

## Biomass estimates of freshwater zooplankton from length-carbon regression equations

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### ABSTRACT

We present length/carbon regression equations of zooplankton species collected from Lake Maggiore (N. Italy) during 1992. The results are discussed in terms of the environmental factors, e.g. food availability, predation, controlling biomass production of particle-feeders and predators in the pelagic system of lakes. The marked seasonality in the length-standardized carbon content of *Daphnia*, and its time-specific trend suggest that from spring onward food availability for *Daphnia* population may be regarded as a simple decay function. Seasonality does not affect the carbon content/unit length of the two predator *Cladocera* *Leptodora kindtii* and *Bythotrephes longimanus*. Predation is probably the most important regulating factor for the seasonal dynamics of their carbon biomass. The existence of a constant factor to convert the diameter of *Conochilus* colonies into carbon seems reasonable for an organism whose population comes on quickly and just as quickly disappears.

Key words: carbon, body length, zooplankton

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### 1. INTRODUCTION

Carbon biomass estimates of zooplankters are essential for the evaluation of secondary production and the construction of models on energy and carbon flux through the zooplankton (Culver & De Mott 1978; Seruya *et al.* 1980). The use of a simple factor to convert from numbers to biomass is biased by the indeterminate growth of cladocerans and the numerous instars of copepods. The relative abundance of different stages and sizes of organisms change during the season, as do the average sizes of mature organisms (Culver 1980). In populations with continuous recruitment, the estimated relation between the size and carbon mass of individuals changes both with the size structure of the population and with the season, reflecting different nutritional conditions. If known, seasonal-specific equations allow an accurate reconstruction of changes in biomass, even in the long-term, whenever length measurements are available.

Among the different methods for estimating biomass, the analysis of dry weight and carbon content in live organisms has been recommended as the most appropriate (Boersma & Vijverberg 1994). In this paper we present the length/carbon regression equations resulting from the analysis of live zooplankton specimen collected from Lake Maggiore (N. Italy) during 1992.

### 2. MATERIALS AND METHODS

From March to November 1992 we analyzed the carbon (Carlo Erba 1106 elemental analyzer) of live individuals of known length and dry weight, selected from zooplankton samples collected from Lake Maggiore

(upper 50 m, Clarke-Bumpus plankton samplers, 76 and 126  $\mu\text{m}$  nets) at *ca* monthly intervals. From the samples, which represented the content of at least 1000 litre of lake water, we selected specimens of both herbivorous and predacious cladocera, namely *Daphnia hyalina-galeata*, *Bythotrephes longimanus*, *Leptodora kindtii*, as well as of a rotifer species (*Conochilus hippocrepis*) which has recently increased in numbers in the lake (Manca & Sonvico 1996). Sorted zooplankters from samples taken throughout the year were analyzed according to Manca *et al.* (1994, 1997), to account for seasonality.

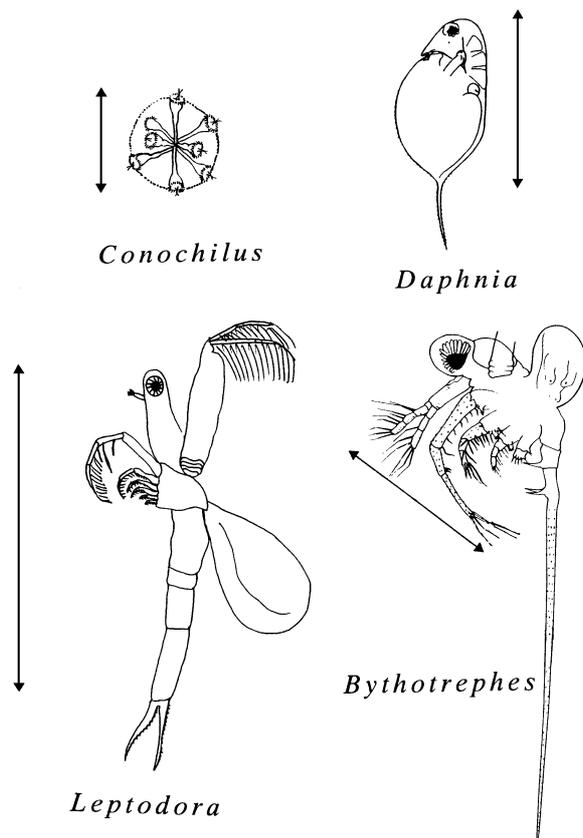
The selected species covered a wide range of body lengths, from 0.8 mm (*Conochilus* colonies, young *Daphnia*) to 9.7 mm (*Leptodora*). Each zooplankter was measured with an ocular micrometer according to its body shape (Fig. 1) (Culver *et al.* 1985). For *Bythotrephes* we separated body from spine length, measuring body length from the apex of the head to the base of the spine, barbs excluded (Burkhardt 1994). In the case of *Conochilus*, we measured the diameter of the spherical colonies (Ruttner-Kolisko 1974). The equation used was in the form:

$$\ln C = \ln a + b \ln L \quad (1)$$

where *a* and *b* are fitted constants, *C* is the weight (carbon, in  $\mu\text{g}$ ) and *L* the body length in mm.

Analysis of variance was performed on each regression to determine whether the slope and the intercept of the line (value of *b* and *a*, respectively) were significantly different from zero (*F*-test). In the case of a wide scattering of the data we calculated the parameters of the equations for different periods of the year, using a *t*-

test for differences among slopes and for differences among intercepts (two-tailed test at  $P < 0.05$ ).



**Fig. 1.** Method of measuring body length for the different zooplankton taxa.

### 3. RESULTS AND DISCUSSION

There was a marked seasonality in the carbon content per unit length of *Daphnia* (Manca *et al.* 1997). As a consequence, the equation for the pooled data (only non-ovigerous females) accounted for only 54% of the total variance.

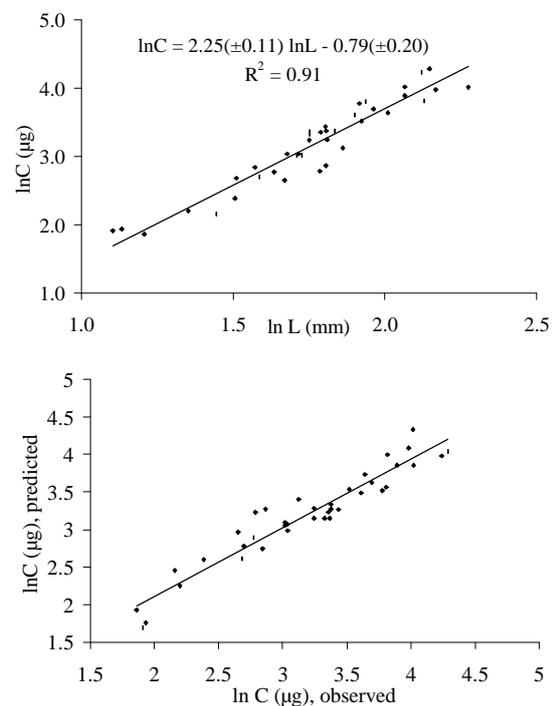
The difference between spring and summer data was essentially due to an exponential decrease of the length-standardized carbon content from spring onward. The slope of the relation carbon/length was the same for different body length classes so we found that, instead of giving different equations for different periods of the year, a simple adjustment of the elevation of the regression line was sufficient to describe the entire set of data and account for the time trend in the Length Carbon Regression. There was no need to adjust the slope with a product (interaction) term ( $d t \ln L$ ). The resulting equation for *Daphnia* (only non-ovigerous females) was as follows:

$$\ln C = 1.830(\pm 0.137) + 1.865(\pm 0.198) \ln L - 0.0033(\pm 0.0006) t \quad (2)$$

where  $C = \mu\text{g}$ ;  $L = \text{mm}$ ;  $t = \text{days}$ ;  $R^2 = 0.76$ ;  $F = 46.47$ ;  $N = 425$ ;  $P < 0.001$  (Manca *et al.* 1997).

The parameters of the time-corrected LCR equation of *Daphnia* did not change significantly when females with eggs in the first three developmental stages (as described by Green 1956) were included (Manca *et al.* 1997). We explained this result considering egg deposition up to this stage as a simple transfer of a certain amount of carbon from one compartment of the mother's body (lipid drops) to another (brood chamber, as eggs) (Manca *et al.* 1994).

The individual carbon content of *Leptodora* increased exponentially with body length (Fig. 2). A single estimate of the parameters was sufficient to describe the pooled data, obtained during the entire growing season of the population in Lake Maggiore. This means that seasonality is not important for the carbon content of this predacious species, and variations are only due to changes in body length.



**Fig. 2.** Length/Carbon regression equation of *Leptodora kindtii* collected from Lake Maggiore (pooled data from June to September). Predicted/observed individual carbon values are also reported.

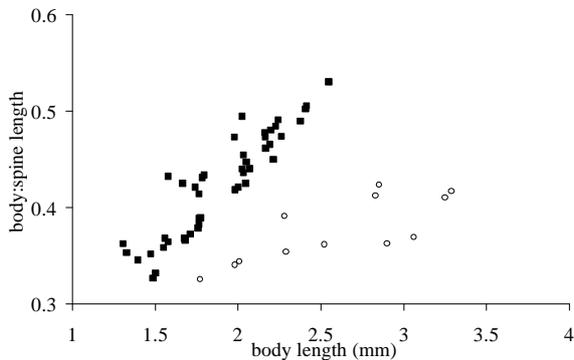
The equation most satisfactorily fitting the experimental data was as follows:

$$\ln C = -0.79(\pm 0.20) + 2.25(\pm 0.11) \ln L \quad (3)$$

with  $R^2 = 0.91$ ;  $F = 389.12$ ;  $N = 49$ ;  $P < 0.001$ .

The slope of the curve is a little more than 2, as commonly reported in literature (Peters 1983). Therefore, the length-standardized carbon content of *Leptodora* increases linearly with body length. Contrary to *Daphnia*, no saturation-type effect is observed for this species (Manca *et al.* 1994).  $C$ : dry weight ratio is fairly constant, around 0.41.

Carbon content of *Bythotrephes* is negatively correlated with body length (spine excluded) at a high significant level ( $r=0.92$ ;  $P<0.001$ ). Spine length does not affect so much the relationship between carbon and body length of *Bythotrephes*.



**Fig. 3.** Relationship between spine and body length in *Bythotrephes*. Full squares refer to *B. longimanus* from Lake Maggiore; open circles to *B. cederstroemi* (data from Burkhardt 1994).

The ratio body: spine length ( $B:S$ ) increases linearly with body length ( $B$ ): younger, smaller individuals of *Bythotrephes longimanus* possess proportionally longer spines than older, larger ones (Fig. 3). A regression equation satisfactorily fits the data, with both slope and intercept of the equation significantly different from zero:

$$B:S = 0.13(\pm 0.02) + 0.15(\pm 0.01) B \quad (4)$$

with  $R^2 = 0.84$ ;  $F = 229.38$ ;  $N = 43$ ;  $P < 0.001$ . Our data are quite different from those of the congeneric species *B. cederstroemii* (Burkhardt 1994); the data do not overlap and the regression lines would have different slopes (Fig. 3). In fact, the tail spine of *B. cederstroemii* is markedly longer than that of *B. longimanus*. Carbon content of *B. longimanus* is well correlated with its body length, spine excluded. Although more scattered than in *Leptodora*, the data obtained at different times of the year are satisfactorily described by a single LCR equation, which accounts for more than 80 per cent of the total variance (Fig. 4). The equation is as follows:

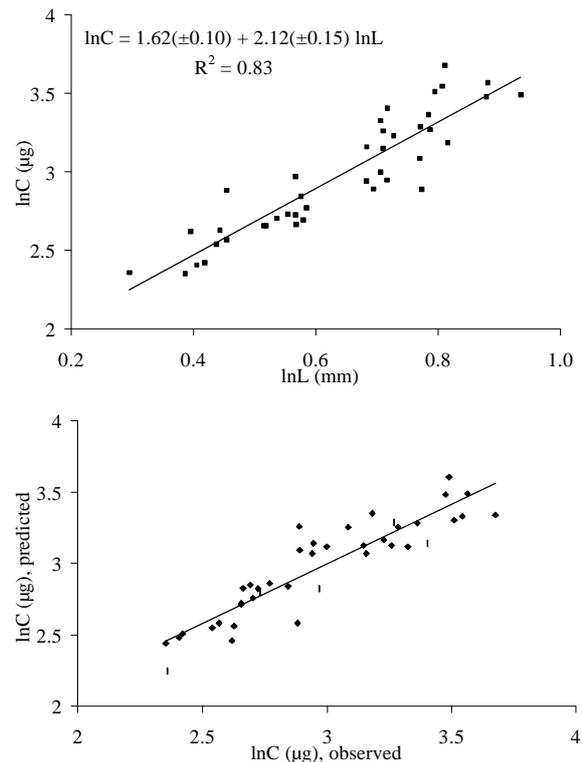
$$\ln C = 1.62(\pm 0.10) + 2.12(\pm 0.15) \ln L \quad (5)$$

with  $R^2 = 0.83$ ;  $F = 192.98$ ;  $N = 47$ ;  $P < 0.001$ .

As for *Leptodora*, slope is quite close to 2, indicating a linear increase of the length-standardized carbon content together with body length.

Finally, the carbon content of *Conochilus hippocrepis* increases linearly with the diameter of the colonies; a constant factor allows the conversion of size into carbon ( $3 \pm 0.6 \mu\text{g mm}^{-1}$ , in a range of 0.8-1.4 mm). No significant variation is found with seasonality. Although related to the body length of the oldest individuals, colony size results in an increase in the number of individuals/colony (Manca & Sonvico 1996). A *Conochilus*

colony has approximately half the carbon content/unit length of a "spring" *Daphnia*.



**Fig. 4.** Length/Carbon regression equation of *Bythotrephes longimanus* collected from Lake Maggiore (pooled data from March to November). Predicted/observed individual carbon values are also reported.

#### 4. CONCLUSIONS

Seasonal variations in the length-standardized carbon content reflect variations in food conditions, which are related to food quality and quantity (Duncan 1985; Manca *et al.* 1994).

The marked seasonality of the length-standardized carbon content of *Daphnia* suggests that food conditions are a very important regulating factor for the growth of *Daphnia* population in Lake Maggiore. Although a seasonal decrease in carbon/unit length is observed in other lakes (Berberovic 1990), the numerical value of parameter  $c$  in equation (2) is probably specific to Lake Maggiore, and likely also to the year of the study. However, the type of time-specific trend observed suggests that, from spring onward, food availability for *Daphnia* population may be represented by a simple decay function. The highest value is found when large individuals of *Daphnia* are present in low numbers, in an environment rich in food. Spring can be regarded, for *Daphnia* population, as a very delicate phase, in which the potential is poised for the subsequent development of the population.

The decrease in length-specific carbon content indicates that the transfer of this potential energy into new

individuals results in an increase in competition. Changes in individual carbon content are also important for organisms that prey on *Daphnia*. To get the same amount of carbon, a higher number of individuals are required in summer than in spring. Apart from being well explained on a metabolic basis, the saturation-type carbon/body length curve of *Daphnia* may be regarded as a stabilising mechanism, able to reduce the damage of individual predation on the larger upper size component of the population.

Food conditions do not seem to play an important role for *L. kindtii* and *B. longimanus* of Lake Maggiore. These two Cladocera change their diet with the season because different prey are available, although they are selective in their food preferences (Branstrator & Lehman 1991; Schultz & Yurista 1996). Indeed, our data suggest that the input of biomass and energy per unit size tends to remain constant, indicating that competition is not an important factor for their populations. Predation is probably the most important regulating factor for the seasonal dynamics of carbon biomass of *L. kindtii* and *B. longimanus* in Lake Maggiore: it acts on both the density and the size structure of the population. It is not restricted to fish, indeed, as *B. longimanus* itself is able to capture and eat *L. kindtii*. In Lake Maggiore, the two predators tend to be separated in time and space: *B. longimanus* is a spring and autumn species, while *L. kindtii* is a typical summer taxon. The former is usually most abundant in the epilimnion, while the latter also inhabits deep waters. *B. longimanus* predation seems to play a role during the late summer phase of decline of the *L. kindtii* population (Manca, pers. obs.).

While unimportant for carbon, the length of *B. longimanus* spine is considered important for repelling predation by young fish (Barnhisel 1991; Burkhardt 1994; Tatrai *et al.* 1995). Its inverse relationship with body length suggests that spine elongation is a mechanism to minimize predation pressure on young individuals. Differences in slope of the equations found for *B. longimanus* and *B. cederstroemii* (Fig. 3) might reflect differences in size of the predator-prey spectra. Classic papers already commented on the relatively small size of *B. longimanus* specimens from deep, subalpine lakes, (Ishreyt 1938) as well as on their ability to produce eggs before moulting (ovigerous one-pair barbs females), as well as on their incomplete development (lacking of three-barbed individuals).

Finally, the existence of a constant factor to convert diameter of *Conochilus* colonies into carbon seems reasonable for an organism whose population comes on quickly and just as quickly disappears.

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