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Research Article

Length-Weight Relationship of 20 Cryptobenthic Fish in Coral and Rocky Reefs in the Gulf of California, Mexico

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We present the length-weight relationships (LWRs) in 20 cryptobenthic reef fish species in the Gulf of California (Mexico). Nine of these species had no LWR records yet. However, the other species had LWRs based on *in-formalin* specimens collected more than 20 years ago. This conservation method has likely affected LWRs parameters. Our study showed higher estimations of the parameter a obtained on fresh specimens than *in-formalin* individuals. On the other hand, parameter b was not affected. Therefore, the biomass estimates using previous LWRs were strongly underestimated. Ergo, the similitude in parameter b between the two conservation methods highlights that the shape of the LWRs is conserved and did not change over the last 20 years. Finally, we compared the LWRs of shared species in the region's two main types of shallow reefs, i.e., coral and rocky reefs. We found that the body fitness was not affected by reefs type, which means that both habitats seem to offer similar living conditions for shared species.

1. Introduction

The cryptobenthic reef fishes (CRFs) are small size species (~less than 50 mm) living hidden in the interstices of the reef's substratum [1]. Although highly abundant and playing essential roles in reefs' trophodynamics and productivity [2–4], CRFs are generally understudied because of their discrete nature. The Gulf of California (GC, Mexico) supports a rich and abundant ichthyofauna with approximately 300 reef fishes' species [5, 6], of which about one-third are CRFs [7]. While some studies have investigated biogeographic patterns of CRFs in this region [8, 9], their ecology is still poorly known (but see [10, 11]).

Length-weight relationships (LWRs) allow for estimating fish biomass thanks to more accessible fish body length data and are essential for fisheries management and conservation for regulating catches [12]. Moreover, LWRs can be used as conditions factors to compare the fitness of individuals [13] that may vary on temporal and spatial scales [12]. Because of their small size, CRFs have a high metabolism, and unfavorable conditions (scarcity or less nutritional prey, higher predation pressure, pollution, etc.) may have rapid negative effects on their fitness and, in turn, on their productivity [1]. CRFs may represent ~60% of consumed reef fish biomass and represent a cornerstone for ecosystem functioning and trophodynamic relationships [4]. Therefore, a less suitable environment for CRFs may affect the equilibrium and functioning of the reef. For example, divergent prey availability between the southern Arabian Gulf and the Gulf of Oman modified LWRs of CRFs with lower fitness in Arabian Gulf, characterized by more extreme environmental conditions [14]. Therefore, knowledge about species LWRs and their spatial and temporal comparison may estimate the individual's living conditions and help understand the health status and functioning of the reefs.

To our knowledge, a single study estimated the LWRs in 17 CRFs species in the GC (La Paz Bay) on individuals collected more than 20 years ago [15]. Additionally, a LWRs study was conducted in the mangrove swamp of La Paz Bay and included a single CRF species [16]. Balart et al. [15] used weights of specimens preserved in formalin, likely affecting the LWRs estimations.

We estimated the LWRs in 24 CRFs species using fresh weight in the present study. Nine of them have not been recorded in Fishbase yet. Then, by comparing the shared species between our research and the anterior of Balart et al. [15]; we investigated the effect of conservation methods on LWRs estimation. Finally, we compared the LWRs between rocky and coral reefs to test whether both habitats offer similar ecological opportunities for shared species.

2. Materials and Methods

We sampled CRFs assemblages from August to November 2020 in two coral and two rocky reefs in La Paz Bay (Figure 1) at 2 to 6 m depth. We injected clove oil and ethanol (ratio 1 : 3) inside a leak-proof bag covering a one-meter squared quadrant. Anesthetized fish were collected by divers using hand nets, placed in tagged plastic bags, and preserved on ice until transport to the laboratory, where specimens were preserved at −20°C. We collected CRFs on 70 quadrants (16 on the reef "El Faro" and 18 for each other three reefs). All fish were identified to species level using specialized keys [5]. The total length (TL) of fish was measured using digital calipers with 0.1 mm precision and weighted using an electronic scale with 0.01 g precision.

First, we explored the length-weight relationships for each species to delete high-leverage points (Figure S1). We then calculated LWRs using Froese's equation (2006) as given as follows:

$$W = a * L^b + \varepsilon, \quad (1)$$

or in its logarithmic form as given as follows:

$$\log W = \log a + b * \log b + \varepsilon, \quad (2)$$

where W is the total weight of the fish (g), L is total length (mm), a is the intersection point with the y axis, b is the slope of the curve, and ε is an error term, assuming that $\varepsilon \sim N(0, \sigma)$. The LWR models were adjusted using nonlinear least squares with the *nls* function in R software [17]. Because the sampling size was highly heterogeneous among species (Table 1), we plot the relationships between each models' coefficients of determination (r^2) against sampling sizes. Finally, we plot the logarithmic values of parameter a against

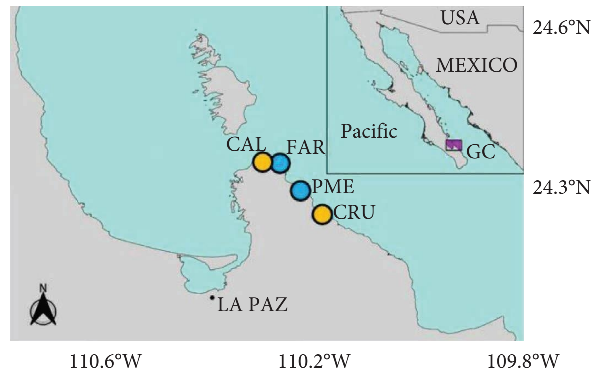


FIGURE 1: Geographic location of the four reef sites where cryptobenthic fishes were collected in La Paz Bay, Gulf of California. Coral and rocky reefs are orange and blue-colored, respectively. CAL: Caleritas, CRU: Las Cruces, FAR: El Faro, PME: Puerto Mexía.

parameter b values to detect questionable LWRs due to narrow size range, not enough data, or outliers to the respective model [12].

Based on the 14 species in common between our study and the collection of Balart et al. [15], we compared a and b parameters between the two studies and how potential differences may affect the estimated biomass. Finally, we selected seven species abundant in both coral and rocky reefs, and we compared their length, weight, and LWRs between the two habitats. Length and weight comparisons were run with student t-tests (Table S1) in R software [17].

3. Results and Discussions

The LWR models generally provided a good fit to the data as r^2 was higher than 0.9 for 21 of the 24 species and below 0.7 for *Coralliozetus micropes* (Table 1). Although the lowest r^2 had a small sampling size and narrow size range, these two parameters do not seem to have affected the fitting of the models (Figure 2(a)). All the parameter b values fell in the acceptable 2.5–3.5 range (Table 1), with values outside this range generally indicating wrong estimates due to sampling size or too narrow range size [18]. The parameter a values were also included in the 95% range values found on teleosts [12]. The relationship between the logarithmic values of parameter a and parameter b indicates some outliers (Figure 2(b)). These divergences do not seem related to the representativity of the studied size range but the body shape of the species. The two non-CRFs species *Cirrhitichthys oxycephalus* (Bleeker, 1855) and *Stegastes rectifraenum* (Gill, 1862) have a short and deep body shape. These two species have higher values of parameter a for a given parameter b value than most studied species with elongated or fusiform body shapes (Figure 2(b)). On the contrary, *Doryrhamphus excisus* (Kaup, 1856) has an eel-like body shape and lower parameter a value (Figure 2(b)). Our observed body shape effect reflects what was observed on teleosts [12].

We found a high difference in parameter a *values* when estimations were made on fresh or *in-formalin* specimens, but parameter b showed complete overlap (Figure 3(a)).

Table 1: Characteristics of the sample and estimated length-weight relationship (LWR) parameters for the 24 studied species. References are indicated when LWR had been studied in previous studies.

Species	Anterior studies	True cryptic (1 = yes, 0 = no)	N	Max size	Size range (cm)	a	95% CI a	b	95% CI b	r^2	Body shape
Acanthemblemaria crockeri (Beebe & Tee-Van, 1938)	A	1	228	6	1.43–3.37	0.014	0.013–0.016	2.738	2.625–2.852	0.93	Elongated
Apogon retrosella (Gill, 1862)	A	0	112	10	1.15–6.16	0.021	0.018–0.024	3.212	3.127–3.298	0.98	Fusiform
Axoclinus nigricaudis (Allen & Robertson, 1991)	—	1	38	4.5	1.21–3	0.018	0.015–0.021	2.894	2.710–3.084	0.98	Elongated
Axoclinus storyae (Brock, 1940)	—	1	23		1.13–2.28	0.019	0.014–0.027	2.959	2.501–3.452	0.93	Elongated
Barbulifer pantherinus (Pellegrin, 1901)	A	1	36	5.2	1.18–2.41	0.016	0.011–0.021	3.298	2.908–3.715	0.91	Elongated
Chriolopis zebra (Ginsburg, 1938)	—	1	72	4.4	0.91–2.78	0.013	0.011–0.016	3.233	3.011–3.467	0.96	Elongated
Cirrhitichthys oxycephalus (Bleeker, 1855)	A	0	17	10	4.42–6.27	0.04	0.016–0.098	2.868	2.347–3.403	0.91	Short & deep
Coralliozetus micropes (Beebe & Tee-Van, 1938)	—	1	11	4	1.61–2.03	0.014	0.004–0.041	2.846	1.078–4.741	0.6	Elongated
Coryphopter usurospilus (Ginsburg, 1938)	A	1	136	6.5	1.36–3.76	0.012	0.011–0.014	3.431	3.312–3.552	0.96	Elongated
Crocodilichthys gracilis (Allen & Robertson, 1991)	A	1	8	6.4	2.4–3.88	0.016	0.010–0.026	2.77	2.394–3.165	0.99	Elongated
Doryrhamphus excisus (Kaup, 1856)	A	1	16	7	1.69–4.59	0.002	0.001–0.002	3.181	2.865–3.524	0.98	Eel-like
Enneactes reticulatus (Allen & Robertson, 1991)	A	1	239	4.9	1.22–4.02	0.032	0.027–0.037	2.459	2.313–2.606	0.83	Elongated
Gobiosoma chiquita (Jenkins & Evermann, 1889)	B	1	27	6.5	1.09–2.34	0.014	0.009–0.021	3.365	2.861–3.940	0.95	Elongated
Lythrypnus pulchellus (Ginsburg, 1938)	A	1	93	4.5	0.7–2	0.019	0.016–0.023	3.044	2.718–3.386	0.85	Fusiform
Lythrypnus rhizophora (Heller & Snodgrass, 1903)	—	1	35	3.4	0.74–2.18	0.019	0.014–0.024	3.333	2.905–3.774	0.91	Fusiform
Malacoctenus hubbsi (Springer, 1959)	—	1	19	9	2.29–4.86	0.018	0.009–0.032	3.092	2.671–3.552	0.97	Fusiform
Paraclinus mexicanus (Gilbert, 1904)	—	1	162	4	0.86–3.34	0.016	0.015–0.018	2.996	2.886–3.108	0.96	Fusiform
Paraclinus sini (Hubbs, 1952)	A	1	22	6	1.74–3	0.011	0.007–0.016	3.53	3.142–3.934	0.96	Fusiform
*Pycnomma semisquamatum** (Rutter, 1904)	—	1	38	6.3	1.25–3.3	0.016	0.011–0.023	3.204	2.833–3.580	0.91	Elongated
Starksia spinipenis (Al-Uthman, 1960)	A	1	13	5	1.79–2.98	0.015	0.011–0.022	3.357	2.994–3.743	0.98	Fusiform
Stathmonotus sinuscalifornici (Chabanaud, 1942)	—	1	24	6.5	0.88–3.08	0.006	0.003–0.01	3.16	2.57–3.85	0.93	Elongated
Stegastes rectifraenum (Gill, 1862)	A	0	14	13.5	0.98–4.04	0.042	0.030–0.057	2.885	2.646–3.150	0.99	Short & deep
Thalassoma lucasanum (Gill, 1862)	A	0	6	15	1.12–2.91	0.024	0.013–0.037	2.84	2.398–3.413	0.99	Fusiform
Tigrigobius puncticulatus (Ginsburg, 1938)	A	1	60	5	1.07–2.61	0.018	0.015–0.022	3.059	2.803–3.319	0.92	Elongated

A: Balart et al. [15]; B: Moreno-Sánchez et al. [16]; * new maximum length record; N = number of specimens; a = is the intersection point with the y axis, b = is the slope of the curve, r^2 = coefficients of determination, a and b parameters and associated (upper-lower) 95% confidence interval (CI).

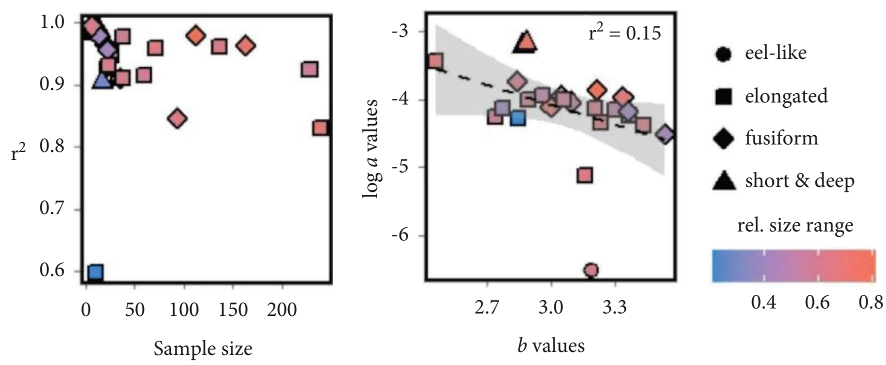


Figure 2: (a) Relationship between the coefficient of determination (r^2) of LWR models and sample size and relative size range. (b) Relationship between parameter *a* (log-scale) and parameter *b*. For each species, the relative size range and the body shape are indicated.

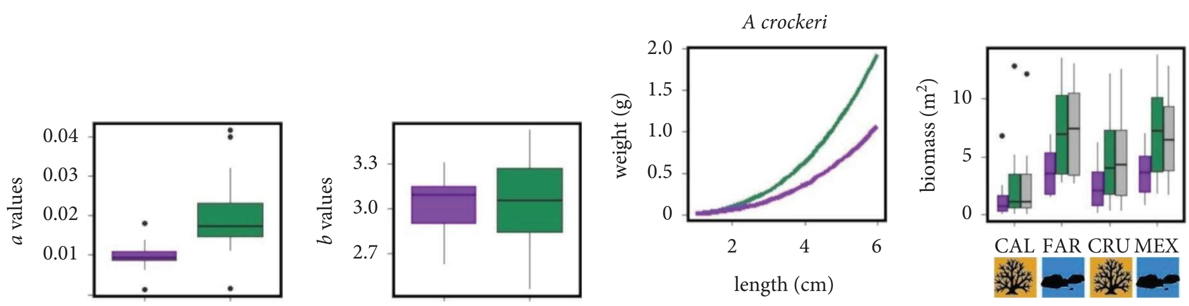
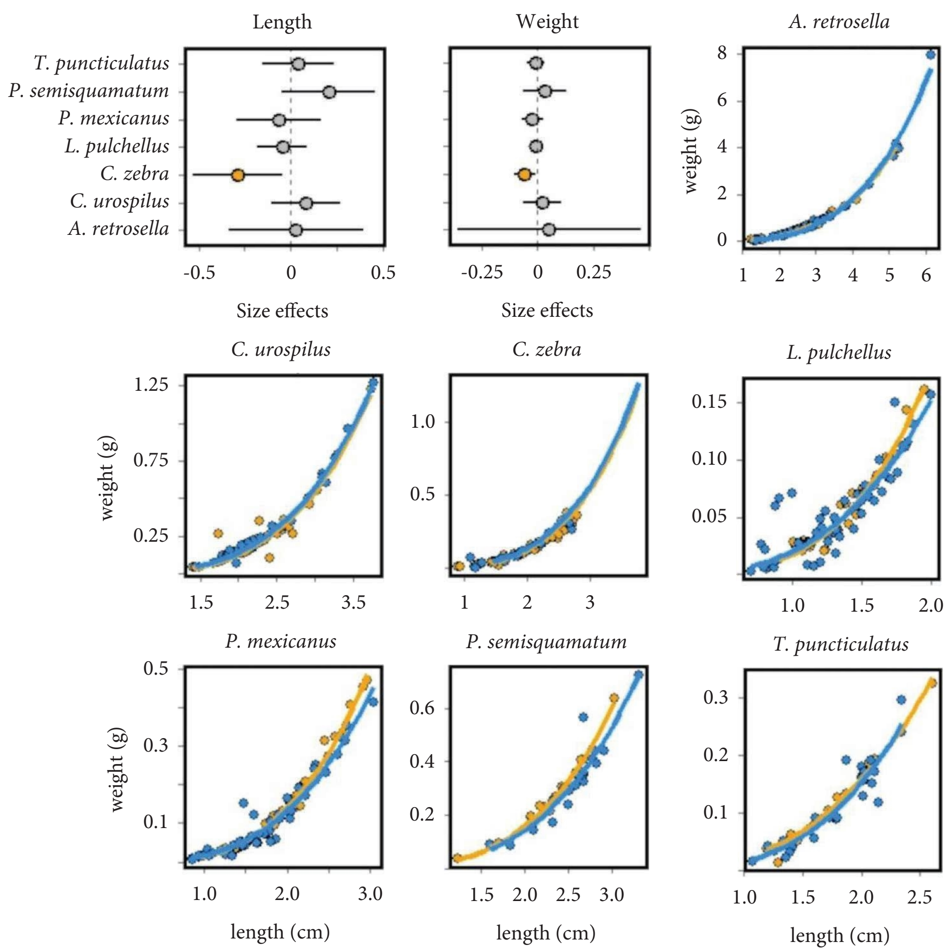


Figure 3: Comparison of LWR based on fresh (green) and *in-formalin* (purple) specimens. (a) Comparison of parameters *a* and *b*. (b) Effect of LWR difference on weight and biomass estimations. For example, the estimated weight of *Acanthemblemaria crockery* along the full simulated range size of the species is shown according to the two conservation methods. The biomass per quadrant of fish assemblages considering the 14 species in common between the present study (fresh specimens) and the anterior study (*in-formalin* specimens, [15] is also shown. Data are represented by site and reef types are indicated (coral and rocky). Three biomass values are shown: (i) the estimated biomass based on LWR parameters using *in-formalin* specimen (purple); (ii) the estimated biomass based on LWR parameters using fresh specimen (green); and the true (weighted) biomass (grey).

That means that the preservation in formalin affected the intercept of the LWRs models (in log scale, equation (2)) but not the slope. That provides a substantial underestimation of the biomass (Figure 3(b)). However, the shape of the LWRs (slope value) seems unaffected. Hence, LWRs based on *in-formalin* specimens will poorly estimate weight or biomass values but can be helpful for comparing the slope, and therefore, the body condition of individuals preserved with the same method. As we found no difference in parameter *b* with the collection made ~20 years ago, the LWRs showed temporal stability, indicating that reefs' environmental conditions did not significantly change in the last two decades or that species were able to adapt.



(a) (b)

Figure 4: Comparison of length, weight and LWR between coral (orange) and rocky (blue) reefs of seven abundant species in the two habitats. (a) The differences between rocky and coral means are sketched with their 95% CI. The only significant difference (CI not crossing zero) is highlighted in orange with higher length and weight in the coral reefs. (b) The LWRs are sketched for the seven species in function of the habitat.

From the abundant species in both coral and rocky reefs, we found that only the gobiid *Chriolepis zebra* (Ginsburg, 1938) had a higher length and weight in coral reefs than in rocky reefs (Figure 4(a), Table S1). However, the LWRs did not differ between the two habitats (Figure 4(b)), meaning that body conditions are similar. A less favorable habitat could affect the fitness of species [14]. Although coral reefs generally host less fish diversity than rocky reefs in the eastern tropical Pacific due to a more homogeneous seascape [19], they seem to offer similar living conditions for shared species.

Data Availability

All data and code necessary to reproduce the results of the paper are published on Zenodo. Doi: 10.5281/zenodo.7388348.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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Supplementary Materials

Table S1: length and weight comparison of cryptobenthic reef fishes between coral and rocky reefs. The estimate representing the difference between rocky and coral means, standard error (SE), and *t* value (Estimate/SE) is indicated. Figure S1: relationship between weight and length of the 24 species studied.

Red dots indicate individuals that were not considered because of unusual values along weight or length axes. Full species names are available in Table 1. (*Supplementary Materials*)

References

[1] S. J. Brandl, C. H. R. Goatley, D. R. Bellwood, and L. Tornabene, "The hidden half: ecology and evolution of cryptobenthic fishes on coral reefs," *Biological Reviews*, vol. 93, no. 4, pp. 1846–1873, 2018.

[2] M. Depczynski and D. R. Bellwood, "The role of cryptobenthic reef fishes in coral reef trophodynamics," *Marine Ecology Progress Series*, vol. 256, pp. 183–191, 2003.

[3] C. H. R. Goatley, A. González-Cabello, and D. R. Bellwood, "Small cryptopredators contribute to high predation rates on coral reefs," *Coral Reefs*, vol. 36, no. 1, pp. 207–212, 2017.

[4] S. J. Brandl, L. Tornabene, C. H. R. Goatley et al., "Demographic dynamics of the smallest marine vertebrates fuel coral reef ecosystem functioning," *Science*, vol. 364, no. 6446, pp. 1189–1192, 2019.

[5] D. R. Robertson and G. R. Allen, *Shorefishes of the Tropical Eastern Pacific: Online Information System*, Smithsonian Tropical Research Institute, Balboa, Panamá, 2015.

[6] D. Olivier, N. Loiseau, D. Petatán-Ramírez et al., "Functional-biogeography of the reef fishes of the islands of the Gulf of California: integrating functional divergence into marine conservation," *Global Ecology and Conservation*, vol. 16, Article ID e00506, 2018.

[7] G. R. Galland, *The Conservation and Ecology of Cryptobenthic Fishes on Rocky Reefs in the Gulf of Califronia*, University of California, San Diego, CA, USA, 2013.

[8] D. A. Thomson and M. R. Gilligan, "Rocky-shore fishes," in *A New Island Biogeography of the Sea of Cortés*, T. J. Case, M. L. Cody, and E. Ezcurra, Eds., pp. 154–180, Oxford University Press, England, UK, 2002.

[9] G. R. Galland, B. Erisman, O. Aburto-Oropeza, and P. A. Hastings, "Contribution of cryptobenthic fishes to estimating community dynamics of sub-tropical reefs," *Marine Ecology Progress Series*, vol. 584, pp. 175–184, 2017.

[10] K. Kotrschal and D. A. Thomson, "Feeding patterns in eastern tropical pacific blennioid fishes (teleostei: tripterygiidae, labrisomidae, chaenopsidae, blenniidae)," *Oecologia*, vol. 70, no. 3, pp. 367–378, 1986.

[11] K. Kotrschal, "Trophic ecomorphology in eastern pacific blennioid fishes: character transformation of oral jaws and associated change of their biological roles," *Environmental Biology of Fishes*, vol. 24, no. 3, pp. 199–218, 1989.

[12] 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.

[13] F. W. Tesch, "Age and growth," in *Methods for Assessment of Fish Production in Fresh Waters*, W. E. Ricker, Ed., pp. 93–123, Blackwell Scientific Publications, Hoboken, NJ, USA, 1968.

[14] S. J. Brandl, J. L. Johansen, J. M. Casey, L. Tornabene, R. A. Morais, and J. A. Burt, "Extreme environmental conditions reduce coral reef fish biodiversity and productivity," *Nature Communications*, vol. 11, no. 1, p. 3832, 2020.

[15] E. F. Balart, A. González-Cabello, R. C. Romero-Ponce et al., "Length-weight relationships of cryptic reef fishes from the southwestern Gulf of California, Mèxico," *Journal of Applied Ichthyology*, vol. 22, no. 4, pp. 316–318, 2006.

[16] X. G. Moreno Sánchez, S. E. Lluch-Cota, L. Hernández-Olalde, F. López Rasgado, and L. A. Abitia-Cardenas, "Weight-length relationships of mangrove fishes from Bahía de La Paz, Gulf of California, Mexico," *Journal of Applied Ichthyology*, vol. 28, no. 4, pp. 671-672, 2012.

[17] R Development Core Team, *R: A Language and Environment for Statistical Computing*, R Foundation for Statistical Computing, Vienna, Austria, 2016.

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

[19] M. Olán-González, H. Reyes-Bonilla, L. Álvarez-Filip, H. Pérez-España, and D. Olivier, "Fish diversity divergence between tropical eastern pacific and tropical western Atlantic coral reefs," *Environmental Biology of Fishes*, vol. 103, no. 11, pp. 1323–1341, 2020.