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# INDIVIDUAL BIOVOLUME OF SOME DOMINANT COPEPOD SPECIES IN COASTAL WATERS OFF BUENOS AIRES PROVINCE, ARGENTINE SEA

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Copepods are key components in the marine communities because of their important role in the transfer of matter and energy from primary producers to higher trophic levels and in the export of organic matter from the euphotic to deeper layers of the oceans (CALBET et al., 2000). Because of their role as prey for fishes at different stages of development, knowledge of zooplankton abundance and biomass in spatial and temporal scales remains a key element of the marine ecosystem approaches (IRIGOIEN et al., 2009).

In fisheries science, accurate estimations of abundance, biomass and production of the different components of the food webs are necessary for the construction and implementation of ecosystem models (CHRISTENSEN; PAULY, 1992).

*Paracalanus parvus*, *Ctenocalanus vanus*, *Calanoides carinatus* and *Oithona nana* are dominant copepod species (50-100 %) in the coastal waters of the Argentine Sea (RAMÍREZ, 1981; VIÑAS et al., 2002). These copepods play an important role in the pelagic food web as the main prey item for larvae (CIECHOMSKI; WEISS, 1974; VIÑAS; RAMÍREZ, 1996) and juveniles and adults of anchovy (ANGELESCU, 1982; PÁJARO, 2002). Thus, an accurate estimation of their biomass and productivity is necessary to quantify the transfer of matter and energy across the planktonic food webs.

So far, there is only one regional work in which the individual biomass of copepods has been estimated (FERNÁNDEZ ARÁOZ, 1991) in the Argentine Sea, but early copepodite stages were not included because of the mesh size (≥ 220 µm) employed.

Our aim was to estimate the individual biomass of all the stages of the above-mentioned copepods by the geometric method and to establish, for each species, significant regression models predicting biovolume from some linear body dimension.

Volumetric methods, such as the one employed in the present study, are the only choice if samples are also to be used for taxonomic purposes (POSTEL et al., 2000) and the geometric approach is the only suitable in the case of small-sized zooplankton (OMORI; IKEDA, 1984).

The conversion of our results into another biomass proxy from the literature may easily be made. In fact, body wet weight can be derived from measurements of body biovolume by applying a factor of 1 for specific gravity (OMORI and IKEDA, 1984). Dry weight can be obtained by multiplying the wet weight by 0.20 and the carbon content can be considered as 40 % of the dry weight (POSTEL et al., 2000).

Samples were obtained on October 18$^{th}$ and November 11$^{th}$ at the permanent coastal station EPEA (38º28'S – 57º41'W), with a Babybongo net (0.18 m diameter) provided with 220 µm and 67 µm meshes. The smallest mesh size was selected in order to retain all the stages of the dominant copepod species *Paracalanus parvus*, *Oithona nana*, *Ctenocalanus vanus* and *Calanoides carinatus*. Samples were fixed in 4% formaldehyde immediately after collection.

A minimum of 30 females and males of each species were measured. The number of copepodite stages measured was variable (Table 1). Measurements were made under a microscope for the smaller species *Oithona nana*, *Paracalanus parvus* and *Ctenocalanus vanus*, and under a stereoscopic microscope for *Calanoides carinatus*. In both cases calibrated eye-piece graticules were used in which 1 division equalled 5.88 µm and 18 µm, respectively. Two persons performed the measurements working no more than 3 hours a day each in order to avoid fatigue as a source of error in the determinations.

Prosome length, width and height, as well as urosome length and width, were measured, in order to apply the model of CHOJNACKI; HUSSEIN (1983) slightly modified (antenna and leg volumes excluded) by FERNÁNDEZ ARÁOZ (1991), in which:

$$V = \pi (LWH)/6 + \pi (lw^2)/4$$

where V= biovolume ($\mu m^3$); L, W and H, prosome length, width and height (µm), respectively; l and w urosome length and width (µm), respectively.

Measurements were performed as follows: L was measured from the furthest projection of the head to the flexure joint between the prosome and the urosome; l from that flexure joint to the insertion of the caudal setae; W, H and w at the widest point of the body.

Mean V was determined for males, females and each of the five copepodite stages.

In order to simplify the number of morphological dimensions to be measured for the estimation of biovolume, the power model ($y = ax^{ß}$ ) was applied between the geometrically estimated V and the following body dimensions: L, W, H and T (total length). The power function was adopted because it is of general use to describe the relationships between size and weight/biovolume in copepods (POSTEL et al., 2000).

Mean body dimensions and estimated biovolume of adults and copepodite stages of the selected species are presented in Table 1.

The size/biovolume regressions derived for adults, copepodites and all stages combined of *O. nana* and *C. carinatus* are shown in Table 2. Due to their morphological similarity, copepodite stages of *C. vanus* and *P. parvus* were grouped together into only one regression, but separate equations for the adults (males and females) of both species were also obtained.

On the basis on the determination coefficients ($R^2$) obtained, W was found to be a better predictor of V than L and T. However, these last dimensions also presented significant positive relationships with V. Thus, the corresponding L/V and T/V regressions are also provided (Table 2).

Table 1. Body dimensions (mean ± standard deviation in µm) and estimated biovolume (mean ± standard deviation x $10^6$ $\mu m^3$) of adults and copepodite stages of *O. nana*, *C. carinatus*, *C. vanus* and *P. parvus.* L, W and H prosome length, width and height, respectively; i and w, urosome length and width, respectively, T total length, V biovolume.

| | N | L | W | H | i | w | T | V |
|---|---|---|---|---|---|---|---|---|
| *Oithona nana* | | | | | | | | |
| C1 | 10 | 219.91±6.0 | 98.78±2.3 | 82.32±3.7 | 82.91±4.1 | 26.46±0.0 | 302.82±6.6 | 0.96±0.1 |
| C2 | 10 | 240.49±5.8 | 114.66±5.7 | 99.96±9.3 | 119.36±2.8 | 28.52±2.8 | 359.86±6.7 | 1.42±0.1 |
| C3 | 10 | 261.07±6.3 | 124.66±6.7 | 102.31±3.2 | 153.47±6.5 | 29.99±2.3 | 414.54±9.3 | 1.84±0.2 |
| C4 | 15 | 305.76±8.0 | 153.27±3.5 | 115.25±8.8 | 196.39±1.5 | 33.71±3.2 | 502.15±10.4 | 3.22±0.2 |
| C5 | 15 | 340.26±6.2 | 182.67±7.8 | 129.36±4.2 | 258.33±8.4 | 37.24±2.4 | 598.58±8.4 | 5.10±0.4 |
| F | 30 | 376.71±13.1 | 196.0±13.0 | 156.15±6.6 | 303.02±23.4 | 40.57±3.6 | 679.73±30.8 | 6.27±0.9 |
| M | 30 | 366.32±12.0 | 172.87±5.3 | 145.53±4.2 | 271.07±7.8 | 34.40±1.9 | 637.39±14.1 | 4.90±0.3 |
| *Calanoides carinatus* | | | | | | | | |
| C1 | 14 | 646.01±30.0 | 262.61±25.1 | 224.45±21.5 | 131.91±23.4 | 109.29±16.7 | 777.92±42.6 | 21.42±4.4 |
| C2 | 14 | 832.5±38.5 | 305.04±26.2 | 260.71±22.4 | 198.51±17.5 | 115.91±9.8 | 1031.01±43.2 | 37.13±7.1 |
| C3 | 14 | 1150.71±56.7 | 388.80±18.9 | 332.31±16.2 | 242.68±27.8 | 119.96±16.2 | 1393.39±71.0 | 80.82±9.2 |
| C4 | 19 | 1563.11±67.4 | 539.94±32.2 | 461.48±27.5 | 425.78±120.7 | 141.39±12.6 | 1988.89±111.2 | 211.38±27.3 |
| C5 | 19 | 2084.66±91.4 | 669.59±56.8 | 572.30±48.6 | 609.54±170.2 | 171.19±23.2 | 2694.21±169.1 | 436.43±83.7 |
| F | 40 | 2429.99±127.4 | 806.50±49.8 | 775.48±47.9 | 641.86±58.6 | 208.59±13.6 | 3071.85±176.8 | 823.81±130.5 |
| M | 40 | 2113.45±100.3 | 676.20±53.4 | 656.50±51.8 | 622.31±75.8 | 185.11±19.2 | 2735.75±164.0 | 513.92±105.8 |
| *Ctenocalanus vanus* | | | | | | | | |
| F | 30 | 1027.04±20.8 | 411.99±14.6 | 408.07±17.8 | 275.18±17.1 | 84.28±7.9 | 1302.22±29.8 | 92.12±7.9 |
| M | 30 | 980.39±20.8 | 393.96±19.5 | 393.57±16.8 | 362.21±14.3 | 95.65±7.2 | 1342.60±30.3 | 82.36±7.3 |
| *Paracalanus parvus* | | | | | | | | |
| F | 30 | 580.83±18.2 | 229.58±13.7 | 215.81±12.9 | 120.30±12.6 | 55.50±3.0 | 701.13±24.2 | 15.44±2.1 |
| M | 30 | 663.33±59.1 | 259.58±28.6 | 249.20±27.4 | 190.90±17.8 | 57.90±4.7 | 854.23±71.5 | 23.62±6.8 |

Table 2. Size-biovolume regressions of selected copepod species. V: biovolume (in $\mu m^3$), L and W: prosome length and width, respectively (in μm), T: total length, F: females, M: males, A: adults and C: copepodites.

| Species | Equation | n | X range (μm) | $R^2$ | p |
|---|---|---|---|---|---|
| *Oithona nana* | | | | | |
| F | Log V = 1.037 + 2.235 log L | 40 | 352.8 - 399.8 | 0.29 | < 0.002 |
| | Log V = 1.988 + 2.097 log W | 40 | 176.4 - 229.3 | 0.92 | < 0.0001 |
| M | Log V = 5.138 + 0.605 log L | 30 | 335.2 -388.1 | 0.11 | n.s. |
| | Log V = 2.999 + 1.649 log W | 30 | 164.6 - 182.3 | 0.70 | < 0.0001 |
| A | Log V = 0.284 + 2.513 log L | 60 | 335.2 – 399.8 | 0.33 | < 0.0001 |
| | Log V = 2.284 + 1.968 log W | 60 | 164.6 – 229.3 | 0.95 | < 0.0001 |
| C | Log V = -2.661 + 3.695 log L | 60 | 205.8 – 352.8 | 0.98 | < 0.0001 |
| | Log V = 0.570 + 2.714 log W | 60 | 94.1 - 194.04 | 0.99 | < 0.0001 |
| A and C | Log V = -1.553 + 3.234 log L | 120 | 205.8 - 399.8 | 0.95 | < 0.0001 |
| | Log V = 0.502 + 2.751 log W | 120 | 94.1 - 229.3 | 0.99 | < 0.0001 |
| | Log V = 0.283 + 2.296 log T | 120 | 288.1 – 735.0 | 0.97 | < 0.0001 |
| *Calanoides carinatus* | | | | | |
| F | Log V = 0.128 + 2.594 log L | 40 | 2146.0 - 2638.4 | 0.69 | < 0.0001 |
| | Log V = 1.564 + 2.528 log W | 40 | 703.0 - 892.4 | 0.94 | < 0.0001 |
| M | Log V = -3.561 + 3.689 log L | 40 | 1961.0 - 2250.4 | 0.67 | < 0.0001 |
| | Log V = 1.944 + 2.389 log W | 40 | 620.8 -776.0 | 0.97 | < 0.0001 |
| A | Log V = -2.254 + 3.297 log L | 80 | 1961.0 - 2638.4 | 0.89 | < 0.0001 |
| | Log V = 1.312 - 2.613 log W | 80 | 620.8 - 892.4 | 0.98 | < 0.0001 |
| C | Log V = -0.094 + 2.628 log L | 80 | 594.0 - 2289.2 | 0.98 | < 0.0001 |
| | Log V = -0.201 + 3.123 log W | 80 | 216.0 - 737.2 | 0.99 | < 0.0001 |
| A and C | Log V = -0.590 + 2.795 log L | 160 | 594.0 - 2638.4 | 0.99 | < 0.0001 |
| | Log V = -0.421 + 3.213 log W | 160 | 216.0 - 892.4 | 0.99 | < 0.0001 |
| | Log V = -0.392 + 2.649 log T | 160 | 702.0 - 3413.3 | 0.98 | < 0.0001 |
| *Paracalanus parvus* | | | | | |
| F | Log V = -0.898 + 2.924 log L | 30 | 537.5 - 612.5 | 0.46 | < 0.0001 |
| | Log V = 1.897 + 2.240 log W | 30 | 200.0 - 262.5 | 0.96 | < 0.0001 |
| M | Log V = -1.544 + 3.190 log L | 30 | 525.0 - 737.5 | 0.92 | < 0.0001 |
| | Log V = 0.839 + 2.742 log W | 30 | 212.5 - 312.5 | 0.98 | < 0.0001 |
| A | Log V = -3.648 +3.928 log L | 60 | 525.0 - 737.5 | 0.91 | < 0.0001 |
| | Log V = 2.284 + 1.968 log W | 60 | 200.0 - 312.5 | 0.95 | < 0.0001 |
| | Log V = -1851 + 3.175 log T | 60 | 633.5 - 956.0 | 0.92 | < 0.0001 |
| *Ctenocalanus vanus* | | | | | |
| F | Log V = -2.151 + 3.358 log L | 30 | 999.6 - 1058.4 | 0.62 | < 0.0001 |
| | Log V = 2.508 + 2.086 log W | 30 | 388.1 - 435.1 | 0.74 | < 0.0001 |
| M | Log V = 0.104 + 2.611 log L | 30 | 940.8 - 1011.4 | 0.36 | < 0.0004 |
| | Log V = 3.718 + 1.617 log W | 30 | 352.8 - 423.4 | 0.76 | < 0.0001 |
| A | Log V = -2.151 + 3.358 log L | 60 | 940.8 - 1058.4 | 0.62 | < 0.0001 |
| | Log V = 2.507 + 2.086 log W | 60 | 352.8 - 435.1 | 0.74 | < 0.0001 |
| | Log V = 5.805 + 0.691 log T | 60 | 1234.8 -1387.7 | 0.05 | n.s. |
| *P. parvus-C.vanus* | | | | | |
| C | Log V = -2.309 + 3.433 log L | 219 | 237.5 - 858.5 | 0.97 | < 0.0001 |
| | Log V = 0.162 + 2.974 log W | 219 | 87.5 - 411.6 | 0.98 | < 0.0001 |
| A and C | Log V = -0.943 + 2.923 log L | 359 | 237.5 - 1058.4 | 0.99 | < 0.0001 |
| | Log V = -0.155 + 3.120 log W | 359 | 87.5 - 435.1 | 0.99 | < 0.0001 |
| | Log V = -1.769 + 3.128 log T | 339 | 282.5 – 1387.7 | 0.98 | < 0.0001 |

The geometric approach has been recently employed by other authors (CALBET et al., 2000; ALCARAZ et al., 2003; GROSJEAN et al., 2004; MC KINNON et al., 2005) to estimate biovolume in image analysis methods combined with automatic classification of zooplankton. These methods estimate

biovolume from measurements of both the length and width of copepods. Biovolume is then used to make weight estimates. Presumably the geometric method suffers from some of the same drawbacks as the length-weight regression method, but may produce more accurate weights by accounting for changes in width and to some extent the condition factor of the copepod during a stage (KIMMERER et al., 2007).

Prosome width was a better biovolume predictor than prosome length. Similar results were reported by FERNÁNDEZ ARÁOZ (1991) for copepods from Patagonian waters and by PEARRE (1980) on the basis of a large number of species analyzed.

Prosome length is somewhat ambiguous to determine in view of the different morphologies of the main copepod groups and the variety of measuring conventions used by different workers. Besides, width seems to be a more critical dimension than length in prey selection by larval fish (HUNTER, 1981).

A general prosome width-biovolume regression (such as those developed here) including all the developmental stages provided for each species studied, can be potentially useful where detailed identification of stages is not desired (CHISHOLM; ROFF, 1990).

Although a mean biovolume is provided for the adults and copepodite stages of the selected species, it is a known fact that size and, consequently, biovolume of copepods vary both seasonally (VIÑAS; GAUDY, 1996; UYE; SANO, 1998) and geographically (CONOVER; HUNTLEY, 1991) in temperate waters. So, for each study period and area, it is more convenient to estimate the biovolume of targeted species from the size measurements and specific size/biovolume equations. In addition, size is more easily and readily measured than weight (COHEN; LOUGH, 1981).

In the present work, no direct estimates of biovolume were made. However, we validated our biovolume measurements by deriving dry weight from measured copepod body area and comparing it with data from the literature. For that, we chose the equation of HOPCROFT et al. (HOPCROFT et al., 1998) for *Oithona nana*. Our biovolumes estimated geometrically were converted into dry weight using the above mentioned conversion factors, assuming that ash free dry weight is 73.6 % of dry weight on average (MAUCHLINE, 1998). As a result our indirect estimations of dry weight were, on average, only 4,6% lower than the direct measurements obtained by HOPCROFT et al. (1998).

We have combined the copepodites of *P. parvus* and *Ctenocalanus* in a single equation. This is a common practical procedure when the species are morphologically very similar and difficult to distinguish by standard optical analysis in the laboratory (WEBBER; ROFF, 1995).

The importance of investigating the trends in zooplankton biomass in relationship to fish recruitment has been clearly demonstrated (BEAUGRAND et al., 2003; IRIGOIEN et al., 2009). The present findings dealing with important prey of larvae, juveniles and adults of anchovy (*Engraulis anchoita*), will contribute to bioenergetic studies concerning this species.

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