Journal of Applied Ichthyology

WILEY

RESEARCH ARTICLE OPEN ACCESS

Length–Weight and Condition Factor of 14 Elasmobranch Species Caught as Bycatch by Artisanal Shrimp Trawls in a Coastal Lagoon System From Northwest Mexico

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Received: 7 May 2025 | **Revised:** 25 November 2025 | **Accepted:** 17 December 2025

Academic Editor: Upali S. Amarasinghe

Keywords: Bahía Magdalena-Almejas | fishes | growth | LWR | northwestern Pacific

ABSTRACT

The lack of biometric data on chondrichthyan species has impeded the implementation of management strategies essential for the conservation of sharks and rays captured using different fishing gears in coastal ecosystems. This study aims to assess morphometric relationships (length–weight [LW], length–dorsal length [DL], and length–disc width [DW]) and the relative weight condition factor (K_{rel}) of 14 elasmobranch species caught by shrimp trawls in the Bahía Magdalena-Almejas (BMA) lagoon system in Mexico from February to December 2014–2022. The length–weight relationships (LWRs) (pooled sexes, females and males) were calculated using the potential model. The growth (allometric or isometric) was determined by comparing the b values for each elasmobranch species with the isometric value ($b = 3.0$) using the t-Student test. Length–length (LL) relationships were determined by applying the linear regression model. Given the body condition is commonly used as a biometric tool to indicate the overall health and energetic status of fish in relation to growth, the K_{rel} was calculated. The assessment was conducted on 440 elasmobranch specimens (70 sharks and 370 rays) across 14 species, 9 genera, and 8 families. The genus *Urobatis* was the most abundant in the total elasmobranch catches obtained ($n = 203$). The parameter b of the LW relationships varied from 2.57 (*Heterodontus mexicanus*) to 3.87 (*Mustelus lunulatus*). Most morphometric relationships (LDL and LDW) showed a significant statistical correlation ($r^2 > 0.85$; $p < 0.05$). The condition factor analysis indicated that most (86%) elasmobranch species were in good somatic condition ($K_{rel} \geq 1$). This study represents the first reference data on the LWRs for the Mexican Horn Shark (*H. mexicanus*), as well as the first assessment on LL relationships (DL and DW) and the relative weight condition factor for all elasmobranch species included. Consequently, this research helps bridge the information gap regarding shark and ray species, contributing to the monitoring and population assessment of bycatch elasmobranchs in the BMA lagoon system.

Lay Summary

The lack of biometric data on shark and ray has impeded the implementation of management strategies essential for its conservation in some coastal ecosystems. This research helps bridge the information gap regarding shark and ray species and aids in future monitoring and fishery assessment of bycatch (shark and ray) in the BMA lagoon system, Mexico.

1 | Introduction

Elasmobranchs, a group of cartilaginous fishes, are characterized by a slow growth and low reproductive rates due to their late maturity and low fecundity, making them highly vulnerable to overexploitation and extinctions [1–4]. The low resilience of this group is primarily influenced by overfishing, the main threat to elasmobranch populations, leading to cascade effects in ecosystems with significant ecological and socioeconomic impacts worldwide [1–3, 5, 6].

In the northwestern region of Mexico, studies on the potential impact of the traditional small-scale multispecies fisheries developed by local cooperatives (artisanal fisheries) on rays and shark populations have focused mainly on assessing the composition and abundance of commercial valued species caught [7–11].

However, the priority has been to understand how these small-scale fisheries affect recruitment rates, management, and conservation of elasmobranch bycatch in coastal ecosystems [1, 3, 4, 6, 12–14]. Size measurements such as the total length (TL), dorsal length (DL), disc width (DW), and weight are commonly used to study growth rates, body condition, sexual maturity, size frequency, and population structure of cartilaginous fishes [15–22].

The Bahía Magdalena-Almejas (BMA) lagoon system is the largest marine-estuarine ecosystem, and the main productive fishing area in the northwestern Mexican Pacific region. The artisanal shrimp trawl fishery is one of the most significant fishing activities here, capturing more than 125 fish species as bycatch [23]. These bycatch species represent 30% of the total fish fauna reported for this coastal environment, including commercially valuable elasmobranch species that are also important for conservation [24]. The lack of biological and socioeconomic data on sharks and rays captured as bycatch using different fishing gears has limited the implementation of effective management strategies for the conservation of cartilaginous fishes in coastal ecosystems [13].

Currently, most of the studies addressing body relationships (e. g., length–weight [LW] and length–length [LL]) of elasmobranchs from the northwestern Mexico have been conducted on species from small-scale commercial capture in locations around BMA, but none specifically for this lagoon ecosystem [25–27]. Therefore, this study aims to assess morphometric relationships (length–total weight (TW), TL–DL, and TL–DW) and the relative weight condition factor for 14 elasmobranch species (five sharks and nine rays) caught by trawls used by the artisanal shrimp fishery in this marine coastal ecosystem.

2 | Material and Methods

2.1 | Study Area

The BMA lagoon system (24°21′– 24°46′ N and 110°30′– 112°15′ W, Figure 1) is in a transition zone between two of the most important biogeographical regions of the Pacific Ocean: California (temperate) and Tropical Eastern Pacific (tropical–subtropical). This ecosystem comprised three subsystems: the Northwestern zone (137 km^2), the Central zone (882 km^2), and the South zone (370 km^2) connected to each other and to the adjacent sea through channels of variable depth. The BMA coastal ecosystem is characterized by the presence of a large extension of mangrove biotopes inhabited by a great variety of fish species that use them as primary habitat for breeding, recruitment, and feeding. Hydrologically, the BMA lagoon system behaves as a negative estuary (34–40 ups) due to the absence of rain and runoffs and high evaporation rates as is common in this arid region. The annual average temperature varies from 18°C to 29°C and the dissolved oxygen from 0.04 to 2.56 mg/L; the tides are semidiurnal [23, 24].

2.2 | Sampling Fish and Data Analysis

Elasmobranch samples were collected monthly from bottom surveys during the close shrimp fishing seasons and from commercial catches throughout the artisanal shrimp fleet during the open shrimp fishery (September–February) from 2014 to 2022. Shark and ray specimens were caught as bycatch using small fiberglass boats (pangas) and shrimp trawl nets with 16-17 m top rope and 35 mm mesh size opening, developed at 2 knots for 1 h [23, 24]. The sampled elasmobranch specimens were frozen (−10°C) immediately after capture and transported to the laboratory. Therefore, after being thawed, the number of captured individuals by species was recorded and taxa were identified using specialized keys and catalogs [28–31]. At least one voucher specimen from each species was fixed with 10% formalin and deposited in the reference fish collection of the Centro Regional de Investigación Acuícola y Pesquera (CRIAP-IMIPAS), La Paz, Baja California Sur, Mexico.

All specimens were macroscopically sexed based on the presence (males) or absence (females) of myxopterygians. Due to their small size, their gonadal maturity could not be determined, so they were considered sexually immature. TL (distance between the tip of the snout to the tip of the upper caudal lobe), DL (distance between the tip of the snout to the insertion of the first dorsal-fin), and DW (distance between the tips of the pectoral-fins) to the nearest 0.1 mm, were measured. They were also weighed (TW) to the nearest 0.01 g.

2.3 | Data Analysis

The length–weight relationships (LWRs) for all elasmobranch species (pooled sexes, females and males) were calculated using the potential equation $W = aL^b$ [32], where W is the calculated TW (g), L is the observed TL of the fish (mm), a is the intercept, and b is the slope of the regression. Log–log plots were generated to identify and remove outliers from the analysis (Froese 2006). The confidence interval (CI) at 95% for the parameter b of the LWR was calculated to determine whether the hypothetical value of isometry (3.0) fell between these limits. The type of growth

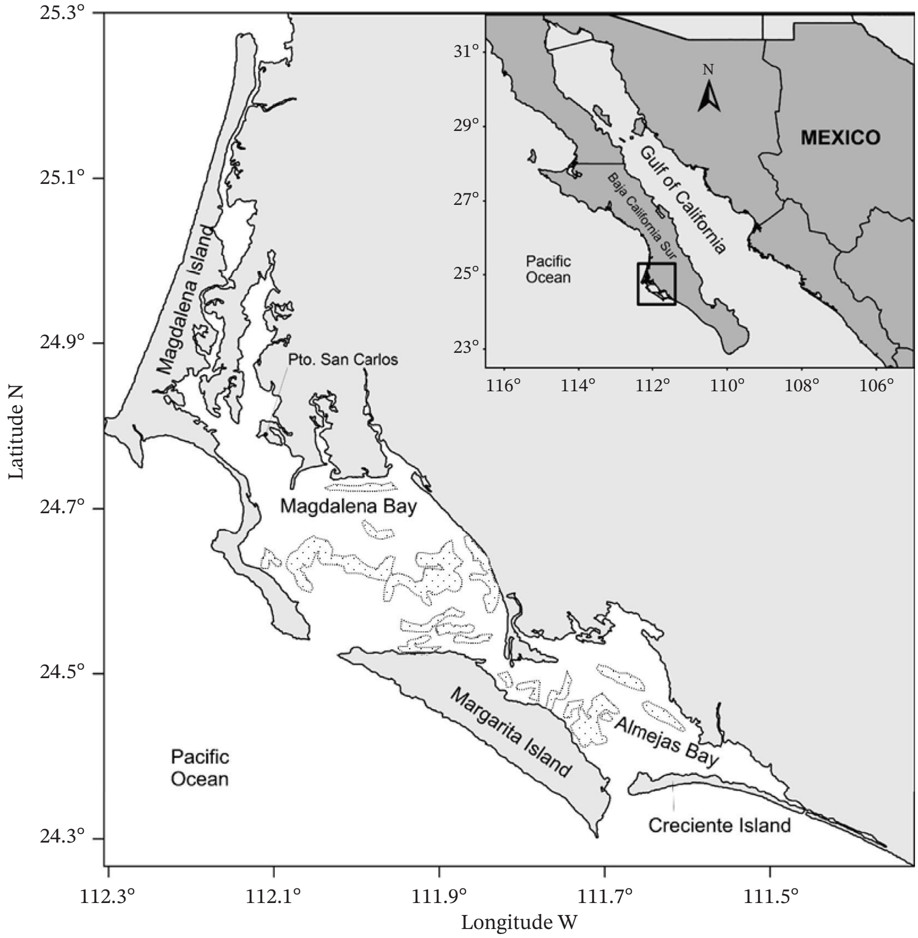

FIGURE 1 | Location of shrimp trawling grounds (dotted polygons) from the Bahía Magdalena-Almejas lagoon system in the northeastern Pacific of Mexico.

(allometric or isometric) was determined by comparing the values of the parameter *b* for each elasmobranch species with the isometric value ($b = 3.0$) using the t-Student test [33]. Moreover, length relationships (LDL and LDW) were determined by applying the linear regression equation $Y = a + \mathrm{b}X$, where Y (dependent variable) is the value of DL or DW, X (independent variable) is the L of fish, and a (intercept) and b (slope) are the linear regression parameters [32]. In both cases, the equations were calculated using Statistica 10 (StatSoft Inc., Tulsa, OK, USA).

Given the body condition is commonly used as a biometric tool to indicate the overall health and energetic status of fish in relation to growth, development, reproduction, and survival [21, 34–37], the relative weight condition factor (K_{rel}) was estimated for the elasmobranch species studied using the equation $K_{\mathrm{rel}} = W/\mathrm{aL}^{\mathrm{b}}$, where W is the estimated TW (g), L is the observed TL (mm) of the fish, and a and b are the parameters derived from the potential model of regression [34, 38–40]. A good well-being state and somatic growth of the elasmobranch species was determined when the $K_{\mathrm{rel}} \geq 1.0$; otherwise, shark and ray species were in poor condition when K_{rel} value was < 1.0 [38, 39, 41, 42]. Differences between the K_{rel} values (pooled and by sex) and the expected value of $K_{\mathrm{rel}} = 1.0$ were determined using a one-sample t-test [33]. The condition factor calculation was performed using Excel software and the t-Student test with PAST 5.1.

3 | Results

In this study, 440 elasmobranchs specimens (70 sharks and 370 rays) from 14 species, 9 genera, and 8 families were examined. These 14 species contribute 3% (relative abundance) of the total fish catches obtained from 2014 to 2022 (Table 1). The elasmobranchs catches were predominantly represented by three species of batoids: *Urobatis halleri* (46%), *Diplobatis ommata* (14.5%), and *Urotrygon rogersi* (5.0%) and two shark species: *Heterodontus francisci* (5.9%) and *Mustelus henlei* (4.3%). These five species collectively comprised 76% of the total elasmobranch catches obtained. Descriptive statistics of morphometric measurements are presented in Table 1.

3.1 | Length–Weight (LW), Length–Length (L-L) and Dorsal Length–Disc Width (L-DW) Relationships

Table 2 summarizes the regression parameters (a and b) with their respective CIs and the coefficients of determination (r^2). Most of the LWRs were significant for pooled sexes, males and females, with r^2 ranging from 0.87 to 0.99. The parameter b of LWR varied from 2.57 (males and females of *H. mexicanus*) to 3.88 (males and females of *M. lunulatus*). Sixty-four percent of the elasmobranch species (three sharks and six rays) exhibited isometric growth, while the other 36% (two sharks and three rays)

TABLE 1 | Descriptive statistics of 14 elasmobranchs from Bahía Magdalena-Almejas lagoon system, Mexico.

Family	Scientific name	*n*	RA %	Length (mm) Min	Length (mm) Max	Length (mm) Mean	Weight (g) Min	Weight (g) Max	Weight (g) Mean	Dorsal length (mm) Min	Dorsal length (mm) Max	Dorsal length (mm) Mean	Disc width (mm) Min	Disc width (mm) Max	Disc width (mm) Mean
Heterodontidae	*Heterodontus francisci* (pooled)	26	0.17	145	700	284	21.5	2500	290.8	—	—	—	—	—	—
	Males	10		173	700	338	37.7	2500	512.0	—	—	—	—	—	—
	Females	16		145	464	251	21.5	778.0	155.7	—	—	—	—	—	—
	Heterodontus mexicanus (pooled)	5	0.03	206	348	273	51.5	238.8	142.6	—	—	—	—	—	—
Triakidae	*Mustelus californicus* (pooled)	6	0.04	254	303	271	39.7	71.0	49.1	—	—	—	—	—	—
	Males	5		254	303	274	42.0	71.0	51.0	—	—	—	—	—	—
	Mustelus henlei (pooled)	19	0.13	246	702	336	37.7	893.8	133.7	—	—	—	—	—	—
	Males	14		246	427	313	37.7	228.2	91.9	—	—	—	—	—	—
	Females	5		288	702	400	62.4	893.8	250.8	—	—	—	—	—	—
	Mustelus lunulatus (pooled)	14	0.09	269	372	310	51.3	176.0	85.9	—	—	—	—	—	—
	Females	6		269	352	305	55.1	132.1	86.8						
Narcinidae	*Diplobatis ommata* (pooled)	64	0.39	87	215	156	10.6	141.2	63.1	38	140	73	44	105	78
	Males	21		87	199	152	10.6	118.7	56.2	38	130	70	44	104	75
	Females	43		97	215	158	14.5	141.2	66.5	45	140	74	47	105	80
Rhinobatidae	*Pseudobatos lecucorhynchus* (pooled)	8	0.06	315	471	364	104.1	407.2	185.0	134	190	149	110	160	124
Trygonorrhinidae	*Zpteryx exasperata* (pooled)	17	0.11	180	810	264	35.2	2500	255.7	85	450	129	89	385	132
	Males	7		180	810	293	35.2	2500	407.4	85	450	148	90	385	147
	Females	10		190	567	244	38.1	965.6	149.4	89	263	116	89	275	123
Urotrygonidae	*Urobatis halleri* (pooled)	203	1.35	105	301	197	10.9	313.7	94.8	58	180	114	60	173	117
	Males	94		105	292	204	10.9	251.4	102.1	58	180	119	60	173	120
	Females	109		113	301	192	14.2	313.7	88.3	65	179	111	69	173	113
	Urobatis maculatus (pooled)	18	0.12	116	351	245	17.1	602.9	180.1	62	200	148	71	197	144
	Males	16		116	351	244	17.1	602.9	181.2	62	200	147	71	197	144
	Urotrygon aspidura (pooled)	12	0.08	210	455	359	81.0	546.4	304.2	125	239	190	131	283	221
	Males	7		210	410	333	81.0	488.0	254.9	125	239	180	131	250	201
	Females	5		323	455	394	214.0	546.4	373.2	174	235	203	200	283	244
	Urotrygon rogersi (pooled)	22	0.14	185	503	332	38.6	783.5	284.1	97	276	180	103	309	205
	Males	9		240	440	342	73.6	566.2	297.4	122	234	182	133	270	202
	Females	13		185	503	325	38.6	783.5	274.8	97	276	179	103	309	208
Gymnuridae	*Gymnura marmorata* (pooled)	13	0.10	165	359	229	112.0	1064.9	365.1	123	297	188	239	503	330
	Males	6		187	359	242	158.0	1064.9	414.1	138	297	202	261	503	361
	Females	7		165	298	218	112.0	755.3	323.1	123	246	175	239	482	304
Myliobatidae	*Myliobatis californica* (pooled)	13	0.10	287	674	496	31.9	1183.1	528.9	158	290	204	260	462	347
	Males	6		350	623	523	103.2	1016.1	620.5	184	290	224	260	462	370
	Females	7		287	674	473	31.9	1183.1	450.5	158	252	187	280	431	327

Note: n = number of organisms, RA %: relative abundance (%) of total fish catches obtained from 2014 to 2022. Biometrics not applied to sharks (—).

TABLE 2 | Parameters of length–weight and length–length relationships for 14 elasmobranchs from the Bahia Magdalena-Almejas lagoon system, Mexico.

Scientific name	LW relationship constants						LDL relationship constants			LDW relationship constants		
	a	*b* ± CI 95%	r^2	*G*	*t*-cal	*p* value	*a*	*b* ± CI 95%	r^2	*a*	*b* ± CI 95%	r^2
Heterodontus francisci (pooled)	0.08^{-4}	2.984 ± 0.080	0.997	I	0.183	0.436	—	—	—	—	—	—
Males ($n = 10$)	0.07^{-4}	3.001 ± 0.181	0.997	I	0.235	0.325	—	—	—	—	—	—
Females ($n = 16$)	0.04^{-4}	3.110 ± 0.208	0.988	I	0.156	0.254	—	—	—	—	—	—
Heterodontus mexicanus (pooled)	0.71^{-4}	2.574 ± 0.889	0.975	A-	6.515	* **0.011**	—	—	—	—	—	—
Mustelus californicus (pooled)	0.06^{-5}	3.246 ± 1.374	0.902	I	2.847	0.052				—	—	—
Males ($n = 5$)	0.08^{-5}	3.195 ± 1.988	0.884	I	2.124	0.074	—	—	—	—	—	—
Mustelus henlei (pooled)	0.48^{-5}	2.904 ± 0.076	0.997	I	0.807	0.252	—	—	—	—	—	—
Males ($n = 14$)	0.13^{-5}	3.132 ± 0.349	0.960	I	1.242	0.157	—	—	—	—	—	—
Females ($n = 5$)	0.24^{-5}	3.013 ± 0.058	0.999	I	0.861	0.235	—	—	—	—	—	—
Mustelus lunulatus (pooled)	0.18^{-7}	3.878 ± 0.678	0.917	A+	2.294	* **0.044**	—	—	—	—	—	—
Females ($n = 6$)	0.17^{-5}	3.097 ± 1.119	0.896	I	1.325	0.740	—	—	—	—	—	—
Diplobatis ommata (pooled)	0.13^{-4}	3.016 ± 0.227	0.960	I	0.458	0.346	2.954	0.446 ± 0.084	0.643	1.915	0.490 ± 0.028	0.951
Males ($n = 21$)	0.18^{-4}	2.951 ± 0.584	0.932	I	0.325	0.254	−3.77	0.481 ± 0.167	0.656	−4.197	0.519 ± 0.069	0.929
Females ($n = 43$)	0.17^{-4}	2.972 ± 0.237	0.971	I	1.235	0.325	6.418	0.428 ± 0.102	0.621	5.171	0.475 ± 0.026	0.971
Pseudobatos lecucorhynchus (pooled)	0.11^{-6}	3.579 ± 0.498	0.986	A+	3.025	* **0.047**	21.62	0.350 ± 0.071	0.959	18.73	0.290 ± 0.055	0.964
Zpteryx exasperata (pooled)	0.32^{-4}	2.715 ± 0.039	0.999	A-	2.087	* **0.036**	−15.9	0.550 ± 0.032	0.988	8.403	0.467 ± 0.011	0.998
Males ($n = 7$)	0.23^{-4}	2.760 ± 0.078	0.999	A-	1.523	* **0.025**	−21.9	0.582 ± 0.110	0.999	8.446	0.465 ± 0.009	0.999
Females ($n = 10$)	0.19^{-4}	2.796 ± 0.091	0.999	I	2.523	0.076	4.525	0.457 ± 0.011	0.999	6.821	0.475 ± 0.031	0.994
Urobatis halleri (pooled)	0.15^{-4}	2.931 ± 0.131	0.938	I	1.436	0.144	−0.68	0.582 ± 0.017	0.954	6.284	0.558 ± 0.011	0.981
Males ($n = 94$)	0.18^{-4}	2.897 ± 0.221	0.928	I	1.568	0.129	−1.88	0.590 ± 0.027	0.951	6.937	0.556 ± 0.019	0.971
Females ($n = 109$)	0.15^{-4}	2.936 ± 0.163	0.945	I	0.912	0.229	−0.32	0.579 ± 0.022	0.962	5.925	0.559 ± 0.012	0.988

(Continues)

TABLE 2 | (Continued)

Scientific name	LW relationship constants						LDL relationship constants			LDW relationship constants		
	a	*b* ± CI 95%	r^2	*G*	*t*-cal	*p* value	*a*	*b* ± CI 95%	r^2	*a*	*b* ± CI 95%	r^2
Urobatis maculatus (pooled)	0.15^{-6}	3.766 ± 0.423	0.945	A+	3.002	*****0.048**	2.663	0.594 ± 0.105	0.900	15.57	0.524 ± 0.046	0.972
Males ($n = 16$)	0.17^{-6}	3.754 ± 0.458	0.931	A+	2.856	*****0.030**	6.798	0.576 ± 0.107	0.905	15.73	0.524 ± 0.051	0.972
Urotrygon aspidura (pooled)	0.11^{-4}	2.891 ± 0.685	0.937	I	0.522	0.327	10.78	0.499 ± 0.110	0.910	−15.5	0.653 ± 0.108	0.954
Males ($n = 7$)	0.66^{-6}	3.376 ± 1.472	0.934	I	0.687	0.282	−5.58	0558 ± 0.195	0.915	−5.78	0.618 ± 0.133	0.976
Females ($n = 5$)	0.25^{-4}	2.757 ± 1.437	0.939	I	0.526	0.065	21.91	0.458 ± 0.151	0.968	−29.0	0.693 ± 0.463	0.883
Urotrygon rogersi (pooled)	0.25^{-4}	2.777 ± 0.266	0.969	I	2.169	0.081	37.00	0.430 ± 0.128	0.708	26.80	0.538 ± 0.164	0.700
Males ($n = 9$)	0.37^{-4}	2.707 ± 0.581	0.964	I	1.182	0.079	0.315	0.530 ± 0.102	0.955	−31.9	0.683 ± 0.078	0.983
Females ($n = 13$)	0.22^{-4}	2.802 ± 0.348	0.973	I	1.214	0.122	53.46	0.386 ± 0.210	0.597	51.84	0.479 ± 0.263	0.594
Gymnura marmorata (pooled)	0.14^{-3}	2.697 ± 0.428	0.953	I	1.578	0.128	−9.24	0.860 ± 0.187	0.903	21.85	1.347 ± 0.622	0.674
Males ($n = 6$)	0.12^{-3}	2.716 ± 0.933	0.954	I	1.325	0.095	−1.57	0.842 ± 0.501	0.845	49.52	1.288 ± 1.118	0.719
Females ($n = 7$)	0.67^{-5}	3.253 ± 0.465	0.991	I	1.241	0.170	−11.2	0.856 ± 0.122	0.985	18.83	1.307 ± 1.238	0.595
Myliobatis californica (pooled)	0.56^{-6}	3.305 ± 0.766	0.935	I	1.023	0.140	78.92	0.252 ± 0.168	0.499	83.38	0.516 ± 0.327	0.585
Males ($n = 6$)	0.30^{-6}	3.408 ± 3.000	0.867	I	1.107	0.192	128.7	0.182 ± 0.443	0.246	152.6	0.420 ± 0.941	0.402
Females ($n = 7$)	0.42^{-6}	3.341 ± 0.519	0.988	I	1.05	0.150	68.9	0.250 ± 0.174	0.732	29.88	0.589 ± 0.227	0.928

Note: a = intercept, b = slope, r^2 = coefficient of determination. *G* (growth): *A* (allometric) positive (+) and negative (−), and *I* (isometric); t-calc and *p* value (obtained from t-Student test), data no calculated to sharks (—).
Abbreviation: CI, confidence interval. The values with the ∗ are values with statistical significance.

showed negative and positive allometric growth (Table 2). To highlight the robustness of the LWRs and better illustrate the type of growth shown by the 14 elasmobranch species, a graph was made showing the linear relationship between Log (a) over slope (b) (Figure 2). The relationships between LDL and LDW were mostly statistically correlated ($r^2 > 0.85$, $p < 0.05$, Table 2).

3.2 | Condition Factor

The value of the parameter b derived from the LW regression (Table 2) was used to calculate the relative weight condition factor for the studied elasmobranchs. The K_{rel} values ranged between 0.4279 (*Myliobatis californica*) and 1.8566 (*U. maculatus*) (Table 3 and Figure 3). The overall analysis of the relative condition factor indicated that 86% (12) of the elasmobranch species were in good somatic condition ($K_{rel} \geq 1.0$). Additionally, 14% of the elasmobranchs showed significant statistical differences compared with an expected mean value of $K_{rel} = 1.0$ ($p < 0.05$, Table 3 and Figure 3). However, when analyzed by sex, some rays show significant differences.

4 | Discussion

The limited information available on the elasmobranch species captured by the small-scale coastal fisheries hampers the effective monitoring of species-specific regulatory measures for their conservation. Coastal and estuarine ecosystems serve as nursery areas for small-sized elasmobranchs, including neonates, juveniles, and subadults, making them particularly susceptible to capture by artisanal trawl fisheries. The high incidence of immature organisms being caught as bycatch before they have had the opportunity to reproduce leads to a decline in elasmobranch populations. This decline could be due to the significant impact on recruitment rates and the sustainability of the fishery [6, 12, 13, 16, 43].

The bycatch of many young batoids (mainly from the order Myliobatiformes) and demersal shark species by the shrimp fishery in the BMA lagoon system confirm the role of this coastal ecosystem as nursery and feeding grounds for various elasmobranch species. These species, due to their poor ability to avoid artisanal prawn trawls as slow swimmers, could be more vulnerable to overexploitation than pelagic species [12], with negative implications for the conservation and sustainability of the coastal shark and ray populations of this region. On this regard, Fahmi and Sumadhiharga [43] and Fauconnet et al. [4] noted that the tendency to catch immature elasmobranchs in coastal and shallow waters is influenced by factors such as fishing gears (shrimp trawls), mesh size, fishing areas, and the operational capacity of fishing boats, as well as the proximity to the area of operation of the small-scale coastal artisanal fishing with the nursery areas used by this cartilaginous fish species during their ontogeny as neonates and/or juveniles [14].

LL and LWRs have been reported as tools for monitoring and fishery assessment of demersal batoids with commercial value [25, 26, 44–48]. However, most studies have focused on commercially valued shark species [14, 15, 17–19, 22, 49, 50] or included both groups of elasmobranchs [27, 51–54]. To our knowledge, this study is the first to report LWRs for the Mexican Horn Shark (*H. mexicanus*), which are currently absent from FishBase [55] and in related studies to the study area [27, 56], and to the Tropical Eastern Pacific [49].

The elasmobranch species reported here fall within the expected range of parameter b-values (2.5–3.5), previously reported for unsexed specimens [55], and close to the ranges reported for elasmobranchs from different locations [14, 17, 19, 20, 36, 45, 47, 51, 53, 54], indicating normal growth dimensions [41]. Some batoids and sharks from adjacent areas to the BMA coastal lagoon system (e.g., Central and South California, Gulf of California, and southeastern Pacific) showed values of the parameter b higher than those reported here for *Gymnura marmorata* (2.69 vs. 3.2), *H. francisci* (2.98 vs. 3.06), *M. californica* (2.94 vs. 3.3), *U. helleri* (2.93 vs. 2.97), and *Zapteryx exasperata* (2.71 vs. 3.92) and lower than those calculated for *D. ommata* (2.82 vs. 3.01), *M. lunnulatus* (2.98 vs. 3.87), *M. henlei* (2.91 vs. 3.21), *Pseudobatos leucorhynchus* (3.05 vs. 3.57), and *Urobatis maculatus* (3.56 vs. 3.76) [25–27, 48, 49, 56]. Such differences could be due to several factors like the sex and gonadal

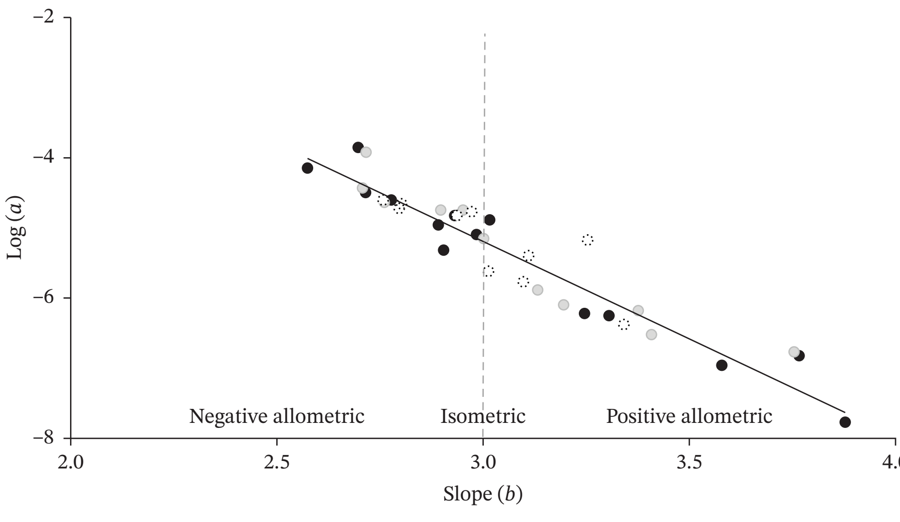

FIGURE 2 | Scatter plot of mean log a over mean b for the length–weight relationship of fourteen elasmobranchs species from the Bahia Magdalena-Almejas lagoon system. Dark circles = both sex pooled, gray circles = males, and white circles = females. Points close to the center of the graph represent isometric growth ($b = 3.0$), while points far from the center correspond to allometry ($b \neq 3.0$).

TABLE 3 | Relative weight condition factor (K_{rel}) for 14 bycatch elasmobranchs from the Bahia Magdalena-Almejas lagoon system, Baja California Sur, Mexico.

Scientific name	Min	Max	Mean ± SD	*t*-value	$p < 0.05$
Heterodontus francisci (pooled)	0.7974	1.2025	1.0072 ± 0.1063	0.3469	0.7315
Males ($n = 10$)	0.8339	2.2845	1.1647 ± 0.4103	1.2698	0.2359
Females ($n = 16$)	0.8371	1.1726	1.0172 ± 0.1020	0.6761	0.5092
Heterodontus mexicanus (pooled)	0.7994	1.0933	0.9793 ± 0.1134	−0.4078	0.7042
Mustelus californicus (pooled)	0.8865	1.1278	1.0291 ± 0.0800	0.8932	0.4126
Males ($n = 5$)	0.8602	1.0907	1.0030 ± 0.0853	0.0811	0.9329
Mustelus henlei (pooled)	0.8234	1.2276	0.9935 ± 0.1088	−0.2583	0.7991
Males ($n = 14$)	0.8283	1.2567	1.0165 ± 0.1185	0.5193	0.6122
Females ($n = 5$)	0.9515	1.0123	0.9918 ± 0.0241	−0.7567	0.4913
Mustelus lunulatus (pooled)	0.8496	1.3211	1.0073 ± 0.1322	0.2075	0.8387
Females ($n = 6$)	0.8454	1.1082	1.0067 ± 0.0975	0.1681	0.8730
Diplobatis ommata (pooled)	0.7311	1.2238	1.0157 ± 0.1107	1.1406	0.2583
Males ($n = 21$)	0.7432	1.2459	0.9859 ± 0.1237	−0.5218	0.6075
Females ($n = 43$)	0.8029	1.1507	0.9828 ± 0.0935	−1.2027	0.2358
Pseudobatos lecucorhynchus (pooled)	0.8879	1.0907	0.9937 ± 0.0702	**37.438**	$\mathbf{2.424^{-8}}$
Zpteryx exasperata (pooled)	0.7497	1.0724	0.9011 ± 0.0940	**4.3269**	$\mathbf{0.521^{-4}}$
Males ($n = 7$)	0.8338	1.0853	0.9705 ± 0.0943	**27.212**	$\mathbf{1.627^{-7}}$
Females ($n = 10$)	0.8250	1.1525	0.9814 ± 0.0943	−0.6216	0.5496
Urobatis halleri (pooled)	0.4839	1.4966	0.9885 ± 0.1678	−0.9797	0.3284
Males ($n = 94$)	0.5222	1.4946	0.9773 ± 0.1611	−1.3647	0.1756
Females ($n = 109$)	0.4712	1.4028	0.9642 ± 0.1694	**2.2028**	**0.0297**
Urobatis maculatus (pooled)	0.5788	1.8566	1.0729 ± 0.2923	1.0581	0.3048
Males ($n = 16$)	0.5624	1.7879	1.0536 ± 0.2960	0.7248	0.4797
Urotrygon aspidura (pooled)	0.8294	1.4255	1.0611 ± 0.1637	1.2945	0.2219
Males ($n = 7$)	0.8194	1.7667	1.0969 ± 0.3129	0.8200	0.4435
Females ($n = 5$)	0.8682	1.0664	1.0097 ± 0.0809	0.2694	0.8009
Urotrygon rogersi (pooled)	0.6589	1.1746	0.9617 ± 0.1262	−1.4244	0.1690
Males ($n = 9$)	0.6559	1.1393	0.9853 ± 0.1432	**20.641**	$\mathbf{3.178^{-8}}$
Females ($n = 13$)	0.7984	1.1795	0.9667 ± 0.1213	−0.9885	0.3424
Gymnura marmorata (pooled)	0.7560	1.3304	0.9679 ± 0.1590	−0.7268	0.4813
Males ($n = 6$)	0.7881	1.3641	1.0133 ± 0.1949	0.1666	0.8742
Females ($n = 7$)	0.8979	1.2418	1.0158 ± 0.1157	0.3604	0.7308
Myliobatis californica (pooled)	0.4279	1.3628	0.9172 ± 0.2170	−1.3761	0.1939
Males ($n = 6$)	0.7238	1.3045	0.9355 ± 0.2138	−0.7391	0.4930
Females ($n = 7$)	0.4564	1.1222	0.9143 ± 0.2146	−1.0567	0.3313

Note: Bold values indicate significant statistic differences.

maturity, size and number of specimens examined, and food availability [41]; therefore, the parameters of our study should be applied to species with similar length ranges.

Sixty-four percent of the elasmobranch species (three sharks and six rays) exhibited isometric growth, while the 21% (including one shark and two rays) exhibited positive allometric growth, and the other 14% (one shark and one ray species) exhibited negative allometric growth (Table 2). The ray *D. ommata* showed isometric growth, contrasting to the allometric growth reported by de la Cruz-Aguero et al. [27], while *U. maculatus* showed allometric growth contrasting with the isometric reported by these authors. On the other hand, the allometric growth reported here for *P. leucorhynchus* was like those reported by Payán et al. [44] for the Colombian Pacific but contrary to the isometric growth reported by Pincay-Espinoza et al. [48] for Ecuador. Motta et al. [17] established that differences in the LWRs between males and females could result from sample sizes, the unequal distribution of sizes for each sex, and the inclusion of immature females, which may be lighter due to the inclusion of spent fish that have a lower condition factor. Although isometric growth is typically the norm and allometric growth is the exception in elasmobranchs, differences between isometry and allometry have been

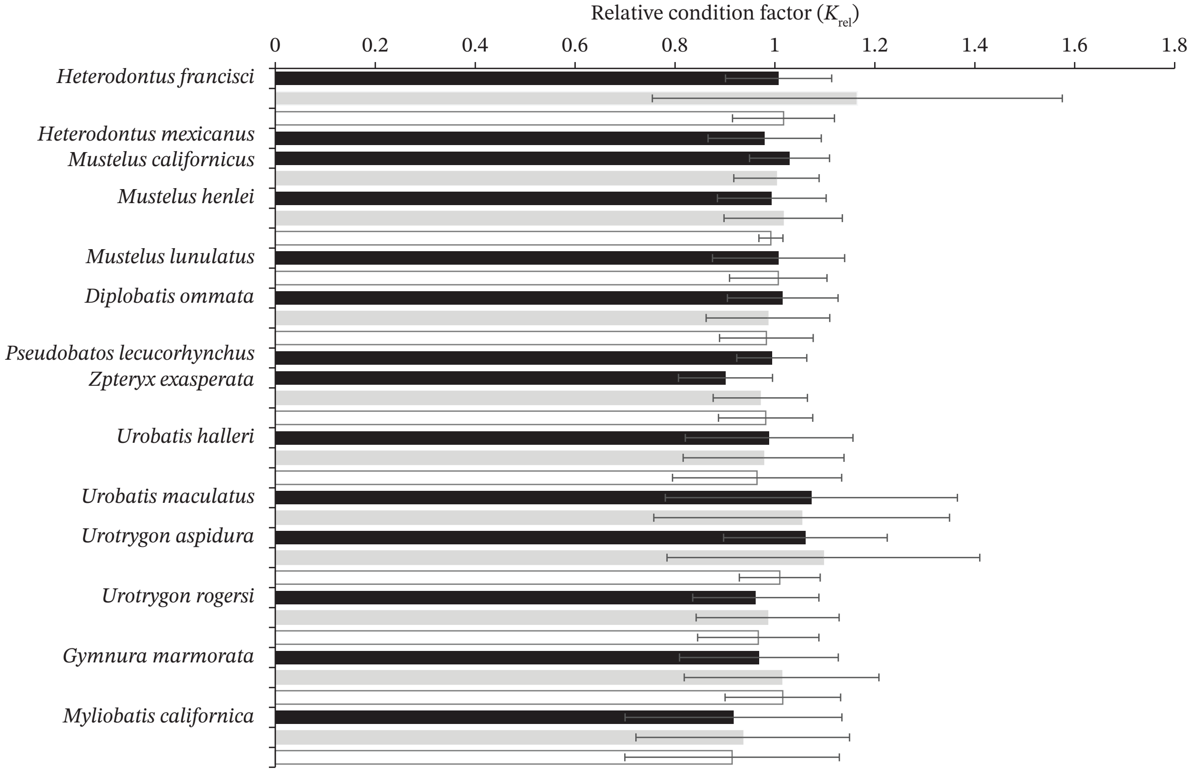

FIGURE 3 | Relative weight condition factor for fourteen elasmobranchs species from the Bahía Magdalena-Almejas lagoon system. Dark bars = pooled sexes, gray bars = males, dotted bars = females, and continuous line inside the bars = standard deviation.

linked to ontogenetic changes in body anatomy as elasmobranchs reach sexual maturity [36]. Froese [39] establishes that values of $b > 3$ as those observed in some shark and ray species reported in this study (Table 2) indicate the tendency of large specimens to be more elongated, while for the smallest ones, it is assumed that they were in better nutritional condition during sampling.

This study represents the first assessment of the LDL and LDW relationships for most of the elasmobranch species included here, all of which were statistically correlated ($r^2 > 0.85$, $p < 0.05$; Table 2). These r^2 coefficient values could be influenced by the variability in the body condition of the collected specimens, the selectivity of the fishing gear, as well as the bias in the representation of the size classes in the sample [14]. According to Nissar et al. [37], comparative growth studies of fish populations are possible when different types of length measurements are employed. Thus, we can analyze differences in body proportions across life history stages to assess potential allometric shifts using log-ratio linear regressions [20, 47], contributing to the accuracy of estimation models for population assessments in the BMA fisheries. This will aid in further fisheries research on the conservation and management of elasmobranchs in this region.

Studies on the relative weight condition factor (K_{rel}) of elasmobranchs are scarce compared with those on bony fishes, mainly due to the relatively smaller number of sharks and rays in the total fishery catches [21, 41]. This study provides the first reference on the relative condition factor of 14 elasmobranch species, with calculated K_{rel} values ($K_{rel} \geq 1.0$), indicating no variation for among species form the BMA lagoon system, suggesting good growth conditions (robustness). Fola-Matthews et al. [41] reported a mean relative weight condition factor of 0.4 (0.1–0.7 pooled, 0.3–0.7 males and 0.2–0.6 females) for *Mustelus mustelus* ($n = 1018$; 390–1420 mm TL) from Nigeria, assuming seasonal variation; comparatively, the *Mustelus* spp. ($n = 6$–19; 246–702 mm TL) from this study showed higher K_{rel} than those reported for these authors. Therefore, the relative weight condition in the fish fitness could be influenced by the age, maturity stage, variation in size composition, the reduced number of specimens analyzed, and abiotic factors [37, 40, 41], as well as by fishing pressure from the shrimp trawl fishery in this ecosystem, as has been reported for bony fishes from other regions [42].

Estimations of the LL (DL and DW) and LWRs, and relative weight condition factor (K_{rel}) are essentials for planning effective conservation strategies and fisheries management, as well as for monitoring the potential impact of trawlers on elasmobranch populations [12, 14].

The tendency to catch as bycatch of many juveniles and subadults of trawled elasmobranch demersal species by the shrimp fishery in the BMA lagoon system confirms the function of this coastal ecosystem as nursery area; however, further studies are necessary to assess the potential impact in the conservation and sustainability of shark and ray's populations in this region. The updated information on LW, LDL, and LLW relationships, and the condition factors provided through this study could contribute to filling the gaps in information on shark and ray species and will be valuable for future monitoring of mixed species fisheries and bycatch assessments of elasmobranchs in the BMA lagoon system. Our results must be considered as corresponding to bycatch juvenile specimens whose capture does no cover an annual cycle.

Acknowledgments

Adrián Felipe González-Acosta, Carlos Hiram Rábago-Quiroz, Gorgonio Ruiz-Campos, Juan Antonio García-Borbón, and María del Carmen Alejo-Plata would like to thank SNII-SECIHTI program; AFGA would also like to thank COFAA and EDI-IPN Programs.

Funding

There was no additional external funding received for this study.

Disclosure

The funders had no role in the study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Ethics Statement

The care and manipulation of the experimental animals in this study complied with the General Law of Sustainable Fishing and Aquaculture of the Ministry of Agriculture, Livestock, Rural Development, Fishing, and Food (Ley General de Pesca y Acuacultura Sustentables - Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación) in Mexico. These animal welfare laws, guidelines, and policies were approved by the National Commission of Fishing and Aquaculture (Comisión Nacional de Pesca y Acuacultura).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data used to support the findings of the study are available from the corresponding author upon request.

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