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Review

Rock oyster *Striostrea prismatica* (Gray, 1825): biology, exploitation and conservation

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ABSTRACT. Oyster or rock oyster (*Striostrea prismatica*) is a bivalve mollusk highly appreciated among traditional seafood in several Latin American countries. Uncontrolled capture and lack of techniques for its culture, threaten their growth and conservation, as a decrease in its population has been reported. This review highlights critical aspects of its biology, ecology, catching activity and potential use in aquaculture. Its presence is registered as a fossil, and its identification is crucial because of its similarity to other species of ostreids. The population structure and its abundance in natural banks are associated with depth, substrate, dynamics of exposure and local environmental conditions. The reproductive activity and gametogenesis vary from an annual increase to continuous reproduction related to its location latitude. The size at first maturity is similar in both sexes and achieves about nine cm in less than a year. In culture experiments, diets in breeding stocks have been studied, resulting in trochophore larvae and "D" larvae, at 12 and 24 h after fertilization. Shell fixation has been achieved in natural collectors, but their culture has not been developed yet. The species is used as an indicator of pollution, associated with microalgae causing harmful outcrops. There are no precise records of its catch, as it is reported in combination with other ostreids species. For its conservation and sustainable exploitation, it is necessary to increase research on its biology to implement management programs and developing culture techniques.

Keywords: *Striostrea prismatica***,** oyster, ecology, fisheries, taxonomy, fossil record, genetics, aquaculture.

INTRODUCTION

Striostrea prismatica (Gray, 1825) is a bivalve mollusk that inhabits the rocky coastline of the intertidal area to the shallow sub-littoral zone, no more than ten meters deep. As a sessile organism, it feds on phytoplankton and suspended organic matter. Its geographical distribution from north to south extends from Magdalena Bay, Baja California Sur (24.2°N) and Mazatlán, Sinaloa (23.2°N) in México to Máncora, Tumbes, Peru (4.1°S) (Keen, 1971; FAO, 1995; Coan & Valentich, 2012; Raith *et al*., 2015).

The study of species represents excellent challenges due to aspects of biological, environment, and social nature such as 1) the environmental conditions of its habitat, which limit the sampling continuity necessary for performing ecologic and physiological studies, 2) phenotypic plasticity, which has been related to the extreme conditions of the habitat, 3) the processes of speciation and hybridization, due to their wide geographic distribution (Rodríguez-Romero & Gasca-Montes de Oca, 2013), which causes confusion in their determination in the field; 4) the underestimation of fishery production, which has led to the species being of little economic interest in some regions where distributed.

This work presents a review of the *Striostrea prismatica* rock oyster to generate and analyze relevant information contributing to know the gaps of knowledge required to undertake future research.

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STATE OF THE ART

Based on the analysis of the information presented in this research document, the bibliographical material collected in Scopus, Redalyc, ScienceDirect and Scielo databases were searched, among others. Besides, information from various Universities virtual libraries was also collected; once all data was managed, it was segregated in those of printed indexed magazines and gray literature (free thesis, congresses summaries, technical reports) then, classified according to the area of knowledge and by year of publication.

The existing information on *Striostrea prismatica* is scarce, unlike other ostreids of commercial interest located in the same geographic distribution. It is also vague due to the wide range of names it has been recognized, thus the revision of documents counted from 1933, year in which the first study known as *Ostrea prismatica* is found, until 2016. Seventy-one documents refer to the species and its synonyms, out of which the literary production in indexed magazines represents 59%; followed by technical reports, theses, congress memoirs and books (10, 9, 7 and 6%, respectively), publications in popular articles and non-indexed magazines represent 3% each; manuals 2% and management plans 1%, which denotes a large proportion of the documents deemed as gray literature.

By area of knowledge, it is observed that most of the efforts are focused on three main areas: ecology, toxicology, and reproductive biology, although for the first one, the trend is to reinforce the presence of the species in areas within the distribution range; while toxicology and reproductive biology are highly addressed given the fact that due to its type of feed, it acts as a bio-indicator of pollution. Other areas where a higher research production can be observed are the taxonomy, fisheries, and aquaculture (Table 1).

Although this resource has always been of commercial importance, less attention has been paid to this particular species, and it is observed that for 60 years (1929-1989) the information generated is limited (10 documents). However, a significant increase was observed in the last three decades in which 61 publications were produced. This research document analyzes the information retrieved and classified by area of knowledge, current taxonomic location, phylogeny and systematics, archeology, fossil record, findings in the ecology of the species, reproductive biology, toxicology and pollution, as well as the analysis of the catching situation in its distribution area and the progress in the development of the culture technology of the species.

TAXONOMIC CLASSIFICATION

Since its first record as *Ostrea rufa* (Lamarck, 1819) the rock oyster currently recognized as *Striostrea prismatica* has undergone several changes within the Order Ostreoida, which ranges from movements at the sub-family level as well as to generic and specific (Chiplonkar & Badve, 1979; Raith *et al.*, 2015).

The rock oyster is known with the following names; *Ostrea prismatica* Gray, 1825, *Ostrea iridescens* Hanley, 1854, *Crassostrea iridescens* (Hanley, 1854), *Ostrea panamensis* Carpenter, 1864, *Ostrea spathulata* Sowerby, 1871, *Ostrea turturina* Rochebrune, 1895, and *Ostrea lucasiana*, Rochebrune, 1895.

Coan & Valentich (2012) divide the Ostreoidea subfamily into two families: Ostreidae and Gryphaeydae, and therefore reclassifying the *Crassostrea iridescens* by changing the gender and the species to *Striostrea prismatica* due to the presence of chomata, (tooth-like structure inside the shell located close to the hinge) which is not present in recent taxa of the *Crassostrea* gender. Likewise, this was supported in Skoglund´s work (2001). Finally, the current taxonomic classification is as follows:

Kingdom: Animalia
Phylum: Mollusca
Class: Bivalvia
Sub-Class: Pteriomorphia
Order: Ostreida
Superfamily: Ostreoidea
Family: Ostreidae
Subfamily: Striostreinae
Gender: *Striostrea*
Scientific name:
Striostrea prismatica (Hanley, 1854);

Common name: stone oyster, milk oyster, rock oyster.

PHYLOGENY AND SYSTEMATICS

The increasing trend to perform studies on phylogeny and systematics, some exercises have been carried out for ostreids including *S. prismatica*, where it has been confirmed that it does not belong to the *Crassostrea* gender; although according to Castillo-Rodríguez *et al.* (1984), based on morphological characters, it is close to *Crassostrea gigas*.

Raith *et al.* (2015) and Mazón-Suástegui *et al.* (2016), in their phylogeny, works with specimens collected in Magdalena Bay B.C.S. and Mazatlán, compared this species to other ostreid species distributed in the region. They used markers such as COI and CIII; ITs,-1 rDNA 28s, confirming the change

Table 1. Publications year, author, area of knowledge, link and document type relate to *Striostrea prismatica*.

Year	Author	Area of knowledge	Link	Document type
2006	Hernández *et al.*	Aquaculture	http://repositorio.uca.edu.ni/1459/1/2006_prog_investigaci%C3%B3n_cultivo_de_moluscos.pdf	Technical report
2011	Marín	Aquaculture	http://www.dspace.espol.edu.ec/xmlui/handle/123456789/16066	Thesis
2012	Guerra-Lima &Vergara-López	Aquaculture	http://www.oceandocs.org/handle/1834/8123	Manual
2013	Argüello-Guevara *et al.*	Aquaculture	http://www.bioone.org/doi/full/10.2983/035.032.0306	Scientific article
2012	Loor	Aquaculture	https://www.researchgate.net/publication/266201014_Influencia_de_dietas_microalgales_sobre_la_tasa_de_ingestion_y_crecimiento_en_juveniles_de_la_ostra_de_roca	Scientific article
1933	Nomland	Archeology	http://www.jstor.org/stable/661940	Scientific article
2013	Laylander *et al.*	Archeology	https://www.academia.edu/27223518/Clues_to_Baja_California_s_Prehistory_from_Marine_Shell	Scientific article
1964	Ramírez & Sevilla	Reproductive biology		Scientific article
1979	Cuevas- Guevara & Martínez-Guerrero	Reproductive biology	http://biblioweb.tic.unam.mx/cienciasdelmar/centro/1979-2/articulo73.html	Scientific article
1974	Ruiz-Durá	Reproductive biology	http://agris.fao.org/agris-search/search.do?recordID=FD7500454	Memories of congress
1992	Fournier	Reproductive biology	http://www.sciencedirect.com/science/article/pii/004484869290039N	Scientific article
1993	Páez-Ozuna *et al.*	Reproductive biology	http://www.sciencedirect.com/science/article/pii/0022098193901258	Scientific article
1997	Frías-Espericueta *et al.*	Reproductive biology	http://biblat.unam.mx/es/revista/revista-de-biologia-tropical/articulo/seasonal-changes-in-the-gonadal-state-of-the-oysters-crassostrea-iridescens-and-crassostrea-corteziensis-filibranchia-ostreidae-in-the-northwest-coast-of-mexico	Scientific article
2008	Liévano-Méndez	Reproductive biology	http://bibliotecavirtual.dgb.umich.mx:8083/jspui/handle/123456789/4706	Thesis
2016	Loor & Sonnenholzner	Reproductive biology	http://onlinelibrary.wiley.com/doi/10.1111/are.12601/full	Disclosure article
2015	Meléndez-Galicia *et al.*	Reproductive biology	http://www.inapesca.gob.mx/portal/documentos/publicaciones/cienciapesquera/CP23/3-Melendez-et-al.-2015-Ciencia-Pesquera.pdf	Non-indexed magazine
2006	Ríos-Jara *et al.*	Ecology	ISBN: 9688006955 9789688006955	Book
2012	Cortes *et al.*	Ecology	http://revistas.ucr.ac.cr/index.php/rbt/article/view/19962/20155	Scientific article
1974	Staurdo-Martínez & Martínez	Ecology	http://www.redalyc.org/pdf/480/48028201.pdf	Scientific article
1989	Campos & Fournier	Ecology	http://revistas.ucr.ac.cr/index.php/rbt/article/view/25382	Scientific article
1995	FAO	Ecology	http://www.fao.org/docrep/010/t0851s/t0851s00.htm	Book
2002	Melchor-Aragón *et al.*	Ecology	http://www.redalyc.org/html/480/48028201/	Scientific article
2003	CONANP	Ecology	http://www.conanp.gob.mx/que_hacemos/pdf/programas_manejo/huatulco.pdf	Management plan
2007	Ramírez-Benítez	Ecology	http://203.140.31.70/project/elsalvador/2271029E1/materials/pdf/2007/2007_06.pdf	Technical report
2007	Trejos-Castillo *et al.*	Ecology	http://www.oceandocs.org/handle/1834/8022	Technical report
2007	Landa-Jaime.*et al.*	Ecology	https://es.scribd.com/doc/230089270/Estudios-Sobre-La-Malacologia-y-Conquiliologia-en-Mexico	Memories of congress
2008	Avilés *et al*.	Ecology	http://www.oceandocs.org/handle/1834/8114	Scientific article
2008	Ordinola *et al.*	Ecology	http://www.imarpe.pe/imarpe/archivos/informes/imarpe_9)_informe_estudio_cuatro_invertebrados_2007_web.pdf	Technical report
2008	Ríos-Jara *et al.*	Ecology	https://www.academia.edu/24072099/Bivalvos_y_gaster%C3%B3podos_Mollusca_de_importancia_comercial_y_potencial_de_las_costas_de_Chiapas_y_Oaxaca_M%C3%A9xico	Scientific article
2010	Ordinola *et al.*	Ecology	http://biblioimarpe.imarpe.gob.pe:8080/handle/123456789/2016	Scientific article
2012	Torreblanca-Ramírez *et al.*	Ecology	http://www.scielo.cl/scielo.php?script=sci_arttext&pid=S0718-19572012000200010	Scientific article
2016	García-Delgado & Leones-Zambrano *et al.*	Ecology	http://repositorio.utm.edu.ec/handle/123456789/33	Thesis
2013	Bastida-Zavala *et al*.	Ecology	http://www.mdpi.com/1660-3397/8/6/1935/htm	Scientific article
2013	Penganos-García *et al*.	Ecology	http://cuid.unicach.mx/revistas/index.php/lacandonia/article/view/458	Scientific article
2013	González-Pazmiño	Ecology	https://www.academia.edu/8274272/Estudio_de_epibiontes_de_Crassostrea_iridescens	Memories of congress
2014	Ezqueda-González *et al*.	Ecology	http://zookeys.pensoft.net/articles.php?id=3697	Scientific article

Continuation

Year	Author	Area of knowledge	Link	Document type
2014	Barraza	Ecology	http://www.ots.ac.cr/rbt/attachments/suppls/sup52-1%20ANCA /01-BARRAZA-Red.pdf	Technical report
2003	Rodríguez-Romero & Montes de Oca	Genetics	https://books.google.com.mx/books?id=DpFrVdvCg34C&pg=PA363&lpg=PA363&dq=La+especiaci%C3%B3n+en+ostiones+del+genero+Crassostrea+de+M%C3%A9xico+y+su+explotaci%C3%B3n.&source=bl&ots=dOH8fXvq0Z&sig=_lBs5uzaOb83sX7fNj_2ZWPM7UI&hl=es&sa=X&ved=0ahUKEwiagIOxzpTQAhXFzVQKHRbADR8Q6AEIHDAA#v=onepage&q=La%20especiaci%C3%B3n%20en%20ostiones%20del%20genero%20Crassostrea%20de%20M%C3%A9xico%20y%20su%20explotaci%C3%B3n.&f=false	Scientific article
2015	Raith *et al.*	Genetics	http://www.bioone.org/doi/full/10.4003/006.033.0206	Scientific article
2016	Mazón-Saustegui *et al.*	Genetics	http://www.sciencedirect.com/science/article/pii/S0956713516300524	Scientific article
1959	Hertlein & Emerson	Paleobiology	http://digitallibrary.amnh.org/bitstream/handle/2246/5285/N1940.pdf?sequence=1	Scientific article
2005	MARENA	Fishery	http://legislacion.asamblea.gob.ni/Normaweb.nsf/($All)/F4BE0B24346DC860062574DB00778A6E?OpenDocument	Technical rules
2006	Patiño-Valencia *et al.*	Fishery	http://www.inapesca.gob.mx/portal/documentos/publicaciones/15III%20foro%20pesca%20riberena2006.pdf	Memories of Congress
2007	Ramírez-Benítez	Fishery	https://www.jica.go.jp/project/elsalvador/2271029E1/materials/pdf/2007/2007_06.pdf	Technical report
2008	Patiño-Valencia & Ulloa	Fishery	http://www.inapesca.gob.mx/portal/documentos/publicaciones/16%20memoria+IV+foro+pesca+ribere%C3%B1a-2008.pdf	Memories of Congress
2013	Hernández-Covarrubias *et al.*	Fishery	http://www.inapesca.gob.mx/portal/documentos/publicaciones/REVISTA/Mayo2014/5-Hernandez-et-al-2014.pdf	Non-indexed magazine
2014	Gonzabay-Rodríguez	Fishery	http://repositorio.ug.edu.ec/bitstream/redug/6087/1/TESIS,%20Carlos%20Gonzabay.pdf	Thesis
2016	Castro-Mondragón *et al.*	Fishery	http://www.redalyc.org/html/416/41649084004/	Scientific article
1971	Keen	Taxonomy	ISBN-10: 0804707367/ISBN-13: 978-0804707367	Book
1979	Chiponkar *et al.*	Taxonomy	http://link.springer.com/article/10.1007/BF03179125	Scientific article
1984	Castillo-Rodríguez *et al.*	Taxonomy	http://biblioweb.tic.unam.mx/cienciasdelmar/instituto/1986-2/articulo 230.html	Scientific article
2001	Skoglund	Taxonomy		Scientific article
2007	Álvarez-Romo *et al.*	Taxonomy	http://www.ibiologia.unam.mx/barra/congresos/pdf/malacologia/molus_islas_navachi.pdf	Scientific article
2012	Cortes *et al.*	Taxonomy	http://revistas.ucr.ac.cr/index.php/rbt/article/view/19962/20155	Scientific article
2012	Coan & Valentich	Taxonomy	ISBN (13) 978-0-936494-43-2	book
1983	De la Garza-Aguilar	Taxonomy	http://saludpublica.mx/index.php/spm/article/viewFile/635/622	Scientific article
1989	Michel & Zengel	Toxicology	http://cat.inist.fr/?aModele=afficheN&cpsidt=2297224	Scientific article
1989	Rosales-Loessener	Toxicology	https://www.researchgate.net/publication/20838883_Lethal_Paralytic_Shellfish_Poisoning_in_Guatemala	Scientific article
1990	Rodríguez *et al.*	Toxicology	http://www.ajtmh.org/content/journals/10.4269/ajtmh.1990.42.267	Scientific article
1991	Saldate-Castañeda *et al.*	Toxicology	http://www.redalyc.org/pdf/106/10633306.pdf	Scientific article
1993	Guerrero-Carbajal	Toxicology	http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/25/016/25016930.pdf	Thesis
1995	Páez-Ozuna *et al.*	Toxicology	http://www.sciencedirect.com/science/article/pii/0022098193901258	Scientific article
1997	Frías-Espericueta *et al.*	Toxicology	http://biblat.unam.mx/es/revista/revista-de-biologia-tropical/articulo/seasonal-changes-in-the-gonadal-state-of-the-oysters-crassostrea-irides cens-and-crassostrea-corteziensis-filibranchia-ostreidae-in-the-north west-coast-of-mexico	Scientific article
1990	Páez-Osuna & Marmolejo-Rivas	Toxicology	https://link.springer.com/article/10.1007%2FBF01702372?LI=true	Scientific article
1999a	Frías-Espericueta *et al.*	Toxicology	http://www.scielo.sa.cr/scielo.php?script=sci_arttext&pid=S0034-77441999000400021	Scientific article
1999b	Frías-Espericueta *et al.*	Toxicology	http://link.springer.com/article/10.1007/s001289900950	Scientific article
1999	Ramirez-Camarena *et al.*	Toxicology	http://www.ots.ac.cr/rbt/attachments/suppls/sup47-1/10_Ramirez_Dino-flagelados.pdf	Scientific article
2001	Soto-Jiménez *et al.*	Toxicology	Selected trace metals in oysters (*Crassostrea iridescens*) and sediments from the discharge zone of the submarines sewage outfall in Mazatlán bay (southeast Gulf of California): chemical fractions and bioaccumulation factors.	Scientific article
2002	Botello *et al.*	Toxicology	https://link.springer.com/article/10.1007%2Fs00128-002-0088-4?LI= true	Scientific article

Continuation

Year	Author	Area of knowledge	Link	Document type
2004	Barraza *et al*.	Toxicology	http://www.scielo.sa.cr/scielo.php?script=sci_arttext&pid=S0034-7744 2004000500003	Scientific article
2004	Gárate-Lizarraga *et al*.	Toxicology	http://www.sciencedirect.com/science/article/pii/S0025326X03005344?via%3Dihub	Scientific article
2004	Sierra-Beltrán *et al*.	Toxicology	http://www.scielo.sa.cr/scielo.php?script=sci_arttext&pid=S0034-7744 2004000500013	Scientific article
2006	Hernández-Orozco *et al*.	Toxicology	http://www.medigraphic.com/pdfs/revbio/bio-2006/bio061g.pdf	Scientific article
2007	Baqueiro-Cárdenas *et al*.	Toxicology	http://www.scielo.org.mx/pdf/rmbiodiv/v78soct/v78socta1.pdf	Review
2007	Hernández-Becerril *et al*.	Toxicology	http://www.tandfonline.com/doi/abs/10.1080/10934520701480219	Scientific article
2008	Herrera-Sepulveda *et al*.	Toxicology	http://www.smbb.com.mx/revista/Revista_2008_1/Floraciones_algales.pdf	Scientific article
2009	Arellano-Camacho	Toxicology	http://132.248.9.195/ptd2009/febrero/0640047/Index.html	Thesis
2010	Band-Schmidt *et al*.	Toxicology	http://www.mdpi.com/1660-3397/8/6/1935/pdf	Scientific article
2011	Band-Schmidt *et al*.	Toxicology	http://www.scielo.org.mx/pdf/hbio/v21n3/v21n3a13.pdf	Scientific article
2011	Páez-Osuna & Osuna-Martínez	Toxicology	http://www.scielo.org.mx/pdf/hbio/v21n3/v21n3a2.pdf	Review
2012	Vargas-Montero *et al*.	Toxicology	http://www.redalyc.org/pdf/578/57809804.pdf	Scientific article
2013	Gárate-Lizarraga *et al*.	Toxicology	https://issuu.com/cicimaroceanides/docs/cicimar_oceanides_28_1_2013_issuu	Scientific article
2015	Alonso-Rodríguez *et al*.	Toxicology	http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S0036-363 42015000400013	Scientific article
2006	Hernández-Orozco *et al*.	Toxicology	http://www.medigraphic.com/pdfs/revbio/bio-2006/bio061g.pdf	Scientific article

of classification providing that *S. prismatica* belongs to a clade other than *Crassostrea*, instead classifying it in a group close to the *Saccostrea* gender. Mazón-Suástegui *et al*. (2016), suggested a greater closeness between *S. prismatica* and *Saccostrea palmula* relative to other species of the family. Furthermore, they suggest that the low genetic divergence observed between both oysters could be due to short histories of reproductive isolation or even the introgression of mitochondrial DNA from one species to another, suggesting that the sample of *S. prismatica* could be a hybrid of *S. palmula* and that the mitochondrial genome could derive from a mother of *S. palmula*

On the other hand, Raith *et al*. (2015) indicate the need for further studies on the species and the other four species recognized within the gender, to determine whether or not they are a monophyletic group.

FOSSIL RECORDS AND ARCHEOLOGY

Calcareous nature of bivalve mollusks such as *S. prismatica* has allowed them to transcend in time, registering a comprehensive fossil record. For ostreids, the earliest records date from the Middle Jurassic (Nikolaus, 2000). However, some authors have established that its origin can be dated from the Triassic (Hautmann, 2001). *S. prismatica* has been reported in Pliocene and Pleistocene reservoirs (Hertlein & Emerson, 1959), at Islas Marías, México.

This same nature has allowed determining the presence of *S. prismatica* in shell deposits of a couple of areas along their area of distribution; one of them is the Baja California Peninsula in Mexico, where shell deposits have been located close to the coast as well as far from it, and where this species has been recorded (Laylander *et al*., 2013). Venezuela is another area where this species has been registered, in a burial where urns with different contents were located, the shells of *S. prismatica* (Nomland, 1933) among them. This report is controversial since the presence of *S. prismatica* has not been reported in the Caribbean. However, it is not excluded that they may have reached to these locations due to commerce or the migration of settlers of that time or otherwise, the weatherization of the relict did not allow adequate identification.

ECOLOGY

Distribution and abundance in the tropical eastern Pacific

Rock oyster has been reported from Peru (Ordinola *et al*., 2010; Campos & Fournier, 1989) to the middle of the Gulf of California (CONANP, 2003; Flores-Rodríguez, 2004; Ríos-Jara *et al*., 2006, 2008; Álvarez-Romo *et al*., 2007; Landa-Jaime *et al*., 2007; Trejos-Castillo, 2007; Villegas-Maldonado *et al*., 2007; Avilés & Córdova, 2008; Castillo-Rodríguez, 2009; Cortés *et al*., 2012; Flores *et al*., 2012; Torreblanca-Ramírez, 2012; Bastida-Zavala *et al*., 2013; Barraza, 2014;

Esqueda *et al.*, 2014). Its range of distribution was expanded from the northern section to the Magdalena Bay, BCS México (Raith *et al.,* 2015).

Abundance in banks

In the Mexican Pacific coast, the conservation state of the oyster banks is unknown. However, in other latitudes where its economic importance is higher such as in Peru, densities of 0.2 ind m^{-2} have been reported with stratified size distribution according to depth, finding the smallest organisms in shallow areas and the largest ones in deep areas (Ordinola *et al.*, 2010). On the other hand, in Costa Rica, densities range up to 176 ind m^{-2} (Campos & Fournier, 1989). Gonzabay-Rodríguez (2014) reported densities that range from 0.22 to 1.63 ind m^{-2} in Ecuador (Table 2).

Population structure

In the size structure analysis of *S. prismatica* in Michoacán, México, from small-scale artisan fishing, six age groups were introduced with maximum sizes of 161 mm and minimum sizes of 47 mm of total height (Liévano-Méndez, 2008).

In Central America locations, such as El Salvador, the population structure of the most exploited banks has been analyzed, finding a size structure ranging from 40 to 120 mm in total length (Ramírez-Benítez, 2007). According to this author, there is a trend to size stratification regarding depth, also related to the degree of exploitation, highlighting the fact that banks with better access conditions have small organisms in shallow areas and large organisms are found in greater depths. In Ecuador, size groups of 80-120 and 120-160 mm of total height have been reported in dry season (August-October), and smaller sizes recorded in the rainy season (Gonzabay-Rodríguez, 2014) (Table 2).

In Table 2 it can be observed that the country that records the largest size is Peru with 228 mm whereas the smallest size is reported in Costa Rica with 20 mm in total height.

Growth and mortality

Regarding the growth of *S. prismatica* (Melchor-Aragón *et al.*, 2002) states that in the Gulf of California, Mexico, the growth parameters $L\infty$, K and t_0 differ in two different seasons (winter-spring and fall-summer), which is attributed to contrast in the availability of food and temperature. Likewise, the natural mortality rate is found in 2.2 ind yr^{-1}. García-Delgado & Leones-Zambrano (2016), report the following growth parameters in Ecuador: $L_\infty = 168.0$ mm; $K = 1.11\ yr^{-1}$; $t_0 = -0.089$ in Punta Napo-San Vicente, the total mortality rate of rock oyster *S. prismatica* was $Z = 2.85 \pm 0.21\ yr^{-1}$), natural mortality rate was $M = 1.15$; catching mortality $F = 1.70$, and exploitation rate $E = 0.60$. At Punta Gorda-Sucre site, higher mortality values were observed; $Z = 5.80 \pm 0.43\ yr^{-1}$; $M = 1.97$; $F = 3.83$, and $E = 0.66$ (Table 3).

Reproductive biology

There are several research works on the reproduction cycle of *S. prismatica* in México, showing variations according to the geographic location of the populations studied (Table 4). The first ones go back to 1964 when Ramírez & Sevilla (1964) studied the species in the coastal line of Guerrero, and they reported spawning from June to August. Later in Oaxaca, undifferentiated organisms were found in January-February, mature organisms in February-April and spawning from April to August with two peaks (Ruiz-Durá, 1974). In the coast of Nayarit, males were observed in maturity from October to November (Stuardo & Martínez-Guerrero, 1975) and afterwards in this same region Cuevas-Guevara & Martínez-Guerrero (1979) described the reproduction cycle of the species by pointing out that gametogenesis occurred from February to June, maturation from June to August and spawning in August and September. These authors state that temperature changes rather than salinity influenced the cycle, but they do not mention the corresponding values. Another study in Nayarit, but based on a gonadic index, showed some differences about the previous results: shorter gametogenesis and maturation periods during February and May and spawning occurred between May and June when the temperature was higher (29°C). However, it had not reached the maximum temperature (Frías-Espiricueta *et al.*, 1997). Páez-Osuna *et al.* (1993) relied on previous studies in order to describe the reproduction cycle of the species in Sinaloa; they reported that the resting stage took place from October to March, gametogenesis in April-May, maturation from June-July and spawning in August-September, were associated with the highest temperatures of the year (29-34°C). On the other hand Meléndez-Galicia *et al.* (2015) while studying populations in Michoacán reported gametogenesis in May and June, maturity in August, spawning in August-September, post-spawning in September-December and resting in February-June and December (Table 4). There are other contributions on the topic, such as the one presented by Frías-Espiricueta *et al.* (1994) who reported bio-accumulation of lead and its relation with the reproduction cycle in Nayarit. Likewise, Liévano-Méndez (2008) showed results on a gonadosomatic index in populations at Michoacán, but only in five months of the year: from September to November and February and March.

Table 2. The number of individuals, shell height, and relative density of the *Striostrea prismatica* oyster recorded in tropical eastern Pacific. *Class ranges (0-40, 40-80, 80-120 and >120 mm) and sampling sites. **Average of June and January 2007.

Country/Region	Location	Height (mm)						Density (ind m^{-2})	Reference
		n	min	max	average	SD	Mode		
Costa Rica - Curú Bay	North	107			84.5	19.9	81	176	Campos & Fournier (1989)
	South	89			69.5	26.9	63		
El Salvador								0.05-2.8*	Ramírez-Benítez *et al.* (2007)
México	Michoacán	164	49	149	88.8				Liévano-Méndez (2008)
México	Acapulco, Guerrero	168	22.90	127.1	57.21	27.72			Castro-Mondragón *et al.* (2016)
Perú-Tumbes	North	55	22	202	122.2	42.9	134		Ordinola *et al.* (2010)
	Center	64	11	200	106.6	52.5	116		
	South	193	11	228	125.3	38.6			
Perú	Tumbes	5056	7	228	107-136**			0.2	Ordinola *et al.* (2013)
	Angahuel	35	45	86	63.45	11.7	75	0.2	Gonzabay-Rodríguez (2014)
Ecuador	La Leona	636	73	139	99.58	19.5	122	1.5	
	Cabuya	266	63	148	99.23	14.81	96	0.6	
	La Loca	63	60	117	91.06	12.7	83	0.4	
Ecuador	San Vicente	362	32.5	160	79.88	23.14			García-Delgado & Leones-Zambrano (2016)
	Punta Sucre	546	36	178	93.36	24.09			
Perú-Tumbes	Intertidal	44	3	65	11.9				Alemán *et al.* (2016)
	Subtidal	359	25	210	92.4				

In other latitudes, Fournier (1992) studied the reproductive cycle of *S. prismatica* in Costa Rica, and unlike the previous studies, he found that the species reproduces continuously during the year without a resting period (Table 4). In this study it was observed that between 50-90% of the organisms spawned during nine months (July-March) of the 14 months of sampling; spawning occurred at the beginning of the rainy season, and it coincided with a decrease of salinity (32-29). Further south in Ecuador, Loor & Sonnenholzner (2016) studied the reproduction process in two different populations, and they discovered a resting stage from June to September, gametogenesis from October to December, maturation in January-February and spawning from March to June (Table 4). However, the spawning was not complete, and the gametes were reabsorbed within the gonad. The authors report that the cycle was influenced by temperature and salinity; particularly maturation and spawning were associated with the highest temperature values and a reduction in salinity.

Previous research studies observed that temperature mainly influences the reproduction cycle of the species and the period with the highest reproductive activity occurs with maximum temperature values. However, salinity variations also seem to affect reproduction, mainly on spawning. The preceding occurs in populations located in places where there is a significant freshwater input either through rainfall or runoff. Feed influence in reproduction is not clearly defined, but Páez-Osuna *et al.* (1993) define *S. prismatica* as a conservative organism since it accumulates reserves during winter, which seem to be used in spring during the gametogenesis and maturation periods.

Cuevas-Guevara & Martínez-Guerrero (1979) research in Nayarit (México) found 22.9% females, 29.4% males and 44.7% undifferentiated organisms. The sex ratio varied throughout the year; undifferentiated organisms prevailed during the resting stage (October to February), females appeared from February and became more numerous during maturation and spawning. Males were present during most of the year, and their proportion increased during the reproduction season. Sex ratio was 1.13:1 (males: females) and no hermaphrodite organisms were observed (Table 5). Further south in Michoacán, similar values were found concerning the sex ratio with 24% females, 31% males and 43% undifferentiated organisms, as well as a ratio of 1:3:1 males: females (Meléndez-Galicia *et al.*, 2015). The only difference was that in this study, 2% of hermaphrodites were observed, which coincides with Fournier (1992) report for Costa Rica population. Likewise in Ecuador, there

Table 3. Von Bertalanffy equation growth parameters and mortality of *Striostrea prismatica* oyster in tropical eastern Pacific.

Parameter	Melchor-Aragón *et al.* (2002) México, Sinaloa		García-Delgado & Leones-Zambrano (2016) Ecuador		Ordinola *et al.* (2010) Peru
	March-April	September-October	Punta Napo-San Vicente	Punta Gorda-Sucre	Tumbes
n	22	16	362	546	312
L_∞ (mm)	134.0	155.0	168.00	199.50	
K (yr^{-1})	0.069	0.098	1.11	1.91	
t_o	-0.660	-0.399	-0.089	-0.048	
$Wt = \alpha * Ht^{\beta}$	$(6.29^{*}10^{-}3)\ Ht^{2.18}$	$(1.11^{*}10^{-3})\ Ht^{2.16}$	$Wt = 0.0003\ Ht^{2.87}$	$Wt = 0.0004\ Ht^{2.80}$	$Wt = 0.0008\ Ht^{3.17}$
Z	0.12	0.30	2.85 ± 0.21	5.80 ± 0.43	

Table 4. Phases of reproduction of *Striostrea prismatica* observed in a latitudinal gradient from north to south in tropical eastern Pacific. *México. **Considering environmental conditions in the southern hemisphere.

Place/Month	J	F	M	A	M	J	J	A	S	O	N	D	Reference
Sinaloa*	Rest	Rest	Rest	Gametogenic	Gametogenic	Mature	Mature	Spawning	Spawning	Rest	Rest	Rest	Páez-Osuna *et al.* (1993)
Nayarit*		Gametogenic	Gametogenic	Gametogenic	Gametogenic	Mature	Mature	Spawning	Spawning				Cuevas-Guevara & Martínez-Guerrero (1979)
Michoacán*	Rest	Rest	Rest	Rest	Gametogenic	Gametogenic	Mature	Mature	Rest				Meléndez-Galicia *et al.* (2015)
Guerrero*						Spawning	Spawning	Spawning					Ramírez & Sevilla (1964)
Oaxaca*	Rest	Gam.	Mat.	Spawning	Spawning	Spawning	Spawning						Ruiz-Durá (1974)
Costa Rica	Spawning	Spawning	Spawning				Spawning	Spawning	Spawning	Spawning	Spawning	Spawning	Fournier (1992)
Ecuador**	Mature	Mature	Spawning	Spawning	Spawning	Rest	Rest	Rest	Gametogenic	Gametogenic	Gametogenic	Gametogenic	Loor & Sonnenholzner (2016)

were similar trends regarding sex ratio, with values between 22.8-34.4% for females, 28.3-28.9% for males and 36.7-48.9% for undifferentiated organisms (Loor & Sonnenholzner, 2016). Only in Costa Rica a higher amount of males (66.4%) and fewer undifferentiated organisms (12%) were detected. However, a female ratio (21.6%) similar to the one from the previous studies was observed (Fournier, 1992) (Table 5). This author discovered organisms in various reproductive stages in all months. However, there was a higher female ratio during the maturation stage as well as more females in the large class sizes.

The trend observed in the previous studies on a higher ratio of males than females in *S. prismatica* during the year could be an indication that the species has a functional protandry behavior. This feature has been observed in species where males prevail; young organisms mature first as males, and the trend is kept during the adult stage (Zaidman *et al.*, 2012). On the other hand, the sizeable undifferentiated organism ratio observed could be related to the fact that females grow at the same ratio as males, but they mature at larger sizes. The preceding has been detected in organisms which growth ratio is slow and have high longevity such as geoduck clam *Panopea zelandica* (Gribben *et al.*, 2004). However, the stormy environmental conditions in Costa Rica seem to modify the previous pattern favoring males over undifferentiated species and facilitating the appearance of hermaphrodites (Fournier, 1992). This condition has been observed in populations that live in extreme or inappropriate conditions where males prevail, and hermaphrodites appear, representing a transition phase from male to female during the reproduction stage (Lango-Reynoso *et al.*, 2016).

Hernández-Covarrubias *et al.* (2013) used multimodal inference to calculate the average maturation size for *S. prismatica* in Nayarit. The best model for females was the one introduced by Brouwer & Griffiths (L_{50} = 91 mm of total height), and for males

Table 5. Sex ratio reported for *Striostrea prismatica* in tropical eastern Pacific. *Two different sites.

Sexual proportion (%)				Ratio Male: Female	Reference
Females	Males	Hermaphrodites	Undifferentiated		
22.9	29.4	-	44.7	1.13 : 1	Cuevas-Guevara & Martínez-Guerrero (1979)
21.6	66.4	2.0	12.0	3 : 1	Fournier (1992)
18.4	26.8	0.4	54.8	-	Hernández-Covarrubias *et al.* (2013)
22.8	28.3	-	36.7	1 : 1	Loor & Sonnenholzner (2014)*
34.4	28.9		48.9	1 : 1	
24.0	31.0	2.0	43.0	1.3 : 1	Meléndez-Galicia *et al.* (2015)

the one by Gompertz (L_{50} = 90 mm of total height), whose total length values match those recorded in the National Fisheries Chart of México. Likewise, Fournier (1992) found that the size in which maturation of gonads starts in the species is 15 mm in the total height of shell for both males and females.

The reports on reproduction for *S. prismatica* in controlled conditions are scarce. Recently, Argüello-Guevara *et al.* (2013) carried out a study on conditioning at two temperatures (22 and 28ºC) and spawning stimulation of breeders in the laboratory, finding a better response at 28°C, where most organisms reached maturity, 60% were female and 51.8% of them spawned. The best induction method for spawning was thermal shock accompanied by exposure of organisms to air (+5°C, 30 min of exposure, -5°C), obtaining 47.2 ± 32.1 million eggs and a fertilization percentage of 95.9 ± 1.4%. The authors described the embryonic development of the species obtaining trochophore larvae (size 58 ± 0.4 µm) between 10-12 h and larvae “D” (size 67.9 ± 2.3 µm) between 22-24 h after fertilization. The average size of the eggs was 46.9 ± 1.5 µm, which is similar to the one found by Loor & Sonnenholzner (2016), who measured fresh oocytes (48 ± 2.8 µm) and fresh hydrated oocytes (47 ± 1.2 µm). These authors found significant differences of the previous values concerning oocytes measured from histological sections (32.3 ± 1.9 µm), which is also lower than the one reported by Fournier (1992), of 42.5 ± 6.7 µm, calculated from histologically processed oocytes.

Toxicology

Environmental toxicology and rock oyster

Due to their great filtering ability for the exchange of gases (breathing) and feeding mechanism, bivalves have been used as indicators of habitat modification and contamination by toxins and chemical compounds contained in coastal waters where they live (Baqueiro-Cárdenas *et al*., 2007; Páez-Osuna & Osuna-Martínez, 2011). The species incorporate pollutants into their soft tissues, causing illness to consumers, even death, and this has become a relevant public health issue (De la Garza-Aguilar, 1983). Different authors have carried out review studies among the presence of pollutants of organic and inorganic origin and their effect on living organisms (Baqueiro-Cárdenas *et al*., 2007; Band-Schmidt *et al*., 2010; Páez-Osuna & Osuna-Martínez, 2011), mainly mollusks in aquatic atmospheres (freshwater, brackish and marine). Baqueiro *et al*. (2007) study is relevant since they suggest the use of species of this taxonomic group as sentinels and indicators of environmental quality of the ecosystems. Since the effect of the pollutants may lead to the disappearance of stenobiotic species, euribiotic species shall prevail, or due to their ability to accumulate pollutants when their concentrations do not reach doses that impact populations; either in bioaccumulation processes throughout the life cycle of the organism or by bio-magnification through trophic chains or the physiological changes produced by contamination. Mollusks response to contamination, relative to their mobility, to avoid an adverse condition (escape and attraction) such as some mussels when released from their byssus (anchor structure), in the presence of irritants or marine gastropods are attracted to areas with a high content of organic matter. High tolerance towards pollutants in which the presence of other taxonomic groups has decreased, mollusks and annelids are still present (*survival mechanism*). Direct and indirect physiologic changes caused by pollutants, induce *behavioral* responses such as spawning advancement in some bivalve mollusks. When pollutants do not interfere in vital processes or the concentrations are low enough to allow tolerance and acclimatization of the organisms, two phenomena are present: bioaccumulation and biomagnification. The first one, where the pollutants (heavy metals) are selectively taken or tolerated, but it is not transferred to its predator, whereas the latter is magnified in the following level (or predator). Pollutants may be incorporated to metabolic cycles, with adverse physiologic and morphologic effects in organisms (effects in metabolism). Due to mollusk’s tolerance and adaptability, mainly bivalves, their use as monitoring organisms for the presence of pollutants and environmental quality indicators in aquatic ecosystems is suggested.

Another review study is the one submitted by Páez-Osuna & Osuna-Martínez (2011), who summarized the information published between 1998 and 2010, on the use of bivalve mollusks in monitoring studies of marine environments in Mexico, among which species of the Mytilidae, Veneridae, Cyrenidae, Mactridae, and Ostreidae families are found. In case of the latter family, there is a higher number of species that have been used as bioindicator organisms of environmental quality. The authors suggest that the organisms used as bio-monitors must feature specific desirable characteristics, such as accumulating high levels of pollutants, having a sessile/sedentary life form or short migrations within the area of study, vast abundance, wide distribution (cosmopolitan), being long-lived, easy to sample, easy to transport and manipulate, show an excellent dose-response relationship, being available throughout the year, showing simple feeding habits, withstand a wide range of weather and environmental conditions, the species must be well-known at a taxonomic level. Additionally, there must be a good knowledge of feeding habits, life-spam history, breeding season, population structure.

Researchers suggest the use of bivalve mollusks due to their advantages compared to other taxonomic groups in aquatic atmosphere such as being abundant, long-lived, adequately-sized, resistant to field and laboratory study, sedentary, simple feeding habits and lifestyle, cosmopolitan species (*e.g.*, *Mytilus edulis*, *M. galloprovincialis*, and *Perna viridis*), tolerant to physical and chemical parameters fluctuations (*e.g.*, salinity and temperature), efficient accumulators of various pollutants, high accumulation of persistent organic pollutants (POPs: *e.g.*, aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex, toxaphene, polychlorinated biphenyls, dioxins, furans). Due to their feeding, they accumulate both pollutants dissolved in water as well as pollutants associated with suspended particles, and they show high pollutant bio-concentration factors and low organic pollutant metabolic capacity.

In this regard, some authors have carried out studies on toxins from "Harmful Algal Bloom" (HAB) in marine organisms and their effect on humans. Said bio-toxins can cause human poisoning, whose symptoms are neurological and gastrointestinal and their main effects are paralytic, amnesiac, diarrheic, and neurotoxic and ciguatera poisoning (Hernández-Orozco & Gárate-Lizárraga, 2006; Herrera-Sepúlveda *et al.*, 2008). The genera of dinoflagellates that produce paralytic poisoning are *Alexandrinum*, *Gymnodinium*, and *Pyrodinium* (Hernández-Becerril *et al.*, 2007; Alonso-Rodríguez *et al.*, 2015). Between 1940 and 2011, Band-Schmidt *et al.* (2010), analyzed information on ecologic and physiologic aspects of the algae *Gymnodinium catenatum* in the Mexican Pacific. They highlight the appearance frequency of the rock oyster, *Crassostrea iridescens* (*Ostrea iridescens*, *Saccostrea iridescens* and/or *Striostrea iridescens*), as a bioindicator organism of toxins produced by this algae In places from the north of Mazatlán and Mazatlán Bay (both in the coast of Sinaloa), Banderas Bay in the coast of Jalisco, Manzanillo Bay in Colima, and Acapulco Bay in the coast of Guerrero. Additional research studies that have also registered the presence and effects of toxins produced by "harmful algal blooms" (HAB) of *Gymnodinium catenatum*, *Gonayaulax monilata*, and *Pyrodinium bahamense* due to ingestion of rock oyster from the coast of the state of Sinaloa, mainly in Mazatlán Bay are those presented by De la Garza-Aguilar (1983), Mee *et al.* (1986), Cortés-Altamirano & Nuñez-Paten (1992), Ramírez-Camarena *et al.* (1999) and Gárate-Lizárraga *et al.* (2004).

As a result of the dinoflagellate *Pyrodinium bahamense* blooming, bio-toxins in rock oyster (*Ostrea iridescens* = *Striostrea prismatica*) are reported in the south, off the coast of Michoacán and Guerrero, between November 1995 and February 1996 (Hernández-Becerril *et al.*, 2007). Two more reports of Guerrero coast, presented by Cabrera & Mancilla *et al.* (2000), and recorded bio-toxins in rock oyster from harmful algal blooms of *Gymnodinium catenatum* in 2000 and *Pyrodinium bahamense* by Gárate-Lizárraga *et al.* (2013). For the coast of Oaxaca, the presence of toxins produced by algal blooming *Gymnodinium catenatum* and *Pyrodinium bahamense* is reported in rock oyster by Saldate-Castañea *et al.* (1991), Cortés-Altamirano *et al.* (1993) and Alonso-Rodríguez *et al.* (2015). In Central America there are studies that report Harmful Algal Blooming (HAB) (Rosales-Loessener *et al.*, 1989; Rodríguez *et al.*, 1990; Sierra-Beltrán *et al.*, 2004; Vargas-Montero *et al.*, 2008), but only on the coast of El Salvador, the presence and high levels of toxins concentration caused by HAB, are reported in rock oyster *S. prismatica* (Barraza *et al.*, 2004) (Table 6).

Typically, bivalve mollusks have been used as indicators of heavy metals pollution contained in waters of the coastal area where they live. This aspect is relevant for public health since this kind of pollutants is responsible for various serious diseases (Frías-Espericueta *et al.*, 1994). In this regard, studies have been carried out in the last decades using rock oyster (*Striostrea prismatica, Crassostrea iridescens, Ostrea iridescens*) as a sentinel species, in relation to the pre-

Table 6. Record of toxins in algae blooms and heavy metal in *Striostrea prismatica*.

Location	Species and/or abundance (cells L^{-1})	Toxicity (µg STX eq 100 g^{-1})	Heavy metals in mg g^{-1} (max-min)	Reference
Sinaloa, México	*Gonayaulax monilata*	4,500	Cd 1.63, Co 2.37, Cr 1.23, Cu 9.32, Ni 2.13, Pb 3.7, Zn 140.5	De la Garza-Aguilar (1983), Páez-Osuna & Marmolejo-Rivas (1990)
	Gymnodinium catenatum/ 10^{-12}			Mee *et al.* (1986)
	Gymnodinium catenatum 0.5 - 2×10^6			Cortés-Altamirano & Nuñez-Pasten (1992)
			Cd 2.4, Mn 10.8, Pb 3.1, Zn 443, Cu 24, Fe 34, Co (2-0.1), Cr (3.4-0.8), Zn (1294-97), Ni (4-0.8)	Frías-Espericueta *et al.* (1999a)
			Cd (3.3-2.2), Co (6.5-4.4), Cr (2.9-1.6), Cu (118-35.8), Fe (271-110), Mn (20.3-11.5), Ni (9.8-3.1) y Zn (822-639)	Frías-Espericueta *et al.*(1999b)
	Gymnodinium catenatum / 3856 - 5,000×10^3	2,951		Ramírez-Camarena *et al.* (1999)
			Cd 0.99, Cr 2.3, Cu 42.1, Fe 2560, Mn 18.8, Ni 5.41, Pb 2.3y Zn 1161	Soto-Jiménez *et al.* (2001)
	Gymnodinium catenatum 0.015×10^6	3,940		Gárate-Lizarraga *et al.* (2004)
			Pb (6.12-8.57)	Osuna-López *et al.* (2007)
			Hg (0.195 - 0.459) mg kg^{-1}	Arellano-Camacho (2009)
Nayarit,México			Pb (2.9 - 1.9)	Frías-Espericueta *et al.* (1994)
Colima, México			Cd (3.4-0.7), Cu (72.7-1.4), Fe (198-61), Mn (19.3-5), Ni (4.4-0.1) y Zn (1105-329)	Páez-Osuna *et al.* (1995)
			Fe (172-76), Ni (21-9), Cu (123-21), Zn (885-216)	Guerrero-Carbajal (1993)
Guerrero, México	*Gymndinium catenatum* / 7,600-37,600	120-209		Cabrera-Mancilla *et al.* (2000)
	Pyrodinium bahamense var. *compressus* 9000 - 198×10^3	46.24-788.85		Gárate-Lizárraga *et al.* (2013)
Oaxaca, México	*Gymnodinium catenatum*/ *Gonyaulax catenella* 0.01-1.7×10^6	3,000		Saldate-Castañeda *et al.* (1991)
	Pyrodinium bahamense var. *compressum* / 1.7×10^{-6}	115-811		Cortés-Altamirano *et al.* (1993)
	Pyrodinium bahamense 1000-32,500	3.8-1.2		Alonso-Rodríguez (2015)
	509.0-6229.2			Band-Schmidt *et al.* (2010)
El Salvador		400-3,977	Cd (nd), Cr 10-19, Cu 20-1300, Pb (nd), Ni 7-14, Zn 800-5200	Michel & Zengel (1998), Barraza *et al.* (2004)

sence and concentration of heavy metals such as lead (Pb) and mercury (Hg), among others in various tissues and organs, assessing its effect in the reproductive activity and growth (Guerrero-Carbajal, 1993, Frías-Espericueta *et al.*, 1994, 1999a; Páez-Osuna *et al.*, 1995; Soto-Jiménez *et al.*, 2001; Osuna-López *et al.*, 2007; Arellano-Camacho, 2009). These authors report concentrations of Pb contained in the specimens collected in Mazatlán Bay located within the detection limits and higher concentrations were obtained in November since the heaviest rainfall in the region takes place by the end of summer, which drags a higher amount of heavy metals from land to sea. They also point out that the accumulation occurs in the gonad, they attribute this to the incorporation of Pb by the organism as a necessary element for the reproductive cycle.

One of the first reports of the Mexican Pacific is the one presented by Páez-Osuna & Marmolejo-Rivas (1990). They assessed the presence and concentration of heavy metals in *Saccostrea iridescens* (*Strisotrea prismatica*), in various locations of the northwest coast of México, from August 1985 to May 1986 with average values ranging from 1.6 in cadmium (Cd) 2.37 in cobalt (Co), 1.23 for chrome (Cr) 932 in copper (Cu) 2.13 in nickel (Ni), 3.7 for Lead (Pb), 1.40 in zinc (Zn) in which they suggest an effect on the oyster's growth. The above is due to variations in concentration of metal during the different seasons of the year, although the results were inconclusive. Likewise, Frías-Espericueta *et al.* (1999b) analyzed once again the concentrations of heavy metals in *S. prismatica* in Mazatlán Bay and found that the concentrations vary with the proximity to urban areas. In the studied locations, they reported that concentrations of Cu and Zn regarding the weight of the organisms were significant, attributing this to the fact that they are necessary elements of the life cycle of organisms. However, they proved that there is no significant relationship between the concentration of the metals and the size of the individuals. Regarding the trace metals variation, associated with the stage of gonadal maturity, Páez-Osuna *et al.* (1995) reported that in organisms stemming from Mazatlán Bay, the volumes of Cd, Cu, Fe, Ni, and Zn, contained in the gonadal tissue, are lower during the periods of its maximum development, in contrast with the Mn maximum accumulation content present during its maturation.

In addition to the presence in rock oyster tissues of heavy metals and toxins by algal blooming, this species is reported as a high bioaccumulation bivalve of polycyclic aromatic hydrocarbons (PAH). Botello *et al.* (2002) report that this species, in contrast to other four studied bivalves, recorded a more considerable amount of hydrocarbon compounds in sampling sites such as Mazatlán, Sinaloa and Puerto Vallarta in the state of Jalisco, México, with average values that exceed 6.9 µg g^{-1}. They associate this result to the various human activities of these industrial and tourist ports respectively, like polycyclic aromatic hydrocarbon (PAH) sources to the marine environment.

Towards the south of the Mexican Pacific, in the coast of El Salvador, the presence and levels of concentration of organic-chlorinated compounds, polynuclear aromatic hydrocarbons, pesticides, and six heavy metals (Cd, Cr, Cu, Pb, Ni and Zn) are reported in sediments and tissues of rock oyster *Ostrea iridescens* (*Striostrea prismatica*). They suggest that the presence and high concentration of Cu and Zn arise from agricultural and industrial activities of coastal areas adjacent to the sampling sites (Michel & Zengel, 1998).

In conclusion, the authors suggest inventories of the malacological resources of the coastal area of the country, particularly in the touristic and industrial development poles as well as those sites that have not yet been significantly affected by humans, so as to be able to establish the necessary levels of the organic compounds, radioisotopes, metals and metalloids present in organisms which could also represent a hazard to the health of the environment. The taxonomic studies shall allow complementing the information and recommending the use of species as bio-monitors of environmental quality according to the studied area. Finally, it should be noted that rock oyster is a fishing resource and habitual consumption in its geographic distribution area, mainly in México, being its monitoring and continuous surveillance of its health status in each region is deemed necessary.

FISHERIES

Exploitation of *Striostrea prismatica* in its range of distribution

Fishery and the culture of ostreids in México are focused on five species, four native and one introduced. *Crassostrea virginica* in the Gulf of Mexico, which sustains fishing production at a national level (SAGARPA, 2013); *Crassostrea rhizophorae* and *Ostrea equestris* in the Gulf of Mexico and the Caribbean Sea (Correa-Sandoval & Rodríguez, 2013) and in the Pacific *Crassostrea corteziensis* and *Crassostrea gigas*, which was introduced for culture in the 1970s and to a lesser extent, they are captured *Striostrea prismatica* and *Saccostrea palmula* (Romo-Piñera, 2005; Ríos-Jara *et al*., 2008; Penagos-García *et al*., 2013).

Given the available statistical data on the oyster resource groups all the species present in the Gulf of Mexico, the Caribbean Sea and the Pacific Ocean, it is difficult to know the net catch volume of *S. prismatica*. However, there are exercises, such as the one completed by Patiño-Valencia (2006) and Patiño-Valencia & Ulloa (2008), in which the data from the catch of two locations of the central Mexican Pacific is used to determine its population decline. Such studies match with what has been established by Arreguín-Sánchez & Arcos (2011) who estimates from official fishing records that most fisheries are found in some sort of depletion. In the rest of the geographic distribution of *S. prismatica*, the conditions on over-exploitation also prevail, such as in El Salvador, Peru, Nicaragua, among others, reporting that the production that corresponds to rock oyster has decreased despite the fact that it is mainly for self-consumption and artisanal fishing (Hernández *et al*., 2006; Ramírez-Benítez, 2007; Ordinola *et al*., 2008, 2010).

Recovery and conservation of natural banks and aquaculture

The most appropriate strategies for the conservation and restoration of over-exploited fishing populations are fishing regulations and the development of culture techniques aimed at decreasing the over-exploitation of natural populations. There are a couple of studies on the restoration of natural banks of *S. prismatica*; such is the case of El Salvador, where it has been possible to increase the population of oyster banks. However, the growth is apparently slow, so it would be necessary to determine if the oceanic conditions in which they were placed are appropriate for the optimal growth of the species (Ramírez-Benítez, 2007).

Several rock oyster conservation and handling policies and strategies have been implemented and are regulated by the fishing administration agencies of the countries that have this resource available. Among these, it is possible to exemplify that in México, Nicaragua and El Salvador, where L_{50} has been deemed as the minimum catch size ranging from 8 and 10 cm, making sure that at least 50% of their population has complied with the first reproductive event; also, the restriction of its capture in periods of maximum reproductive activity, the restriction of fishing permits and a specific number of dozens per day and per person (DOF, 1994, 2010; CENDEPSCA 2002; Hernández *et al.*, 2006).

According to Hernández-Covarrubias *et al.* (2013) the minimum catch size established in México for rock oyster has been respected, which corresponds to an L_{50} of 9 cm in total length. However, the opinion of fishermen from communities of Jalisco and Nayarit in the Mexican Pacific coast is that the rest of self-consumption fishermen and poachers do not abide by said measurement, which prevents from carrying out a sustainable fishing activity that would allow the restoration of natural banks. In this regard and on the initiative of several fishing cooperatives of the coast of Jalisco, a ban was established from 23 May, 2011 to 1 September, 2012 (DOF, 2011) for the coast of this state.

As far as aquaculture is concerned, the research on this species is limited. In Latin America, particularly in Nicaragua, attempts were made to develop culture techniques from spat collection, having some of them fixed for growing out, but they were not brought to a commercial size since the materials and equipment used for the research process were vandalized (Hernández *et al.*, 2006). Over the last five years, Ecuador is the country that has spent more efforts to promote its culture. The studies carried out in that country have focused on the design of diets that are appropriate for reproductive conditioning since in bivalve mollusks this is a determining factor for gametogenesis and the quality of gametes. Marín (2011) designed a diet for *S. prismatica* with the mixture of microalgae *Tetraselmis maculata* and *Chaetoceros gracilis*. Authors proved that this diet optimizes gonadal development after 30 days of conditioning. Likewise in Ecuador, different conditioning treatments have been attempted in which temperature has been deemed as the primary factor for starting the gametogenic cycle, (Argüello-Guevara *et al.*, 2013). Likewise, various spawning induction stimuli and settlement substrates have been tested. Based on these studies it was determined that the optimal temperature for the gametogenic development of *S. primatica* is 28°C. It was further observed that it is possible to obtain successful spawning responses through temperature and salinity changes. In the case of larval settlement, a process in which bivalve mollusks leave the larval stage and start the juvenile stage (Sevilla-Hernández, 1993), different substrates were tested, such as the shell of *Crassostrea gigas*, valves of *S. prismatica* and plastic sheets. However, they were not adequate since they proved a relatively low settlement rate (Argüello-Guevara *et al.*, 2013).

In other studies related to feeding, it has been tested that *S. primatica* juveniles showed better growth in culture conditions fed with *Chaetoceros gracilis* (4.03 g) and *Isochrysis galbana* (0.15 g). They showed higher growth rates than those fed with *T. maculata*, since diatoms and dinoflagellates are rich in essential fatty acids such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), which are essential in the growth of bivalves and it is suggested that these diets can be used in other development processes of this bivalve (Loor, 2012).

PERSPECTIVES

The evident impact that rock oyster populations experience throughout the eastern tropical Pacific denotes the need for diagnostic studies of the current status in catching areas. The implementation of regulatory mechanisms is necessary, even if they are moderately successful, as suggested by fishermen from the Mexican Central Pacific. There are various proposals; one with high correlation is the alternation of catch areas in time and space complemented with other handling alternatives, such as the review and adaptation of the closed season. They should focus on the assessment of the dynamics of the species populations that provides necessary information for the design and implementation of programs with a high social commitment by fishermen, managers, and consumers, along with an innovative food conservation processes generating an added value to the resource. Given the phenotypic plasticity of Ostreids, species determination with morphological tools is still imprecise. Therefore, it is necessary to delve into the field of classic taxonomy (internal and external morphologic analysis) and the support of current molecular techniques for a proper determination. It is necessary to delve into reproductive biology to achieve sustainable culture, explore through experiments in controlled conditions, the best diets for the maturation of breeders, and determine fertility rates, settlement substrate preferences, assess optimal densities for larvae culture and during pre-fattening conditions.

The above must follow an agenda that can be established jointly with fundamental scientific objectives, and the participation of diverse interested sectors, that encourage the conservation of the populations in areas with fishing activity in all their geographic distribution, look for a continuous aquaculture monitoring program and its periodic report to direct users and the general public, recording and evaluating the impact and effects of climate change on natural banks and cultural experiences.

CONCLUSIONS

During this review, it became evident that little scientific attention has been paid to this resource. The lack of published scientific documents has made it necessary to refer a large number of undergraduate and postgraduate theses, which have not yet been published but contributed to a better knowledge of this species.

Even though it is a species of economic interest and culture potential in all countries of its distribution, it is concluded that the knowledge is still limited. The effects of catching pressure on the species are primarily ignored or whether if climate change and pollution are factors with a direct negative impact on their populations. Perhaps, the few studies focused on this species are based on the operational complexity to study it, since its habitat restricts the access because of the high oceanic dynamics in the area, restricting access in some seasons of the year. This factor has allowed some degree of population conservation.

There are several research studies on the effect of bioaccumulation of heavy metals and bio-toxins generated by harmful algae blooming (HAB). However, they are not even enough or sufficiently updated material to know the implications in public health. It is also a priority to increase the study in both, ecologic-biological matters and economic issues of the species, focusing on the implementation of conservation strategies, such as handling plans and aquaculture techniques. It is imperative to establish the proper handling of natural populations, to schedule a synchronized ban according to the best understanding of the species seasonality factor, along with its range of geographical distribution. Therefore, it is essential to develop studies on reproduction with a broad geographic range in which gametogenesis, larval behavior, dispersion patterns, and settlement are analyzed. This would allow adjusting the ban (closure) to different environmental conditions.

Scientific research that results in larger biologic, ecologic and technologic knowledge of the species must be addressed as a national goal, in which government, private institutions, research centers and universities are involved. In the case of México, the current knowledge has been developed by the particular interest of researchers or research groups and not under a coordinated scheme among the bodies as mentioned above. Rock oyster *S. prismatica* is a crucial resource that must be thoroughly studied with the necessary programs to achieve not only the appropriate maintenance of its natural populations but also the technology to produce it through aquaculture.

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