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Length–weight relationships of 11 deep-sea fishes from the western Bay of Bengal and Andaman waters, India

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Summary

Length–weight relationships (LWRs) are presented for 11 deep-sea fishes caught in the western Bay of Bengal and Andaman waters during August 2010 using a 38 m high speed demersal trawl II (HSDT II, crustacean version, codend mesh size 40 mm) and a 45.6 m Expo model demersal trawl (codend mesh size 30 mm). The *b* values ranged from 2.34 to 3.3 and the coefficient of variation (r^2) ranged from .82 to .98. LWR estimates of eight deep-sea fishes are provided for the first time. The estimated LWR values were compared with the Bayesian LWR estimates available in FishBase, based on models developed to improve the accuracy and predictability of species-specific growth parameters of data-poor species.

1 | INTRODUCTION

Length–weight relationships (LWRs) are of great importance in the area of fisheries research as they are used to predict the condition and growth pattern, as well as calculate the biomass from the length, and to convert growth in length to growth in weight (Froese, 2006; Froese, Thorson, & Reyes, 2014; Froese, Tsiklirans, & Stergiou, 2011; Le Cren, 1951; Sandoval-Huerta, Madrigal-Guridi, Domínguez-Domínguez, Ruiz-Campos, & González-Acosta, 2015). The biology, ecology and life history characteristics of deep-sea fishery resources from the Indian EEZ are scarce and scattered (Deepu, Divya, & Kurup, 2007; Kumar, Thomy, Deepa, Hashim, & Sudhakar, 2016; Sreedhar, Sudhakar, & Meenakumari, 2013; Venu & Kurup, 2002, 2006). Estimation of LWR equations are very important in the fishery assessment where they are used to predict the weight-at-age from the length-in-yield assessments (Garcia et al., 1998; Pauly, 1993), calculating the condition indices (Anderson & Gutreuter, 1983), and for morphological comparison of growth rate of different populations (Petrakis & Stergiou, 1995).

In this paper, the estimates of LWR parameters of 11 deep-sea fishes from the western Bay of Bengal and Andaman waters are presented, which include the first estimates for eight deep-sea fishes. The authors believe that the results of the study can contribute greatly toward the better understanding of the growth patterns of less studied deep-sea fishes of Indian waters and to improve the accuracy of the Bayesian LWR estimates for the data-poor species.

2 | MATERIALS AND METHODS

The samples were collected during the deep-sea fishery explorations onboard FORV *Sagar Sampada* of the Centre for Marine Living Resources and Ecology, Govt. of India, during August 2010. The five sampling stations were located at depth ranges of 231–514 m (10°57′–18°30′N; 80°00′–93°13′E). A 38 m highspeed demersal trawl II (HSDT II, crustacean version, codend mesh size 40 mm) and 45.6 m Expo model Demersal Trawls (mesh size 30 mm) were used for trawling operations. The depth of operation, time and duration of towing operations were recorded. Morphometric and meristic measurements were taken for all species and identified up to species level using standard identification keys (Alcock, 1898, 1899; FAO, 1984). Total lengths and weights were measured to an accuracy of 0.1 cm and 0.1 g, respectively. Samples were preserved in 5% formaldehyde and detailed examination of each species was carried out in the laboratory.

The LWR was estimated by least square regression method and r^2 (coefficient of determination), which indicates the robustness of the sample analysed (Froese, 2006; Froese et al., 2014; Le Cren, 1951; Zar, 1999). Relationship was expressed by the regression equation $W = aL^b$, which was converted into its logarithmic form $\text{Log}_{10}\, W = \text{Log}_{10} a + b\, \text{Log}_{10}\, L$. The meristic values of the fishes studied were transformed into logarithmic values for identifying and excluding possible outliers in the data (Froese et al., 2011), which were

TABLE 1 Length–weight relationships (LWRs) of deep-sea fishes from shelf regions of western Bay of Bengal and Andaman waters captured during August 2010

			Total length (cm)		Total weight (g)		Parameters of relationships				
Species	Order	*N*	Min	Max	Min	Max	*a*	*b*	95% CL *a*	95% CL *b*	r^2
Polymixia fusca Kotthaus, 1970	Polymixiiformes	95	13.0	23.8	33.0	183.5	0.0163	2.94	0.113–0.0237	2.81–3.07	.96
Chlorophthalmus nigromarginatus Kamohara, 1953	Aulopiformes	20	18.9	22.2	54.0	91.0	0.0032	3.31	0.0007–0.0159	2.79–3.84	.91
Setarches guentheri Johnson, 1862	Scorpaeniformes	51	6.6	11.9	2.6	35.0	0.0156	2.94	0.011–0.0221	2.79–3.1	.97
Tydemania navigatoris Weber, 1913	Tetraodontiformes	45	7.3	10.0	8.3	16.0	0.0004	2.34	0.0001–0.0018	2.0–2.67	.82[a]
Physiculus natalensis Gilchrist, 1922	Gadiformes	25	13.8	20.7	18.0	50.0	0.0185	2.64	0.0041–0.0822	2.12–3.17	.83[a]
Physiculus roseus Alcock, 1891	Gadiformes	90	15.4	21.8	22.0	51.0	0.0231	2.5	0.0117–0.0453	2.27–2.73	.84[a]
Synagrops japonicus (Döderlein, 1883)	Perciformes	22	13.3	20.0	24.0	85.0	0.0151	2.86	0.0081–0.0284	2.63–3.1	.98
Heteropriacanthus cruentatus (Lacépède, 1801)	Perciformes	41	13.0	20.0	26.5	94.0	0.0145	2.93	0.0102–0.0206	2.80–3.05	.98
Chelidoperca investigatoris (Alcock, 1890)	Perciformes	124	11.0	**18.1**	16.0	55.0	0.0288	2.59	0.0199–0.0417	2.46–2.73	.92
Acropoma japonicum Günther, 1859	Perciformes	88	7.8	15.8	4.6	43.5	0.0104	3.02	0.0075–0.0144	2.90–3.15	.96
Neoscopelus microchir Matsubara, 1943	Myctophiformes	33	13.0	23.5	22.0	97.5	0.0216	2.7	0.0108–0.0432	2.45–2.95	.94

a and *b*, = parameters of the LWR equation; CL, confidence limit; max, maximum; min, minimum; *N*, sample size; r^2, coeffient of correlation.
Bold indicates new maximum TL.
[a]Tentative estimates due to low sample size or too narrow size range.

excluded from the analysis. Curvilinear plots with length and weight data were generated and visually examined to check the observed outliers in the dataset (Froese, 2006). The *b* value for each species was evaluated using a *t* test at .05 significance level to check whether the value was significantly different from the isometric value 3 (Miranda, Galicia, Monks, & Pulido-Flores, 2009; Pauly, 1993). The *b* values estimated during the present study were compared with the estimations of the previous studies to verify the existence of spatial variation in LWR. LWRs were estimated with data from both the sexes combined. Estimated *b* values were compared with the modelled values of Froese et al. (2014) following the Bayesian approach deposited in FishBase.

3 | RESULTS

Table 1 shows the species name, sample size, minimum and maximum length (TL) and weight (TW) determined, and provides the LWR parameters *a* and *b*, 95% CL of *a* and *b*, and coefficient of determination, r^2.

Sample numbers selected for the study ranged from 20 (*Chlorophthalmus nigromarginatus*) to 124 (*Chelidoperca investigatoris*). The *b* values observed in the study ranged from 2.34 (*Tydemania navigatoris*) to 3.31 (*C. nigromarginatus*). The r^2 values ranged from .82 (*T. navigatoris*) to .98 (*Synagrops japonicus*, *Heteropriacanthus cruentatus* and *Acropoma japonicum*).

4 | DISCUSSION

The Indian EEZ is rich in deep-sea fish resources showing diverse morphology and life history traits (Gopalakrishnan, Varghese, Ali, & Pandian, 1988; Hashim, 2012; Khan et al., 1996; Vijayakumaran & Philip, 1988). Reliable LWRs were missing for most species. Although the LWRs presented in this study are first estimates for most species, some of them must be taken as tentative because of the limited sample size and limited size range covered. There was also only a onetime snapshot sampling in August 2010, and seasonal or interannual variations cannot be judged.

The *b* values reported for *S. guentheri* (*b* = 2.94) in this study are in line with the studies of Diaz, Roa, Garcia, Acero, and Navas (2000) and Sreedhar et al. (2013), indicating slightly higher *b* values (3.15 and 3.31). However, such slight differences could be real or be the result of sampling biases because of the different fishing methods used. There is a need to standardize sampling procedures in order to obtain comparable results. No estimates are available for *C. nigromarginatus*, but the values conform with the estimation of Froese et al. (2014) based on the Bayesian approach. The *b* values obtained for *S. guentheri* (*b* = 2.94) are in accord with estimates of Sreedhar et al. (2013), and *P. natalensis* for those of Thomas, Venu, and Kurup (2003). Both estimates can be compared with the present study as they used same fishing gear for their surveys. The r^2 values are low for several species; thus the estimates should be considered as tentative. Size ranges covered for estimating the LWR for *P. roseus* are very narrow, hence it is essential to use large data sets with different size-classes for calculating the LWR, to better understand the growth pattern of the fish. The *b* value of *P. fusca* calculated using the Bayesian approach was in accordance with the present estimate. Although the coefficient of correlation for the LWR of *H. cruentatus* is very high (r^2 = .98), the samples are from only 35% of the known size range (Froese & Pauly, 2017). Further estimations with broader size classes are a necessity to reach meaningful conclusions.

The *b* values estimated for *C. investigatoris* and *N. microchir* from different regions varied greatly (Diaz et al., 2000; Jayaprakash et al., 2006; Thomas et al., 2003). Variations in the growth parameters have been discussed by several authors (Jayaprakash et al., 2006; Sreedhar et al., 2013; Thomas et al., 2003), but most studies did not consider that non-standardized sampling procedures might have partially caused this variation. Previous studies have reported that factors such as maturity, season, depth of capture, area, sex, length class, sample size, gear selectivity and hydrographical differences have significant effects on the LWRs and growth patterns in fishes (Kumar et al., 2016; Mommsen, 1998; Sreedhar et al., 2013; Thomas et al., 2003). Using length-weight data from locally available fish stocks improves the LWR estimations significantly; caution must be exercised to restrict the application to specific length ranges from which the LWR is estimated (Morey et al., 2003). However, the authors confirm the predictability of length–weight estimates in data-poor species, especially deep-sea fishes, from the body shapes using the Bayesian approach.

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REFERENCES

Alcock, A. W. (1898). Natural history notes from H.M. Indian marine survey ship "Investigator". Series II, No. 25. A note on the deep–sea fishes, with descriptions of some new genera and species,including another probably viviparous ophidioid. *Annals and Magazine of Natural History*, *2*(8), 136–156. https://doi.org/10.1080/00222939808678029

Alcock, A. W. (1899). *A descriptive catalogue on the Indian deep-sea fishes in the Indian Museum: Being a revised account of the deep-sea*

fishes collected by the Royal Indian marine survey ship Investigator III. Calcutta, India: Indian Museum. https://doi.org/10.5962/bhl.title.4684

Anderson, R., & Gutreuter, S. (1983). Length, weight and associated structural indices. In L. Nielsen & D. Johnson (Eds.), *Fisheries techniques*, *American Fisheries Society* (pp. 283–300). Bethesda, MD: American Fisheries Society.

Deepu, A. V., Divya, V. H., & Kurup, B. M. (2007). Catch and biology of *Alepocephalus bicolor* (Alcock 1891) from the southwest coast of India. *Journal of the Marine Biological Association of India*, *49*(2), 239–242.

Diaz, L. S., Roa, A., Garcia, C. B., Acero, A., & Navas, G. (2000). Length-weight relationships of demersal fishes from the upper continental slope off Colombia. *Naga*, *The ICLARM Quarterly*, *23*, 23–25.

FAO (1984). FAO species identification sheets for fishery purposes. In W. Ficher & G. Bianchi (Eds.), *Western Indian Ocean (Fishing area 51*, *Vol. 1-4)*. Rome, Italy: Food and Agricultural Organization of the United Nations.

Froese, R. (2006). Cube law, condition factor and weight–length relationships: History, meta-analysis and recommendations. *Journal of Applied Ichthyology*, *22*(4), 241–253. https://doi.org/10.1111/j.1439-0426.2006.00805.x

Froese, R., & Pauly, D. (2017) FishBase. World Wide Web electronic publication. Retrieved from www.fishbase.org

Froese, R., Thorson, J. T., & Reyes, R. B. Jr. (2014). A Bayesian approach for estimating length-weight relationship in fishes. *Journal of Applied Ichthyology*, *30*, 78–85. https://doi.org/10.1111/jai.12299

Froese, R., Tsiklirans, A. C., & Stergiou, K. I. (2011). Editorial note on weight-length relations of fishes. *Journal of Applied Ichthyology*, *41*, 261–263.

Garcia, C. B., Duarte, J. O., Sandoval, N., Von Schiller, D., Melo, G., & Navajas, P. (1998). Length–weight relationships of demersal fishes from the Gulf of Salamanca, Colombia. *Naga*, *The ICLARM Quarterly*, *21*, 30–32.

Gopalakrishnan, K., Varghese, B. C., Ali, D. M., & Pandian, P. (1988). Deep sea fin fish resources of Indian Exclusive Economic Zone (beyond 150m). Proceedings of the National Workshop Fisheries Resource Data Fish Indus. (FSI, Bombay).

Hashim, M. (2012). Distribution, diversity and biology of deep-sea fishes in the Indian EEZ. PhD thesis, Cochin University of Science and Technology, Kerala, India.

Jayaprakash, A. A., Kurup, B. M., Sreedhar, U., Venu, S., Thankappan, D., Pachu, A. V., … Sudhakar, S. (2006). Distribution, diversity, length-weight relationship and recruitment pattern of deep-sea finfishes and shellfishes in the shelf-break area off southwest Indian EEZ. *Journal of the Marine Biological Association of India*, *48*(1), 56–67.

Khan, F. M., Zacharia, P. U., Nandakumaran, K., Mohan, S., Arputharaj, M. R., Nagaraja, D., & Ramakrishnan, P. (1996). Catch, abundance and some aspects of biology of deep-sea fish in the south eastern Arabian Sea. In V. K. Pillai, S. A. H. Abidi, V. Ravindran, K. K. Balachandran, & V. V. Agadi (Eds.), *Proceedings of second workshop on scientific results of FORV Sagar Sampada* (pp. 331–346). New Delhi, India: Department of Ocean Development. 564 pp.

Kumar, K. V. A., Thomy, R., Deepa, K. P., Hashim, M., & Sudhakar, M. (2016). Length weight relationship of six deep-sea fishes from the shelf regions of western Bay of Bengal and Andaman waters. *Journal of Applied Ichthyology*, *32*, 1334–1336. https://doi.org/10.1111/jai.13164

Le Cren, E. D. (1951). Length-weight relationship and seasonal cycle in gonad weight and condition in perch (*Perca fluviatilis*). *Journal of Animal Ecology*, *20*, 201–219. https://doi.org/10.2307/1540

Miranda, R., Galicia, D., Monks, S., & Pulido-Flores, G. (2009). Weight–length relationships of some native freshwater fishes of Hidalgo State, Mexico. *Journal of Applied Ichthyology*, *25*, 620–621. https://doi.org/10.1111/j.1439-0426.2009.01319.x

Mommsen, T. P. (1998). Growth and metabolism. In D. H. Evans (Ed.), *The physiology of fishes* (pp. 65–97). New York, NY: CRC Press. 491 pp.

Morey, G., Moranta, J., Massuti, E., Grau, A., Linde, M., Riera, F., & Morales, N. (2003). Weight–length relationships of littoral to lower slope fishes from the western Mediterranean. *Fisheries Research*, *62*, 89–96. https://doi.org/10.1016/S0165-7836(02)00250-3

Pauly, D. (1993). Fishbyte section editorial. *Naga*, *The ICLARM Quarterly*, *16*, 1–26.

Petrakis, G., & Stergiou, K. I. (1995). Weight–length relationships for 33 fish species in Greek waters. *Fisheries Research*, *21*(3–4), 465–469. https://doi.org/10.1016/0165-7836(94)00294-7

Sandoval-Huerta, E. R., Madrigal-Guridi, X., Domínguez-Domínguez, O., Ruiz-Campos, G., & González-Acosta, A. F. (2015). Length–weight and length–length relations for 14 fish species from the central Mexican Pacific coast. *Acta Ichthyologica et Piscatoria*, *45*(2), 199–201. https://doi.org/10.3750/AIP2015.45.2.10

Sreedhar, U., Sudhakar, G. V. S., & Meenakumari, B. (2013). Length-weight relationship of deep-sea demersal fishes from the Indian EEZ. *Indian Journal of Fisheries*, *60*, 123–125.

Thomas, J., Venu, S., & Kurup, B. M. (2003). Length-weight relationship of some deep-sea fish inhabiting the continental slope beyond 250m depth along the West Coast of India. *Naga*, *The ICLARM Quarterly*, *26*, 17–21.

Venu, S., & Kurup, B. M. (2002). Distribution and biology of the deepsea fish *Psenopsis cyanea* (Alcock, 1890) inhabiting continental slope of west coast of India. *Journal of the Marine Biological Association of India*, *44*(1–2), 176–186.

Venu, S., & Kurup, B. M. (2006). Distribution and biology of deep-sea fishes *Neoepinnula orientalis* (Gilchrist and von Bonde, 1924) and *Psenes squamiceps* (Lloyd, 1909) from west coast of Indian EEZ. *Journal of the Marine Biological Association of India*, *48*(1), 24–28.

Vijayakumaran, K., & Philip, K. P. (1988). *Deep sea demersal fishery resources off the north Kerala*, *Karnataka and Konakan coast*. Symposium on tropical marine living resources. Cochin, India: Marine Biological Association India.

Zar, J. H. (1999). *Biostatistical analysis* (5th edn). Eaglewood Cliffs, NJ: Prentice Hall, 944 pp.

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