Chapter 1

Ecology, Fishery and Aquaculture in Gulf of California, Mexico: Pen Shell *Atrina maura* (Sowerby, 1835)

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Abstract

The pen shell *Atrina maura* bears economic importance in northwest Mexico. This chapter considers a review on diverse ecology, fishery, and aquaculture topics of this species, carried out in northwest Mexico. In ecology, biology, abundance, spatial prospecting, sex ratio, size structure, reproductive cycle, first maturity sizes, variation of gonadosomatic indexes and growth are discussed. In fishery, the information analysed corresponds to the structure of the organisms in the banks susceptible to capture, institutional and ecological interaction for fishing regulation, evaluation of fishing effort, improvement in fishing performance using the knowledge and attitudes of the fishermen on fisheries policies in the Gulf of California, resilience and collapse of artisanal fisheries and public politics. In aquaculture, they are long-line culture, bottom culture, reproductive cycle, growth, production of larvae and seeds, biochemistry of oocytes, nutritional quality of the muscle, evaluation of diets based on microalgae, immunology in larval and juvenile and probiotic use. The present work shows a status based on information published in theses and articles indexed 15 years ago to the date on the ecology, fishery and aquaculture in the pen shell *Atrina maura* carried out in the lagoon systems of northwest Mexico.

Keywords: growth, reproduction, culture, immunology, populations, estuaries

1. Introduction

1.1. Taxonomic position

The taxonomy of the pen shell according to Keen (1971):

Phylum: Mollusca (Linnaeus 1758)

Class: Bivalvia

Subclass: Lamellibranchia

Order: Anisomyaria

Family: Pinnidae

Genus: *Atrina maura* (Sowerby 1835)

Synonymy: *Pinna lanceolata* (G.P. Sowerby 1835)

1.2. Biologic

1.2.1. Current status

The Pinnidae ('mussels, scallops, oysters or pen shells') are bivalve marine mollusks that during their life cycle have a planktonic stage and later will incorporate to the benthos where they live until they die. *A. maura* adults measure approximately between 170 and 350 mm, they live in muddy or sandy bottom places, where they strongly attach themselves to the substrate by using their fixation organ; also, due to the proximity of the organisms, they tend to form dense banks by living in groups with other species of lamellibranchs [1]. The shell of these organisms is triangular, reduced in the anterior part and has a pointy shape, whereas the posterior one is a long, flat and well-developed part similar to a wide fan, with a rounded truncated edge, the shape of the shell is strongly influenced by a series of adaptations related to the species life style. The reduction of the anterior part and of the anterior adductor muscle is associated to the substrate fixation by byssal threads, as it occurs with other anisomyarian mollusks [2]. The shell is colonized by a great amount of epibionts that make it look irregular; usually on the shell, there are numerous species of algae, mollusks, polychaetes, bryozoans, ascidians, etc. The outer surface is purplish-amber or dark brown in colour, while the inner surface is shiny [3] (**Figure 1**).

In the Pinnidae, the opening and closing of the valves does not occur in the normal way by the ligament, since the only function of this structure is to keep the valves together; therefore, it takes place by the flexion of the posterior part of the shell, which has high protein content. These organisms have a big posterior adductor muscle located at the central part of the shell (the organism's tissue that is put on the market), as well as a small anterior muscle located at the umbonal vertex. There are two more pairs of muscles that help the movement of the organism's foot, which are the anterior retractor pedals that together with the foot carry out the excavation and motility function [4]. These organisms can even bear the loss of the anterior

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Figure 1. *Atrina maura* procured from the bottom culture at San Buto estuary in Baja California Sur, México [20].

adductor muscle or even the fusion of the ventral margins of the shell, as long as the posterior part can still be closed by the action of the posterior adductor muscle [5]. The byssus is kept in a chamber found at the posterior basal region of the foot; the bundle of fibrous strands can measure 25 cm in length. The byssus gland is near the area where the foot begins. The soft parts hold a series of characters that differ from other bivalves and are confined mainly in the area between both adductor muscles and overstepping this region, the mantle's lobs and the elongated gills are found, which are extended toward the posterior region, overtaking the adductor muscle [4]. The mantle is attached to the shell as it occurs with other species with similar living habits (some Mytilidae), so it is very retractable without a pallial line. The mantle's retraction confers the family great regeneration ability since all the posterior part of the shell can be rebuilt. The mantle's cavity is divided by a septum that forms the external and internal chambers [5]. The mouth is a tiny orifice located at the anterior portion of the labial lips and continues with the oesophagus, a narrow circular canal that connects with the stomach, where the intestine begins, running toward the posterior area and coming out from the digestive gland, entering the gonad until it reaches the posterior adductor muscle [4]. A very distinctive and unique organ from the Pinnidae family is the pallial organ, whose function has been controversial for a long time. Originally, it was considered as a cleansing organ, in charge of extracting broken pieces from the shell that would remain in the pallial cavity [6, 7]. The heart is located in the dorsal region at the same level as the posterior adductor muscle. The crystalline style begins in the stomach up to the posterior intestine grip, and it secretes enzymes that aid in digestion [8]. The respiratory organ is composed by gills or ctenidia that resemble light brown elongated leaf shape structures which appear in groups of four, located by pairs on each side of the organisms [4]. There are waste ducts that cover the mantle in an anterior-posterior direction, starting from the mouth's palps reaching up to the end of the posterior back part of the gills, completing the division between the inhalant and exhalant chambers.

These canals allow the disposal of pseudofeces and other type of wastes from the inhalant chamber, which can be used to clean the sandy cavity and other residues introduced by the swell before the animal shuts its valves [5]. *A. maura* is a gonochoric organism whose zygotes arise from the union of female and male gametes deriving from those organisms with separated genders. The sexual maturity state can be determined by the gonad's coloration, which sometimes can be observed macroscopically when the valves are opened. The females present a deep orange coloured gonad (like the colour of a brick), and the males have a whitish gonad [9]. The fertilization is external and the larval development is planktonic with trochophore and veliger larvae [10]. The gonads are anastomosed glandular structures that branch out invading the digestive gland. As the maturation progresses, the gonad occupies an even larger space, and it turns out to be more notorious up to the point in which it reaches the typical follicular tubular-acinar system structure that characterizes all bivalves [8, 11].

2. Ecology

2.1. Current status

The organisms of the Pinnidae family spend a short but important stage of their life cycle in the plankton and later will incorporate to the benthic zone where they will live until they die.

2.2. Distribution and habitat

Since the first research of [12], in the Eastern Pacific, it is known that the Pinnidae family (in Mexico, commonly known as 'Callo de Hacha') has a wide biogeographic distribution that runs from the Baja California Peninsula, Mexico, down to Panama. However, in many cases, the regional boundaries of this distribution are unknown. As part of the Pinnidae population, four species have been identified: *Pinna rugosa, Atrina tuberculosa, Atrina oldroydii* and *Atrina maura*, the latter presents a relative abundance of approximately 95% [1]. These scallops are distributed in the Indo-Pacific from the southwest of Africa to Malaysia and New Zealand and the north of Japan, they are found in Mediterranean waters and America [13–15]. In the American continent, the *A. maura* species has a wide biogeographic distribution from the Baja California Peninsula down to the south of Peru, forming not so dense banks in bays and coastal lagoons on both littorals of the California Peninsula. Nevertheless, in many cases, the regional boundaries of this distribution are unknown [1, 12]. In the Mexican Pacific, there are four species of the Pinnidae family, particularly in the Gulf of California, *Atrina maura, Atrina tuberculosa, Atrina oldroydii* and *Pinna rugosa* are distributed [9]. These are benthic organisms that live in protected intertidal zones, as well as in estuaries with slimy-clay, muddy-sandy, sandy limestone or sandy-rocky bottoms [16]. These animals can be found from the lower limit of the tide up to a maximum of 10 meters, although some have been recorded in more than 45 m of depth in some bays. *A. maura* lives semi-buried in different types of substrates such as soft substrates that can have roots and rhizomes of sea grass, small gravels, biodetritic waste and sand grains to which these animals attach to by using their byssus. *A. maura* is a halotolerant and thermotolerant species, which makes it suitable for culture in the Gulf of California for having an adequate environmental production framework [17].

3. Fisheries

3.1. Current status

Atrina maura also known as 'Hacha China' represents one of the most valuable fishery resources in the coasts of the Mexican Pacific; it is highly valued in the national and international market, because it has an edible adductor muscle that can be commercialized. These animals are dominant mollusks in the benthic community of the sites they live in, where they form dense size banks of variable permanence [1]. The Gulf of California fishery comprises four species: *Pinna rugosa, A. maura, A. tuberculosa* and *A. oldroydii*, which represent approximately 25% of the national scallop catch [9]. The commercialized part of the organism is the posterior adductor muscle, known as 'callo', that has a wide demand due to its nutritional quality, texture, taste and high prices in the national market, reaching up to $120 and 180 (Mexican pesos) per kilogram in the beach buying it directly from the fishermen, and if the product is sold by an intermediary, the price to the public can reach up to $300 Mexican pesos per kilogram [18, 19]. The product is sold fresh or iced, and it is mainly marketed in Nayarit, Sinaloa, Sonora, Baja California, Baja California Sur and in the most important cities of the country such as México City, Guadalajara and Monterrey [9].

During the past 30 years, the exploitation of these scallops has increased, overfishing *A. maura* in some zones of the Mexican Pacific [20]. Catch records in Baja California Sur (*A. maura, P. rugosa* and *A. oldroydii*) between 1985 and 1995 show a maximum intake of 1148 tons of fresh product (adductor muscle). Since 1991, there has been a low catch trend, reaching a minimum catch of 91 tons in 1995 [9]. According to Mexican official sources, the catch of pen shells has been included within the catch of other species of clams. Between 1966 and 2010, the pen shell represented 25% of the pen shell production as reported by the fisheries sub-delegation in Baja California Sur showing the highest catch volume in 2004 and 2008 with 280 tons, whereas the lowest value occurred in 2000 with only 20 tons, respectively [21] (**Figure 2**).

Due to the decrease in the production by fishing and the lack of culture development, the current global production levels have not been able to satisfy the national market demand, so different alternatives have been searched in order to allow a sustainable exploitation of this wild resource, such as the one that is taking place in some Seri fishing communities from Punta Chueca and Kino Viejo in Sonora, by using a population growth function which emulates how the carrying capacity affects small scale fishing communities, as well as the different institutional development levels, the opportunity to adopt new institutions and the degree in which the fishing effort is reduced, thus avoiding overfishing of the species. With these

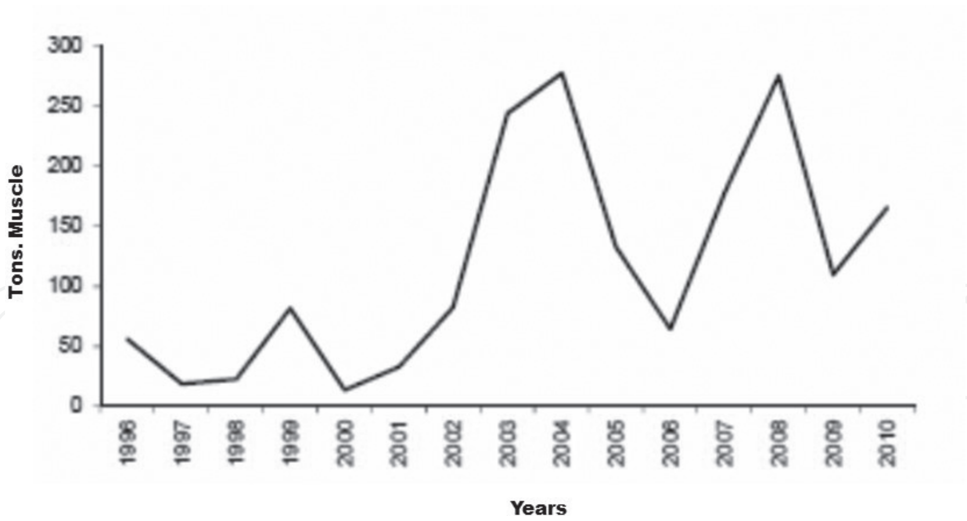

Figure 2. Catch volume expressed in weight tons of total live weight of pen shell *A. maura* in Baja California Sur, from 1996 to 2010 (source: Ref. [21]).

measures, the fishing Seri communities of Punta Chueca have avoided overfishing of the pen shell banks; while in their neighbour fishing community in Kino Viejo occurs otherwise, where exploitation of the resource without a proper measure occurs, in spite of the fact that these two communities are only separated by a 30 km distance.

With these two cases, there was a need to create governmental organizations because there are not enough ones to regulate and keep a sustainable fishery through the time. As soon as the communities adopt strong and solid institutions, there will be more chances of sustaining the resource. In which moment should institutions be adopted and in what measure the fishing effort must decrease? This will depend on the ecological capacity of the species in those places where the fishing takes place, as well as the fishing capacity among sites, even in those settings of similar institutional development [22]. In addition, studies have been made in order to increase the production levels through biotechnical alternatives that can be applied to aquaculture to solve the problem faced by *A. maura* in the coasts of the Mexican Pacific [23], specifically in a regional level (Gulf of California) like the realization of projects that generate information regarding the production [20, 24], larval survival up to the phase of pre-fattening and fattening [25], genetic improvement and triploid and seed production [26], economic feasibility [27], among others.

4. Aquaculture

4.1. Current status

Bivalve aquaculture in Mexico is performed almost exclusively in the coasts of the Pacific Ocean and Gulf of California, where more than 54 species of mollusks are exploited [28], as they have water bodies suitable for the development of cultures. It occupies the fourth place in Latin America after Chile, Brazil and Peru. The production data from FAO began in 1987 with 20 tons, and subsequently, the production increased to 2200 tons in 1990. In 1993, there was a decrease in the production to 1053 tons and increasing afterwards in 1995 up to 2500 tons and to 3038 tons in 1997. After this year, the production decreased again to an average of 1500 annual tons, which sustained until 2005 [29].

In the coasts of the Mexican Pacific, the pen shell *Atrina maura* is one of the most important commercialized mollusks, with a broad national and international market. The natural populations of this species are increasingly seen as decimated due to overfishing. That is why research has been directed toward the experimentation of diverse culture stages of such a valuable mollusk. Nevertheless, there have not been any successful results about its production under controlled conditions over time. The entrepreneurial and educational sector has a big interest on this resource as they have invested in lab facilities for seed production, using a developed methodology by the Company Acuacultura Robles S.A. de C.V., Centro de Reproducción de Especie Marinas del Estado de Sonora (CREMES) and el Centro de Investigaciones Biológicas del Noroeste (CIBNOR), from La Paz, Baja California Sur, as well as from Sea Farmer S.A. de C.V. in the northern part of Sinaloa. The seeds that are produced in the lab have been planted in the sea, but it has been observed that there has been a struggle with huge mortality rates; as a result, there is no culture technique that can escalade up to an industrial level. Therefore, it has been of great importance the collaboration between the academic and industrial sector with the aim of conducting studies to deal with those bottlenecks that take place during the larval phase of the species which substantially affects the seed production in an industrial level. Regarding the culture stages in the phase of pre-fattening and fattening, there is no problem whatsoever; once a certain size has been achieved, the fattening stage does not demand a higher maintenance and care because those are phases in which more level of research has been developed. On the other hand, it has been considered to contribute with cultures in a wild level and therefore promotes the occurrence of the species in its natural habitat.

4.2. Seed production

Bivalve seed production is practically based on the Pacific oyster *Crassostrea gigas* and in a lower degree in the Cortez oyster (*Crassostrea corteziensis*), the Mediterranean mussel (*Mytilus galloprovincialis*), the Pacific scallop (*Argopecten ventricosus)* and the rainbow-lipped pearl oyster (*Pteria sterna)*. Production of emerging species under a commercial level has been carried out such as the case of the lion's paw scallop *Nodipecten subnodosus* and the pen shell *Atrina maura*, but such production has not been maintained over time [29]. *A. maura* is a species with a highly cultured potential in the northwest of Mexico because of its nutritional content, resistance to transport and handling, as well as for its highly commercial value [20]. Within the past years, there have been huge efforts to perform diverse studies in order to know the basic biology, physiology and reproductive biology of the species [30]. For example, some research has been done to accomplish the seed production in labs to carry out cultures in the natural environment with high success probabilities [31]. Nevertheless, the species *A. maura* must be handled under physical-chemical optimum conditions as well as nutritional ones in those zones of culture, in which unfortunately there is not enough research done about the subject, which has made this situation to be considered as a big problem for seed production [32]. On the other hand, there is a need to perform studies in search of other alternatives to solve such a problem; one would be the manipulation of the species reproductive cycle under specific conditions during gametogenesis.

This is important because natural banks have been significantly diminished due to overfishing since there is no law that regulates this activity, which in turn limits the massive removal of seed from their natural environment [31, 33]. In turn, the seed production obtained from artificial collectors seems uncertain for a sustainable aquaculture activity. There are some studies regarding the recollection of juvenile pen shells in the Gulf of California [33, 34] and in the Pacific coast of the Baja California Peninsula [35, 36]. In 1988, the first juveniles of *A. maura* were produced at the Centro Reproductor de Especies Marinas del Estado de Sonora (CREMES). In 1991, a new attempt was performed with encouraging results due to the increase of produced seeds. By the end of 1994 and the beginning of 1995, the first commercial production of seeds in the lab was produced with over 800,000 organisms ranging between 15 and 25 mm in length. In 1996, the production increased to double, but there was a massive mortality of 4 or 5 days after being delivered to the producer [37]. In 2004 [19], biotechnology was developed to artificially produce larvae and diploid and triploid seeds of *A. maura* under lab conditions, establishing the proper temperature, feeding and care parameters for each of the stages such as the spawning induction, larval culture, fixation, metamorphosis and pre-fattening stage. In 2009 [38], a comparative study between the growth and survival of floating and swimming larvae of *A. maura* under intense culture lab conditions was performed, observing a higher growth in swimming larvae whereas the floating larvae showed the lowest sizes; survival was lower for both types of larvae but being higher (around 16%) for the swimming type. In 2011 [39], a lab production of larvae and seeds of *A. maura* was analysed, determining each one of the stages of the larval cycle, as well as the period of time for the growth of each stage, concluding that the pen shell larvae and seed production are different from that of other bivalves. In this species, a lower survival rate was recorded which seems to be linked to the buoyancy of the larvae within larval cultures, combined with the production facilities which must be suitable for the species culture.

4.3. Culture

In Mexico, there are few research advances regarding *A. maura* that can determine with certainty the establishment of a sustainable culture. The first study for this type of activity was initiated at the early 80s with the research carried out in San Blas, Nayarit by a group of workers from the former Secretaria de Pesca. The accomplished advances regarding the extraction and transport of breeders, the spawning induction and at a certain point the handling of larvae turned out to be encouraging, and therefore, some hundred larvae were produced, which were followed up to the fattening stage in the field [19].

The fattening culture could start after capturing seeds in collectors that come from natural populations or from juveniles produced under controlled lab conditions. In both cases, the culture is extended to the sea until a commercial size is reached (200 mm in valve height). This type of culture is performed in extensive systems so the nutritional or feeding studies and the carrying capacity of the ecosystems in which the fattening is carried out are essential, since the growth rate, survival, accumulation of energy reserves and biochemical composition of tissues depend on them.

This carrying capacity is defined by terms of appropriate feeding particle availability in the area as well as by physical and chemical variables that allow culture of juvenile and adult biomass which constitute the sustainability of the culture [40].

4.3.1. Culture technologies

The use of two types of fattening techniques has developed based on the location of the organisms in the water column, which are the suspension and bottom cultures.

4.3.1.1. Suspension cultures

In those suspension cultures, the fundamental principle requires that the organisms are confined in boxes or in any artefact (pearl baskets, 'Nestier', purse nets, Japanese lanterns, etc.), and keeping them by modules along the water column, assisted by supporting and floatation structures to keep them suspended over the surface or at a specific depth, such as the 'Long line' or stem lines, floating rafts, etc.

In 2012 [20], a suspended culture of *A. maura* was performed after produced seeds, evaluating their growth in San Buto estuary. Baja California Sur, Mexico, observing significant differences in both the size and weight growth of *A. maura* according to the length, width and thickness ($p = 0.0001$) during the experimental period. This trend was shown in the total weight of the organisms, having a final average value of 39.11 ± 3.13 g by the end of this stage, and in the case of the adductor muscle, a final average weight of 0.77 ± 0.09 g (**Figure 3**).

4.3.1.2. Bottom cultures

Bottom cultures are defined as the planting of freely dispersed seeds over the ocean floor in which they are expected to develop until they reach a commercial size [20]. Both technologies have been widely used with different species and in different parts of the world, and in each species and locality obtaining different results among them [41].

The culture of *A. maura* has high potential because it can develop under temperatures of 16–30°C, and due to the fact that it presents fast growth rates. The first culture was started at the beginning of the 1990 decade. With the first group of seeds obtained in the lab of the Dirección de Fomento Pesquero del Estado de Sonora, who donated some seed batches (between 1000 and 2000 seeds per social group) that were distributed in different localities at the northwest part of the country (Gulf of California), some good results were obtained. Such results were satisfying in terms of survival and growth that even until now the seed demands from the different social and private groups continue [19]. In 1997 [32], an experimental culture of *A. maura* was carried out at Agiabampo lagoon, in Sonora, considering the seed transport, pre-growth and final growth phase. In this study, it was observed that the species adapts to artificial pre-growth conditions and stands being planted subsequently in the sea bottom after 17 months of culture; the organisms reached an average size of 208 mm, with an adductor muscle weight of 22.75 g and an accumulated population rate of 28%. Another research [31] performed an experimental culture in Bahía Magdalena Baja California Sur obtaining adductor muscles around 14 g in weight in a period of 20 months of culture, although the harvest time

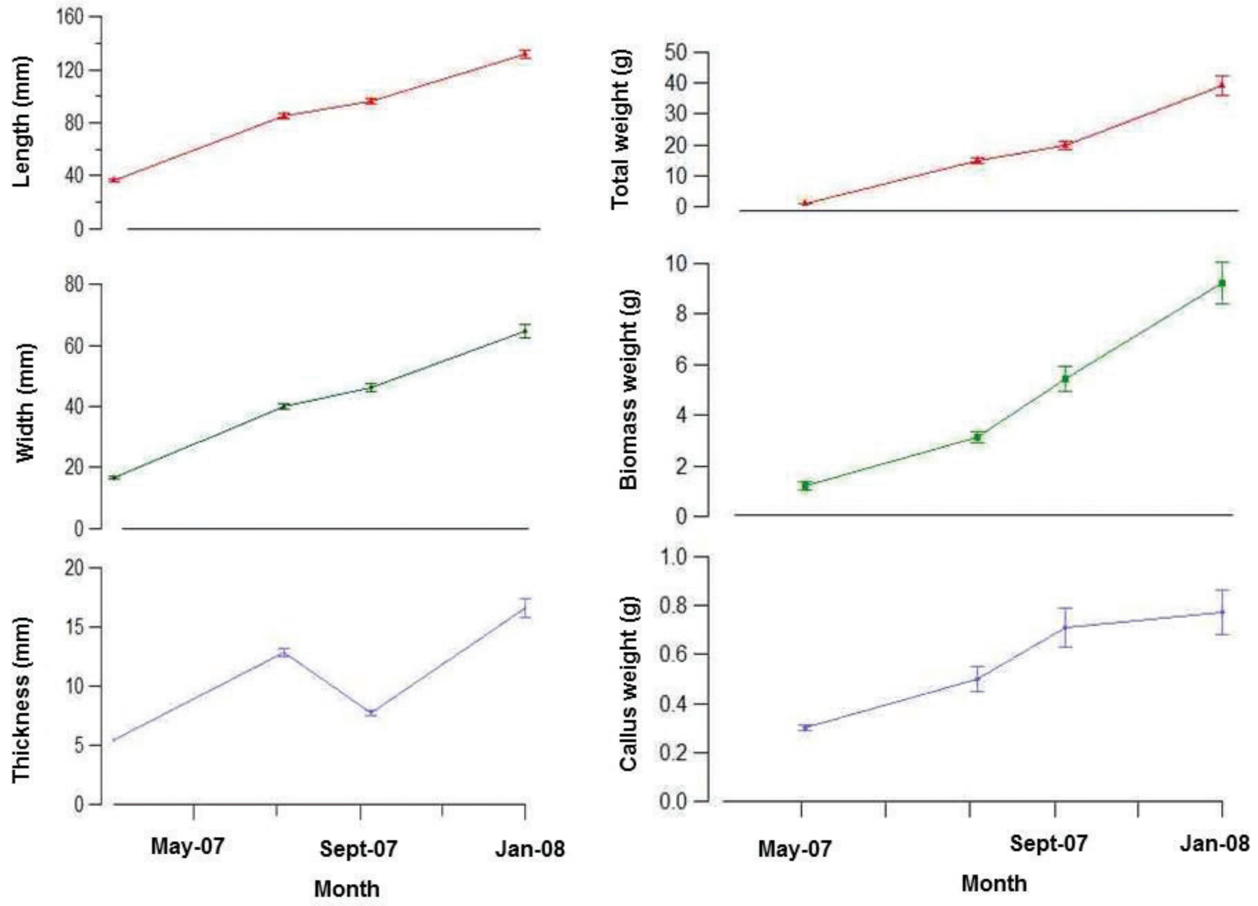

Figure 3. Growth in length, width, thickness, total weight, adductor muscle weight and biomass weight (media ± standard error) of the shell of *Atrina maura* during the fattening stage at San Buto estuary, Baja California Sur, Mexico.

was of approximately 2 years. In 2008 [63], the growth and survival of a culture of *A. maura* in La Palmita cove, Navolato, Sinaloa, was evaluated revealing that the organisms reached an average size of 167.81 mm in length and a total weight of 153.16 g with a survival rate of 71.57% during 19 months of culture.

In 2012 [20], a bottom culture of *A. maura* was carried out at San Buto estuary, Baja California Sur, Mexico, where a total of 584 organisms were analysed under three experimental densities of 12, 24 and 48 org/m^2, resulting in similar average sizes under the three densities: 243.61 ± 3.37 mm of length, 148.17 ± 3.77 mm in width and 44.86 ± 0.41 mm of valve thickness. Regarding the total weight (382.89 ± 19.08 g), biomass weight (107.2 ± 5.96 g) and adductor muscle weight (18.39 ± 1.24g), the results were similar under all three densities. The survival rate during the study was greater for those organisms kept in the density of 24 org.m^{-2} (90%) rather than in the other two densities.

4.4. Growth

The growth in bivalves is affected by a complex combination of biological and environmental factors such as temperature, salinity, oxygen concentration, quantity and quality of food, affecting the size, reproductive condition and genetic characteristics of animals, etc. These growth aspects in mollusks are sometimes difficult or impossible to manipulate under aquaculture situations that assure an optimum growth; however, a limited control can be executed over such conditions by a careful selection of culture sites [42–44]. Different studies agree that growth rate is one of the main factors that determine the feasibility of those cultures of bivalve mollusks. The growth is inversely proportional to the population density due to the intraspecific competition over available resources in the environment [45–47], and the increase of 'fouling' can also decrease the growth rate, which also differs among size classes and change according to geographical regions [48]. Food availability is limited in reproductive periods, the gonadic growth is favoured as an evolutionary strategy in mollusks, and therefore, it is probably that the species starts forming gonads in small sizes, focusing the energy mainly for reproduction more than for somatic growth [49].

Fewer are the studies performed on organisms of the Pinnidae family related to growth. In 2011 [50], growth was analysed in a bottom culture of *A. maura* under two tide levels at San Buto estuary in Bahía Magdalena and Baja California Sur, Mexico, using the von Bertalanffy model, where it was revealed that *A. maura* reached a maximum valve height of 127 mm during the first year of life and of 207 mm in the second year; survival rate after transplanting the organisms was high (99%), and after 8 months of culture, it was of 78% for both tide levels. In 2015 [51], growth and survival were evaluated for pen shell organisms, *A. maura*, that were harvested for 15 months (May 2010–August 2011), at La Piedra estuary, Guasave, Sinaloa, Mexico. A total of 3000 seeds were obtained (61.50 ± 0.5 mm of valve height, 4.98 ± 0.2 g of total average weight). The temperature (26.15 ± 6.35°C), dissolved oxygen (6.94 ± 1.67 mg/L), pH (6.79 ± 1.5) and water salinity (32.25 ± 7.25 ups) were recorded every other week. Final growth values were of 193.17 ± 11.50 mm for shell height and of 156.54 ± 25.30 g for the weight. Significant differences were found in both, the shell height and total weight, during the culture. Growth rate was of 0.29 mm/d and 0.33 g/d for the shell height and weight, respectively. The morphometric relation of valve height with total weight was allometric (2.39), and showed a positive correlation ($r = 0.88$). The final survival rate was of 92.79%. A recommendation was given for future cultures of *A. maura* at the mentioned estuary, considering the effect of the environmental variables on the species growth.

4.5. Reproduction

Studies about reproduction are important because they provide necessary information for obtaining seeds in aquaculture [52]. One of the bases to know the reproductive biology of an organism is the determination of the reproductive cycle, based on the analysis of the ecology and physiology of the species. The reproductive cycle is defined as the group of events that start with the activation of the gonad, going through gametogenesis, maturity and spawning (or gamete release) and gonad recession. In every bivalve, the gonadic development consists on gonad growth drawn from an undifferentiated germinal epithelium with mesodermic origin which remains dormant within the connective tissue after each reproductive cycle. During this stage known as 'undifferentiated', no gametes are observed, and it is characterized by intense metabolic activity conducted to store reserve substances. Subsequently, the germinal epithelium proliferates and originates the gametes. Generally, during the reproductive season, the spawning consists of a series of partial releases of the gonadic content of a certain population percentage that varies within a very small percentage and 100% of the overall population [53].

Reproductive studies of bivalves indicate that gamete maturity is mainly controlled by temperature and food and secondarily by salinity and the light period. In temperate environments, temperature is the main regulatory component, but in tropical environments, emphasis has been given to food availability which in turn acts as the regulatory factor on the reproductive cycle of many species [54]. In relation with the reproductive matters of *A. maura*, some research has been done about the reproductive biology and studies on the cytology of gonads of *A. maura* [18, 22, 30], where the cytologic evolution of the ultra-structural histologic level of the gonads was determined, showing similar aspects as those described for *Pinna nobilis* [30]. In 2000 [55], the variations of protein and lipid concentration in gonads of *A. maura* were established before the maturation process. The results showed that unlike other mollusks, the energy used during the gonadic maturation process was provided by the food as no evidence was found toward the nutrient supply from other somatic compartments. Rodríguez-Jaramillo [56] compared morphometric variables and the quality of female eggs of *A. maura* by inducing gametogenesis in three temperatures (20, 25 and 30°C) under lab conditions; on the other hand, a histochemical analysis was also performed which determined the lipid concentration in oocytes, revealing that temperature does influence the size of oocytes as well as triglyceride quantity. By comparing the spawning of those females brought from their natural habitat with that of females from a lab, a significant difference was found in the lipid index of immature normal oocytes where the lipid index of oocytes coming from natural spawning environments was more heterogeneous than the one from mature lab females. In another study about the reproductive cycle of *A. maura* [23], in Bahía Magdalena, Baja California Sur, only one reproductive period was observed with synchronous spawning that took place from January to March, giving the evidence that this species habits different biogeographic regions and has a great reproductive plasticity, adapting to local environments because reproduction is an endogenous answer genetically controlled by the environment known as the reproductive latitudinal gradient. In 2007 [57], it was found that this species reproduces itself year-round with two important reproductive peaks, one from April to July and the other one from October to November and with only one resting phase from August to September. The reproductive cycle showed a direct relation with the gonadosomatic index and an inverse relation with muscle activity, as well as a spawning and post-spawning period directly related with water temperature. The influence of phenomena such as 'El Niño' and 'La Niña' over the reproductive cycle of *A. maura* at la Ensenada de La Paz, Baja California Sur, Mexico [8] is different; during 'El Niño' (2004–2005), a high proportion of mature organisms (55%), high condition index values (ICG) (33–44%) and low spawning proportions were recorded with the decrease of temperature, whereas a high proportion of organisms with gonads under a reabsorption phase (17–100%) was registered in those areas with highest temperature anomalies; therefore, assuming negative effects of 'El Niño' during spawning processes turn out to be abnormal. In contrast, during 'La Niña', lower values of ICG (29–36%) were found and a decrease in the amount of mature organisms was noticed. The latter reveals that there were massive spawning events (36–71%) when the temperature increases. In conclusion, *A. maura* at the Ensenada de La Paz Baja California Sur showed an opportunistic reproductive strategy, which allows gamete reabsorption when unfavourable environmental conditions prevail and a distribution of the exceeding energy for reproduction purposes under favourable conditions. In 2016 [58], the advantages and disadvantages of three methods used to estimate the potential fecundity in commercial valued organisms of *A. maura* were analysed in northwest Mexico. Gonadic samples were taken during the reproductive season in March of 2003 and were processed by histological combined techniques with the Cavalieri Principle, stereological analysis of the gonad with the gauge method and the theoretical radius estimate of the oocytes. Comparing with other methods, the determination of the potential fecundity by the gauge method was precise in *A. maura* ($9.8 – 15 \times 10^6$ cells ind^{-1}). The reproductive cycle and the growth of *A. maura* were determined at the Ensenada Pabellones lagoon system in Sinaloa [59], where the sex proportion was of 0.57 females:1.72 males within the studied population. In reference to growth, there were no valve height difference between the males and females. The average height of those sample specimens ranged between 50.99 ± 4.86 mm and 218.16 ± 8.87 mm. Histological results confirmed that *A. maura* is a gonochoric organism that presents a synchronic development of the gonads. Maturation and spawning stages were observed during the entire study period except of March and May of 2008. The frequency of the development of the gonad stages obtained on a monthly bases suggested that this species reproduces twice a year with an important reproductive period from June to September, a minor reproductive period from November to February and two resting periods from July and August and in January and February of 2009.

4.6. Sensory and nutritional quality of the adductor muscle ('Callo')

In 2010 [60], the effect on seasonality and tide level on the adductor muscle quality of *A. maura* was assessed at San Buto estuary Baja California Sur, Mexico, by determining the optimum harvest periods, the muscle mass index (IRM) and some physical variables such as quality, texture, colour, percentage of water release and pH. Likewise, the proximal composition and gonadic index were analysed. According to the muscle mass index, June turned out to be the best month to harvest organisms because it showed the highest IRM value (26.9%), while not enough evidences were found in order to consider that the tide level was a decisive factor that could be affecting texture quality. Furthermore, the muscle colour of *A. maura* showed high chromatic values related with a dark colour and low luminosity indexes. A proximal analysis indicated a high protein content which represents good nutrient quality muscles. As for the pH, no relation between these variations and the percentage of released water was found, as there was no relation with the season or tide level. The quality of the adductor muscle [20] was evaluated in a bottom culture at San Buto estuary, Baja California Sur, Mexico, under three different densities (12, 24 and 48 org m^{-2}), showing a high correlation between the pH and the ability of water retention (CRA), where low pH values correspond to high CRA values. In terms of the components of colour parameters in the adductor muscles under the different culture densities, two types of colorations appeared, and based on the obtained values, a small part was white, and a big one was darker (cream colour). The most luminous part was the smallest in the 24 org.m^2 density, and the less luminous was the bigger part at 12 and 48 org.m^2 densities. Regarding texture, the muscle with best hardness and adhesiveness was found at the 48 org.m^2 density, which matches with the biggest adductor muscles in size and weight, whereas the most elastic and cohesive muscles were those found in the 24 org.m^2 density, revealing that those pH values recorded in these densities were found within the established ranges for considering an adductor muscle as a fresh product and therefore having a better texture. In some commercial catch samples of the pen shell, *A. maura* [61] diverse features related with the dietary quality were analysed and compared. The quality of the adductor muscle was analysed by sensory (preference and hedonic test) and instrumental methods (colour analysis, capacity of water retention, pH, colour, texture and proximal chemical analysis). The results revealed that the sensorial panel used for the preference analysis and hedonic acceptability only showed a significant preference for the general appearance of *A. maura*, and no differences in the colour and texture parameters were detected by the sensorial evaluation. The quality comparison by instrumental methods indicated that the adductor muscle of *A. maura* had less luminosity. Higher pH values in *A. maura* originated less luminosity; nevertheless, it gives it an advantage for a better capacity of water retention (CRA) and could even have influence in the higher hardness and chewiness found in the species.

4.7. Genetics

The degree of variability and the population genetic structure, as well as the estimates of demographic and phylogenetic history patterns of *A. maura* were evaluated by the isolation and characterization of the sequences of the gene COI [62]. A total of 45 nucleotidic sequences of the gene COI with a longitude of 650 bp from Guerrero Negro, Bahía Magdalena and La Paz Baja California Sur Mexico were evaluated. High haplotypic diversity (0.7333–0.9714) and lower nucleotidic diversity (0.00185–0.002912) were found for the three studied localities. A total of seven haplotypes were identified from which three are endemic for La Paz Baja California Sur. These results indicated that this could be a consequence of the larval dynamics of the species mainly related with its prolonged larval plankton stage and to the fact that during this stage its distribution is being highly influenced by the pattern of marine currents along the Pacific and Gulf of California. On the other hand, the neutral evolutionary tests suggest a population expansion event for the species in La Paz and the presence of a bottleneck for Guerrero Negro and Bahía Magdalena.

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