PENSOFT.

ACTA ICHTHYOLOGICA ET PISCATORIA

Length–weight relations of 16 mesopelagic fishes (Actinopterygii: Myctophiformes and Stomiiformes) from the eastern Mediterranean Sea

Nicholas BADOUVAS[1], Stylianos SOMARAKIS[2], Konstantinos TSAGARAKIS[1]

1 *Hellenic Centre for Marine Research (HCMR), Institute of Marine Biological Resources and Inland Waters (IMBRIW), Anavyssos, Greece*
2 *Hellenic Centre for Marine Research (HCMR), Institute of Marine Biological Resources and Inland Waters (IMBRIW), Heraklion, Crete, Greece*

https://zoobank.org/D07B954C-4F27-4CBF-99CC-71B0BDAA19DE

Corresponding author: Konstantinos Tsagarakis (kontsag@hcmr.gr)

Academic editor: Rodolfo Reyes ♦ **Received** 14 November 2022 ♦ **Accepted** 27 November 2022 ♦ **Published** 19 December 2022

Citation: Badouvas N, Somarakis S, Tsagarakis K (2022) Length–weight relations of 16 mesopelagic fishes (Actinopterygii: Myctophiformes and Stomiiformes) from the eastern Mediterranean Sea. Acta Ichthyologica et Piscatoria 52(4): 279–283. https://doi.org/10.3897/aiep.52.97577

Abstract

For many mesopelagic fishes, even basic knowledge regarding their biology is missing, greatly impeding their effective management. Here we present length–weight relations for 16 mesopelagic fishes sampled during research surveys in the Greek seas (eastern Mediterranean). The following species were studied: *Benthosema glaciale* (Reinhardt, 1837); *Ceratoscopelus maderensis* (Lowe, 1839); *Diaphus holti* Tåning, 1918; *Diaphus metopoclampus* (Cocco, 1829); *Diaphus rafinesquii* (Cocco, 1838); *Hygophum benoiti* (Cocco, 1838); *Hygophum hygomii* (Lütken, 1892); *Lampanyctus crocodilus* (Risso, 1810); *Lobianchia dofleini* (Zugmayer, 1911); *Myctophum punctatum* Rafinesque, 1810; *Notoscopelus elongatus* (Costa, 1844); *Symbolophorus veranyi* (Moreau, 1888) [**Myctophidae**]; *Argyropelecus hemigymnus* Cocco, 1829; *Maurolicus muelleri* (Gmelin, 1789) [**Sternoptychidae**]; *Stomias boa* (Risso, 1810); *Chauliodus sloani* Bloch et Schneider, 1801 [**Stomiidae**].With the exception of *Diaphus holti* and *Symbolophorus veranyi*, parameter *b* diverged significantly from isometry. Only two species (*Benthosema glaciale* and *Chauliodus sloani*) displayed negative allometry, while for the remaining 12 species a positive allometry was found, with the highest parameter *b* values estimated for *Stomias boa* and *Diaphus rafinesquii*. The median value of parameter *b* for all species was 3.236 and 50% of its values ranged from 3.173 to 3.323. Some variations of the parameter *b* were observed between our findings and other studies from the Atlantic and the western Mediterranean.

Keywords

LWR, Mediterranean Sea, mesopelagic fish, micronekton, myctophids, twilight zone

Introduction

Mesopelagic fishes constitute the most abundant group of vertebrate animals on the planet (Irigoien et al. 2014) and represent a high diversity of species (López-Pérez et al. 2020) with the family Myctophidae having the higher number of species among them. These species inhabit the part of the ocean known as the mesopelagic zone, usually set between 200–1000 m of depth, also referred to as the twilight zone, forming Deep Scattering Layers detected in oceanic mid-waters by echosounders (Godø et al. 2009; Kaartvedt et al. 2019). The majority of the mesopelagic fish species are known for their diel vertical migrations to the epipelagic layer during the night, following the ascension of their zoo-planktonic prey to shallower oceanic depths, while during daytime they descend back to the mesopelagic zone to avoid predation (Kaartvedt et al. 2019).

Mesopelagic fishes play an important ecological role, linking primary consumers to top predators (Woodstock and Zhang 2022), many of which are commercial pelagic and demersal fishes (or protected, endangered, or threatened species) (Catul et al. 2011). Therefore, they constitute an important part of open ocean energy dynamics and contribute considerably to the transfer of organic carbon from the surface to the deep sea via their diel vertical migrations (Kaartvedt et al. 2019). Mesopelagic fishes have been regarded as a potential harvestable resource since the 1970s either for human consumption or as raw material supply to the fish meal and marine oil industry, but efforts in this direction were mainly exploratory or economically unsustainable (Caiger et al. 2021). In the recent decade, their global biomass estimate has been substantially revised upwards (Irigoien et al. 2014), and interest in commercial exploitation is being revisited. Despite their ecological importance and fisheries potential, these species remain one of the least investigated components of the marine environment. For many mesopelagic fishes, even basic knowledge regarding their biology is missing, greatly impeding their effective and sustainable management (Hidalgo and Browman 2019; Caiger et al. 2021).

Length–weight relations (LWRs) constitute essential knowledge for the application of fish stock assessment and management, necessary for the estimation of fish biomass from sampled length data and for ecological modeling and the estimation of growth in fish (Froese 2006). Length–weight relation studies for Mediterranean mesopelagic fishes have been particularly scarce (Battaglia et al. 2010), especially in the eastern basin, where information is almost absent. In the presently reported study, we estimated the length–weight relations for 16 mesopelagic fish species, representing 3 families, sampled during research surveys in the Greek seas.

Materials and methods

Fish samples were collected with pelagic trawls and midwater frames, during dedicated mesopelagic surveys as well as other routine acoustic surveys (Leonori et al. 2021), onboard the R/V *Philia* in the Greek seas (North Aegean Trough, northern Euboean Gulf, Saronic Gulf, Cretan Sea, Gulf of Corinth) (Fig. 1) from November 2018 to December 2019. Sampled fish were immediately packed and frozen onboard until their transfer to the laboratory for examination, where the total length (TL) of each individual was measured to the nearest 1 mm and the total weight (W) to the nearest 0.001 g, using a high precision digital scale. The LWRs were estimated for 16 fish species, 12 of which represented the family Myctophidae, two species to the family Sternoptychidae, and two to the family Stomiidae (Table 1). The following species were studied: *Benthosema glaciale* (Reinhardt, 1837); *Ceratoscopelus maderensis* (Lowe, 1839); *Diaphus holti* Tåning, 1918; *Diaphus metopoclampus* (Cocco, 1829); *Diaphus rafinesquii* (Cocco, 1838); *Hygophum benoiti* (Cocco, 1838); *Hygophum hygomii* (Lütken, 1892); *Lampanyctus crocodilus* (Risso, 1810); *Lobianchia dofleini* (Zugmayer, 1911); *Myctophum punctatum* Rafinesque, 1810; *Notoscopelus elongatus* (Costa, 1844); *Symbolophorus veranyi* (Moreau, 1888) [**Myctophidae**]; *Argyropelecus hemigymnus* Cocco, 1829; *Maurolicus muelleri* (Gmelin, 1789) [**Sternoptychidae**]; *Stomias boa* (Risso, 1810); *Chauliodus sloani* Bloch et Schneider, 1801 [**Stomiidae**].

Measured fish weight (W) [g] and length (TL) [cm] data were fitted to the power function

$$W = a\mathrm{TL}^b$$

where a and b are the intercept and slope of the power equation, respectively. Data were transformed, using their natural logarithmic values and adjusted to a linear regression model by application of the least squares method, as to estimate length–weight parameters a, b (Kuriakose 2017). Intercept values (parameter a) give an indication of the expected weight at 1 cm of length for each species (Olivar et al. 2013). Confidence intervals (CI) of the parameters were calculated at the 95% confidence level and the resulting parameter b was evaluated, using a Student's t-test (López-Pérez et al. 2020), as to inspect whether or not the sampled populations' divergence from isometric growth ($b = 3$) was statistically significant, consequently indicating positive ($b > 3$) or negative ($b < 3$) allometry (Froese 2006).

The estimated values of the parameter b were compared to values reported for the same species in similar studies from the western Mediterranean (Olivar et al. 2013), the North (Fock and Ehrich 2010) and the tropical Atlantic (López-Pérez et al. 2020).

Results

A total of 6214 fish individuals were used in the current length–weight analysis, but they were not equally distributed across species (Table 1). Fitted length–weight equations gave high coefficients of determination (r^2) with values ranging from 0.943 for *Argyropelecus hemigymnus* to 0.983 for *Diaphus metopoclampus*. With the exception of *Diaphus holti* and *Symbolophorus veranyi*, the parameter b diverged significantly from isometry. Only two species (*Benthosema glaciale* and *Chauliodus sloani*) displayed negative allometry, while for the remaining 12 species a positive allometry ($b > 3$) was found, with the highest growth coefficient claimed by *Stomias boa* and *Diaphus rafinesquii*. The median value of parameter b for all species was 3.236 and 50% of its values ranged from 3.173–3.323.

Considerable variations of the parameter b between our findings and other studies from the Atlantic and the western Mediterranean were observed, especially compared to those from the North Atlantic (Table 2) (Fock and Ehrich 2010; Olivar et al. 2013; López-Pérez et al. 2020).

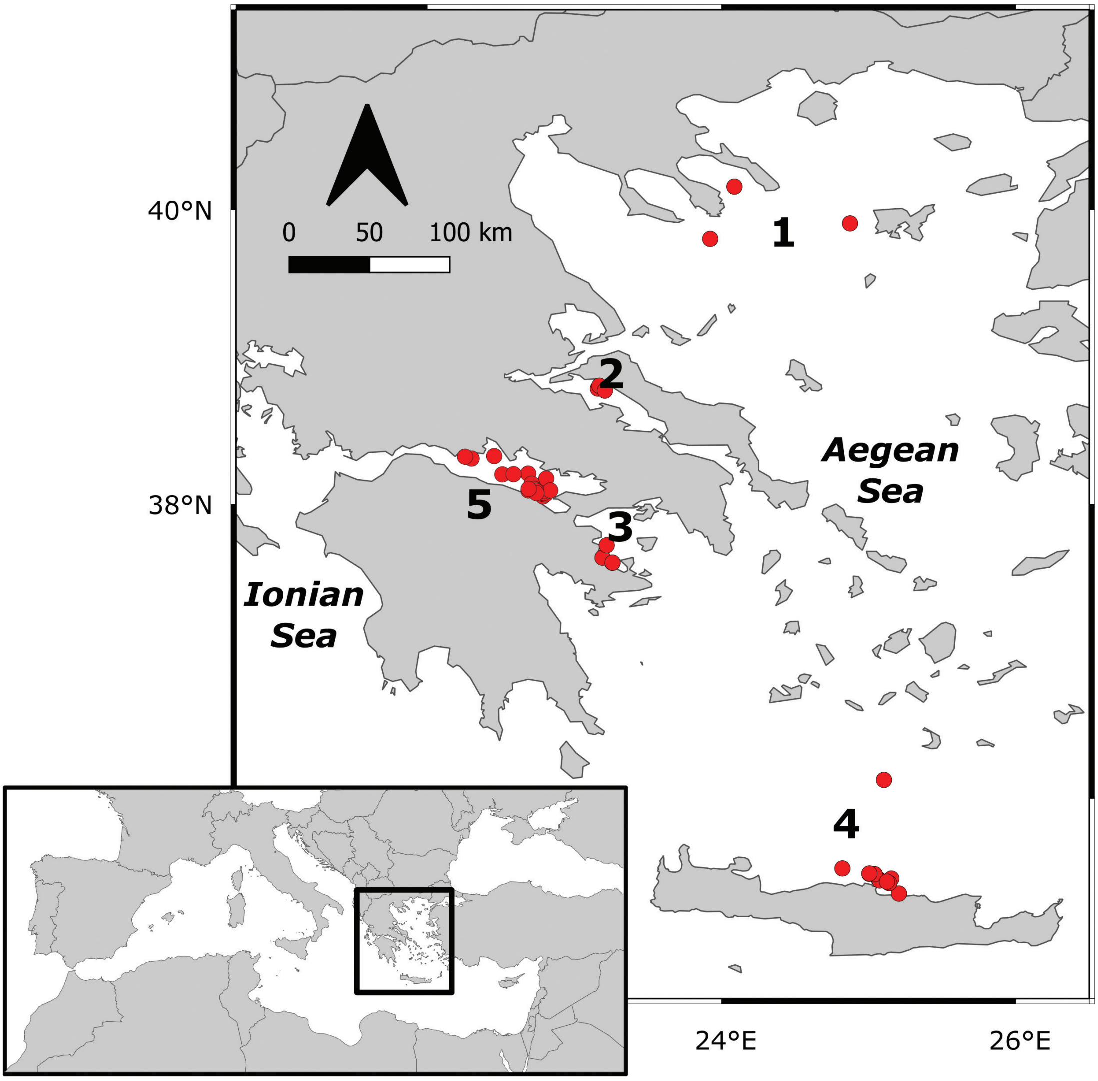

Figure 1. Sampling locations: North Aegean Trough (1), northern Euboean Gulf (2), Saronic Gulf (3), Cretan Sea (4), Gulf of Corinth (5).

Table 1. Length–weight relation parameters of 16 mesopelagic fish species sampled in Greek seas.

Species	*a*	95%CI of *a*	*b*	95%CI of *b*	*n*	r^2	Length [cm]	Weight [g]	*P*-value	Growth type
Myctophidae										
Benthosema glaciale	0.0106	0.0099–0.0115	**2.916**	**2.863–2.969**	691	0.944	2.0–7.4	0.055–2.925	0.002	– allometry
Ceratoscopelus maderensis	0.0038	0.0036–0.0040	**3.243**	**3.209–3.277**	1318	0.964	1.9–8.9	0.02–4.709	<0.001	+ allometry
Diaphus holti	0.0095	0.0081–0.0111	3.066	2.967–3.166	175	0.955	2.3–6.8	0.079–6.175	0.193	isometry
Diaphus metopoclampus	0.0075	0.0055–0.0104	**3.332**	**3.164–3.501**	30	0.983	3.9–9.6	0.832–15.707	<0.001	+ allometry
Diaphus rafinesquii	0.0050	0.0034–0.0072	**3.521**	**3.302–3.740**	41	0.965	1.7–9.4	0.028–11.49	<0.001	+ allometry
Hygophum benoiti	0.0049	0.0046–0.0053	**3.318**	**3.273–3.363**	498	0.977	1.9–7.8	0.028–4.834	<0.001	+ allometry
Hygophum hygomii	0.0058	0.0045–0.0075	**3.281**	**3.131–3.432**	78	0.961	3.3–8.1	0.292–5.63	<0.001	+ allometry
Lampanyctus crocodilus	0.0023	0.0019–0.0027	**3.314**	**3.214–3.415**	244	0.946	2.7–17.0	0.025–40.312	<0.001	+ allometry
Lobianchia dofleini	0.0067	0.0059–0.0076	**3.228**	**3.141–3.314**	194	0.966	2.7–6.0	0.138–2.003	<0.001	+ allometry
Myctophum punctatum	0.0055	0.0051–0.0060	**3.220**	**3.167–3.272**	423	0.972	2.2–10.0	0.056–8.532	<0.001	+ allometry
Notoscopelus elongatus	0.0043	0.0038–0.0049	**3.189**	**3.118–3.261**	146	0.982	2.9–12.5	0.128–13.561	<0.001	+ allometry
Symbolophorus veranyi	0.0055	0.0039–0.0078	3.190	2.997–3.383	24	0.982	4.4–12.5	0.625–18.732	0.053	isometry
Sternoptychidae										
Argyropelecus hemigymnus	0.0092	0.0086–0.0098	**3.325**	**3.262–3.389**	653	0.943	0.5–4.8	0.003–1.419	<0.001	+ allometry
Maurolicus muelleri	0.0069	0.0068–0.0071	**3.168**	**3.137–3.199**	1437	0.966	1.9–6.3	0.049–2.65	<0.001	+ allometry
Stomiidae										
Stomias boa	0.0004	0.0003–0.0005	**3.523**	**3.394–3.653**	67	0.980	5.5–25.3	0.253–43.026	<0.001	+ allometry
Chauliodus sloani	0.0026	0.0021–0.0031	**2.775**	**2.681–2.868**	195	0.947	4.6–19.9	0.127–12.805	<0.001	– allometry

Values of parameter *b*, estimated to diverge significantly from isometry are indicated in bold; *P*-values are from Student's *t*-tests for divergence of *b* from isometric growth (b = 3).

Table 2. Values of parameter *b* and length ranges (LR) of mesopelagic fishes from other regions.

Species	North Atlantic Fock and Ehrich 2010		Tropical Atlantic López-Pérez et al. 2020		W. Mediterranean Olivar et al. 2013		This study	
	LR	*b*	LR	*b*	LR	*b*	LR	*b*
Argyropelecus hemigymnus	18–40	**2.750**	—	—	13–34	**3.032**	5–48	3.325
Benthosema glaciale	21–81	**3.020**	15–35	**3.251**	14–47	**3.093**	20–74	2.916
Ceratoscopelus maderensis	27–85	3.172	—	—	16–64	3.191	19–89	3.243
Chauliodus sloani	57–293	**3.028**	—	—	—	—	46–199	2.775
Diaphus holti	10–69	**3.350**	11–50	3.006	25–53	**3.360**	23–68	3.066
Diaphus metopoclampus	48–66	**3.074**	19–40	3.353	—	—	39–96	3.332
Diaphus rafinesquii	28–84	3.433	11–70	**2.850**	—	—	17–94	3.521
Hygophum benoiti	35–54	**3.052**	—	—	13–48	**2.983**	19–78	3.318
Hygophum hygomii	44–48	**3.052**	—	—	39–58	3.136	33–81	3.281
Lampanyctus crocodilus	38–183	3.240	—	—	22–128	3.345	27–170	3.314
Lobianchia dofleini	28–62	**2.609**	13–30	3.130	21–43	3.338	27–60	3.228
Maurolicus muelleri	27–60	3.296	—	—	—	—	19–63	3.168
Myctophum punctatum	22–89	**3.448**	16–69	3.221	19–60	**3.052**	22–100	3.22
Notoscopelus elongatus	—	—	—	—	30–107	3.248	29–125	3.189
Stomias boa	70–205	**3.184**	53–153	**3.042**	—	—	55–253	3.523
Symbolophorus veranyi	34–113	3.248	—	—	23–90	3.181	44–125	3.19

Bold values indicate differentiations higher than 5% or with different allometric pattern (positive vs negative) compared to the current study. Length ranges are given for standard length (SL) in mm, except in the current study which are total lengths (TL). SL–TL conversion formulas can be retrieved from Froese and Pauly (2022).

Discussion

The current study attempted to assess length–weight equations for mesopelagic fish populations from the eastern Mediterranean Sea, setting the base for further biological studies necessary to support future management and research. Length–weight relations in the region have been examined in a localized context for only a few of the species considered here (e.g., *Argyropelecus hemigymnus*, *Diaphus metopoclampus*, *Stomias boa*; see Deval et al. 2014, *Lampanyctus crocodilus*, *Chauliodus sloani*; see Bayhan et al. 2020), while for others, to our knowledge, information is completely absent from the eastern basin or even from the entire Mediterranean (*Diaphus rafinesquii*). Length–weight parameters have been suggested to reflect environmental variations in species' habitats, as well as adaptive mechanisms and intrinsic characteristics, which affect their ontogenetic development (Froese 2006; Eduardo et al. 2020b). In the presently reported study, fish samples derived from multiple seasons and across a wide geographical area encompassing open seas and enclosed gulfs and possibly including populations with indications of genetic differentiations (e.g., *Hygophum benoiti*) (see Sarropoulou et al. 2022); therefore, results can help derive conclusions for the estimated values of parameter *b* at the species level (Froese 2006).

For the majority of fishes studied herein, *b* was within the expected range of 2.5 and 3.5, (Froese 2006), although *Stomias boa* and *Diaphus rafinesquii* exhibited slightly higher values (3.52). The positive allometric growth observed in the majority of species is an indication of a more robust body growing faster in mass than in length, an attribute which may be essential for their diel vertical migrations (Olivar et al. 2013; López-Pérez et al. 2020). Contrarily, the negative allometric growth pattern, displayed here by two species, may be related to living in deep waters and to the absence of extended vertical migration (López-Pérez et al. 2020); this explanation seems plausible for *Chauliodus sloani* for which a temperature barrier inhibits its migration in warm regions (Eduardo et al. 2020a), but probably not for *Benthosema glaciale*, which shows a partial vertical migratory activity elsewhere (Dypvik et al. 2012), as well as in the study area (authors' unpublished data).

Some intraspecific differentiations of the allometric coefficient among the current study and similar works were identified, which were more diverse compared to estimates from the North Atlantic. These can be attributed to fish growth affected by internal and external triggers (such as diet and habitat temperature) (Mazumder et al. 2016), to discrete population characteristics, but also to the sampled size ranges (Czudaj et al. 2022), and the type of length measurements (López-Pérez et al. 2020).

Acknowledgments

This work was part of the project MesoBED "Mesopelagic fish: Biology, ecological role and distribution of a disregarded trophic link", funded by the Hellenic Foundation for Research and Innovation and the General Secretariat of Research and Innovation (Greece) (Project No. 449).

References

Battaglia P, Malara D, Romeo T, Andaloro F (2010) Relationships between otolith size and fish size in some mesopelagic and bathypelagic species from the Mediterranean Sea (Strait of Messina, Italy). Scientia Marina 74(3): 605–612. https://doi.org/10.3989/scimar.2010.74n3605

Bayhan Y, Ergüden SA, Ergüden D (2020) Length–weight relationships for three deep sea fish species in north eastern Mediterranean, Turkey. Aquatic Sciences and Engineering 35: 89–93. https://doi.org/10.26650/ASE2020683520

Caiger PE, Lefebve LS, Llopiz JK (2021) Growth and reproduction in mesopelagic fishes: A literature synthesis. ICES Journal of Marine Science 79(3): 765–781. https://doi.org/10.1093/icesjms/fsaa247

Catul V, Gauns M, Karuppasamy PK (2011) A review on mesopelagic fishes belonging to family Myctophidae. Reviews in Fish Biology and Fisheries 21(3): 339–354. https://doi.org/10.1007/s11160-010-9176-4

Czudaj S, Möllmann C, Fock HO (2022) Length–weight relationships of 55 mesopelagic fishes from the eastern tropical North Atlantic: Across- and within-species variation (body shape, growth stanza, condition factor). Journal of Fish Biology 101(1): 26–41. https://doi.org/10.1111/jfb.15068

Deval MC, Güven O, Saygu İ, Kabapçioğlu T (2014) Length–weight relationships of 10 fish species found off Antalya Bay, eastern Mediterranean. Journal of Applied Ichthyology 30(3): 567–568. https://doi.org/10.1111/jai.12382

Dypvik E, Røstad A, Kaartvedt S (2012) Seasonal variations in vertical migration of glacier lanternfish, *Benthosema glaciale*. Marine Biology 159(8): 1673–1683. https://doi.org/10.1007/s00227-012-1953-2

Eduardo LN, Lucena-Frédou F, Mincarone MM, Soares A, Le Loc'h F, Frédou T, Ménard F, Bertrand A (2020a) Trophic ecology, habitat, and migratory behaviour of the viperfish *Chauliodus sloani* reveal a key mesopelagic player. Scientific Reports 10(1): 20996. https://doi.org/10.1038/s41598-020-77222-8

Eduardo LN, Mincarone MM, Lucena-Frédou F, Martins JR, Afonso GVF, Villarins BT, Frédou T, Lira AS, Bertrand A (2020b) Length–weight relationship of twelve mesopelagic fishes from the western tropical Atlantic. Journal of Applied Ichthyology 36(6): 845–848. https://doi.org/10.1111/jai.14084

Fock HO, Ehrich S (2010) Deep-sea pelagic nekton biomass estimates in the North Atlantic: Horizontal and vertical resolution of revised data from 1982 and 1983. Journal of Applied Ichthyology 26: 85–101. https://doi.org/10.1111/j.1439-0426.2010.01450.x

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 (Eds) (2022) FishBase. [Version 08/2022] http://www.fishbase.org

Godø OR, Patel R, Pedersen G (2009) Diel migration and swimbladder resonance of small fish: Some implications for analyses of multifrequency echo data. ICES Journal of Marine Science 66(6): 143–1148. https://doi.org/10.1093/icesjms/fsp098

Hidalgo M, Browman HI (2019) Developing the knowledge base needed to sustainably manage mesopelagic resources. ICES Journal of Marine Science 76(3): 609–615. https://doi.org/10.1093/icesjms/fsz067

Irigoien X, Klevjer TA, Røstad A, Martinez U, Boyra G, Acuña JL, Bode A, Echevarria F, Gonzalez-Gordillo JI, Hernandez-Leon S, Agusti S, Aksnes DL, Duarte CM, Kaartvedt S (2014) Large mesopelagic fishes biomass and trophic efficiency in the open ocean. Nature Communications 5(1): 3271. https://doi.org/10.1038/ncomms4271

Kaartvedt S, Langbehn TJ, Aksnes DL (2019) Enlightening the ocean's twilight zone. ICES Journal of Marine Science 76(4): 803–812. https://doi.org/10.1093/icesjms/fsz010

Kuriakose S (2017) Estimation of length weight relationship in fishes. Pp. 215–220. In: Kuriakose S, Mini KG, Sathianandan TV (Eds.) Course manual ICAR funded summer school on advanced methods for fish stock assessment and fisheries management. CMFRI; Kochi, Kerala, India.

Leonori I, Tičina V, Giannoulaki M, Hattab T, Iglesias M, Bonanno A, Costantini I, Canduci G, Machias A, Ventero A, Somarakis S, Tsagarakis K, Bogner D, Barra M, Basilone G, Genovese S, Juretić T, Gašparević D, Felice AD (2021) The history of hydroacoustic surveys on small pelagic fishes in the European Mediterranean Sea. Mediterranean Marine Science 22(4): 751–768. https://doi.org/10.12681/mms.26001

López-Pérez C, Olivar MP, Hulley PA, Tuset VM (2020) Length–weight relationships of mesopelagic fishes from the equatorial and tropical Atlantic waters: Influence of environment and body shape. Journal of Fish Biology 96(6): 1388–1398. https://doi.org/10.1111/jfb.14307

Mazumder SK, Das SK, Bakar Y, Ghaffar MA (2016) Effects of temperature and diet on length–weight relationship and condition factor of the juvenile Malabar blood snapper (*Lutjanus malabaricus* Bloch & Schneider, 1801). Journal of Zhejiang University. Science. B. 17(8): 580–590. https://doi.org/10.1631/jzus.B1500251

Olivar MP, Molí B, Bernal A (2013) Length–weight relationships of mesopelagic fishes in the north-western Mediterranean. Rapports et procès-verbaux des réunions Commission internationale pour l'exploration scientifique de la Mer Méditerranée 40: 528.

Sarropoulou X, Tsaparis D, Tsagarakis K, Badouvas N, Tsigenopoulos CS (2022) Different patterns of population structure and genetic diversity of three mesopelagic fishes in the Greek Seas. Mediterranean Marine Science 23: 536–545. https://doi.org/10.12681/mms.28567

Woodstock MS, Zhang Y (2022) Towards ecosystem modeling in the deep sea: A review of past efforts and primer for the future. Deep-sea Research. Part I, Oceanographic Research Papers 188: 103851. https://doi.org/10.1016/j.dsr.2022.103851