

## Development and energy content of a brackish-water copepod, *Apocyclops royi* (Lindberg) reared in a laboratory<sup>1</sup>

WEN-BEEN CHANG and CHI-HSIANG LEI<sup>2</sup>

Institute of Zoology, Academia Sinica, Nankang,  
Taipei, Taiwan 115, Republic of China

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**Wen-Been Chang and Chi-Hsiang Lei** (1993) Development and energy content of a brackish-water copepod, *Apocyclops royi* (Lindberg) reared in a laboratory. *Bull. Inst. Zool., Academia Sinica* 32(1): 62-81. The cyclopoid copepod *Apocyclops royi* produced six nauplius, five copepodite instars, and an adult stage when reared in a laboratory under 25°C, 30‰ salinity, and with excess food resources. The durations of all nauplius were short and nearly isochronal beyond the copepodid I stage. Generation length was sixteen days. Regression equations for prosome length (P.L.) and body length (B.L.) vs. dry weight (D.W.), plus ash free dry weight (AFDW) were expressed as follows:

a). Nauplii:

$$\ln(D.W.) = 1.0128 \ln(B.L.) - 2.633 (R^2 = 0.768)$$

$$\ln(AFDW) = 1.1771 \ln(B.L.) - 3.120 (R^2 = 0.756)$$

b). Copepodites and Adults:

$$\ln(D.W.) = 1.5289 \ln(P.L.) - 3.876 (R^2 = 0.964)$$

$$\ln(AFDW) = 0.9255 \ln(P.L.) - 2.445 (R^2 = 0.891)$$

$$\ln(D.W.) = 1.2924 \ln(B.L.) - 3.504 (R^2 = 0.978)$$

$$\ln(AFDW) = 0.7821 \ln(B.L.) - 2.220 (R^2 = 0.903)$$

The mean ash content of this species was 2.47%, and the mean energy content of later copepodite stages was 5.13 cal/mg D.W. or 5.33 cal/mg AFDW.

**Key words:** *Apocyclops royi*, developmental stages, Laboratory rearing, Energy content, Brackish-water copepod.

*Apocyclops royi* (Lindberg) is a newly-recorded cyclopoid copepod species found in the Tan-Shui River estuary and brackish-water shrimp ponds in I-Lan and Tainan, Taiwan (Chang et al., 1991). The species has also been reported in freshwater regions of mainland China by Tai and Chen (1979). Adult and later copepodite stages of *A. royi* feed on the eggs and gravid segments of the

cestode *Hymenolepis gracilis* (see Su and Lin, 1985) and nauplii of artemia (pers. obs.). In the Tan-Shui River estuary, this species occurs commonly and subdominantly year-round in zooplankton.

It is important to accurately estimate biomass and production for predator-prey interactions in aquatic ecosystems (Chisholm and Roff, 1990). Copepods generally dominate metazoan zooplankton both in abun-

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2. Dr. Lei passed away on September 12, 1990.

dance and biomass; their biomass and energy content can be estimated by various methods, most readily by the relationship between length and weight. Regression equations are useful since they allow for the option of calculating species biomass separately, or combining species into higher taxonomic or functional groups.

Compared with other copepods, *Apocyclops royi* is easily reared under laboratory conditions. In spite of its importance in this area as a secondary producer, the life history of this species has not been studied. In order to acquire basic information on its life history, as well as to utilize it as a food source for fish larvae, we cultivated this copepod in our laboratory. This paper describes the developmental stages, energy content, and length-weight relationship of *A. royi*.

## MATERIALS AND METHODS

### Development

Ovigerous *Apocyclops royi* (Lindberg) females were selected from plankton samples collected from the Tan-Shui River estuary, and were laboratory-reared for several generations in glass beakers containing 400 ml of filtered, aerated seawater of 30 ‰ salinity. Sea water was filtered through a 0.45 µm millipore membrane. They were fed algae (*Tetraselmis chui*) at an excessive concentration of  $> 10^5$  cells/ml. The glass beakers were kept in a growth chamber at 25°C, 600 lux, and a 16L:8D photoperiod. Females were kept individually in 50 ml beakers containing approximately 30 ml of filtered seawater and covered with polyethylene wrap to prevent evaporation.

Soon after hatching, nauplii (the newly hatched larvae) developed to the adult stage, on diets of *Tetraselmis chui*. Specimens at different developmental stages were preserv-

ed in 5% formaline solution to assist in the drawing of body forms and appendages.

### Length-weight relationship and energy content

After measuring body and prosome length (Gooding, 1957; Pearre, 1980), animals were quickly washed with ammonium formate and distilled water over a vacuum filter. Since the prosome contains most of the animal's body tissue, prosome length was measured from the head to the flexure joint (Pearre, 1980). This section is easy to measure in comparison with body length since the urosome is often flexed. Animals were then placed in pre-weighed aluminum foil pans (dried at 500°C and weighed on a CANH C-31 Microbalance to 0.1 µg, about 1–2 mg), and dried at 60°C for 48h (Harris and Paffenhofer, 1976). Samples were then cooled in a desiccator and allowed to equilibrate to a constant weight. Samples were burned in a muffle furnace at 500°C (Edmondson and Winberg, 1971; Harris and Paffenhofer, 1976; Geller and Muller, 1985; Chisholm and Roff, 1990) and weighed (as described above) to determine ash content.

Krylov (1968) determined a simple relationship of weight (W) as being proportional to the cube of length (L). In order to account for shape differences, however, it is necessary to introduce a constant (A), so that the equation becomes

$$W = AL^3,$$

with A assuming a different value for individual copepod species. The antilog of a log-normal model for a length-weight regression (Bird and Prairie, 1985; Geller and Muller, 1985) is:

$$\ln W = \ln A + B \times \ln L$$

These observations are commonly

transformed to natural logarithms before analyzing both the independent variable (length) and dependent variable (weight) (Dumont *et al.*, 1975; Bottrell *et al.*, 1976; McCauley, 1984; Bird and Prairie, 1985). Such a transformation is necessary in order to conform more closely to an assumption of linear regression analysis regarding homogeneity of error variance over the range of the equation (see Prepas, 1984, pp. 315-318). This transformation also helps to make observations fall more or less along a straight line rather than a curve.

The energy content of fresh copepodite at later stages was measured using a Phillison oxygen micro-bomb calorimeter (Moshiri, 1968). Preliminary calibrations were made via the combustion of ten benzoic acid pellets ranging from 8.45 to 18.67 mg. The bomb was charged with oxygen to a pressure of 35 atm, then immersed in cold water to check for leaks and to bring the temperature of the bomb close to that of the cold junction block of the bomb stand. When a thermal equilibrium was reached — as judged by a constant trace on a recorder — a pellet was ignited due to the closing of a wire circuit. After cooling, the bomb was disassembled, and the pellet-holding platinum tray was reweighed to determine the amount of remaining ash.

## RESULTS

### Development

The average duration of each instar at 25°C is shown in Table 1; as noted, the nauplius I instar of this species lasts for only a few minutes. Complete development from egg to copepodite VI took approximately 16 days under laboratory conditions. The characters of various stages are described as follows:

#### *Nauplius stage I (N I)*

Body (Fig.1-A): 0.110mm average length and resembling a typical cyclopoid nauplius in having a dorsoventrally flattened egg-shaped body. The posterior end of the body has a pair of slender setae which are directed outwards. The labrum is large and almost round in shape, and has fine hairs covering its surface; it retains this appearance until the last naupliar stage. A mouth is present but an anus is absent during this stage.

Antennules (Fig.2-A): Show two long setae terminally. A notable feature of this species is the absence of an aesthete on the antennules during all six naupliar

Table 1. Duration of nauplius and copepodid stages of *Apocyclops royi* under laboratory-reared conditions

Instar	Nauplius stage					
	I	II	III	IV	V	VI
Duration (day)	few minutes	0.5	0.5	0.5	1	1
Instar	Copepodid stage					
	I	II	III	IV	V	VI (adult)
Duration (day)	2	2	2	2	2	2

stages.

Antenna (Fig.2-G): Coxa with a masticatory blade; basipodite with 2 spines; endopodite with 1 spine and 3 setae, and exopodite composed of fused segments with 6 setae.

Mandible (Fig.2-M): Coxa with 1 seta; basipodite with 2 setae; endopodite consisting of 2 segments — the inner with 2 setae, the other with 4 spines; exopodite of fused segments with 5 setae.

#### *Nauplius stage II (N II)*

Body (Fig.1-B): 0.122mm in average length and bearing an overall resemblance to nauplius I. The posterior end of the body becomes slightly elongated, and a shallow notch appears in the caudal region with a single seta on either side of the notch.

Antennule (Fig.2-B): Same as in Stage I, but with 3 setae terminally.

Antenna (Fig.2-H): Same as in Stage I, but endopodite with 1 spine with 4 setae, and exopodite of fused segment with 7 setae.

Mandible (Fig.2-N): Same as in Stage I, but exopodite becomes 2 segments with 5 setae; inner segment of endopodite with 3 setae.

#### *Nauplius stage III (N III)*

Body (Fig.1-C): 0.152mm in average length; differs from preceding stage in having two setae on either side of the caudal notch.

Antennule (Fig.2-C): Same as in Stage II, but with 4 setae terminally.

Antenna (Fig.2-I): Same as in Stage II, but coxa with 2 masticatory blades.

Mandible (Fig.2-O): Same as in Stage II, but exopodite becomes 3 segments with 5 setae.

Maxillule (Fig.2-S): Represented by a stout spine.

#### *Nauplius stage IV (N IV)*

Body (Fig.1-D): 0.209mm in average length; body is distinctly broader at the anterior end and more narrow posteriorly.

Antennule (Fig.2-D): Same as in Stage III, but with 6 setae terminally.

Antenna (Fig.2-J): Same as in Stage III, but endopodite with 2 spines with 4 setae, and exopodite made of fused segment with 9 setae.

Mandible (Fig.2-P): Same as in Stage III, but exopodite becomes 4 segments with 5 setae, and middle segment of endopodite now has 5 spines.

Maxillule (Fig.2-T): Represented by a lobe fringed with three long, stiff setae.

#### *Nauplius stage V (N V)*

Body (Fig.1-E): 0.240mm in average length; has a caudal armature consisting of 6 setae, of which the innermost pair appears as two short, blunt projections.

Antennule (Fig.2-E): Same as in Stage IV, but with 9 long setae terminally.

Antenna (Fig.2-K): Same as in Stage IV, but coxa with 2 masticatory blades and 1 seta; basipodite with 3 spines; endopodite with 2 spines and 5 setae.

Mandible (Fig.2-Q): Same as in Stage IV

Maxillule (Fig.2-U): Same as in stage IV, but becomes double segmented with 6 setae on the distal segment.

#### *Nauplius stage VI (N VI) (last naupliid instar)*

Body (Fig.1-F): 0.265mm in average length; innermost pair of setae of the caudal lobes are well developed.

Antennule (Fig.2-F): Same as in Stage V, but with 13 long setae terminally.

Antenna (Fig.2-L): Same as in Stage V, but basipodite with 4 spines; endopodite with 2 spines and 6 setae.

Mandible (Fig.2-R): Same as in Stage IV.

Maxillule (Fig.2-V): Same as in Stage V.

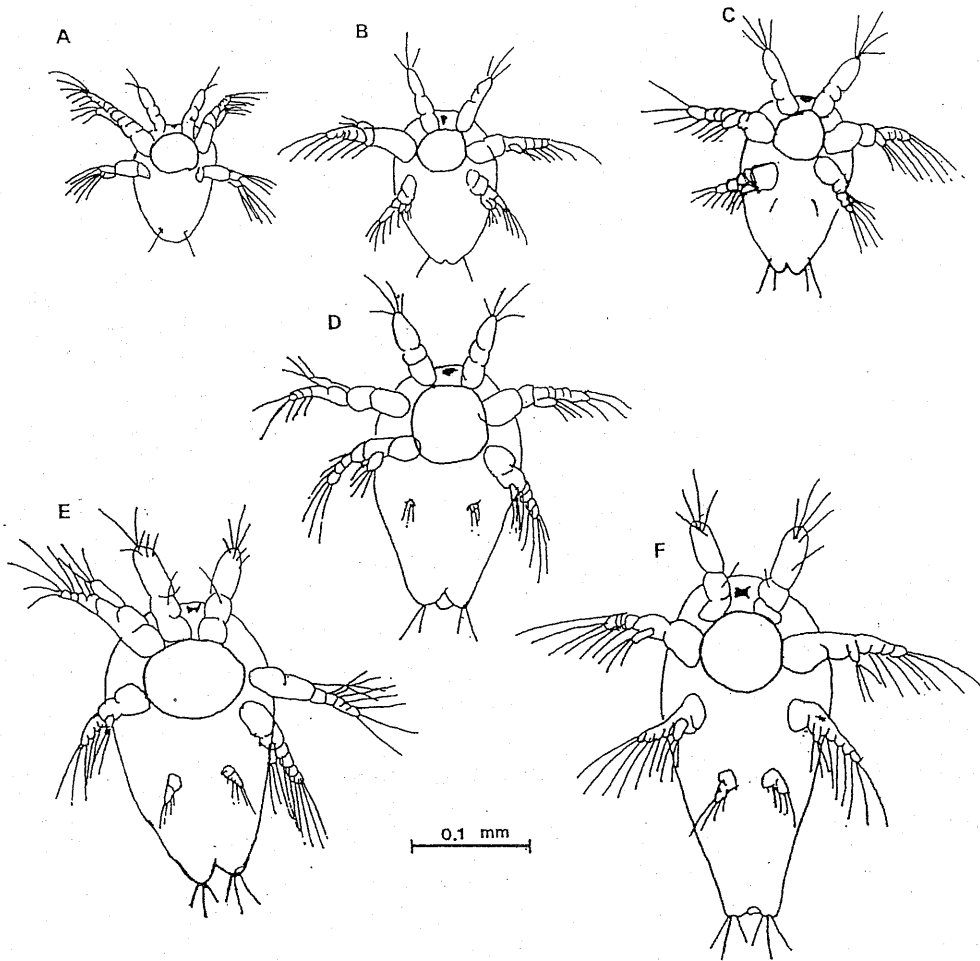


Fig. 1. *Apocyclops royi* (Lindberg). (ventral)

A: Nauplius I; B: Nauplius II; C: Nauplius III; D: Nauplius IV; E: Nauplius V; F: Nauplius IV.

### *Copepodid I (C I)*

Body (Fig.3-A): 0.42mm in average body length; body shape and appendages assume general adult appearance, having anteriorly a broader cephalothorax and posteriorly a narrower urosome which terminates in a caudal furca. Mouthparts are similar in structure to adults, with the main difference being in size. The cephalothorax has 4 segments as in adults, but the urosome is unsegmented. Caudal furca is

fringed with five setae, of which one is long and four are short.

Antenna (Fig.4-A): With 3 segments; 4 setae on distal segment, 3 setae on middle segment, and 1 seta on coxa.

Antennules (Fig.4-G): Six segments.

Two pairs of biramous swimming legs are attached to the posterior margins of the first two thoracic segments.

1st Leg (Fig.5-A): Both coxa and basipodite with no setae; endopodite has a single segment with 6 setae; exopodite has a single

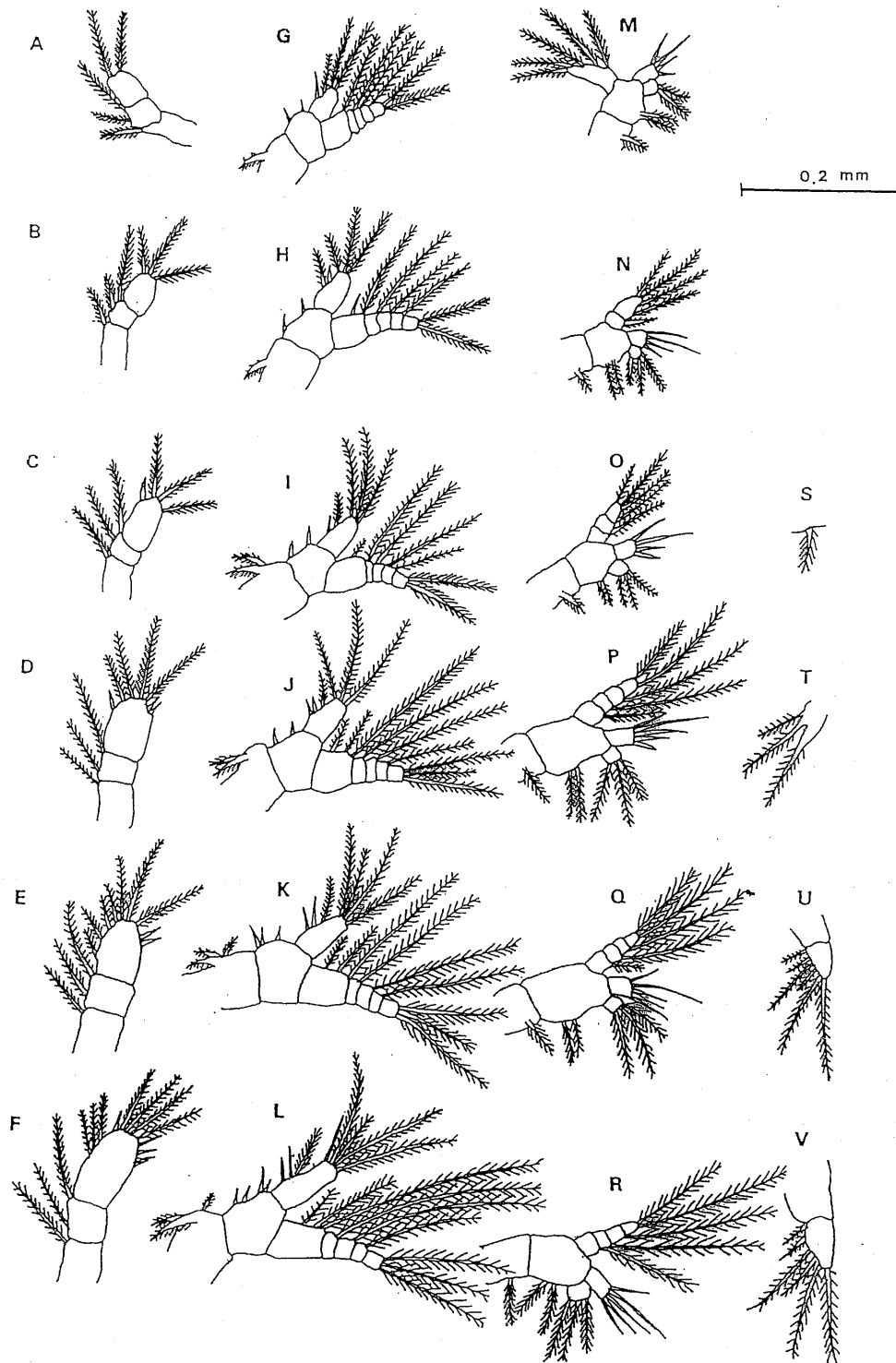


Fig. 2. *Apocyclops royi* (Lindberg).  
 A-F: antennules of nauplii I-VI; G-L: antennae of nauplii I-VI;  
 M-R: mandibles of nauplii I-VI; S-V: maxillules of nauplii III-VI.

segment with 3 outer spines and 3 setae.

2nd Leg (Fig.5-G): Same as 1st leg, but exopodite a single segment with 3 outer spines and 4 setae.

#### *Copepodid II (C II)*

Body (Fig.3-B): 0.51mm in average body length; urosome becomes double segmented. A third pair of swimming legs appears on the third segment of the thorax. Setation of the caudal furca assumes adult number and proportion.

Antenna (Fig.4-B): Same as in Stage I, but with 5 setae on distal segment and 4 setae on middle segment.

Antennules (Fig.4-H): Seven segments.

1st Leg (Fig.5-B): Same as in Stage I, but endopodite has 2 segments — first with 1 seta, second with 1 spine and 5 setae; exopodite has 2 segments — 1st with an outer spine, 2nd with 3 outer spines and 5 setae.

2nd Leg (Fig.5-H): Same as 1st leg, but 2nd segment of endopodite with 1 spine and 5 setae; 2nd segment of exopodite with 3 outer spines and 4 setae.

3rd Leg (Fig.5-M): Both coxa and basipodite with no setae; endopodite has a single segment with one spine and 5 setae; exopodite consists of a single segment with 3 outer spines and 4 setae.

#### *Copepodid III (C III)*

Body (Fig.3-C): 0.65mm in average body length; has a tri-segmented urosome and with 9 segments antennule. Fourth pair of swimming legs appears on the last thoracic segment, and fifth pair is seen as two spines pointing towards the postero-lateral margin of the first urosomal segment.

Antenna (Fig.4-C): Same as in Stage II, but with 6 setae on middle segment.

Antennules (Fig.4-I): With 9 segments.

1st Leg (Fig.5-C): Same as in Stage II, but first

segment of exopodite with 1 spine and 1 seta.

2nd Leg (Fig.5-I): Same as in Stage II, but first segment of exopodite with 1 spine and 1 seta.

3rd Leg (Fig.5-N): Same as in Stage II, but endopodite with 2 segments — first with 1 seta, second with 1 spine and 5 setae; exopodite of 2 segments — first with an outer spine, second with 3 outer spines and 5 setae.

4th Leg (Fig.5-R): Both coxa and basipodite with no setae; endopodite consists of a single segment with a spine and 5 setae; exopodite has a single segment with 4 outer spines and 3 setae.

#### *Copepodid IV (C IV)*

Body (Fig.3-D): 0.85mm in average body length; differs from preceding stage in having a urosome with 4 segments. The first urosomal segment has developed a pair of slender setae on the lateral side, which — together with the spine developed in copepodite III — forms the fifth leg.

Antenna (Fig.4-D): Same as in Stage III, but with 7 setae on the distal and middle segment.

Antennules (Fig.4-J): Same as in Stage III.

1st Leg (Fig.5-D): Same as in Stage III, but basipodite with 1 seta.

2nd Leg (Fig.5-J): Same as in Stage III, but basipodite with 1 seta, and second segment of exopodite with 4 outer spines and 5 setae.

3rd Leg (Fig.5-O): Same as in Stage III, but first segment of exopodite with 1 spine and 1 seta; second segment with 4 outer spines and 5 setae. Second segment of endopodite with 1 spine and 6 setae.

4th Leg (Fig.5-S): Same as in Stage III, but endopodite 2 segments — first with 1 seta, second with 1 spine and 5 setae; exopodite has 2 segments — first with an outer spine, second with 3 outer spines and 3 setae.

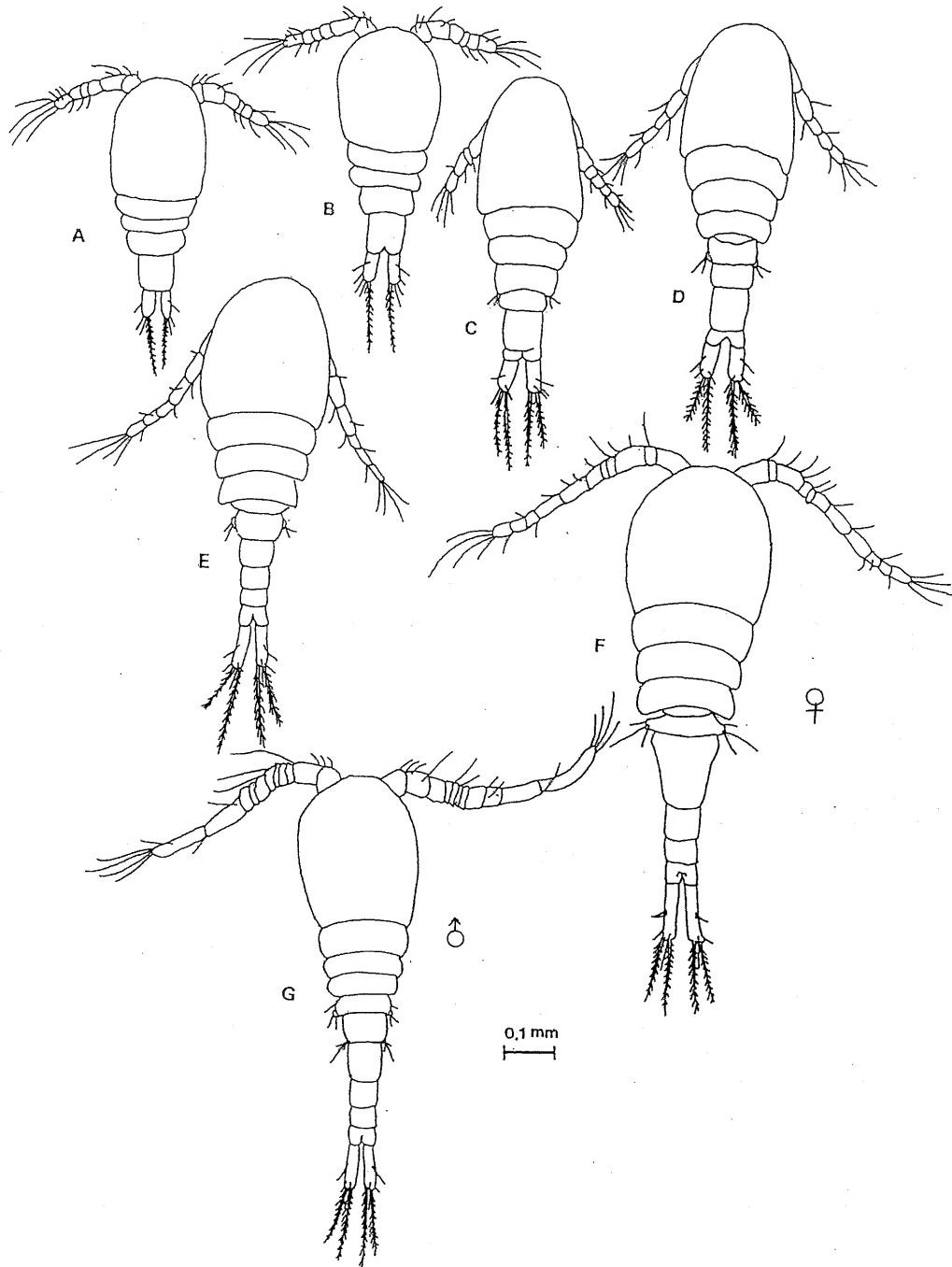


Fig. 3. *Apocyclops royi* (Lindberg). (dorsal)  
A: copepodid stage I; B: copepodid stage II; C: copepodid stage III;  
D: copepodid stage IV; E: copepodid stage V; F&G: copepodid stage VI (adult).



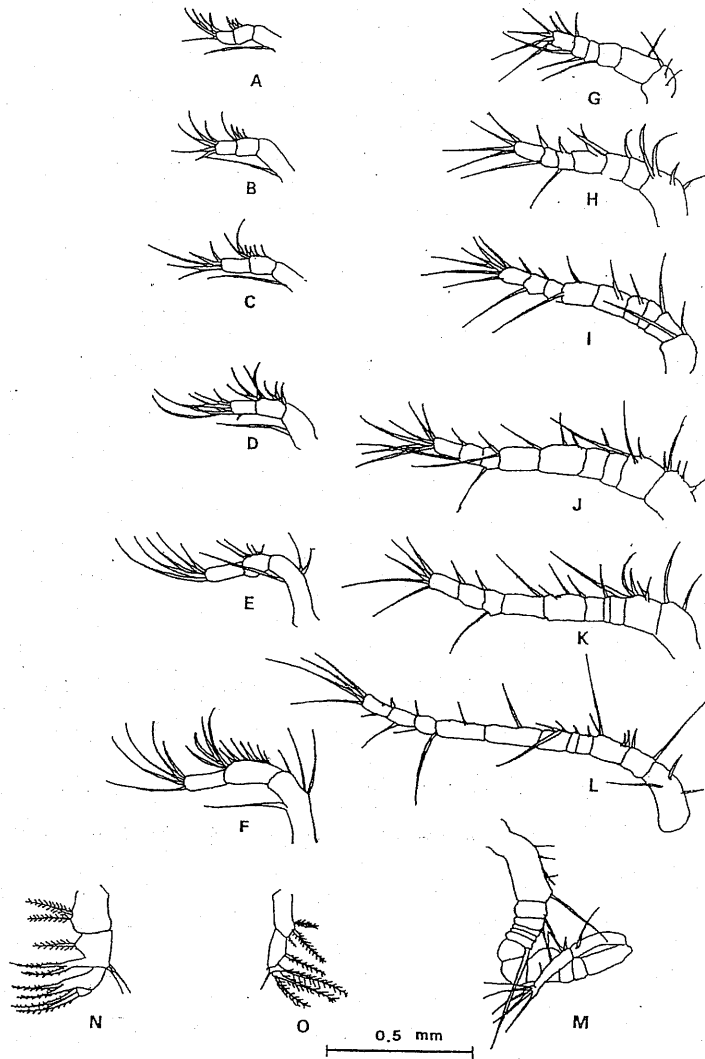


Fig. 4. *Apocyclops royi* (Lindberg).

A-F: antennae of copepodites I-adult; G-K: antennules of copepodites I-V;  
 L-W: female and male antennae of adults; N: second maxilla of adults;  
 O: maxilliped of adults.

#### *Copepodid V (C V)*

Body (Fig.3-E): 0.98mm in average body length; segmentation of the body is the same as in adults.

Antenna (Fig.4-E): Same as in Stage IV.

Antennules (Fig.4-K): With 10 segments.

1st Leg (Fig.5-E): Same as in Stage IV, but basipodite with 2 setae; second segment of endopodite with 1 spine and 6 setae.

2nd Leg (Fig.5-K): Same as in Stage IV, but second segment of endopodite with 1 spine and 6 setae.

3rd Leg (Fig.5-P): Same as in Stage IV, but

basipodite with 1 seta.

4th Leg (Fig.5-T): Same as in Stage IV, but second segment of exopodite with 3 outer spines and 5 setae.

5th Leg (Fig.5-V): First segment completely fused with the last thoracic segment, and

outer seta attached to a small protuberance on the last thoracic segment; second segment has gradually broadened posteriorly, with an inner spine and an outer seta.

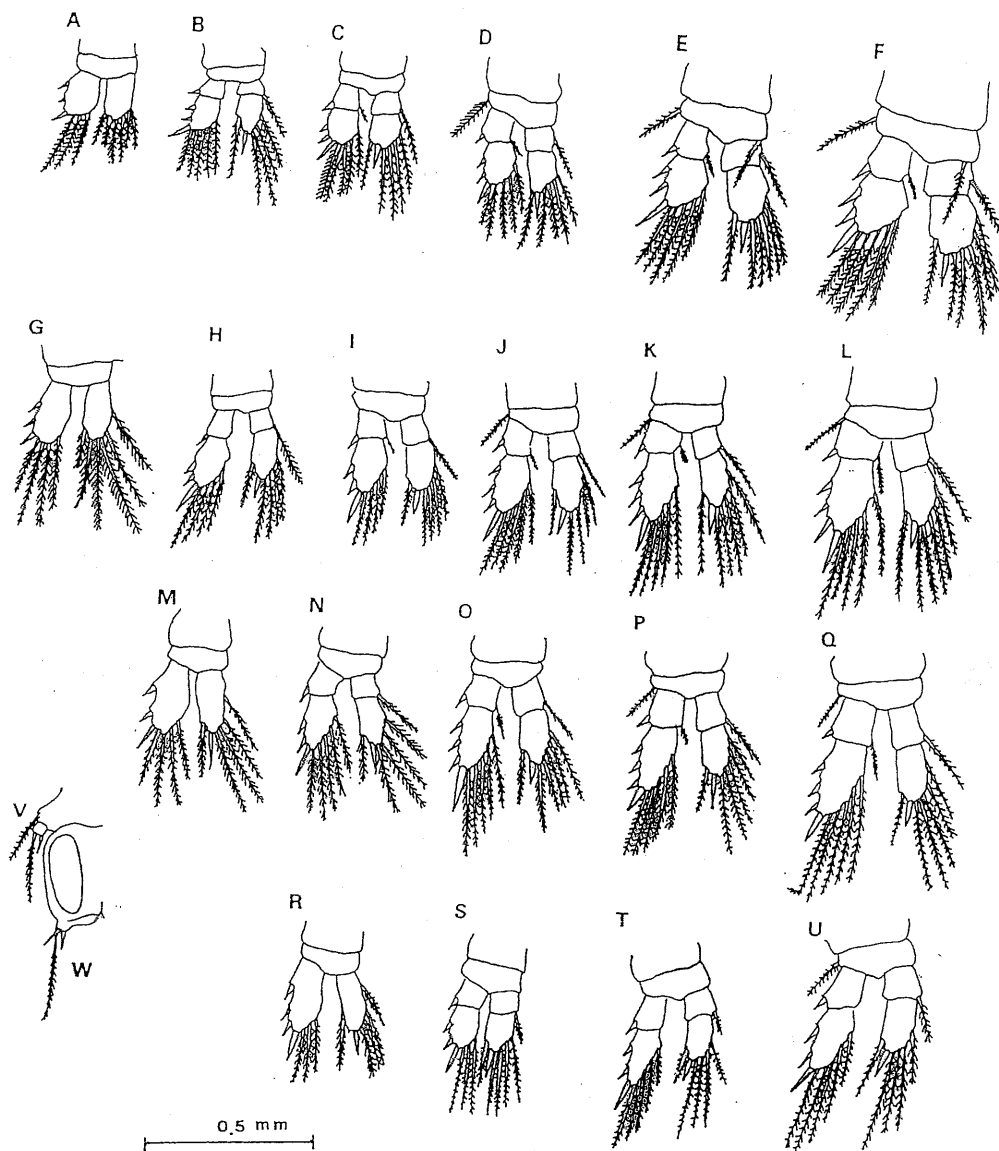


Fig. 5. *Apocyclops royi* (Lindberg).

A-F: 1st swimming legs of copepodid I-adult; G-L: 2nd swimming legs of copepodid I-adult;  
M-Q: 3rd swimming legs of copepodid II-adult; R-U: 4th swimming legs of copepodid III-adult;  
V: 5th swimming legs of adult; W: 6th swimming legs of adult.

*Adult stage (C VI)*

Body (female) (Fig.3-F): 1.03mm in average body length, not including furcal seta.

Antennules (Fig.4-L): With eleven segments, moderately long and stout; when reflexed, reaches almost to the posterior end of the third thoracic segment.

Antenna (Fig.4-F): Same as in Stage V.

Mandible rather small, consisting of the usual structure. First maxilla moderately simple, terminating in 5 tooth-like projections.

Second maxilla (Fig.4-N): Moderately large.

Maxilliped (Fig.4-O): Rather small.

The morphologies of the first to the fifth legs (Fig.5-F, 5-V) are the same as those in stage V; only the fourth leg has one seta on the basipodite.

Body (male) (Fig.3-G): 0.87mm in average length, not including furcal seta; moderately smaller and more slender than female. The structures of the second antenna, mandible, first and second maxillae, and maxilliped are similar to those of females, but first antenna (Fig. 4-M) resembles cat-

tle horns; sixth leg (Fig. 5-W) is noted by having 2 spines and one seta on the posteriolateral margin of the second urosomal segment.

**Length-weight relationship and energy content**

Length-weight relationships for all *Apocyclops royi* stages are shown in Table 2. Linear regression equations for prosome length (P.L.) and body length (B.L.) vs. dry weight (D.W.) (Fig. 6), plus ash free dry weight (AFDW) were calculated from approximately 126 samples as follows:

*Nauplii*

$$\ln(D.W.) = 1.0128 \ln(B.L.) - 2.633 \quad (R^2 = 0.768)$$

$$\ln(AFDW) = 1.1771 \ln(B.L.) - 3.120 \quad (R^2 = 0.756)$$

*Copepodites and adults*

Table 2. Mean size of body length and mean dry weight of *Apocyclops royi* during growth from nauplius I to adult female in the laboratory

Development stage		Prosome length ( $\mu\text{m}$ )	Body length ( $\mu\text{m}$ )	Dry weight ( $\mu\text{g}$ )
nauplius	I		110.0 $\pm$ 8.9	0.233 $\pm$ 0.037
	II		122.5 $\pm$ 2.9	0.270 $\pm$ 0.036
	III		152.5 $\pm$ 19.5	0.383 $\pm$ 0.141
	IV		209.5 $\pm$ 23.2	0.594 $\pm$ 0.109
	V		240.3 $\pm$ 30.0	0.653 $\pm$ 0.114
	VI		265.0 $\pm$ 18.2	0.772 $\pm$ 0.057
copepodid	I	294.0 $\pm$ 26.1	424.8 $\pm$ 42.7	0.805 $\pm$ 0.069
	II	344.3 $\pm$ 18.4	513.9 $\pm$ 36.1	0.971 $\pm$ 0.091
	III	415.2 $\pm$ 45.0	647.9 $\pm$ 81.2	1.363 $\pm$ 0.256
	IV	521.1 $\pm$ 29.5	846.0 $\pm$ 54.7	1.976 $\pm$ 0.193
	V	588.4 $\pm$ 11.8	976.5 $\pm$ 22.6	2.289 $\pm$ 0.146
(adult)	VI	618.0 $\pm$ 16.9	1034.1 $\pm$ 35.6	2.408 $\pm$ 0.107

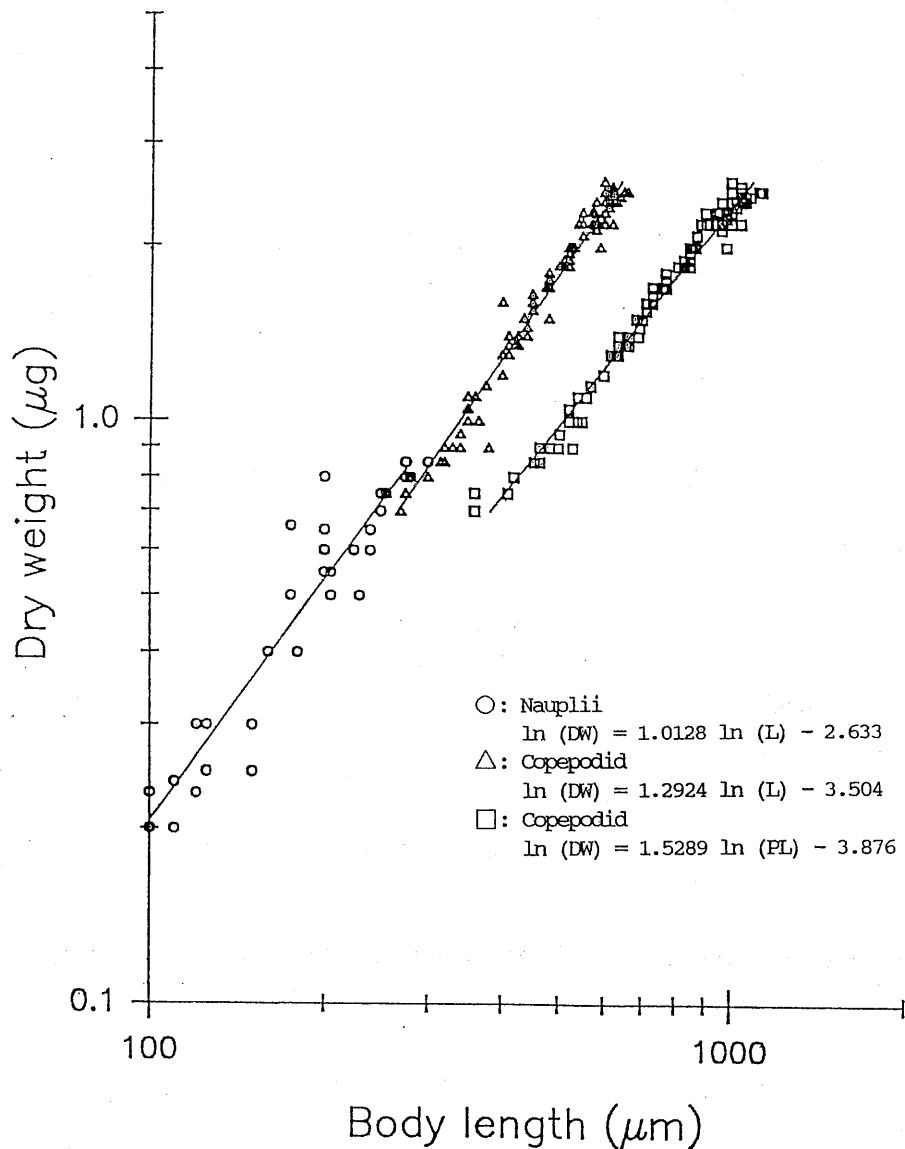


Fig. 6. Length-weight relationships of *Apocyclops royi* (Lindberg): body length (L) versus dry weight (DW) for nauplii (open circle); body length versus dry weight (open triangle); prosome length (PL) versus dry weight (open square) for copepodid.

$$\ln(\text{D.W.}) = 1.5289 \ln(\text{P.L.}) - 3.876 \quad (R^2 = 0.964)$$

$$\ln(\text{AFDW}) = 0.9255 \ln(\text{P.L.}) - 2.445 \quad (R^2 = 0.891)$$

$$\ln(\text{D.W.}) = 1.2924 \ln(\text{B.L.}) - 3.504 \quad (R^2 = 0.978)$$

$$\ln(\text{AFDW}) = 0.7821 \ln(\text{B.L.}) - 2.220 \quad (R^2 = 0.903)$$

The ash content of this species was observed as 2.47% (SD = 0.93) of dry weight. Mean energy content of later copepodite stage samples was 5.13 cal/mg D.W. (SD = 0.14), or 5.33 cal/mg AFDW (SD = 0.12).

## DISCUSSION

Table 3 lists published data on postembryonic stages of development in some cyclopoid copepods at various temperatures. The duration of *Apocyclops royi* instars obtained in this study shows faster naupliar development at 25°C, this is similar to other warm-water species, including *Acanthocyclops robustus*, *Mesocyclops decipiens*, *Thermocyclops hyalinus* and *T. neglectus* (Smyly, 1974; Maier, 1989). However, the cold-water species *Cyclops vicinus* (Smyly, 1974; Maier, 1989) has longer naupliar development at 20°C. It is possible that the effect of temperature might be nullified when an unlimited amount of food is available, or when experimental diets are superior to natural diets (Whitehouse and Lewis, 1973). Smyly (1970) showed that in *Acanthocyclops viridis* development time varied from 23 days

to 62 days at 15°C according to diet. It is reasonable to expect that food availability affects development time (Geiling and Campbell, 1972). Corkett and McLaren (1970) demonstrated that the development time of *Pseudocalanus minutus* nauplii is significantly longer when food resources are scarce.

Food quality was probably of little importance, as sufficient food was added at least every other day. However, food quantity may have played an important role in development (Maier, 1989). When reared on a generous phytoplanktonic diet at 25°C, *A. royi* naupliar development times are similar to those of other warm water species listed in Table 3. However, its copepodite development time is longer than the warm-water species, although similar to the cold-water species of this study (Table 3). It is possible that cyclopoid copepods become increasingly carnivorous following each moult. In particular,

Table 3. Comparison of *Apocyclops royi* with data from the literature on the duration times in days of combined naupliar and copepodite stages at different temperatures for some cyclopoid copepods.

Species	T(°C)	DN	DC	Reference(s)
<i>Apocyclops royi</i>	25	3.5	12.0	Present study
<i>Acanthocyclops robustus</i>	25	—	4.5	Maier, 1989
	25	3.2	6.5	Vijverberg, 1980
	25.1	4.0	5.4	Zankai, 1987
<i>Cyclops vicinus</i>	20	16.6	9.7	Munro, 1974
	20	—	8.9	Maier, 1989
<i>Mesocyclops decipiens</i>	26.5	8.4	11.6	Saunders & Lewis, 1988a and b
<i>M. edax</i>	—	—	12.9	Carter, 1974
<i>M. leuckarti</i>	24	18.0	15.0	Gras & Saint-Jean, 1981a and b
<i>Paracyclops fimbriatus</i>	21	13.5	11.3	Sarvala, 1979
<i>Thermocyclops crassus</i>	25	—	10.8	Maier, 1989
<i>T. hyalinus</i>	26	6.0	11.0	Burgis, 1971 and 1974
<i>T. neglectus</i>	20	6.6	4.4	Magadza & Mukwena, 1979
	24	16.0	15.5	Gras & Saint-Jean, 1981a and b

Note: DN: Naupliar duration (time between egg hatching and moult into C1).

DC: Copepodite duration (time between moult into C1 and moult into adulthood).

copepodid instars tend to be carnivorous, especially on other cyclopoid nauplii (Smyly, 1974). *A. royi* are predominantly herbivorous in their early stages, but predominantly carnivorous at later copepodite stages. Our observations show that *A. royi* can and do eat *Artemia* nauplii (> 1.0 mm); it is apparent that size of prey is not important. A similar observation was previously made for *Acanthocyclops viridis* (cf. Smyly, 1970); pure algal food may delay moulting from CV to adult. In the present study, *A. royi* were fed only one algae, and this may have contributed to slower postembryonic development.

Detailed data on the duration of development stages of planktonic copepods are lacking, since in most studies measurements were limited to total development time from egg hatching to stages CI or CVI. On the basis of studies of the species *Acartia* (Landry, 1975) and *Pseudocalanus* (McLaren, 1978), it has been postulated that under optimal food conditions all life stage durations are similar (referred to as isochronal development by Miller *et al.*, 1977). Besides copepodid stages, the duration of nauplius development of *Apocyclops royi* in this study was less stable than those in the studies cited above. However, in several studies of freshwater copepods (*Acanthocyclops viridis*, *Cyclops vicinus*, *Mesocyclops leuckarti*, *Microcyclops fuscus* and *Eudiaptomus* spp.) and other marine species (*Calanus helgolandicus*, *Rhincalanus nasutus* and *Eurytemora affinis*), the duration of postembryonic stages were not constant (Smyly, 1961; Mullin and Brooks, 1967; Geiling and Campell, 1972; Ivanova, 1973; Munro, 1974; Heinle and Flemer, 1975; Gophen 1976).

Regressions of simple and easily measurable expressions of length versus dry weight and AFDW are powerful tools for estimating biomass, which is fundamental to production studies. Length-weight regressions are subject to considerable error (McCauley, 1984); these regressions are

power functions, and therefore lengths must be measured as accurately as possible to minimize errors in dependent weight estimates (Bird and Prairie, 1985). The high  $R^2$  values for length-weight regression obtained in this study (0.756–0.978) confirm that most of the variation in weight is accounted for as a function of length.

In related literature, data on variances in length-weight relationships are only given for the exponent (B) (Bottrell *et al.*, 1976); these variances are compared with the present study in Table 4. Our comparison shows that the values measured in *A. royi* are distinctly lower than those in other cyclopoid copepods. It is not clear whether this species has specifically lower average weights than other cyclopoid copepods, or whether artifacts are involved. However, the weight of eggs and embryos carried by ovigerous females is treated differently in previous studies. Vijverberg and Frank (1976) regarded clutch weight as part of the female's overall weight; food concentration significantly influenced the intercept (Ln A) of length-weight relationships but not the slope (B). The two equation constants varied independently according to food species (Geller and Muller, 1985). If available food was edible for all development stages of herbivores, only (Ln A) changed with food concentration. If the food was only suitable for either adults or juveniles, (B) was also variable. In the present study, *A. royi* were fed only on one type of algae, and this food may be unsuitable for the copepodite stages; this would have contributed to a slower growth rate. It should also be noted that length-weight regressions can differ considerably between seasons in temperate waters due to variations in temperature and food availability (Cohen and Lough, 1981; Geller and Muller, 1985). This would also lead to variations in energy density — mainly as a consequence of lipid storage. Weight loss has been primarily attributed to loss of stored lipids (Omori, 1978); lack of oil sacs may also

Table 4. Comparison of *Apocyclops royi* with data from the literature on the linear regression relating length (L, mm) with dry weight (W,  $\mu\text{g}$ ) of some cyclopoid copepoda.

Equation:  $\text{Ln}(W) = \text{Ln} a + b \times \text{Ln}(L)$   
 slope (b), intercept (Ln a)

Species	Ln a	b	L	Instars	R <sup>2</sup>	ref
<i>Apocyclops royi</i>	-2.733	1.0128	①	NI~NIV	0.77	(7)
	3.876	1.5289	②	CI~ad	0.96	(7)
<i>Cyclops vernalis</i>	2.2266	3.230	②			(3)
	2.4511	0.7825	②	CV~ad		(1)
<i>C. scutifer</i>	1.4919	1.985	①			(4)
	1.3048	2.500	①			(4)
	2.5442	2.3696	①	NI~NIV		(1)
<i>C. viridis</i>	1.2286	2.6398	①	CI~ad		(1)
	1.0866	1.5493	①	NI~ad		(1)
	2.7412	1.6785	①	ad		(1)
<i>C. vicinus</i>	1.4497	2.1160	①	N~CV		(1)
	2.0577	2.5530	①	N~ad		(1)
<i>C. strenuus</i>	2.4342	1.9694	②			(1)
	2.0186	1.9948	②	ad		(1)
	1.5386	2.3418	②	N~ad		(1)
<i>C. abyssorum</i>	2.2128	2.2947	②	CI~ad		(1)
<i>Diaptomus pallidus</i>	1.5013	1.730	②			(3)
<i>D. Siciloides</i>	1.05	2.46	①			(2)
<i>D. gracilis</i>	1.2431	2.2634	①	N~ad		(1)
<i>Mesocyclops edax</i>	1.6602	3.968	①			(3)
<i>M. leuckarti</i>	1.3035	2.49	①			(5)
	1.2700	2.2570	②	C~ad		(1)
<i>Oithona</i> spp.	-7.07	1.10			0.77	(6)
<i>Thermocyclops hyalinus</i>	1.3035	2.49	①			(5)
	0.6772	0.8928	②	C~ad		(1)
Cyclopoids combined	-11.64	1.96			0.85	(6)
copepod nauplii	0.6977	0.469	①			(3)

Note: References (ref) for these equations are: (1) Bottrell *et al.* (1976); (2) Pace & Orcutt (1981); (3) Rosen (1981); (4) Persson & Ekbohm (1980); (5) Burgis (1974); (6) Chisholm and Roff (1990); (7) Present study. Lengths measured (L) refer to ① total length: does not include caudal setae; ② prosome length: only thoracal segments measured, not including furcal rami. Instars refer to nauplii (N), copepodites (C), and adults (ad).

be related to the fact that reproduction appears to occur continuously in the laboratory. In our study however, the length-weight

regression of *A. royi* did not vary significantly; this is likely due to relatively constant temperature and availability of food (Hopcroft

and Roff, 1990).

As cited in the literature, the calorific values of copepods are variable and often difficult to interpret. It is likely that some of these variations are due to physiological differences related to the season of the year in which the plankton were caught (Farkas and Herodek, 1960), or to trophic differences in the ecosystems from which they came. Previously calculated calorific values for different species of cyclopoida range from 5,400 to 5,819 cal/g ash free dry weight (see Table 5) (Comita and Schindler, 1963; Moshiri and Cummins, 1969; Schindler *et al.*, 1971; Vijverberg and Frank, 1976); our value of 5,330 is on the low end of the scale. Therefore, although our observed values are within the

previously-cited range, they are different from those cited in the literature when actual values for a particular species or taxonomic group are compared.

Energy transformation studies have pointed out the need for determining the amount of heat that various organisms (as taken from a wide taxonomic range and a large variety of environments) can produce. Some data are available for plankton, but very few are available for copepods — either marine or fresh-water. Calorific values for a number of crustacea species, as determined by oxygen bomb calorimetry, appear in Table 5. This information is presented in calories per gram dry weight, as well as calories per gram ash free dry weight. The energy con-

Table 5. Comparison of *Apocyclops royi* with data from the literature on the calorific values of some crustacea.

Species or taxonomic group	Sex	cal/g DW	Reference(s)
<i>Apocyclops royi</i>		5130	Present study
<i>Diaptomus arcticus</i>	♂	5468	Comita & Schindler, 1963
	♀	5526	Comita & Schindler, 1963
<i>D. leptopus</i>	♂	5396	Comita & Schindler, 1963
	♀	5436	Comita & Schindler, 1963
<i>D. siciloides</i>		5849*	Moshiri, 1968
<i>Calanus finmarchicus</i>		5914	Comita & Schindler, 1963
<i>C. helgolandicus</i>		5400*	Slobodkin & Richman, 1961
<i>Trigriopus californicus</i>		5515*	Slobodkin & Richman, 1961
<i>Mesocyclops edax</i>	♀	5478	Comita & Schindler, 1963
<i>Cyclops vernalis</i>		5819*	Moshiri, 1968
Cyclopoida		5400*	Vijverberg & Frank, 1976
			Schindler <i>et al.</i> , 1971
<i>Daphnia pulex</i>		4478	Comita & Schindler, 1963
<i>Daphnia galeata mendotae</i>		5511*	Moshiri, 1968
<i>Daphnia magna</i>		5898*	Moshiri, 1968
<i>Bosmina coregoni</i>		5439*	Moshiri, 1968
<i>Balanus cariosus</i> (without plates)		5283*	Paine, 1964
<i>Artemia</i> sp. (nauplii)		6737*	Slobodkin & Richman, 1961

\*: cal/g AFDW.



tent of copepods and other microcrustaceans in calories per gram varied from 4,427 for immature crayfish to 5,643 for the female *Diaptomus siciloides*; however, the highest values were measured in *Artemia nauplii* (6,737). Whereas some copepods were above 5,300 (for example, *Calanus helgolandicus* (5,400) and *Trigriopus californicus* (5,515)) average values were above 5,467 (Comita and Schindler, 1963; Slobodkin and Richman, 1961). Data on the cal/mg DW value of *A. royi* (5,130) were lower than those taken from field samples, since the latter copepods were in an overwintering form and had a large amount of fat stored in their bodies.

It must be noted, however, that previously-reported calorific values were all expressed as cal/g ash free dry weight, including the weight of the chitin. Vijverberg and Frank (1976) assumed that chitin contributes 7 percent to dry weight, and that ash content is 10 percent of dry weight. Comita and Schindler (1963) reported an absence of inorganic ash for copepods and cladocerans. Paine (1964) showed that, where animal tissues are involved, temperatures below 500°C lead to incomplete incineration of samples. Evidence also indicates that temperatures of 600°C or higher are liable to cause volatilization of some inorganic salts (Grove *et al.*, 1961). Winberg (1971) also recommended that samples be incinerated in muffle ovens at temperatures that do not exceed 500~550°C. Phillipson (1964) reported ash values ranging from 9.8 to 11.7 percent for *Calanus finmarchicus*, while Birge and Juday (1922) reported varying ash values for a number of fresh-water zooplankton species — ranging from 1.2 percent for *Lepidodera* to 8.3 percent for *Daphnia galeata*. The value reported here was only 2.47 percent.

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# 實驗室培養之汽水性短角異劍水蚤 *Apocyclops royi* (Lindberg) 的發育期及其能含量

張文炳 雷淇祥

本報告所述之短角異劍水蚤 *Apocyclops royi* (Lindberg) 是一種汽水性之小型橈腳類，為臺灣地區之新記錄種，於淡水河河口域及宜蘭和台南地區之養殖池中都會採集到。根據採自野外並經實驗室培養幾個世代後之族群中，觀察各發育期之形態特徵共計有六個無尾幼蟲期、五個橈腳幼蟲期及成蟲期。在溫度為25°C，鹽度為30‰，食物充分提供之實驗室條件下，完成整個發育過程共需約十六天時間。這種橈腳類的平均能含量約為 5.13 cal/mg D.W. (5.33 cal/mg AFDW)；平均灰份含量約為乾重的 2.47%。體長與體重間之關係式如下所示：

一、無尾幼蟲期：

$$\ln(\text{乾重}) = 1.0128 \ln(\text{全體長}) - 2.633 \quad (R^2 = 0.768)$$

$$\ln(\text{去灰份後乾重}) = 1.1771 \ln(\text{全體長}) - 3.120 \quad (R^2 = 0.756)$$

二、橈腳幼蟲期及成蟲期：

$$\ln(\text{乾重}) = 1.5289 \ln(\text{頭胸長}) - 3.876 \quad (R^2 = 0.964)$$

$$\ln(\text{去灰份後乾重}) = 0.9255 \ln(\text{頭胸長}) - 2.445 \quad (R^2 = 0.891)$$

$$\ln(\text{乾重}) = 1.2924 \ln(\text{全體長}) - 3.504 \quad (R^2 = 0.978)$$

$$\ln(\text{去灰份後乾重}) = 0.7821 \ln(\text{全體長}) - 2.220 \quad (R^2 = 0.903)$$

## Antennal twisting as courtship behavior in a local blister beetle, *Epicauta hirticornis* (Coleoptera: Meloidae)<sup>1</sup>

YIEN-SHING CHOW<sup>2</sup>, RONG KOU, RU-SHIOW TSAI, HSIAO-YUNG HO

Institute of Zoology, Academia Sinica, Taipei,  
Taiwan 115, Republic of China

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**Yien-Shing Chow, Rong Kou, Ru-Shiow Tsai, Hsiao-Yung Ho (1992)** Spiral complex of insect antennae. *Bull. Inst. Zool., Academia Sinica* 32(1): 82-86. The blister beetle, *Epicauta hirticornis* Haag-Rutenberg, shows unique pre-copulating behavior. When males dorsally mount females, their antennae continuously wave to female antennae; often the male's right or left antenna grasps on the corresponding female antennae, thereby forming a double helix. The frequencies of establishing right- or left-handed antenna spiral complexes are equal. If the female's left antenna cannot be grasped, the male will form a spiral with female's right antenna, and vice versa. When both male and female antennae are entwined, they vibrate at a frequency of 7-12 c/s. This vibration is similar to the precopulatory sexual display of wing fluttering by male moths. The blister beetle's connection with cantharidin is also discussed.

**Key words:** Blister beetle (*Epicauta hirticornis*), Copulatory behavior, Double helix structure, Cantharidin.

From atoms, molecules such as L-amino acids and B DNA (Hegstrom and Kondepudi, 1990) to living organisms, nature is asymmetric with respect to chirality, or left- and right-handedness. Chiral symmetry and asymmetry can be demonstrated experimentally in a laboratory. When sodium chlorate (NaClO<sub>3</sub>) is crystallized from an unstirred aqueous solution, equal numbers of levo and dextro NaClO<sub>3</sub> salt are found. However, when the solution is stirred, almost all of the NaClO<sub>3</sub> salt found in a particular sample had the same chirality either levo or dextro (Kondepudi *et al.*, 1990). We used the twisted

antennae of courting male and female blister beetles, *Epicauta hirticornis* Haag-Rutenberg, to demonstrate that this phenomenon not only occurs on the molecular level but also in the behavior of living organisms. In June 1989, at a local mountain area near our Institute, numerous blister beetles were found aggregating on the leaves of flower glory-bowewer tree, *Clerodendrum cyrtophyllum* Turcz., and a novel sexual behavior was observed. During courtship, a male beetle mounts a female and his antenna winds about hers to form a double helix from behind. The sexual behavior of Meloidae was first reported by Selander (1964), and has subse-

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