Regional Studies in Marine Science 62 (2023) 102976

Contents lists available at ScienceDirect

Regional Studies in Marine Science

journal homepage: www.elsevier.com/locate/rsma

Using a fisherman's harvest in Acapulco, México, to characterize population structure, allometry, and body condition in the edible intertidal mollusc *Chiton articulatus* (Chitonida: Chitonidae)

Carlos Valencia-Cayetano [a,d], Sergio García-Ibáñez [a,d,*], Omar Hernando Avila-Poveda [b,c,d,**], Jesús Guadalupe Padilla-Serrato [a,c], Juan Violante-González [a], Rafael Flores-Garza [a]

[a] *Facultad de Ecología Marina (FEM), Universidad Autónoma de Guerrero (UAGro), Acapulco, Guerrero, México*
[b] *Facultad de Ciencias del Mar (FACIMAR), Universidad Autónoma de Sinaloa (UAS), Mazatlán, Sinaloa, México*
[c] *Programa de Investigadoras e Investigadores por México, Consejo Nacional de Ciencia y Tecnología (CONACyT), Ciudad de México, México*
[d] *Proyecto Quitón del Pacífico tropical mexicano, Mazatlán, Sinaloa, México*

ARTICLE INFO

Article history:
Received 17 December 2022
Received in revised form 18 March 2023
Accepted 17 April 2023
Available online 28 April 2023

Keywords:
Allometry scaling
Mollusc harvest
Chiton
Length–weight relationship
Traditional fishing
Human exploitation
Ontogenetic allometry

ABSTRACT

The large benthic mollusc *Chiton articulatus*, known locally as "sea cockroach", is commercialized among tourists and locals at Acapulco Bay for its muscular foot (i.e., the edible meat), so it is harvested intensely. However, it has not been declared a fishing resource. Acapulco Bay is the main harvesting and consumption site for this species; thus, it is a proxy fishing area compared to other sites, where it is harvested sporadically. The population size structure, allometry (through length–weight relationship), and body condition of *C. articulatus* were characterized based on monthly harvest data obtained over course of one year in Acapulco Bay. The harvest was carried out by an exclusive chiton fisherman known as the "cucarachero" or "sea cockroach harvester". The total harvest was 16,211 specimens/fisherman/year, with an estimate of 88–121 kg/fisherman/year of chiton. 97% of the total catch was concentrated between 30–60 mm in total length, i.e., the juvenile to adult stages. The length–weight relationship showed positive allometry during the sub-juvenile to juvenile stages (b = 3.16) but negative allometry during the subadult (b = 2.51) and adult stages (b = 2.84). The entire size range showed negative allometry (b = 2.78), which is consistent with an indeterminate length growth. The body condition "*K*" ranged on average between 16.3 and 20, showing significant differences between class intervals; however, over time, three condition periods were generated that related to the reproductive season and feeding of the species. While the size structure of *C. articulatus* in Acapulco appears to be stable over time, the size classes at sexual maturity are strongly harvested, which could lead to a depleted population structure. Currently, 15 fishermen collect chitons in Acapulco, collectively representing approximately 1.5 ± 0.3 tons/year. This information could be useful for making future management decisions related to the harvest of the species and establishing catch quotas.

1. Introduction

The rocky intertidal zone is unique in terms of its environmental conditions and faunal assemblages. This is the meeting place of land and sea, subject to continuous environmental shifts, where a wide variety of marine invertebrates live. Many marine invertebrate species (particularly molluscs) inhabiting this environment may have cultural, social, and commercial value, so their harvest and catch are expected to increase in the future (Thompson et al., 2002; Anderson et al., 2011). Since prehistoric times, intertidal invertebrates have been important in traditional medicine (Herbert et al., 2003), food, and the manufacture of offerings and work instruments (Velázquez-Castro et al., 2017). More recently, their popularity has escalated as a target for human exploitation, contributing to livelihood and well-being with socioeconomic value (Allen, 2017).

Human harvesting of marine invertebrates from intertidal rocky shores is known to alter the size structure and density of their populations, with varied consequences (Riera et al., 2016; Baliwe et al., 2022). Several studies comparing populations in

* Corresponding author at: Facultad de Ecología Marina (FEM), Universidad Autónoma de Guerrero (UAGro), Acapulco, Guerrero, México.
** Corresponding author at: Facultad de Ciencias del Mar (FACIMAR), Universidad Autónoma de Sinaloa (UAS), Mazatlán, Sinaloa, México.
E-mail addresses: 10775@uagro.mx (S. García-Ibáñez), oavila@uas.edu.mx, ohavilapo@conacyt.mx (O.H. Avila-Poveda).

https://doi.org/10.1016/j.rsma.2023.102976
2352-4855/

non-harvested and harvested areas have demonstrated that, in harvested areas, the size frequency distribution is skewed towards organisms with small sizes (Sousa et al., 2020a) – for example, the gastropod *Concholepas concholepas* (Castilla and Duran, 1985) and the limpets *Patella ferruginea* (Espinosa et al., 2009; Coppa et al., 2016), *P. aspera* (Sousa et al., 2020b), *Cymbula granatina*, *C. oculus,* and *Scutellastra argenvillei* (Baliwe et al., 2022). Harvesters generally tend to select the largest specimen available, leading to reduced densities and mean or modal sizes, truncating the population age (or size) structure. This "recruitment overfishing" (Fenberg and Roy, 2008, 2012; Riera et al., 2016) leads to a smaller size at sexual maturity (Espinosa et al., 2009), reduced reproductive outcomes (Fenberg and Roy, 2008), recruitment failure (Riera et al., 2016), and compromised resilience of exploited stocks (Stenseth and Rouyer, 2008).

When an ecosystem is altered by human exploitation, it can be assessed through fisheries' biological aspects, such as the population size structure, to understand the dynamics and status population (Neumann and Allen, 2007). Length–weight relationships are used to calculate biomass in stock assessment models (Morato et al., 2001; Jellyman et al., 2013; Osei et al., 2021) and to assess individual body growth allometry (Baxter and Jones, 1986), mortality rates, fecundity, some reproduction topics (Anderson and Neumann, 1996), and body condition indices as an indicator of the level of individual or population fitness (Froese, 2006; Stevenson and Woods, 2006; Peig and Green, 2009, 2010).

In México, there are approximately 15 species of marine invertebrates belonging to the phyla Mollusca, Crustacea, as well as some Echinodermata, with commercial importance. These species have been declared and registered as fishery resources, and their regulation was updated in the latest version of the National Fisheries Charter (DOF, 2018). However, other coastal marine invertebrates are also harvested and marketed, although they lack fishery status or regulation. This is the case of the polyplacophore mollusc *Chiton articulatus*, known as "chiton". A report published by the FAO nearly three decades ago predicted that *C. articulatus* had the economic potential to become a coastal artisanal fishery (Poutiers, 1995).

This species, known locally as "Dog's Tongue" or "Sea Cockroach", inhabits the rocky intertidal zone and is endemic to the Mexican Tropical Pacific along eight latitudinal degrees (between latitudes 15°N – 23°N), over approximately 1900 km of coastline between Puerto Angel, Oaxaca (15°39′36″N) and Barras de Piaxtla, Sinaloa (23°38′51″N) (Bullock, 1988; Reyes-Gómez, 2004; Reyes-Gómez et al., 2022). In addition, its distribution includes the three oceanic islands of San Benedicto, Socorro, and Clarion within the Revillagigedo Archipelago, Colima (18°49′N; Ferreira, 1983).

Chiton articulatus is harvested for its muscular foot (i.e., the edible meat portion), for the elaboration of dishes and appetizers with commercial values equal to or greater than those of shrimp dishes in restaurants (García-Ibáñez et al., 2013; Avila-Poveda and Valencia-Cayetano, pers. obs.). Harvesting occurs in several places throughout the geographic distribution of this species (Holguín-Quiñones, 2006; Flores-Garza et al., 2012; García-Ibáñez et al., 2013; Avila-Poveda, pers. obs.) but mostly in the Bay of Acapulco, México, where the greatest supply and demand are found (García-Ibáñez et al., 2013; Olea-de la Cruz et al., 2013). Therefore, Acapulco Bay can be considered the main harvesting (fishing) area for *C. articulatus,* providing a good scenario to explore its potential for harvesting. This is especially important given the social, economic, and culturally importance of chiton harvest in the locality, which engages approximately 12–15 chiton harvestmen or "fishermen", known locally as "cucarachero" or "the sea cockroach harvester" (i.e., exclusive chiton artisanal fisherman; Valencia-Cayetano, pers. obs.).

Chiton articulatus is the largest, most abundant Polyplacophora mollusc in the Mexican Tropical Pacific. These characteristics make it a target species for harvest (García-Ibáñez et al., 2013) with biotechnology potential (Çakmak et al., 2022), despite not being under Mexican fishing law. The objective of this study is to evaluate the population size structure, allometry (through length–weight relationship), and body condition of *C. articulatus* harvested monthly over one year. The samples were obtained from different extraction points along Acapulco Bay, México, and were harvested by a single "cucarachero".

2. Materials and methods

2.1. Harvest site characteristics

Acapulco Bay is located in the state of Guerrero in southern México (16°51′42″N, 99°53′11″W, Fig. 1) and is considered one of the most important tourist harbors on the Mexican Pacific coast (Marmolejo-Rodríguez et al., 2017). The Acapulco Bay bathymetric is up to 50 m, referred to as the mean sea level (Ortiz-Huerta et al., 2018). Geomorphically, the Guerrero coastline is a morphotectonic region flanked by a seismic gap that extends from the Orozco Fracture Zone ("OFZ") to the O'Gorman Fracture Zone ("OGFZ"). The continental shelf of Guerrero is 2 km narrow with a coastal landscape characterized by low deltaic alluvial plains, with estuaries and deltas, sandbanks, and berms alternating with metamorphic rocky points, steep and rocky cliffs, platforms, and wave-cut notches in bedrock, marine terraces, and river terraces (Ramirez-Herrera and Urrutia-Fucugauchi, 1999). The chiton harvest area consists of rocky intertidal zones, mainly in sites exposed to wave action. They present a diversity of substrates, with variable dimensions from boulders to large blocks of rock, with diverse textures from smooth to rough and a large presence of cracks and cavities that serve as habitats for several intertidal benthic invertebrates, including *C. articulatus*. Five harvest zones were defined as a posteriori (A1–A5), according to the spatial clustering of fishing sites (Fig. 1).

2.2. Data measurement in chitons

For one year between May 2018 and May 2019, the commercial chiton harvesting by a "cucarachero" was recorded twice a month. This "cucarachero" lives from the chiton harvest and has been dedicated exclusively and continuously to chiton fishing for over 25 years, for 6 days each week. The "cucarachero" selected the harvest site. The fishing gear was a metal rod approximately 80 cm long, with a sharp end and a rubber grip (see Fig. 3 in Olea-de la Cruz et al., 2013). The harvesting procedure consisted of inserting the metal rod at one edge and through the mantle girdle to the pallial groove of the chiton to produce leverage and be able to remove it from the substrate to which it has adhered in cracks or crevices in the rocks. Harvesting was always done in the morning, regardless of the tide level, because the fisherman needed to return before noon to sell the chitons. The harvesting time was approximately 1.37 $\pm$ 0.36 h per day. The total body length (TL) of each specimen on its anteroposterior axis, including the mantle girdle, was recorded with a digital Vernier caliper ($\pm$ 0.1 mm). Organisms showing extreme damage to the mantle girdle due to extraction and those with curling were excluded ($<$10% of the catches). The total body weight (TW $\pm$ 0.01 g), which includes the shell, i.e., the collective whole of valves – also called plates or sclerites – was recorded (Avila-Poveda, 2013).

2.3. Population size structure

Population size structure is the frequency of individuals within different size classes of a population (Neumann and Allen, 2007).

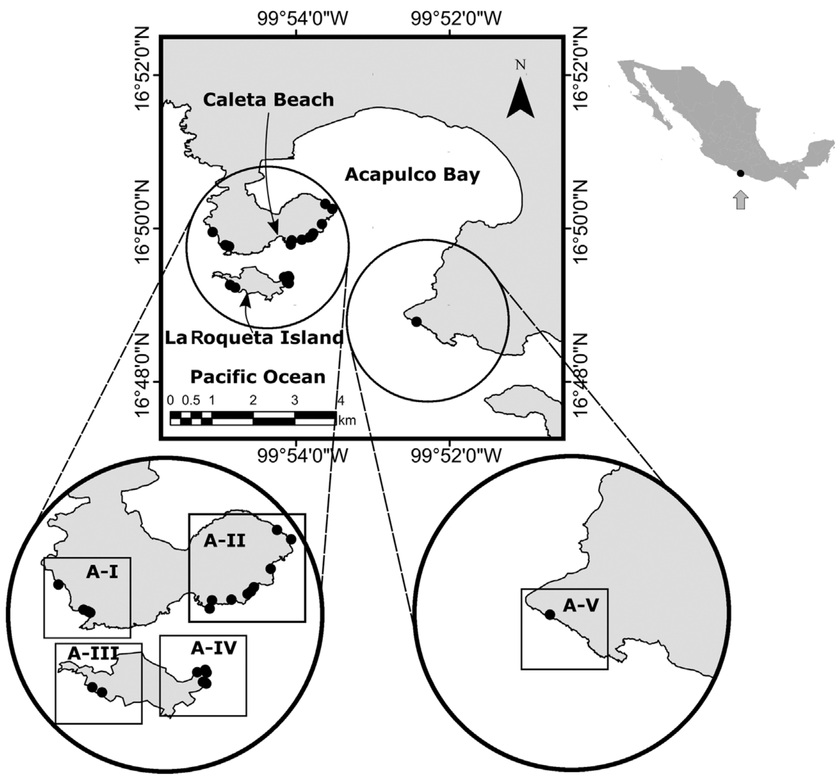

Fig. 1. Sampling area and harvest sites (A-I to A-V) at Acapulco Bay, Guerrero, México. The map projection is WGS84. Made with shapefiles of CONABIO (http://www.conabio.gob.mx/informacion/gis/).

Relative frequency histograms were plotted for both TL and TW, using Sturges' rule to define class intervals (Sturges, 1926; Scherrer, 1984). A Kruskal–Wallis nonparametric test followed by Dunn's post hoc test (Zar, 2010) with Bonferroni's correction was performed by month between TL and TW to differentiate catch size groups. The resulting pairwise comparisons were then grouped using the cldList function in the rcompanion package (http://rcompanion.org/). Length–frequency distributions between harvested areas close to the marketing site (A1–A2) and distant sites A3–A5 (Fig. 1) were compared with the Kolmogorov–Smirnov test. This uses the maximum deviation (D) between the TL cumulative frequency distributions for each harvest area (Zar, 2010).

2.4. Allometry (through length–weight relationship)

The relationship of body size to shape as an application to understand the growth rates of the body parts of the chitons was fitted using the logarithmic form of the allometric equation between length and weight (Hopkins, 1992):

$$\log_{10} \mathrm{TW} = \log_{10} a + b(\log_{10} \mathrm{TL})$$

where TW is total body weight (g), TL is total body length (mm), a is the intercept, and b represents the allometry scaling coefficient or change that deviates from isometry. A perfectly allometrically scaling organism would see all length-based properties change with mass to the power of 1/3; therefore, $b = 3$ indicates isometric allometry, $b > 3$ shows "positive allometry", and $b < 3$ is called "negative allometry" (Hopkins, 1992; Froese, 2006). Allometry was estimated over the entire size range and for each life stage, comprising scaling effects during the growth of an individual owing to "ontogenetic allometry" – also called "growth allometry" or "heterauxesis" (Peig and Green, 2010) – then considering three life stages following Avila-Poveda and Abadia-Chanona (2013): sub-juvenile to juvenile (0–28 mm TL), subadult (28–40 mm TL), and adult (>40 mm TL). Subsequently, the average allometry coefficient (b) for each life stage was estimated and plotted against the size range. The t-Student test was performed using the FSA package (https://github.com/droglenc/FSA), to determine if the scaling relationship deviated from the isometric. The linear correlation between TW and TL data sets was analyzed using Pearson's r correlation coefficient.

2.5. Body condition

The body condition of a species is assumed to reflect biological characteristics such as health, well-being, reproductive state, and the general "conditions of nutrition" brought about by environmental conditions such as habitat quality, water quality, and food availability (Nash et al., 2006). It is assumed that the heavier an animal is at a given length, the higher the factor and (by implication) the better its "health and fitness condition". Thus, higher K values indicate good physiological condition (Ricker, 1975), so body condition "K" was estimated using Fulton's condition factor (Ricker, 1975):

$$K = \frac{\mathrm{TW}}{\mathrm{TL}^b} * 100,000$$

where TW and TL, respectively, are the observed total body weight and total body length, and b is the allometry scaling coefficient determined by length–weight regression, which is a better scaling description than the underlying assumption of an isometric growth raised to the 3rd power (Stevenson and Woods, 2006). A multiplier scaling factor of 100,000 was applied to scaling small decimals when metric units of grams and millimeters were used, so that the numbers can be more easily comprehended (Neumann et al., 2012). K was explored by class intervals and size; size groups were identified monthly, as well as by fitting a multinomial model to the data (Montgomery et al., 2010). Finally, the Kruskal–Wallis test was applied, followed by

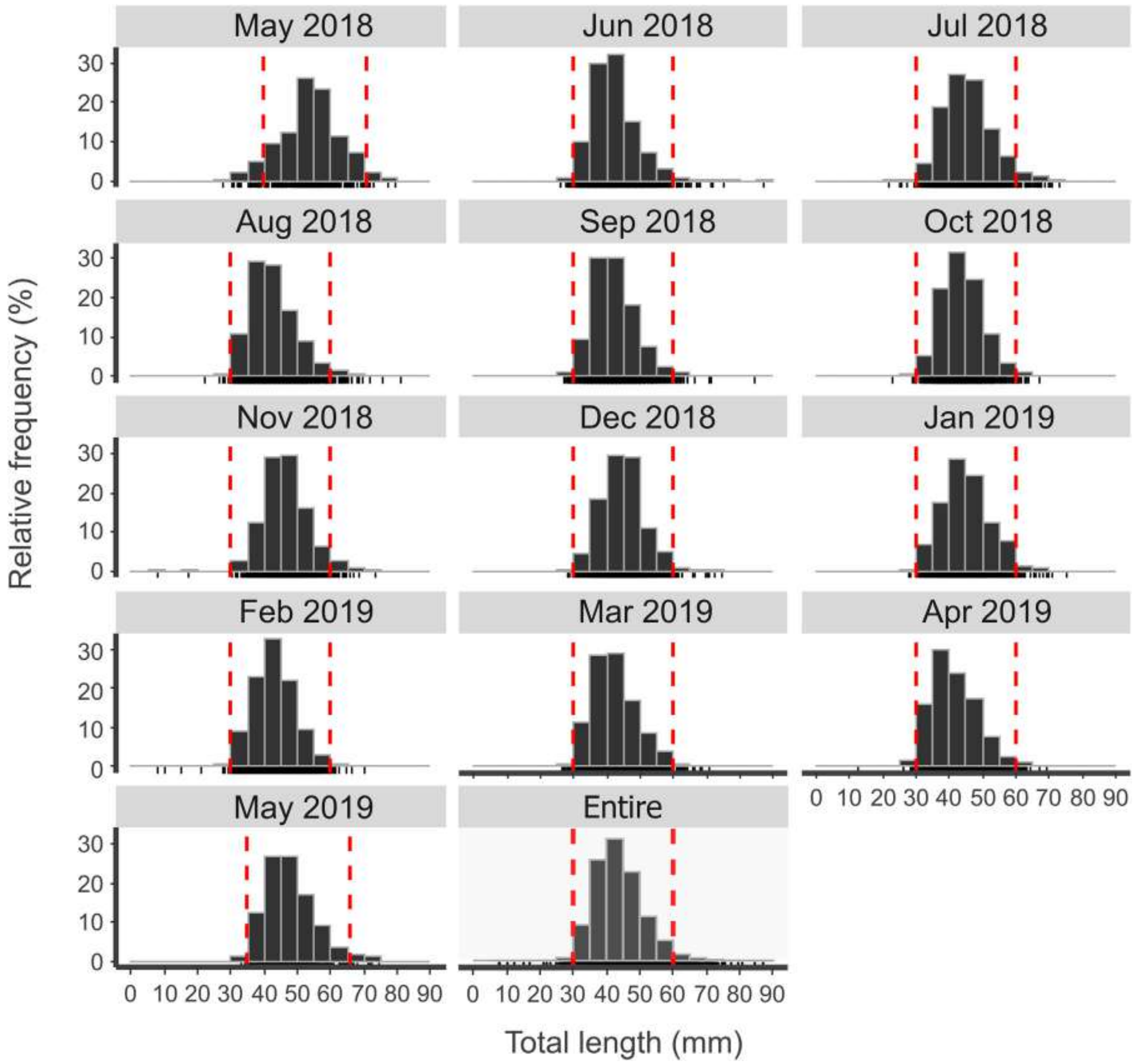

Fig. 2. Entire and monthly frequency distribution of TL of *Chiton articulatus* harvested in Acapulco, México. The dotted lines delimit the rank of harvest concentration. The rug plot on the horizontal axes of the histogram displays the individual cases at the extremes of the distribution.

Dunn's post hoc test with Bonferroni's correction (Zar, 2010), to determine the significant differences between class intervals. The resulting pairwise comparisons were then grouped using the cldList function in the rcompanion package. Statistical analyses were performed using R v. 3.6.2 (https://www.R-project.org/). The significance level was $\alpha \leq 0.05$.

3. Results

3.1. Population size structure frequency distribution

An annual total of 16,211 specimens of *C. articulatus* were harvested, of which 14,742 specimens without damage or curling represented 91%. Their total length and total weight distribution are described below. Following the average weight of the highest proportion of chiton harvested (5.79 ± 0.01 g [mean ± SE]; n = 15,204; 94%), there is an estimate of between 88 and 121 kg/fisherman/year.

The entire TL distribution (Fig. 2) ranged between 7.8 mm and 87.0 mm (43.67 ± 0.06 mm), with a size concentration between 30 mm and 60 mm in TL (43.3 ± 0.05 mm; $n = 14{,}304$), which represents 97% of the total organisms measured. Specimens less than 30 mm in TL represented 0.7% (27.5 ± 0.42 mm, $n = 104$), while specimens greater than 60 mm in TL represented 2.3% of the total harvest (64.52 ± 0.22 mm, $n = 334$). Monthly, TL distribution showed that both May 2018 and May 2019 had more extended distribution ranges than the other months (35 to 70 mm) (Fig. 2).

The entire TW distribution (Fig. 3) ranged between 0.04 g and 39.16 g (6.33 ± 0.02 g), with the highest proportion concentrated between 2 g and 12 g (5.79 ± 0.01 g, $n = 15{,}204$) representing 93.8% of the total harvest. Specimens less than 2 g represented 0.5% (1.54 ± 0.05 g, $n = 76$), while specimens greater than 12 g represented 5.7% of the total harvest (15.46 ± 0.12 g, $n = 931$). Monthly, TW distribution showed greater variations; May 2018 had a wider range than the other months (2 g to 20 g) (Fig. 3).

The Kolmogorov–Smirnov test analysis indicated differences in TL between the collection area near the point of sale (Caleta beach, Fig. 1) and the collection area far from the point of sale (A1 vs. A3, A4, A5, D = 0.16, D = 0.24, D = 0.06, $P < 0.05$; A2 vs. A3–A5, D = 0.05, D = 0.26, D = 0.17, $P < 0.05$, respectively). Meanwhile, no difference was shown between nearby regions (A1 vs. A2, D = 0.031, $P = 0.062$). The size composition of nearby

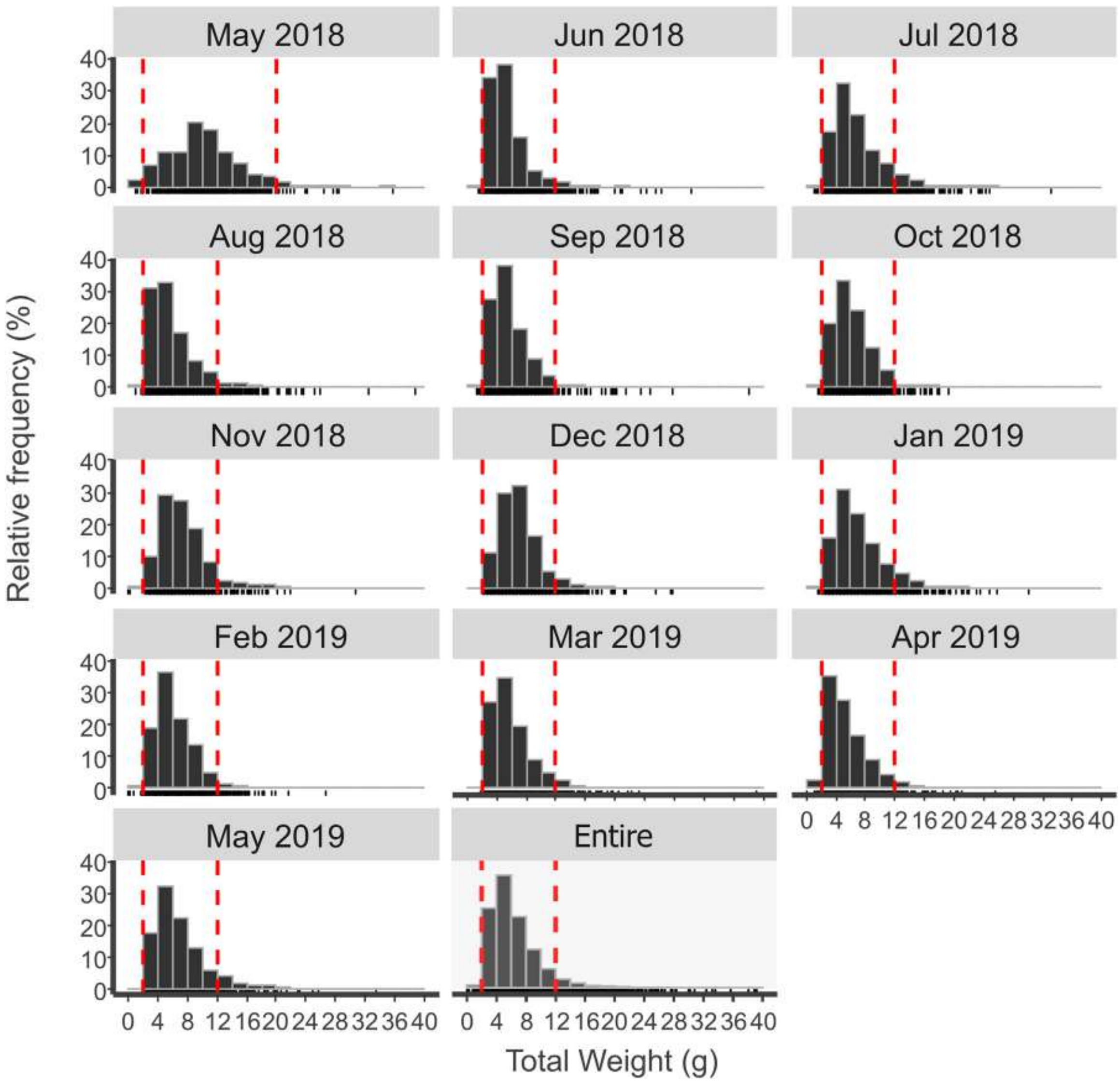

Fig. 3. Entire and monthly frequency distribution of TW of *Chiton articulatus* harvested in Acapulco, México. The dotted lines delimit the rank of harvest concentration. The rug plot on the horizontal axes of the histogram displays the individual cases at the extremes of the distribution.

areas was lower than that of distant areas, supporting the idea that harvesting influences size structure.

3.2. Monthly variation of TL and TW of C. articulatus

Significant differences in TL were observed between months ($H = 1230.4$, $df = 12$, $P < 0.001$). The highest TLs corresponded to May 2018, November 2018, and May 2019, with medians ranging from 46.06 to 54.31 mm. In July 2018, October 2018, December 2018, and January 2019, the intermediate values of catch sizes were recorded, with medians ranging from 42.60 to 44.84 mm. Low TL values corresponded to the months of June 2018, August 2018, September 2018, March 2019, and April 2019 (Fig. 4a).

For the median TW, significant groups were distinguished ($H = 1{,}203.3$, $df = 12$, $P < 0.001$). Organisms with the highest TW were recorded in May 2018 (median 9.85 g). Organisms with intermediate TW corresponded to the months of July 2018, October 2018, November 2018, December 2018, January 2019, February 2019, and May 2019 (range medians 5.7 to 6.8 g). Low TW corresponded to June 2018, August 2018, September 2018, March 2019, and April 2019 (medians 4.6 to 5.2 g) (Fig. 4b).

3.3. Allometry (length–weight relationships)

The length–weight relationship was significant (F-value = 148,274; P < 0.001); thus, the linear correlation explains 95% of the TW variation for the TL data sets (Pearson's r correlation coefficient: r = 0.95): $TW = 0.000162 * TL^{2.78}$.

The scaling relation between length and weight for all chitons (independent of each life stage) showed negative allometry ($b = 2.78$, *C.I.* = 2.77 to 2.80; *t-test* b, $P < 0.001$) (Fig. 5), indicating length increases faster than weight. According to life stages, the b-value for the sub-juvenile to juvenile life stages ($n = 29$) was $b = 3.16$ (*t-test* = 1.07, $P = 0.29$), showing positive allometry. Both the subadult ($n = 4{,}812$) and adult ($n = 9{,}889$) life stages presented negative allometry ($b = 2.51$, $b = 2.84$, respectively), which differs from isometric allometry ($P < 0.001$) (Fig. 5). Monthly, b-values were estimated between 2.54 to 3.14, being statistically different from isometric allometry with the valor of 3 (*t-test* = −8.238, $P < 0.001$).

3.4. Body condition "K"

Following a complete TL frequency distribution, Fulton's condition factor "K" showed significant differences between class

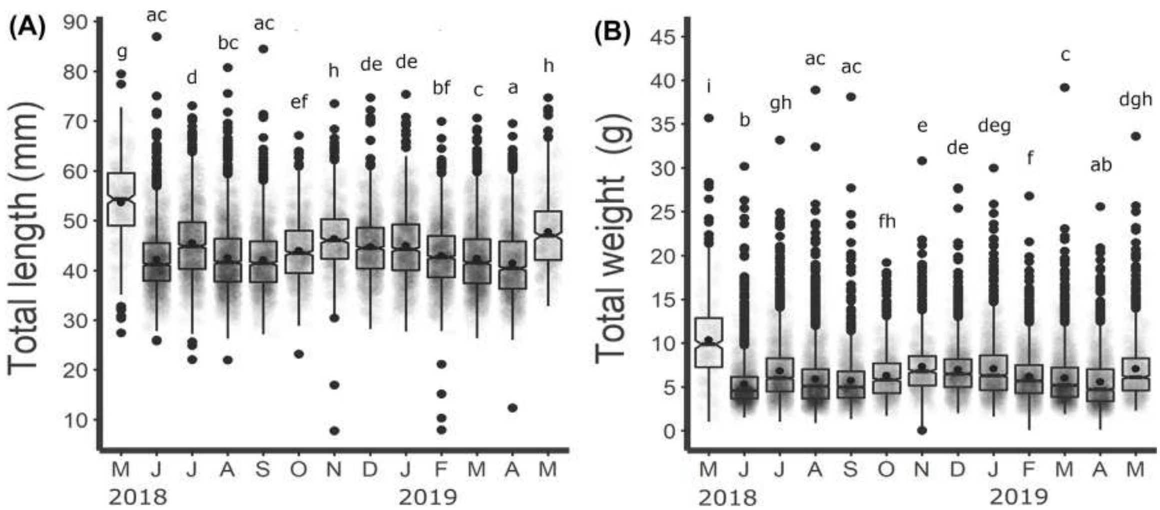

Fig. 4. Monthly variation of total length (a) and total weight (b) of *Chiton articulatus* harvested in Acapulco, México from May 2018–May 2019. Letters indicate *post hoc* comparisons according to Dunn's test (different letters indicate significant differences, $p < 0.05$). The notches show the approximate 95% confidence interval for the median. Dots indicate the arithmetic mean and shade the distribution of the data.

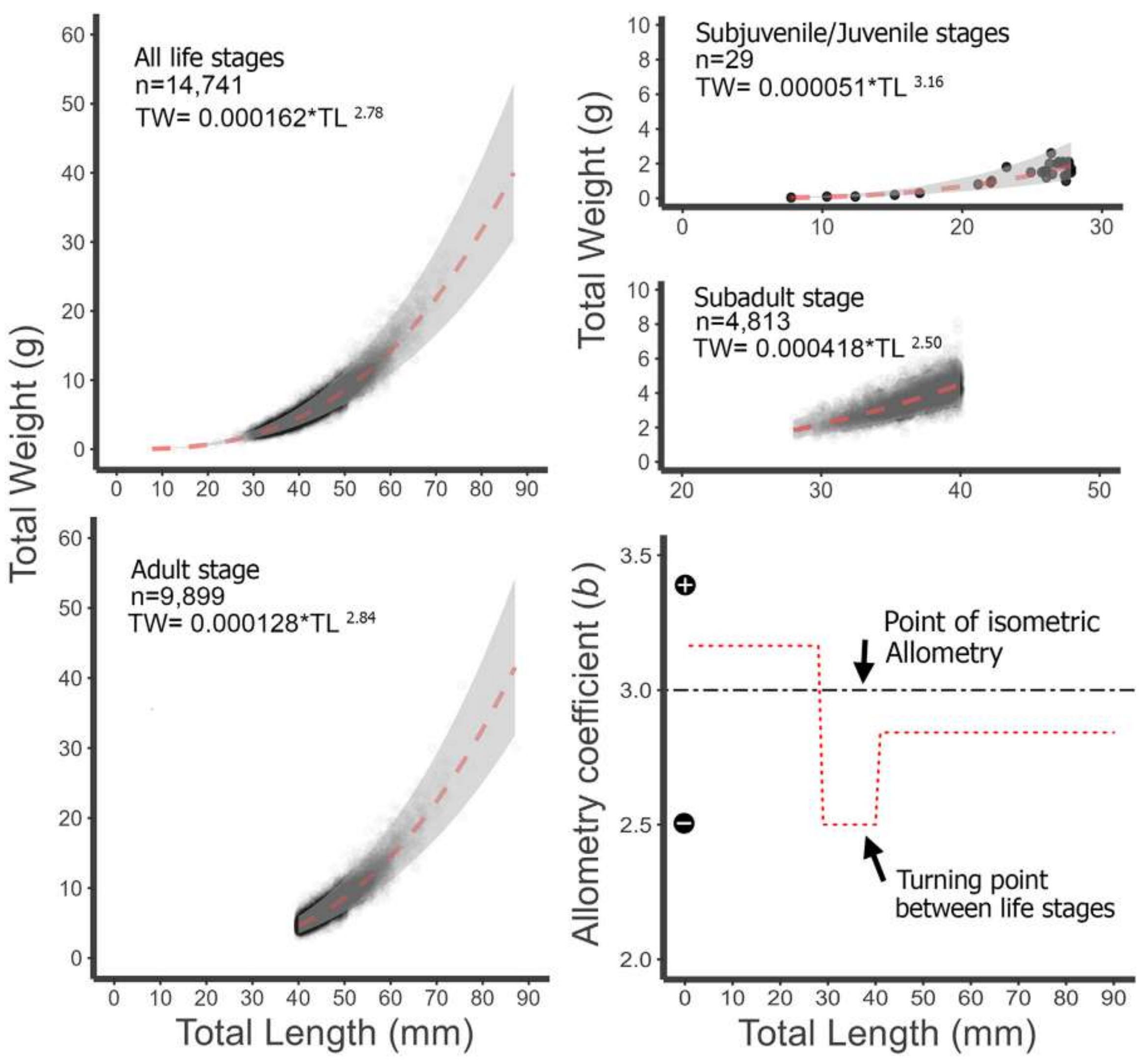

Fig. 5. Length–weight relationship and variation of allometry coefficient (b) for the entire size range and each life stage of *Chiton articulatus* collected by a harvestman ("cucarachero") in Acapulco, México. The shaded area represents the 95% confidence interval "*C.I.*". Positive allometry indicates that weight increases faster than length, while negative allometry indicates that length increases faster than weight.

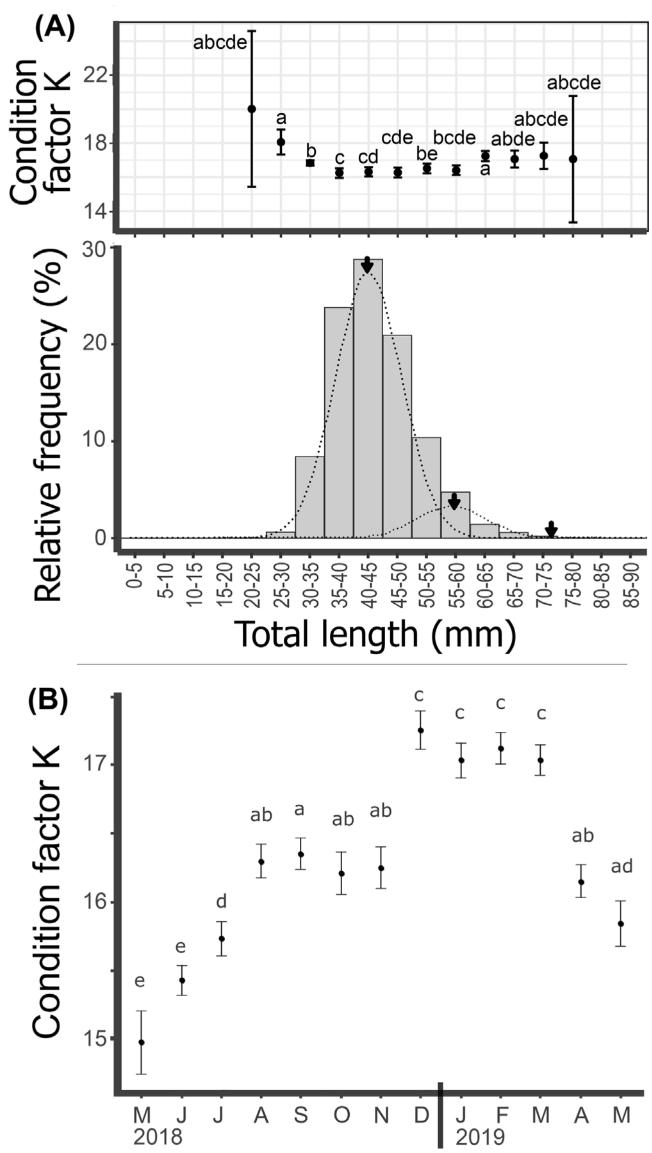

Fig. 6. Fulton's condition factor "*K*" of *Chiton articulatus* in Acapulco Guerrero, México. (A) *K* factor through the entire TL frequency distribution. (B) *K* factor through time. Arrows in frequency distribution indicate the modal groups that establish the number of size groups. Class intervals $N \leq 2$ were excluded. Different letters indicate significant differences at $p < 0.05$ according to Dunn's test. Values in condition factor *K* are mean ± SE.

intervals ($H = 130, df = 11, P < 0.001, n =$ 14,721), ranging from 8 to 29.6 (Fig. 6a); both the lower interval class (20 to 35 mm TL) and the upper interval class (70 to 80 mm TL) showed high dispersion. The highest-class interval (40–45 mm TL) was K = 16.3 ± 0.03 (Fig. 6a).

Monthly variation of the body condition "*K*" showed significant differences that could be divided into 3 periods of condition. The first period, with the highest K-values from 17.2 ± 0.7 to 17 ± 0.05, occurred over 4 months, from December 2018 to March 2019. The second period occurred 4 months before and 2 months after the highest K-values, with K-values between 16.3 ± 0.06 and 16.2 ± 0.07 from August to November 2018 and K-values from 16.15 ± 0.06 to 15.8 ± 0.08 later in April and May 2019. A third period was increased for 3 months from May to July 2018, with K-values ranging from 15 ± 0.1 to 15.8 ± 0.06 (Fig. 6b).

4. Discussion

4.1. Population size structure

To date, it is known that approximately 15 fishermen extract chitons in Acapulco. Based on our analysis, it is anticipated that these harvestmen collectively harvest about 1.5 ± 0.3 tons of chitons over one year. This estimate is limited to extrapolation from the data of an only fisherman, so it would be ideal to be able to verify the number of fishermen, as well as their harvest and its exclusivity for chitons. This could be useful for making future management decisions related to the harvest of the species and establishing catch quotas.

The harvest of *C. articulatus* was selective, concentrating on chitons between 30 and 60 mm TL. According to the fisherman, chitons that are too small provide poor muscle yield and therefore are not of interest. This claim is supported by our analyses, as we observed a few organisms less than 30 mm TL, which could be considered bycatch of chitons on top of the larger ones. Otherwise, fishermen indicate that large chitons are scarce near the coast and that they are found in remote and difficult-to-access places where the waves break with a strong force, making it dangerous to harvest chitons and resulting in fatalities for fishermen. Our analysis shows few chitons larger than 60 mm TL, which supports this claim.

Selective harvesting can lead to two scenarios that bias the size distribution of the population. First, size-selective fishing removes large organisms due to their high value (Fenberg and Roy, 2008; Miethe et al., 2019). Second, fishing can be selective between protected and non-protected areas, resulting in a clear reduction in the non-protected zone (Castilla and Duran, 1985; Riera et al., 2016; Sousa et al., 2020a). Historical records show that the length range of *C. articulatus* has varied, with reported lengths of 108 mm (Ferreira, 1983), 104 mm (Bullock, 1988), 87 mm (Flores-Campaña et al., 2007), 78 mm (Avila-Poveda, 2013), and lately, between 75 and 42 mm (Galeana-Rebolledo et al., 2014; Castro-Mondragón et al., 2016). This variation does not necessarily imply a spatiotemporal decrease in size but rather reflects the focus of previous studies on areas other than population size structure. Recent growth studies estimate an asymptotic length or maximum theoretical length (L_∞) close to 81 mm (Avila-Poveda et al., 2020), and samplings in the northernmost distribution area (Barras de Piaxtla, Sinaloa) reveal chitons close to 92 mm in TL (Avila-Poveda, pers. obs.). In fact, in insular regions, large chitons – some exceeding 108 mm – predominate today (Holguín-Quiñones and Michel-Morfín, 2002; Michel-Morfin, Universidad de Guadalajara, pers. comm.).

Hence, the reduction in specimens larger than 60 mm TL at Acapulco could be the result of recruitment overfishing (Hilborn and Walters, 1992), which has eliminated larger organisms from the population. Multiple factors may have contributed to this reduction, such as fishing pressure, size selectivity patterns, natural mortality, unrestricted access to coastal areas, proximity to urban centers where the chitons are marketed, and the easy and free access to harvesting sites by fishermen, tourists and local people (Holguín-Quiñones and Michel-Morfín, 2002; Holguín-Quiñones, 2006; García-Ibáñez et al., 2013). The absence of large organisms can have diverse ecological consequences, such as changes in community structure, high mortality rates, effects related to reproductive investment, changes in growth rate, and fecundity (Fenberg and Roy, 2008). Therefore, this issue should be examined further in future studies. Growth overfishing does not appear to have occurred during the study period. This may be because most organisms at the beginning of their life stages remain cryptically in crevices, under other invertebrates such as urchins and among filamentous algae (Avila-Poveda, pers. obs); therefore, given their small size, they are imperceptible and do not have commercial value.

On the other hand, with regards to the mean TL harvest, it is important to note that the value recorded in our study is higher than that reported by other studies in Acapulco by Rojas-Herrera (1988) ($n = 2583$; mean = 36.15) and Castro-Mondragón et al. (2016) ($n = 115$, mean = 40.79 ± 7.6). Our findings are, however, consistent with García-Ibáñez et al. (2013), who reported TL means of 43.55 mm (2009), 43.41 mm (2010), and 41.53 mm (2011). While their study reports a declining trend in mean length, our results indicate that the size structure of *C. articulatus* from Acapulco has remained stable over time, with minor interannual variations. However, it is noteworthy that the size classes surrounding the size at sexual maturity in the population structure are being heavily harvested, which could potentially lead to the depletion of the population. The size at sexual maturity ($TL_{50\%}$) for *C. articulatus* has been reported to range from 51.8 to 58.6 mm TL (Abadia-Chanona et al., 2015; Avila-Poveda et al., 2021), which aligns with the minimum optimal catch size of 59.54 mm TL calculated by Rojas-Herrera (1988). It is also important to note that fishermen often have a good understanding of the location and density of the stock and may concentrate their fishing efforts in areas with the highest density (Prince and Hilborn, 1998). This may result in yields and associated size metrics, such as mean length, remaining relatively stable even as populations are depleted, ultimately leading to a gradual decline in availability until local disappearance (Prince and Hilborn, 1998).

In the same way, the size structures of the samples collected in different studies may be biased towards either smaller or large size distributions, depending on the objectives and sampling methods used (Elahi et al., 2020). For instance, previous biological investigations carried out along the Guerrero coast, including population or community-based studies that included *C. articulatus*, have reported mean TL values ranging from 18.39 to 25.34 mm. While our study includes a proportion of catch that falls within this range, it is far from the overall mean harvest. Conversely, commercial catch sampling is typically not randomly or systematically allocated but instead directed towards areas with the highest biomass and concentration of large-size organisms.

It has been observed that a body size cline is associated with the southernmost latitudes in *C. articulatus* (Guillen et al., 2021) as well as other chiton species from coastal habitats in the southeastern Pacific (Ibáñez et al., 2021), such as *Plaxiphora aurata* (López-Gappa and Tablado, 1997). However, the harvesting of chitons in Acapulco may have a significant impact on development and size population, given that Acapulco is located at the lower end of the distribution range. As a result, chiton populations in Acapulco may experience size reductions due to harvesting pressures, which in turn could contribute to the observed body size cline associated with lower latitudes.

Thus, it is crucial to consider the differences between the main methods available when describing the size structure of *C. articulatus* for fishery management. Combining methods at the same spatial and temporal scales can help mitigate methodological biases and provide a more accurate proxy of the size structure of the population subjected to continuous harvesting (Bustamante and Castilla, 1990). Neglecting to account for these differences may result in inaccurate management reference points that fail to adequately capture the size structure and population dynamics of the species.

4.2. Allometry (through length–weight relations)

The length–weight relationship for the *C. articulatus* population harvest in Acapulco Bay exhibits negative allometry for the entire size range between 7.76 and 87 mm TL, indicating that length increases faster relative to weight (Baxter and Jones, 1978). Allometry coefficients have been reported in various studies of *C. articulatus* along its geographical range, such as $TW = 0.0001{*}TL^{2.8404}$ at Isla Pájaros, Venados y Lobos, Mazatlán, Sinaloa (23°13′N; Flores-Campaña et al., 2007), $TW = 0.0002{*}TL^{2.7300}$ at Socorro Island, Colima (18°41′N; Holguín-Quiñones and Michel-Morfín, 2002), $TW = 0.0002{*}TL^{2.7700}$ at Acapulco, Guerrero (16°50′N; Rojas-Herrera, 1988), and $TW = 0.0002{*}TL^{2.7176}$ for an adult population at Puerto Angel, Oaxaca (15°39′N; Avila-Poveda, 2013). The allometry of *C. articulatus* appears to vary latitudinally, with higher *b*-values in subtropical localities such as Mazatlán, Sinaloa, than in tropical localities such as Puerto Angel, Oaxaca. This variation may be explained by the ectothermic nature of the species, consistent with previous findings indicating an increase in length and growth rate with increased latitude (López-Gappa and Tablado, 1997; Guillen et al., 2021).

The allometry of chiton species can differ, with some, such as *Acanthopleura gemmata* (b = 2.5158; Eman et al., 1992 as *A. spiniger*), *Plaxiphora aurata* (b = 2.66; López-Gappa and Tablado, 1997), *Chiton albolineatus* (b = 2.7097; Flores-Campaña et al., 2012) and *Radsia goodallii* ($b = 2.948$, Herrera et al., 2003), exhibiting negative allometry, while others, such as *Acanthochitona defilippii*, *Liolophura japonica*, *Lepidozona coreanica* and *Ischnochiton comptus,* exhibit positive allometry with values of $b = 3.14$, $b = 3.07$, $b = 3.35$ and $b = 3.35$, respectively (Tokeshi et al., 2000). These differences may be influenced by environmental factors and habitat adaptations or driven by the increase in relative body volume during development and/or gonad resting in polyplacophores (Baxter and Jones, 1978; Avila-Poveda and Abadia-Chanona, 2013).

These interspecific variations in allometry are associated with ontogenetic changes in body proportions throughout early life stages (Avila-Poveda, 2013; Ibáñez et al., 2018). In our study, we observed a change in allometry around 30 to 40 mm TL that is consistent with the transition from the juvenile stage to the adult stage in *C. articulatus*, confirming the size range previously established through the histology of gonadal ontogenesis for each life stage of this species (see Fig. 17 in Avila-Poveda and Abadia-Chanona, 2013). This change can be explained by a shift in energy allocation from growth to reproductive activities such as gonad maturation (Lord and Shanks, 2012). As the chiton reaches maturity, more energy is invested in reproduction than growth, resulting in a lower relative growth rate in weight compared to juveniles. This finding is consistent with previous studies, where similar shifts in energy allocation were observed during ontogeny (e.g., Avila-Poveda, 2013). On the other hand, the negative allometry observed through the *C. articulatus* adult life stage indicates that length increases relatively faster than weight, which supports an indeterminate growth or infinity asymptotic body length indicated in polyplacophorans (Lord and Shanks, 2012).

It is important to consider these changes in allometry when developing management strategies for exploited species, as changes in scaling allometry can have implications for population dynamics and the effectiveness of management measures. Further research is needed to better understand the underlying mechanisms driving these ontogenetic shifts in allometry and how they can be incorporated into management frameworks.

4.3. Body condition

Fulton's condition factor *K* showed little variation through the total lengths of class intervals, with K-value means ranging from 16 to 20. The condition factor appears to be inversely related to the reproductive activity of the species over time. Although *C.*

articulatus has ripe gonads throughout the year (Abadia-Chanona et al., 2018; Avila-Poveda et al., 2021), only two periods of maximum gonad investments, with the highest GSI values up to 6% of body mass, occur around May and September–October (Abadia-Chanona et al., 2018). Therefore, the reproductive season is 6 months long, from April to September (Avila-Poveda et al., 2021), and corresponds to low K-values of 16.3. This fluctuation in the condition factor suggests that during the reproductive season, *C. articulatus* may reduce its feeding or change its diet from macroalgae to microalgae, detritus, and organic matter (Prado-Padilla, 2022). The energy for reproduction (ripe gonad) may come at the expense of the storage of other organs (Avila-Poveda, 2013).

The increase in K coincides with a period of increased frequency of the population with spawning and/or resting gonads (i.e. gonads that lose weight relative to the body) as reported by Abadia-Chanona et al. (2018), along with the incursion of cold water near the coast (Gutiérrez-Zavala and Cabrera-Mancilla, 2019), which increases primary productivity (García-Ibáñez et al., 2013) and serves as the basis for the feeding of *C. articulatus*. This enhances their body condition and leads to new production of gametes. These findings could be useful for establishing closures and management measures for the species. Likewise, the subtle relative increase in K observed through the increase in total length of *C. articulatus* could relate to Lord and Shanks (2012) finding that some species with indeterminate growth (including chitons) do not reduce energy allocation to growth with age but instead display continuous volumetric growth that facilitates increases in feeding rate and reproductive output with age and size.

5. Conclusion

Our study demonstrates that the unregulated fishing and intense harvesting of *C. articulatus* in Acapulco Bay harms the population structure, leading to a reduction in size classes around the size reached at sexual maturity. This could potentially lead to overexploitation and population decline. However, it must be noted that the sampling was carried out by only one "cucarachero", at different extraction points along Acapulco Bay. Such sampling may introduce bias, as the harvest practices and techniques of this "cucarachero" may not be representative of all harvestmen in the area. Therefore, further studies using different sampling techniques and including multiple harvesters are needed to fully understand the population dynamics of *C. articulatus* in Acapulco Bay. The length–weight relationship exhibited negative allometry, indicating that smaller individuals have relatively greater weights compared to larger individuals. Understanding these factors can help to better estimate the biomass and size distribution of the population, which are important parameters for the development of effective management strategies. It is imperative to implement sustainable management practices to ensure the preservation of this species. Our results suggest that the condition factor of individuals varied throughout the year and was influenced by factors such as reproductive condition and food availability. Our findings highlight the urgent need for effective conservation measures to protect *C. articulatus*.

CRediT authorship contribution statement

Carlos Valencia-Cayetano: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Sergio García-Ibáñez:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing. **Omar Hernando Avila-Poveda:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Jesús Guadalupe Padilla-Serrato:** Validation. **Juan Violante-González:** Validation. **Rafael Flores-Garza:** Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgments

Valencia-Cayetano C received a CONACYT scholarship, and the results presented here are part of his MSc Thesis at FEM-UAGro. We extend special thanks to Sr. Oscar (Conejito), the chiton fisherman or "cucarachero", for allowing us to evaluate his work tasks. We thank the staff of the Laboratorio de Ecología Cuantitativa, Facultad de Ecología Marina, UAGro, for their assistance with sampling. Avila-Poveda OH and Padilla-Serrato JG are both CONACYT Research Fellows hosted in their corresponding work affiliation under project no. 2137 and project no. 402, respectively. The authors received no funding for this work.

Ethical statement

Each of the chitons was provided by the fisherman "cucarachero". No chitons were sacrificed; they were only measured.

References

Abadia-Chanona, Q.Y., Avila-Poveda, O.H., Arellano-Martinez, M., Ceballos-Vazquez, B.P., Flores-Campaña, L.M., Moreno-Sanchez, X.G., Ramirez-Perez, J.S., 2015. Talla inicial de madurez sexual (tim) y/o talla de madurez sexual (tm50%) –medida de manejo pesquero para el poliplacóforo *Chiton (Chiton) articulatus*: caso de estudio. Foro Ib Rec. Mar. Acuic. 7, 389–398, [In Spanish].

Abadia-Chanona, Q.Y., Avila-Poveda, O.H., Arellano-Martinez, B.P., Benitez-Villalobos, F., Parker, G.A., Rodriguez-Dominguez, G., García-Ibañez, S., 2018. Reproductive traits and relative gonad expenditure of the sexes of the free spawning *Chiton articulatus* (Mollusca: Polyplacophora). Invertebr. Reprod. Dev. 62, 268–289.

Allen, M.J. (Ed.), 2017. Molluscan in Archaeology: Methods, Approaches and Applications. Oxbow Books, Oxford, UK.

Anderson, S.C., Flemming, J.M., Watson, R., Lotze, H.K., 2011. Rapid global expansion of invertebrate fisheries: trends, drivers, and ecosystem effects. PLoS ONE 6, e14735.

Anderson, R.O., Neumann, R.M., 1996. Length, weight, and associated structural indices. In: Murphy, B.E., Willis, D.W. (Eds.), Fisheries Techniques. American Fisheries Society, Bethesda, MD, pp. 447–481.

Avila-Poveda, O.H., 2013. Annual change in morphometry and somatic and reproductive indices of *Chiton articulatus* adults (polyplacophora: chitonidae) from Oaxaca, Mexican Pacific. Am. Malacol. Bull. 31, 65–74.

Avila-Poveda, O.H., Abadia-Chanona, Q.Y., 2013. Emergence, development, and maturity of the gonad of two species of chitons "sea cockroach" (mollusca: Polyplacophora) through the early life stages. PLoS ONE 8, e69785.

Avila-Poveda, O.H., Abadia-Chanona, Q.Y., Alvarez-García, I.L., Arrellano-Martinez, M., 2021. Plasticity in reproductive traits of an intertidal rocky shore chiton (polyplacophora: Chitonida) under pre-ENSO and ENSO events. J. Mollusc. Stud. 87, eyaa033.

Avila-Poveda, O.H., Rodriguez-Dominguez, G., Ramirez-Perez, J., Perez-Gonzalez, R., 2020. Plasticity in growth parameters of an intertidal rocky shore chiton (polyplacophora: Chitonida) under pre-ENSO and ENSO events. J. Mollusc. Stud. 86, 72–78.

Baliwe, N.G., Pfaff, M.C., Branch, G.M., 2022. Assessing the effects of no-take zones in a marine protected area spanning two ecoregions and rock substrate types. Front. Mar. Sci. 9, e893260.

Baxter, J.M., Jones, A.M., 1978. Growth and population structure of *Lepidochitona cinereus* (Mollusca: Polyplacophora) infected with *Minchinia chitonis* (Protozoa: Sporozoa) at Easthaven, Scotland. Mar. Biol. 46, 305–313.

Baxter, J.M., Jones, A.M., 1986. Allometric and morphological characteristics of *Tonicella marmorea* (Fabricius, 1780) populations (Mollusca: Polyplacophora: ischnochitonidae). Zool. J. Linn. Soc. 88, 167–177.

Bullock, R.C., 1988. The genus *Chiton* in the new world (Polyplacophora: Chitonidae). Veliger 31, 141–191.

Bustamante, R.H., Castilla, J.C., 1990. Impact of human exploitation on populations of the intertidal southern bull-kelp *Durvilaea antarctica* (Phaeophyta, Durvileales) in central Chile. Biol. Cons. 52, 205–220.

Çakmak, E., Koc-Bilican, B., Avila-Poveda, O.H., Karaduman, T., Cansaran-Duman, D., Williams, S.T., Kaya, M., 2022. Discovery of protein-based natural hydrogel from the girdle of the 'sea cockroach' *Chiton articulatus* (Chitonida: Chitonidae). PeerJ 10, e13386.

Castilla, J.C., Duran, L.R., 1985. Human exclusion from the rocky intertidal zone of central Chile: the effects on *Concholepas concholepas* (Gastropododa). Oikos 45, 391–399.

Castro-Mondragón, H., Flores-Garza, R., Valdez-González, A., Flores-Rodríguez, P., García-Ibáñez, S., Rosas-Acevedo, J.L., 2016. Diversidad de especies de mayor importancia y composición de tallas de los moluscos en la pesca ribereña en Acapulco, Guerrero, México. Acta Univ. 26, 24–34.

Coppa, S., De Lucia, G.A., Massaro, G., Camedda, A., Marra, S., Magni, P., Perilli, A., Di Bitetto, M., García-Gómez, J.C., Espinosa, F., 2016. Is the establishment of MPAs enough to preserve endangered intertidal species? The case of *Patella ferruginea* in mal di ventre island (w Sardinia, Italy). Aquat. Conserv. 26, 623–638.

Olea-de la Cruz, F.G., García-Ibáñez, S., Flores-Garza, R., Flores-Rodríguez, P., Rojas-Herrera, A.A., 2013. Pesca, oferta y demanda de la cucaracha de mar *Chiton articulatus* (mollusca: Polyplacophora) en aguas de la zona costera del estado de Guerrero, México. Cienc. Pesq. 21, 69–81.

Diario Oficial de la Federación (DOF), 2018. ACUERDO por el que se da a conocer la actualización de la carta nacional pesquera 2017. https://www.dof.gob.mx/nota_detalle.php?codigo=5525712&fecha=11/06/2018#gsc.tab=0.

Elahi, R., Miller, L.P., Litvin, S.Y., 2020. Historical comparisons of body size are sensitive to data availability and ecological context. Ecology 101, e03101.

Eman, W.M., Ismail, N.S., Abou Gabal, 1992. Age and growth of chiton *Acanthopleura spiniger* from the northwestern region of the red sea. Indian J. Mar. Sci. 21, 274–277.

Espinosa, F., Rivera-Ingraham, G.A., Fa, D., García-Gómez, J.C., 2009. Effect of human pressure on population size structure of endangered ferruginean limpet: toward future management measures. J. Coast. Res. 25, 857–863.

Fenberg, P.B., Roy, K., 2008. Ecological and evolutionary consequences of size-selective harvesting: how much do we know? Mol. Ecol. 17, 209–220.

Fenberg, P.B., Roy, K., 2012. Anthropogenic harvesting pressure and changes in life history: insights from a rocky intertidal limpet. Am. Nat. 180, 200–210.

Ferreira, A.J., 1983. The chiton fauna of the Rivillagigedo Archipelago, México. Veliger 25, 307–322.

Flores-Campaña, L.M., Arzola-González, J.F., León-Herrera, R., 2012. Body size structure, biometric relationships and density of *Chiton albolineatus* (Mollusca: Polyplacophora) on the intertidal rocky zone of three islands of Mazatlan Bay, SE of Gulf of California. Rev. Biol. Mar. Oceanogr. 47, 203–2011.

Flores-Campaña, L.M., González-Montoya, M.A., Ortiz-Arellano, M.A., Arzola-González, F., 2007. Estructura poblacional de *Chiton articulatus* en islas pájaros y venados de la bahía de Mazatlán, Sinaloa, México. Rev. Mex. Biodivers 28, 23S–31S.

Flores-Garza, R., García-Ibáñez, S., Flores-Rodríguez, P., Torreblanca-Ramírez, C., Galeana-Rebolledo, L., Valdés-González, A., Suastegui-Zárate, A., Violante-González, J., 2012. Commercial important marine mollusks for human consumption in Acapulco, México. Nat. Resour. 3, 11–17.

Froese, R., 2006. Cube law, condition factor and weight-length relationships: history, meta-analysis and recommendations. J. Appl. Ichthyol. 22, 241–253.

Galeana-Rebolledo, L., Flores-Garza, R., Reyes-Gómez, A., García-Ibáñez, S., Flores-Rodríguez, P., Torreblanca-Ramírez, C., Valdés-González, A., 2014. Species richness and community structure of class polyplacophora at the intertidal rocky shore on the marine priority region no. 33 Mexico. Open J. Ecol. 4, 43–52.

García-Ibáñez, S., Flores-Garza, R., Flores-Rodríguez, P., Violante-González, J., Valdés-González, A., Olea-de-la Cruz, F.G., 2013. Diagnostico pesquero *Chiton articulatus* (Mollusca: Polyplacophora) en Acapulco, México. Rev. Biol. Mar. Oceanogr. 48, 293–302.

Guillen, C., Marquez-Farias, J.F., Avila-Poveda, O.H., 2021. Body size variation in an intertidal polyplacophora along a tropical latitudinal gradient. In: 9th European Congress of Malacological Societies Euromal, 5th To 9th of September 2021. Available at https://www.youtube.com/watch?v=TQifKHpAi-g.

Gutiérrez-Zavala, R.M., Cabrera-Mancilla, E., 2019. Especies Marinas de Valor Comercial En El Estado de Guerrero, México. Instituto Nacional de Pesca y Acuacultura.

Herbert, D.G., Hamer, M.L., Mander, M., Mkhize, N., Prins, F., 2003. Invertebrate animals as a component of the traditional medicine trade in KwaZulu-Natal, South Africa. Afr. Invertebr. 44, 327–344.

Herrera, A., Bustamante, R.H., Shepherd, S.A., 2003. The fishery for endemic chitons in the Galapagos islands. Not. Galapagos 62, 24–28.

Hilborn, R., Walters, C., 1992. Quantitative Fisheries Stock Assessment. Choice, dynamics and uncertainty, Chapman and Hall, New York.

Holguín-Quiñones, O.E., 2006. Moluscos bentónicos de interés económico y potencial de las costas de michoacán, Colima y Jalisco, México. In: Jiménez-Quirós, M.C., Espino-Bar, E. (Eds.), Los Recursos Pesqueros Y Acuícolas de Jalisco, Colima Y MichoacáN. SAGARPA–INP–CRIP, Manzanillo, Mexico, pp. 121–130.

Holguín-Quiñones, O.E., Michel-Morfín, J.E., 2002. Distribution, density, and length-weight relationship of *Chiton articulatus* Sowerby, 1832 (Mollusca: Polyplacophora) on isla Socorro, Revillagigedo Archipelago, Mexico. J. Shellfish Res. 21, 239–241.

Hopkins, K.D., 1992. Reporting fish growth: A review of the basics. J. World Aquac. Soc. 23, 173–179.

Ibáñez, C.M., Carter, M.J., Aguilera, M.A., Pardo-Gandarillas, M.C., Rezende, E.L., 2021. Body size variation in polyplacophoran molluscs: Geographical clines and community structure along the south-eastern Pacific. Glob. Ecol. Biogeogr. 30, 1781–1795.

Ibáñez, C.M., Sepúlveda, R.D., Sigwart, J.D., 2018. Comparative allometric variation in intertidal chitons (Polyplacophora: Chitonidae). Zoomorphology 137, 249–256.

Jellyman, P.G., Booker, D.J., Crow, S.K., Bonnedt, M.L., Jellyman, D.J., 2013. Does one size fit all? An evaluation of length-weight relationships for new Zealand's freshwater fish species. N. Z. J. Mar. Freshw. Res. 47, 450–468.

López-Gappa, J., Tablado, A., 1997. Growth and production of an intertidal population of the chiton *Plaxiphora aurata* (Spalowski, 1795). Veliger 40, 263–270.

Lord, J.P., Shanks, A.L., 2012. Continuous growth facilitates feeding and reproduction: impact of size on energy allocation patterns for organisms with indeterminate growth. Mar. Biol. 159, 1417–1428.

Marmolejo-Rodríguez, A.J., Morales-Blake, A.R., González-Chavarín, I., Hernández-Becerril, D., Alonso-Rodríguez, R., Rodríguez-Palacio, M.C., Sánchez-González, S., Magallanes-Ordóñez, V.R., 2017. Trace elements from the central Pacific Mexican shelf: Geochemical associations and anthropogenic influences. Estuar. Coast. Shelf Sci. 198, 461–470.

Miethe, T., Reecht, Y., Dobby, H., 2019. Reference points for the length-based indicator $L_{max5\%}$ for use in the assessment of data-limited stocks. ICES J. Mar. Sci. 76, 2125–2139.

Montgomery, S.S., Walsh, C.T., Haddon, M., Kesby, C.L., Johnson, D.D., 2010. Using length data in the schnute model to describe growth in a metapenaeid from waters off Australia. Mar Freshw. Res. 61, 1435–1445.

Morato, T., Afonso, P., Lourinho, P., Barreiros, J.P., Santos, R.S., Nash, R.D.M., 2001. Lenght-weight relationships for 21 coastal fish species of the Azores, north-eastern Atlantic. Fish. Res. 50, 297–302.

Nash, R.D., Valencia, A.H., Geffen, A.J., 2006. The origin of Fulton's condition factor-setting the record straight. Fish 31, 236–238.

Neumann, R.N., Allen, M.S., 2007. Size structure. In: Guy, C.S., Brown, M.L. (Eds.), Analysis and Interpretation of Freshwater Fisheries Data. American Fisheries Society, Bethesda, MD, pp. 375–421.

Neumann, R.M., Guy, C.S., Willis, D.W., 2012. Length, weight, and associated indices. In: Zale, A.V., Parrish, D.L., Sutton, T.M. (Eds.), Fisheries Techniques. American Society, Bethesda, MD, pp. 637–676.

Ortiz-Huerta, L.G., Ortiz, M., García-Gastélum, A., 2018. Far-field tsunami hazard assessment along the Pacific coast of Mexico by historical records and numerical simulation. Pure Appl. Geophys. 175, 1305–1323.

Osei, I.K., Yankson, K., Obodai, E.A., Okyere, I., 2021. Implications of overlooked seasonal growth dynamics in tropical fisheries assessment: A test case of an oyster (*Crassostrea tulipa*) fishery in the Densu Delta, Ghana. Fish. Res. 244, e106118.

Peig, J., Green, A.J., 2009. New perspectives for estimating body condition from mass/length data: the scaled mass index as an alternative method. Oikos 118, 1883–1891.

Peig, J., Green, A.J., 2010. The paradigm of body condition: a critical reappraisal of current methods based on mass and length. Funct. Ecol. 24, 1323–1332.

Poutiers, J.M., 1995. Quitones (anfineuros, locaricados, poliplacóforos). In: Fischer, W., Krupp, F., Schneider, W., Sommer, C., Carpenter, K.E., Nien, V.H. (Eds.), GuÍa FAO Para la Identificación de Especies Para Los Fines de la Pesca, Pacífico Centro-Oriental: Plantas E Invertebrados, Vol. I. FAO, Roma, pp. 299–304, [In Spanish].

Prado-Padilla, M.G., 2022. Variación Estacional En la Composición de Pigmentos Y Su Relación Con Procesos Fisiológicos En Tejidos Del Quitón *Chiton Articulatus* (Polyplacophora: Chitonida) Habitante Del Intermareal Rocoso (MSc. thesis). Facultad de Ciencias del Mar, Universidad Autónoma de Sinaloa, Mazatlán.

Prince, J., Hilborn, R., 1998. Concentration profiles and invertebrate fisheries management. In: Jamieson, G.S., Campbell, A. (Eds.), Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. Canadian Special Publication of Fisheries and Aquatic Sciences 125, Ottawa, pp. 187–196.

Ramirez-Herrera, M.T., Urrutia-Fucugauchi, J., 1999. Morphotectonic zones along the coast of the Pacific continental margin, southern Mexico. Geomorphology 28, 237–250.

Reyes-Gómez, A., 2004. Chitons in Mexican waters. Boll. Malacol. 5 (Supplement), 69–82.

Reyes-Gómez, A., Flores-Garza, R., Galeana-Rebolledo, L., Hernández-Vera, G., Gálvan-Avila, C.M., Torreblanca-Ramírez, C., Flores-Rodríguez, P., García-Ibáñez, S., Ríos-Jara, S., 2022. Intertidal chitons (Mollusca: Polyplacophora) from the rocky coastline of guerrero, México, with the description of a new species. Zootaxa 5155, 541–492.

Ricker, W.E., 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191, 1–382.

Riera, R., Pérez, Ó., Álvarez, O., Simón, D., Díaz, D., Monterroso, Ó., Núñez, J., 2016. Clear regression of harvested intertidal mollusks. A 20-year (1994–2014) comparative study. Mar. Environ. Res. 113, 56–61.

Rojas-Herrera, A.A., 1988. Análisis biológico-pesquero de la cucaracha de mar *Chiton articulatus* Sowerby, 1832 de Acapulco, Guerrero, México. In: Memorias Del Congreso Del IX Congreso Nacional de ZoologÍa. Universidad de Juárez Autónoma de Tabasco y Sociedad Mexicana de Zoología, Villahermosa, Tabasco, pp. 151–156.

Scherrer, B., 1984. Biostatistique. Gaëtan Morin éditeur, Québec, [in French].

Sousa, R., Henriques, P., Vasconcelos, J., Pinto, A.R., Delgado, J., Riera, R., 2020a. The protection effects of marine protected areas on exploited molluscs from an oceanic archipelago. Aquat. Conserv. 30, 717–729.

Sousa, R., Pinto, A.R., Vasconcelos, J., Riera, R., 2020b. Does harvesting affect the relative growth in *Patela aspera* röding, 1978? Eur. Zool. J. 87, 395–401.

Stenseth, N.C., Rouyer, T., 2008. Destabilized fish stocks. Nature 452, 825–826.

Stevenson, R.D., Woods, W.A., 2006. Condition indices for conservation: new uses for evolving tools. Integr. Comp. Biol. 46, 1169–1190.

Sturges, H.A., 1926. The choice of a class interval. J. Am. Stat. Assoc. 21, 65–66.

Thompson, R.C., Crowe, T.P., Hawkins, S.J., 2002. Rocky intertidal communities: past environmental changes, present status and predictions for the next 25 years. Environ. Conserv. 29, 168–191.

Tokeshi, M., Ota, N., Kawai, T., 2000. A comparative study of morphometry in shell-bearing molluscs. J. Zool. 251, 31–38.

Velázquez-Castro, A., Zúñiga Arellano, B., Valentín-Maldonado, N., 2017. Los objetos de concha de las ofrendas del templo mayor de tenochtitlan. Estud. Cult. Nahuatl. 54, 61–78.

Zar, H.J., 2010. Biostatistical Analysis. Pearson Prentice Hall, New Jersey.