

The Ostracode *Cypridopsis vidua*:  
Physiological Response Due to  
Thermal Stress

A Thesis Submitted to the Faculty of  
Baylor University  
in Partial Fulfillment of the  
Requirements for the Degree  
of  
Masters of Science

By  
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Waco, Texas  
December 1973

## ABSTRACT

Upper temperature effects were measured on the mean oxygen consumption, carbon dioxide production, ingestion, assimilation, and egestion rates of the ostracode *Cypridopsis vidua* to determine positive or negative effects of temperature stress. Oxygen consumption and carbon dioxide production were near the literature reportings of the Class Ostracoda, with a linear increase with increasing temperatures. Respiratory Quotients were very low. Ingestion and assimilation rates were positively linearly related with temperature to 30C and 25C. respectively, above which each was negatively affected. Assimilation efficiency dropped from 70 percent at 15C to 16 percent at 35C. Ingestion and assimilation rates increased per mg biomass with decreasing size of organism. Active avoidance of 30 and 35C temperatures was observed.

#### ACKNOWLEDGEMENTS

This study was funded by the Office of Water Resources Research Grant B-091-TEX. I appreciate the critical examinations of this manuscript by Dr. Owen T. Lind, Dr. David Eldridge, Dr. Gustavo Morales, Dr. Stanley Rouk, Dr. F. Raymond Wilson, and Dr. Frederick Gehlbach.

Special thanks are due to Dr. Owen T. Lind, Mr. David Lukins, and Mrs. Linda Wysong who contributed their time and effort to this study on my behalf.

Thanks goes to Mr. Matthew R. Thompson, A.I.A., who kindly donated his architectural ability in the drawing of the plankto-benthic sampler.

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## INTRODUCTION

"Temperature is one of the most important environmental factors controlling the activities and evolution of organisms and is one of the easiest to measure" (Brock, 1967). It is one of the most important factors governing the occurrence and behavior of aquatic life (Gunter, 1957). Consequently, such awareness of the biological significance of temperature has caused concern for the effects of thermal effluents by cooling water discharges from power plant generators.

Power plant discharges in the United States average 11C above ambient temperatures and may reach 30C above ambient during the summer months (Parker and Krenkel, 1969). It is projected that by 1980,  $2 \times 10^6$  megawatts of electrical energy will be required to meet daily demands of this country. This demand will require one-sixth of the nation's daily freshwater run-off (Freidman, 1969). The increased use of the freshwater resource as a cooling system has stimulated investigations of the possible effects on the aquatic fauna.

This study investigated the relationship between benthic micro-invertebrate physiology and elevated temperatures and related these findings to power plant discharges.

The ostracode *Cypridopsis vidua*, as a representative of the benthic micro-invertebrate community, was chosen since it was abundant at the study site and was directly subjected to the heated power plant effluents. It's role as an omni-

verous consumer of both dead and living organic matter makes it an important member of the micro-benthic community.

Three parameters were used to measure possible effects on the organism's physiology at elevated temperatures: (1) mean metabolic rate, expressed as oxygen consumed and carbon dioxide produced (Respiratory Quotient); (2) mean feeding rate and efficiency of food conversion, expressed as ingested, assimilated, and egested food and the effect of size on these rates; (3) thermal preference, expressed as the preferred temperature range.



## LITERATURE REVIEW

Many effects on benthic macro-invertebrate fauna by increased temperatures from power plant discharges have been documented. The benthic community structure of the Schuylkill River was depressed by 7 percent (reduced numbers of species with or without reduced production) as a result of thermal loading (increase of 20C over ambient) (Wortz and Dolan, 1960).

Reduction in number of individuals, species diversity, and biomass of macro-invertebrate riffle organisms affected by the thermal plume was substantial in the Big Kaypush Rapids area (Coutant, 1962). The data suggest a normal population structure tolerance to 32.2C with extensive loss in number and diversity of organisms accompanying further increases in temperature. Wojtalik and Waters (1970) found increased temperatures caused a variation in drift amplitude (expressed as numbers of individuals) for *Baetis vagans* (Ephemeroptera).

Microcrustacean feeding and assimilation rates vary with temperature. Fuller (1937) demonstrated that feeding rates for *Calanus firmarchicus* varied with temperature between 3-13C with a preferred feeding temperature of 8C. *Daphnia magna* showed an increased feeding rate in a 5-24C temperature range while being fed *Saccharomyces cerevisiae*. Decreases in feeding rates were observed at 28C and 33C with the same species (McMahon, 1965). *Daphnia magna* increased its assimilation

rate between 10-20C (Schindler, 1968). *Daphnia rosea* increased filtering rates up to 20C above which filtering rate significantly declined (Burns and Rigler, 1967).

Oxygen consumption rates vary with increased temperatures. Oxygen consumption in *Gammarus oceanicus*, a benthic amphipod, during "resting" metabolism varied little with increased temperatures, but active individuals showed increases with temperatures with a  $Q_{10}$  of 1.9 between 5-18C (Suomalainen, 1958; Halcrow and Boyd, 1967). Fish and Preece (1970) showed that oxygen consumption of the amphipods *Bathyporeia pilsoa* and *B. pelagica* increased linearly with increased temperature. Oxygen consumption in *Diaptomus articus*, *D. clavipes*, *D. leptopus*, *D. siciloides*, and *D. oregonesis* all increased significantly with increased temperatures between 5-25C (Comita, 1968). Oxygen consumption in *Daphnia magna* significantly increased with a rise in temperature between 10-20C (Schindler, 1968).

#### Class Ostracoda

*Cypridopsis vidua* is a highly adaptive organism with a wide geographical distribution. It has both freshwater and marine representatives. It has been reported in North America, Paraguay, North Africa, Europe, Western Russia, and the Azores. Taxonomic considerations of the genus *Cypridopsis* in North America are capsuled in a review article that shows a wide distribution that includes Tennessee, Louisiana, and Canada (Ferguson, 1968). *Cypridopsis vidua* is also found in

areas of high salinity; such as, the eutrophic dune waters of the Netherlands (Du Saar, 1971). It is adapted to a wide variety of environments: mountain lakes, brackish water, streams, lakes, and ponds. The genus *Cypridopsis* has a fossil record dating to the Pennsylvanian Period (Kesling, 1951).

Most considerations of the Class Ostracoda are taxonomic; however, there has been some research concerning the gross physiology and behavior of this class. Kesling (1951) summarized what was known about ostracode molt stages. *Cypridopsis vidua* was shown to withstand temperatures up to 34C. Growth rates of this ostracode were shown to increase with increased temperature

Environmental tolerance limits for a marine ostracode *Hemicythere conradi* have been demonstrated. This ostracode showed positive phototaxis, a temperature tolerance range of 6-36C, and an inability to withstand drying of the environment and consequent rise of salinity to 65 ppt (Kornicker and Wise, 1960).

Some freshwater ostracode species have been found to withstand pond drying in a mid-season torpid state. *Cypridopsis vidua*, however, has not been found in this condition (Delmore, 1969).

Ostracodes are negative phototrophs (Kesling, 1951; Kornicker and Wise, 1960; Hagerman, 1970). *Candona* sp. a cavernicolous ostracode has been killed by exposure to

sunlight (Maguire, 1960).

There have been few direct measurements of ostracode gross physiological responses. Respiratory rates of the marine ostracode *Hirschmannia viridis* show little increase in the oxygen consumption rate with a temperature rise from 10-20C, but increased with increased temperature at temperatures lower than 10C (Hagerman, 1970). *Cypridina higerdorfii* and *Procypris* sp., respectively, consumed 13.73 microliters of oxygen per milligram dry weight and 13.00 microliters of oxygen per milligram dry weight at 30C (Ikeda, 1970).

Because of the calcareous carapace unique to this class, feeding studies have been limited. The omnivorous-benthic feeding behavior of the freshwater ostracode has been of some interest. During feeding, *Chlamydotheca arcuata* accumulates quantities of Aldrin and Dieldrin (Kawatski and Schmulbach, 1971).

## METHODS AND MATERIALS

### Sampling and Culturing

Tradinghouse Creek Reservoir is located east of Waco, Texas, in McLennan County (31°34'N, 96°57'W). Physical and chemical characteristics have been described (Venables, 1972) and are summarized in Table 1.

Qualitative samples were taken of the benthic community during August and September, 1971. Samples were taken with a plankto-benthic sampler designed for benthic micro-invertebrate (Crustacean) sampling in the littoral zone (fig. 1). This sampler proved to be very similar to an ostracode sampler developed independently by Du Saar (1971). Samples were taken at the site where heated discharge enters the reservoir (depth <1m). Organisms were returned to the laboratory, removed by dropper pipette, and placed in an aged (one week) medium of 2g wheat, 3g hay to a liter of distilled water and incubated at 25C according to the method of George Needham (1937). The ostracodes were maintained at 25C in a constant temperature chamber utilizing a twelve-twelve photoperiod. Dr. Gustavo Morales, Baylor University, Department of Geology, identified the ostracode as *Cypridopsis vidua*.

### Metabolism

Respiration (oxygen consumption and carbon dioxide production) was measured manometrically (Umbreit, 1939) using a

Table 1

Summary of Physical-Chemical Data at Tradinghouse Creek  
Reservoir Bottom Data (depth = 7m) Applicable to this Study  
from Station "4" Near Heated Discharge

Date	Temp. (°C)	Dissolved Oxygen (ppm)	pH
March-Sept., 1971	11-32.5	8.5-10.0	7.8-8.6
Sept.-March, 1972*	33.0	9.4	8.4

\*Bottom samples only taken one time during the 7/71-3/72 interval.

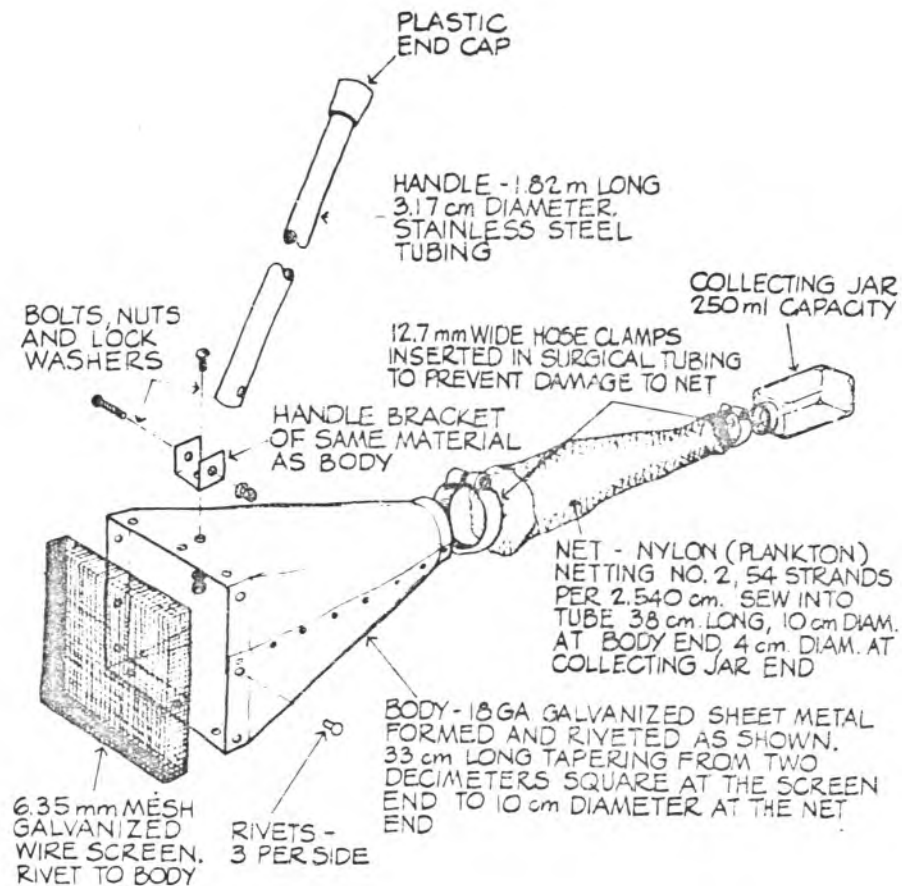


Figure 1. Plankto-Benthic Sampler designed for the qualitative or quantitative collection of the experimental organism, *Cypridopsis vidua*.



Warburg apparatus estimating gas exchange to the nearest half of a microliter. Measurements using 100-300 adult individuals (length: 0.60-0.65 mm) per reaction flask, were done in triplicate in a 0.45  $\mu$  filtered, oxygen saturated lake water for each temperature (15, 20, 25, 30, 35, and 40C). Measurements were made at the same time of day (1300-1500 hours). Organisms were acclimated for 48 hours at each experimental temperature prior to actual runs according to the method of Kibby (1971). Respiratory Quotients:

$$R. Q. = \frac{\text{microliters of respired carbon dioxide}}{\text{microliters of consumed oxygen}}$$

and Van't Hoff's temperature coefficients:

$$Q_{10} = \left( \frac{K_1}{K_2} \right) \frac{10}{T_2 - T_1}$$

were calculated.

Analysis of Variance and the Least Significant Difference test (Sokal and Rohlf, 1969) were used to determine non-random variation in the data ( $p < 0.05$ ). A regression analysis was also completed on the oxygen and carbon dioxide data against temperature.

#### Ingestion, Assimilation, and Egestion

Ingestion was defined as the amount of radio-tagged food found in the gut after the organism had packed its gut (one-half hour was found to be sufficient) (Schindler, 1968). Assimilation was defined as the amount of radioactivity left



in the ostracode after one-half hour ingestion and three hours feeding on a non-radioactive source. Egestion was defined as ingestion less assimilation.

Ostracodes have a high self-absorption coefficient (2.35-5.03) (amount of radioactivity not able to be counted due to interference of the body tissues and carapace) when using any  $^{14}\text{C}$  tagged compound in feeding experiments (McGregor and Wetzel, 1968). It was, therefore, determined to use  $^{55}\text{Fe}$  (as Ferrous Citrate), an x-ray emitter, to overcome this problem.

*Cypridopsis vidua* is a detritus feeder. Detritus was manufactured from mature cultures of  $^{55}\text{Fe}$  tagged *Chlorella vulgaris*. Algal cultures were heat killed at 65C for one hour, cooled and combined with an aliquot of 25 ml of mixed bacteria from an attenuated culture. This food system was allowed to decompose one week. Then it was autoclaved and 100 ml aliquots were filtered onto several 0.45  $\mu$  Millipore filters. Radioactivity of this material was determined by liquid scintillation techniques (micro-fuge tubes and toluene-base scintillator). The filtrant was then dried, weighed to determine specific activity, and used for ingestion and assimilation experiments.

Ingestion and assimilation experiments were as follows (fig. 2): (1) approximately 300 adult ostracodes were acclimated at each experimental temperature for 24 hours, then placed in a feeding chamber (three inch section of 1½ inch diameter stainless steel pipe covered at one end with

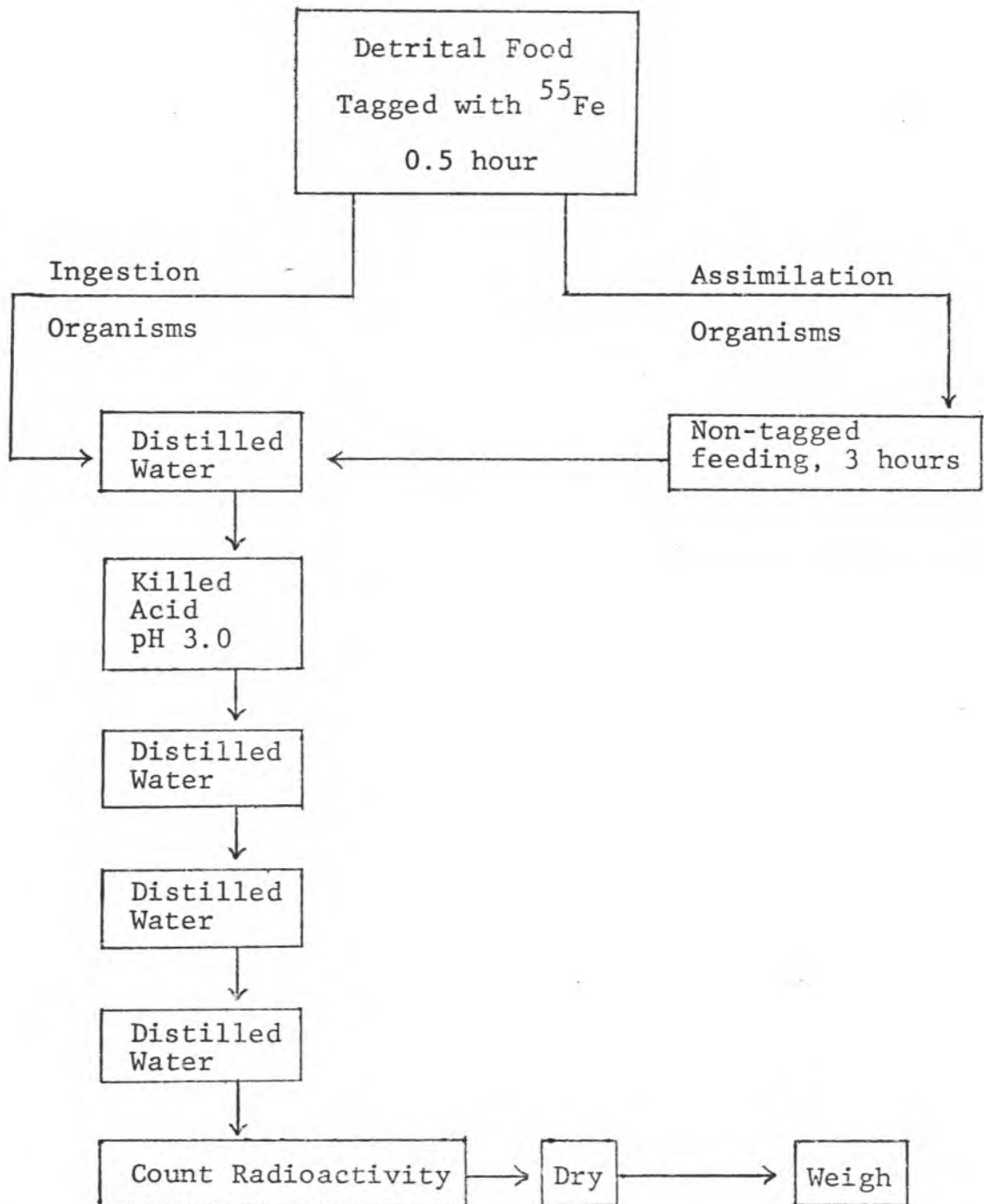


Figure 2. Flow chart illustrating ingestion and assimilation experiments for the ostracode *Cypridopsis vidua* showing use of  $^{55}\text{Fe}$  in the study.

No. 2 mesh nylon netting held in place by a hose clamp) which was placed on a tagged food filter for one-half hour (food was readily available through the netting); (2) the entire sample of approximately 300 individuals were separated into two sub-samples with approximately 50 percent of the individuals in each; (3) one sub-sample (assimilation) was placed on a non-tagged food filter for three hours (this allowed the organisms to clear their guts of radio-tagged food); (4) the second sub-sample (ingestion) was rinsed in distilled water, then in dilute hydrochloric acid (pH 3.0) to remove any adsorbed iron (this caused the death of the organisms), and then rinsed three more times in distilled water; (5) then organisms of the second sub-sample (ingestion) were separated and placed in micro-fuge tubes for liquid scintillation analysis; (6) after three hours of clearing process, organisms of the first sub-samples (assimilation) were put through steps #4 and #5.

Measurements of the radioactivity were made on a Beckman S. C. 100 Liquid Scintillation counter. Best window opening for  $^{55}\text{Fe}$  was determined by an efficiency curve for the pure isotope. Lead-based scintillators recommended for heavy gamma-emitters were ineffective for  $^{55}\text{Fe}$ . Consequently, a toluene-base scintillator was used for the standard curve analysis and sample counting. All samples were counted to 5 percent error and corrected for background. Dry weights for organisms in groups were done on a Cahn Microbalance

(after counting procedures).

The effects of heat on ingestion, assimilation, and egestion were measured at 15, 20, 25, 30, 35, and 40C.

The effect of size of an individual on ingestion and assimilation was also measured using the same procedures for groups, but substituting single individuals.

Regression analysis, Analysis of Variance, and Least Significant Difference Test (Sokal and Rohlf, 1969) were used to determine non-random variation in the data.

A length of carapace:weight ratio was computed to determine any usable correlation. This ratio could be effective in further investigations as a time-saver.

#### Thermal Preference

A thermal gradient was used to determine thermal preference. The gradient was set in 5 x 0.5 ft. wide rectangular glass enclosure with a depth of 12 mm filtered lake water. A gradient (10-40C) was established using ice and an immersion heater (in a 500 ml beaker of water) at opposite ends of the tank. The gradient was monitored with thermistors placed at five degree intervals along the edge of the tank. Ostracodes were acclimated at 25C for 48 hours prior to the experiment, and then evenly dispersed throughout the gradient. At thirty minute intervals, numbers of ostracodes were counted in a 12 mm band across the enclosure on either side of a given thermistor. Preference was determined as an average after six counting sessions were conducted with separate

groups of ostracodes.

## RESULTS

### Oxygen Consumption and Carbon Dioxide Production

Oxygen consumption of *Cypridopsis vidua* had a positive linear correlation with temperature ( $Y = 5.81 + .675X$ ;  $r = 0.998$ ) (Fig. 3). Variance increased at higher temperatures. The oxygen consumption curve increased with temperature much as would be expected of an ectothermic organism. No maximum consumption plateau was reached during the experiments. Organisms died after twelve hours during acclimation at 40C exposure. All oxygen data are means of adult grouped (adults: length 0.6-0.65 mm) measurements.

Van't Hoff temperature coefficients show significant decrease with increase in temperature ( $Y = 5.575 + -0.146X$ ;  $r = 0.96$ ) (Table 2).

Respiratory quotients remained constant during all temperatures indicating a constant metabolism throughout the experimental period (Table 3).

Carbon dioxide production was also positively correlated (linear) with increased temperature ( $Y = -3.52 + 3.73X$ ;  $r = 0.99$ ) (Fig. 4). Variance increased with temperature to 25C. Reduced variance was observed at 30 and 35C. Some plateauing effect was observed between the 30 and 35C levels (40C: lethal temperature for twelve hour exposure).

Table 2  
Van't Hoff Temperature Coefficients  
for Oxygen Consumption in the Ostracode  
*Cypridopsis vidua*

Temperature ( $^{\circ}\text{C}$ )	$T^{\circ}$ Coefficient
15-20	3.56
20-25	2.55
25-30	1.61
30-35	1.44

Table 3

Respiratory Quotients Computed from the Mean Oxygen Consumption and Carbon Dioxide Production at Each Experimental Temperature for the Ostracode *Cypridopsis vidua*

Temperature ( $^{\circ}\text{C}$ )	R. Q.
15	.53
20	.49
25	.48
30	.57
35	.53



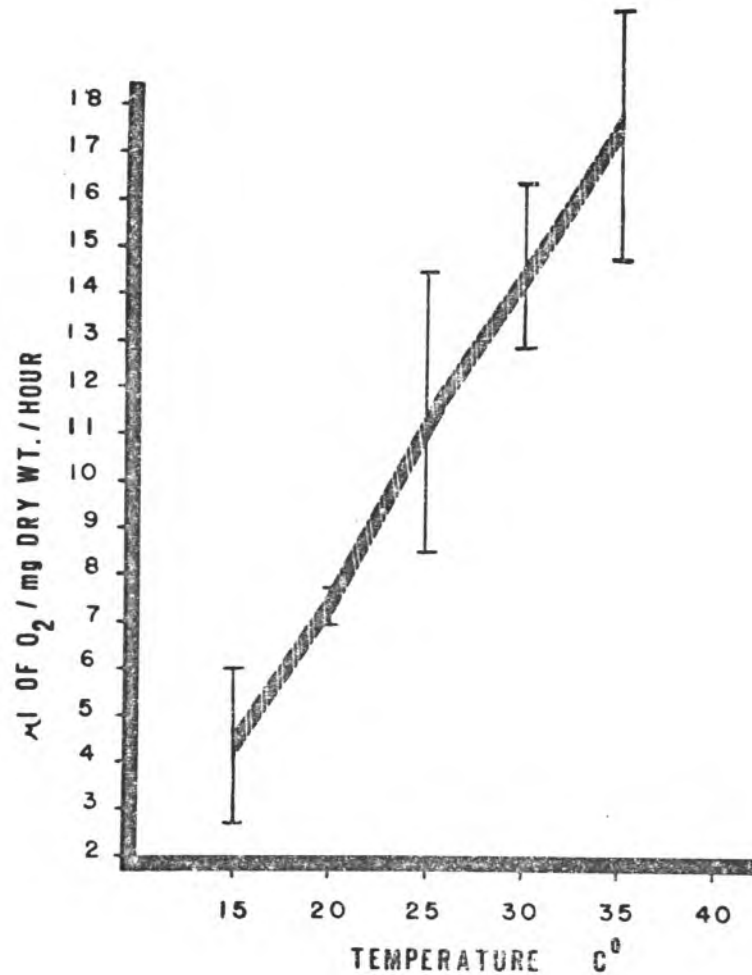


Figure 3. Microliters of oxygen consumed per milligrams dry weight per hour for groups of individuals of *Cypridopsis vidua*. Each data point is a mean ( $\pm$  one S. D.) of at least three group runs at each temperature level. ( $Y = -5.80 + 0.67X$ ;  $r = 0.99$ ).

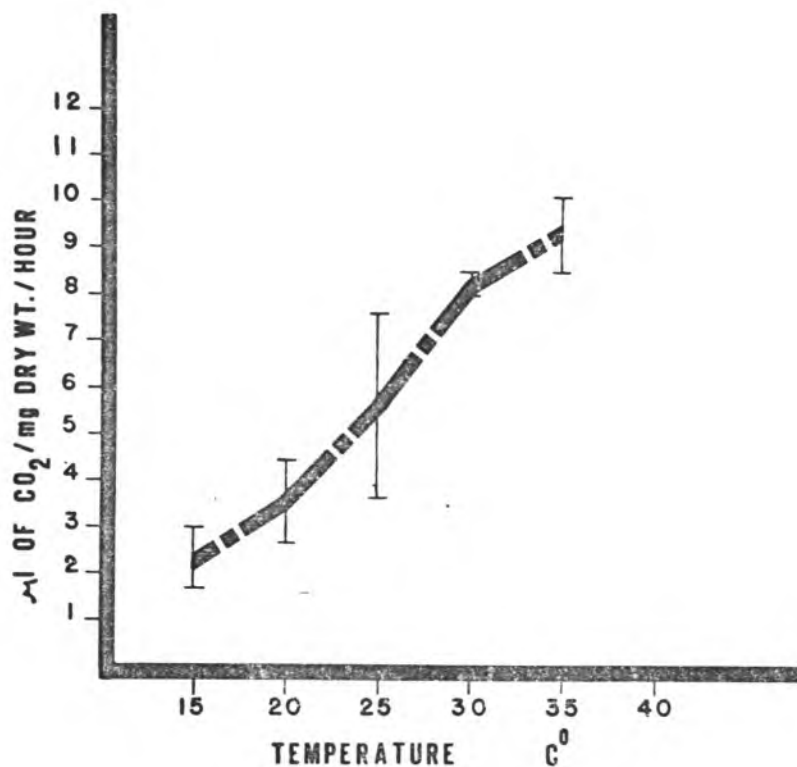


Figure 4. Carbon dioxide production for *Cypridopsis vidua*, plotted for grouped samples. Mean values are plotted at each temperature for at least three separate experiments ( $\pm$  one S. D.). ( $Y = -3.52 + 0.37X$ ;  $r = 0.99$ ).

### Ingestion, Assimilation, Egestion

Ingestion (Fig. 5) was positively and linearly correlated with temperature up to 30C ( $Y = .365 + 0.013X$ ;  $r = 0.985$ ). Above 30C, ingestion mean deviated from this correlation. Ingestion rate at 35C was reduced significantly. Variance increased with increased temperatures, particularly at 30 and 35C.

Assimilation (Fig. 6) had a positive linear correlation with increased temperature to 25C ( $Y = .226 + 0.011X$ ;  $r = 0.92$ ). Assimilation above 25C deviated from this correlation and is negatively affected by temperature. Variance decreased slightly with increased temperatures.

Egestion data (Fig. 7) was positively and logarithmically correlated with temperature ( $\ln Y = -0.101 + \ln 1.53X$ ;  $r = 0.94$ ). Since egestion = ingestion - assimilation, no valid statement of variance can be projected.

These experiments were done with adult organisms (length: 0.6-0.65 mm). This is an important consideration, as there is high variability in feeding and assimilation rates among the different size classes (Tables 4 and 5). Smaller instars are more active in feeding and assimilation rates than the larger instars (ingestion and assimilation rates compared between size classes: rate/mg dry weight for organisms of a size class). These data may be biased by the calcification of a heavier carapace at late instar stages (seventh and eighth).

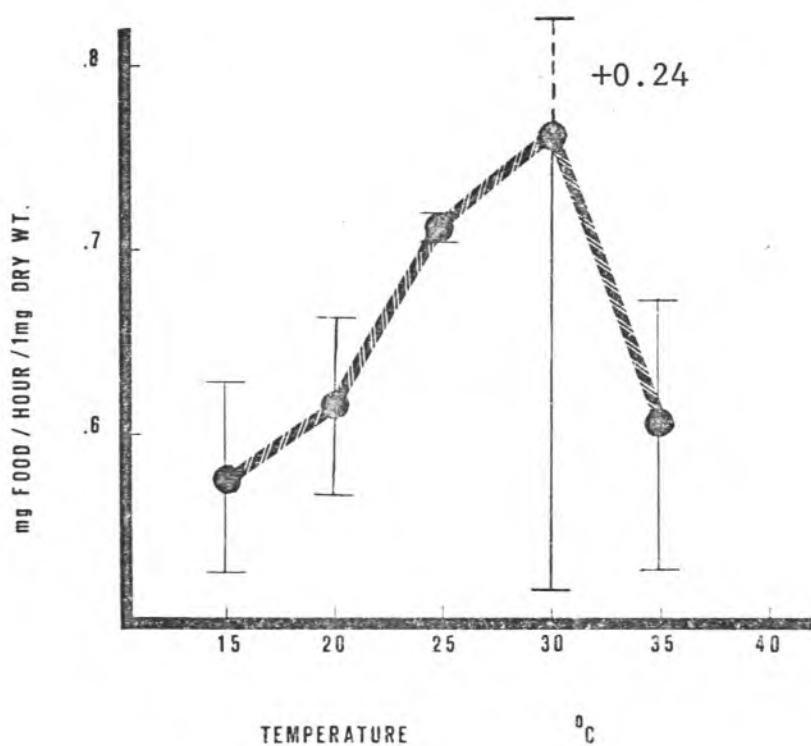


Figure 5. Mean ingestion data for the ostracode *Cypridopsis vidua* plotted for grouped experiments. Each point represents the mean value ( $\pm$  one S. D.) for four runs. (Up to 30C,  $Y = -0.365 + 0.013X$ ;  $r = 0.99$ ).

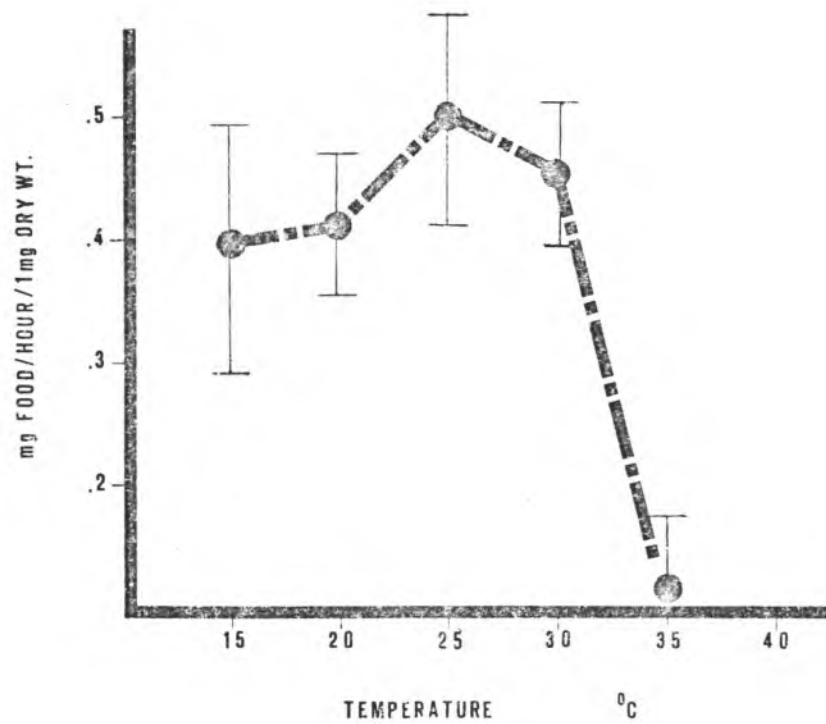


Figure 6. Assimilation plot for the ostracode *Cypridopsis vidua* (grouped experiments: adults). Each data point represents the mean value ( $\pm$  one S. D.) for four separate runs at each temperature. (Up to 25,  $Y = 0.225 + 0.011X$ ;  $r = 0.92$ ).

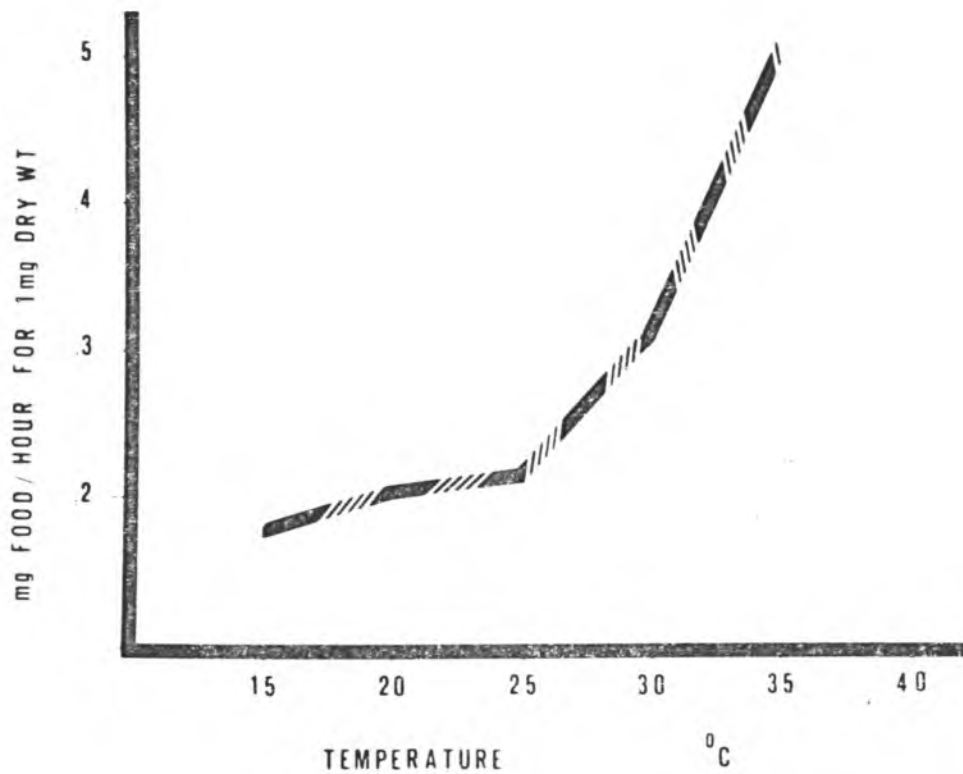


Figure 7. Egestion plot for adult groups of the ostracode *Cypridopsis vidua*. Mean values expressed as the difference between the mean ingestion and the mean assimilation values at each temperature. ( $\ln Y = -0.101 + \ln 1.53X$ ;  $r = 0.94$ ).

Table 4

Ingestion Values for Individual Ostracodes *Cypridopsis vidua*  
Corrected to one Milligram Dry Weight Equivalents at 25C

Size of Organism in Mg Dry Weight	Mg of Food Ingested/ Mg Dry Wt. Biomass/hr.
.002	2635.13
.009	1285.75
.010	826.56
.012	1510.24
.014	1017.57
.016	317.48
.017	721.34
.019	455.91

Table 5

Assimilation Rates of Individual Ostracodes *Cypridopsis vidua*  
Corrected to One Milligram Dry Weight Equivalents at 25C

Size of Organism in Mg Dry Weight	Mg of Food Assimilated/ Mg Dry Weight Biomass/hr.
.001	875.178
.002	2276.23
.003	1287.69
.008	449.36
.020	405.35
.025	298.64
.028	154.37



Length to weight ratios reveal that the calcareous carapace that surrounds the ostracode may vary in weight considerably (Fig. 7). This makes weight estimates by length comparisons impractical and imprecise.

#### Thermal Preference

The thermal preference of the ostracode *Cypridopsis vidua* in the experimental temperature range 15-40C was difficult to determine, since three temperature ranges had similarly high numbers of individuals (Table 6). This is supported by the data on food conversion efficiencies which show similar high efficiencies at 15, 20, and 25C; after 25C, reduced efficiency was observed (Table 7). In the thermal preference experiment, 30-40C levels showed reduced numbers of individuals.

Table 6

Thermal Preference of the Ostracode *Cypridopsis vidua* Expressed  
As Mean Numbers of Organisms Per Five Temperature Regimes

Temperature Ranges °C	Mean Number of Individuals ( $\pm$ one S.D.)
15-19	28.10 $\pm$ 12.1
20-24	18.83 $\pm$ 5.31
25-29	19.83 $\pm$ 5.91
30-34	5.66 $\pm$ 4.32
35-39	1.0 $\pm$ 1.27

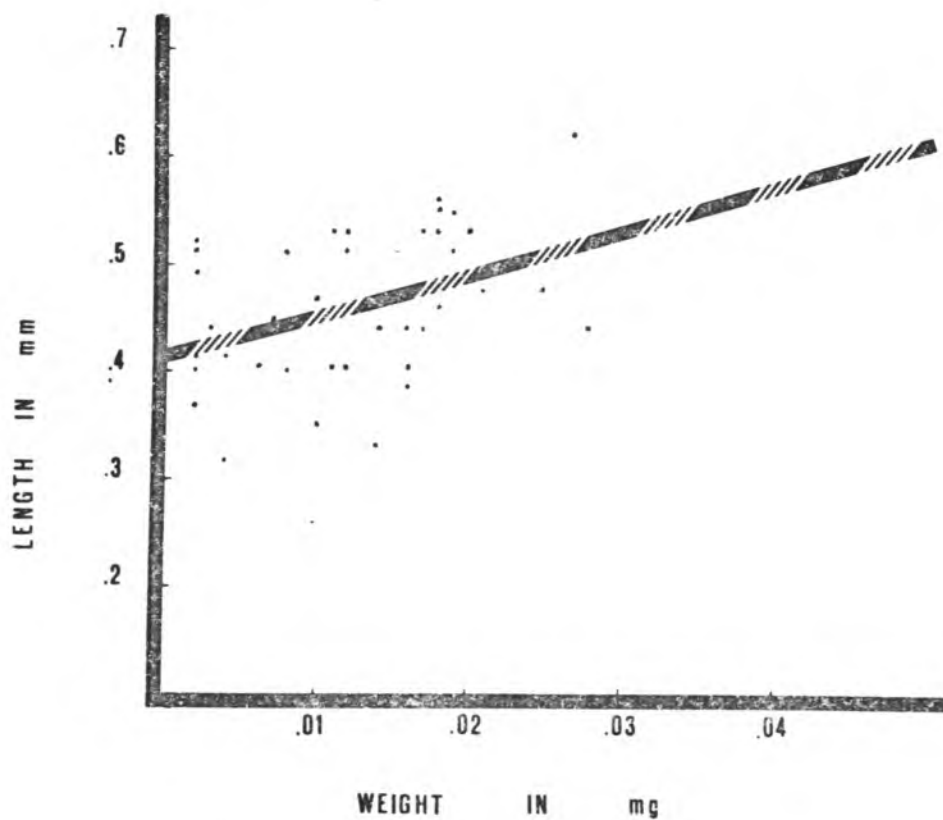


Figure 8. Length to weight relationships of *Cypridopsis vidua*, plotted for individuals of all size classes.

Table 7

Heat Effects on the Feeding and  
Efficiency of Assimilation in the Ostracode  
*Cypridopsis vidua*

Expressed as Mean ( $\pm$  1 S. D.) mg of detrital food/hour/mg Dry Weight Biomass

Temperature ( $^{\circ}$ C)	Ingestion	Assimilation	% Efficiency
15	573.98 $\pm$ 50.66	398.70 $\pm$ 125.11	69.46
20	616.94 $\pm$ 47.59	413.70 $\pm$ 65.36	67.10
25	719.12 $\pm$ 2.37	505.33 $\pm$ 84.53	70.20
30	764.27 $\pm$ 239.36	455.76 $\pm$ 56.99	59.63
35	607.30 $\pm$ 76.703	101.204 $\pm$ 50.31	16.66

## DISCUSSION

### Oxygen Consumption and Carbon Dioxide Production

Oxygen consumption in *Cypridopsis vidua* over a temperature range of 15-35C increased linearly from 735.94 - 2970.78  $\mu\text{l O}_2/\text{g wet weight/hour}$ . These data are comparable to ostracode metabolism reportings by Ikeda and Hagerman. Oxygen consumption in *Cypridopsis hilgendorffii* was 2450.00  $\mu\text{l O}_2/\text{g wet weight/hour}$  at 30C (Ikeda, 1970). In the same study, oxygen consumption in *Pyrocypris* sp. was 2250.00  $\mu\text{l O}_2/\text{g wet weight/hour}$  at 30C. Oxygen consumption by *Hirschmannia viridis* over a temperature range of 5-30C was 1500.00 - 6000.00  $\mu\text{l O}_2/\text{g wet weight/hour}$  (Hagerman, 1970). Hagerman also reported a non-linear increase in oxygen consumption rate between 10-20C. Unlike *H. viridis*, *C. vidua* showed a continual increase in oxygen consumption between 15-25C. This suggests that *C. vidua* may be ill-adapted to short-term heat exposures to which it is naturally subjected, due to the fact that no plateauing of oxygen consumption rate was noted at a preferred temperature. *C. vidua* did demonstrate lower changes in oxygen consumption over similar temperatures than did *H. viridis*. This difference may not be attributed to length of acclimation period, as they were similar in duration. This linear response of oxygen consumption is not unlike oxygen consumption rates for other ectothermic animals.

Oxygen consumption rates for the Class Ostracoda are generally higher than those of other classes of Crustacea (Table 8). However, some branchiopods (*Daphnia pulex* - 1295.00  $\mu\text{l O}_2/\text{g wet weight/hour}$  at 20C) and copepods (*Cyclops leuckarti* - 1450.00  $\mu\text{l O}_2/\text{g wet weight/hour}$  at 20C; *Diaptomus graciloides* - 1000.00  $\mu\text{l O}_2/\text{g wet weight/hour}$  at 20C) are comparable to oxygen consumption rates of *C. vidua* at 20C (1235.00  $\mu\text{l O}_2/\text{g wet weight/hour}$ ) (Wolverkamp and Waterman, 1960). Higher oxygen consumption rates in the Class Ostracoda may be due in part to the integumentary respiration potential of this group (they also have gill-type respiratory mechanism). In the case of *C. vidua*, increasing oxygen consumption rates may be due to the adaptation to the natural environment in which it is found (sediments: very low oxygen concentration, especially at higher temperatures where oxygen saturation in water is reduced). *C. vidua* may be adapted to low oxygen saturations causing a greater efficiency of oxygen utilization than is normal (for Classes such as Branchipoda and Copepoda) in the presence of an abundant oxygen supply.

Carbon dioxide production was proportionately higher than for other classes as exhibited by the very low R. Q. values (0.4 - 0.5) throughout the experimental period (Table 3). This low R. Q. value may be due in part to the metabolism of organic acids found abundantly in a bacterially decomposed detritus. This metabolism of detritus has been

Table 8

Literature Comparisons of Oxygen Consumption for Crustacean  
Types to Those of  
the Ostracode *Cypridopsis vidua*

Species	Temp. (t) (°C)	O <sub>2</sub> /gm wet <sup>2</sup> wt/hr
Branchiopoda		
<i>Artemia salina</i> <sup>1</sup>	23.5	236-739
<i>Daphnia longispina</i> <sup>2</sup>	20.0	560
<i>Daphnia magna</i> <sup>3</sup>	20.0	200
<i>Daphnia pulex</i> <sup>3</sup>	20.0	1295
Copepoda		
<i>Cyclops leuckarti</i> <sup>2</sup>	20.0	1450
<i>Diaptomus graciloides</i> <sup>2</sup>	20.0	1000
Seven Marine spp. <sup>4</sup>	20.0	580-1820
Isopoda		
<i>Asellus aquaticus</i> <sup>5</sup>	10.0	505-863
Amphipoda		
<i>Gammarus limnaeus</i> <sup>6</sup>	23.0	110-750
Ostracoda		
<i>Cypridina hilgendorffii</i> <sup>7</sup>	30.0	2450
<i>Pyrocypris</i> sp.	30.0	2250
<i>Hirschmannia viridis</i> <sup>8</sup>	5.0	1500 approx.
	10.0	3000 approx.
	15.0	3000 approx.
	20.0	3250 approx.
	25.0	5500 approx.
	30.0	6000 approx.
<i>Cypridopsis vidua</i>	15.0	735.94
	20.0	1235.07
	25.0	1949.10
	30.0	2478.14
	35.0	2970.78

1. Gilchrist, 1954.
2. Shtcherbakov, 1935.
3. Richman, 1958.
4. Conover, 1959.

5. Fox and Washbourn, 1935.
6. Krog, 1954.
7. Ikeda, 1970.
8. Hagerman, 1970.

shown to produce greater amounts of carbon dioxide than non-decomposed substratum. This may be a real expression of a natural system because carbon dioxide production in snails increased six times when the food source was changed from whole eel grass to a detrital material of eel grass (Adams and Angelovic, 1970). R. Q. values for other micro-crustaceans range in the normal 0.6 - 1.24 values, with one exception of 0.4 - 0.5 in *Trichodactylus petropolitanus* (Wolverkamp and Waterman, 1960). Caution must be taken to avoid hard-and-fast statements concerning types of metabolism represented by the respiratory quotient, since it is a highly variable index.

Temperature coefficients for tropical crustacean species tend to decrease with increasing temperatures and range from 2.0 to 2.25 at 30C to 2.5 to 6.0 at 15C (Rao and Bullock, 1954). *C. vidua* fits this trend with temperature coefficients of 1.44 at 35C to 3.56 at 15C. Bělehrádek (1935) pointed out that temperature coefficients commonly increase with the adaptation of the protoplasm to higher temperatures. This may be used to show *C. vidua* to be more closely adapted metabolically to 15-25C temperature range. No temperature coefficients are available for the Class Ostracoda. However, *C. vidua* shows comparable temperature coefficients with *Daphnia magna*, *Calanus finmarchicus*, and *Gammarus limnaeus* (Table 9).

#### Ingestion, Assimilation, and Egestion

Ingestion rates of *Cypridopsis vidua* increased linearly



Table 9

Literature Comparisons of Van't Hoff Temperature Coefficients  
Values for Crustacean Oxygen Consumption related to those for  
the Ostracode *Cypridopsis vidua*

Species	Temp. (t) (°C)	Q <sub>10</sub>	Comment
Branchiopoda			
<i>Daphnia magna</i> <sup>1</sup>	8 - 18	3.19	Temperate
	18 - 28	1.73	
<i>Branchinecta paludosa</i> <sup>2</sup>	0 - 15	2.60	Arctic
<i>Simocephalus vetulus</i> <sup>3</sup>	8 - 15	1.18	Temperate
	15 - 20	2.88	
	20 - 25	2.19	
Copepoda			
<i>Calanus finmarchicus</i> <sup>2</sup>	0 - 20	1.83 - 2.3	Temperate
Mysidacea			
<i>Hemimysis lamornae</i> <sup>4</sup>	10 - 20	1.88	Temperate
Isopoda			
<i>Rocinela signata</i> <sup>2</sup>	25 - 30	1.8 - 2.6	Tropical
Amphipoda			
<i>Gammaracanthus loricatus</i> <sup>2</sup>	0 - 5	1.9 - 2.2	Arctic
<i>Gammarus limnaeus</i> <sup>5</sup>	0 - 20	2.0	Temperate
Ostracoda			
<i>Cypridopsis vidua</i>	15 - 20	3.56	Tropical
	20 - 25	2.55	
	25 - 30	1.61	
	30 - 35	1.44	

1. Obreshkove and Abramowitz, 1932.
2. Scholander, Flagg, Walters, and Irving, 1953.
3. Hoshi, 1951.
4. Grainger, 1956.
5. Krog, 1954.

with temperature up to 30C. Ingestion rates above 30C declined to an upper level critical thermal maximum at 40C. This trend of linear increases in ingestion rate followed by a declining rate above optimum feeding temperature is a well-documented phenomenon in micro-crustaceans, particularly Branchiopoda. Filtering rates in *Daphnia magna* were shown to increase with increasing temperature below 20C. This species (*D. magna*) had a peak filtering rate at 28C, then a rapid decline (McMahon, 1965). Filtering rates in *Daphnia galeata* and *D. magna* increase with increasing temperatures over a range of 15-25C. At 25C, the mean filtering rates of these two species was two to three times higher than their rates at 15C (2.38 and 2.80, respectively) (Burns and Rigler, 1967; Burns, 1969). This decline after optimum feeding temperature is achieved suggests temperature limitation of the mechanics of the feeding process. It may be that the organism is limiting its activity and expenditure of energy while compensating for the internal utilization of stored material allowing minimal activity. It may be that long-term acclimation (one to two weeks) would allow compensation in ingestion rates to meet higher temperature stress (35-40C).

These organisms were cultured at room temperature (25C). It is interesting to note variance is reduced at the cultured temperature. This infers that temperature acclimation may take longer than 48 hours.

High variance in the ingestion data at 30C may be

caused by different reactions to the heat stress. Visual observations revealed some ostracodes when stressed became inactive, while other individuals did react irradically at high activity levels influencing other individuals in their immediate vicinity to do likewise. Sampling of individuals at that level may have been biased by non-random (accidental) selection of inactive individuals for a given sub-sample.

Assimilation rates for *C. vidua* increased linearly to 25C. Rates of assimilation were affected by temperature much differently than ingestion, as exhibited by the different slopes of initial response. Assimilation processes were negatively affected by temperature at 25C (five degrees lower than the processes governing ingestion). Long-term acclimation may resolve this difference.

Decline in ingestion and assimilation rates at 30C and 25C, respectively, is probably due to the increased rate of protein denaturation at these levels relative to the increased amount of organic material to be utilized. Denaturation of protein at critical levels occurs at about 37C. This would account for the high mortality rate at 40C.

$$\text{Assimilation Efficiency} = \frac{\text{Assimilation at } n}{\text{Ingestion at } n}$$

has been used to determine efficiency of food conversion for a species or within a trophic level (Clarke, 1946; Engelmann, 1966). Kozlovsky (1967) showed that this efficiency index tended to increase in value through increasing trophic levels.

His critical evaluation of the literature placed 83.5 percent as an upper limit reported for primary consumers.

*Cypridopsis vidua* was found to assimilate up to 70.2 percent of all algal detritus ingested. This value is well within the range described by Kozlovsky. Lufferova and Sorokin (1970) showed that *Cypridopsis vidua* could assimilate 69.0 percent of *Chlorella* (live) cells (Table 10). Detritus of *Potamogeton* with bacteria and protozoa showed highest assimilation efficiency (84.6 percent). This study did not experiment with algal detritus (*Chlorella*). Percent assimilation for the ostracode *Dolerocypris fasciata* was 81.0 percent (bacterial detritus) (Manakov and Sorokin, 1970).

Temperature control of percent assimilation is documented by Conover (1966). *Calanus hyperboreus*, a cold-water copepod, did not increase its percentage of assimilation between 2-11C when feeding on diatoms. This phenomenon was probably a result of its isolated thermal history (adaptive controls are probably not sufficiently developed to compensate for above normal temperature increases). *C. vidua* showed increasing assimilation rates with rising temperature to 25C, above which it declined.

Egestion rates for *Cypridopsis vidua* were positively logarithmically correlated to increasing temperatures. This trend is not common to all invertebrates studied. Fecal pellet production in *Hyalella azteca* increased linearly with increasing temperatures between 5-20C (Hargrave, 1972).

Table 10

Literature Comparisons of Assimilation Efficiency to that of  
of the Ostracode *Cypridopsis vidua*

Organism	A % Efficiency	Parameter
<i>Daphnia pulex</i> <sup>1</sup>	31.1	energy
<i>Calanus hyperboreus</i> <sup>2</sup>	19.1	weight
<i>Eurycercus lamellatus</i> <sup>3</sup>	20	energy
<i>Abramis brama</i> <sup>4</sup>	76	carbon
<i>Draptomus siciloides</i> <sup>5</sup>	48	energy
<i>Bittium varium</i> <sup>6</sup>	46.3	weight
<i>Dolerocypris fasciata</i> <sup>7</sup>	81	weight
<i>Cypridopsis vidua</i>	68.6	weight

1. Richman, 1958.
2. Conover, 1962.
3. Smirnov, 1962.
4. Sorokin, 1966.
5. Comita, 1964.
6. Adams and Angelovic, 1970.
7. Monakov and Sorokin, 1970.

Studies and data concerning egestion are generally limited to peripheral computations of ingestion values (egestion - growth + assimilation = ingestion) and/or assimilation values (ingestion - egestion = assimilation + respiration). Egestion in this study seemed to be a reciprocal expression of assimilation efficiency (Fig. 7). This relationship may be usable as a gross estimate of assimilation efficiencies within upper trophic levels, since fecal pellet production is easily measured in most classes of micro-crustaceans.

#### Effect of Body Size

Ingestion and assimilation rates per mg of biomass increased with decreasing size of individual organisms for *Cypridopsis vidua*. This has also been demonstrated in *Daphnia pulex* (Richmond, 1958). On a percent body weight basis, young *Hyallela azteca* egest (ingestion - assimilation, therefore, ingestion must increase as long as ingestion is greater than assimilation) three to four times more sediments than do adults (Hargrave, 1972). The implication is that young organisms are less efficient in assimilation of ingested materials and must, therefore, handle greater volumes of food per time per mg biomass than do larger organisms (even though assimilation is some higher per mg biomass in younger organisms). Larger organisms in turn have a larger gut which increases the residence time of the ingested food. This allows for more digestion of the ingested material.

### Length of Carapace:Weight Ratio

Length:weight ratios of *Cypridopsis vidua* proved to be useless as a tool, since the correlation coefficient of the data proved to be insignificant (at  $p > 0.20$ ). The relationship was linear, but variation in weight of the calcareous carapace of the seventh and eighth instar stages caused the ratio to be too variable. This linear relationship is not consistent with data involving *Daphnia pulex*. Edmondson (1955) found the length:weight relationship in *D. pulex* to be logarithmic. A later study defined this relationship as  $W = 0.028L - 0.22$  (Richmond, 1958).

### Thermal Preference

Preferendum temperature was difficult to obtain due to overlapping of numbers of individuals at three of the temperature ranges (Table 6). It should be noted that *C. vidua* did actively avoid 30C and 35C temperatures. The overlapping of numbers may be partially due to cold-induced inactivity which may have resulted in a collection of numbers of individuals at sub-optimum temperatures. Thermal history will determine the organism's preferred range for feeding (which may be well below maximum capability for ingestion, since it may be possible to overload an enzymatic system) and thermal optimum (Kibby, 1971). This will account for the slight overlapping in number of individuals at 20 and 25C, since organisms were cultured at room temperature. Genetic control



of the thermal preference would still be influenced by the thermal history of Tradinghouse Creek Reservoir.

*Heterocypris salinus* and *Cypridopsis aculeata* had observed temperature ranges of 5-32C and 5-28C, respectively, with both having a 15C optimum temperature (Ganning, 1971). This 15C optimum is lower than the projected optimum of 20-25C for *C. vidua*.

#### Temperature Effects on Gross Metabolism

Temperature above 25C caused a stress for *Cypridopsis vidua*. This is also true for other micro-crustacean types already discussed. Above 25C, the factors influencing assimilation begin to become negatively heat affected and by 30-35C are almost non-functional. Ingestion rates start to become negatively heat affected at 30C and by 35C are drastically affected. This reduction of ingestion and assimilation rates above 25C (assimilation rates were reduced at a faster rate than ingestion rates) caused the assimilation efficiency to fall from 69.46 percent at 15C to 16.66 percent at 35C. This drop in assimilation efficiency is accompanied by maximal metabolic activity (oxygen consumption and carbon dioxide production). This combination during heat exposure will cause death in the organism (this was noted in *Cypridopsis vidua* at 40C after 12 hours). These conditions of 25-35+C temperatures are present in the immediate area of the discharge at Tradinghouse Creek Reservoir for eight months out of the year (Venables, 1972). Effects of thermal loading in



Tradinghouse Creek Reservoir must be considered potentially harmful as temperatures exceeding 30C are found many times during the year for more than 24-48 hour exposures.

These negative effects on the herbivore population will cause a build-up of detrital material from the primary producer trophic level (due to reduced grazing). Accumulation of this detritus would place an additional load on the bacterial decomposers.

Reduction in numbers of individuals in the herbivore level will also affect higher trophic levels. For example, Altig (1967) reported that ostracodes, by numbers of individuals and frequency of occurrence (69.1 percent), were a dominant food type for *Siren intermedia*, which is a secondary consumer. The removal of ostracodes as a food source will negatively affect the secondary consumer. *S. intermedia* are dominant species in some aquatic habitats with biomass estimates exceeding  $83.7 \text{ g/m}^2$  (Gehlbach, unpublished, 1973). It can be projected that often consumers (such as predacious game fish) will indirectly have to alter their feeding pattern also as a result of reduction of numbers of individuals at primary consumer trophic level.

Such gross metabolic effects are potentially harmful to the primary herbivore trophic levels at Tradinghouse Creek Reservoir. Power plants that are located on stream or river ecosystems are potentially more harmful to the environment, since thermal effluents directly affect all the water and

associated biota passing by the station. Whereas, lake or reservoir stations, such as Tradinghouse Creek Reservoir, affect only a limited amount of the system (depending on the power station capacity, circulation pattern and rate, and size of the cooling reservoir). Locations of power stations must be selected on the basis of maximal dilution of the thermal effluent to reduce any negative effects.

More studies are necessary to determine if my results are universal at the primary herbivore level. Comparative studies involving herbivore populations from more and less thermally influenced receiving systems must be undertaken to determine if acclimation over long periods can compensate for this altered metabolism and feeding responses of the primary consumer level.

## SUMMARY

1. Mean oxygen consumption rate was positively linearly correlated with increasing temperatures (15-35C). Van't Hoff temperature coefficients ranged from 3.56 - 1.44 at 15-30C, showing a lack of adaptation to the increasing temperatures. No plateauing was noted at any temperature.

2. Mean carbon dioxide production was high, which resulted in low Respiratory Quotients (0.4 - 0.57). Carbon dioxide production was positively linearly correlated with increasing temperatures (15-35C).

3. Mean ingestion rates were positively linearly correlated with increasing temperature to 30C. Reduction in the ingestion rate above 30C was significant.

4. Mean assimilation rates were positively linearly correlated with increasing temperatures to 25C. Reduction in the assimilation rates above 25C was significant causing a reduction in assimilation efficiencies from 70 percent to 16 percent.

5. Thermal preference range for *Cypridopsis vidua* was not obtained due to broad temperature selection. Active avoidance of 30+C temperatures was observed.

# APPENDIX I

Individual Flask Data for Oxygen and Carbon Dioxide  
Values at Different Temperatures ( $^{\circ}\text{C}$ )  
for the Ostracode *Cypridopsis vidua*

Temperature	ul $\text{O}_2$ /lg dry wt.	S. D.	ul $\text{CO}_2$ /lg dry wt.	S. D.
15	5,667.03 2,502.08 4,881.86	+1,648.07	2,142.49 3,082.31 1,782.32	+671.19
20	6,891.89 7,450.64 7,559.73	+ 358.26	4,445.75 2,568.71 3,659.31	+942.62
25	10,437.00 9,079.00 15,049.20	+3,129.43	3,690.65 5,277.77 7,752.61	+2,047.08
30	14,780.49 12,821.30 16,344.63	+1,765.32	8,512.13 8,010.66 8,300.39	+251.75
35	19,831.06 14,495.36 18,356.41	+2,755.36	8,350.20 10,086.35 9,478.43	+880.97

Individual Flask Data for Oxygen and Carbon Dioxide  
 Values: Converted to Wet Weight Equivalent for  
 Literature Comparison  
 (Dry Weight is 17.84% of Wet Weight for  
 the Ostracode *Cypridopsis vidua* )

Temperature (°C)	ul O <sub>2</sub> /lg wet wt.	S. D.	ul CO <sub>2</sub> /lg wet wt.	S. D.
15	1010.99 446.37 870.92	294.02	382.22 549.88 317.97	119.74
20	1348.66 1229.51 1329.19	63.91	793.12 458.26 652.82	168.16
25	1861.96 1619.69 2684.78	558.29	658.41 941.55 1383.07	365.20
30	2636.84 2287.32 2915.88	314.93	1518.56 1429.10 1480.79	44.91
35	3537.86 2585.97 3274.78	491.56	1489.68 1799.40 1690.95	157.17

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## VITA

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