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Research Article

Length-Weight Relationships and Relative Condition Factor of 53 Species of Shallow-Water Fish in the Colombian Caribbean Sea

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Length-weight relationships (LWR) were described for 53 species of shallow-water fish caught with bottom trawls in a depth range between 7.3 and 108.1 m during September 2013 in the Colombian Caribbean Sea (fishing area 31 of the FAO). A linear regression was performed using the logarithmically transformed data to calculate *a* and *b* coefficients and their 95% confidence interval of the LWR for 53 fish species corresponding to 28 families and 44 genera. Six fish species showed a maximum total length greater than that reported in FishBase: *Astrapogon alutus* (102.00 mm), *Eucinostomus harengulus* (162.00 mm), *Haemulopsis corvinaeformis* (293.00 mm), *Cyclopsetta chittendeni* (390.00 mm), *Etropus crossotus* (224.00 mm), and *Bairdiella ronchus* (415.00 mm). A total of 24 species (45.3%) exhibited isometric growth, 21 species (39.6%) negative allometric, and 8 species (15.1%) positive allometric. This study shows the first estimates of LWR for 25 species of shallow-water fish in the Colombian Caribbean Sea. We found interdependence of growth parameters as a function of fish body shape. The analysis of the relative condition factor indicated that 21 fish species (39.6%) showed poor growth conditions. The results obtained from this study contribute to fill information gaps on shallow-water fish populations and also help fisheries scientists in future population assessment studies in the Colombian Caribbean Sea.

1. Introduction

Shallow-water fish represent about 90% of the catch in artisanal fisheries, which has a very important role in the local economy and food security in the Colombian Caribbean Sea [1–4]. Additionally, fish species are also an important fraction of the bycatch fauna in the industrial shrimp trawl fishery both at the local level [5–8] and in other regions around the world [9–11].

The length-weight relationships (LWR) provide information on the type of growth, the state of the species, habitat conditions, and the morphometric characteristics of the species, mainly in the species subjected to fishing exploitation [12–17]. LWR parameters are obtained from length-frequency data, which are very useful for estimating biomass and comparing the life history of species between regions [12, 15, 18]. However, LWR parameters may vary between habitats and regions, so accurate estimation of local parameters is essential for comparative studies in fish stock assessment [19, 20]. Additionally, the condition factor based on LWR data is relevant for examining the welfare of fish populations [15, 21, 22]. However, despite their importance, information on LWRs and condition factors is only available for a limited number of fish species [15, 23] and is very scarce in data-poor fisheries from the Colombian Caribbean Sea.

In this way, the goal of this study was to determine the LWR and the relative condition factor of 53 species of shallow-water fish in the Colombian Caribbean Sea with the purpose of contributing to the knowledge of the biology of shallow-water fish, located within the United Nations Food and Agriculture Organization fishing area 31 (FAO).

2. Materials and Methods

2.1. Sampling. The study area was located between Punta Gallinas (12°10′N, 71°14′W) and Urabá Gulf (9°03′N, 76°53′W) in the Colombian Caribbean Sea, fishing area 31 from FAO (Figure 1). Samples of shallow-water fish species were collected on a research survey using trawl sampling at depths between 7.3 and 108.1 m in September 2013. The sampling period corresponds to the rainy season, which is characterized by heavy rains and weak winds [24]. A total of 5094 fish were captured, to which the total length (TL in mm) of each individual was recorded from the tip of the mouth to the extended tip of the caudal fin using an ichthyometer with a precision of 1 mm, and the total body weight (W in g) was recorded with a precision of 1 g using an electronic scale. The care and use of experimental animals complied with Autoridad Nacional de Licencias Ambientales de Colombia (ANLA), animal welfare laws, guidelines, and policies as approved by the University of Magdalena reference number 1293–2013. The information of the body shape and the parameters of the length-weight relationships (LWR) for each one of the fish species was discussed in the FishBase (https://www.fishbase.se/) 02/2023 database [25].

2.2. Statistical Analyses. The LWR parameters of the fish species were determined by applying the following allometric equation [15, 26, 27]:

$$W_i = aL_i^b, \tag{1}$$

where W_i is the total body weight (g), L_i is the total length (mm), a (intercept) and y b (slope) are the estimated parameters applying the linear regression model with the log-transformed data according to the following equation:

$$\log W_i = \log a + b \log L_i + \epsilon_i. \tag{2}$$

The corrected back-transformed predicted value of the response variable was calculated by multiplying the back-transformed predicted value by the correction factor (*cf*), where RSE is the residual standard error and $\log_e(10)$ is used to adjust for the base of the logarithm used [28]:

$$cf = e\frac{[\log_e(10)\text{RSE}]^2}{2}. \tag{3}$$

To evaluate the type of isometric growth if $b = 3.0$, negative allometric if $b < 3.0$, and positive allometric if $b > 3.0$, a t-student test was used to determine significant differences from the estimated value of b and its 95% confidence interval (C.I.) [29].

To evaluate the influence of body morphology on the growth parameters a (intercept) and b (slope) of the LWR of the fish species, a robust multiple regression model was applied with the data grouped according to body shape (eel-like, elongated, fusiform, short and/or deep), indicating the negative allometric, isometric allometric, and positive allometric growth zones [15, 23].

The relative condition factor (K_{rel}) of the evaluated fish was determined according to the following equation [15, 27]:

$$K_{rel} = \frac{W}{aL^b}, \tag{4}$$

where W is the observed body weight (g) of an individual and aL^b is the estimated weight from the length-weight relationships for that individual's length. A good growth state of the species was identified when the K_{rel} value ≥1.0, while the species was in poor growth conditions when the K_{rel} value <1.0 [22, 27]. A one-sample t-test was used to verify significant differences between the K_{rel} and the expected value of $K_{rel} = 1.0$ [29]. All statistical and graphical analyses were performed in the R 4.2.3 language [30], using the modelr, FSAmisc, moments, and ggplot2 packages [31–34].

3. Results

A total of 53 fish species belonging to 28 families were analyzed, of which the Sciaenidae and Haemulidae families were the most representative with 7 and 6 species, respectively (Table 1). Regarding body shape, 29 species showed a fusiform body shape, 13 short and/or deep, 9 elongated, and 2 eel-like. The most abundant species were *Eucinostomus gula* (Quoy & Gaimard, 1824) with 618 specimens, followed by *Menticirrhus americanus* (Linnaeus, 1758), *Larimus breviceps* (Cuvier, 1830), and *Etropus crossotus* (Jordan & Gilbert, 1882) with 467, 453 and 414 specimens, respectively (Table 1). Total lengths (TL) for all species ranged from 24.00 mm to 940.00 mm (Table 1). Species with a maximum total length greater than that reported in FishBase were *Astrapogon alutus* (Jordan & Gilbert, 1882) (102.00 mm), *Eucinostomus harengulus* (Goode & Bean, 1879) (162.00 mm), *Haemulopsis corvinaeformis* (Steindachner, 1868) (293.00 mm), *Cyclopsetta chittendeni* (Bean, 1895) (390.00 mm), *E. crossotus* (224.00 mm), and *Bairdiella ronchus* (Cuvier, 1830) (415.00 mm) (Table 1).

Linear regressions were significant for all species ($p < 0.05$), with coefficients of determination (r^2) between 0.81 and 0.99, except for *E. gula* with the lowest value of 0.77 (Table 2). The intercept of the linear regression (a) showed a range of values between $2.1120E-08$ for *Gymnothorax ocellatus* Agassiz, 1831 and $1.1419E-02$ for *Balistes capriscus* Gmelin, 1789, while the slope parameters (b) were between 1.79 for *B. capriscus* and 3.69 for *G. ocellatus* (Table 2). About 24 species (corresponding to 45.3%) showed isometric growth ($b = 3.0$), 21 species showed (39.6%) negative allometric growth ($b < 3.0$), and 8 species showed (15.1%) positive allometric growth ($b > 3.0$) (Table 2, t-student test and the C.I. analysis of b). It is important to highlight that 9 species evaluated do not have LWR values in FishBase (https://www.fishbase.se/), and the first LWR report for 25 species of shallow-water fish in the Colombian Caribbean Sea is shown in Table 2.

The parameters of the LWR linear regression, the intercept (a) and slope (b), are highly dependent on the body shape of the fish species (Figure 2). Thus, eel-like species

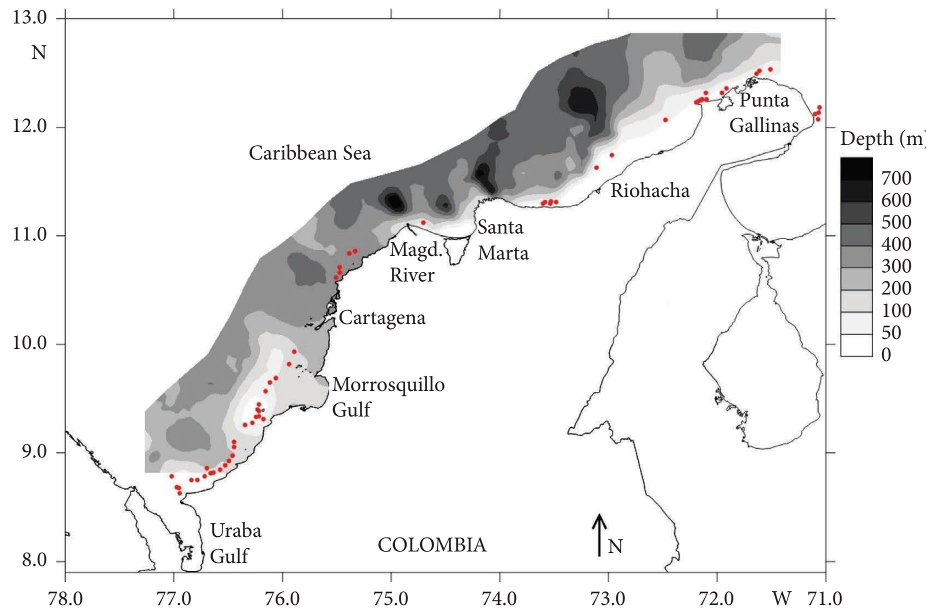

Figure 1: Study area in the Colombian Caribbean Sea. Red circles indicate the sampled stations.

tend to be positive allometric, while elongated species tend to be isometric or positive allometric. However, the fusiform and short and/or deep species tend to be negative allometric but some are isometric or positive allometric. Robust multiple regression of log(a) as a function of b and body shape explained 88% of the variance, intercept (a) = 3.4203 ± 0.4217, slope (b) = −2.8190 ± 0.1451, and $r^2 = 0.881$. The values of the relative condition factor (Krel) varied between 0.94 for *Rhomboplites aurorubens* (Cuvier, 1829) and 1.03 for *G. ocellatus* (Table 2). A total of 21 species (39.6%) showed a Krel value <1.0 although without significant statistical differences compared to an expected mean value Krel = 1.0 ($p > 0.05$, more detail of t-test in Table 2).

4. Discussion

92.5% of the fish species evaluated presented a range of parameter b between 2.5 and 3.5 [15], indicating normal growth dimensions [35, 36], except for *B. capriscus*, *Diodon holocanthus* Linnaeus, 1758, *R. aurorubens* with values of $b < 2.5$, and *G. ocellatus* with $b > 3.5$, which showed a narrow length range with respect to the maximum total length reported in FishBase (https://www.fishbase.se/) [25], common in values of $b < 2.5$ or >3.5 [15, 37].

Compared with other studies in the Colombian Caribbean Sea and the LWR information reported in FishBase (https://www.fishbase.se/), some variations of the b parameter and the type of growth of the species were observed, which may be related to factors such as ontogeny, feeding (amount, quality and size), sex, maturity stage, health, seasonality, habitat, length range, and sample size [26, 27, 38–41]. The differences found in growth can also be attributed to the different sampling methodologies and fishing gear used. In this study, data were collected from a research cruise (independent of the fishery), and trawls were used, which is a nonselective fishing gear, which allowed sampling with a wide spectrum of lengths of fish species. Additionally, the study area presents a high variety of habitats such as coral reefs, seagrass meadows, soft bottoms, among others [42–44], which are important for the life cycle of the species and depending on their state of conservation can be determinant in the health condition and the morphometric characteristics of the sampled species.

We demonstrate the interdependence of the parameters (intercept and slope) of the LWR depending on the body shapes of the fish, similar to what was reported in other studies [15, 45]. Regarding the relative condition factor, we found that around 39.6% of the species evaluated are probably in poor growth conditions, which may be related to high fishing pressure derived from industrial and artisanal fisheries that operate in the study area. All the fish species analyzed are part of the target catch and/or bycatch of the fisheries, and the fishermen use fishing gear with low catch selectivity such as trawl nets, seine nets, and gillnets that could affect the welfare of fish species and cause negative impacts on habitat [2, 6, 7, 46–48]. Although the results of this study were obtained from mixed sexes, they are of great importance for fisheries management, since there is no specific fishing gear for catching each sex and the regulations derived from fisheries apply to the entire population [17].

LWR information is reported for 9 assessed species that currently have no data in FishBase (https://www.fishbase.se/) [25]. In this study, the first estimates of LWR for 25 species of shallow-water fish species in the Colombian Caribbean Sea are presented. This work contributes with biological information on the LWR and the relative condition factor of demersal fish from shallow waters that can be very useful for future research on the assessment of marine populations, which is important for the management and conservation of fish species exploited as target catch and/or bycatch by industrial and artisanal fisheries in the Colombian Caribbean Sea and FAO fishing area 31.

Table 1: Descriptive statistics for the 53 shallow-water fish in the Colombian Caribbean Sea.

Family	Species	Author	Category	Body shape	*N*	Total length (mm) mean ± SD (range)	Total weight (g) mean ± SD (range)
Achiridae	*Achirus achirus*	(Linnaeus, 1758)	BIF	Short and/or deep	9	139.78 ± 15.84 (117.00 – 167.00)	57.87 ± 21.44 (32.50 – 94.50)
Apogonidae	*Astrapogon alutus*	(Jordan & Gilbert, 1882)	BIF	Short and/or deep	10	53.60 ± 24.89 (24.00 – **102.00**)	2.99 ± 3.71 (0.30 – 11.90)
Ariidae	*Cathorops mapale*	Betancur-R. & Acero P., 2005	TCAF, BIF	Elongated	109	200.48 ± 38.41 (113.00 – 280.00)	81.86 ± 45.73 (12.50 – 199.90)
Balistidae	*Balistes capriscus*	Gmelin, 1789	BAF, BIF	Short and/or deep	75	295.87 ± 47.66 (180.00 – 442.00)	307.75 ± 104.59 (108.00 – 700.80)
Batrachoididae	*Porichthys plectrodon*	Jordan & Gilbert, 1882	BIF	Elongated	322	87.33 ± 17.17 (52.00 – 170.00)	7.24 ± 5.21 (1.33 – 41.00)
Bothidae	*Bothus ocellatus*	(Agassiz, 1831)	BIF	Short and/or deep	28	152.71 ± 13.03 (121.00 – 178.00)	50.81 ± 12.03 (25.90 – 75.80)
Carangidae	*Chloroscombrus chrysurus*	(Linnaeus, 1766)	BAF, BIF	Fusiform	73	127.15 ± 37.26 (63.00 – 246.00)	23.62 ± 19.39 (2.80 – 117.90)
	Selene setapinnis	(Mitchill, 1815)	BAF, BIF	Fusiform	72	138.69 ± 26.92 (48.00 – 205.00)	33.81 ± 18.04 (1.40 – 93.90)
Dactylopteridae	*Dactylopterus volitans*	(Linnaeus, 1758)	BIF	Fusiform	7	80.57 ± 29.75 (55.00 – 139.00)	9.69 ± 11.43 (2.60 – 34.80)
Diodontidae	*Diodon holocanthus*	Linnaeus, 1758	BIF	Short and/or deep	13	183.00 ± 16.09 (163.00 – 212.00)	266.29 ± 57.24 (202.04 – 393.00)
Fistulariidae	*Fistularia petimba*	Lacepède, 1803	BIF	Elongated	7	731.00 ± 148.30 (520.00 – 940.00)	202.78 ± 117.13 (65.00 – 373.99)
Gerreidae	*Diapterus rhombeus*	(Cuvier, 1829)	TCAF, BIF	Fusiform	310	163.11 ± 33.77 (97.00 – 232.00)	89.79 ± 49.57 (14.10 – 258.20)
	Eucinostomus argenteus	Baird & Girard, 1855	BAF, BIF	Fusiform	15	132.47 ± 17.38 (104.00 – 154.00)	36.44 ± 15.21 (15.10 – 62.50)
	Eucinostomus gula	(Quoy & Gaimard, 1824)	BAF, BIF	Fusiform	618	133.34 ± 19.96 (68.00 – 184.00)	37.68 ± 15.46 (3.70 – 102.10)
	Eucinostomus harengulus	Goode & Bean, 1879	BAF, BIF	Fusiform	23	149.26 ± 10.60 (121.00 – **162.00**)	43.59 ± 9.59 (27.80 – 60.80)
Haemulidae	*Haemulon aurolineatum*	Cuvier, 1830	BAF, BIF	Fusiform	138	173.14 ± 25.60 (94.00 – 250.00)	77.36 ± 28.53 (12.20 – 139.50)
	Haemulon bonariense	Cuvier, 1830	TCAF, BIF	Fusiform	186	183.09 ± 41.15 (81.00 – 269.00)	107.00 ± 57.07 (7.10 – 275.30)
	Haemulon boschmae	(Metzelaar, 1919)	BAF, BIF	Fusiform	27	126.56 ± 20.39 (68.00 – 150.00)	26.81 ± 10.93 (5.30 – 45.20)
	Haemulon plumierii	(Lacepède, 1801)	TCAF, BIF	Fusiform	21	252.10 ± 26.29 (204.00 – 291.00)	244.10 ± 67.92 (127.20 – 360.50)
	Haemulopsis corvinaeformis	(Steindachner, 1868)	BIF	Fusiform	35	225.69 ± 23.38 (180.00 – **293.00**)	176.28 ± 53.57 (92.60 – 329.80)
	Orthopristis rubra	(Cuvier, 1830)	BAF, BIF	Fusiform	8	192.88 ± 15.84 (175.00 – 225.00)	121.95 ± 28.87 (87.60 – 179.80)
Holocentridae	*Holocentrus adscensionis*	(Osbeck, 1765)	BAF, BIF	Fusiform	9	186.56 ± 67.65 (88.00 – 270.00)	101.23 ± 81.23 (9.00 – 232.45)
Lutjanidae	*Lutjanus synagris*	(Linnaeus, 1758)	TCAF, BIF	Fusiform	158	218.70 ± 63.98 (70.00 – 446.00)	188.85 ± 153.20 (6.20–1,250.00)
	Rhomboplites aurorubens	(Cuvier, 1829)	TCAF, BIF	Fusiform	9	170.78 ± 46.89 (131.00 – 264.00)	69.97 ± 49.46 (30.40 – 159.00)
Mullidae	*Pseudupeneus maculatus*	(Bloch, 1793)	BAF, BIF	Fusiform	13	194.23 ± 28.42 (167.00 – 267.00)	101.18 ± 59.28 (54.60 – 265.40)
	Upeneus parvus	Poey, 1852	BAF, BIF	Fusiform	134	165.38 ± 27.83 (80.00 – 225.00)	65.60 ± 33.06 (5.50 – 145.20)
Muraenidae	*Gymnothorax ocellatus*	Agassiz, 1831	BAF, BIF	Eel-like	9	444.11 ± 77.29 (336.00 – 555.00)	143.42 ± 83.94 (44.80 – 284.20)
Ophidiidae	*Lepophidium profundorum*	(Gill, 1863)	BIF	Elongated	195	155.94 ± 35.40 (61.00 – 256.00)	21.50 ± 16.89 (1.50 – 94.90)
Ostraciidae	*Acanthostracion polygonium*	Poey, 1876	BIF	Short and/or deep	39	173.41 ± 35.10 (93.00 – 263.00)	96.40 ± 55.45 (21.20 – 278.00)
Paralichthyidae	*Cyclopsetta chittendeni*	Bean, 1895	BIF	Short and/or deep	40	216.95 ± 70.51 (117.00 – **390.00**)	144.56 ± 135.09 (16.80 – 513.40)
	Etropus crossotus	Jordan & Gilbert, 1882	BIF	Short and/or deep	414	113.14 ± 24.65 (49.00 – **224.00**)	19.36 ± 13.50 (1.30 – 117.40)
	Paralichthys tropicus	Ginsburg, 1933	BIF	Short and/or deep	7	291.00 ± 28.21 (262.00 – 335.00)	268.84 ± 84.48 (191.10 – 430.00)
	Syacium papillosum	Ranzani, 1842	BIF	Short and/or deep	12	207.25 ± 47.33 (90.00 – 260.00)	109.75 ± 56.07 (6.90 – 188.60)
Priacanthidae	*Priacanthus arenatus*	Cuvier, 1829	BAF, BIF	Fusiform	9	235.44 ± 53.54 (174.00 – 350.00)	226.42 ± 191.78 (86.80 – 708.00)

Table 1: Continued.

Family	Species	Author	Category	Body shape	*N*	Total length (mm) mean ± SD (range)	Total weight (g) mean ± SD (range)
Sciaenidae	*Bairdiella ronchus*	(Cuvier, 1830)	BIF	Short and/or deep	55	311.00 ± 51.92 (143.00 – **415.00**)	376.04 ± 152.12 (54.50 – 714.00)
	Ctenosciaena gracilicirrhus	(Metzelaar, 1919)	BIF	Fusiform	19	138.53 ± 24.56 (93.00 – 182.00)	49.24 ± 24.40 (12.70 – 101.90)
	Cynoscion virescens	(Cuvier, 1830)	BAF, BIF	Fusiform	24	215.83 ± 74.33 (153.00 – 385.00)	116.72 ± 142.71 (29.00 – 479.00)
	Isopisthus parvipinnis	(Cuvier, 1830)	BAF, BIF	Fusiform	56	142.73 ± 32.39 (98.00 – 269.00)	30.32 ± 26.59 (7.80 – 161.10)
	Larimus breviceps	Cuvier, 1830	BAF, BIF	Fusiform	453	168.14 ± 36.99 (91.00 – 263.00)	77.46 ± 52.60 (9.30 – 278.14)
	Menticirrhus americanus	(Linnaeus, 1758)	BAF, BIF	Fusiform	467	140.04 ± 26.57 (92.00 – 241.00)	51.90 ± 34.50 (13.50 – 233.00)
	Micropogonias furnieri	(Desmarest, 1823)	TCAF, BIF	Fusiform	13	317.85 ± 40.98 (258.00 – 385.00)	382.22 ± 132.05 (197.50 – 603.50)
Scorpaenidae	*Scorpaena plumieri*	Bloch, 1789	BIF	Fusiform	11	232.82 ± 21.22 (196.00 – 266.00)	302.56 ± 81.31 (179.50 – 460.60)
Serranidae	*Diplectrum bivittatum*	(Valenciennes, 1828)	BIF	Fusiform	267	101.85 ± 18.09 (43.00 – 156.00)	14.30 ± 6.65 (0.90 – 35.90)
	Diplectrum radiale	(Quoy & Gaimard, 1824)	BIF	Elongated	8	130.63 ± 78.19 (68.00 – 236.00)	73.51 ± 91.30 (6.20 – 199.20)
Sparidae	*Calamus pennatula*	Guichenot, 1868	BAF, BIF	Short and/or deep	15	242.60 ± 25.50 (203.00 – 295.00)	240.99 ± 71.94 (143.80 – 370.70)
Synodontidae	*Saurida normani*	Longley, 1935	BIF	Elongated	7	136.29 ± 48.90 (88.00 – 221.00)	27.46 ± 28.95 (4.80 – 87.50)
	Synodus foetens	(Linnaeus, 1766)	BIF	Elongated	81	233.69 ± 76.03 (88.00 – 404.00)	117.54 ± 104.06 (7.10 – 406.00)
	Synodus intermedius	(Spix & Agassiz, 1829)	BIF	Elongated	49	102.64 ± 32.61 (62.00 – 162.00)	11.48 ± 11.29 (1.40 – 35.80)
	Synodus poeyi	Jordan, 1887	BIF	Elongated	61	131.82 ± 31.80 (60.00 – 218.00)	19.77 ± 13.39 (1.90 – 76.30)
Tetraodontidae	*Lagocephalus laevigatus*	(Linnaeus, 1766)	BIF	Short and/or deep	43	244.33 ± 102.78 (88.00 – 461.00)	351.32 ± 294.38 (16.60 – 1,353.50)
Trichiuridae	*Trichiurus lepturus*	Linnaeus, 1758	BAF, BIF	Eel-like	74	403.41 ± 130.40 (200.00 – 880.00)	46.75 ± 56.99 (2.60 – 400.00)
Triglidae	*Prionotus punctatus*	(Bloch, 1793)	BAF, BIF	Fusiform	226	144.43 ± 63.79 (36.00 – 309.00)	62.78 ± 74.29 (1.30 – 349.90)
	Prionotus stearnsi	Jordan & Swain, 1885	BIF	Fusiform	11	90.55 ± 21.19 (46.00 – 119.00)	8.31 ± 4.72 (1.20 – 17.60)

TCAF: target catch of artisanal fishing, BAF: bycatch of artisanal fishing, BIF: bycatch from industrial shrimp trawl fishing, *N*: sample size, SD: standard deviation. Bold, maximum total length longer than in FishBase.

Table 2: Length-weight relationships (LWR) for the 53 shallow-water fish in the Colombian Caribbean Sea.

Family	Species	Relationship parameters							K_{rel} mean ± SD	t-test
		a	95% C.I. of a	b	95% C.I. of b	r^2	t-student	Growth type		
Achiridae	*Achirus achirus* (Δ)	9.5210E − 06	4.0745E − 07–2.2248E − 04	3.15	2.52–3.79	0.95	0.59	I	1.02 ± 0.08	0.54
Apogonidae	*Astrapogon alutus* (*) (Δ)	8.8472E − 05	2.6382E − 05–2.9669E − 04	2.53	2.22–2.84	0.98	0.01	A (−)	0.98 ± 0.18	0.59
Ariidae	*Cathorops mapale* (*)	6.0830E − 06	3.6134E − 06–1.0241E − 05	3.08	2.98–3.17	0.97	0.13	I	1.00 ± 0.10	0.70
Balistidae	*Balistes capriscus*	1.1419E − 02	3.6052E − 03–3.6169E − 02	1.79	1.58–1.99	0.81	0.00	A (−)	0.99 ± 0.14	0.72
Batrachoididae	*Porichthys plectrodon* (*) (Δ)	1.3031E − 05	8.7358E − 06–1.9439E − 05	2.93	2.84–3.02	0.93	0.13	I	0.99 ± 0.16	0.91
Bothidae	*Bothus ocellatus* (Δ)	3.2994E − 05	7.7398E − 06–1.4065E − 04	2.83	2.54–3.12	0.94	0.24	I	1.01 ± 0.06	0.56
Carangidae	*Chloroscombrus chrysurus*	1.4010E − 05	9.9172E − 06–1.9792E − 05	2.92	2.84–2.99	0.99	0.02	A (−)	0.99 ± 0.11	0.65
	Selene setapinnis	2.4261E − 05	1.5614E − 05–3.7698E − 05	2.85	2.76–2.94	0.98	0.00	A (−)	1.01 ± 0.08	0.63
Dactylopteridae	*Dactylopterus volitans* (Δ)	4.6947E − 05	1.0711E − 05–2.0578E − 04	2.72	2.38–3.06	0.99	0.09	I	1.02 ± 0.09	0.54
Diodontidae	*Diodon holocanthus*	1.8501E − 03	3.1976E − 04–1.0705E − 02	2.28	1.94–2.61	0.95	0.00	A (−)	1.00 ± 0.04	0.53
Fistulariidae	*Fistularia petimba* (Δ)	3.0659E − 07	2.3138E − 08–4.0624E − 06	3.06	2.67–3.46	0.99	0.70	I	0.97 ± 0.07	0.53
Gerreidae	*Diapterus rhombeus*	9.6654E − 06	7.2853E − 06–1.2823E − 05	3.12	3.07–3.18	0.98	0.00	A (+)	0.99 ± 0.12	0.83
	Eucinostomus argenteus	3.6918E − 06	3.9395E − 07–3.4597E − 05	3.28	2.82–3.74	0.95	0.21	I	0.98 ± 0.11	0.57
	Eucinostomus gula	1.0411E − 04	6.0014E − 05–1.8062E − 04	2.60	2.49–2.72	0.77	0.00	A (−)	1.01 ± 0.25	0.99
	Eucinostomus harengulus (Δ)	3.8667E − 05	2.2960E − 06–6.5119E − 04	2.78	2.22–3.34	0.83	0.43	I	0.99 ± 0.09	0.58
Haemulidae	*Haemulon aurolineatum*	6.3848E − 05	2.8560E − 05–1.4274E − 04	2.71	2.55–2.86	0.90	0.00	A (−)	0.99 ± 0.16	0.79
	Haemulon bonariense	6.6635E − 05	4.4704E − 05–9.9326E − 05	2.72	2.65–2.80	0.96	0.00	A (−)	1.02 ± 0.15	0.78
	Haemulon boschmae (*) (Δ)	8.5785E − 05	2.0865E − 05–3.5270E − 04	2.60	2.31–2.89	0.93	0.01	A (−)	0.98 ± 0.14	0.63
	Haemulon plumierii	8.2429E − 05	9.5007E − 06–7.1517E − 04	2.69	2.30–3.08	0.92	0.11	I	1.00 ± 0.08	0.57
	Haemulopsis corvinaeformis	4.2668E − 05	1.0832E − 05–1.6806E − 04	2.81	2.55–3.06	0.94	0.13	I	0.98 ± 0.08	0.58
	Orthopristis rubra (Δ)	9.4879E − 05	8.6810E − 07–1.0370E − 02	2.67	1.78–3.56	0.90	0.40	I	1.01 ± 0.07	0.53
Holocentridae	*Holocentrus adscensionis*	1.8285E − 05	1.2568E − 05–2.6603E − 05	2.92	2.84–2.99	1.00	0.03	A (−)	1.01 ± 0.03	0.52
Lutjanidae	*Lutjanus synagris*	4.2730E − 05	3.3509E − 05–5.4489E − 05	2.80	2.76–2.85	0.99	0.00	A (−)	1.00 ± 0.09	0.72
	Rhomboplites aurorubens	2.0501E − 04	2.2191E − 05–1.8940E − 03	2.46	2.02–2.89	0.96	0.02	A (−)	0.94 ± 0.12	0.56
Mullidae	*Pseudupeneus maculatus*	1.2465E − 06	4.6422E − 07–3.3472E − 06	3.44	3.25–3.63	0.99	0.00	A (+)	1.00 ± 0.04	0.53
	Upeneus parvus	9.9269E − 06	5.1430E − 06–1.9161E − 05	3.06	2.93–3.19	0.94	0.39	I	0.99 ± 0.16	0.76
Muraenidae	*Gymnothorax ocellatus* (Δ)	2.1120E − 08	1.3922E − 10–3.2040E − 06	3.69	2.87–4.52	0.94	0.09	I	1.03 ± 0.16	0.58
Ophidiidae	*Lepophidium profundorum* (*) (Δ)	1.3767E − 06	8.9321E − 07–2.1220E − 06	3.24	3.16–3.33	0.97	0.00	A (+)	1.00 ± 0.16	0.83
Ostraciidae	*Acanthostracion polygonium*	1.2059E − 04	4.4143E − 05–3.2942E − 04	2.62	2.42–2.81	0.95	0.00	A (−)	1.00 ± 0.13	0.65
Paralichthyidae	*Cyclopsetta chittendeni* (*) (Δ)	9.6709E − 06	4.6838E − 06–1.9968E − 05	3.02	2.88–3.15	0.98	0.79	I	1.00 ± 0.13	0.66
	Etropus crossotus(Δ)	1.5346E − 05	1.0524E − 05–2.2378E − 05	2.94	2.86–3.02	0.93	0.15	I	1.00 ± 0.19	0.96
	Paralichthys tropicus (*) (Δ)	1.2862E − 05	9.0810E − 08–1.8216E − 03	2.97	2.09–3.84	0.94	0.92	I	1.01 ± 0.07	0.53
	Syacium papillosum (Δ)	5.7514E − 06	2.7944E − 06–1.1837E − 05	3.12	2.98–3.25	1.00	0.08	I	0.99 ± 0.06	0.53
Priacanthidae	*Priacanthus arenatus*	1.9215E − 05	2.9014E − 06–1.2725E − 04	2.95	2.61–3.30	0.98	0.76	I	1.01 ± 0.08	0.54

Table 2: Continued.

Family	Species	Relationship parameters							K_{rel} mean ± SD	t-test
		a	95% C.I. of *a*	*b*	95% C.I. of *b*	r^2	*t*-student	Growth type		
Sciaenidae	*Bairdiella ronchus*	1.4658E − 04	7.4014E − 05–2.9030E − 04	2.56	2.44–2.68	0.97	0.00	A (−)	0.99 ± 0.08	0.61
	Ctenosciaena gracilicirrhus	1.3123E − 05	5.7726E − 06–2.9833E − 05	3.05	2.89–3.22	0.99	0.52	I	0.99 ± 0.06	0.55
	Cynoscion virescens	9.7699E − 06	4.6848E − 06–2.0375E − 05	2.97	2.83–3.11	0.99	0.65	I	1.02 ± 0.09	0.58
	Isopisthus parvipinnis (Δ)	3.2284E − 06	1.9078E − 06–5.4630E − 06	3.20	3.09–3.31	0.99	0.00	A (+)	1.00 ± 0.08	0.62
	Larimus breviceps	6.6557E − 06	5.5977E − 06–7.9136E − 06	3.14	3.11–3.18	0.99	0.00	A (+)	1.00 ± 0.08	0.80
	Menticirrhus americanus (Δ)	7.9225E − 06	5.9011E − 06–1.0636E − 05	3.15	3.09–3.21	0.96	0.00	A (+)	1.00 ± 0.13	0.89
	Micropogonias furnieri	2.2028E − 05	7.6548E − 06–6.3391E − 05	2.89	2.70–3.07	0.99	0.20	I	0.99 ± 0.04	0.52
Scorpaenidae	*Scorpaena plumieri*	5.3476E − 05	1.0429E − 06–2.7419E − 03	2.85	2.13–3.57	0.90	0.65	I	1.02 ± 0.09	0.55
Serranidae	*Diplectrum bivittatum* (Δ)	7.6705E − 05	4.7257E − 05–1.2450E − 04	2.61	2.50–2.71	0.90	0.00	A (−)	1.02 ± 0.16	0.91
	Diplectrum radiale (Δ)	3.3058E − 05	2.2310E − 05–4.8985E − 05	2.87	2.78–2.95	1.00	0.01	A (−)	1.00 ± 0.05	0.52
Sparidae	*Calamus pennatula*	6.5724E − 05	5.1364E − 06–8.4099E − 04	2.75	2.28–3.21	0.93	0.26	I	0.98 ± 0.08	0.56
Synodontidae	*Saurida normani*	5.6733E − 06	6.5191E − 07–4.9373E − 05	3.07	2.62–3.51	0.98	0.71	I	1.01 ± 0.14	0.56
	Synodus foetens (Δ)	1.2590E − 05	8.4589E − 06–1.8737E − 05	2.89	2.82–2.97	0.99	0.00	A (−)	0.98 ± 0.11	0.69
	Synodus intermedius (Δ)	9.0737E − 07	4.5565E − 07–1.8069E − 06	3.45	3.30–3.60	0.98	0.00	A (+)	1.00 ± 0.16	0.71
	Synodus poeyi (*) (Δ)	1.4002E − 05	8.2102E − 06–2.3880E − 05	2.87	2.76–2.98	0.98	0.02	A (−)	0.99 ± 0.12	0.66
Tetraodontidae	*Lagocephalus laevigatus* (Δ)	1.2197E − 04	7.6717E − 05–1.9391E − 04	2.65	2.56–2.73	0.99	0.00	A (−)	1.00 ± 0.15	0.67
Trichiuridae	*Trichiurus lepturus*	3.6270E − 08	1.4463E − 08–9.0958E − 08	3.43	3.28–3.58	0.96	0.00	A (+)	1.01 ± 0.21	0.82
Triglidae	*Prionotus punctatus*(Δ)	3.5803E − 05	3.0406E − 05–4.2157E − 05	2.80	2.77–2.84	0.99	0.00	A (−)	1.00 ± 0.12	0.80
	Prionotus stearnsi (*) (Δ)	4.2278E − 05	1.0538E − 05–1.6962E − 04	2.68	2.37–2.99	0.98	0.04	A (−)	0.98 ± 0.12	0.56

a: intercept, *b*: slope, C.I.: lower and upper confidence (95%), r^2: determination coefficient, *t*-student: *p*-value of *t*-student, I: isometric growth, A (−): negative allometric growth, A (+): positive allometric growth, Krel: relative condition factor, *t*-test: *p* value of one-sample *t*-test, (*) No available data of LWR in FishBase, (Δ) First report of the LWR in the Colombian Caribbean Sea.

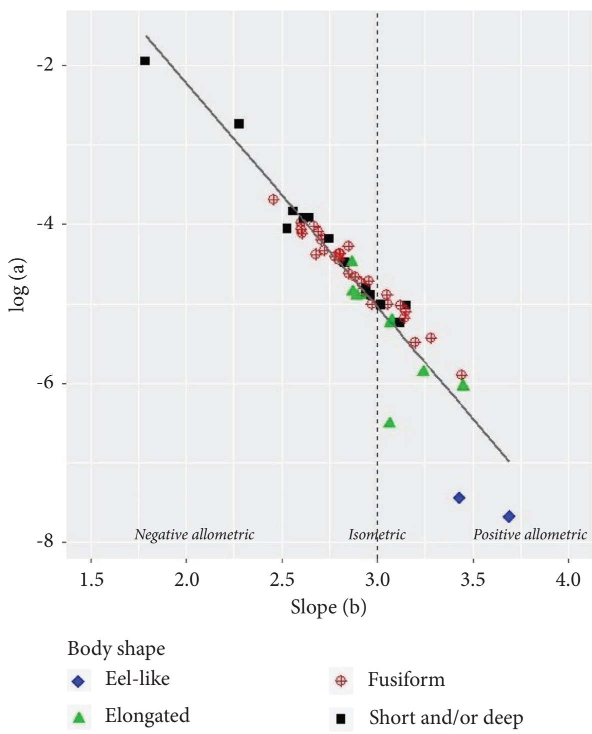

Figure 2: Scatter plot of mean log *a* over mean *b* for 53 fish species with body shape information (see legend) in the Colombian Caribbean Sea. The regression line is based on robust regression analysis, and areas of negative allometric, isometric, and positive allometric change in body weight relative to body length are indicated.

5. Conclusions

In this study, the first estimates of LWR for 25 species of shallow-water fish species in the Colombian Caribbean Sea are presented. We demonstrate the interdependence of the parameters (intercept and slope) of the LWR depending on the body shapes of the fish. 39.6% of the species evaluated are probably in poor growth conditions, which may be related to high fishing pressure derived from industrial and artisanal fisheries. This work contributes with biological information on the LWR and the relative condition factor of demersal fish from shallow waters that can be very useful for the management and conservation of fish species exploited.

Data Availability

The data used to support the findings of this study are available upon request to jparamo@unimagdalena.edu.co or arodriguezj@unimagdalena.edu.co.

Disclosure

This study was part of Alfredo Rodriguez's PhD thesis.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] J. Paramo, L. Guillot-Illidge, S. Benavides, A. Rodriguez, and C. Sánchez, "Aspectos poblacionales y ecológicos de peces demersales de la zona norte del Caribe colombiano en relación con el hábitat: una herramienta para identificar Áreas Marinas Protegidas (AMPs) para el manejo pesquero," *Caldasia*, vol. 31, no. 1, pp. 123–144, 2009.

[2] M. Rueda, O. Doncel, E. A. Viloria et al., "Atlas de la pesca marino-costera de Colombia: 2010-2011," *Serie de publicaciones del INVEMAR, INVEMAR*, ANH, Santa Marta, Colombia, 2012.

[3] FAO, *Colombia pesca en cifras 2014*, FAO, Roma, Italia, 2015.

[4] Sepec, *Servicio estadístico pesquero colombiano*, 2019,http://sepec.aunap.gov.co/.

[5] J. E. Viaña, J. A. Medina, M. E. Barros, L. Manjarrés, J. Altamar, and M. Solano, "Evaluación de la ictiofauna demersal extraída por la pesquería industrial de arrastre en el área norte del Caribe colombiano (Enero/2000-Junio/2001)," in *Pesquerías demersales del área norte del Mar Caribe de Colombia y parámetros biológico-pesqueros y poblaciones del recurso pargo*, L. Manjarrés, Ed., pp. 115–151, Universidad del Magdalena, Santa Marta, Colombia, 2004.

[6] A. Rodriguez and J. Paramo, "Distribución espacial del pargo rayado *Lutjanus synagris* (Pisces: lutjanidae) y su relación con las variables ambientales en el Caribe colombiano," *Actualidades Biológicas*, vol. 34, no. 96, pp. 55–66, 2017.

[7] D. Bustos, M. Rueda, J. Viaña et al., "Evaluación interanual del impacto de las pesquerías industriales de arrastre de camarón sobre la biodiversidad marina de Colombia," *Proceedings of the annual Gulf and Caribbean Fisheries Institute*, vol. 65, pp. 370–374, 2013.

[8] Invemar, *Informe del estado de los ambientes y recursos marinos y costeros en Colombia 2018*, Serie de Publicaciones Periódicas, Santa Marta, Colombia, 2019.

[9] Y. Ye, A. H. Alsaffar, and H. M. Mohammed, "Bycatch and discards of the Kuwait shrimp fishery," *Fisheries Research*, vol. 45, no. 1, pp. 9–19, 2000.

[10] R. Gillett, "Global study of shrimp fisheries," FAO Fisheries, Rome, Italy, FAO Fisheries Technical Paper, 2008.

[11] J. Mendo, T. Mendo, P. Gil-Kodaka et al., "Bycatch and discards in the artisanal shrimp trawl fishery in Northern Peru," *PLoS One*, vol. 17, no. 6, Article ID e0268128, 2022.

[12] K. Erzini, "An empirical study of variability in length-at-age of marine fishes," *Journal of Applied Ichthyology*, vol. 10, no. 1, pp. 17–41, 1994.

[13] J. M. S. Gonçalves, L. Bentes, P. G. Lino, J. Ribeiro, A. V. Canario, and K. Erzini, "Weight-length relationships for selected fish species of the small-scale demersal fisheries of the south and south-west coast of Portugal," *Fisheries Research*, vol. 30, no. 3, pp. 253–256, 1997.

[14] T. Morato, P. Afonso, P. Lourinho, J. Barreiros, R. S. Santos, and R. D. Nash, "Length-weight relationships for 21 coastal fish species of the Azores, north-eastern Atlantic," *Fisheries Research*, vol. 50, no. 3, pp. 297–302, 2001.

[15] R. Froese, "Cube law, condition factor and weight-length relationships: history, meta-analysis and recommendations," *Journal of Applied Ichthyology*, vol. 22, no. 4, pp. 241–253, 2006.

[16] T. E. Kampouris, E. Kouroupakis, and I. E. Batjakas, "Morphometric relationships of the global invader *Callinectes sapidus* rathbun, 1896 (Decapoda, Brachyura, portunidae) from papapouli lagoon, NWAegean Sea, Greece. With notes on its ecological preferences," *Fishes*, vol. 5, no. 1, p. 5, 2020.

[17] F. Falsone, M. L. Geraci, D. Scannella et al., "Length-weight relationships of 52 species from the south of sicily (central mediterranean Sea)," *Fishes*, vol. 7, no. 2, p. 92, 2022.

[18] M. N. Santos, M. B. Gaspar, P. Vasconcelos, and C. C. Monteiro, "Weight-length relationships for 50 selected fish species of the Algarve coast (southern Portugal)," *Fisheries Research*, vol. 59, no. 1-2, pp. 289–295, 2002.

[19] A. M. Vaz-dos-Santos and B. Gris, "Length-weight relationships of the ichthyofauna from a coastal subtropical system: a tool for biomass estimates and ecosystem modelling," *Biota Neotropica*, vol. 16, no. 3, Article ID e20160192, 2016.

[20] R. Sousa, J. Vasconcelos, and R. Riera, "Weight-length relationships of four intertidal mollusc species from the northeastern Atlantic Ocean and their potential for conservation," *Molluscan Research*, vol. 40, no. 4, pp. 363–368, 2020.

[21] S. K. Koushlesh, A. Sinha, K. Kumari et al., "Length-weight relationship and relative condition factor of five indigenous fish species from Torsa River, West Bengal, India," *Journal of Applied Ichthyology*, vol. 34, pp. 169–171, 2017.

[22] N. Jisr, G. Younes, C. Sukhn, and M. H. El-Dakdouki, "Length-weight relationships and relative condition factor of fish inhabiting the marine area of the Eastern Mediterranean city, Tripoli-Lebanon," *The Egyptian Journal of Aquatic Research*, vol. 44, no. 4, pp. 299–305, 2018.

[23] M. Kulbicki, N. Guillemot, and M. Amand, "A general approach to length-weight relationships for New Caledonian lagoon fishes," *Cybium*, vol. 29, pp. 235–252, 2005.

[24] M. L. Bastidas-Salamanca and A. Figueroa-Casas, "Seguimiento satelital de las condiciones océano-atmosféricas asociadas a los eventos de precipitación en Colombia durante el evento La Niña 2010-2011," *Boletín Científico CIOH*, vol. 32, pp. 123–134, 2014.

[25] R. Froese and D. Pauly, *FishBase*, 2023,https://www.fishbase.se/.

[26] A. B. Keys, "The weight-length relation in fishes," *Proceedings of the National Academy of Sciences*, vol. 14, no. 12, pp. 922–925, 1928.

[27] E. D. L. Cren, "The length-weight relationship and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*)," *Journal of Animal Ecology*, vol. 20, no. 2, pp. 201–219, 1951.

[28] D. H. Ogle, *Introductory Fisheries Analyses with R*, Chapman and Hall/CRC, New York, NY, USA, 2016.

[29] J. H. Zar, *Biostatistical Analysis*, Prentice Hall, New Jersey, NJ, USA, 2010.

[30] R. Development Core Team, *A Language and Environment for Statistical Computing*, R Foundation for Statistical Computing, Vienna, Austria, 2023.

[31] H. Wickham, *ggplot2: Elegant Graphics for Data Analysis*, Springer-Verlag, New York, NY, USA, 2016.

[32] L. Komsta and F. Novomestky, "Moments: moments, cumulants, skewness, kurtosis and related tests, R package version 0.14.1," 2022, https://CRAN.R-project.org/package=moments.

[33] D. H. Ogle, "FSAmisc. Miscellaneous functions for simple fisheries stock assessment methods, R package version 0.0.3," 2022, https://github.com/droglenc/FSAmisc.

[34] H. Wickham, "Modelr: modelling functions that work with the pipe, R package version 0.1.10," 2022, https://CRAN.R-project.org/package=modelr.

[35] T. B. Bagenal and F. W. Tesch, "Age and growth," in *Methods for Assessment of Fish Production in Fresh Waters*, T. B. Bagenal, Ed., Blackwell Scientific Publications, Oxford, UK, 1978.

[36] M. King, *Fisheries Biology, Assessment and Management*, Wiley-Blackwell, London, UK, 2007.

[37] K. D. Carlander, *Handbook of Freshwater Fishery Biology*, The Iowa State University Press, Ames, IA, USA, 1977.

[38] P. Safran, "Theoretical analysis of the weight-length relationship in fish juveniles," *Marine Biology*, vol. 112, no. 4, pp. 545–551, 1992.

[39] P. B. Moyle and J. J. Cech, *Fishes: An Introduction to Ichthyology*, Prentice Hall, New Jersey, NJ, USA, 2004.

[40] R. Froese, A. C. Tsikliras, and K. I. Stergiou, "Editorial note on weight-length relations of fishes," *Acta Ichthyologica et Piscatoria*, vol. 41, no. 4, pp. 261–263, 2011.

[41] T. Correa-Herrera, L. F. Jiménez-Segura, and M. Barletta, "Fish species from a micro-tidal delta in the Caribbean Sea," *Journal of Fish Biology*, vol. 89, no. 1, pp. 863–875, 2016.

[42] G. Díaz-Pulido, "Ecosistemas marinos y costeros," in *Informe nacional sobre el estado de la biodiversidad en Colombia 1997*, M. E. Chaves and N. Arango, Eds., Instituto de Investigación de Recursos Biológicos Alexander von Humboldt, PNUMA, Ministerio del Medio Ambiente, Bogotá, Colombia, 1998.

[43] Invemar, "Informe del estado de los ambientes marinos y costeros en Colombia: año 2003," *Series de Publicaciones Periódicas*, INVEMAR, Santa Marta, Colombia, 2004.

[44] O. Delgadillo-Garzón and P. Zapata-Ramírez, "Evaluación rápida de peces arrecifales y su relación con la estructura del sustrato en las Islas del Rosario, Área Marina Protegida del Caribe colombiano," *Revista de la Academia Colombiana de Ciencias Exactas Fisicas y Naturales*, vol. 33, pp. 273–284, 2009.

[45] C. López-Pérez, M. P. Olivar, P. A. Hulley, and V. M. Tuset, "Length-weight relationships of mesopelagic fishes from the equatorial and tropical Atlantic waters: influence of environment and body shape," *Journal of Fish Biology*, vol. 96, no. 6, pp. 1388–1398, 2020.

[46] C. Barreto and C. Borda, *Evaluación de recursos pesqueros colombianos*, ICA, Produmedios, Bogotá, Colombia, 2008.

[47] J. Paramo and U. Saint-Paul, "Morphological differentiation of southern pink shrimp *Farfantepenaeus notialis* in Colombian Caribbean Sea," *Aquatic Living Resources*, vol. 23, no. 1, pp. 95–101, 2010.

[48] L. Manjarrés, F. Cuello, L. O. Duarte, and R. Acevedo, "Evaluación experimental del efecto de dispositivos reductores de pesca acompañante en una pesquería artesanal de arrastre camaronero del Golfo de Salamanca, Caribe colombiano," *Boletin de Investigaciones Marinas y Costeras*, vol. 43, no. 2, pp. 329–349, 2016.