Latin American Journal of Aquatic Research, 53(3): 535-540, 2025
DOI: 10.3856/vol53-issue3-fulltext-3354

Short Communication

Length-carbon relation for four species of pelagic copepods from the Mexican Central Pacific

Yadian Israel La Rosa-Izquierdo[1]
Sergio Hernández-Trujillo[2] & Franklin García-Fernández[2]
[1]Instituto Mexicano de Investigación en Pesca y Acuacultura Sustentable, La Paz, México
[2]Centro Interdisciplinario de Ciencias Marinas, Instituto Politécnico Nacional, La Paz, México
Corresponding author: Yadian Israel La Rosa-Izquierdo (yadian2016@gmail.com)

ABSTRACT. The objective of this study is to generate length-carbon biomass predictive models corresponding to four dominant species of copepods (*Subeucalanus subcrassus*, *Centropages furcatus*, *Eucalanus inermis*, and *Acartia tonsa*) from the pelagic ecosystem of the Mexican Central Pacific. In general, the wet weight of the organisms of all the species analyzed increased with the increase in body size, although it is notable that for all species, this increase in wet weight did not occur linearly. The highest values of carbon content were observed in *C. furcatus* at intermediate-size intervals (1.06 and 1.15 mm). The carbon percentage to dry weight varied between 9.3 and 23.8% in this study. *E. inermis* and *S. subcrassus* showed the lowest and highest records, respectively. *A. tonsa*, a frequent and abundant species that links picoplankton to microzooplankton in the food web, showed, on average (12.2%), the lowest carbon-dry weight ratio of the analyzed species, ranging between 11.1 and 13.8%.

Keywords: Copepoda; tropical species; biomass; carbon content; dry weight

Zooplankton biomass, measured as dry weight or carbon content, is used to estimate zooplankton production and develop models of energy and carbon flux within the zooplankton community (McConville et al. 2017, Schaafsma et al. 2018). Also, calculating the length-weight relationship allows the estimation of biomass when primary length data are available (Uye 1982).

For copepods, length-weight regressions have been calculated for approximately 100 species (Mauchline 1998) out of around 15,000 known species (Walter & Boxshall 2024) from various regions and habitats (Uye 1982, Ara 2001). However, these predictive models have been obtained mainly for temperate species (Uye 1982, Mauchline 1998) and to a lesser extent for species from tropical (Chisholm & Roff 1990) and subtropical regions (Lehette & Hernández-León 2009). Only a few studies have measured individual carbon content (Hessen 1989, Hernández-Trujillo et al. 2014). This restriction leads to the appearance of an underlying bias in estimates of copepod biomass in tropical regions, as predictive models are primarily developed for temperate species.

Considering this problem, the objective of this study is to develop length-carbon biomass predictive models for four dominant species of copepods from the pelagic ecosystem of the Mexican Central Pacific.

Zooplankton samples were obtained at the NAVI sampling station (19°9'44"N, 104°43'39"W), Jalisco, Mexico. Samples were collected between 05:00-06:00 h on March 29, 31, and April 5, 2022. A zooplankton net with a mesh size of 250 µm was used, with an

Associate Editor: Crisantema Hernández

oblique tow from 80 m depth to the surface with a duration of 10 min at 3 km h^{-1} speed, from a boat 22 ft length equipped with an outboard motor. Once the sample was taken, it was transferred to a cooler with surface water for transport to the laboratory.

Subsequently, the identification, counting and separation of living organisms by species was performed. Four dominant copepods, *Subeucalanus subcrassus* (Giesbrecht, 1888), *Centropages furcatus* (Dana, 1849), *Eucalanus inermis* (Giesbrecht, 1893) and *Acartia tonsa* (Dana, 1849) were selected, considering the species with the highest abundances.

The measurement of prosoma length (PL) was carried out on adults at the copepodite VI development stage. An initial measurement of the PL of the selected organisms was taken to determine specific size ranges. A second measurement was then taken, and the organisms were separated into groups of *n* individuals considering their size (Table 1). The PL was measured from a photograph taken with a digital camera (AxioCam ERc5s; Carl Zeiss) and measured using the software AxioVision with a resolution of 1 µm, coupled to a stereomicroscope (Stemi 305, Carl Zeiss). Measurements were taken on a random sample of female and male individuals to generate a combined length-mass regression model for both sexes in each species (Uye 1982).

Groups of organisms determined by size intervals were formed (Table 1). Each separate group was placed in 5×9 mm tin capsules. To remove the moisture from the samples, the opened capsules were placed in a drying oven at 60°C for 12 h. After that time, they were stored in a desiccator. Subsequently, each capsule was weighed on a Sartorius ENTRIS224-1S ±1 µg microbalance.

The samples of 1 mg or more of dry weight were processed for carbon content analysis using a particle analyzer (Elementar Vario MICRO cube elemental analyzer interfaced to an Elementar VisION IRMS [Elementar Analysen Systeme GmbH, Langenselbold, Germany]). This value of 1 mg is the minimum amount required to reach the detection threshold in the equipment used to measure the carbon content of the samples. With the carbon data obtained, specific carbon-length regression equations were constructed. To estimate the dry weight and carbon content of a corresponding organism, the total weight of the batch was divided by the number of organisms present in it, resulting in the average dry weight and average carbon content.

The general trend is that the wet weight of the species analyzed increased with the increase in body size (Table 1). However, this increase did not occur linearly for all species.

For *S. subcrassus* adults, the PL ranged from 1.60 to 2.10 mm. The carbon content per organism varied between 8.561 and 46.091 µg ind^{-1}, presenting the largest increases in the intervals 1.60 to 1.79 and 2.00 to 2.10 mm. The exponential length-carbon regression equation showed the best fit (R^2 = 0.75) for *S. subcrassus* (Fig. 1a). The dry weight also increases with the size intervals (Table 1). The carbon-dry weight ratio, expressed as the percentage of carbon in the dry weight of each organism, ranged between 18.9 and 23.7%, highlighting that the lowest percentage was recorded for the largest size interval of *S. subcrassus.*

For the *C. furcatus*, a total of six PL intervals were established, with a minimum and maximum size measured of 1.00 and 1.20 mm, respectively (Table 1). The carbon content per organism varied between 2,828 and 7,592 µg ind^{-1}. The highest carbon content values of *C. furcatus* were observed at intermediate size intervals (1.06 and 1.15 mm) (Fig. 1b). The logarithmic carbon-length regression equation showed the best fit (R^2 = 0.71) (Fig. 1b). With the increase in PL the dry weight tends to decrease. (Table 1). The carbon-dry weight ratio ranged between 12.8 and 21.9%.

For *E. inermis*, the PL varied between 3 and 4.4 mm, which was divided into nine intervals (Table 1). The carbon content per organism varied between 11,176 and 55,118 µg ind^{-1}. The linear carbon-length regression equation (R^2 = 0.95) showed the best fit (Fig. 1c). The percentage of carbon in the dry weight of each organism ranged between 9.3 and 20.3%, showing the lowest percentage value recorded in our study (9.3%), despite being the largest species analyzed.

For *A. tonsa*, only four PL intervals were established due to the proximity between the minimum and maximum length measurements of 0.85 and 0.95 mm, respectively (Table 1). The carbon content per organism varied between 0.957 and 1.431 µg ind^{-1}. The logarithmic carbon-length regression equation showed the best fit (R^2 = 0.84) (Fig. 1d). The dry weight of *A. tonsa* presented the highest values for specimens of intermediate sizes (0.85-0.94 mm). In contrast, the extreme size interval (small and large individuals) presented similar dry weight values (Table 1). *A. tonsa* showed, on average (12.2%), the lowest carbon-dry weight ratio of the analyzed species, ranging between 11.1 and 13.8%. This species is a frequent and abundant epipelagic copepod that links picoplankton to microzooplankton in the food web.

A. tonsa and *S. subcrassus* presented PLs within the range of records reported in the literature (Razouls et al. 2024). However, *E. inermis* and *C. furcatus* presented PLs considerably below the reported ranges (Razouls et al. 2024), which could be explained by the variability

Table 1. Carbon content by size range. SI: size intervals, NO: number of organisms measured per size interval, AWW: average wet weight per organism, ADW: average dry weight per organism, ACC: average carbon content per organism. % CDW: percentage of carbon by dry weight.

Species	SI (mm)	NO	AWW (µg)	ADW (µg)	ACC (µg)	% CDW
Subeucalanus subcrassus	<1.60	59	524	40.68	8.56	21.05
	1.60-1.69	142	507	38.73	8.01	20.68
	1.70-1.79	66	789	60.61	13.89	22.92
	1.80-1.89	80	644	57.50	13.56	23.59
	1.90-1.99	92	766	63.04	14.57	23.11
	2.00-2.09	19	895	73.68	17.51	23.77
	≥ 2.10	7	2557	242.86	46.09	18.98
Centropages furcatus	<1.00	41	239	19.51	2.83	14.49
	1.00-1.05	33	148	36.36	4.65	12.80
	1.06-1.10	44	423	34.09	7.20	21.11
	1.11-1.15	75	375	34.67	7.59	21.90
	1.16-1.20	68	419	32.35	6.84	21.14
	>1.20	75	521	34.67	6.25	18.02
Eucalanus inermis	<3.00	15	1353	80.00	11.18	13.97
	3.00-3.19	15	1073	100.00	15.51	15.51
	3.20-2.39	5	2440	160.00	22.87	14.29
	3.40-3.59	4	1850	175.00	24.54	14.03
	3.60-3.79	5	2920	180.00	24.97	13.87
	3.80-3.99	9	3300	211.11	30.16	14.29
	4.00-4.19	2	3200	200.00	40.68	20.34
	4.20-4.40	2	5150	500.00	46.61	9.32
	>4.40	7	6929	428.57	55.12	12.86
Acartia tonsa	<0.85	165	78	8.48	0.96	11.28
	0.85-0.89	165	156	11.52	1.28	11.13
	0.90-0.94	165	154	9.70	1.22	12.58
	≥0.95	165	213	10.30	1.43	13.89

of the PL of some copepods in cold and temperate water environments (Razouls et al. 2024), as well in warm environments (Kozak et al. 2014, La Rosa 2023).

S. subcrasssus showed a conspicuous increase in carbon content in organisms larger than 2.10 mm, also reflected in the same way for the dry weight; the highest carbon content values of *C. furcatus* were recorded for intermediate sizes. The changes in the carbon content of *S. subcrassus* and *C. furcatus* can be determined by the condition factor of the organisms (Hernández-Trujillo et al. 2014). The condition factor has been used as a measure of the general condition of individuals, and, like other metazoans, copepods have condition changes. At the same time, they grow, or the reproductive process is activated (Durbin & Durbin 1978). These changes tend to remain relatively constant in shape, becoming heavier when food and temperature allow them to produce gametes (Mauchline 1998) and lighter once they have spawned or when nutritional conditions are not coupled to oogenesis and spermatogenesis.

Comparing our results with the unique copepod length-carbon regression equation determined for *C. furcatus* with organisms collected in Mexican waters (Hernández-Trujillo et al. 2013), our research yields carbon content values 5.7% lower than that found by Hernández-Trujillo et al. (2013) in copepods from La Paz Bay. Two factors may influence these results. First, the size or PL of the copepods, since, as we mentioned previously, the PLs recorded in this research for *C. furcatus* were below the average proposed by Razouls et al. (2024) and wider than that analyzed by Hernández-Trujillo et al. (2013). The second factor that could have influenced the results is the possible differences in environmental conditions and food availability between the sampling locations of the organ-

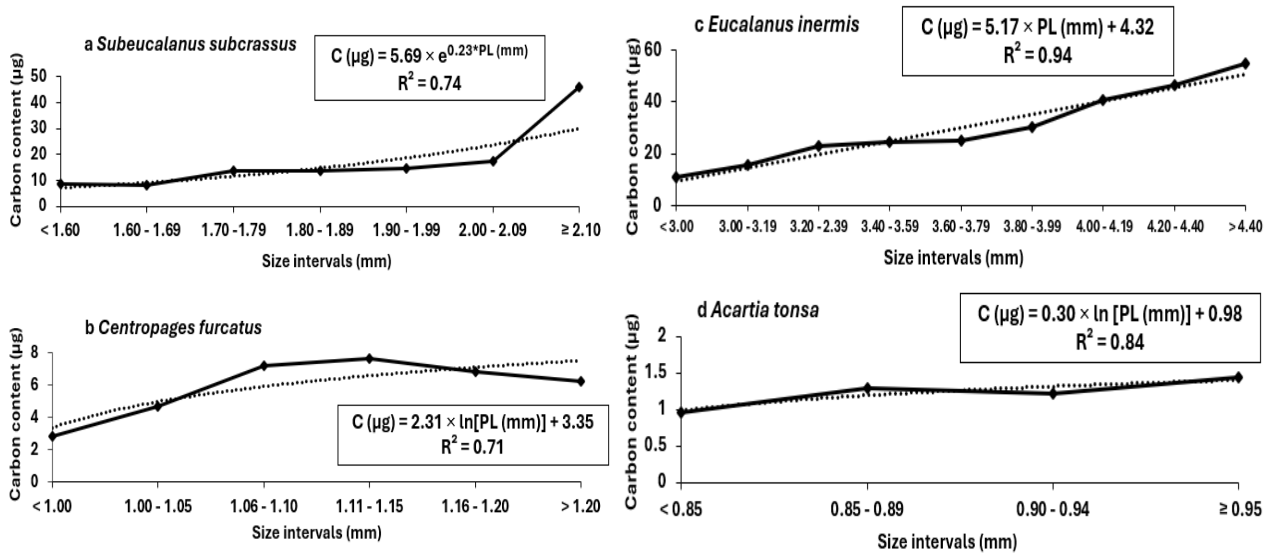

Figure 1. Carbon content (C) by size intervals (black line). Fitting the regression equation (dashed line). Length-carbon regression equation (inside box). a) *Subeucalanus subcrassus*, b) *Centropages furcatus*, c) *Eucalanus inermis*, d) *Acartia tonsa*. PL: prosoma length.

isms, as previous studies suggest that food limitation is the primary factor responsible for the decrease in the growth rate of copepods (Yeghissian 2018).

The length-carbon regressions for all analyzed species confirm the expected positive relationship between PL and carbon content (Kerkar et al. 2020). It is generally accepted that carbon contributes approximately 40-45% of the dry mass of copepods (Postel et al. 2000). Although some authors have reported wider intervals (20-60%) for some species of copepods (Hernández-Trujillo et al. 2013). In our research, these percentages ranged between 12.2 and 22.01%, depending on the species. Notably, the average percentages of carbon in dry weight were intraspecific and interspecific variables, indicating the influence of the dimensions of the trophic niche and the feeding strategies of the species (Kozak et al. 2020). Another element to consider is the quality of the food consumed by the organism, as it is known that copepods can switch between dietary elements of different quality and availability, even within the same species (Meunier et al. 2016).

The usefulness of the regression models obtained in this work (carbon-PL) is not only valid for calculating the biomass of copepods, but they can also constitute a useful tool when they carry out secondary production and monitoring studies in marine ecosystems with different levels of anthropogenic intervention (Hernández-Trujillo et al. 2014).

Low carbon content values in copepods can be reflected in the decrease in energy transfer from the euphotic zone to deeper ocean layers (biological carbon pump) and variations in the energy exchange of primary producers to higher trophic levels, including some species of commercial importance. Only a few studies worldwide have measured the individual carbon content of copepod species (Uye 1982, Uye & Kayano 1994, Cataletto & Fonda-Umani 1994). In tropical and subtropical regions, the number of works on this topic is even smaller (Castilho-Noll & Arcifa 2007, Hernández-Trujillo et al. 2013). Despite its limitations, our study provides new data that contribute to a more precise estimate of the carbon content contribution of copepods to pelagic ecosystems in tropical regions, including areas of ecological and commercial interest such as the Pacific Mexican Central.

Among the limitations of this study is that, due to the sampling method used, only a portion of the copepod size spectrum (>250 μm) was captured. Additionally, and for the same reason, organisms of all life stages (e.g. eggs, nauplii, copepodites) of the analyzed species were not obtained. Progress in constructing numerical models to describe the zooplankton length-mass relationship is ongoing, providing valuable insights into predicting zooplankton dynamics and the groups that are key intermediates in the marine pelagic food web in ecosystems where fisheries are managed. Despite the problems presented by research on specific carbon content estimates and the time consumption in organism collection and experimental processing, in the Mexican Pacific, these studies should continue to be performed, in our opinion, focusing mainly on the numerically dominant species of the ecosystem (e.g. *Calanus pacificus*, *Oncaea venusta*, *Canthocalanus pauper*), since they represent the main portion of the carbon biomass and the food web of higher trophic levels. We also recommend that future studies include volumetric measurements of the organisms.

Credit author contribution

Y.I. La Rosa-Izquierdo: conceived and designed research, carried out samplings, analyzed data, wrote the manuscript; S. Hernández-Trujillo conceived and designed research, carried out samplings, analyzed data, wrote the manuscript; F. García-Fernández analyzed data, wrote the manuscript. All authors read and approved of the final manuscript.

Conflict of interest

The authors declare that they have no conflict of interest.

Ethical approval

All international, national, and institutional guidelines for sampling of organisms for the study were followed.

ACKNOWLEDGMENTS

To the academic group of CICIMAR for the help, attention, and suggestions provided. This study was granted by Secretaría de Investigación y Posgrado (SIP) del Instituto Politécnico Nacional. SIP 20160625, SIP 20200686, SIP 2021387. The Instituto Politécnico Nacional, CONACYT, and the Department of Studies for the Sustainable Development of Coastal Zones are affiliated with the South Coast University Center of the University of Guadalajara. Special thanks to Ph.D. Carmen Franco Gordo, for the time and valuable ideas contributed. The dataset generated or analyzed during this study is available from the authors upon specific request.

REFERENCES

Ara, K. 2001. Length-weight relationships and chemical content of the planktonic copepods in the Cananéia Lagoon estuarine system, Sao Paulo, Brazil. Plankton Biology and Ecology, 48: 121-127.

Castilho-Noll, M.S.M. & Arcifa, M.S. 2007. Length-weight relationships for zooplanktonic species of a tropical Brazilian lake: Lake Monte Alegre. Acta Limnologica Brasiliensia, 19: 93-100.

Cataletto, B. & Fonda-Umani, S. 1994. Seasonal variations in carbon and nitrogen content of *Acartia clausi* (Copepoda, Calanoida) in the Gulf of Trieste (northern Adriatic Sea). Hydrobiologia, 292: 283-288.

Chisholm, L.A. & Roff, J.C. 1990. Size-weight relationship and biomass of tropical neritic copepods off Kingston, Jamaica. Marine Biology, 106: 71-77. doi: 10.1007/BF02114676

Durbin, E.G. & Durbin, A.G. 1978. Length and weight relationships of *Acartia clausi* from Narragansett Bay, R.I. Limnology and Oceanography, 23: 958-969. doi: 10.4319/lo.1978.23.5.0958

Hernández-Trujillo, S., Esqueda-Escárcega, G.M. & Futema-Jiménez, S. 2013. Prediction models of copepods biomass from the mass-length and carbon content-length relationship. Journal of Marine Biology and Oceanography, 2: 2. doi: 10.4172/2324-8661.100 0116

Hernández-Trujillo, S., Esqueda-Escárcega, G.M., Futema-Jiménez, S., et al. 2014. Relación peso-longitud de *Labidocera diandra* y *Labidocera johnsoni* (Calanoida: Pontellidae). Hidrobiológica, 24: 303-306.

Hessen, D.O. 1989. Factors determining the nutritive status and production of zooplankton in a humic lake. Journal of Plankton Research, 11: 649-664. doi: 10.1093/plankt/11.4.649

Kerkar, A.U., Venkataramana, V. & Tripathy, S.C. 2020. Morphometric estimation of copepod carbon biomass in coastal Antarctica: a case study in Prydz Bay. Journal of Crustacean Biology, 40: 58-66. doi: 10.1093/jcbiol/ruz077

Kozak, E.R., Franco-Gordo, C., Godínez-Domínguez, E., et al. 2020. Seasonal variability of stable isotope values and niche size in tropical calanoid copepods and zooplankton size fractions. Marine Biology, 167: 1-13. doi: 10.1007/s00227-020-3653-7

Kozak, E. R., Franco-Gordo, C., Suárez-Morales, E., et al. 2014. Seasonal and interannual variability of the calanoid copepod community structure in shelf waters of the Eastern Tropical Pacific. Marine Ecology Progress Series, 507: 95-110. doi: 10.3354/meps10811

La Rosa-Izquierdo, Y.I. 2023 Estimación de biomasa de copépodos pelágicos en el Pacífico Central Mexicano. Tesis de Doctorado, Instituto Politécnico Nacional, La Paz.

Lehette, P. & Hernández-León, S. 2009. Zooplankton biomass estimation from digitized images: a comparison between subtropical and Antarctic organisms.

Limnology and Oceanography: Methods, 7: 304-308. doi: 10.4319/lom.2009.7.304

Mauchline, J. 1998. The biology of calanoid copepods. Advances in Marine Biology. Academic Press, Cambridge.

McConville, K., Atkinson, A., Fileman, E.S., et al. 2017. Disentangling the counteracting effects of water content and carbon mass on zooplankton growth. Journal of Plankton Research, 39: 246-256. doi: 10.1093/plankt/fbw094

Meunier, C.L., Boersma, M., Wiltshire, K.H., et al. 2016. Zooplankton eat what they need: copepod selective feeding and potential consequences for marine systems. Oikos, 125: 50-58.

Postel, L., Fock, H. & Hagen, W. 2000. Biomass and abundance. In: ICES zooplankton methodology manual. Academic Press, Cambridge, pp. 83-192.

Razouls, C., Desreumaux, N., Kouwenberg, J., et al. 2024. Biodiversity of marine planktonic copepods (morphology, geographical distribution and biological data). Sorbonne University, Paris. [http://copepodes.obs-banyuls.fr/en]. Reviewed: September 15, 2024.

Schaafsma, F.L., Cherel, Y., Flores, H., et al. 2018. The energetic value of zooplankton and nekton species of the Southern Ocean. Marine Biology, 165: 1-35. doi: 10.1007/s00227-018-3386-z

Uye, S.I. 1982. Length-weight relationships of important zooplankton from the Inland Sea of Japan. Journal of the Oceanographical Society of Japan, 38: 149-158. doi: 10.1007/BF02110286

Uye, S.I. & Kayano, Y. 1994. Predatory feeding behavior of *Tortanus* (Copepoda: Calanoida): life-stage differences and the predation impact on small planktonic crustaceans. Journal of Crustacean Biology, 14: 473-483.

Walter, T.C. & Boxshall, G. 2024. World of copepods database. [https://www.marinespecies.org/copepoda]. Reviewed: September 12, 2024.

Yeghissian, T.G. 2018. Multi-decadal, seasonal, and spatial variation of calanoid copepod body size in Delaware Bay. Doctoral Dissertation, University of Delaware, Delaware.

Received: October 25, 2024; Accepted: April 29, 2025