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Length-weight and length-length relationships of 16 marine fish species in Vietnam

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Abstract

In this study, the length-weight relationships (LWRs) and length-length relationships (LLRs) of 16 marine fish species—important component of fishery production models—were estimated. The specimens were collected monthly from commercial gillnet fisheries from November 6, 2018 to October 30, 2019 in Vietnamese waters. In total, 7,426 individuals had their total length (TL), fork length (FL) and total body weight (W) measured. LWRs were calculated using the logarithmic transformation of the linear regression equation $logW = loga + b*logTL$, while LLRs were determined using a linear regression model: $TL = a + b*FL$. In addition, 95% confidence intervals (CIs) were estimated for the model parameters. The results showed that all regression parameters were highly significant ($p < 0.001$), with coefficients of determinations (R^2) > 0.9412 for all species. The *a* (intercept) values ranged from 0.0025 to 0.4, and the *b* (slope) values ranged from 2.53 to 3.28. TL and FL were highly correlated ($p < 0.001$ and $R^2 > 0.9422$ for all parameters), and *a* and *b* ranged from -9.12 to 15.85 and 0.87 to 1.45, respectively. The results provide the key morphology parameters, which are beneficial for fishery researchers and managers in stock assessment, administration and conservation.

Keywords: Vietnamese fisheries, Morphology, Allometry, Stock assessment, Fisheries management

Vietnam has an extensive coastline of more than 3,260 km and an exclusive economic zone (EEZ) of more than one million km^2, including islands and archipelagos, bays, lagoons and fjords, which provide a diverse residential habitat and environment for marine species. More than 2,000 marine species, including approximately 130 commercial species, have been recorded in Vietnamese waters (Uyen, 2017). The exploitation of marine fishery resources is the major economic contributor to coastal provinces, provides employment opportunities for the local population and is an important source of animal protein and micronutrients (Raakjær et al., 2007; Pomeroy et al., 2009; Nguyen et al., 2017). The marine fishery economic sector contributes 5% of the gross domestic product and provides approximately 4 million jobs for the local population (VASEP, 2020). Vietnam is one of the top ten seafood exporting countries in the world, and in 2019, marine landings in the country reached 3.73 million tons, with an export value of more than five billion USD (FAO, 2020; VASEP, 2020). However, marine resources have shown signs of decline resulting from the decrease in the catch rate of key fisheries over time and in the catch sizes of many species (Nguyen et al.,

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2021; 2022a). To solve these issues and maintain sustainable fisheries, the government of Vietnam approved the national development program on efficient and sustainable fishing for the period from 2022 to 2025, with guidance for 2030, in which it emphasizes a Total Allowable Catch (TAC) and quota allocation management system (Vietnam, 2022). Although the sustainable exploitation of marine fish species brings clear benefits, it is difficult to develop effective management guidelines for most commercial species in Vietnam because there is no information on their biological and demographic characteristics (Nguyen and Nguyen, 2014). In particular, length-weight relationship (LWR) and length-length relationship (LLR) data, which are important components of fishery production and stock assessment models, do not exist for any of the species populations assessed in this study.

Length-weight relationships (LWRs) and length-length relationships (LLRs) calculated according to correlation coefficients and regressions make it possible to evaluate fish biomass, stock assessments, ecological studies and taxonomic identification and are very important for the management and conservation of fisheries to regulate catches (Froese, 2006). In addition, LWRs can be used as condition factors to compare the health of individuals and populations that can be influenced by environmental conditions and sexual variables (Tesch, 1968; Froese, 2006). In some cases, it is not possible to measure total length (TL) in the port because the fishermen carry out preliminary treatments at sea, including the removal of fins and tails, to improve the quality of the fish (Nguyen et al., 2022a), resulting in the loss of biometric data, which are necessary for fishery analyses and modeling. Size conversions (e.g. TL calculated based on FL) are therefore necessary for species comparison (Nguyen et al., 2022b). The classification of fish development and growth relies on positive and negative allometries (Froese, 2006).

In Vietnam, very few studies on the LWR and LLR of marine fish species have been documented. As far as we know, work has been done on Yellowfin (*Thunnus albacares* Bonnaterre, 1788) and Bigeye (*Thunnus obesus* Lowe, 1839) Tuna (Nguyen et al., 2022b), mudskipper (*Periophthalmus variabilis* Eggert, 1935) (Dinh et al., 2022a), mullet (Ellochelon vaigiensis Quoy and Gaimard, 1825) (Dinh et al., 2022b), and a few other fish species in the Gulf of Tonkin, northern Vietnam (Wang et al., 2011). In this context, this study aimed to provide information on the LWRs and LLRs of 16 marine fish species in Vietnam, to identify the growth type of each species and to contribute to understanding the biological and demographic information of these fish communities.

The specimens were collected using gillnets in the Gulf of Tonkin (Latitude: 19.615°N – 20.28°N; Longitude: 106.631°E – 107.375°E), center (Latitude: 11.068°N – 11.431°N; Longitude: 109.192°E – 109.688°E) and south (Latitude: 9.085°N – 9.955°N; Longitude: 106.625°E – 107.559°E) of Vietnam from November 6, 2018 to October 30, 2019 (Figure 1). The gillnets were 450 m long x 28 m high, constructed in dark green polyethylene (PE) twine with a diameter of 1.5 mm, forming knotted mesh opening sizes ranging from 125 to 180 mm (Nguyen et al., 2023). The depth at the sampling site ranged from 46 to 128 m (mean: 76 m) (Figure 1). Fishing operations were carried out at night, with a mean soak time of 6.9 hours (ranging from 2.2 to 11.8 hours). After removing the gillnets, the catch was separated to the species level based on the FishBase classification (Froese and Pauly, 2023). TL was measured from the tip of the snout to the end of the longest lobe of the caudal fin, and FL was measured from the tip of the jaw to the center of the tail fork. Both sizes were measured in millimeters using a measurement board. The total weight (W), measured in grams, was recorded for each individual using a digital scale.

The parameters of the LWRs were calculated after the logarithmic transformation of the power regression $W=aTL^b$ into the linear regression $\log W=\log a+b*\log TL$. The TL and FL relationships were established using a linear regression model with the formula $TL=a+b*FL$, in which a is the intercept and b is the regression parameter (slope of the model). Before adjusting the regression analysis, outliers were tested and removed following the method of Froese (2006). The *b* values obtained from the regression models can inform the growth patterns of the fish, including positive allometric, negative allometric and isometric ones (Froese, 2006). If the value of *b* is significantly smaller than three, the fish has negative allometric growth; if *b* is significantly greater than three, the fish has positive allometric growth; and if b is close to three (not significantly different from three), the fish has isometric growth (Froese, 2006). To confirm the significant difference of *b* values from the isometric values (*b*= ~3), a 95% confidence interval (CI) ($\alpha = 0.05$) was applied, obtained from the equation $ts = (b\text{-}3)/sb$, in which *ts* is the t-test value and *sb* is the standard error of the slope (*b*) (Sokal and Rohlf, 1987). The levels of statistical significance of the coefficient of determination (R^2) were also estimated. The open software R-statistical (V4.1.2) (R Core Team, 2021) was used to carry out all the analyses, prepare the data and produce the figures. LWRs and LLRs were assessed with the Simple Fisheries Stock Assessment Method package (Ogle et al., 2023).

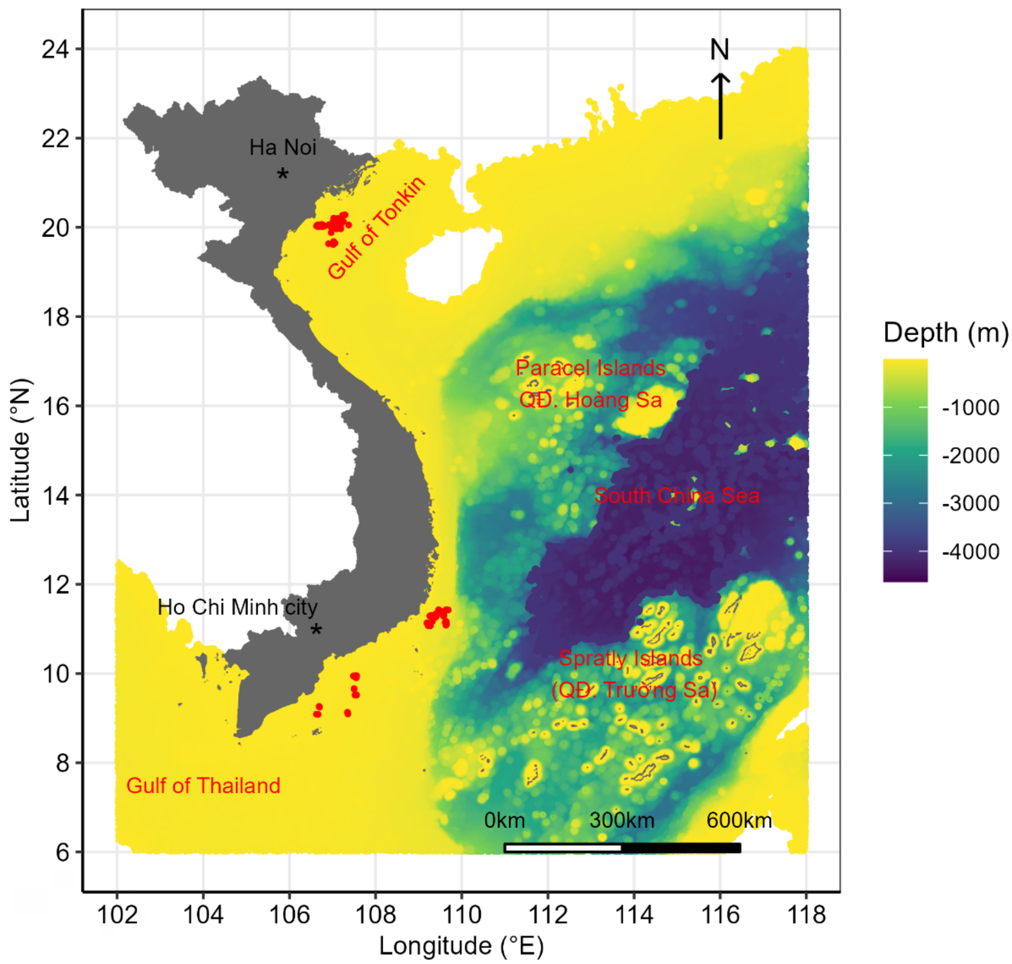

Figure 1. Map of Vietnam including the study sites in the South China Sea. Each red dot indicates the position of each gillnet deployed. Multiple sets could be deployed in the same or close locations.

In total, 7,426 specimens, belonging to 16 species, 10 families and seven orders had their LWRs and LLRs analyzed (Table 1). All species were captured in sufficient numbers to conduct the statistical analysis. The results indicated that the estimated regression of the LWRs was statistically significant ($p < 0.001$) for all parameters and all species and that R^2 ranged from 0.9412 to 0.9991 (Table 2). The total variation of *a* was from 0.0025 to 0.4, and *b* ranged from 2.53 to 3.28 (Table 2). The relationship between TL and FL was highly linear ($R^2 > 0.9422$) and significant ($p < 0.001$) for all species (Table 2). The intercept (*a*) ranged from -9.12 (*Coryphaena hippurus* Linnaeus, 1758) to 15.85 (*Scomberomorus guttatus* Bloch and Schneider, 1801). The regression coefficient (*b*) ranged from 0.87, for *Scomberomorus guttatus*, to 1.45, for *Mene maculate* (Bloch and Schneider, 1801) (Table 2).

Table 1. Summary details of the number of samples (n), weight (W) and length (TL: Total length; FL: Fork length) of 16 fish species collected from November 6, 2018 to October 30, 2019 using gillnets in Vietnamese waters.

Order	Family	Species	n	W (g)		TL (cm)		FL (cm)	
				min	max	min	max	min	max
Carangaria incertae sedis	Menidae	*Mene maculate* Bloch & Schneider, 1801	66	111	252	17.7	24.5	15.1	21.7
	Polynemidae	*Leptomelanosoma indicum* Shaw, 1804	730	280	4400	35	81	29.5	71
		Eleutheronema tetradactylus Shaw, 1804	80	400	5000	36	84	31	73
Carangiformes	Carangidae	*Parastromateus niger* Bloch, 1795	114	300	1400	29	44.5	25.5	40
	Coryphaenidae	*Coryphaena hippurus* Linnaeus, 1758	70	775	5000	84	101.5	71	85
	Istiophoridae	*Istiophorus platypterus* Shaw, 1792	110	1110	7800	42	147	37	125
Carcharhiniformes	Carcharhinidae	*Carcharhinus sorrah* Müller & Henle, 1839	125	550	8400	67	109	55	87
Eupercaria incertae sedis	Lutjanidae	*Lutjanus erythropterus* Bloch, 1790	94	220	1350	23	43	21.2	39.7
Perciformes	Epinephelidae	*Epinephelus areolatus* Forsskål, 1775	90	141	1968	22	53	20.4	49
Scombriformes	Scombridae	*Katsuwonus pelamis* Linnaeus, 1758	880	220	1600	10.3	51	9.5	45
		Thunnus albacares Bonnaterre, 1788	146	1000	19000	50	108	45.6	99
		Thunnus obesus Lowe, 1839	132	1500	26500	41	103	37.7	94.6
		Acanthocybium solandri Cuvier, 1832	260	4000	11800	84	127	73	111
		Scomberomorus commerson Lacepède, 1800	4130	660	24100	49.5	140	45	130
		Scomberomorus guttatus Bloch & Schneider, 1801	166	700	4000	46	85.5	37	81.5
Siluriformes	Ariidae	*Netuma thalassina* Rüppell, 1837	233	630	17600	56	117	51	106

Table 2. Descriptive statistics and estimated parameters of the length-weight relationship and length-length relationship of 16 fish species from Vietnamese waters.

Order	Family	Species	LWRs			LLRs		
			a **(95%CI)**	b **(95%CI)**	R^2	a **(95%CI)**	b **(95%CI)**	R'^2
Carangaria incertae sedis	Menidae	*Mene maculate* Bloch & Schneider, 1801	0.11 (0.02-0.3)	2.54 (1.8-3)	0.9655	-0.05 (-0.07--0.02)	1.45 (0.95-1.55)	0.9715
	Polynemidae	*Leptomelanosoma indicum Shaw, 1804*	0.0025 (0.001-0.006)	3.28 (3.05-3.5)	0.9816	2.25 (1.67-2.98)	1.107 (1.07-1.12)	0.9839
		Eleutheronema tetradactylus Shaw, 1804	0.0095 (0.005-0.02)	2.97 (2.71-3.22)	0.9924	1.74 (0.98-2.54)	1.14 (1.07-1.21)	0.9963
Carangiformes	Carangidae	*Parastromateus niger Bloch, 1795*	0.008 (0.0001-0.003)	3.15 (2.33-3.95)	0.954	2.76 (1.12-3.65)	1.05 (0.94-1.15)	0.9739
	Coryphaenidae	*Coryphaena hippurus* Linnaeus, 1758	0.015 (0.003-0.02)	2.76 (1.73-3.12)	0.9474	-9.12 (-13--5.21)	1.29 (0.84-1.75)	0.9486
	Istiophoridae	*Istiophorus platypterus* Shaw, 1792	0.1 (0.02-0.9)	2.55 (1.98-3.01)	0.9518	2.28 (1.95-3.25)	1.13 (1.06-1.21)	0.9929
Carcharhiniformes	Carcharhinidae	*Carcharhinus sorrah* Müller & Henle, 1839	0.23 (0.05-0.39)	2.53 (1.62-3.24)	0.974	1.82 (0.65-2.71)	1.21 (1.07-1.34)	0.9707
Eupercaria incertae sedis	Lutjanidae	*Lutjanus erythropterus* Bloch, 1790	0.027 (0.02-0.035)	2.88 (2.8-2.95)	0.9991	0.0065 (0.003-0.009)	1.082 (1.07-1.094)	0.9923
Perciformes	Epinephelidae	*Epinephelus areolatus* Forsskål, 1775	0.014 (0.013-0.015)	2.99 (2.97-3.01)	0.995	0.0095 (0.006-0.01)	1.08 (1.07-1.12)	0.9957
Scombriformes	Scombridae	*Katsuwonus pelamis* Linnaeus, 1758	0.4 (0.21-0.71)	2.72 (2.47-2.96)	0.9682	0.062 (0.01-0.1)	1.09 (1.07-1.1)	0.9954
		Thunnus albacares Bonnaterre, 1788	0.0157 (0.008-0.03)	3.021 (2.87-3.17)	0.9412	-0.28 (-0.5--0.12)	1.095 (1.088-1.1)	0.9889
		Thunnus obesus Lowe, 1839	0.084 (0.052-0.13)	2.73 (2.62-2.83)	0.9476	-0.55 (-1--0.09)	1.09 (1.08-1.1)	0.9788
		Acanthocybium solandri Cuvier, 1832	0.052 (0.07-0.3)	2.55 (2.13-2.98)	0.9638	8.39 (5.78-13.36)	1.03 (0.9-1.15)	0.9422
		Scomberomorus commerson Lacepède, 1800	0.0042 (0.003-0.005)	3.097 (3.04-3.15)	0.9715	3.54 (2.59-4.48)	1.04 (1.03-1.05)	0.9877
		Scomberomorus guttatus Bloch & Schneider, 1801	0.0083 (0.0006-0.02)	2.96 (2.19-3.73)	0.978	15.85 (8.82-20.8)	0.87 (0.76-0.98)	0.9528
Siluriformes	Ariidae	*Netuma thalassina* Rüppell, 1837	0.032 (0.006-0.057)	2.76 (2.4-3.1)	0.95	5.68 (3.25-8.64)	1.05 (0.97-1.11)	0.9768

The values of the allometric coefficient *b* for all the species assessed in our study, which indicates the isometric growth pattern, are within the expected range of the meta-analysis (2.5 – 3.5) reported by Froese (2006). Our results show that the coefficient parameters for the length-weight and length-length relationships are highly significant ($p < 0.001$), with $R^2 > 0.9412$. This indicates that the analyzed models are well fit and robust. Moreover, the specimens were sampled onboard the fishing vessels, with no shrinking or dehydration of the body of the fish, which occur when the samples are fixed in alcohol and formaldehyde (Parker, 1963). The sampling of specimens from commercial fisheries resulted, for the most part, in matured-sized individuals. Therefore, the model parameters (*a* and *b*) and the values of the coefficient of determination could be improved by sampling all length and weight ranges of the fish in the population, including small fish.

Hyperallometry ($b > 3$; min CI of $b > 3$) was observed in two species (*Polynemus indicus* Linnaeus, 1758 and *Scomberomorus commerson* Lacepède, 1800), with the length increase rate being lower than the weight increase rate (Froese, 2006; Karachle and Stergiou, 2012). The species *Mene maculate* (Bloch and Schneider, 1801), *Lutjanus erythropterus* (Bloch, 1790), *Thunnus obesus* (Lowe, 1839) and *Acanthocybium solandri* (Cuvier, 1832) have hypoallometric characteristics, with a lower rate of weight increase than of length increase ($b < 3$; max CI of $b < 3$) (Froese, 2006; Karachle and Stergiou, 2012). The remaining species are isometric, with proportional weight and length increase rates (CI of b varying within 3) (Froese, 2006; Karachle and Stergiou, 2012).

LWRs also depend on intraspecific (e.g. sex and age), temporal (e.g. season) and environmental (e.g. temperature, salinity and food availability) conditions (Cort et al., 2015; Compaire and Soriguer, 2020). The variation in species growth between our study and some other reports may be related to differences in the studied areas and fishing gear used. Our study was conducted in the upwelling areas of the South China Sea (Hu and Wang, 1988; Kuo et al., 2000; Xie et al., 2003), which are rich in organic material and prey sources. Therefore, most of the species evaluated in this study show faster growth rates than those in other marine areas (Uchiyama and Boggs, 2006; Sawant and Raje, 2009; Zhu et al., 2009; Ahmed et al., 2014; Fakhri et al., 2015; Lelono et al., 2021). We collected specimens using commercial gillnets that captured substantial mature-sized fish, while other studies have used multiple methods, such as trawling, longlining, angling, purse seine fishing and port-based sampling, which included a wide range of sizes (Sawant and Raje, 2009; Zhu et al., 2009; Ahmed et al., 2014; Fakhri et al., 2015; Lelono et al., 2021; Nguyen et al., 2022). In addition to incomplete information on the LWRs and LLRs of the species investigated, the length-at-age, length-at-maturity and growth rate of these species in Vietnamese waters–important biological factors needed to carry out a stock assessment–are unknown. This suggests that there is room for further research into the ecology and demographics of marine species.

Although knowledge about LWRs is critical for the fish ecology model, LLRs provide the key body shape parameter that can be used to back-calculate between TL, FL and W. In some cases, TL and W are not available because fishermen remove fins, viscera and gills before handling fish (Nguyen et al., 2022a). TL is used to determine the legal sizes for commercial and recreational fishing in Vietnam (Nguyen et al., 2021). Therefore, reliable LLRs are needed for data conversion and management. The LLR analysis is consistent with the LWRs in terms of fish growth patterns, as most species have isometric growth patterns, with an LLR coefficient not significantly greater than the value of unity ($b = 1$). In other words, the caudal fin does not increase proportionally to the increase in the length of the fish. However, two species were found to have hyperallometric ($b > 1$) and four were found to have hypoallometric ($b < 1$) characteristics.

In conclusion, information on the biological aspects and morphological parameters of marine fish species in Vietnamese waters is quite insufficient (Nguyen and Nguyen, 2014). Thus, fish stock assessments, ecological studies and taxonomic identification cannot be carried out for many marine species, including the 16 species investigated in this study. This is the first time that LWRs and LLRs have been documented for these species in Vietnam. This study fills scientific information gaps in basic biological knowledge and provides useful information for the development and management of sustainable fisheries, studies on fish population dynamics and scientific tools for future studies. The length-weight and length-length relationships of the 16 species described here provide new information and biological parameters in Vietnam. This can help researchers and fisheries managers carry out further studies and develop appropriate management strategies and policies.

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