Individual biomass, based on body measures, of copepod species considered as main forage items for fishes of the Argentine shelf

Planktonic copepods
Argentine shelf waters
Individual biomass
Size-weight relationships

Copépodes planctoniques
Plateau continental argentin
Biomasse individuelle
Relations taille-poids

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ABSTRACT

Mean wet weights, prosome length-weight and prosome width-weight relationships are established for the later stages of the copepods *C. carinatus*, *C. australis*, *A. tonsa*, *C. vanus*, *C. brachiatus* and *D. forcipatus* from San Jorge Gulf. Individual biomass was estimated by the morphometric method. The potential model relating size and weight was selected for the best fit. Prosome width was a better weight predictor than prosome length in almost all developmental stages and both sexes of the species.

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RÉSUMÉ

Biomasse individuelle, basée sur des mesures morphologiques, des espèces de copépodes considérées comme la nourriture de base des poissons du plateau continental argentin

Les poids humides moyens et les relations longueur du prosome-poids et largeur du prosome-poids ont été établis pour les copépodites des espèces *C. carinatus*, *C. australis*, *A. tonsa*, *C. vanus*, *C. brachiatus* et *D. forcipatus* du golfe San Jorge. La biomasse individuelle a été déterminée par la méthode morphométrique. Le modèle potentiel a été sélectionné pour la relation taille-poids en tenant compte du meilleur ajustement. Entre la longueur et la largeur du prosome, cette dernière a été la meilleure variable explicative du poids dans la plupart des stades de développement et chez les deux sexes des espèces étudiées.

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INTRODUCTION

The San Jorge Gulf (45° and 47°S) maintains through its wide mouth an extensive connection with Argentine shelf waters. Surface temperatures range from 7° to 16°C and slight salinity variations are to be found (33.20 to 33.50). References on hydrological and biological aspects of the San Jorge Gulf are found in Thomsen (1962), Lusquiños and Valdez (1971), Kreeper and Rivas (1979), Reta (1986) and Perez Seijas *et al.* (1987). It is known to be a productive area (Ciechomski and Weiss, 1974 *a*); Boschi, 1986; Perez Comas, 1990) since the spawning and breeding of some species of economical value occurs, such as the anchovy (*Engraulis anchoita*), hake (*Merluccius hubbsi*) and shrimp (*Pleoticus muelleri*).

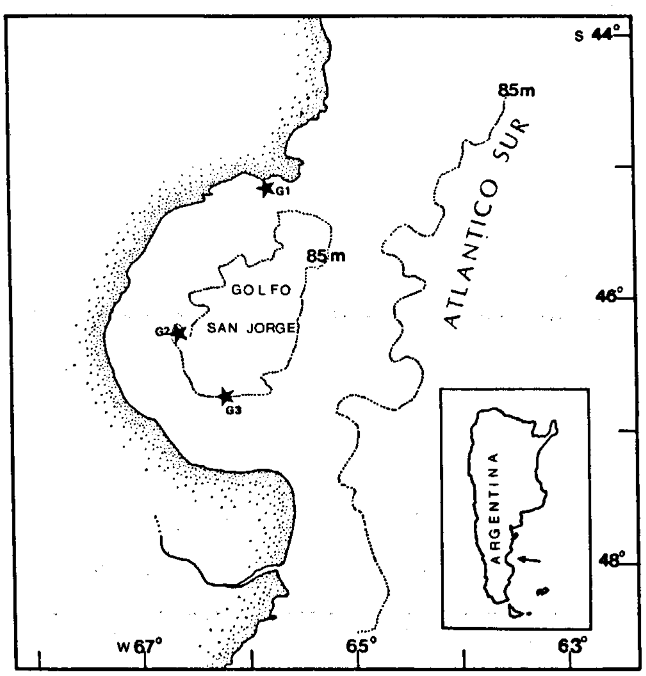
Since zooplankton is an important food resource of these fisheries species (Ciechomski, 1967; Ciechomski and Weiss, 1974 *b*; Angelescu and Anganuzzi, 1981;

Angelescu, 1982; Angelescu and Prenski, 1987), ecological studies are needed to establish accessibility and availability of the resource in terms of size and biomass. In the extensive bibliography on planktonic copepods of the Argentine shelf waters (Ramírez, 1966 *a*; 1966 *b*; 1969; 1970; 1971; 1977; 1981; Carreto *et al.*, 1981), there is no information on their individual biomass and size-biomass relationships.

Since estimation of copepod dry weights is difficult, and is affected by preserving agents, the morphometric method was applied here to estimate individual volumes feasible to be converted into weight unities.

METHODOLOGY

Zooplankters were collected from San Jorge Gulf during October 1985. Samples were taken with a Bongo net (mesh size, 300 µm) and preserved with formaldehyde. *Acartia tonsa* (Dana 1849), *Calanus australis* (Brodskii 1959) and *Calanoides carinatus* (Krøyer 1848) were collected from station G1, *Centropages brachiatus* (Dana 1849) from station G2, and *Drepanopus forcipatus* (Giesbrecht 1888) from station G3 (Fig. 1) of the cruise R/V *Holmberg* (March 1985). Only later developmental stages are treated, since they represented most of the biomass and were better sampled by the mesh size used. At least thirty individuals were sorted according to each developmental stage, sex and species. Individual volumes were computed from their linear dimensions applying the formula proposed by Chojnacki and Hussein (1983), with slight modifications (antenna and leg volumes were not considered):



Figure

Map of San Jorge Gulf. Locations of the stations (G1, G2 and G3) used in this study.

$V = \pi (LTH)/6 + \pi (lt^2)/4$

where: V volume (mm^3), L and T prosome length and width (mm), H prosome height (mm), l and t urosome length and width (mm). Volumes were converted to wet weights assuming that the specific gravity of the animals is 1 and therefore that 1 mm^3 = 1 mg wet mass (Winberg, 1971; Omori and Ikeda, 1984).

Prosome length was measured from the furthest projection of the head to the flexure joint between prosome and urosome, and urosome length from that flexure joint to the insertion of the caudal setae. Widths and heights were measured at the widest point of the body. The absolute error in measurements was equivalent to a half division on the scale of the ocular micrometer. Relative errors in prosome length and width for the smallest individual (*Ctenocalanus vanus* IV female) were encompassed between 0.86-1 % and 2.5-3 %, respectively. Therefore, it can be assumed that those variables were measured with virtually no error.

Prosome length-weight and prosome width-weight relationships were calculated for each data set separately (species, sex and stage) using power, lineal, exponential and logarithmic models. The selection of the best fit was based on the major correlation index obtained (Ostle, 1979). The data were transformed to natural logarithms and the parameters of the linearized equations were estimated by the least squares method.

Among all the regression equations of the weight-prosome length and weight-prosome width performed, the choice was based on the major determination adjusted coefficient (Kendall, 1980).

Possible anomalies in the selected models were graphically analyzed by plotting the series of estimated, observed and residual values against each observation (Draper and Smith, 1966). F-tests and t-tests were used to determine the significance of the regression (coefficient and intercept, respectively).

The overlap of two regressions was tested (H_0: $a_1 = a_2$, $b_1 = b_2$) according to the statistic U of the likelihood test ratio (Fomby *et al.*, 1984). Even when the regression parameters were different (slopes or intercepts or both), these strong and weak mean-quadratic-error criteria were applied to determine the degree to which merging of the data was justified (Fomby *et al.*, 1984).

RESULTS AND DISCUSSION

Mean dimensions and volumes

Mean dimensions and volumes are listed in Table 1. Mean prosome length increments between stages of the species ranged from 120 to 200 µm per molt. Particularly, between CV and CVI males of *Ctenocalanus vanus* it was 21 µm while *Drepanopus forcipatus* between the same stages decreased 86 µm. Quite similar values were found by Fernández Aráoz (MS) for both species from San Jorge waters: increments for CV to CVI males were 10 and 8 µm respectively in winter and summer for *Ctenocalanus vanus*

Table 1

Body dimensions and estimated volumes by species, sex and stage of spring Calanoid copepods from San Jorge Gulf. Values are means ± standard error of the means, n the number of observations.

Species/sex/stage	n	Prosome length (mm)	Prosome width (mm)	Prosome height (mm)	Urosome length (mm)	Volume (mm^3)
Ctenocalanus vanus						
CVI F	30	0.921 ± 0.0076	0.358 ± 0.0038	0.340 ± 0.0038	0.339 ± 0.0039	0.0612 ± 0.0017
CVI M	30	0.915 ± 0.0051	0.378 ± 0.0026	0.366 ± 0.0026	0.439 ± 0.0045	0.0691 ± 0.0010
CV F	30	0.792 ± 0.0035	0.318 ± 0.0034	0.295 ± 0.0031	0.301 ± 0.0030	0.0404 ± 0.0085
CV M	30	0.894 ± 0.0048	0.358 ± 0.0059	0.333 ± 0.0040	0.351 ± 0.0052	0.0581 ± 0.0017
CIV F	30	0.663 ± 0.0039	0.251 ± 0.0019	0.229 ± 0.0019	0.223 ± 0.0029	0.0208 ± 0.0003
CIV M	30	0.693 ± 0.0026	0.265 ± 0.0027	0.249 ± 0.0020	0.259 ± 0.0016	0.0249 ± 0.0004
Drepanopus forcipatus						
CVI F	60	1.214 ± 0.0159	0.486 ± 0.0083	0.450 ± 0.0088	0.599 ± 0.0090	0.1542 ± 0.0072
CVI M	30	0.915 ± 0.0064	0.480 ± 0.0031	0.436 ± 0.0043	0.559 ± 0.0044	0.1061 ± 0.0020
CV F	30	1.038 ± 0.0095	0.418 ± 0.0057	0.375 ± 0.0057	0.443 ± 0.0056	0.0906 ± 0.0032
CV M	30	1.001 ± 0.0058	0.425 ± 0.0040	0.401 ± 0.0053	0.419 ± 0.0041	0.0930 ± 0.0025
CIV F	30	0.880 ± 0.0053	0.341 ± 0.0037	0.299 ± 0.0030	0.323 ± 0.0037	0.0493 ± 0.0011
CIV M	30	0.872 ± 0.0050	0.340 ± 0.0046	0.307 ± 0.0048	0.308 ± 0.0030	0.0499 ± 0.0016
Centropages brachiatus						
CVI F	29	1.303 ± 0.0141	0.505 ± 0.0061	0.410 ± 0.0058	0.641 ± 0.0093	0.1548 ± 0.0048
CVI M	19	1.146 ± 0.0112	0.417 ± 0.0054	0.361 ± 0.0056	0.607 ± 0.0057	0.0969 ± 0.0027
Acartia tonsa						
CVI F	30	1.131 ± 0.0067	0.358 ± 0.0035	0.334 ± 0.0037	0.318 ± 0.0023	0.0739 ± 0.0015
CVI M	30	0.928 ± 0.0036	0.285 ± 0.0021	0.264 ± 0.0019	0.292 ± 0.0017	0.0383 ± 0.0006
CV F	30	0.997 ± 0.0046	0.304 ± 0.0032	0.276 ± 0.0024	0.281 ± 0.0017	0.0460 ± 0.0050
Calanus australis						
CVI F	30	2.855 ± 0.0228	0.950 ± 0.0116	0.882 ± 0.0106	0.870 ± 0.0085	1.2990 ±0.0372
Calanoides carinatus						
CVI F	30	2.506 ± 0.0193	0.830 ± 0.0068	0.773 ± 0.0071	0.784 ± 0.0085	0.8737 ± 0.0171

and - 66 and - 60 µm respectively in winter and summer for *Drepanopus forcipatus*. Apparently CV males of *Ctenocalanus vanus* grow little and those of *Drepanopus forcipatus* become shorter in molting to adult.

Mean volume increments ranged between 20 and 63 μm^3 per molt excepting males CV-CVI of both *Ctenocalanus vanus* and *Drepanopus forcipatus* which showed lower values, 11 and 13.1 μm^3, respectively. These increments were quite similar to values found (Fernández Aráoz, MS) in winter and summer CV to CVI males of *Ctenocalanus vanus* and *Drepanopus forcipatus* (7.2 and 3.6 μm^3, 16.3 and 15.9 μm^3, respectively);

While volume and length values of adult females of *Drepanopus forcipatus, Acartia tonsa* and *Centropages brachiatus* were, on average, higher than those of their respective males, they were quite similar in both sexes of *Ctenocalanus vanus* adults.

Ratios between the main morphometric variables implicit in Table 1, reveal some characteristics of copepod shape. The calanoid copepods studied are typically ellipsoidal, with a prosome length: width ratio of 3 in the large *Calanus australis* and *Calanoides carinatus*, and from 2.42 to 2.75 in the smaller species. For a given species, this ratio remains relatively constant with development to adult form, reflecting no substantial change of shape. *Drepanopus forcipatus* adult males appear to be an exception, since the ratio of 2.3 in CV males becomes 1.9 in adults. Similar ratios were found in Fernández Aráoz (MS) for specimens of San Jorge Gulf waters, being 2.36 and 1.87 in summer CV and adults, respectively, and 2.4 and 1.9 in winter CV and adults, respectively. This reflects a change of shape from the elongate CIV and CV to the rounded adults.

The prosome width: height ratio was close to 1, reflecting a prosome section essentially circular. A slight increase (1.23) in *Centropages brachiatus* suggests a more flattened body.

The prosome length: urosome length ratio was more variable for all species and stages, ranging from 1.64 (*Drepanopus forcipatus* adult males) to 3.56 (*Acartia tonsa* adult females).

The constancy between the main body dimensions supports the suitability of the method applied here to estimate microcrustacean biomass. The method of Shemleva (1965), unlike that of Chojnacki and Hussein (1983), overestimates the resulting biomass since it assumes the prosome width: prosome height ratio equals 1. For example, in *Centropages brachiatus* adult females and males the overestimation reaches 21.44 and 14.6 %, respectively, as compared with

the present results. These were calculated including the prosome height variable, which improves precision in the resulting biomass, turning this method more suitable whatever the flattening of the crustacean may be.

Size-weight relationships

The relation between size and weight of a copepod has most often been described as $W = \alpha L^{\beta}$, where α and β are parameters of the model, W the weight and L the size (Krylov, 1968; Kamshilov, 1951, *from* Robertson, 1968; Pertsova, 1966; Gruzov and Alekseyeva, 1970; Chojnacki and Hussein, 1983). Differences are found with regard to the exponent (log slope) β, since some authors assume it equals 3, while others estimate it from the population data. Also, total length has been widely used to predict weight, although prosome length has recently become more usual. The abandonment of total length is based on the fact that this variable is subjected to greater measurement error, since copepod urosomes frequently become bent, telescoped or stretched. This study used prosome length and width since this body part is more rigid and stable.

The power model was selected here for the best fit, in agreement with the works referred to above. However, the present method for weight determination, as well as the predictor variables used in the regressions, differ from those applied by other authors. Therefore, its comparisons with those works is difficult; moreover, equations for each sex, developmental stage and species were calculated here separately, which is not always true of other studies.

Results in Table 2 show that prosome width was a better predictor of weight than prosome length in almost all stages and sexes of the species studied. Width accounted for 69-98 % of the total weight variation of the species, excepting CIV females of *Ctenocalanus vanus* and adult males of *Drepanopus forcipatus*. Prosome length accounted for 55-97 % of the total weight variation of some stages of the species.

Since single width-weight equations were satisfactory in almost all stages and sexes of the species studied, statistical comparisons between sexes at a given stage are performed (Tab. 3). Differences were not found in CVI of both *Ctenocalanus vanus* and *Centropages brachiatus*, and CIV and CV of *Drepanopus forcipatus*. Therefore, common regression lines, included in Table 2, were fitted to the merged data where sex identification is not required to generate their weights. Tests for CIV of *Ctenocalanus vanus* and CVI of *Acartia tonsa* did not justify the grouping of sexes in common equations.

Table 2

Size-weight selected equations of spring Calanoid copepods from San Jorge Gulf. Combined equations were included according to tests in Table 3. PL is prosome length (mm), PW is prosome width (mm), W is wet weight (mg), F females and M males. The number of observations (n), the adjusted determination coefficient (R^2 adj.), the standard error of the regression coefficient (S_b), the range of the independent variables (mm) are presented for the model of the best fit, $W = \alpha X^{\beta}$.

Species/sex/stage	n	Equation	R^2 adj.	Sb	C.I.b	X range (mm)
Ctenocalanus vanus						
CVI F	30	LnW = - 2.5498 + 3.0541 LnPL	0.87	0.2183	± 0.4471	0.859-1.016
CVI F + CVI M	60	LnW = - 0.4705 + 2.2675 LnPW	0.83	0.1327	± 0.2654	0.327-0.399
CV F	30	LnW = - 1.1753 + 1.7789 LnPW	0.81	0.1650	± 0.3379	0.266-0.351
CV M	30	LnW = - 1.1660 + 1.6408 LnPW	0.88	0.1149	± 0.2353	0.254-0.411
CIV F	30	LnW = - 3.0339 + 2.0489 LnPL	0.55	0.3506	± 0.7180	0.629-0.726
CIV M	30	LnW = - 1.6086 + 1.5691 LnPW	0.81	0.1403	± 0.2873	0.230-0.290
Drepanopus forcipatus						
CVI F	60	LnW = - 2.6262 + 3.6436 LnPL	0.97	0.0771	± 0.1558	0.968-1.392
CVI F	60	LnW = 0.1110 + 2.8083 LnPW	0.98	0.0563	± 0.1138	0.363-0.607
CVI M	30	LnW = - 2.0393 + 2.3283 LnPL	0.73	0.2630	± 0.5386	0.847-0.968
CV F	30	LnW = - 2.5494 + 3.6325 LnPL	0.86	0.2740	± 0.5611	0.932-1.162
CV M	30	LnW = - 2.3836 + 4.3087 LnPL	0.84	0.3529	± 0.7227	0.944-1.077
CV F + CV M	60	LnW = - 0.1817 + 2.5671 LnPW	0.91	0.1048	± 0.2097	0.363-0.472
CIV F + CIV M	60	LnW = - 0.8504 + 1.9979 LnPW	0.86	0.1054	± 0.2108	0.278-0.405
Centropages brachiatus						
CVI F	29	LnW = - 2.5441 + 2.5281 LnPL	0.74	0.2844	± 0.5836	1.107-1.374
CVI F + CVI M	48	LnW = - 0.2629 + 2.3659 LnPW	0.94	0.0840	± 0.1697	0.363-0.571
Acartia tonsa						
CVI F	30	LnW = - 0.7181 + 1.8406 LnPW	0.78	0.1843	± 0.3774	0.327-0.399
CVI M	30	LnW = - 3.0030 + 3.5118 LnPL	0.73	0.3923	± 0.8034	0.895-0.956
CVI M	30	LnW = - 0.9220 + 1.8677 LnPW	0.79	0.2255	± 0.4618	0.266-0.315
CV F	30	LnW = - 0.8780 + 1.8507 LnPW	0.89	0.1294	± 0.2660	0.278-0.351
Calanus australis						
CVI F	30	LnW = - 3.5263 + 3.6011 LnPL	0.91	0.2122	± 0.4246	2.535-3.030
CVI F	30	LnW = - 0.3741 + 2.3584 LnPW	0.91	0.1409	± 0.2886	0.820-1.030
Calanoides carinatus						
CVI F	30	LnW = 0.2420 + 2.0426 LnPW	0.69	0.2548	± 0.5218	0.750-0.892

Table 3

Statistical comparisons among regression lines for the spring Calanoid copepods from San Jorge Gulf. U is the statistic of the likelihood ratio, sl the significance level of equation comparisons, sl SMQE and sl WMQE the significance level for the strong and weak mean-quadratic-errors, respectively. F females and M males.

Species/sex/stage	U	s.l.	s.l.SMQE	s.l.WMQE
Drepanopus forcipatus				
CIV F *vs.* CIV M	1.197	0.30		
CV M *vs.* CV F	0.649	0.52		
CV (F + M) *vs.* CIV (F + M)	30.835	0.003	0.000	0.000
Ctenocalanus vanus				
CV F *vs.* CV M	41.169	0.003	0.000	0.000
CVI F *vs.* CVI M	0.413	0.66		
Centropages brachiatus				
CVI F *vs.* CVI M	1.528	0.228		
Acartia tonsa				
CVI F *vs.* CVI M	27.908	0.002	0.000	0.000

In addition to its statistical superiority, width rather than length controls fish prey selection, as noted by many authors. Copepod prosome width is clearly a better parameter to estimate the biomass of fish ingested prey, so that considerable ecological significance can be associated to this variable.

CONCLUSIONS

1) Ratios between the main body dimensions of copepod species were quite constant, which support the validity of the morphometric method applied to estimate individual biomasses.

2) For approximate and more accurate estimations of copepod weight, respectively, average volumes (wet mass) are provided by species, sex and stage, as well as size-weight equations.

3) Power models were the best fits for the size-weight relationships.

4) Prosome width was better than prosome length for predicting weight.

5) Statistical comparison among regressions showed differences in increments between sexes of the same stage in some of the species.

6) The superiority of prosome width as a predictor of weight should be tested for other geographical and seasonal conditions as well as for some developmental stages not considered in this work.

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