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Comparison of Reported Length-weight Relationships for the Dominant Copepod Prey of Larval Herring (*Clupea harengus*) in the Georges Bank-Gulf of Maine Area

by

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Introduction

Bioenergetic studies of larval fish feeding and survival, such as those done by Laurence (1977), Radtke and Dean (1979), and Lasker (1970), require an estimation of the dry weight and caloric value of the prey consumed based upon gut contents. Estimates of prey biomass also are necessary for studies into the relationship between larval fish feeding (gut contents) and their natural food supply (Ivlev, 1961). Ecosystem studies are being conducted by the Northeast Fisheries Center on the Continental Shelf from the Gulf of Maine to Cape Hatteras focusing on the critical zooplankton - fish linkages, also are based upon biomass measures (Sherman, et al. 1977, and Sherman, 1980). Studies of the length-weight (biomass) relationships of marine plankton are numerous in the literature because length is measured more easily and rapidly than weight.

In this paper, a comparison and evaluation is made of several existing length-weight conversion methods for the dominant species of copepods consumed by autumn-spawned larval sea herring in the Georges Bank - Gulf of Maine area. The most accurate length-weight relationships evaluated here will be used as part of a larger investigation into the relationship between larval herring survival and their feeding dynamics and morphological condition (see Cohen and Lough, 1979, for description of this program rationale and methodology). Caloric conversion values for some of the copepods studied here have been determined by Laurence (1976). An evaluation of the dry weight - caloric equivalents reported in the literature will not be made in this paper.

The dominant food organisms of larval herring in the Georges Bank - Gulf of Maine area based upon the work of Cohen and Lough (1979) are the adults and juveniles of the following copepod species:

1. Pseudocalanus sp.
2. Paracalanus parvus
3. Centropages typicus
4. Centropages hamatus
5. Oithona sp.
6. Calanus finmarchicus

Some recent work on Acartia clausi (Durbin and Durbin, 1978) also is included because the methods and results are reliable and therefore are useful in the evaluation of other earlier studies of this species.

Length-weight measurements of copepods from the Northwest Atlantic are used whenever possible because geographic and seasonal differences exist in body size and biomass (Comita et al., 1966; Conover, 1968; Siefkin and Armitage, 1969). Length and weight are inversely proportional to temperature when food levels are relatively constant, and directly proportional to food concentrations when temperature is fairly constant (Deevey, 1960; Durbin and Durbin, 1978; Mullin and Brooks, 1970; Landry, 1978; and Bogorov, 1934). McLaren (1963) states that in general, food concentration affects the developmental rate of organisms which in turn determines the temperature which will be experienced by them at different stages of growth.

The lack of uniformity of laboratory methods creates an additional source of variability in these data. In the translations of several articles cited it is not always clearly stated whether the values represent wet or dry weight (Anonymous, 1976; Gruzov and Alekseyeva, 1970; and Chislenko, 1968). Therefore, the studies of Davis (1977), Durbin and Durbin (1978), Schwartz (1977), and Corkett and McLaren (1978), where the wet or dry weight is specified, are used as standards with which to compare the results of other authors for the same species. Botrell *et al.* (1976) have assumed that Chislenko's nomograph represents wet weight. Since nomographs are derived from theoretical and not actual data, it is assumed in this study that they may be used to determine dry weight provided that the values obtained correspond to known dry weights obtained from other studies and that the relationship between wet weight and dry weight is constant throughout the life of the organism.

Most authors agree that the cephalothorax length of copepods is not significantly affected by formalin preservation, but there is some question as to the extent of its effect on dry weight, carbon, nitrogen, and other chemical constituents (Lovegrove, 1966, and Fudge, 1968). Mullin and Brooks (1970) and Durbin and Durbin (1978) found that the changes level off after the samples have equilibrated for several months. Corkett and McLaren (1978) suggest that the lack of a consistent relationship between preserved and unpreserved dry weight of copepods collected at the same time is due to the seasonally changing fat content (soluble in formalin); when fat content is low there will be less discrepancy between the weights than when it is high. Landry (1978) states that in high food concentations, Acartia clausi copepodites accumulate excess carbon in a formalin-soluble form (probably lipid) which is not detected in the weight of formalin-preserved animals, and he further suggests that this accumulated carbon is a good measure of immediate condition. Durbin and Durbin (1978) recommend calculating a condition factor for copepods as is commonly done in fishery biology in order to obtain a better estimate of energy content.

Because of all these possible sources of variation in the logarithmic length-weight relationship the basic equation:

$$\mathrm{Log}_{10}\mathrm{Wgt} = b\mathrm{Log}_{10}L + \mathrm{Log}_{10}a$$

a & b = constants
Wgt = dry weight (mg)
L = length (mm)

should be evaluated for each sample collected and each species prior to preservation. In our study this procedure is no longer possible and so we have to select the best available estimate considering geographic location, season, and long-term effects of preservation (see Cohen and Lough, 1979, for a description of sample collection).

Methods

A. Individual species biomass

Several length-weight regression equations for each species are available from the literature. These equations have been standardized to a linear or exponential form for comparison, and L (in mm.) and W (in mg.) are substituted for length and weight, respectively, when other letters were used by the original authors. Durbin and Durbin (1978) and Robertson (1968) used fresh specimens in their investigations; all the other equations apply to formalin-preserved animals. Tables I - VII summarize these equations for the seven species of copepods along with size and stage limitations and any seasonal and geographic information available.

All equations for a given species are plotted on one graph (Figs. 1-7) with any size and stage restrictions indicated. Confidence intervals are available for the length measurements of Pseudocalanus sp. (Davis, 1977) and Acartia clausi (Durbin and Durbin, 1978) and are included on the respective curves.

B. Total sample biomass

Twenty-one .333 mm mesh, 20 cm bongo samples collected during the fall of 1974 on Jeffreys Ledge are used in the calculation of total sample biomass (see Lough and Cohen, 1977 for details of sampling). The displacement volumes of the crustacean fraction of these samples(consisting mainly of the seven copepod species investigated here) were determined according to procedures recommended by Ahlstrom and Thraikill (1963) and converted to dry weights using the equation:

$$\mathrm{Log}_{10}\mathrm{DV} = -1.828+0.848\ \mathrm{Log}_{10}\mathrm{DW}$$

(Wiebe et al., 1975)

DV=displacement volume ($m\ell/m^3$)

DW=dry weight (mg)

The values obtained are compared to the sum of the weights of the individual copepods composing the sample calculated with the nomographs of Chislenko (1968) using a two-tailed t-test on the difference between each pair of results.

Results

A. Individual species biomass

The wide variation in the length-weight relationships for the seven species demonstrated in the graphs (Figs. 1-7) is to be expected because of all the inherent sources of variation previously mentioned. Unfortunately, a quantitative comparison of the curves is not possible because confidence intervals are not available in most cases. All reported values probably represent dry weight because the results of Davis (1977), Schwartz (1977), Durbin and Durbin (1978), Corkett and McLaren (1978), and Robertson (1968) are known to be dry weights and their results usually agree with those of the other authors. Divergence in the plotted curves tends to increase with length in all species, perhaps as variation in length increases, especially in Pseudocalanus sp. (range for adult females can vary from 0.67 - 1.9 mm - Corkett and McLaren, 1978).

Davis (pers. comm.) has found that Corkett and McLaren's (1978) exponential equation fits his own data better than his original linear equation, and so Corkett and McLaren's equation will be considered the most applicable for Pseudocalanus sp. on Georges Bank.

B. Total sample biomass

Table VIII presents the results of a comparison of the total sample biomass (dry weight) calculated according to Wiebe et al. (1975) and the sum of the dry weights of the dominant copepod components calculated according to Chislenko (1968). The total sample biomass determined by the Chislenko method is greater than that determined by the method of Wiebe et al. in 19 out of 21 comparisons. The difference between each pair of values is highly significant at the <0.01 level. Displacement volume tends to be quite variable because of differences in the amount of interstitial water retained by the sample (Wiebe et al., 1975). An additional source of error may stem from some uncertainty in the calculation of the volume of water filtered by the bongo nets in this series of data.

Summary and Recommendations

More accurate length-weight relationships can be obtained by processing an appropriate number of unpreserved individuals from all stages of each copepod species of interest from each field sample collected. Length, ash-free dry weight, carbon, nitrogen, and caloric content values determined for each stage can then be substituted into the general equation, $\mathrm{Log}_{10}\mathrm{Wt} = \mathrm{bLog}_{10}\mathrm{L} + \mathrm{Log}_{10}\mathrm{a}$ (Landry , 1978). Then, only the mean length and number of individuals in each stage need to be recorded at a given time and location in order to calculate dry weight and convert the information into energy content (Landry, 1978, and Durbin and Durbin, 1978).

Since this procedure is not possible with previously collected samples an alternative method must be used. Based upon the data presented here and the goals of the larger investigation into larval herring feeding dynamics, Chislenko's nomographs are recommended (see Tables I-VII for numbers) in order to calculate the dry weights of all the larval herring prey items except Pseudocalanus sp. where the equation of Corkett and McLaren (1978) is recommended. Nomographs can be selected to produce values in close agreement with those studies used as standards in this paper (Davis, 1977; Durbin and Durbin, 1978; Schwartz, 1977; and Corkett and McLaren, 1978). The procedure of Wiebe et al. (1975) yielding total biomass values would require extra calculations and assumptions about the volume occupied by each stage of each species in the sample in order to determine the fraction of the total sample (or weight) contributed by the individual components needed in our investigation. Their method is more useful for comparing geographic and seasonal differences in total zooplankton biomass. Isaacs and Fleminger (1969) present another method of estimating biomass in terms of wet weight based upon specific length-weight conversions but their information applies to samples collected with a 0.500-mm mesh bongo net which generally consists of larger organisms than are of interest here.

Vast amounts of time and money could be saved during future survey work if an in situ method of recording zooplankton biomass could be perfected (Mullin and Huntley, pers. comm.). This same procedure, the "weight-dependent" method (consult M. Mullin or M. Huntley of Univ. California, LaJolla for details), could be applied to preserved samples as they are sorted using image analysis techniques or to the data obtained from in situ electronic zooplankton counters like the one described by Herman and Dauphinee (1980).

Beers (1970) has extensively reviewed and evaluated the literature in this general subject area and made recommendations for future work basically in agreement with those suggested here. He suggests using more accurate, expensive, and time-consuming techniques of estimating biomass in studies involving a limited taxonomic group of organisms, and encourages the development of in situ methods of biomass measurement for routine surveys.

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Table 1. Length-weight relationships for Pseudocalanus sp.

Author	Equation	Size range(mm)	Geographic location	Season
Anonymous (1976?)	$W=(0.0237)L^{3.745}$ [1]		Georges Bank	
Robertson (1968)	$W=(0.01816)L^{2.39}$ [2]	C5 & C6	North Atlantic & North Sea	
Gruzov & Alekseyeva (1970)	$W=(0.015)L^{2.918}$ [3] mean error= ±17%		Gulf of Guinea	
Davis (1977)	$W=(0.0046097L-0.00184735)$ [4] $r^2 = .95$		Georges Bank	Winter
Corkett & McLaren (1978)	$W=(0.0119)L^{3.64}$		Canadian Arctic	
Chrislenko (1968)	Table XI #3 $W=(0.0181)L^{3.0694}$			

1 P. elongatus
2 Paracalanus and Pseudocalanus
3 Pseudocalanidae
4 P. minutus

Table 2. Length-weight relationships for Paracalanus parvus.

Author	Equation	Size range (mm)	Geographic location	Season
Shmeleva (1963)	$W=(0.034)L^{2.419}$		Adriatic Sea	
Robertson (1968)	$W=(0.01816)L^{2.39}$ [1] $r^2=.65$	C5 and C6	North Atlantic & North Sea	
Gruzov and Alekseyeva (1970)	$W=(0.015)L^{2.918}$ [2] mean error = ±17%		Gulf of Guinea	
Chislenko (1968)	Table XI #7 $W=(0.0181)L^{3.0694}$			

1 Paracalanus and Pseudocalanus
2 Pseudocalanidae

Table 3. Length-weight relationships for *Centropages typicus*.

Author	Equation	Size range (mm)	Geographic location	Season
Anonymous (1976?)	$W=(0.0214)L^{3.87}$		Georges Bank	
Gruzov and Alekseyeva (1970)	$W=(0.028)L^{3.009}$ [1] mean error=±15%		Gulf of Guinea	
Chislenko (1968)	Table XI #9 $W=(0.02937)L^{3.0111}$			

[1] Centropagidae

Table 4. Length-weight relationships for *Centropages hamatus*.

Author	Equation	Size range(mm)	Geographic location	Season
Pertsova (1967)	$W=(0.0334L+0.0142)^3$	0.4-1.4	White Sea	
Robertson (1968)	$W=(0.01816)L^{2.39}$ $r^2 = .65$	C5 & C6	North Atlantic & North Sea	
Gruzov & Alekseyeva (1970)	$W=(0.028)^{3.009}$ [1] mean error=±15%		Gulf of Guinea	
Chislenko (1968)	$W=(0.02937)L^{3.0111}$			

[1] Centropagidae

Table 5. Length-weight relationships for *Oithona* spp.

Author	Equation	Size range (mm.)	Geographic location	Season
Shmeleva (1963)	*Oithona* spp. $W=(0.013)L^{2.174}$		Atlantic & Adriatic Seas	
Shmeleva (1963)	*Oithona similis* $W=(0.016)L^{2.213}$		Adriatic	
Chislenko (1968)	Table XI #5 $W=(0.0309)L^{3.069}$			

Table 6. Length-weight relationships for *Calanus finmarchicus*.

Author	Equation	Size range (mm)	Geographic location	Season
Anonymous (1976?)	$W=(0.0257)L^{3.141}$	1.3-4.0	Georges Bank	
Robertson (1968)	$W=(0.006458L)^{3.9}$ $r^2=.77$	C5 & C6	North Atlantic & North Sea	
Gruzov and Alekseyeva (1970)	$W=(0.015)L^{2.918}$ [1] mean error = ±17%		Gulf of Guinea	
Schwartz (1977)	$W=(0.002305)x10^{.6966L}$		Georges Bank	Spring
Chislenko (1968)	Table XI #7 $W=(0.0181)L^{3.0694}$			

[1] Calanidae

Table 7. Length-weight relationships for *Acartia clausi*.

Author	Equation	Size range (mm)	Geographic location	Season
Robertson (1968)	$W=(0.01318)L^{2.86}$ $r^2= .78$	C5 & C6	North Atlantic & North Sea	
Durbin & Durbin (1978)	$W=(0.013185)L^{3.1858}$ $r^2= .77$	C1	Narragansett Bay	
" "	$W=(0.009923)L^{3.0778}$ $r^2= .98$	C2-C5	Narragansett Bay	
" "	$W=(0.01237)L^{3.6276}$ $r^2= .94$	C6	Narragansett Bay	
Gruzov & Alekseyeva (1970)	$W=(0.017)L^{3.066}$ [1] Mean error= ±20%		Gulf of Guinea	
Chislenko (1968)	Table XI #2 $W=(0.0090)L^{2.969}$			

[1] Acartiidae

Table 8. Comparison of total sample biomass calculated according to Wiebe et al. (1975) with the sum of the individual sample components calculated according to Chislenko (1968).

Station	Haul	Displacement volume (ml/m^3)	Total dry weight Wiebe (1975) mg (W_1)	Sum. of components of dry weight Chislenko (1968) mg (W_2)	$W_1 - W_2$
1	2	0.491	61.789	70.40	- 8.611
1	3	0.489	61.61	91.13	-29.52
1	4	0.364	43.41	66.27	-22.86
1	5	0.15	15.28	22.59	- 7.31
2	1	0.047	9.16	19.41	-10.25
2	2	0.348	41.19	61.85	-20.66
2	3	0.545	70.02	109.80	-39.78
2	4	0.667	88.72	75.49	+13.23
2	5	0.65	86.11	97.51	-11.4
3	1	0.187	19.77	17.91	+ 1.86
3	2	0.268	30.24	43.66	-13.42
3	3	0.119	11.67	59.32	-47.65
3	4	0.25	27.91	49.93	-22.02
3	5	2.42	405.10	550.72	-145.62
4	1	0.909	8.49	16.97	- 8.48
4	2	0.26	29.26	39.24	- 9.98
4	3	0.580	75.24	107.36	-32.12
4	4	0.97	138.01	239.28	-101.27
4	5	0.742	100.64	175.86	-75.22
5	1	0.35	41.68	89.85	-48.17
5	2	0.056	4.81	13.49	- 8.69

t = -3.80565
d.f. = 20
sig. = 0.00129 (highly significant)

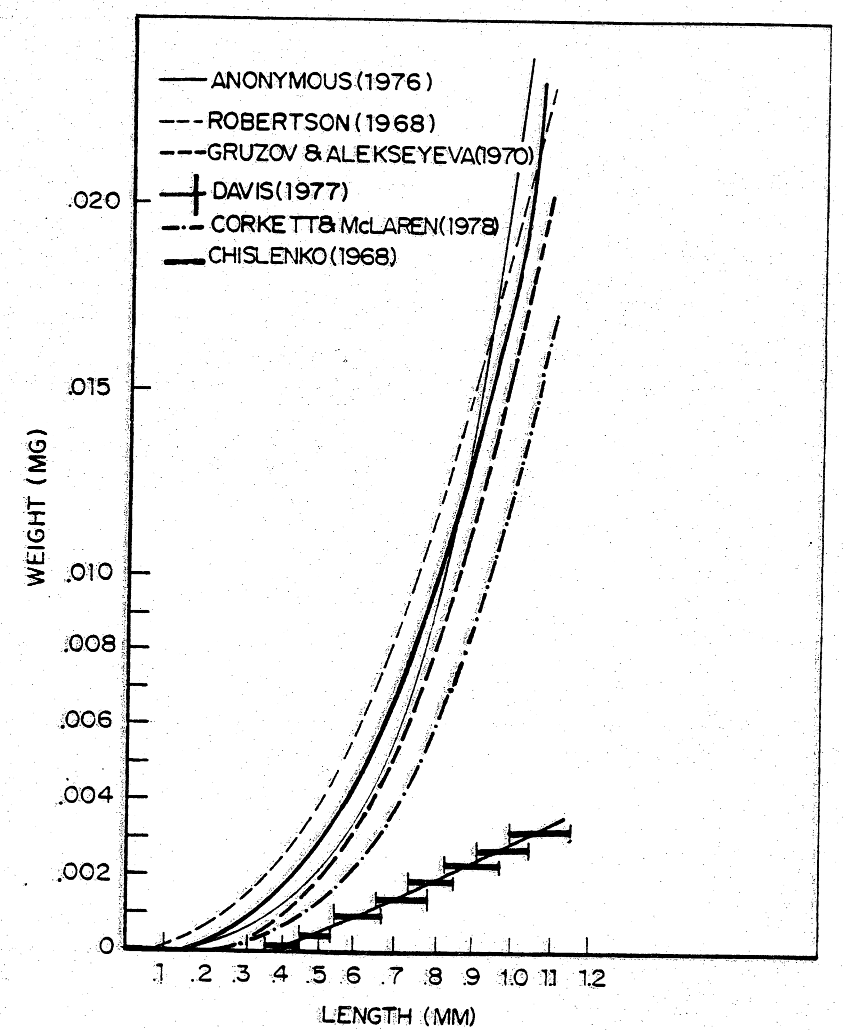

Figure 1. Length-weight relationships for Pseudocalanus sp.

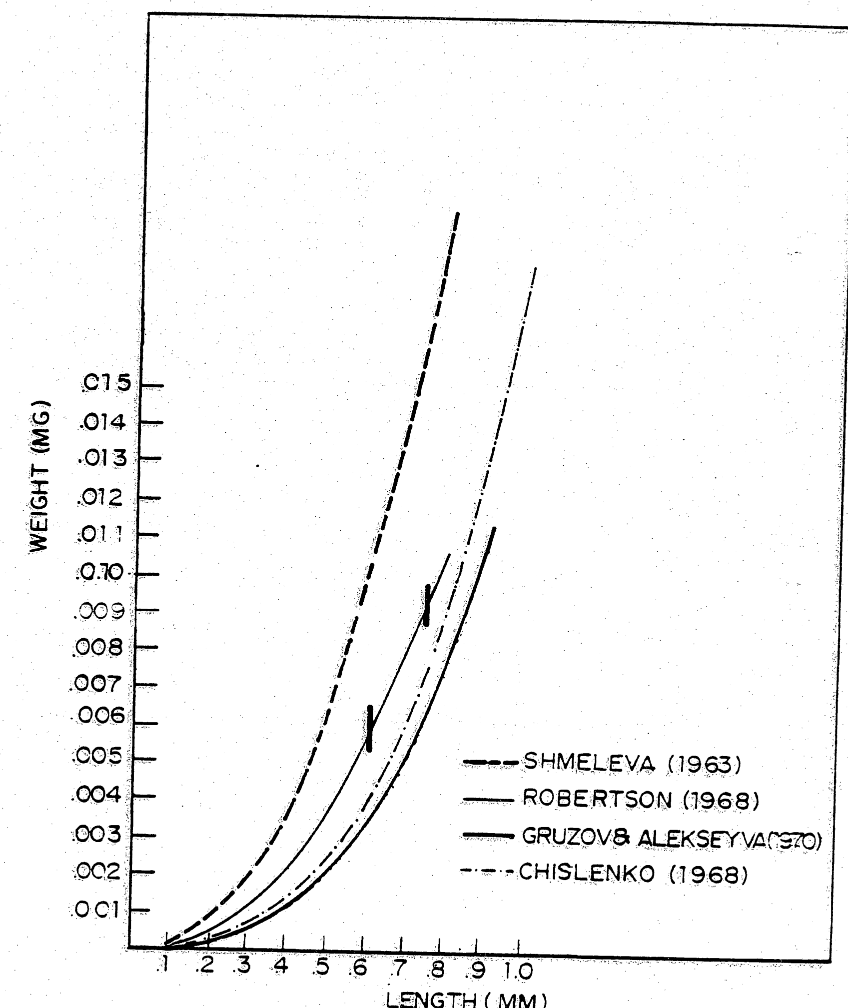

Figure 2. Length-weight relationships for Paracalanus parvus.

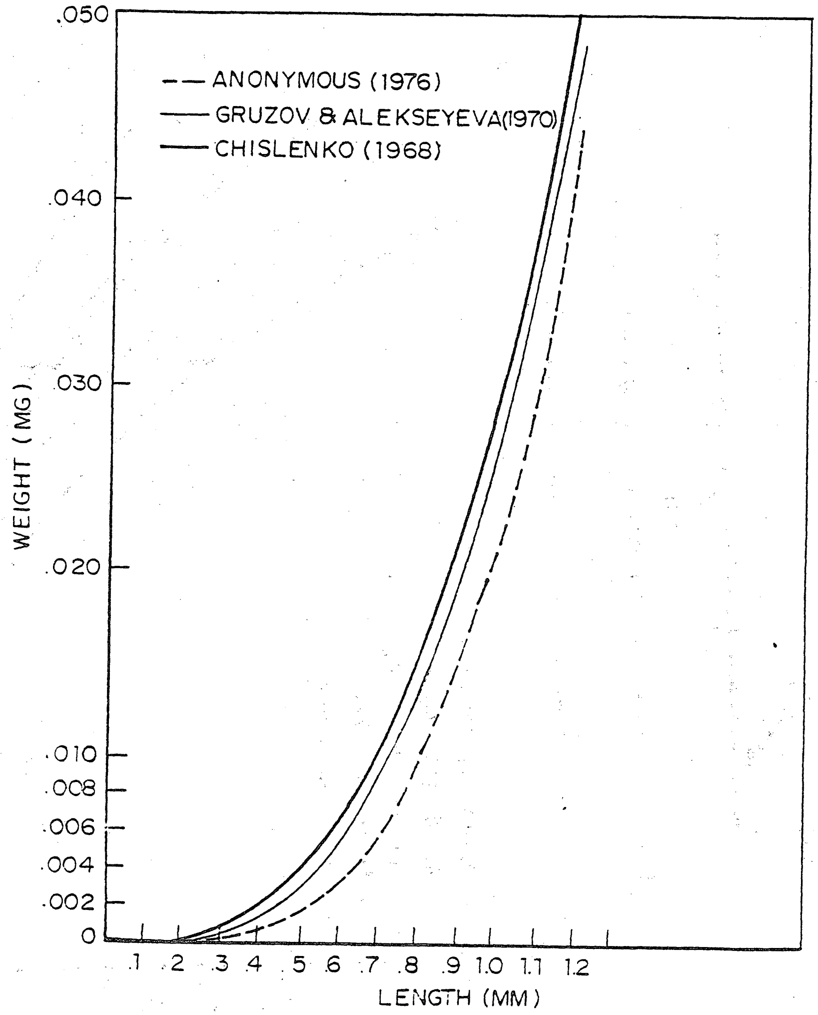

Figure 3. Length-weight relationships for <u>Centropages typicus</u>.

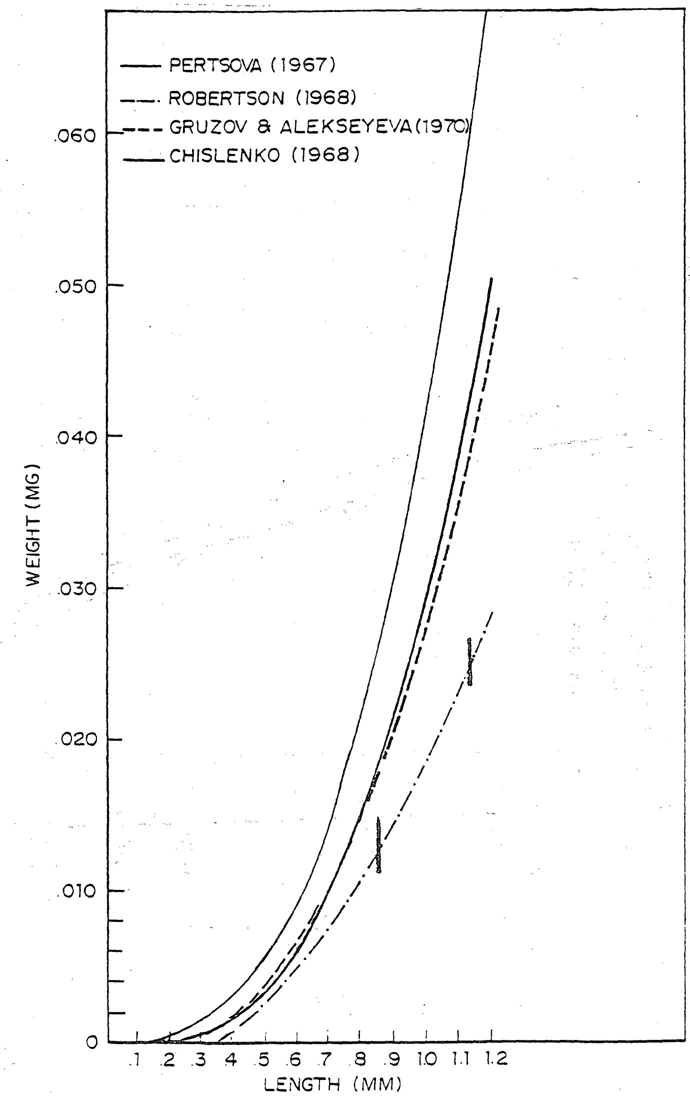

Figure 4. Length-weight relationships for <u>Centropages</u> <u>hamatus</u>.

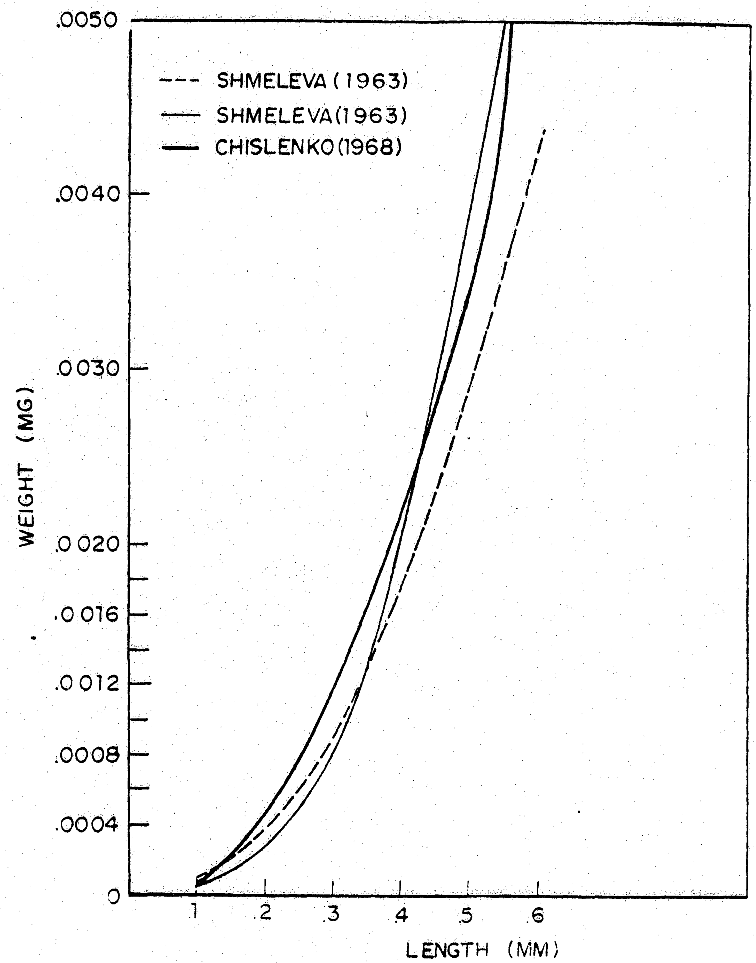

Figure 5. Length-weight relationships for Oithona spp.

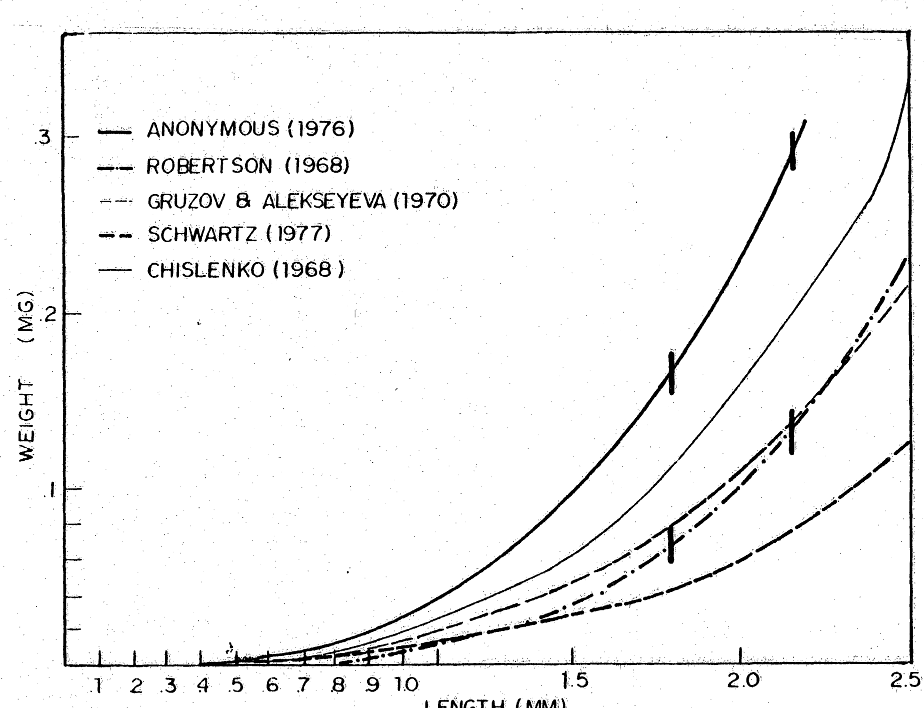

Figure 6. Length-weight relationships for Calanus finmarchicus.

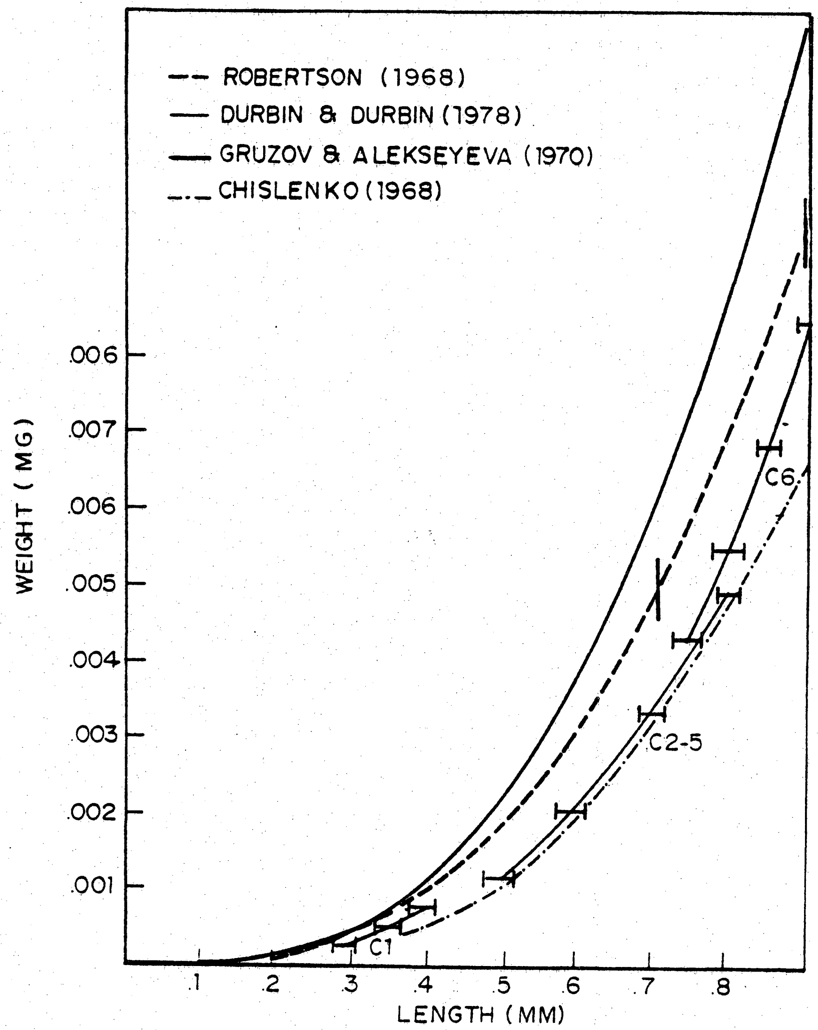

Figure 7. Length-weight relationships for *Acartia clausi*.