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Research Article

Length-Weight and Length-Length Relationships of 39 Demersal Fish Species of an Estuarine-Coastal Ecosystem from the Northwestern of the Baja California Peninsula, Mexico

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The length-weight (LW) and length-length (LL) relationships of 39 demersal fish species belonging to 19 families were calculated. Fish samples were collected monthly during the open (September–February) and close (March–August) shrimp fishing seasons from 2014 to 2022 by the artisanal fishery in the Bahía Magdalena-Almejas lagoon system (BMA), using small boats and a shrimp bottom trawl with 16–17 m top rope and 38 mm mesh opening. Total (TL) and standard (SL) lengths and total weight (TW) were measured for all fish specimens. The *b* parameter of the LW relationship ranged from the minimum of 2.483 for *Cynoscion parvipinnis* to 3.775 as the maximum for *Bagre panamensis* while, for the LL relationship, the parameter *b* ranged from 0.685 for *Balistes polylepis* to 0.994 for *Orthopristis cantharinus*. Both LW and LL relationships were highly correlated ($r^2 > 0.95$; $P < 0.05$). The parameter *b* of the LW relationship indicated that 59% of the fish species showed isometric and 41% allometric growth. Information on LW and LL relationships is updated for thirteen species, and four are reported for the first time: *Citharichthys xanthostigma*, *Ophidion galeoides*, *Pleuronichthys guttulatus*, and *P. ritteri*. This study will be useful to update the LW relationship parameters for data-poor fish species and contribute to the accuracy of fish stock assessment in the BMA fisheries.

1. Introduction

Worldwide Mexico contributes 1,688,000 tons per year of fishing production, of which the Mexican state of Baja California Sur (BCS) provides an average of 144,000 tons of fishing products, ranked in fourth place after the states of Sonora, Sinaloa, and Baja California [1]. The main capture of marine coastal fishes of commercial value in BCS includes several species as the barred sand bass, California yellowtail, California halibut, ocean whitefish, Pacific red snapper, Pacific sierra, shortfin corvina, and the spotted sand bass; all of them captured in the Bahia Magdalena-Almejas (BMA) lagoon system, one of the most important areas of fishing production in this Mexican state.

The shrimp trawl fishery (STF) developed in the BMA lagoon system is one of the most important fishing activities in BCS, which produces an average annual biomass of 1,000 tons [1]. As a bycatch, more than 125 cartilaginous and bony fish species are caught by the STF, including some fishes of commercial interest as well as others of ecological importance for its conservation [2].

Estimating the biomass of fish populations is essential in fisheries and ecological studies, given that the population biomass is related to abundance and biological processes such as growth, mortality, or recruitment in response to local and seasonal environmental conditions [3–5]. Thus, the length-weight relationship (LWR) has been frequently used to estimate the weight (to calculate the biomass and to approximate the recruitment) of fish when its length is unknown because the measurement of individual weight can be complicated and time-consuming activity in the field [6, 7].

The studies that involve LWR analysis have increased over time because the parameters provided by LW are required to determine the conversion of growth-in-length equations to growth-in-weight models [8]. Likewise, this information is necessary for determining stock structure and estimating fish conditions and other applications in fisheries resource management [9, 10]. The analysis of SL and TL parameters through a simple linear regression of the pooled data recorded throughout the study period was included; LL relationships are commonly used in fisheries for size conversion (e.g., calculated TL to SL) useful for understanding aspects of population dynamics and management [11–13].

The length-weight (LW) and length-length (LL) relationships were estimated for 39 demersal fish species collected from bottom surveys and commercial catches in the BMA lagoon system. To the best of our knowledge, there is no information on the LW and LL relationships for some of these fish species (e.g., Froese and Pauly) [11], while, for the others, the studies are from restricted areas [8, 9].

2. Materials and Methods

During the open (September–February) and close (March–August) shrimp fishing seasons from 2014 to 2022, monthly fish sampling was carried out throughout the shrimp trawling ground in BMA (Figure 1). Fish samples were collected using small boats ("panga") and a shrimp bottom trawl with 16–17 m top rope and 38 mm mesh opening.

The collected fishes were placed on ice to be transported to the laboratory, where the specimens were stored and frozen (−10°C). The fishes were taxonomically identified using specialized keys and catalogs [13–16]. At least one voucher specimen from each fish species was fixed with 10% formalin and finally deposited in the fish collection of the Centro Regional de Investigacion Acuicola y Pesquera (CRIAP-IMIPAS) in La Paz, Baja California Sur (Mexico). Each specimen was measured in standard length (SL) and total length (TL) at the nearest 0.1 mm and total weighed (TW) to the nearest 0.01 g.

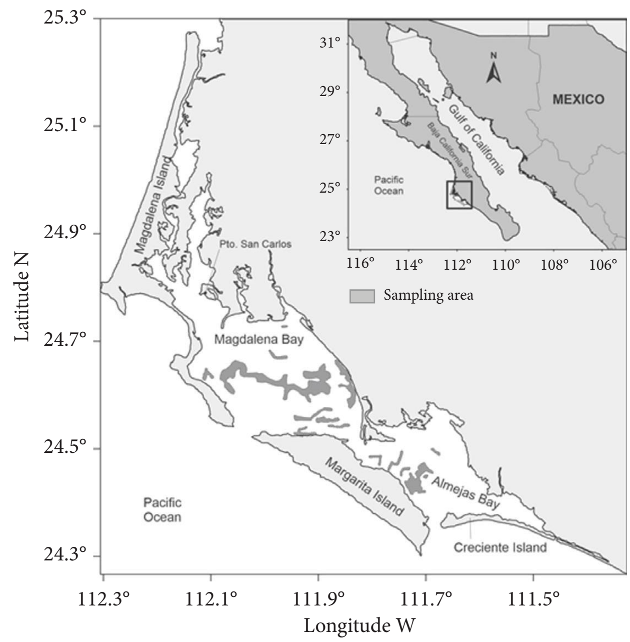

Figure 1: Study area in the Bahia Magdalena-Almejas lagoon system. Shaded polygons indicate the fishing trawling grounds.

The LW relationships for all species were calculated using the potential model TW = $a\,\mathrm{TL}^{\mathbf{b}}$, where TW is the total weight (g), TL is the total length of the fish (cm), a is the intercept, and b is the slope. Previously, log-log plots of the length-weigh pairs were carried out to identify and exclude extreme outliers from the analysis [3, 17]. The confidence interval (CI) at 95% for b was calculated to determine whether the hypothetical value of isometry (3.0) fell between these limits. To determine the type of growth (allometric or isometric), the b values for each species were compared with the isometric value ($b = 3.0$) [17, 18].

The LL relationships were estimated by applying the linear regression equation $\mathrm{SL} = a + b$ TL, where SL is the standard length (cm). In both cases, the equations were computed with Statistica 10 (StatSoft Inc., Tulsa, OK, USA).

3. Results

A total of 14,040 fish specimens of 39 species belonging to 19 families were collected. The six most abundant species were *Eucinostomus dowii* (Gill, 1863), *E. gracilis* (Gill, 1862), *Paralabrax maculatofasciatus* (Steindachner, 1868), *Etropus crossotus* (Jordan and Gilbert, 1882), *E. peruvianus* (Hildebrand, 1946), and *Diplectrum pacificum* (Meek and Hildebrand, 1925), which comprised 70.4% of the total fish abundance (Table 1).

The parameters of LW and LL relationships calculated for 39 fish species are presented in Table 2. The parameter b of LW relationships ranged from the minimum value of 2.483 for *Cynoscion parvipinnis* Ayres and 1861 to the maximum value of 3.775 for *Bagre panamensis* (Gill, 1863). While, for the LL relationship, the parameter b ranged from 0.685 for *Balistes polylepis* (Steindachner, 1876) to 0.994 for *Orthopristis cantharinus* (Jenyns, 1840), both LW and LL relationships were highly correlated ($r^2 > 0.95$) (Table 2).

Table 1: Biometrics of 39 demersal fish species from the Bahía Magdalena-Almejas lagoon system.

Family	Scientific name	*n*	Total length (cm)			Standard length (cm)			Total weight (g)		
			Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Achiridae	*Achirus mazatlanus*	282	8.5	21.9	14.9	6.4	16.8	11.6	10.8	197.9	72.8
Ariidae	*Bagre panamensis*	20	12.5	26.5	15.3	9.6	20.7	12.0	11.0	180.4	28.3
	Occidentarius platypogon	526	9.7	48.2	16.1	7.1	38.4	12.1	6.4	1034.4	39.8
Balistidae	*Balistes polylepis*	151	5.8	33.1	16.0	4.9	23.5	12.5	5.1	441.4	96.8
Batrachoididae	*Porichthys analis*	192	6.7	36.0	16.5	5.9	32.5	14.8	2.0	422.8	47.6
Cynoglossidae	*Symphurus fasciolaris*	32	12.4	19.3	16.3				18.1	60.9	40.8
	Symphurus williamsi	34	10.8	18.7	14.3				10.3	57.0	27.3
Engraulidae	*Anchoa nasus*	21	9.5	15.0	11.8	7.6	13.2	10.1	5.4	26.9	11.3
Ephippidae	*Chaetodipterus zonatus*	32	10.2	20.0	13.6	8.3	15.6	10.9	41.2	251.8	90.5
Gerreidae	*Eucinostomus dowii*	2244	8.4	19.9	12.7	6.0	15.7	10.0	7.1	118.6	26.9
	Eucinostomus gracilis	1866	7.0	19.2	11.9	5.4	14.5	9.2	2.5	134.8	21.75
Haemulidae	*Haemulopsis axillaris*	713	8.1	26.0	14.1	6.6	20.9	11.6	6.8	244.7	45.3
	Haemulopsis elongatus	106	10.6	24.0	15.0	8.5	19.3	12.2	16.3	154.5	43.6
	Hamulopsis nitidus	364	8.3	19.5	12.9	6.9	16.1	10.5	7.0	108.4	30.3
	Orthopristis cantharinus	32	12.0	15.4	13.1	9.8	13.3	11.0	22.5	47.6	29.8
	Orthopristis chalceus	145	6.4	23.2	15.2	5.2	18.7	12.1	3.5	167.8	46.7
	Orthopristis reddingi	323	11.0	21.6	15.3	8.5	17.4	12.4	13.4	118.5	49.3
Mullidae	*Pseudupeneus grandisquamis*	90	10.6	23.6	18.3	8.5	19.4	14.5	17.6	188.2	90.6
Ophidiidae	*Ophidion galeoides*	54	14.3	25.7	17.8				19.8	114.8	41.6
Paralichthydae	*Citharichthys xanthostigma*	25	7.5	20.0	11.2	6.2	16.5	9.3	4.4	76.5	19.7
	Etropus crossotus	1602	4.9	19.6	9.5	3.7	16.3	7.7	1.5	72.2	10.5
	Etropus peruvianus	1199	5.2	20.0	9.4	4.5	16.5	7.6	2.0	88.8	9.7
	Hippoglossina bollmani	30	17.6	37.0	25.2	14.0	31.0	20.6	51.8	481.2	170.2
	Paralichthys californicus	73	14.1	39.0	25.3	11.4	35.0	21.3	32.2	642.2	196.4
	Syacium ovale	66	6.5	21.5	12.0	5.6	18.9	9.9	2.6	116.7	24.2
	Xystreurys liolepis	24	6.8	25.1	13.6	5.2	21.4	11.3	2.1	220.7	40.5
Pleuronectidae	*Pleuronichtys guttulatus*	37	10.6	27.3	21.0	8.5	22.5	17.1	14.4	281.2	140.2
	Pleuronichthys ritteri	243	9.0	21.6	14.9	7.1	17.5	11.8	10.2	148.6	47.2
Sciaenidae	*Cynoscion parvipinnis*	25	14.6	33.4	20.1	12.1	27.3	16.8	31.6	287.3	98.7
	Elattarchus archidium	20	13.5	19.2	16.9	10.5	15.5	13.6	24.2	80.2	56.7
Serranidae	*Diplectrum pacificum*	1192	7.0	26.9	16.0	5.5	21.7	12.8	4.3	313.1	56.1
	Paralabrax maculatofasciatus	1788	8.3	29.8	15.1	6.6	22.7	12.3	9.2	327.8	52.6
Sparidae	*Calamus brachysomus*	54	9.0	25.0	17.5	7.1	19.8	13.4	11.0	277.5	116.1
Synodontidae	*Synodus lucioceps*	52	9.5	35.6	23.1	8.8	31.2	20.1	6.6	294.4	93.5
	Synodus scituliceps	81	6.7	27.8	13.5	10.3	45.5	24.3	3.7	250.7	34.9
Triglidae	*Prionotus ruscarius*	68	10.1	39.6	22.1	8.2	32.2	18.1	16.0	680.3	190.3
	Prionotus stephanophrys	89	6.7	27.8	13.5	5.6	22.7	10.9	3.7	250.7	34.9
Tetraodontidae	*Sphoeroides annulatus*	48	8.6	43.8	22.5	6.6	36.5	18.4	21.1	1505.8	33.4
	Sphoeroides lobatus	97	7.5	35.8	15.7	6.1	30.0	12.9	10.3	971.9	117.5

Min = minimum, Max = maximum, and *n* = number of organisms.

Twenty-three (59%) of the fish species showed isometric growth, and the other 16 (41%) were allometric (Table 2); the relation between positive (nine species) and negative (seven species) allometric growth is presented in Figure 2. Information on LW and LL relationships is updated here for thirteen species, and four of them are lacked in Fishbase: *Citharichthys xanthostigma* (Gilber, 1890), *Ophidion galeoides* (Gilbert, 1890), *Pleuronichthys guttulatus* (Girard, 1856), and *P. ritteri* (Starks and Morris, 1907). Additionally, LWR parameters are provided for three species: *Hippoglossina bollmani* (Gilbert, 1890), *Orthopristis cantharinus* (Jenyns, 1840), and *Symphurus williamsi* (Jordan and Culver, 1895). Likewise, information on LL relationships is provided here for six species: *Anchoa nasus* (Kner and Steindachner, 1867), *Elattarchus archidium* (Jordan and Gilbert, 1882), *E. peruvianus*, *Synodus scituliceps* (Jordan and Gilbert, 1882), *Sphoeroides annulatus* (Jenyns, 1842), and *S. lobatus* (Steindachner, 1870).

4. Discussion

Three families (Gerreidae, Serranidae, and Pleuronectidae) include the most abundant species, reflecting the importance of the BMA lagoon system as a nursery, feeding, and shelter ground for fish species of commercial value like serranids and for ecological conservation like gerreids. Particularly,

Table 2: Parameters of length-weight and length-length relationships for 39 demersal fish species caught in the Bahia Magdalena-Almejas lagoon system.

Family	Scientific name	TL-SL relationship constants			TL-TW relationship constants			G
		a	$b \pm$ CI 95%	r^2	a	$b \pm$ CI 95%	r^2	
Achiridae	*Achirus mazatlanus*	−2.461	0.792 ± 0.014	0.976	9.00 *E* − 06	3.153 ± 0.120	0.922	A^+
Ariidae	**Bagre panamensis**	2.590	0.772 ± 0.041	0.989	1.20 *E* − 07	3.775 ± 0.125	0.995	A^+
	Occidentarius platypogon	−7.665	0.802 ± 0.013	0.964	3.00 *E* − 06	3.181 ± 0.014	0.994	A^-
Balistidae	**Balistes polylepis**	15.270	0.685 ± 0.017	0.977	2.23 *E* − 04	2.518 ± 0.052	0.984	A^-
Batrachoididae	*Porichthys analis*	−0.760	0.898 ± 0.011	0.993	4.00 *E* − 06	3.156 ± 0.067	0.970	A^+
Cynoglossidae	*Symphurus fasciolaris*	—	—	—	1.50 *E* − 05	2.899 ± 0.321	0.935	I
	Symphurus williamsi	—	—	—	2.00 *E* − 06	3.289 ± 0.282	0.959	I
Engraulidae	**Anchoa nasus**	−13.086	0.958 ± 0.183	0.930	3.00 *E* − 07	3.654 ± 0.376	0.938	A^+
Ephippidae	*Chaetodipterus zonatus*	4.859	0.763 ± 0.031	0.988	1.14 *E* − 04	2.743 ± 0.170	0.973	A^-
Gerreidae	*Eucinostomus dowii*	0.177	0.788 ± 0.009	0.922	6.00 *E* − 06	3.161 ± 0.034	0.927	A^+
	Eucinostomus gracilis	−1.213	0.784 ± 0.010	0.929	9.00 *E* − 06	3.059 ± 0.051	0.900	A^+
Haemulidae	*Haemulopsis axillaris*	2.060	0.805 ± 0.006	0.989	1.70 *E* − 05	2.951 ± 0.034	0.980	I
	Haemulopsis elongatus	−1.076	0.818 ± 0.033	0.957	3.60 *E* − 05	2.786 ± 0.136	0.909	I
	Hamulopsis nitidus	6.921	0.759 ± 0.017	0.957	8.00 *E* − 06	3.091 ± 0.061	0.965	A^+
	Orthopristis cantharinus	−21.315	0.994 ± 0.065	0.973	3.30 *E* − 05	2.812 ± 0.309	0.908	I
	Orthopristis chalceus	−6.296	0.837 ± 0.018	0.982	2.00 *E* − 06	3.318 ± 0.109	0.953	A^+
	Orthopristis reddingi	2.927	0.794 ± 0.020	0.950	2.60 *E* − 05	2.862 ± 0.071	0.946	A^-
Mullidae	*Pseudupeneus grandisquamis**	1.233	0.786 ± 0.029	0.971	1.30 *E* − 05	3.014 ± 0.137	0.964	I
Ophidiidae	*Ophidion galeoides*	—	—		1.70 *E* − 05	2.834 ± 0.121	0.965	I
Paralichthydae	*Citharichthys xanthostigma*	−2.037	0.844 ± 0.022	0.997	1.70 *E* − 05	2.911 ± 0.243	0.975	I
	Etropus crossotus	−0.937	0.819 ± 0.007	0.968	1.40 *E* − 05	2.954 ± 0.023	0.958	I
	Etropus peruvianus	−0.348	0.814 ± 0.009	0.963	1.00 *E* − 05	3.023 ± 0.026	0.948	I
	Hippoglossina bollmani	−13.057	0.867 ± 0.044	0.983	1.20 *E* − 05	2.964 ± 0.179	0.977	I
	Paralichthys californicus	−3.739	0.857 ± 0.032	0.976	6.00 *E* − 06	3.087 ± 0.178	0.976	I
	Syacium ovale	−2.194	0.843 ± 0.023	0.988	8.00 *E* − 06	3.057 ± 0.103	0.982	I
	*Xystreurys liolepis**	−3.715	0.867 ± 0.024	0.995	1.00 *E* − 06	3.515 ± 0.174	0.995	A^+
Pleuronectidae	*Pleuronichtys guttulatus*	−8.702	0.853 ± 0.056	0.972	2.80 *E* − 05	2.871 ± 0.398	0.901	I
	Pleuronichthys ritteri	−0.133	0.794 ± 0.014	0.981	8.00 *E* − 06	3.099 ± 0.084	0.963	I
Sciaenidae	**Cynoscion parvipinnis**	−4.916	0.863 ± 0.036	0.995	1.64 *E* − 04	2.483 ± 0.121	0.990	A^-
	Elattarchus archidium	−5.955	0.847 ± 0.070	0.973	2.60 *E* − 05	2.883 ± 0.379	0.951	I
Serranidae	*Diplectrum pacificum**	−5.813	0.836 ± 0.008	0.970	2.00 *E* − 06	3.387 ± 0.038	0.962	A^+
	Paralabrax maculatofasciatus	0.280	0.814 ± 0.007	0.969	1.60 *E* − 05	2.969 ± 0.022	0.967	I
	*Calamus brachysomus**	3.498	0.743 ± 0.024	0.987	2.40 *E* − 05	2.936 ± 0.194	0.987	I
Synodontidae	*Synodus lucioceps**	3.422	0.855 ± 0.025	0.990	4.00 *E* − 06	3.098 ± 0.195	0.964	I
	Synodus scituliceps	−2.543	0.876 ± 0.014	0.994	7.00 *E* − 06	2.978 ± 0.111	0.969	I
Triglidae	**Prionotus ruscarius**	−2.887	0.832 ± 0.014	0.995	4.80 *E* − 05	2.768 ± 0.144	0.975	A^-
	Prionotus stephanophrys	−7.659	0.865 ± 0.025	0.981	8.00 *E* − 06	3.082 ± 0.078	0.979	I
Tetraodontidae	*Sphoeroides annulatus*	−3.413	0.832 ± 0.013	0.997	1.46 *E* − 04	2.663 ± 0.147	0.974	A^-
	Sphoeroides lobatus	−3.608	0.846 ± 0.008	0.997	2.40 *E* − 05	2.984 ± 0.093	0.974	I

a = intercept, b = slope, r^2 = coefficient of determination, and CI = confidence interval. *G*: growth type, A: allometric, and I isometric. b values greater (in bold) and lower (*) than those reported in FishBase data.

E. dowii and *E. gracilis* commonly inhabit marine-estuarine ecosystems of northwestern Mexico throughout their life cycle (larvae, juveniles, and adults), alternating their abundances seasonally [18–21].

The parameter b of LW relationships for all species here examined ranged between the expected values of 2 to 4 as have been reported in FishBase (https://www.fishbase.se) [12], as well as for marine-estuarine species inhabitant coastal-lagoon ecosystems of northwestern Mexico [18–21]. Ten species included in this study showed b values comparatively higher than those reported in FishBase [11]; conversely, *C. parvipinnis*, *E. archidium*, *Prionotus ruscarius* (Gilbert and Starks, 1904), and *Pseudupeneus grandisquamis* (Gill, 1863) showed lower b values (Table 2). Particularly, *D. pacificum* and *O. chalceus* had b values higher than those previously reported for the Bahia Magdalen-Almejas lagoon systems [2]. According to Biolé et al. [10], higher b values are caused by the presence of small-size specimens (juveniles in the sample as was reported in this study) (Table 1).

Since fish samples of each species included juvenile and adult specimens collected during several seasons, the parameters a and b of LW and LL relationships were treated as mean annual values; thus, the results should be used with caution outside of length ranges indicated in this study (e.g.,

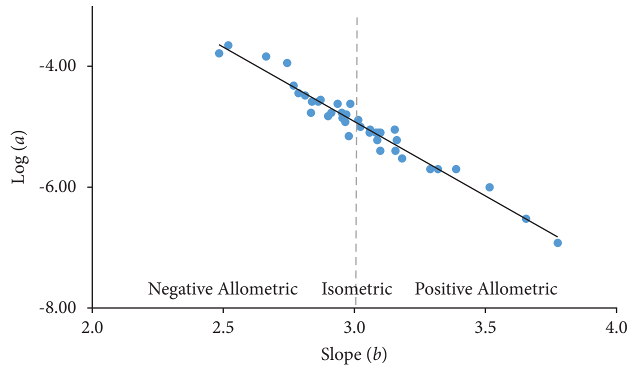

FIGURE 2: Scatter plot of mean log a over mean b for the length-weight relationship of 39 demersal fish species from the Bahia Magdalena-Almejas lagoon system.

González-Acosta et al. [18], Rábago-Quiroz et al. [2], and Ruiz-Campos et al. [12, 19]).

Changes in the body anatomy of fishes, related to isometry and allometry, are determined during the ontogeny until reach sexual maturity. In this regard, Barros et al. [22] established fish's growth isometrically during the juvenile phase as adults vary from allometric positive in males to allometric negative in females. Therefore, 59% of the demersal fish species here examined could correspond to juveniles and 41% to adult specimens, according to the maximum size reported in Table 1. In addition, it has been established that large fish specimens with negative allometric growth change their body shape depending on their nutritional condition, whereas those with positive allometry or isometric growth are influenced by latitudinal factors [12]. However, the influence of these variables should be corroborated in further studies.

Most of the fish species (95%) studied here are included as "Least Concern" (LC) and 5% as "Data Deficient" (DD): *C. parvipinnis* and *O. cantharinus*, by the IUCN Red List [23]. Taxa included in both categories have a low risk of extinction (with resilient life histories) and insufficient knowledge to be evaluated but this does not mean that this species is not threatened. Consequently, the lack of species-specific data makes it difficult to assess the impact caused by overexploitation of fish populations [24]. Thus, the updated information of parameters derived from LW and LL relationships will be useful for data-poor fish species, contributing to the accuracy of estimation models for population assessments in the BMA fisheries. Likewise, this study will be used to further fisheries research (estimating biomass and demography assessment) as well as for conservation and management of ichthyologic resources in this region.

Data Availability

The data used to support the findings of the study can be obtained from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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