CALORIC VALUES OF SOME NORTH ATLANTIC CALANOID COPEPODS

Evaluation of the dynamics of energy exchange of a marine ecosystem necessitates a knowledge of the caloric equivalents of its living constituents. This information, in combination with information on growth, metabolism, and assimilation rates can lead to predictions of energy conversion between trophic levels and estimates of production.

Researchers have accumulated a considerable quantity of data concerning the caloric value of marine organisms (Cummins 1967; Thayer et al. 1973; Tyler 1973); however, values recorded for marine, planktonic copepod species have been few (Slobodkin and Richman 1961; Comita et al. 1966; Cummins 1967). My research reports the caloric values for seven species of marine copepods, six of which apparently have not been previously recorded. These studies are part of an overall investigation of the bioenergetics of the early life stages of some North Atlantic fish species.

Materials and Methods

Plankton samples were collected in July and August 1972 off Narragansett Bay, R.I. except for samples of *Pseudocalanus minutus* which were collected in April 1971 off the coast of Delaware. All samples were preserved in 5% Formalin[1] and were prepared and combusted in July and August 1972. Laboratory preparation included rinsing the samples in distilled water for 1 h, sieving through a coarse mesh screen to remove large detritus, and hand sorting adults of the various copepod species under a dissecting microscope. Pure copepod species samples were dried for 24 h at 90°C and desiccated in a silica gel desiccator after which they were made into pellets for combustion. All combustion was done in a Parr 1241 automatic, adiabatic calorimeter adapted for a microbomb. Combustion samples for each copepod species were done in triplicate. Percent ash for each copepod species was determined by ashing uncombusted pellets in triplicate at 500°C for 4 h in a muffle furnace.

Results

Mean values for the caloric determinations of the seven species of copepods (Table 1) were as follows: 5,251.9 cal/g dry weight, 5,626.3 cal/g ash-free dry weight, and 6.70% ash. Statistical analysis of the means of caloric values for each species (Duncan's New Multiple Range Test, Steel and Torrie 1960) indicated that *Calanus finmarchicus* had significantly higher values of both calories per gram dry weight and calories per gram ash-free dry weight than all other species, that *Temora longicornis* had significantly lower values for calories per gram ash-free dry weight than all species except *Centropages hamatus*, and that the differences between *Acartia tonsa*, *Tortanus discaudatus*, *P. minutus*, *Centropages typicus*, and *C. hamatus* were minimal (Table 1).

Temora longicornis had the highest percent ash. *Acartia tonsa* and *P. minutus* also had relatively high ash values in comparison with the other species, while *Calanus finmarchicus* was intermediate and higher than the three remaining species (Table 1).

TABLE 1. — Caloric and ash values for some North Atlantic copepods. Species are recorded in order from largest to smallest mean value under each category. Those species side-scored have similar means (Duncan's New Multiple Range Test, $P = 0.05$).

Species	Mean	Standard deviation
cal/g dry weight		
Calanus finmarchicus	6,425.1	±187.0
Tortanus discaudatus	5,398.3	±14.6
Centropages typicus	5,244.7	±183.3
Acartia tonsa	5,160.0	±78.8
Pseudocalanus minutus	5,070.9	±181.7
Centropages hamatus	4,998.6	±246.3
Temora longicornis	4,466.3	±92.8
cal/g ash-free dry weight		
Calanus finmarchicus	6,835.2	±191.2
Acartia tonsa	5,664.1	±86.6
Tortanus discaudatus	5,642.0	±15.3
Pseudocalanus minutus	5,541.9	±198.6
Centropages typicus	5,503.4	±192.3
Centropages hamatus	5,212.3	±256.9
Temora longicornis	4,984.7	±103.6
% ash		
Temora longicornis	10.40	±0.16
Acartia tonsa	8.90	±0.16
Pseudocalanus minutus	8.50	±0.11
Calanus finmarchicus	6.00	±1.82
Centropages typicus	4.70	±0.28
Tortanus discaudatus	4.32	±0.07
Centropages hamatus	4.10	±0.13

Discussion

Since the species in this study were preserved in Formalin for short periods of time and rinsed in distilled water to remove the Formalin before processing, the estimates of caloric and ash content

[1]Reference to trade names does not imply endorsement by National Marine Fisheries Service, NOAA.

and dry weight may have been slightly affected due to an unknown loss of chemical constituents. Methods of preservation of animals before combusting or determining chemical composition and weights have been a subject of debate. Omori (1970) showed there was considerable variation with no apparent trend of chemical composition and weight of *Calanus cristatus* that were frozen, dried, or preserved in Formalin. Except for dry weight, which was lowest in Formalin-preserved specimens, he found no clear relationship between percent ash, carbon, nitrogen, and hydrogen composition and the methods of preservation. Faustov and Zotin (1965) determined that fixing by drying or in 4% Formalin had no significant effect on the caloric value of fish embryos and, consequently, results obtained with fresh or fixed material could be directly compared. In the present study, samples of fresh and preserved (5% Formalin) *C. finmarchicus* were compared. Calories per gram dry weight and percent ash were less for the preserved sample, however, the differences were minimal (274.8 cal/g dry weight and 3.78% ash which corresponds to 275.0 cal/g ash-free dry weight) and only slightly greater than one standard deviation (Table 1).

In view of the apparent lack of specific effects of preservation method on chemical composition, weights, and caloric values reported in the literature and the results with *C. finmarchicus* in this research, it may be concluded that the values presented in this paper are only slightly underestimated, if at all. Also, since all samples in this study were treated the same way, relative comparisons between them should be valid.

Attempts to explain the differences in caloric values on the basis of phylogeny proved inadequate. All species are calanoid copepods and, although *C. finmarchicus* and *P. minutus* are members of a different, more primitive taxonomic subdivision under the Calanoida than the other species (Sars 1903), the values for *P. minutus* were statistically more similar to the lower values for the other species than to *C. finmarchicus*.

There is a lack of information on the specific chemical composition of the species tested in this research with the exception of *C. finmarchicus*. *Calanus finmarchicus* is known to have a reasonably high fat content. Comita et al. (1966) noted that, upon fixation, globules of fat were extruded from living specimens and that a layer of oil formed on the surface of the fixed sample. They determined the caloric value of the fat of *C. finmarchicus* to be 9,500 cal/g. Fisher (1962) determined the lipid content for a number of marine Crustacea and found the concentrations in *C. finmarchicus* to be consistently among the higher values recorded. Although there are no fat content values for the six other species tested in this research to compare with *C. finmarchicus*, the implication is that the lipid content in *C. finmarchicus* may be the cause of its higher caloric value. The caloric determinations of *C. finmarchicus* recorded in this research (Table 1) compare closely with the results of other workers (Slobodkin 1962; Comita and Schindler 1963; Comita et al. 1966). In fact, the caloric values of *C. finmarchicus* have been some of the highest recorded for copepods.

Temora longicornis had lower caloric values than the other species and the highest percentage of ash (Table 1). This may be the result of its morphology which is somewhat different compared to the other species. It has a proportionately rounder and deeper cephalothorax that may contribute to a higher percentage of inorganic exoskeleton.

The overall means for the caloric values of all the species (5,251.9 cal/g dry weight and 5,626.3 cal/g ash-free dry weight) are similar to composite sample caloric values recorded by other investigators. A calculation based on the data of Ostapenya et al. (1967) using their values of calories per gram dry weight and percent organic matter for Gulf of Mexico plankton samples, which were predominantly copepods including *Acartia* sp., *Centropages* sp., and *Temora* sp. (separate values for each of these genera were not reported), produced a mean value of 5,187 cal/g ash-free dry weight. A similar confirming value of 5,016 cal/g dry weight was obtained using the percent organic matter in the dry material in my research (calculated by subtracting the mean percent ash, 6.70%, from 100) and the regression relationship between that and ash-free dry weight devised by Platt et al. (1969).

Seasonal changes in the caloric value of zooplankton have been verified in several studies (Comita et al. 1966; Conover 1968; Siefken and Armitage 1968). The species in this study undoubtedly undergo seasonal variations also, and this is a subject for future investigation. However, all the species used in this research, with the exception of *P. minutus*, were collected at approximately the same time in the same general area and can be used for a comparison of the potential energy available to predators at a particular time and place.

Examination of data on the abundance of adult and nauplii stages in the Narragansett Bay and Block Island Sound areas (Deevey 1952; Faber 1966) for the time of year samples for this research were collected (July-August) showed that, although all seven species were present, only *A. tonsa*, *T. longicornis*, and *C. hamatus* were available in sufficient quantity to be considered major prey organisms. They represented 24.6, 10.8, and 10.4%, respectively, of the total copepods available, while the other four species were less than 3%. The results of this study in calories per gram ash-free dry weight (Table 1) show that *A. tonsa* had the second highest value while *C. hamatus* and *T. longicornis* had the two lowest values. In fact, the difference between *A. tonsa* and *T. longicornis* is 680 cal/g. This indicates, assuming equivalent assimilation rates, that predators utilizing the copepods like *A. tonsa* with higher caloric values may have an advantage in acquiring energy for growth and metabolic processes. Predators feeding on copepods with lower values, especially *T. longicornis*, would have to consume more prey organisms for an equivalent energy intake and, given the same density of plankton, would spend more energy searching for their prey.

Acknowledgments

I thank John B. Colton, Jr. for his critical review of the manuscript and Stephen Hale for his technical assistance.

Literature Cited

COMITA, G. W., AND D. W. SCHINDLER.
1963. Calorific values of microcrustacea. Science (Wash., D.C.) 140:1394-1396.

COMITA, G. W., S. M. MARSHALL, AND A. P. ORR.
1966. On the biology of *Calanus finmarchicus*. XIII. Seasonal change in weight, calorific value and organic matter. J. Mar. Biol. Assoc. U.K. 46:1-17.

CONOVER, R. J.
1968. Zooplankton—Life in a nutritionally dilute environment. Am. Zool. 8:107-118.

CUMMINS, K. W.
1967. Calorific equivalents for studies in ecological energetics. 2nd ed. Univ. Pittsburg, Pittsburg, 52 p.

DEEVY, G. B.
1952. Quantity and composition of the zooplankton of Block Island Sound, 1949. Bull. Bingham Oceanogr. Collect., Yale Univ. 13:120-164.

FABER, D. J.
1966. Seasonal occurrence and abundance of free-swimming copepod nauplii in Narragansett Bay. J. Fish. Res. Board Can. 23:415-422.

FAUSTOV, V. S., AND A. I. ZOTIN.
1965. Changes in the heat of combustion of the eggs of fishes and amphibians during development. Akad. Nauk SSSR (Doklady) Biol. Sci. 162:965-968.

FISHER, L. R.
1962. The total lipid material in some species of marine zooplankton. Rapp. P.-V. Réun., Cons. Perm. Int. Explor. Mer 153:129-136.

OMORI, M.
1970. Variations of length, weight, respiratory rate and chemical composition of *Calanus cristatus* in relation to its food and feeding. *In* J. H. Steele (editor), Marine food chains, p. 113-126. Univ. Calif. Press, Berkeley.

OSTAPENYA, A. P., L. M. SUSHCHENYA, AND N. N. KHMELEVA.
1967. Caloricity of plankton from the tropical zone of the ocean. [In Russ., Engl. abstr.] Okeanol. Keanologiza 6:1100-1107.

PLATT, T., V. M. BRAWN, AND B. IRWIN.
1969. Caloric and carbon equivalents of zooplankton biomass. J. Fish. Res. Board Can. 26:2345-2349.

SARS, G. O.
1903. An account of the crustacea of Norway, Vol. 4, Copepoda Calanoida. Bergen Museum, Christiana, 171 p.

SIEFKEN, M., AND K. B. ARMITAGE.
1968. Seasonal variation in metabolism and organic nutrients in three *Diaptomus* (Crustacea: Copepoda). Comp. Biochem. Physiol. 24:591-609.

SLOBODKIN, L. B.
1962. Energy in animal ecology. Adv. Ecol. Res. 1:69-101.

SLOBODKIN, L. B., AND S. RICHMAN.
1961. Calories/gm in species of animals. Nature (Lond.) 191:299.

STEEL, R. G. D., AND J. H. TORRIE.
1960. Principles and procedures of statistics. McGraw-Hill Book Co., Inc., N.Y., 481 p.

THAYER, G. W., W. E. SCHAAF, J. W. ANGELOVIC, AND M. W. LACROIX.
1973. Caloric measurements of some estuarine organisms. Fish. Bull., U.S. 71:289-296.

TYLER, A. V.
1973. Caloric values of some North Atlantic invertebrates. Mar. Biol. (Berl.) 19:258-261.

GEOFFREY C. LAURENCE

Northeast Fisheries Center Narragansett Laboratory
National Marine Fisheries Service, NOAA
Narragansett, RI 02882

METHOD FOR RESTRAINING LIVING PLANKTONIC CRUSTACEANS[1]

Studies of the feeding and swimming mechanisms of small, active planktonic crustaceans require restraining the organisms so that water flow and limb movements can be observed under the microscope. The usual technique is to place the organism in a watch glass or cavity slide (Cannon 1928; Gauld 1966) or to secure the dorsal side of the animal to a drop of stopcock grease in

[1]Contribution No. 3488 from the Woods Hole Oceanographic Institution. This work was supported by NSF Grant GA-41188.