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Research Article

Length-Weight Relationships for 32 Species of Cryptobenthic Reef Fishes from the Red Sea

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Cryptobenthic reef fishes (CRFs) are often neglected in reef biodiversity assessments, trophodynamic studies, and biomass models. This oversight is due to the challenges associated with recording them in traditional underwater visual surveys and the scarcity of literature detailing their life history, ecology, and body growth parameters. Given their pivotal role in the functioning and maintenance of coral reef ecosystems, addressing these information gaps for CRF species is of great importance. In this study, we have computed the length-weight relationships (LWRs) for 32 CRF species spanning seven families in the Red Sea. This marks the first comprehensive report of LWR parameters for CRFs from this region, and for 31 of these species, it serves as their first LWR data report. The coefficient of determination (r^2) ranged from 0.82 to 0.99, indicating a good fit for the LWRs. Half of the presented species belong to the Gobiidae family, including three undescribed species. In addition, we present LWRs for species from the families Blenniidae (5 spp.), Tripterygiidae (2 spp.), Apogonidae (4 spp.), Pseudochromidae (3 spp.), Plesiopidae (1 spp.), and Scorpaenidae (1 spp.). This research contributes invaluable insights into the growth patterns of CRFs not only in a global context but also beyond, as 50% of the recorded species are endemic to the region. The data generated holds great significance for conducting functional diversity analyses, ecosystem assessments, and coral reef health monitoring. By capturing this critical information, this work provides foundational metrics to take significant strides toward the conservation of these essential coral reef fishes.

1. Introduction

Cryptobenthic reef fishes (CRF) significantly differ from larger and conspicuous reef fishes. They are difficult to observe because of their minute size (less than 5 cm in length), their cryptic behavior, and their association with the benthic habitats [1, 2]. As a result of these characteristics, traditional reef fish studies exclude CRFs from their assessments, leaving a significant knowledge gap in the understanding of coral reef diversity and functioning. The omission of CRFs from fish surveys conceals up to 50% of fish individuals and up to 40% of fish species of coral reefs [3]. Despite the increasing research and inclusion of CRFs over the last few decades, the knowledge around diversity, ecology, diet, habitat, movement, and life cycle, among others, is limited and absent for many species. Even with CRFs' high diversity and abundance across coral reefs, we still lack a substantial and comprehensive understanding of the ecological functions they provide in these ecosystems. Among all the potential ecosystem functioning roles CRFs can have, it is worth highlighting their role as abundant and constant protein sources for marine organisms of higher trophic levels [4]. On the other hand, because of their size, their metabolic requirements and thresholds make them highly vulnerable to environmental stressors and habitat alterations [3, 5, 6], impacting communities, population dynamics, and individual physiological resilience.

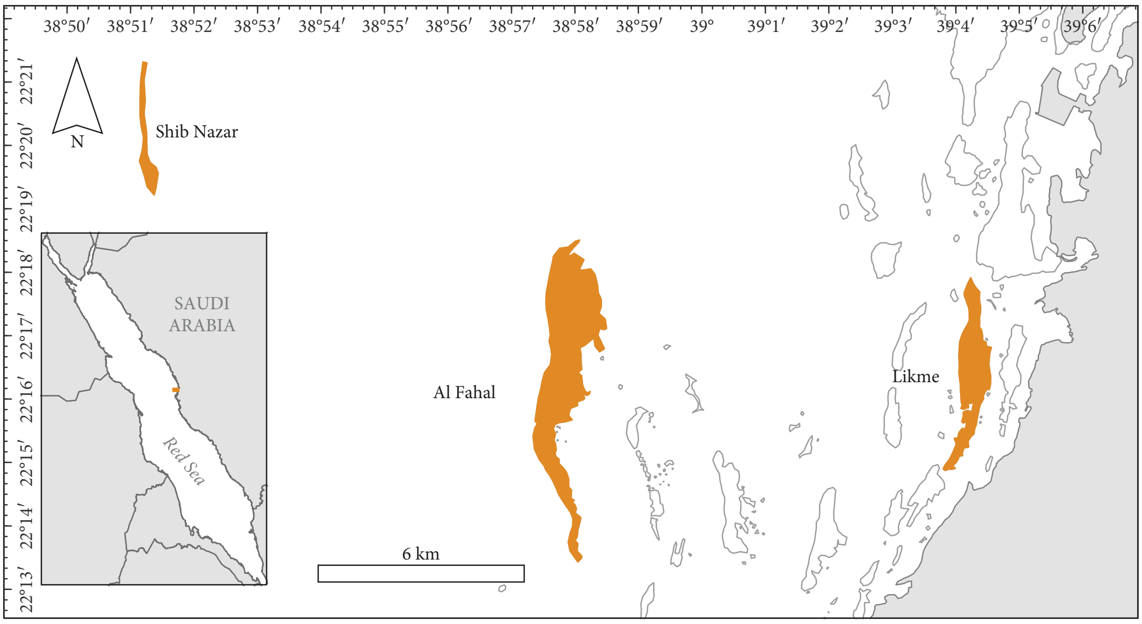


Figure 1: Map illustrating the location of the collections of CRFs in the Saudi Arabian coast of the central Red Sea. Map created by Ute Langner.

Traditionally, length-weight relationships (LWRs) have been used to estimate fish biomass based on easier-to-obtain fish length data as opposed to weight data. It is a tool that has become essential for fisheries management, conservation of endangered species, and catch restrictions or regulations [7]. In coral reef ecological studies, it is a tool that allows the integration of biomass calculations based on size estimations from *in situ* visual surveys [8] for both spatial and temporal comparisons. LWRs have also been used to compare fitness by calculating individual body condition factors [9] with contrasting environmental conditions [10, 11] or for optimizing aquaculture conditions [12]. Knowledge of CRF species LWRs is essential for integrating these species into functional diversity analysis, ecosystem functioning assessments, and coral reef health monitoring. Currently LWRs models for many fishes, especially CRFs, are based on models conducted at the family or subfamily level or from species with similar body shape. Our study is the second dedicated effort to estimate the length-weight relationships of cryptobenthic reef fishes (20 species from the Gulf of California, [13]) and the first for the Red Sea.

The aim of the study is to estimate the LWRs for CRF from direct measurements of length and weigh. A total of 32 species of cryptobenthic reef fishes were collected and measured from the Central Red Sea. Of these, 50% are endemic to the Red Sea. Published data on LWRs is lacking for all these species studied except for *Asterropteryx semipunctata* Rüppell 1830 (family Gobiidae); however, these specimens were all from the Indian Ocean with no Red Sea data [14].

2. Methods

Collections took place in July 2023 on the Saudi Arabian coast of the Central Red Sea (Figure 1). Collections were from three different reefs at an increasing distance from the shore. In each reef, six habitats: back reef (5 m), back crest (2 m), reef flat (1 m), exposed crest (2 m), shallow slope (5 m), and deep slope (15 m) were sampled. Knowing that CRF communities vary spatially in the Red Sea [15], sampling was designed with the purpose of covering a wide range of habitats within a reef. This also provided specimens from a range of environmental conditions that could influence growth and body condition and could help offset the fact that collections were only conducted during a single timepoint. For some species this might influence the relationship by incorporating reproduction or seasonal influences. Specimens were collected within 1 m^2 quadrats with the use of rotenone [16] and hand nets on scuba, immediately placed on ice, and transported to the laboratory. Each specimen was identified to the species level, photographed in a photo tank, weighed with an accuracy of 0.001 g (fresh weight), and measured (total length) with a digital caliper with an accuracy of 0.1 mm. We selected species for which we collected at least 20 specimens, resulting in a final number of 32 species. The samplings were done under the approved ethics protocol number 20IAUCUC05 issued by the KAUST Institutional Animal Care and Use Committee.

We visualized the length-weight relations to remove outliers, likely due to errors during data recording and entry. After the data cleanup using Froese's equation (7), we calculated the LWRs of the selected species as follows:

$$W = a * L^b, \tag{1}$$

where W is the weight of the fish in grams (g), L is the total length in centimeters (cm), a is the intercept in the y-axis, and b is the slope. Using nonlinear least squares implementing the *R* function *nls* [17], we adjusted the LWRs

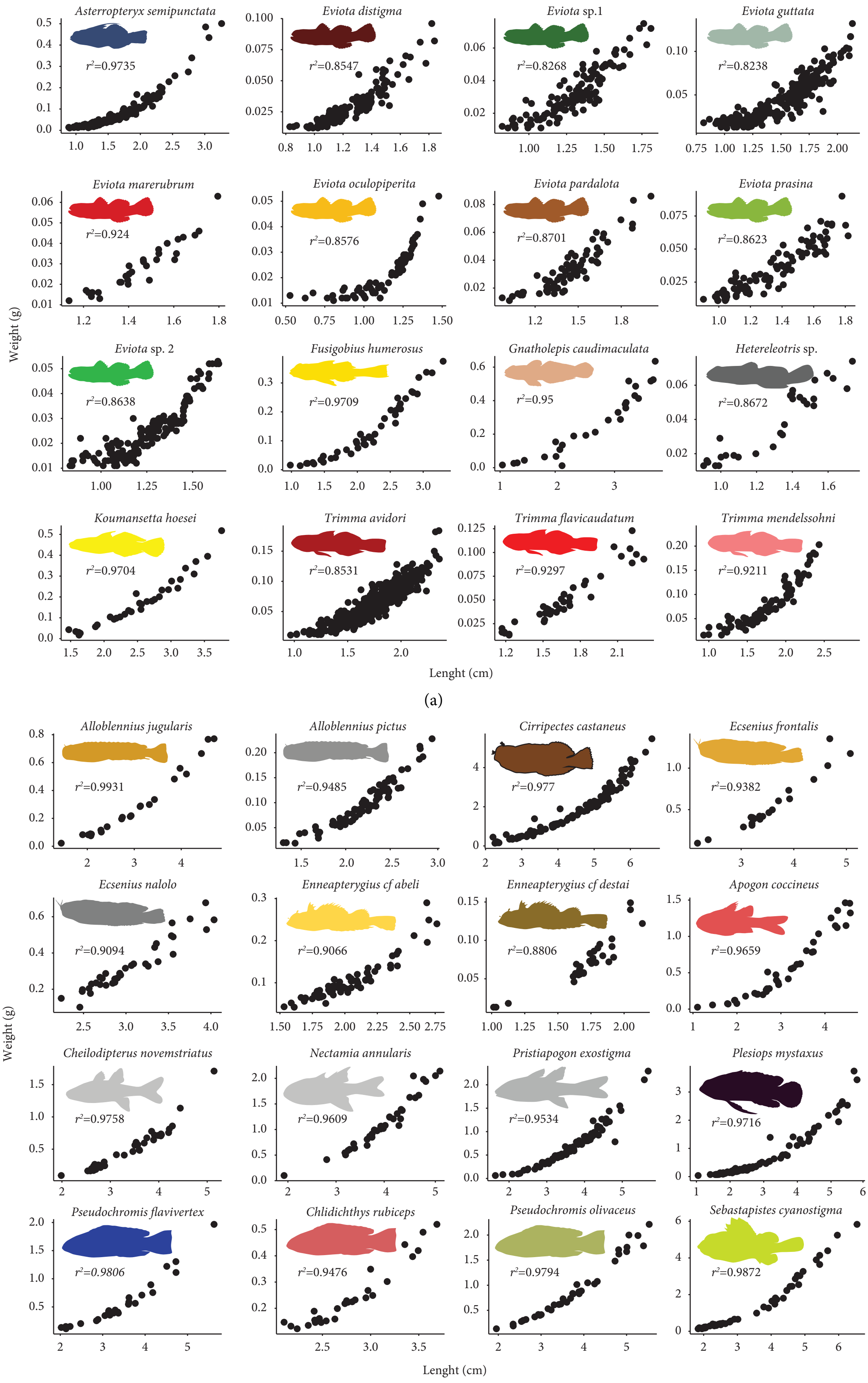
Table 1: Growth parameters of 32 species of CRF species from the Red Sea.

Family	Species	N	Size range (cm)	Maximum length (cm)	Weight range (g)	a	b	b 95% CI	r^2	Mean condition factor (K)	Endemic
Blenniidae	*Alloblennius jugularis* (Klunzinger 1871)	23	1.446–4.699	5	0.022–0.771	0.0132	2.6445 (0.0625)	2.5179–2.776	0.993	0.8923 (0.1122)	Y
	Alloblennius pictus (Lotan 1970)	78	1.3–2.97	2.6	0.019–0.228	0.0086	2.9992 (0.0889)	2.8228–3.178	0.949	0.8629 (0.1058)	Y*
	Ecsenius frontalis (Valenciennes 1836)	21	2.171–5.074	8	0.096–1.354	0.0146	2.7878 (0.1736)	2.439–3.1503	0.938	1.0861 (0.1113)	Y*
	Ecsenius nalolo Smith 1959	35	2.238–4.037	6.5	0.101–0.677	0.0184	2.5474 (0.1441)	2.2601–2.8412	0.909	1.1147 (0.1571)	
	Cirripectes castaneus (Valenciennes 1836)	109	2.207–6.594	9.2	0.14–5.474	0.016	3.0676 (0.0617)	2.9441–3.1946	0.977	1.8241 (0.3814)	
Apogonidae	*Apogon coccineus* Rüppell 1838	41	1.103–4.578	6	0.026–1.463	0.0186	2.8663 (0.1160)	2.6436–3.1017	0.966	1.5517 (0.2724)	
	Cheilodipterus novemstriatus (Rüppell 1838)	43	1.986–5.142	8	0.092–1.71	0.0092	3.1716 (0.0826)	3.0045–3.3418	0.976	1.1319 (0.1279)	
	Nectamia annularis (Rüppell 1829)	36	1.921–5.095	7	0.101–2.142	0.0173	2.98 (0.1194)	2.7406–3.2253	0.961	1.6784 (0.1367)	Y*
	Pristiapogon exostigma (Jordan and Starks 1906)	80	1.638–5.687	12	0.063–2.293	0.0157	2.848 (0.0779)	2.6943–3.0029	0.953	1.2676 (0.1398)	
Tripterygiidae	*Enneapterygius cf. abeli*	69	1.532–2.709	2.5	0.042–0.29	0.01	3.2199 (0.1188)	2.9781–3.4636	0.907	1.1833 (0.1462)	
	Enneapterygius cf. destai	29	1.015–2.138	2.1	0.013–0.149	0.0109	3.3782 (0.2910)	2.7906–3.9833	0.881	1.3401 (0.1756)	Y

TABLE 1: Continued.

Family	Species	N	Size range (cm)	Maximum length (cm)	Weight range (g)	a	b	b 95% CI	r^2	Mean condition factor (K)	Endemic
Gobiidae	*Asterropteryx semipunctata* Rüppell 1830	181	0.889–3.262	6.5	0.011–0.501	0.0129	3.1485 (0.0360)	3.0778–3.2201	0.974	1.4063 (0.2519)	
	Eviota distigma Jordan and Seale 1906	126	0.828–1.839	2	0.012–0.096	0.0146	2.9109 (0.1068)	2.6984–3.1253	0.855	1.4439 (0.2771)	
	Eviota sp. 1	123	0.823–1.81	1.81	0.011–0.075	0.0151	2.6901 (0.1178)	2.4565–2.9273	0.827	1.4199 (0.3446)	Y
	Eviota guttata Lachner and Karnella 1978	218	0.815–2.133	3.2	0.012–0.132	0.0127	2.8353 (0.1027)	2.631–3.0452	0.824	1.2323 (0.3958)	
	Eviota marerubrum Tornabene, Greenfield and Erdmann 2021	30	1.136–1.795	1.7	0.012–0.063	0.0071	3.5794 (0.2038)	3.1634–4.0064	0.924	0.8868 (0.1134)	Y
	Eviota oculopiperita	69	0.528–1.478	1.2	0.011–0.052	0.0141	3.0156 (0.2019)	2.5585–3.5079	0.858	1.6733 (0.0833)	Y
	Eviota pardalota Greenfield and Bogorodsky 2014	71	0.971–2.007	2.2	0.011–0.086	0.0105	3.0545 (0.1407)	2.774–3.337	0.87	1.0776 (0.1990)	
	Eviota prasina (Klunzinger 1871)	99	0.903–1.818	3.1	0.011–0.09	0.0144	2.7766 (0.1285)	2.5274–3.0353	0.862	1.3499 (0.2826)	
	Eviota sp. 2	174	0.831–1.643	1.64	0.011–0.053	0.0119	2.9007 (0.0917)	2.7122–3.0925	0.864	1.2123 (0.3065)	Y
	Fusigobius humerosus Kovačić, Bogorodsky and Alpermann 2023	45	0.983–3.303	3.12	0.014–0.375	0.0116	2.9788 (0.1020)	2.7813–3.1834	0.971	1.1236 (0.1836)	Y
	Gnatholepis caudimaculata Larson and Buckle 2012	26	1.111–3.686	4.4	0.0119–0.635	0.0119	2.9852 (0.2262)	2.5496–3.482	0.95	1.1698 (0.2975)	
	Heteroleotris sp.	29	0.904–1.736	1.73	0.013–0.074	0.0185	2.5446 (0.2359)	2.0937–3.0345	0.867	1.6356 (0.3736)	
	Koumansetta hoesei Kovačić, Bogorodsky, Mal and Alpermann 20	32	1.473–3.757	4.1	0.017–0.518	0.0101	2.9373 (0.1133)	2.7102–3.1736	0.97	0.9313 (0.1798)	Y*
	Trimma avidori (Goren 1978)	511	0.965–2.359	2.5	0.011–0.184	0.011	3.0283 (0.0634)	2.9056–3.1525	0.853	1.1053 (0.2241)	Y*
	Trimma flavicaudatum (Goren 1982)	40	1.17–2.334	2.4	0.013–0.123	0.012	2.6681 (0.1275)	2.4186–2.9253	0.93	0.9943 (0.1508)	Y*
	Trimma mendelssohni (Goren 1978)	94	0.933–2.866	4	0.016–0.232	0.0154	2.7345 (0.0868)	2.5657–2.9048	0.921	1.3625 (0.3603)	
Pseudochromidae	*Chlidichthys rubiceps* Lubbock 1975	28	2.102–3.688	3.9	0.122–0.52	0.0115	2.9186 (0.1374)	2.6359–3.209	0.948	1.0723 (0.1504)	Y
	Pseudochromis flavivertex Rüppell 1835	26	2.023–5.626	7.2	0.112–1.967	0.0145	2.8521 (0.0860)	2.6774–3.0308	0.981	1.2247 (0.1584)	Y
	Pseudochromis olivaceus Rüppell 1835	36	1.955–5.53	9	0.133–2.213	0.0254	2.6159 (0.0792)	2.4596–2.7778	0.979	1.5242 (0.1523)	Y*
Plesiopidae	*Plesiops mystaxus* Mooi 1995	97	1.051–5.773	9	0.038–3.743	0.0202	2.9105 (0.0704)	2.7731–3.0559	0.972	1.8758 (0.3885)	
Scorpaenidae	*Sebastapistes cyanostigma* (Bleeker 1856)	52	1.837–6.545	6.4	0.137–5.832	0.0345	2.7823 (0.0618)	2.6642–2.9038	0.987	2.4762 (0.2635)	

N corresponds to the sample size, CI to the confidence interval, and SE to standard error of the b parameter. The maximum length corresponds to the total length published for each species in FishBase [20]. Values in parenthesis represent the standard error. Species endemic to the Red Sea is marked with a Y, and species endemic to the Red Sea, including the Gulf of Aden, is marked with a Y*.



(a)

(b)

FIGURE 2: Length-weight relationship plots for 32 species of CRFs. Panel (a) includes 16 species from the family Gobiidae. Panel (b) includes 16 species from 6 families of CRFs found in the Red Sea. The r^2 of the length-weight relationship is indicated for each species. Silhouettes indicate the typical body shape for each species.

models for each CRF species. We also included the mean Fulton's condition factor (K) for each species [18]:

$$K = 100 * \frac{W}{L^3}. \tag{2}$$

We plotted the LWR relationships in R statistics of the 32 CRF-selected species to visualize their growth (Figure 2).

3. Results and Discussion

A total of 2,671 specimens belonging to 32 species and seven families of CRFs were included in the analysis. Samples per species ranged from 21 (*Ecsenius frontalis*) to 511 (*Trimma avidori*) and covered a range of body lengths within each species (Supplementary Materials S1 and S2). This was supported by a r^2 above 0.82 for all species (Table 1). The most represented family was Gobiidae, with 16 (50%) species, the most species-rich family on coral reefs and common across Red Sea reefs [15, 19]. This was followed by Blenniidae with five, Apogonidae with four, Pseudochromidae, and Tripterygiidae with three species; a single species represented the families Plesiopidae and Scorpaenidae. Based on the broad sampling design, this is representative of CRF communities in the region.

The coefficient of determination (r^2) for Length-Weight Relationships (LWRs) ranged from 0.82 (*Eviota* sp. 1 and *Eviota guttata* Lachner and Karnella 1978) to 0.99 (*Alloblennius jugularis*) and provides an indicator for the growth model, where values higher than 0.7 suggest the model is a good fit. Our results indicate that we can have confidence in all 32 CRF growth models. The b parameter, which represents the growth type of the fish (3 for isometric, <3 for negative allometric, >3 for positive allometric), spanned from 2.5 (*Ecsenius nalolo* and *Hetereleotris* sp.) to 3.5 (*Eviota marerubrum*). Species with b values below 3 tend to become slimmer as they grow in length, while those with b values exceeding 3 tend to gain weight as they grow in length, potentially indicating optimal growth conditions. Most species revealed b values below 3 (23 of 32 species, 72%), while both species of Tripterygiidae were above 3 (3.32–3.58). The lower b values in the majority of the evaluated species could indicate physiological stress, food shortage, or it could be an attribute of fish species with high metabolic rates and low tolerance to environmental fluctuations such as CRFs. Even though Fulton's K is most useful over broader spatial or temporal comparisons that were not the primary focus of this study, this data could be considered as a baseline for future studies collecting similar species. Interestingly, 29 out of 32 species of CRF showed K values above 1, which could indicate healthy growth conditions [7].

For the one species where data already exists (*A. semipunctata*), our study yielded a b value of 3.15 (95% CI: 3.08–3.22), which is higher than the previously reported value of 2.97 from Zanzibar (see [14]). However, it is important to note that their growth model was done within different sampling sites, leading to a wide range of b values spanning from 2.4 to 3.5. While our b value for the growth model of *A. semipunctata* falls within the range modeled by Mnemba et al. [14], it is essential to emphasize the importance of performing LWRs for Red Sea species within the Red Sea. This recommendation is based on recognizing potential disparities in growth patterns and physiology attributable to environmental factors specific to the Red Sea (e.g., elevated temperatures and salinity, low productivity), even when external data sources are available. Moreover, some Red Sea fishes believed to belong to widespread cryptobenthic species may be undescribed species endemic to the Red Sea (e.g., [21, 22]).

Modeled r^2 values for some Gobiidae species, like *Eviota*, *E. guttata*, *Eviota* sp. 1, *Eviota oculopiperita*, and *Trimma avidori,* were lower than the 0.85 even though sample sizes were high ($n = 69–511$). Instead of attributing this to measurement errors, we propose that natural differences in habitats and environmental conditions may influence these values. Notably, the LWRs for these species reveal high variation compared to other species. This suggests that understanding these variations requires considering the ecological context of each species (Figure 2).

From collected specimens, we modeled LWRs for 32 species of CRF from the Red Sea. Our study represents the first significant effort to record these parameters directly from specimens in the Red Sea and for a widespread number of CRF species. Until now, LWRs were not accessible for most of these species (except for *A. semipunctata*), greatly enhancing the data availability for this fish group, encompassing half of which are endemic to the region. The data presented in this study should be useful to increase our knowledge of CRF species in the Red Sea and globally and can be applied to studies that aim to include (i) biomass estimates based on size frequency data, (ii) model biomass dynamics, and (iii) model trophodynamics of coral reefs with the inclusion CRF. Including CRF into fish community analysis helps to provide a more holistic picture as this group includes almost 50% of the diversity and abundance of fishes found on coral reefs.

Data Availability

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

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Supplementary Materials

S1: size frequency of 16 species of cryptobenthic reef fishes. Size intervals each 0.5 cm. S2: size frequency of 16 species of cryptobenthic reef fishes. Size intervals each 0.05 cm. (*Supplementary Materials*)

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