Guerrero, Oaxaca, and Chiapas), given that the culture of bivalves has been practically null in this region. It would be desirable for universities and research centers in these areas that lack studies on bivalves to start implementing gradual lines of research on these organisms.

For established species, it is necessary to continue improving things; for example, the regularization of concessions for the cultivation of *C. gigas* is still a problem, and so is the certification of cultivation sites. Regarding the culture of *C. corteziensis*, this could be extended further north (SON), but producers do not want to adapt their processes to cultures taking more time in colder waters. In the case of *C. sikamea* and *M. galloprovincialis*, local consumption should be promoted since all the production is for export. For the Kumamoto oyster, a way should be found to expand cultivation sites in the northern part of the region. For *P. mazatlanica*, repopulation programs must be established because stocks are still very scarce; this requires continuous spat production. Something similar is essential for *P. sterna* regarding spat availability since it is becoming scarce. More commercial farms could be established for these pearls and mabes-producing species, but investors must be persuaded that this can be a long-term sustainable venture.

Progress has somewhat stopped for pectinids in developing species. The case of *A. ventricosus* is complicated by the intermittency of its populations, which indirectly affects cultures because the stocks are necessary for the availability of spat and reproducers. The intermittency is not due to overexploitation but other causes that should be studied.

On the other hand, the situation of *N. subnodosus* corresponds mainly to avoiding the re-introduction of spat-carrying pathogens from the Gulf of California (SON) to the peninsular Pacific coasts (BC, BCS), which in the past made commercial projects unfeasible in Laguna Manuela BC and Bahía Tortugas BCS, and affected natural populations subject to fishing exploitation (IMIPAS 2023). Spat of *N. subnodosus* produced at CIBNOR laboratories (LEM and CTT) were cultivated in more than 25 sites on both coasts of BCS (Fig. 3). Therefore, the health certification of broodstock adults from northern Pacific coasts of BCS is of vital importance to avoid the problems mentioned above. Regarding its low tolerance to environmental changes, particularly high temperatures, it is necessary to continue looking for places and/or systems where scallops tolerate environmental changes to cultivate them sustainably over time, as the "Perlas de La Paz" farm does on a small scale at great depth (>30 m) (https://www.facebook.com/Perlasdelapaz.com.mx/videos/nuevo-producto-primer-cosecha-de-almeja-mano-de-le%C3%B3n-totalmente-sustentable-cult/475452010982354/).

The problem for the pen shell *A. maura* is well defined; it is necessary to solve the difficulties that arise in the hatchery concerning umbo larval mortality. Many studies have been carried out to try to solve this

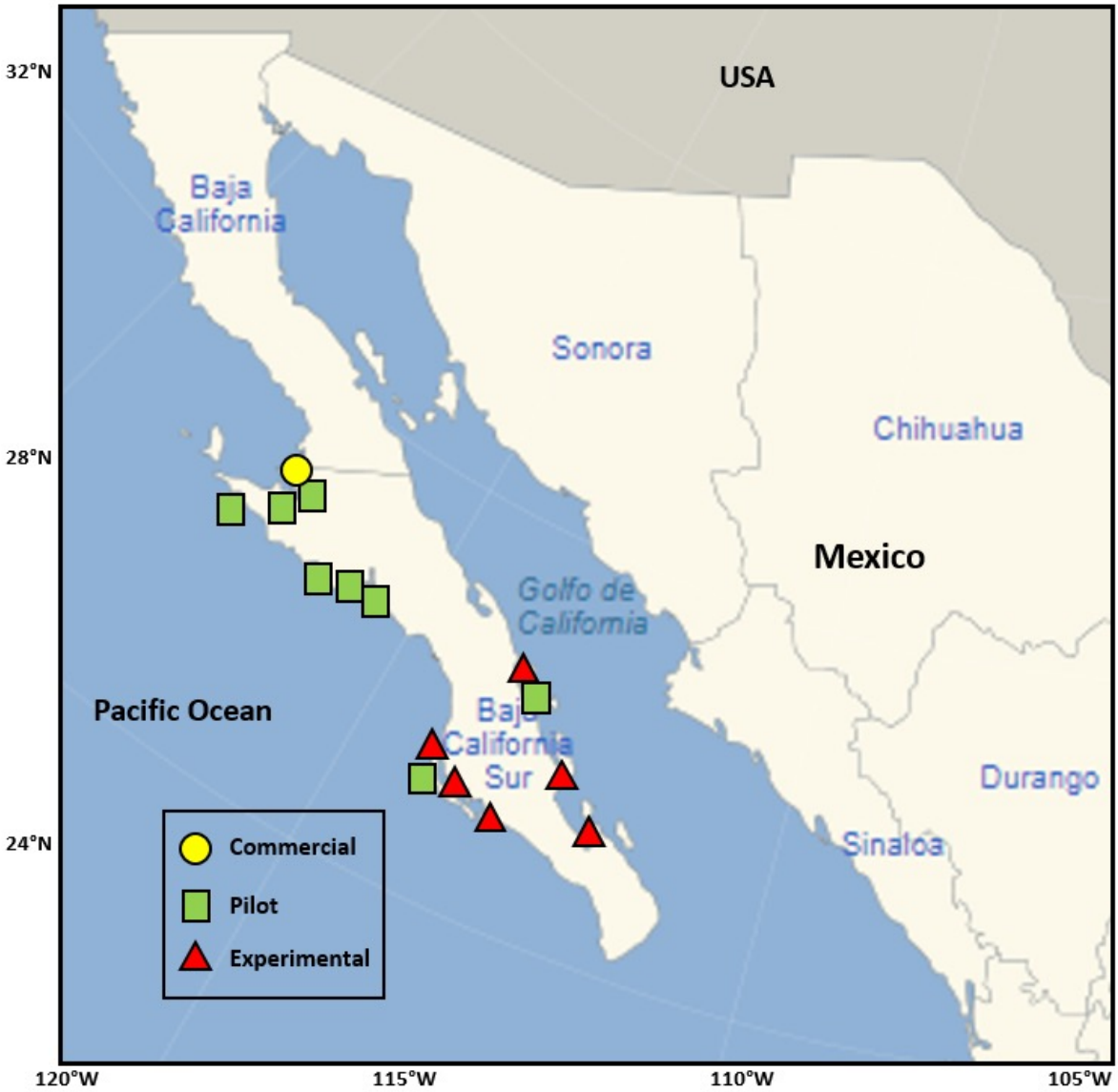

Figure 3. Sites where spat of the pectinid *Nodipecten subnodosus* was cultivated at different levels in Baja California Sur. Modified from Freites et al. (2011) and Mazón-Suástegui et al. (2011a).

problem. Still, it must continue until viable solutions have a reliable production protocol. Regarding the pen shell *P. rugosa*, work should be done on recovering populations by strengthening studies on spat production under controlled conditions. Advances in managing *C. fluctifraga* through aquaculture are recent but encouraging; it is indispensable to continue studying this species to consolidate its cultivation, which may be in the short term. Similarly, the advances in aquaculture are also very notable for *P. generosa*, which need to be continued to establish the activity. Extensive bivalve cultures seem to work well; we have the case of *A. tuberculosa*, which can extend to more areas and other groups or serve other species.

It is necessary to try to study the species that have been studied only at an experimental level and those with potential but without studies, select the most suitable and find a way to use them sustainably.

CONCLUSIONS

It is not easy to establish whether studies on bivalve aquaculture in Mexico are few, many, or sufficient. Still, a laudable effort has been made with target species of Pacific and Atlantic coasts. The studies have been fundamental to developing aquaculture production systems for several species of bivalves. However, the

studies have mainly focused on the country's northwest, performed by certain institutions, and on some species, particularly *C. gigas*. Many of the advances have been thanks to students and their theses, which simultaneously consolidate human resources.

Interestingly, all three introduced species are characterized by established cultures, but only *C. gigas* appears in official records. Except for *C. corteziensis*, the established endemic species have a very limited production that does not exist in official archives. In the case of pearl oysters, the problem of spat shortages must be addressed to sustain the activity. Something similar happens for pen shells, but the difference is that this has been ensuing for a long time and has not allowed the development of cultures over time (except Seri people). There has been good progress in aquaculture for scallop species, but studies must be reinforced to overcome the problems encountered. There are notable advances with the black venus and geoduck clams that indicate that consolidation of their cultures is advised in the short or medium term.

The study of bivalves must be implemented, at least gradually, in some of the institutions located on the Pacific coast and the Atlantic coast of the country to develop sustainable forms of production. Although some efforts have been made to support the cultivation of the eastern oyster *C. virginica* in the Gulf of Mexico (different forms of spat collection, establishment of a commercial hatchery, and culture of "loose" spat), production continues decreasing. It is necessary to persist in innovating and implementing new management forms until sustainable cultivations are created that stabilize production.

In terms of production, Mexico has a modest production of bivalves that has a lot of room to develop. Still, the activity needs to advance in management, organize producers, increase technical innovation, and advance commercial efficiency. Readers can use a supplementary document presenting a list of all the studies in this review (available on request), organized by species and year of publication (List-articles-theses-by-species.pdf).

Credit author contribution

J. Chávez-Villalba: conceptualization, methodology, original draft, and final version; E. Alcántara-Razo: conceptualization, database creation, and review. All authors contributed to the study conception and design, commented on previous versions, and read and approved the final manuscript.

Conflict of interest

The authors have no relevant financial or non-financial interests to disclose and declare no potential conflict of interest in this manuscript.

Funding

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

ACKNOWLEDGMENTS

The support of the CIBNOR library in obtaining some of the articles is appreciated.

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Received: July 15, 2024; Accepted: September 12, 2024