Publication status: This preprint has been published elsewhere.
DOI of the published preprint: https://doi.org/10.1590/2675-2824073.25031

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https://doi.org/10.1590/SciELOPreprints.12565

Submitted on: 2025-07-10
Posted on: 2025-07-31 (version 1)
(YYYY-MM-DD)

Ocean and Coastal Research

Running Title: LWRs of Fishes and Invertebrates

Length-weight relationships and relative condition factor of some commercially important fishes and invertebrates in the southwestern sea of Vietnam

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ABSTRACT

Length-weight relationships (LWRs) and relative condition factor (Kn) of some commercially-important fish and invertebrate species including *Atule mate* (Cuvier, 1833), *Dendrophysa russelii* (Cuvier, 1829); *Encrasicholina heteroloba* (Rüppell, 1837); *Euthynnus affinis* (Cantor, 1849); *Mulloidichthys vanicolensis* (Valenciennes, 1831); *Nemipterus mesoprion* (Bleeker, 1853); *Pennahia anea* (Bloch, 1793); *Rastrelliger brachysoma* (Bleeker, 1851); *Sardinella gibbosa* (Bleeker, 1849); *Saurida elongata* (Temminck & Schlegel, 1846); *Saurida undosquamis* (Richardson, 1848); *Scolopsis taenioptera* (Cuvier, 1830); *Upeneus tragula* Richardson, 1846; *Sepiella inermis* (Van Hasselt, 1835); *Parapenaeopsis maxillipedo* (Alcock, 1905); *Portunus pelagicus* (Linnaeus, 1758) were determined using 12,727 specimens collected from two fisheries independent surveys and monthly port sampling between November 2022 to October 2023. The slope (b) values of the LWRs ranged from 2.613 for *S. inermis* to 3.528 for *R. brachysoma*. Eleven species exhibited positive allometric growth, three had negative allometric growth and two species had isometric growth.

KEYWORDS: LENGTH-WEIGHT RELATIONSHIPS, ISOMETRIC GROWTH, CONDITION FACTOR, FISHES, INVERTEBRATES

INTRODUCTION

The Southwestern Sea (SWS) of Vietnam, as part of the Gulf of Thailand, is a shallow water seabed, characterized by tropical climate with two distinct monsoon seasons: the rainy season (RS; April - September) and the dry season (DS; October - March). Ecologically, it encompasses two ecological production units (VI and VII) in the Sea of Vietnam (Bell et al., 2021), featuring high biological diversity and productivity, with most species of fish and invertebrates exhibiting rapid growth rates and short lifespans (Pham and Nguyen, 1997). Fisheries in SWS are small-scale, and composed of a large number of fishing vessels using diverse fishing gears (e.g., purse seine, handline, gillnet, ringnet, etc.). Fisheries management in SWS faces considerable challenges in establishing management measures, since the quality of available data is often inadequate for determining stock status of most species. In data-deficient contexts, adaptive fisheries management using indicators synthesized from both fisheries-dependent and independent surveys is a practical approach (Raakjær et al., 2007).

Length-weight relationships (LWRs) are essential not only for stock assessment (Garcia et al., 1998; Jennings et al., 2001; King, 2007) but also for taxonomic and morphological studies (Le Cren, 1951; Frota et al., 2004; Froese, 2006; Paraskevi and Konstantinos, 2012). In the context of biomass estimation, the LWR equation is a pivotal factor employed to convert length of species to weight (King, 2007). Relative condition factor (Kn) reflects the health status and growth performance of species by comparing the observed body weight to the expected weight derived from the population's length–weight relationship (Le Cren, 1951). LWRs and Kn are species-specific that can exhibit stochastic variability due to sex, longevity, and seasonal or inter-annual influences (Le Cren, 1951; Mazumder et al., 2016; Compaire and Soriguer, 2020).

In this study, the LWRs and Kn were estimated for some commercially important fish and invertebrate species from the SWS of Vietnam, with the objective of enhancing stock assessment and advancing our understanding of their biology.

METHODS

Data collection

Fish and invertebrate specimens were collected during fisheries independent surveys (FIS) and port sampling (PS) in 2022 and 2023. The FIS was carried out by a commercial fishing boat KG60012TS, a wooden-hulled vessel with an overall length of 13.6 m, equipped with a 230 horse-power engine. The bottom trawl net used for data sampling had a 16m headrope, 18m footrope, and an 18mm cod-end stretched mesh. The sampling strategy was a systematic design, with 20 sampling stations (Figure 1). Two trawl surveys were carried out in November 2022 and June 2023 representing the DS and RS, respectively. Sampling was conducted in accordance with the methodology described by Sparre and Venema (1998). The trawl was towed at 2.3-2.5 knots during the surveys for 45-60 minutes. Fishes and invertebrates trawled onboard were sorted, identified and frozen then sent to the laboratory of the Research Institute for Marine Fisheries for biological analysis.

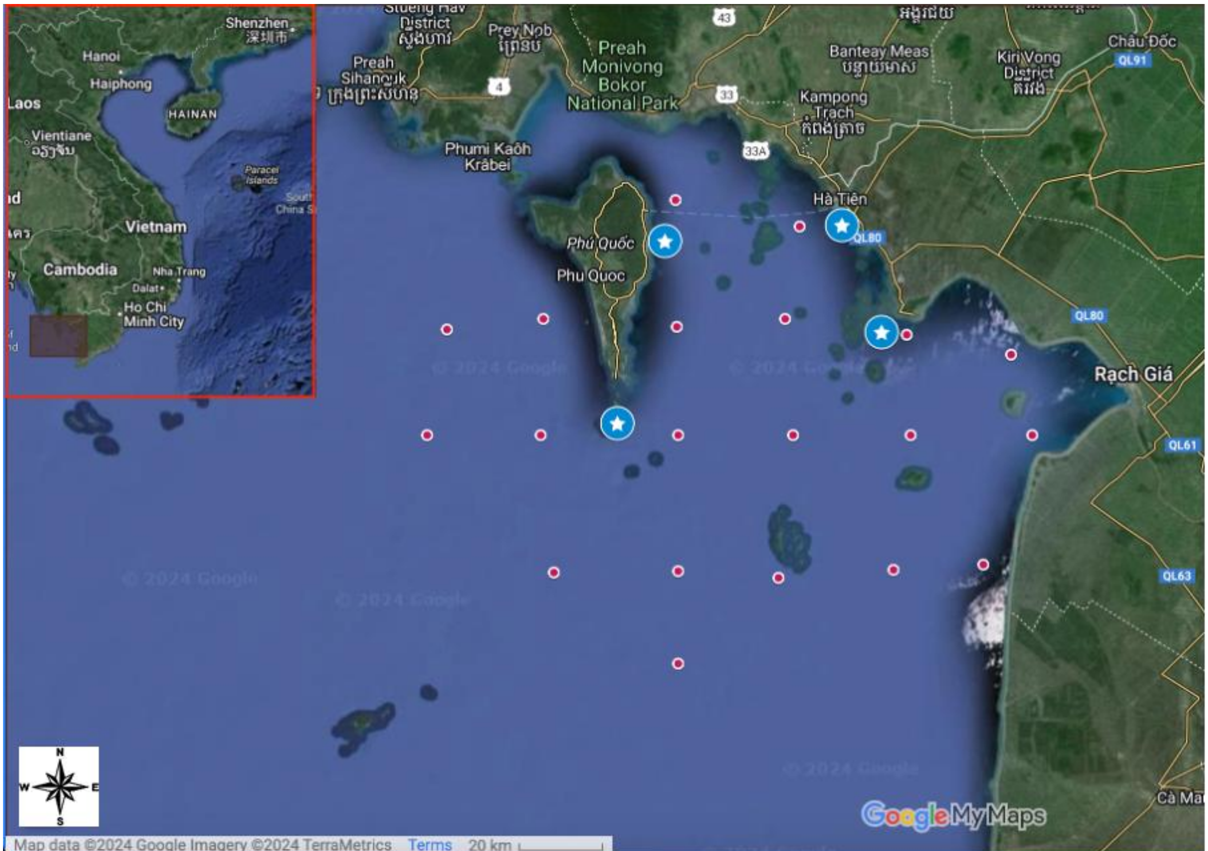

Figure 1. Port sampling (PS) sites (star) and trawl sampling stations (red dotted) of the fisheries independent surveys (FIS) in the SWS of Vietnam

The PS was conducted monthly during the periods from November 2022 to October 2023 at the landing sites along the coast of Kien Luong, Ha Tien districts, and Phu Quoc Island of Kien Giang province, Vietnam. Samples of 16 fishes and invertebrates species were randomly taken from the catches of trawl nets, gillnets, purse seines, and collapsible traps when the fishing boat disembarked for catches unloading.

Individual length measurements of fishes and invertebrates were conducted using calipers, and measured to the nearest millimeter. We measured the total length (TL) for species with no forked tail, fork length (FL) for species with a forked tail, carapace width (CW) for crabs, mantle length (ML) for squids, and body length (BL) for shrimp. The body weight (g) of individual fish and invertebrates was measured on land using a digital scale with an accuracy of 0.01 g.

A total of 12.727 specimens of 12 fish and four invertebrate species belonging to 11 families were collected for biological analysis (Table 1), including *Atule mate, Dendrophysa russelii, Encrasicholina heteroloba, Euthynnus affinis*, *Mulloidichthys vanicolensis*, *Nemipterus mesoprion, Pennahia anea, Rastrelliger brachysoma, Sardinella gibbosa, Saurida elongata*, *Saurida undosquamis, Scolopsis taenioptera*, Upeneus tragula, *Sepiella inermis*, *Parapenaeopsis maxillipedo, Portunus pelagicus*. There were 9,819 specimens sampled monthly by PS and additional 2,911 individuals of *A. mate*, *D. russelii*, *S. undosquamis* and *S. inermis* were collected at sea during FIS. The sample size ranged from 75 individuals for *N. mesoprion* to 1,433 for *S.*

undosquamis.

Table 1. Number of specimens collected during the periods from Nov 2022 to Oct 2023. FIS: fisheries independent survey, PS: port sampling; N: sample size; FL: fork length; TL: total length; ML: mantle length; BL: body length; CW: carapace width

Group	Family	Species	Data Type	N	L range (cm)	W range (g)	Length Type
Fish	Carangidae	Atule mate (Cuvier, 1833)	FIS	22	11.4-16.5	21.4-80.3	FL
			PS	936	6.3-24.0	3.2-238.1	FL
			All	958	6.3-24.0	3.2-238.1	
	Clupeidae	*Sardinella gibbosa* (Bleeker, 1849)	PS	1,090	5.2-16.0	1.6-51.9	FL
	Engraulidae	*Encrasicholina heteroloba* (Rüppell, 1837)	PS	1,119	4.3-8.0	0.6-4.8	FL
	Mullidae	*Mulloidichthys vanicolensis* (Valenciennes, 1831)	FIS	1325	5.1-15.2	2.6-61.8	FL
		Upeneus tragula Richardson, 1846	FIS	263	5.3-9.8	2-18.6	FL
	Nemipteridae	*Nemipterus mesoprion* (Bleeker, 1853)	FIS	75	6-13.8	4.1-42.5	FL
		Scolopsis taenioptera (Cuvier, 1830)	FIS	460	5.2-21.5	4.3-146.5	FL
	Scombridae	*Euthynnus affinis* (Cantor, 1849)	PS	154	16.8-38.1	75.8-930	FL
		Rastrelliger brachysoma (Bleeker, 1851)	PS	1,186	7.1-21.2	3.5-167	FL
	Sciaenidae	*Dendrophysa russelii* (Cuvier, 1829)	FIS	64	6.3-12.0	2.3-21.9	TL
			PS	1,081	7.5-16.3	4.5-60.0	TL
			All	1,154	6.3-16.3	2.3-60.0	
		Pennahia anea (Bloch, 1793)	FIS	89	7.2-18.4	4.4-84.4	TL
	Synodontidae	*Saurida elongata* (Temminck & Schlegel, 1846)	FIS	152	7-17.8	2.9-62.1	FL
		Saurida undosquamis (Richardson, 1848)	FIS	408	5.3-26.4	1.2-159.7	FL
			PS	1,025	8.8-27.5	3.5-209.3	FL
			All	1,433	5.3-27.5	1.2-209.3	
Cephalopod	Sepiidae	*Sepiella inermis* (Van Hasselt, 1835)	FIS	50	3-7.9	5.8-82.2	ML
			PS	1,143	1.8-12.3	0.9-224.3	ML
			All	1,193	1.8-12.3	0.9-224.3	
Crustacean	Penaeidae	*Parapenaeopsis maxillipedo* (Alcock, 1905)	PS	953	4.2-10.0	1.2-15.2	BL
	Portunida	*Portunus pelagicus* (Linnaeus, 1758)	PS	1,132	5.8-	11.9-	CW

Group	Family	Species	Data Type	N	L range (cm)	W range (g)	Length Type
	e				14.2	231.6	
	Total	16		12,727			

Data analysis

LWRs of fishes and invertebrates were estimated by transformation of the power equation $W = aL^b$ to the linear regression log(W)=log(a)+b*log(L) where W is weight in g and L is the length in cm, a is the intercept and b is the slope (Le Cren, 1951). Based on the estimated b, the growth of a fish or invertebrate species (growth type: GT) is considered negative allometric (b<3), isometric (b=3), or positive allometric (b>3) (Bayer, 1987). The 95% confidence interval (CI) and standard error (se) of LWR coefficients were also estimated to determine if the hypothetical value of isometry is within these estimated limits.

Relative condition factor (Kn) was calculated using the Le Cren (1951) formula: $Kn = W/(a \times L^b)$. A higher Kn generally indicates that an individual has a higher weight relative to its length than the average for species.

LWRs and Kn of fishes and invertebrates were analyzed using combined-sex data to provide general information on growth patterns of species. Additionally, separate analyses by sex and maturity stage were conducted to examine potential differences in growth across life history stages.

All data were analyzed and plotted using R Studio (R Core Team, 2021), following the guidelines of Ogle (2016).

RESULTS

Length frequency distribution of fishes and invertebrates are given in Figure 2. Several species demonstrated bimodal distributions representing multiple cohorts, including *A. mate*, *E. affinis*, *P. anea*, *R. brachysoma*, *S, elongata*, and *S. undosquamis*. Conversely *E. heteroloba*, *P. maxillipedo*, and *U. tragula* followed a more restricted unimodal distribution, potentially indicating that the sampling/fishing is concentrated on a single cohort.

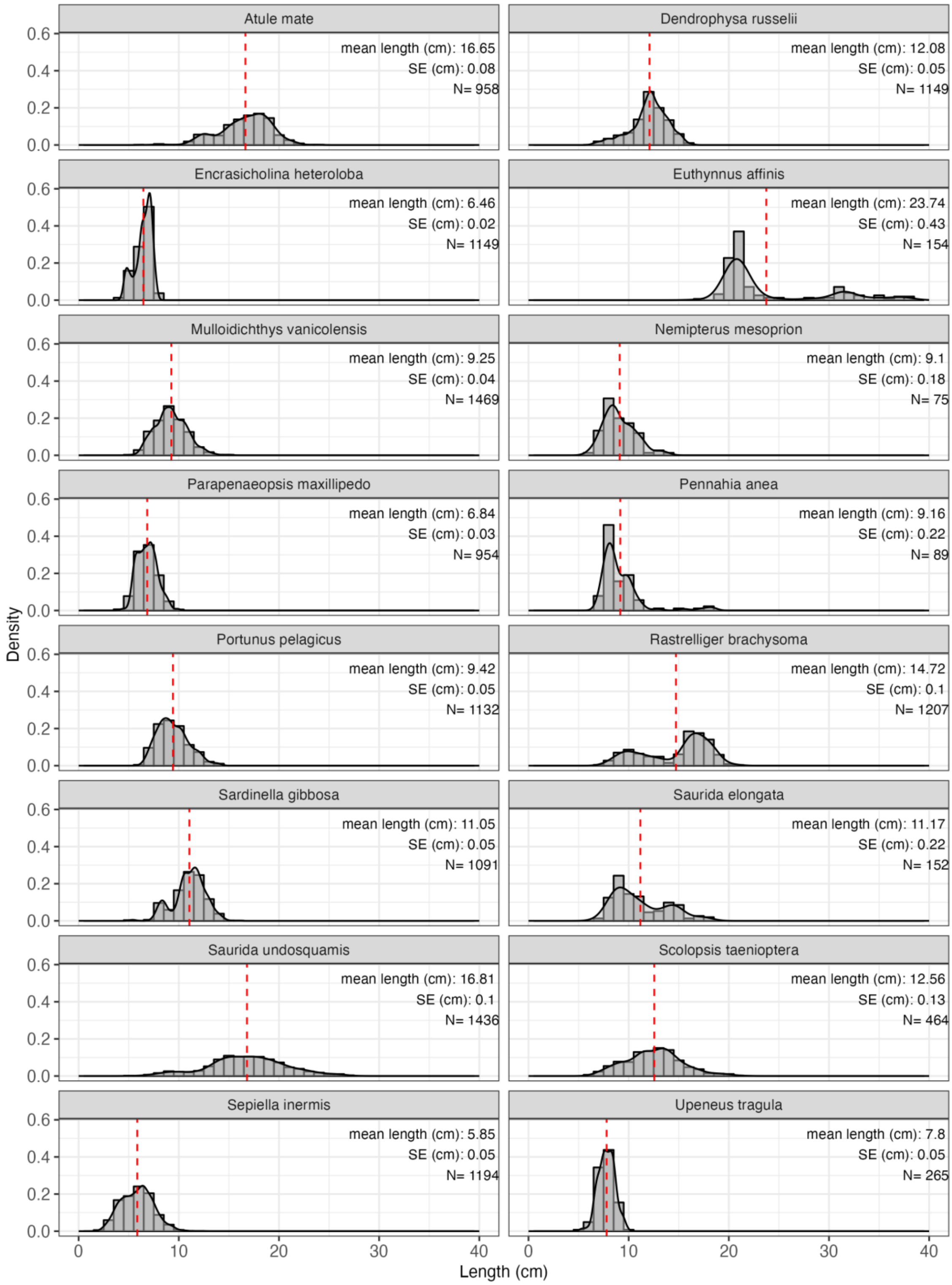

Figure 2. Length frequency distribution of 16 commercially important species in the SWS of Vietnam. The vertical red dash lines denote the mean length of species

Parameters of the LWR equation, growth type and Kn of fish and invertebrate species in the SWS of Vietnam are presented in Table 2. Among the studied species, b values ranged from 2.613 (*S. inermis*) to 3.528 (*R. brachysoma*). All estimated LWRs showed a significant correlation with the coefficient of determination (r^2) ranging from 0.91 to 0.99 (p<0.05). Student t-test and analysis of b value indicated that 11 species had positive allometric (b>3); three were negative allometric growth (b<3) including *S. taenioptera, S. inermis, P. maxillipedo* and two species considered as isometric growth, consisting of *N. mesoprion* and *P. anea*.

Table 2. Parameters of the LWR equation, Kn and growth type (GT) for fish and invertebrate species in the SWS of Vietnam. N: sample size; a: intercept; b: slope; r^2: coefficient of determination, SE (b) standard error of b value; CI (b): 95% confident interval of the b value, A^+: positive allometric growth; A^-: negative allometric growth; I: Isometric growth

Species	Sex	N	a	b	CI (b)	SE (b)	r^2	Mean of Kn	SE of Kn	GT
Atule mate	All	958	0.01306	3.074	3.046-3.103	0.014	0.98	1.613	0.004	A^+
	F	431	0.01421	3.045	2.998-3.092	0.024	0.97	1.619	0.006	
	M	476	0.01346	3.063	3.011-3.116	0.027	0.97	1.614	0.006	
	Juv	51	0.00928	3.212	3.11-3.314	0.051	0.99	1.554	0.015	
Dendrophysa russelii	All	1145	0.0059	3.291	3.253-3.33	0.02	0.96	1.223	0.004	A^+
	F	699	0.00618	3.275	3.223-3.327	0.026	0.96	1.234	0.005	
	M	435	0.00568	3.303	3.238-3.367	0.033	0.96	1.210	0.007	
	Juv	11	0.00291	3.636	2.855-4.417	0.345	0.92	1.071	0.047	
Encrasicholina heteroloba	All	1119	0.00666	3.131	3.079-3.183	0.027	0.93	0.856	0.003	A^+
	F	511	0.00681	3.114	3.036-3.192	0.04	0.92	0.848	0.005	
	M	608	0.00659	3.14	3.07-3.21	0.036	0.93	0.863	0.004	
Euthynnus affinis	All	154	0.00784	3.217	3.171-3.262	0.023	0.99	1.553	0.009	A^+
	F	19	0.01023	3.147	2.939-3.355	0.099	0.98	1.690	0.017	
	M	21	0.01276	3.073	2.803-3.344	0.129	0.97	1.652	0.019	
	Juv	114	0.00817	3.202	2.965-3.44	0.12	0.86	1.512	0.008	
Mulloidichthys vanicolensis	All	1325	0.01425	3.093	3.059-3.126	0.017	0.96	1.762	0.005	A^+
	F	755	0.01447	3.088	3.043-3.133	0.023	0.96	1.772	0.007	
	M	533	0.0131	3.128	3.074-3.182	0.028	0.96	1.747	0.008	
	Juv	37	0.1041	2.05	1.462-2.639	0.29	0.59	1.749	0.057	
Nemipterus mesoprion	All	75	0.02001	2.948	2.828-3.068	0.06	0.97	1.791	0.018	I

Species	Sex	N	a	b	CI (b)	SE (b)	r^2	Mean of Kn	SE of Kn	GT
	F	29	0.01614	3.048	2.737-3.358	0.151	0.94	1.808	0.029	
	M	24	0.02297	2.885	2.686-3.084	0.096	0.98	1.782	0.028	
	Juv	22	0.05279	2.459	2.029-2.889	0.206	0.88	1.780	0.039	
Pennahia anea	All	89	0.01654	2.924	2.82-3.029	0.053	0.97	1.343	0.024	I
	F	22	0.00684	3.3	2.99-3.61	0.149	0.96	1.369	0.020	
	M	21	0.01378	2.996	2.885-3.107	0.053	0.99	1.454	0.020	
	Juv	46	0.02125	2.818	2.427-3.208	0.194	0.83	1.343	0.024	
Rastrelliger brachysoma	All	1186	0.00343	3.528	3.509-3.548	0.01	0.99	1.412	0.006	A^+
	F	404	0.00821	3.224	3.147-3.302	0.039	0.94	1.551	0.006	
	M	383	0.00588	3.341	3.263-3.418	0.04	0.95	1.534	0.007	
	Juv	399	0.00758	3.178	3.133-3.223	0.023	0.98	1.154	0.004	
Sardinella gibbosa	All	1090	0.00718	3.225	3.182-3.267	0.022	0.95	1.236	0.004	A^+
	F	529	0.01216	3.012	2.94-3.083	0.036	0.93	1.257	0.005	
	M	467	0.01206	3.013	2.922-3.103	0.046	0.9	1.250	0.006	
	Juv	94	0.01359	2.87	2.736-3.003	0.067	0.95	1.040	0.007	
Saurida elongata	All	152	0.00702	3.115	3.034-3.196	0.041	0.97	0.929	0.009	A^+
	F	33	0.00364	3.365	3.193-3.537	0.084	0.98	0.926	0.018	
	M	52	0.00611	3.168	3.037-3.3	0.065	0.98	0.942	0.011	
	Juv	67	0.01104	2.912	2.469-3.355	0.222	0.73	0.920	0.017	
Saurida undosquamis	All	1433	0.00615	3.124	3.093-3.154	0.015	0.97	0.879	0.004	A^+
	F	723	0.00644	3.107	3.054-3.16	0.027	0.95	0.884	0.005	
	M	649	0.00814	3.028	2.979-3.077	0.025	0.96	0.888	0.005	
	Juv	61	0.03317	2.275	1.969-2.581	0.153	0.79	0.728	0.014	
Scolopsis taenioptera	All	463	0.02425	2.877	2.836-2.919	0.021	0.98	1.797	0.013	A^-
	F	339	0.02123	2.93	2.879-2.982	0.026	0.97	1.785	0.007	
	M	111	0.01946	2.959	2.916-3.003	0.022	0.99	1.766	0.012	
	Juv	10	0.01477	3.09	2.295-3.886	0.345	0.91	1.787	0.056	
Upeneus tragula	All	263	0.01016	3.263	3.141-3.386	0.062	0.91	1.754	0.012	A^+

Species	Sex	N	a	b	CI (b)	SE (b)	r^2	Mean of Kn	SE of Kn	GT
	F	140	0.01104	3.228	3.045-3.411	0.092	0.9	1.780	0.016	
	M	102	0.01126	3.208	2.977-3.44	0.117	0.88	1.736	0.020	
	Juv	21	0.00882	3.328	2.959-3.698	0.176	0.95	1.663	0.035	
Sepiella inermis	All	1193	0.34541	2.613	2.576-2.649	0.019	0.94	18.130	0.130	A^-
	F	483	0.30571	2.685	2.625-2.745	0.03	0.94	17.459	0.160	
	M	543	0.35183	2.596	2.523-2.668	0.037	0.9	17.608	0.153	
	Juv	167	0.55429	2.255	2.07-2.44	0.094	0.78	21.765	0.553	
Parapenaeopsis maxillipedo	All	953	0.01662	2.937	2.889-2.984	0.024	0.94	1.481	0.005	A^-
	F	640	0.01723	2.929	2.873-2.984	0.028	0.94	1.509	0.006	
	M	313	0.02199	2.764	2.674-2.854	0.046	0.92	1.424	0.009	
Portunus pelagicus	All	1132	0.03958	3.228	3.186-3.269	0.021	0.95	6.621	0.024	A^+
	F	514	0.04519	3.161	3.098-3.224	0.032	0.95	6.495	0.033	
	M	618	0.03726	3.26	3.206-3.314	0.027	0.96	6.724	0.033	

Table 2 presents the Kn values observed for the studied species. Three fish species had a Kn below 1.0 (*E. heteroloba*; *S. undosquamis*; *S. elongata*) and ten species with the mean Kn fluctuated between 1.223 to 1.791. The relatively high Kn were observed in two invertebrate species including *S. inermis* and *P. pelagicus* reflecting particularly robust physiological condition in these taxa.

DISCUSSION

The LWRs differed among species and dependent on life history traits. The Kn reflects the health status and growth performance of species in relation to the physical and biological changes in environmental factors (Le Cren, 1951). Food availability is considered the main factor influencing the growth of species (Jobling, 1994). The Kn of each population varies yearly or seasonally (Jennings et al., 2001) and also depends on the life span of species.

In this study, the b values of fishes differed but aligned with the expected range as indicated by Froese (2006), between 2.5-3.5. In invertebrate species, b values vary across taxonomic group. Cephalopods such as squids and cuttlefish, as well as shrimps, typically exhibit b<3, indicating negative allometric growth (Siddique et al., 2016; Hari et al., 2024; Jahan and Mahmud, 2025). In contrast, crabs often show b>3, reflecting positive allometric growth (Hamid et al., 2018; Rohmayani et al., 2018). In the present study, the cuttlefish *Sepiella inermis* exhibited the b value of 2.613, consistent with negative allometry. This value is higher than the estimate reported by Siddique et al. (2016) of 1.979 and comparable to that found by Jahan and Mahmud (2025). Önsoy and Salman (2022) reported that the b values of Sepiida range between 2.36-2.82.

Our findings on Kn are well-aligned with previous studies, showing values similar to those of fishes, which are typically in the range 1.0-2.0 (Tran et al., 2021; 2022a; 2022b; Dinh et al., 2022c; Ragheb, 2023). Kn values are relatively high in crabs (Hamid et al., 2018; Rohmayani et al., 2018) and cephalopods (Önsoy and Salman, 2022). Rohmayani et al. (2018) reported that the Kn of the blue swimming crab *Portunus pelagicus* from the Java Sea, Indonesia ranged between 4.22 and 11.7. Önsoy and Salman (2022) indicated that the mean Kn of Sepiida order is 12.51± 2.61, varying from 3.02 to 31.31.

Sexually dimorphic and variable ontogenetic growth patterns were observed for the species. During the juvenile stage, *A. mate, D. russelii, E. affinis, S. taenioptera,* and *U. tragula* had a higher b value than those in the adult stages, indicating that weight growth was faster during the juvenile stage. This indicates that juveniles were accruing weight across length intervals at a higher rate as compared to the adult stages. On the contrary, *M. vanicolensis, N. mesoprion, P. anea, R. brachysoma, S. gibbosa, S. elongata,* and *S. undosquamis* showed slower weight growth in the juvenile stage but faster growth when adults.

LWRs of marine species in Vietnam are poorly described. Recently, LWRs have been determined for *Trypauchen vagina, Periophthalmus variablilis, Periophthalmus chrysospilos,* and *Ellochelon vaigiensis* in the Mekong delta of Vietnam (Dinh, 2016; Dinh et al., 2022a; 2022b; 2022c; 2022d). Tran et al. (2021) studied the LWRs of the mudskipper (*Periophthalmus modestus*) in the Red River Delta of Vietnam. Nguyen (2024) reported the LWRs of 16 marine fish species in the Sea of Vietnam analysed from data sampled from 3 different eco-regions of the Gulf of Tonkin, the Central and the Southeast areas (Nguyen, 2024). In this study, none of these species had previously reported parameters of LWRs in the Sea of Vietnam. Thus, these results represent a valuable contribution to regional fisheries science, particularly for stock assessment applications. LWRs are fundamental tools for converting length data into biomass estimates, especially when weight measurements are unavailable. The established LWRs, therefore, enhance the quality of biological information accessible to fisheries managers, supporting the formulation of species-specific and ecosystem-based management strategies.

CONCLUSION

This study provided the first data on the LWRs and Kn of 12 fish and 4 invertebrate species in the SWS of Vietnam, with positive allometric growth observed in eleven species, negative allometric growth in three species, and isometric growth in two species. The Kn values of most studied species ranged from 1.0 to 2.0, except for crab *Portunus pelagicus* and cuttlefish *Sepiella inermis*. The coefficient of determination for LWRs of the combined sexes among species showed a significant correlation ($r^2 > 0.9$). These results can provide necessary information for stock assessment in Vietnam, particularly for species with limited or no prior LWR information.

ACKNOWLEDGMENTS

We would like to thank Dr. James Bell from the Centre for Environment, Fisheries and Aquaculture Science (Cefas, UK) for his helpful and valuable comments on the first draft of this work. Thanks also to colleagues and crews who participated in the fisheries independent surveys at sea and port samplings. We also thank two reviewers for their useful comments on this study.

FUNDING

This study received financial support from the People's Committee of Kien Giang Province under contract No. 06/2022/HD-CCTSKG-VHS.

AUTHOR CONTRIBUTION

Vu Viet Ha: Conceptualization, Methodology, Project Administration, Funding Acquisition, Supervision, Formal Analysis, Writing, Review and Editing.
Tu Hoang Nhan: Investigation, Data curation.

COMPETING INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

All data are available from the corresponding author upon reasonable request

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