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PENSOFT.

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Identification of pen shells (Bivalvia: Ostreida: Pinnidae) collected off northern Iloilo, Philippines using their morphological characters

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Abstract

This study describes morphological characteristics of pen shells collected along the coast of northern Iloilo, Philippines. A total of 380 pen shell individuals with intact shells and their adductor muscles were carefully examined and measured. Eleven species were studied, namely: *Atrina pectinata* (Linnaeus, 1767), *Atrina inflata* (Dillwyn, 1817), *Atrina vexillum* (Born, 1778), *Atrina seminuda* (Lamarck, 1819), *Atrina rigida* ([Lightfoot], 1786), *Pinna bicolor* Gmelin, 1791, *Pinna atropurpurea* Sowerby, 1825, *Pinna deltodes* Menke, 1843, *Pinna muricata* Linnaeus, 1758, *Pinna incurva* Gmelin, 1791, and *Pinna nobilis* Linnaeus, 1758. The species were identified based on the nine characteristics of the valve for the genus *Pinna* and eight for the genus *Atrina*. These characteristics were then correlated with their adductor muscles' morphology. Analysis of variance revealed that the three most dominant species investigated under genus *Atrina*, namely *Atrina pectinata*, *Atrina inflata*, and *Atrina vexillum*, were found to be significantly different in the eight characters of the valve ($P < 0.05$). Moreover, three representative *Pinna* species, *Pinna bicolor*, *Pinna atropurpurea*, and *Pinna deltodes*, were significantly ($P < 0.05$) different based on shell width, dorsal posterior shell margin, sulcus width, and dorsal posterior margin to dorsal nacreous margin. The observed high correlation ($P < 0.05$) between adductor muscle properties and different shell length characteristics for five dominant species can be used as a predictor of growth and suggests that the increase in the size of adductor muscle correlates to the increase in the size of the mentioned shell characteristics. No previous study of this kind was conducted in the Philippines. This work provides relevant information for related biological research on other pen shell species and for the management of pen shell resources in northern Iloilo and, possibly, other regions in the world.

Keywords

adductor muscle, *Atrina pectinata*, fisheries management, growth predictor, *Pinna bicolor*, taxonomy

Introduction

The family Pinnidae (Order: Ostreida) belongs to the class Bivalvia and is commonly known as pen shell (Deudero et al. 2015). They are large, thin, wedge-shaped shells (Burns and Smith 2011) that are nearly burrowed in soft substrates in shallow waters. A total of 61 species is known worldwide (Deudero et al. 2015). In the Philippines, 15 species occur (Poppe 2010; Schultz and Huber 2013; Lemer et al. 2016), including four species in northern Iloilo (Laureta 2008).

Morphologically, pen shells are cryptic (Lemer et al. 2016) and are extremely prone to breakage, and this makes their identification confusing and challenging (Idris et al. 2008). Although they can repair their damaged shells by themselves, the repaired shells are always different from intact ones in form and sculpture (Rosewater 1982; Idris et al. 2008). Species of the genus *Atrina* have a continuous nacreous area that occupies the entire anterior inner valve surface (Rosewater 1982; Scheltema and Williams 1983). In contrast, species of the genus *Pinna*, another genus of the family Pinnidae, have a nacreous area that is divided into dorsal and ventral lobes by an anteroposteriorly directed sulcus (Souji et al. 2014).

Aside from northern Iloilo, other active fisheries for pen shells are localized in various areas in the Philippines, but the species of interest is always *Atrina pectinata* (Linnaeus, 1767) because of the high demand for its adductor muscle by the export market, particularly in Taiwan. Each year about 20 tonnes of this species are captured by local divers in the southwestern region of the Visayan Sea (Del Norte-Campos et al. 2021) while about 18 tonnes are gathered in the Province of Eastern Samar (Diocton and Adalla 2019). Meanwhile, the mantle of *Atrina pectinata* is consumed locally. Similar practices are noted in Sorsogon Province, in the southeastern region of the main island of Luzon (Amano and Mojados 2020). Pen shell fishery is a major activity in coastal areas throughout the Visayan Sea, but it is rarely documented. In this study area, which forms part of the Visayan Sea, a small number of poor fishers who are mostly educated only up to primary level, conduct gathering operations 20 days per month to support their households mainly from the sales of adductor muscles, but they also land various fin fish species and other bivalve species as bycatch (Jela unpublished*). Due to the high economic value and food value of adductor muscles (Greenwald 1996; Katsanevakis et al. 2011; Leal-Soto et al. 2011; Basso et al. 2015), it is likely that demand for pen shells will continue to increase while a decline in production persists.

Pen shells have a large posterior adductor muscle that is responsible for the opening and closing of the shell. It appears as dark and light phases, which are respectively called blocking and working muscles (Czihak and Dierl 1961). It is the most important energy storage site in many marine bivalves and accumulates mostly protein and carbohydrate reserves to sustain gametogenesis (Saucedo and Southgate 2008). The age of the pen shell can be discerned through the scar created by the posterior adductor muscle (Garcia-March et al. 2011); however, it is difficult to count its early years because of the nacre deposition in later life that conceals the few scars that represent the year of life of the pen shell (Richardson et al. 2004).

In managing wild pen shell resources, it is important to make an accurate identification of species occurring in a certain locality. Previously, Laureta (2008) identified a total of four pen shells of the family Pinnidae in the Visayan Sea off the coasts of northern Iloilo. However, this count is likely low because the Visayan Sea is home to diverse bivalves. Moreover, a preliminary cursory investigation of adductor muscles that are sold in the market revealed varied shapes and forms, suggesting the occurrence of not just four species and that the pen shell fishery is no longer limited to *Atrina pectinata*. However, sorting of the adductor muscles to determine species is difficult because no information is known about the morphological characteristics of collected species of the family Pinnidae in the area.

Obtaining morphological data of pen shells at the landing sites is not possible due to the existing fishing method, which requires underwater extraction of the meat each time a pen shell is encountered. With the aid of a compressor, divers extract individual pen shells from their habitat, shuck all the meat, and leave empty shells at the sea bottom. This method is preferred because more meat can be collected during each dive. Moreover, the shells are no longer loaded on their small boats because of their bulkiness. Also, there is no motivation for landing the shells because there is no market for them. Therefore, categorization of species monitoring based on shell shape and size is not possible. However, it was observed that the adductor muscles landed at local markets with their mantle have different shapes. Thus, an alternative morphological characterization strategy based on the shapes of the adductor muscles can be adopted. The information obtained would provide insights as to which species need to be managed. More detailed measurements of their morphological characteristics would also provide information about pen shell diversity in the area.

This study focuses on species of the family Pinnidae. First, it aims to update the checklist of *Atrina* and *Pinna* species that occur in the coastal waters of the Visayan Sea, off northern Iloilo, in the Philippines. This information is useful for future research related to the taxonomy, morphology, and genetic diversity of pen shell species in the Philippines. The second objective seeks to determine some relations in the characters of landed adductor muscles and the pen shells, which may be used for identifying species for better management.

Materials and methods

Study area. This study was carried out in the coastal waters of northern Iloilo, part of the Visayan Sea, Philippines (Fig. 1A). Pen shells were directly collected by fishers from the seabed during low tide; this corresponds to 0 m depth in our data sheet. Divers were contracted to collect pen shells also at water depths of 5, 10, 15, and 20 m, which were established at each of the designated six sampling stations where they reportedly occur (Fig. 1B).

* Jela CB (2023) Taxonomy, ecology and fishery of pen shells and some aspects of the reproductive biology of *Atrina pectinata* in the northern Iloilo, Philippines. Doctoral dissertation, University of the Philippines, Visayas, Miagao, Iloilo, Philippines, 102 pp.

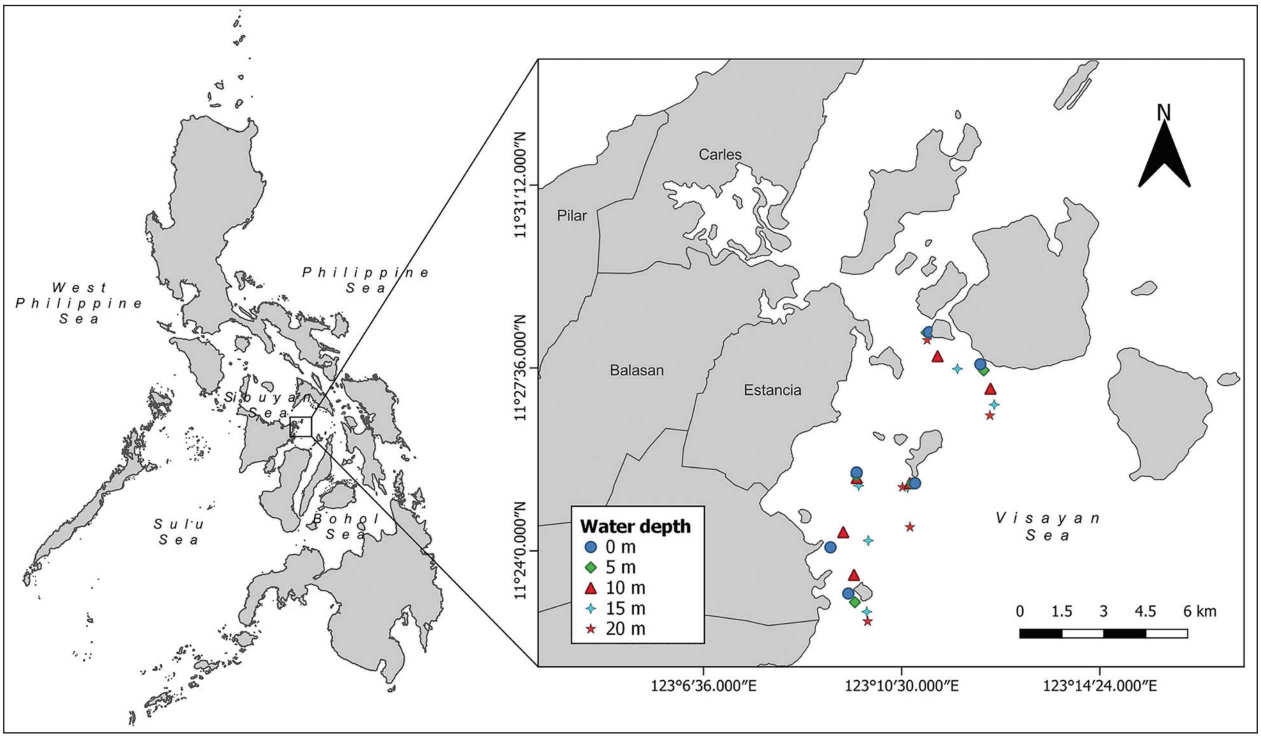

Figure 1. Map of the Philippines showing the province of Iloilo, Philippines (**A**), and location of six sampling stations at five water depths (0 m, 5 m, 10 m, 15 m, and 20 m) (**B**) in the coastal waters of northern Iloilo, part of Visayan Sea, Philippines.

Sample collection and measurements. A total of 380 intact adult individuals of various pen shell species were collected using compressor diving, stored in a styrofoam box, preserved with ice, brought to the biological laboratory of Northern Iloilo State University, and carefully examined for morphological measurements and identification. The specimens were cleaned with a metal knife to remove epibionts and washed with tap water to remove dirt. Shells were carefully shucked individually and flesh was removed. The right valve of each shell was measured using a Vernier caliper to the nearest 0.01 mm following the method of Idris et al. (2008), with emphasis on the following parameters (distances): 1) total shell length (TSL); 2) length of anterior to posterior adductor margin (LAPAM); 3) posterior adductor to posterior shell margin (PAPSM); 4) dorsal posterior shell margin (DPSM); 5) dorsal margin (DM); 6) shell width (ShW); 7) sulcus width (SuW); 8) posterior adductor margin to posterior nacreous margin (PAMPNM); and, 9) dorsal nacreous length (DNL).

The measurements are not the same for all species because of varied morphologies. It is important to note that the dorsal posterior shell margin differs in *Atrina* and *Pinna* species. Measurement of nacreous length started at the end of the muscle scar because the nacreous layer was apparent at the end of the posterior margin of the anterior adductor muscle scar. Moreover, for species of the genus *Pinna*, the sulcus width was also measured (Fig. 2). The dorsal posterior shell margin of different species with different morphologies was identified by dividing the posterior margin into equal parts (dorsal and ventral margin). The dorsal posterior shell margin was then measured. The shell specimens were then photographed, labeled, and stored.

Species identification. The specimens were identified based on their morphological characteristics such as shell structure, specifically in the way the parts are organized, and sculpture, as indicated by length, color patterns, and other related traits. Identification guides include the works of Grave (1911), Winckworth (1929), Butler and Keough (1981); Scheltema and Williams (1983); Poutiers (1998), Leal (2002), Idris et al. (2008), and Laureta (2008).

Data analysis. The mean and standard deviation of the different shell and adductor muscle morphometric characters were calculated for each species. One-way analysis of variance was used to estimate the differences in the means of the different parameters of the shells. Post-hoc tests were subsequently applied to show how the various parameters differed. This analysis was performed using the SPSS package, ver. 20. Before analysis, the normality of data was tested using the Kolmogorov–Smirnov test. Using three dominant species of the two pen shell genera in this study, the relation between shell and adductor muscle morphology was determined by linear regression.

Results

Five species of the genus *Atrina*, namely, *Atrina pectinata*, *Atrina inflata* (Dillwyn, 1817), *Atrina vexillum* (Born, 1778), *Atrina seminuda* (Lamarck, 1819), and *Atrina rigida* ([Lightfoot], 1786) and six species of the genus *Pinna*, namely, *Pinna bicolor* Gmelin, 1791, *Pinna atropurpurea* Sowerby, 1825, *Pinna deltodes* Menke, 1843, *Pinna muricata* Linnaeus, 1758, *Pinna incurva* Gmelin, 1791, and *Pinna nobilis* Linnaeus, 1758 were collected from the

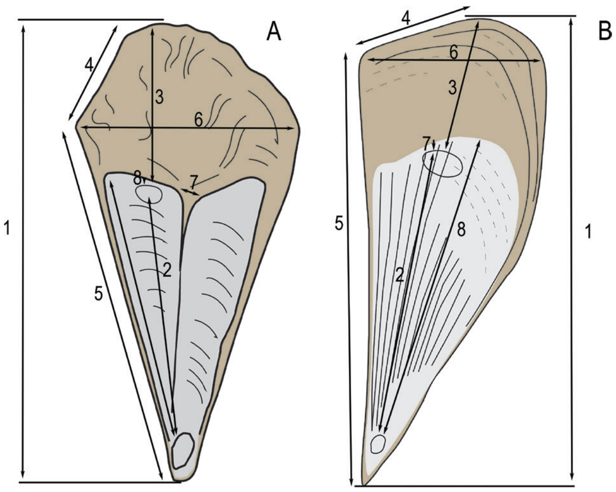

Figure 2. A diagram of the interior right valve of genus *Pinna* (**A**) showing the position of the nacreous layer and 8 characteristics of the shell. 1 = total shell length (TSL); 2 = length of anterior to posterior adductor margin (LAPAM); 3 = posterior adductor to posterior shell margin (PAPSM); 4 = dorsal posterior shell margin (DPSM); 5 = dorsal margin (DM); 6 = shell width (ShW); 7 = sulcus width (SuW); 8 = posterior adductor margin to posterior nacreous margin (PAMPNM) and 9 = dorsal nacreous length (DNL). A diagram of the interior right valve of genus *Atrina* (**B**) showing the position of the nacreous layer and 8 characteristics of the shell. 1 = total shell length (TSL); 2 = length of anterior to posterior adductor margin (LAPAM); 3 = posterior adductor to posterior shell margin (PAPSM); 4 = dorsal posterior shell margin (DPSM); 5 = dorsal margin (DM); 6 = shell width (ShW); 7 = posterior adductor margin to posterior nacreous margin (PAMPNM); and 8 = dorsal nacreous length (DNL).

waters of northern Iloilo. Table 1 summarizes the measurements of shell characteristics of the samples collected while Table 2 provides descriptive characteristics of those species. Figures 3, 4 show the images of the shells of these species. The dominant species were *A. pectinata*, *A. inflata*, *A. vexillum*, *P. bicolor*, *P. atropurpurea*, and *P. deltodes*.

Differences in shell morphology of dominant species. Only the dominant species were used to compare the shell morphology of pen shell species. These include three species of the genus *Atrina*, namely, *A. pectinata*, *A. inflata*, and *A. vexillum*, and three species of the genus *Pinna*, namely, *P. bicolor*, *P. deltodes*, and *P. atropurpurea*. These were subjected to length–length analysis. The other species were not analyzed because the number of specimens for them was inadequate. Figure 5 presents eight morphometric measurements of the three dominant *Atrina* species. They were significantly different in all the characteristics measured in this study (ANOVA, $P < 0.05$). Post-hoc analyses revealed that the total shell length, length of posterior adductor to posterior shell margin, dorsal margin, and dorsal nacreous length of *A. pectinata* was always significantly higher ($P < 0.05$) than their corresponding values in *A. vexillum* and *A. inflata*. The length of its anterior to posterior adductor margin was significantly different relative to *A. inflata* ($P < 0.05$) but was similar to *A. vexillum*. Only *A. pectinata* and *A. inflata* differed in terms of the dorsal posterior shell margin ($P < 0.05$). The shell width of *A. pectinata* was significantly lower than *A. vexillum* ($P < 0.05$) but not different from *A. inflata*. And, the posterior adductor margin to the posterior nacreous margin of *A. pectinata* was significantly higher compared to *A. inflata* and *A. vexillum* due to the 0 value of the posterior adductor margin to posterior nacreous margin of *A. vexillum* ($P < 0.05$). Meanwhile, Figure 6 shows the morphometric characteristics of the three dominant *Pinna* species. These species differed based on the dorsal posterior shell margin, the width of the shell, the sulcus width, and the posterior adductor margin to the posterior nacreous margin (ANOVA, $P < 0.05$). The three species differed only in several characteristics. The dorsal posterior shell margin of *P. deltodes* was significantly higher than those of *P. atropurpurea* and *P. bicolor*, but *P. atropurpurea* and *P. bicolor* also differed ($P < 0.05$). The shell width of *P. bicolor* was significantly different ($P < 0.05$) relative to *P. deltodes* and *P. atropurpurea*, which were similar. The three species had

Table 1. Principal metric shell characters of eleven pen shell species of the genera *Atrina* and *Pinna* (family Pinnidae) based on literature sources.

Species	*n*	Metric shell character [mm]								
		TSL	LAPAM	PAPSM	DPSM	DM	ShW	SuW	PAMPNM	DNL
A. pectinata[1]	55	199.95 ± 47.07	106.57 ± 30.91	72.92 ± 18.75	52.56 ± 33.37	181.40 ± 40.70	93.16 ± 27.27	0.00	8.06 ± 1.51	125.95 ± 27.95
A. inflata[2]	47	164.40 ± 25.27	94.61 ± 14.40	61.08 ± 14.39	92.21 ± 35.40	131.12 ± 20.02	101.54 ± 17.88	0.00	3.11 ± 1.74	107.90 ± 16.94
A. vexillum[2]	17	173.45 ± 33.87	96.37 ± 21.47	55.51 ± 14.57	70.76 ± 24.57	117.66 ± 17.21	115.76 ± 22.09	0.00	0.00	101.55 ± 16.50
A. seminuda[3]	1	274.00	138.00	102.00	29.00	219.00	161.00	0.00	19.00	162.00
A. rigida[3]	1	240.00	140.00	45.00	115.00	160.00	145.00	0.00	0.00	145.00
P. bicolor[2]	43	299.10 ± 50.12	137.30 ± 27.79	122.61 ± 20.95	41.43 ± 5.38	251.37 ± 48.79	98.80 ± 17.35	2.37 ± 0.47	4.73 ± 1.92	157.59 ± 29.25
P. atropurpurea[2]	34	293.87 ± 39.58	135.20 ± 20.97	121.55 ± 15.18	50.54 ± 4.45	248.03 ± 38.11	122.4 ± 7.84	4.94 ± 0.78	7.56 ± 4.49	158.02 ± 31.80
P. deltodes	10	280.18 ± 93.34	142.71 ± 32.36	131.42 ± 18.80	89.58 ± 45.10	269.29 ± 41.35	120.95 ± 15.76	9.10 ± 0.94	9.38 ± 0.67	177.44 ± 49.58
P. muricata[2]	2	225.50 ± 0.71	109.50 ± 9.19	102.00 ± 2.83	54.00 ± 8.49	223.5 ± 4.95	123.50 ± 10.61	4.00 ± 0.00	2.12 ± 0.18	135.50 ± 27.8
P. incurva[5]	1	257.00	93.00	130.00	31.00	240.00	96.00	1.00	5.00	122.00
P. nobilis[6]	1	419.00	172.00	205.00	93.00	365.00	133.00	8.00	14.00	223.00

Values are expressed as mean ± standard deviation. References: [1] = Poutiers (1998), [2] = Winckworth (1929), [3] = Leal (2008), [4] = Scheltema (1983), [5] = Stella et al. (2015), [6] = Basso et al. (2015); *n* = number of specimens; Measurements: TSL = total shell length , LAPAM = length of anterior to posterior adductor margin, PAPSM = posterior adductor to posterior shell margin, DPSM = dorsal posterior shell margin, DM = dorsal margin, ShW = shell width, SuW = sulcus width, PAMPNM = posterior adductor margin to posterior nacreous margin, DNL = dorsal nacreous length.

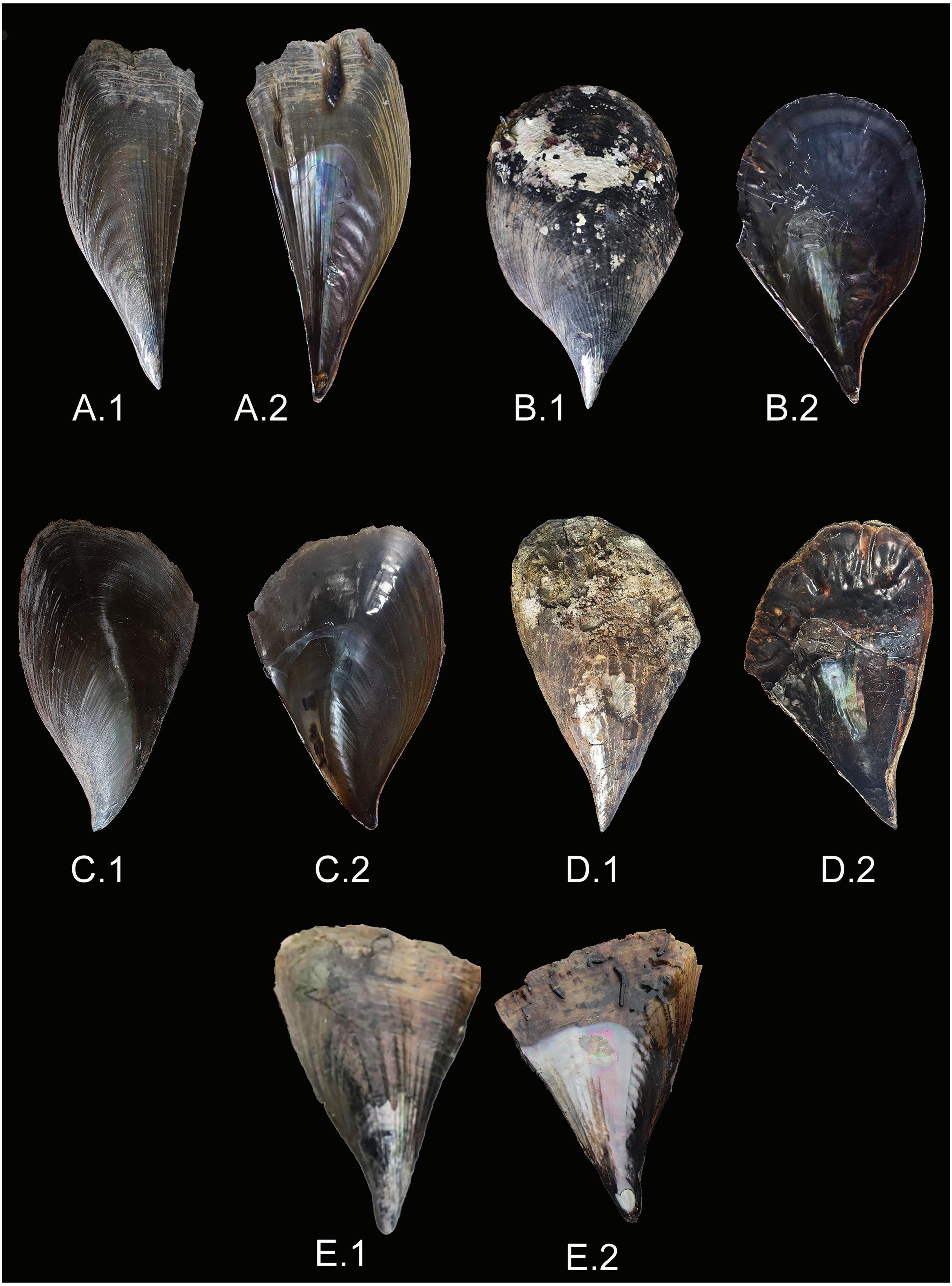

Figure 3. Photographs of selected species of the genus *Atrina* showing the external and internal surface of the right valve collected from northern Iloilo, Philippines. External valve (**A.1**, **B.1**, **C.1**, **D.1**, **E.1**), internal valve (**A.2**, **B.2**, **C.2**, **D.2**, **E.2**). *Atrina pectinata* (A.1–A.2), *A. vexillum* (B.1–B.2), *A. inflata* (C.1–C.2), *A. seminuda* (D.1–D.2), and *A. rigida* (E.1–E.2).

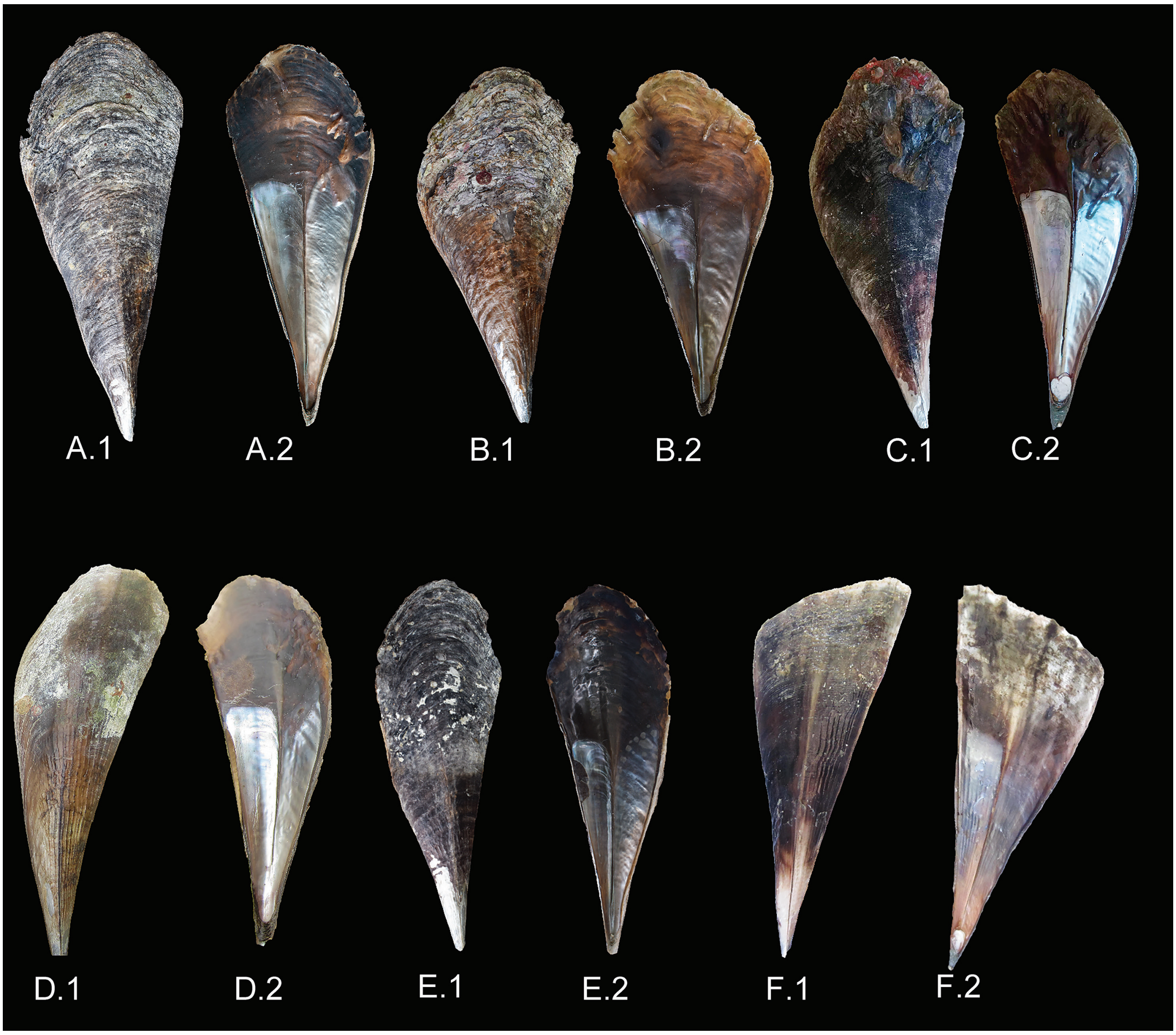

Figure 4. Photographs of selected species of the genus *Pinna* showing the external and internal surface of the right valve collected from northern Iloilo, Philippines. External valve (**A.1**, **B.1**, **C.1**, **D.1**, **E.1**, **F.1**), internal valve (**A.2**, **B.2**, **C.2**, **D.2**, **E.2**, **F.2**). *Pinna bicolor* (A.1–A.2), *P. deltodes* (B.1–B.2), *P. atropurpurea* (C.1–C.2), *P. incurva* (D.1–D.2), *P. nobilis* (E.1–E.2), and *P. muricata* (F.1–F.2).

Table 2. Descriptive characters of eleven pen shell species of the genera *Atrina* and *Pinna* (family Pinnidae) based on literature sources.

Species	Description/Comment	Reference
A. pectinata	Large, thin, fragile, and triangularly wedge shaped; shell external surface slightly shiny, light-tannish grey tinged with brownish toward the umbone	Poutiers 1998
A. inflata	Strongly swollen shape shell	Winckworth 1929
A. vexillum	Dark to almost black color of shell	Winckworth 1929
A. seminuda	Large, fan-shaped, and triangular with 15 narrow radial ribs separated by larger interspaces	Leal 2008
A. rigida	Large, triangular in shape, and surface of shell with 15 radial ribs	Leal 2002
P. bicolor	External valve of shell dark purple with nearly straight ventral margin and dorsal margin	Winckworth 1929
P. atropurpurea	External valve of shell dark purple; ventral margin and dorsal margin nearly straight	Winckworth 1929
P. deltodes	Shell length reached up to 370.8 mm; dorsal and ventral regions flared posteriorly and nearly rounded at apex with highest point between dorsal and ventral margins	Scheltema 1983
P. muricata	Triangulated, whitish in color, blotch of dark purple	Winkworth 1929
P. incurva	Narrowly attenuated shell; light yellow at posterior and reddish-brown towards anterior	Stella et al. 2015
P. nobilis	World's largest triangular-shape bivalve	Basso et al. 2015

different sulcus widths ($P < 0.05$). The posterior adductor margin to the posterior nacreous margin of *P. bicolor* was significantly lower ($P < 0.05$) than those of *P. atropurpurea* and *P. deltodes*, which were similar.

Adductor muscle morphology. Representative specimens of the posterior adductor muscles of the most dominant species belonging to the genera *Atrina* (Fig. 7) and *Pinna* (Fig. 8) are illustrated for comparison. Table 3

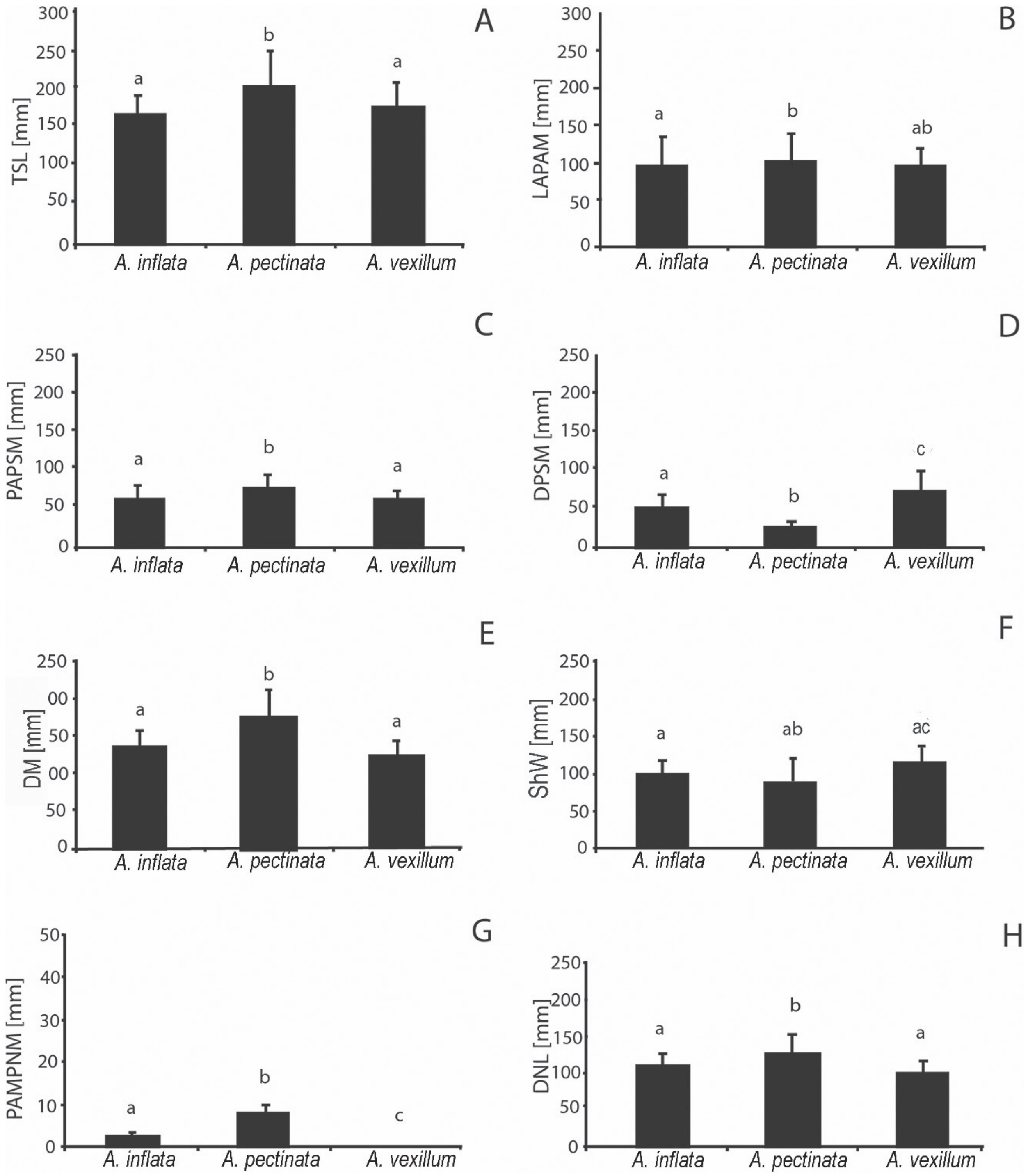

Figure 5. Measurements of eight morphometric characters of *Atrina inflata* (n = 45), *A. pectinata* (n = 231), and *A. vexillum* (n = 17). Values are expressed as the mean ± standard deviation. TSL = total shell length (**A**), LAPAM = length of anterior to posterior adductor margin (**B**), PAPSM = posterior adductor to posterior shell margin (**C**), DPSM = dorsal posterior shell margin (**D**), DM = dorsal margin (**E**), ShW = shell width (**F**), PAMPNM = posterior adductor margin to posterior nacreous margin (**G**), DNL = dorsal nacreous length (**H**). Small letters above the columns indicate the results of post-hoc tests.

presents additional information about the adductor muscles of the five dominant species examined.

Relation between shell length characters and adductor muscles of dominant species. The regression equations between the different length characteristics and their respective adductor length and thickness for five dominant pen shell species (r^2, 0.23–0.94) are shown in Table 4. This procedure was not performed on *P. deltodes* because the number of samples was inadequate. All eight length characteristics of *A. pectinata* and *A. inflata* were all positively significantly correlated (P < 0.05) with their adductor muscle length and thickness. In the case of *A. vexillum*, dorsal nacreous

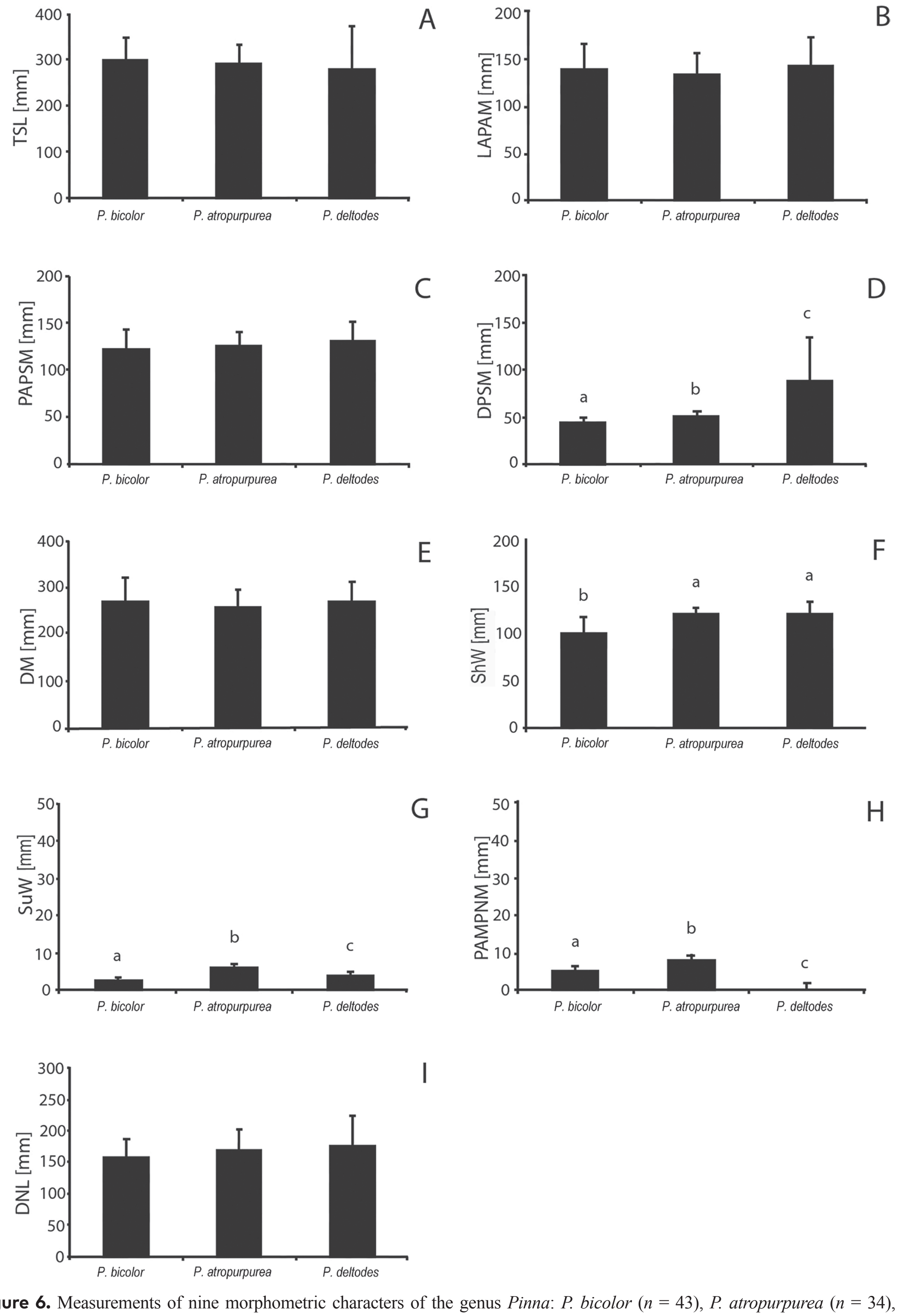

Figure 6. Measurements of nine morphometric characters of the genus *Pinna*: *P. bicolor* (n = 43), *P. atropurpurea* (n = 34), and *P. deltodes* (n = 10). Values are expressed as the mean ± standard deviation. TSL = total shell length (**A**), LAPAM = length of anterior to posterior adductor margin (**B**), LPAPSM = length of posterior adductor to posterior shell margin (**C**), LDPSM = length of dorsal posterior shell margin (**D**), DM = dorsal margin (**E**), ShW = shell width (**F**), SuW = sulcus width (**G**), PAMPNM = posterior adductor margin to posterior nacreous margin (**H**), DNL = dorsal nacreous length (**I**). Small letters above the columns indicate the results of post-hoc tests.

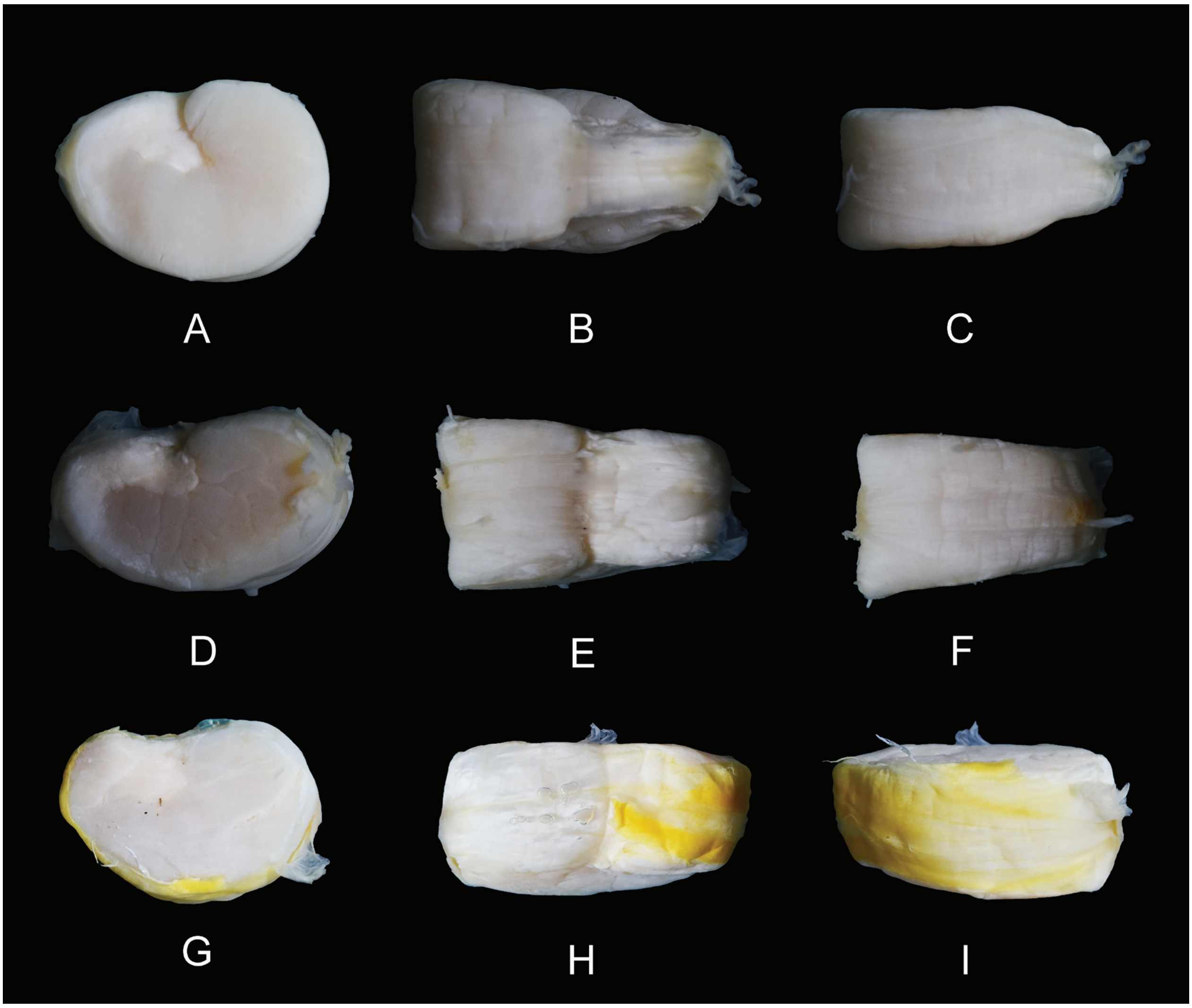

Figure 7. Photographed images of the posterior adductor muscles of *Atrina pectina* (**A**, **B**, **C**), *Atrina inflata* (**D**, **E**, **F**), and *Atrina vexillum* (**G**, **H**, **I**) collected from northern Iloilo, Philippines.

Table 3. Selected biometric characters of the adductor muscle of five pen shell species of the genera *Atrina* and *Pinna* (family Pinnidae) collected from northern Iloilo, Philippines.

Species	n	Biometric characters			Descriptive characters
		AMW [g]	AMT [mm]	AML [mm]	
A. pectinata	53	7.99 ± 5.30	13.52 ± 5.68	21.13 ± 8.04	Fibers smooth, packed with epithelial tissue with no fissures and cavities. Most of muscle comprised of dark muscles
A. inflata	47	7.47 ± 4.55	17.30 ± 3.45	24.42 ± 6.31	Tubular-like, asymmetrical, dark muscle 57.14 percentage points thicker than light muscle, light muscle attached to dark muscle by epithelial tissue, longitudinal fissure easily recognizable at external side of surface of adductor muscle
A. vexillum	17	12.61 ± 10.59	14.81 ± 6.26	24.25 ± 9.30	Shape nearly circular, fibers packed with yellow epithelial tissue, comprised of high percentage of dark muscles, fissures, and cavities observed in muscles
P. bicolor	43	11.52 ± 4.35	12 ± 4.57	19.46 ± 8.54	Fibers well packed with thick epithelial tissue.
P. atropurpurea	34	11.82 ± 4.95	14.24 ± 4.81	22.20 ± 4.87	Dark muscle occupying almost half of total area, fissures visible in light muscles

Values are expressed as mean ± standard deviation. n = number of specimens, AMW = adductor muscle weight, AMT = adductor muscle thickness, AML = adductor muscle length.

length (DNL) was not correlated with its adductor muscle thickness, whereas DNL and dorsal margin were not correlated with its adductor muscle length. Meanwhile, all nine shell length characteristics of *P. bicolor* were positively correlated with its adductor muscle thickness (r^2, 0.59–0.88) and length (r^2, 0.47–70). The shell length characteristics of *P. atropurpurea* were also positively correlated with its adductor muscle thickness (r^2, 0.40–0.84) and length (r^2, 0.38–0.84). The total shell length and adductor muscle thickness of *P. bicolor* and *P. atropurpurea* exhibited a high correlation (r^2 = 0.88 and r^2 = 0.84, respectively P < 0.05). (Table 4).

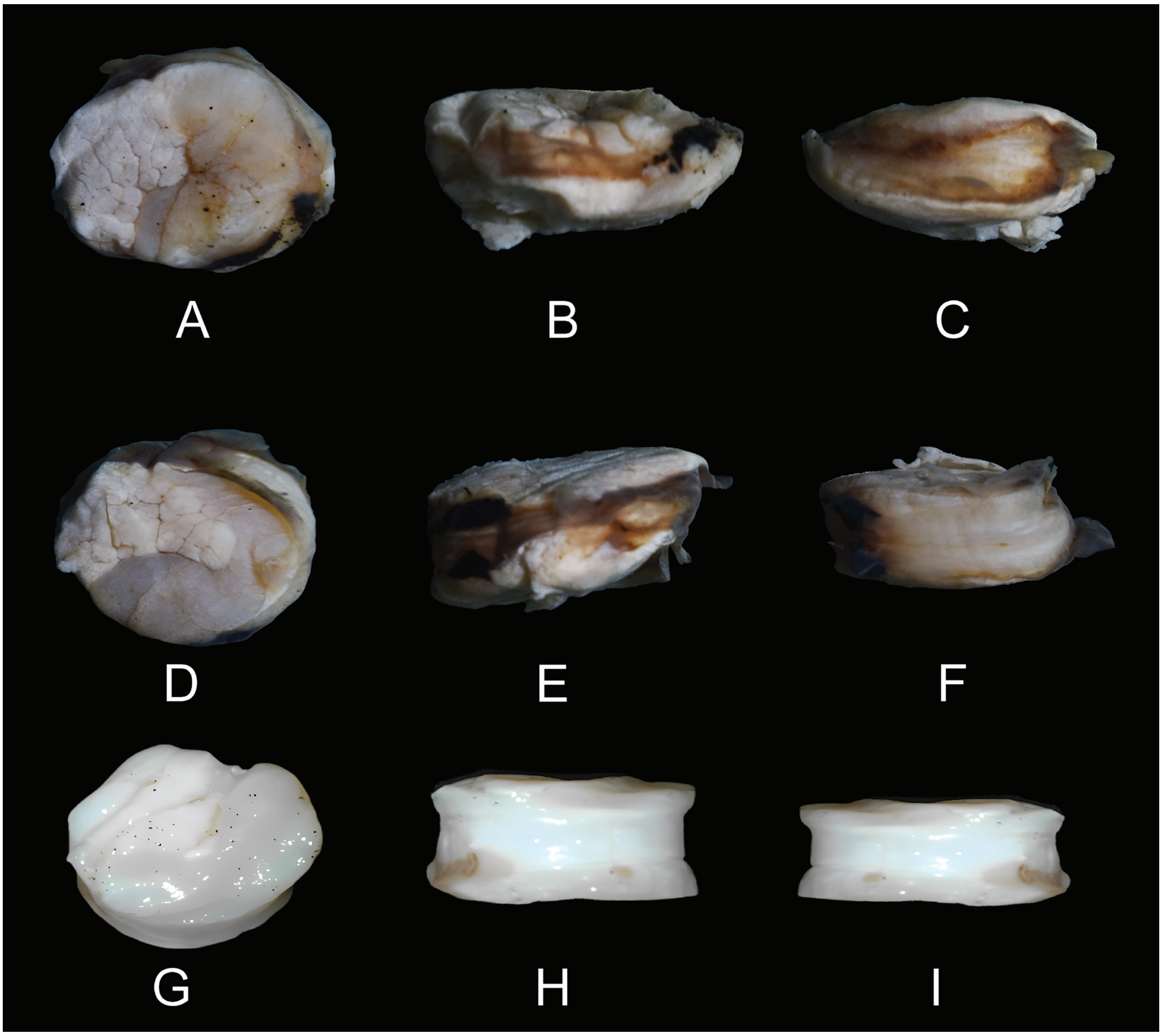

Figure 8. Photographed images of the adductor muscle of *Pinna bicolor* (**A**, **B**, **C**), *Pinna atropurpurea* (**D**, **E**, **F**), and *Pinna deltodes* (**G**, **H**, **I**) collected from northern Iloilo, Philippines.

Discussion

Species of the family Pinnidae are cryptic and can easily adapt to environmental changes (Lemer et al. 2014). The results of the presently reported study revealed that they indeed differ in size, structure, and color. These characteristics can be confusing, especially for early career scientists, as their shells can easily be broken (Idris et al. 2008). Although it is already known that the presence of a longitudinal sulcus separating the dorsal and ventral lobes of the nacreous layer in species of the genus *Pinna* distinguishes them from species of the genus *Atrina* (see Rosewater 1982), the possible presence of species not previously recorded in this area is still worth investigating.

Five species of the genus *Atrina* and six species of the genus *Pinna* representing the family Pinnidae were identified. The number of identified species updates the previous record for this area (Laureta 2008). A comprehensive presentation of the differences in shell morphology of the most abundant species, *A. pectinata*, *A. inflata*, *A. vexillum*, *P. bicolor*, *P. atropurpurea*, and *P. deltodes*, is believed to be the first attempt for these species, which may be useful later for comparative studies when new records are made.

The ecological conditions of the coastal habitats in northern Iloilo apparently define the pen shell species that dominate in an area. For example, many of the six species investigated are different from other areas where pen shells are known to thrive, such as in Sugai Pulai, Malaysia (Idris et al. 2008). The single specimen of *P. nobilis*, which was previously noted to be the largest pen shell species recorded (Basso et al. 2015) and reportedly most dominant in the Mediterranean Sea (Zavodnik et al. 1991; Richardson et al. 1999; Cappello et al. 2019), was also the largest among all the pen shells collected at this study site. Other species that occurred only once, namely, *A. seminuda*, *A. rigida*, and *P. incurva*, are recorded for the first time in this area; this information is important to

Table 4. Relations of thickness (AMT) and length (AML) of adductor muscles with various shell length characters of five pen shell species of the genera *Atrina* and *Pinna* (family Pinnidae) collected off northern Iloilo, Philippines.

Species	Shell length parameter	Regression equation in relation to AMT	r^2	Regression equation in relation to AML	r^2
A. pectinata	TSL	TSL = 118.18 + 6.1775AMT	**0.65**	TSL = 115.12 + 3.6141AML	**0.70**
	LAPAM	LAPAM = 64.95 + 3.7165AMT	**0.68**	LAPAM = 57.0798 + 3.6865AML	**0.53**
	PAPSM	PAPSM = 50.933 + 1.6319AMT	**0.49**	PAPSM = 48.9457 + 1.1068AML	**0.40**
	DPSM	DPSM = 16.455 + 0.5544AMT	**0.53**	DPSM = 15.588 + 0.3827AML	**0.46**
	DM	DM = 113.62 + 5.2092AMT	**0.62**	DM = 102.35 + 3.7313AML	**0.55**
	ShW	ShW = 42.959 + 3.7025AMT	**0.68**	ShW = 38.45 + 2.5204AML	**0.60**
	PAMPNM	PAMPNM = 5.9356 + 0.1743AMT	**0.57**	PAMPNM = 5.6912 + 0.12AML	**0.50**
	DNL	DNL = 79.162 + 3.5137AMT	**0.63**	DNM = 82.243 + 3.4853AML	**0.55**
A. inflata	TSL	TSL = 38.411 + 7.2823AMT	**0.94**	TSL = 77.9 + 3.5417AML	**0.78**
	LAPAM	LAPAM = 32.859 + 3.742AMT	**0.86**	LAPAM = 54.255 + 0.7746AML	**0.68**
	PAPSM	PAPSM = 8.3944 + 0.1451AMT	**0.86**	PAPSM = 13.942 + 0.0216AML	**0.68**
	DPSM	DPSM = –26.772 + 4.2591AMT	**0.81**	DPSM = –5.9699 + 0.1653AML	**0.74**
	DM	DM = 48.778 + 4.9386AMT	**0.80**	DM = 72.092 + 2.5437AML	**0.75**
	ShW	ShW = 24.212 + 0.5108AMT	**0.81**	ShW = 48.975 + 2.1814AML	**0.67**
	PAMPNM	PAMPNM = 1.1411 + 0.1053AMT	**0.79**	PAMPNM = 1.7861 + 0.0482AML	**0.59**
	DNL	DNL = 30.729 + 4.5414AMT	**0.81**	DNL = 56.923 + 0.1445AML	**0.64**
A. vexillum	TSL	TSL = 95.015 + 5.3281AMT	**0.80**	TSL = 91.46 + 3.4011AML	**0.69**
	LAPAM	LAPAM = 57.606 + 2.8578AMT	**0.69**	LAPAM = 55.284 + 1.8414AML	**0.61**
	PAPSM	PAPSM = 30.051 + 0.9754AMT	**0.77**	PAPSM = 33.665 + 0.0576AML	**0.47**
	DPSM	DPSM = 31.616 + 0.3508AMT	**0.40**	DPSM = 16.745 + 2.66AML	**0.53**
	DM	DM = 96.02 + 1.6189AMT	**0.40**	DM = 98.573 + 0.8836AML	0.25
	ShW	ShW = 80.021 + 2.7749AMT	**0.47**	ShW = 70.652 + 2.0813AML	**0.56**
	DNL	DNL = 89.426 + 1.0767AMT	0.23	DNL = 87.379 + 0.7421AML	0.23
P. bicolor	TSL	TSL = 169.58 + 10.566AMT	**0.88**	TSL = 204.44 + 4.7226AML	**0.61**
	LAPAM	LAPAM = 75.166 + 5.314AMT	**0.77**	LAPAM = 86.519 + 2.6928AML	**0.69**
	PAPSM	PAPSM = 80.544 + 3.5058AMT	**0.59**	PAPSM = 87.839 + 1.7866AML	**0.53**
	DPSM	DPSM = 30.323 + 0.9515AMT	**0.66**	DPSM = 31.532 + 0.5245AML	**0.70**
	DM	DM = 160.45 + 9.1931AMT	**0.74**	DM = 177.6 + 4.7868AML	**0.70**
	ShW	ShW = 62.051 + 3.1587AMT	**0.69**	ShW = 66.768 + 1.7051AML	**0.70**
	SuW	SuW = 1.6609 + 0.0812AMT	**0.63**	SuW = 1.901 + 0.0377AML	**0.47**
	PAMPNM	PAMPNM = 3.8235 + 0.1302AMT	**0.65**	PAMPNM = 4.0774 + 0.0672AML	**0.61**
	DNL	DNL = 97.88 + 4.8372AMT	**0.70**	DNL = 106.2 + 2.5549AML	**0.68**
P. atropurpurea	TSL	TSL = 136.44 + 2.654AMT	**0.84**	TSL = 153.29 + 6.7133AML	**0.84**
	LAPAM	LAPAM = –55.099 + 6.4382AMT	**0.78**	LAPAM = 62.818 + 3.4563AML	**0.80**
	PAPSM	PAPSM = 78.469 + 3.7725AMT	**0.51**	PAPSM = 81.516 + 2.0957AML	**0.56**
	DPSM	DPSM = 33.683 + 1.355AMT	**0.77**	DPSM = 36.574 + 0.667AML	**0.66**
	DM	DM = 120.85 + 10.931AMT	**0.68**	DM = 130.25 + 6.0454AML	**0.74**
	ShW	ShW = 99.603 + 1.8321AMT	**0.64**	ShW = 101.38 + 1.0035AML	**0.68**
	SuW	SuW = 3.2058 + 0.2142AMT	**0.40**	SuW = 3.5594 + 0.1104AML	**0.38**
	PAMPNM	PAMPNM = 3.4914 + 0.3815AMT	**0.79**	PAMPNM = 3.9787 + 0.2034AML	**0.79**
	DNL	DNL = 45.005 + 10.03AMT	**0.78**	DNL = 58.218 + 5.3281AML	**0.78**

Pinna deltodes was not included due to insufficient samples for regression analysis. Values in **bold** font represent a significant correlation at 0.05 level. Values are expressed in millimeters. TSL = total shell length, LAPAM = length of anterior to posterior adductor margin, PAPSM = posterior adductor to posterior shell margin, DPSM = dorsal posterior shell margin, DM = dorsal margin, ShW = shell width, SuW = sulcus width, PAMPNM = posterior adductor margin to posterior nacreous margin, DNL = dorsal nacreous length.

note because it can be used to make ecological reports about pen shell diversity in northern Iloilo and can be included in the management plan for these resources. There are now 11 species compared to the previous record for this area (Laureta 2008), and four of these were observed to be rarely occurring (see Tables 1, 2, 3). This strongly suggests that there may still be unrecorded species that could be discovered if a more comprehensive survey covering a larger area including deeper waters is made. This may be the subject of a more comprehensive study worth considering in the future.

The analysis of pen shell morphology relied on nine internal and external characteristics of the valve among species of the genus *Pinna* and eight characteristics among species of the genus *Atrina*. The external surface sculpture of the valves and the size and position of the adductor muscles, which create distinctive scars on the inner side of the valves, were used to define individual species of the family Pinnidae, as suggested by Rosewater (1961). The comparisons made revealed that the three *Pinna* species, *P. bicolor*, *P. atropurpurea*, and *P. deltodes*, were found to be different based on shell width, dorsal posterior shell margin, sulcus width, and dorsal posterior margin to dorsal nacreous margin, similar to the study of Idris et al. (2008). The differences of the adductor muscle scar from the posterior nacreous margin appeared to be influenced by the different positions of the muscle within the shell. Meanwhile, the difference in the length of the dorsal margin was due to the different curvatures of their shell.

Although no new species were identified in this study, following this comprehensive examination of specimens collected with a more comprehensive survey will lead to the generation of a comprehensive checklist of pen shell species in northern Iloilo. The application of this same method to other known pen shell-occurring areas in the Philippines, such as in the Samar Sea, where an active fishery exists (Diocton and Adalla 2019), may also be worth considering.

The considerable size of the adductor muscle and its nutritional value (Wu and Wu 2017) make pen shells of great interest to fisheries. It serves as a source of income (Diocton and Adalla 2019; Del Norte-Campos et al. 2021) and food (Greenwald 1996) for many artisanal fishers. However, in northern Iloilo, only adductor muscles are landed and sold in the market, leaving empty shells scattered in the substrate. This practice by fishers presents challenges in assessing the state of pen shell populations in the area or the management of these resources unless strategies to regulate the resources are introduced soon. Under such conditions, these resources may be overexploited, just like most wild fishery resources (Pauly et al. 1998).

It is important to note that no previous characterization of the adductor muscle was made for pen shells, and the use of this information may give previously unexplored insights about these resources. The linear regression analyses and correlations made with various shell length parameters with adductor muscle thickness and length may enable fishery scientists to determine the impacts of pen shell fisheries on the resources more precisely by closely monitoring the adductor muscles that are sold in the market, but this would even be more realistic if smaller-sized individuals are also represented. With the expected depletion of pen shell resources as harvesting pressure increases, pen shell juveniles may be harvested and secretly sold or brought home for domestic consumption. Perhaps, it is important to include size limitation measures among the strategies to regulate the harvesting of pen shells to ensure the sustainability of this important resource in the area.

Based on the different forms of the marketed adductor muscles, it is evident that species other than *A. pectinata*, which commands the highest value among all pen shell species, are also accepted for general consumption. The linear regression analyses and correlations between various shell characters and several adductor characters of the six dominant species were done to infer the state of wild pen shell populations. Through this, it is evident that certain characteristics can be used to discriminate the different species under *Pinna*. The appropriate procedure to do this is to relate the dimensions of the adductor muscles with various characteristics of their shells. Using extracted information from the dominant species, it seems possible to determine the species of their source organisms.

The described and analyzed morphological characteristics of the adductor muscle of *A. pectinata*, *A. inflata*, *A. vexillum*, *P. bicolor*, and *P. atropurpurea* suggest that the relations of thickness and length of adductor muscles with the various lengths characters of the shell can be used to differentiate the species by looking at the characteristics of the adductor muscles. The high correlations between various adductor muscle characteristics and shell length characters indicate that they could be a good for taxonomic purposes. The specific and distinct identity of each species in this study has provided information on the diversity of pen shells as well as an opportunity for the newly discovered species to be included in the catalog of bivalves in northern Iloilo, Philippines. Also, through the marketed adductor muscles, it is possible to assess the level of pressure posed by fishers on wild pen shells in this area using established modeling methods. Thus, this study may be useful in stock assessment and in monitoring the sizes of shucked pen shells.

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