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## EXPERIMENTAL AND FIELD STUDIES ON ECOLOGICAL ENERGETICS OF *ASELLUS AQUATICUS* L. (ISOPODA)

### II. RESPIRATION AT VARIOUS TEMPERATURES AS AN ELEMENT OF ENERGY BUDGET\*

**ABSTRACT:** Respiratory rates of *Asellus aquaticus* measured at 10 and 15°C in volumetric respirometers were used for calculation of predictive and functional regressions for respiration-weight dependence in this species. Predictive regression coefficient  $b$  was 0.787 at 10°C, 0.828 at 15°C, its average value of 0.807 being almost identical with that reported by Winberg (1950) for all *Crustacea*. Functional regression coefficient  $\nu$  equalled to 1.033, 0.969, and 1.001, respectively. Using  $\nu$  instead of  $b$  in the case of *A. aquaticus* would change the biological interpretation of respiration-weight dependence making it totally dependent on weight. The predictive and functional regression equations were recalculated for 20°C acc. to the "normal curve" (Winberg 1956b, 1968) and  $Q_{10}$  value assessed for *A. aquaticus* by the author.

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#### 1. INTRODUCTION

In a complete energy study it is necessary to assess the amount of energy which is liberated by an organism in the form of heat and used for sustaining its life. Thus this element of energy budget is often righteously called "cost of maintenance" (Petrušewicz and

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\*Praca wykonana w ramach problemu węzłowego nr 09.1.7 („Produktywność ekosystemów słodkowodnych”).

Macfadyen 1970) and in terms of ecological physiology – respiratory metabolism (Phillipson 1966) or simply: metabolism or respiration (Duncan and Klekowski 1975).

It is relatively easy to measure respiratory rate of individuals in laboratory, however, for assessment of respiration of a whole ecological unit (e.g., population) existing in nature some approximations must be made, often based on such experimental measurements.

In studies of respiratory metabolism a well known dependence has been ascertained between the respiratory rate and the weight of individuals. It is described by an exponential equation:  $R = a \cdot W^b$ , where:  $R$  is the amount of oxygen consumed by an individual per hr ( $\mu\text{l}$  or  $\text{ml O}_2$ ),  $W$  is weight of respiring individual (wet,  $\text{mg}$  or  $\text{g}$ ),  $a$  is oxygen consumption by unit weight ( $\text{mg}$  or  $\text{g}$ ) per hour and  $b$  is exponent which relates the two variables ( $R$  and  $W$ ). The particular value of exponent  $b$  has some biological meaning in that it describes whether the respiratory rate is more dependent on body surface ( $b = 0.67$ ) or on weight ( $b = 1.00$ ) (Bertalanffy 1957). Exponent  $b$  is independent of units of  $R$  and  $W$  whereas  $a$  is dependent on them (Duncan and Klekowski 1975).

Metabolic rate (Klekowski, Wasilewska and Paplińska 1974, Duncan and Klekowski 1975) is a transformation of this equation and describes the above mentioned dependence in terms of unit weight:  $MR = a \cdot W^{b-1}$ , where  $MR$  is amount of oxygen consumed by unit weight ( $\text{mg}$ ,  $\text{g}$ ) per hr. Metabolic rate may be convenient mean for further calculations of population metabolism but it will be not discussed in the present paper.

Equation for respiratory rate is calculated by the method of least squares (Simpson, Roe and Levontin 1960) and takes a form of straight line on a graph of  $R$  against  $W$  with double logarithmic scale.

Ricker (1973) in his extensive study on linear regressions applied in fisheries has analyzed many cases of predictive and functional regressions, among them the one describing oxygen consumption-body weight dependence. His suggestion was that “a functional regression is needed to describe a natural relationship of this sort and the  $GM$  regression,  $\nu$ , is the most appropriate estimate of it because the variability in the data is likely to be mainly natural. And because the data series are typically non-normal and open ended – a functional regression should also be used for prediction” (Ricker 1973). In the light of this statement it seems interesting to test rather ample data gathered on respiration of an aquatic poikilotherm, *Asellus aquaticus* L., at two temperatures by calculating both types of regressions: traditional one, predictive regression  $R$  on  $W$  and functional regression  $R$  on  $W$  with coefficient  $\nu$  which is “the geometric mean estimate of the functional regression  $R$  on  $W$ , or, more briefly, the  $GM$  regression” (Ricker 1973). The difference between these two regressions is that the first one (predictive  $R$  on  $W$ ) minimizes the sum of squares of vertical distances from the points to the line whereas the second one (functional  $GM$  regression) minimizes the sum of products of the vertical and horizontal distances of each point from the line (Ricker 1973).

*Asellus aquaticus* seems to be a convenient choice for such comparison since it belongs to aquatic *Crustacea* which deserved an extensive study of respiration by Winberg (1950, 1956a) and thus the present results can easily be verified by confronting them with the papers cited. Besides evaluating the validity of Ricker's (1973) approach to oxygen consumption-body weight dependence the chosen regression equations calculated for this species at two temperatures will allow to define the respiratory rates necessary for further estimation of cost of maintenance in a natural population of this species.

## 2. MATERIAL AND METHODS

The animals for respiration measurements were collected from a small pond in the Kampinos Forest near Warsaw and brought to the laboratory. Prior to the measurements they have been acclimated either to 10 or 15°C for at least 14 days, being then fed with decaying leaves of alder tree, *Alnus glutinosa* (L.) Gaertn. Oxygen consumption was measured in volumetric respirometers (Klekowski 1975) with a spherical respiratory chamber filled with 0.5 ml aerated tap water. For carbon dioxide absorption 0.1 ml of 15% NaOH was used. The measurements lasted three hours (from 9,30 to 12,30) with readings done every 15 min. exclusive the period of gaseous compensation (20–30 min.) prior to closing the system and the first reading. After terminating the measurements the animals were weighed with 0.01 mg accuracy and their sex identified. Five to six respirometers were used daily and the specimens were placed individually into each respirometer. During measurements the respirometers were submerged in a water bath with thermostatically regulated temperature to 0.1°C accuracy.

Before the mean value of oxygen consumption by an individual was calculated the rough results (readings) were plotted on a millimeter paper against time and a straight line parallel to experimental curve was drawn, which served for taking off the mean value of oxygen consumed rather than calculating arithmetic mean of reading during 3-hour run. This was dictated by a certain bending of the curves due to the diurnal rhythm in respiration of this species. According to Lang and Ružičkova-Langova (1951) the smallest respiratory activity in *A. aquaticus* occurs in mid-day hours. Besides, this way of elaborating results seems to be more appropriate since it neglects some unaccountable deviations of the O<sub>2</sub> consumption line and reflects its general trend only. Thus obtained respiratory rates were related to standard conditions of temperature and pressure (0°C and 760 mm Hg). The spherical shape of the respiratory chamber and the little amount of water both ensured inconsiderable movements of the animal during the measurement so that what was measured was something between resting and standard metabolism rather than routine or active metabolism.

Measurements at 10°C were carried out in December 1970 and January 1971, and these at 15°C – in March and April 1973. The range of wet weight of individuals tested was: 3.68–39.93 mg at 10°C and 5.95–63.35 mg at 15°C, with mean values of 17.65 mg and 12.98 mg, respectively.

There were 104 measurements taken at 10°C (54 males and 50 females) and 90 measurements at 15°C (45 males and 45 females), 194 in total.

Calculations of predictive regressions of  $W$  on  $R$  and  $R$  on  $W$  were done with the use of Compucorp 344 Micro Statistician according to its program and 95% confidence limits of  $a$  and  $b$  as well as the significance of difference between exponents  $b$  – according to formulae given by Simpson, Roe and Levontin (1960). Significance of difference between  $a$  values of predictive regressions of  $R$  on  $W$  was tested with formulae reported by S. Cianciara (unpublished data) as based on statistical textbooks (Bailey 1959, Oktaba 1974). Calculations of functional  $GM$  regressions, exponent  $\nu$ , its 95% confidence limits and values  $u$  were done acc. to Ricker (1973).

Units used in calculation of all regressions were for  $R$  –  $\mu\text{l O}_2/\text{ind.} \cdot \text{hr}$  and for  $W$  – mgs wet weight. Most of equations were recalculated for units of  $R$  – ml O<sub>2</sub>/ind. hr and  $W$  – g wet weight, according to the method reported by Duncan and Klekowski (1975).

## 3. RESULTS AND DISCUSSION

Equations of predictive and functional regressions describing oxygen consumption-body weight dependence in males, females, and both sexes of *A. aquaticus* are presented in Table I.

Table I. Regression equations of oxygen consumption-body weight dependence in *A. aquaticus*

$W$  — wet weight of individual in mg (1) and in g (2);  $R$  —  $O_2$  consumed/ind. · hr in  $\mu$ l (1) and in ml (2). For explanation of other symbols see the text

Temperature °C	Sex	No. of measurements	Type of regression and equations			
			predictive		functional (GM)	
			$R = a \cdot W^b$		$R = u \cdot W^v$	
			1	2	1	2
10	males	54	$0.1997 W^{0.7510}$	$0.0358 W^{0.7510}$	$0.1014 W^{0.9843}$	$0.0910 W^{0.9843}$
	females	50	$0.1390 W^{0.8195}$	$0.0400 W^{0.8195}$	$0.0688 W^{1.0677}$	$0.1099 W^{1.0677}$
	both sexes	104	$0.1664 W^{0.7865}$	$0.0381 W^{0.7865}$	$0.0819 W^{1.0333}$	$0.1031 W^{1.0333}$
15	males	45	$0.2909 W^{0.8506}$	$0.1036 W^{0.8506}$	$0.1506 W^{1.0880}$	$0.2766 W^{1.0880}$
	females	45	$0.3183 W^{0.8287}$	$0.0975 W^{0.8287}$	$0.2515 W^{0.9292}$	$0.1542 W^{0.9292}$
	both sexes	90	$0.3136 W^{0.8287}$	$0.0954 W^{0.8287}$	$0.2181 W^{0.9691}$	$0.1763 W^{0.9691}$

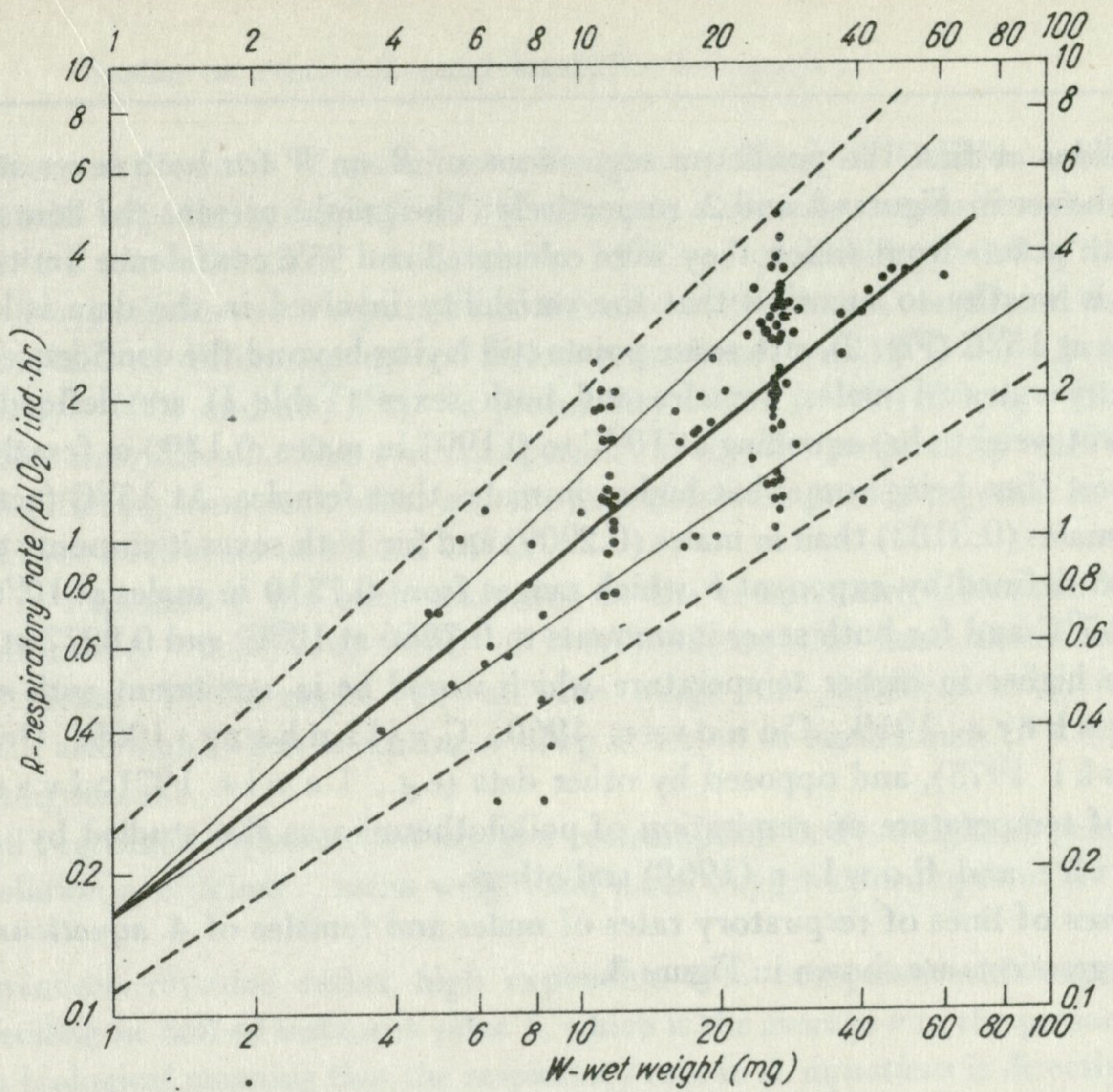


Fig. 1. Respiratory rate ( $R$ ) of *A. aquaticus* against wet weight of individuals ( $W$ ) at  $10^{\circ}\text{C}$   
 Predictive regression (bold line):  $R = 0.1663 W^{0.7866 \pm 0.1312}$  (95% confidence limits of  $b$  (solid lines)  
 and  $a$  and  $b$  (broken lines))

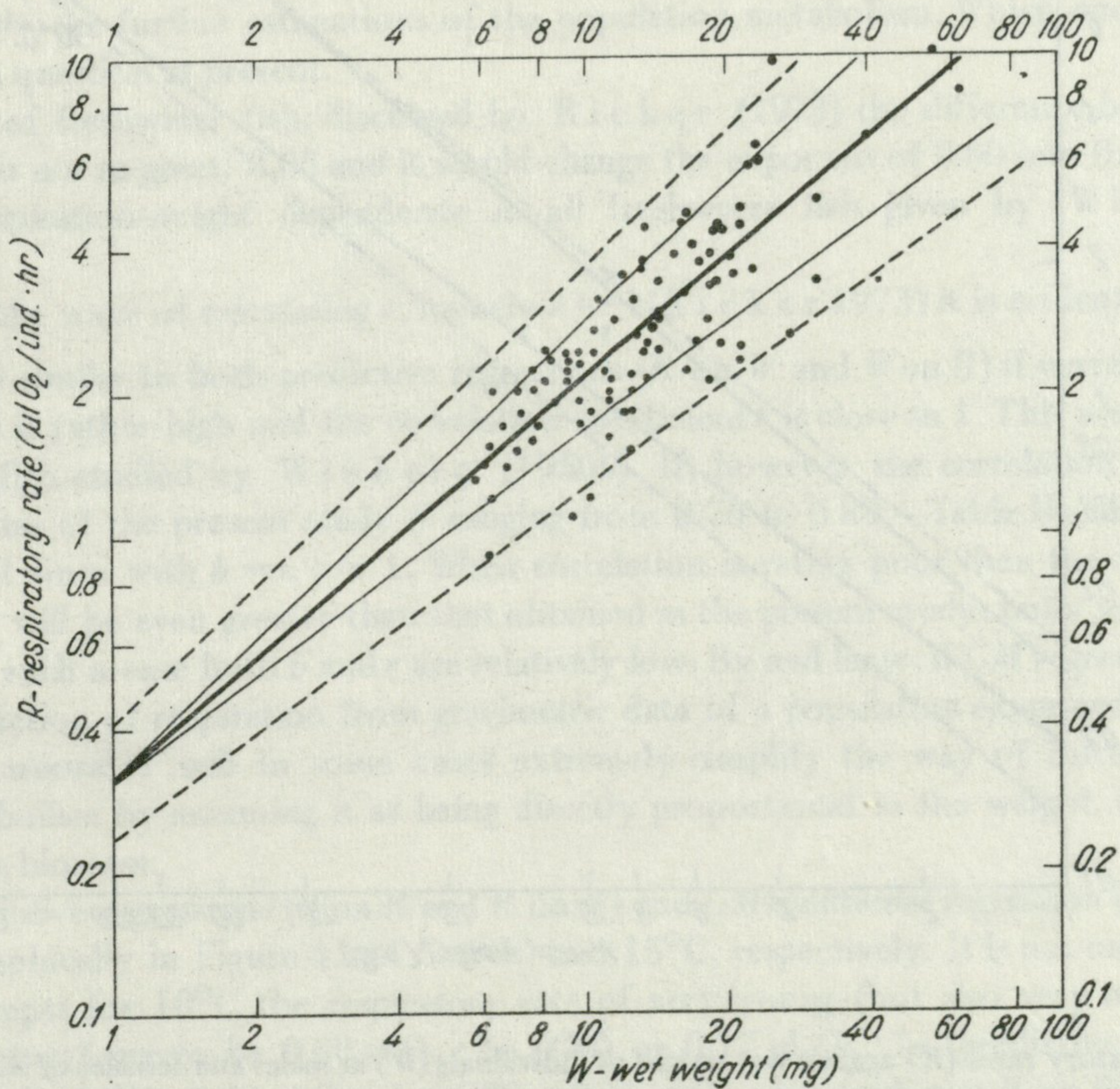


Fig. 2. Respiratory rate ( $R$ ) of *A. aquaticus* against wet weight of individuals ( $W$ ) at  $15^{\circ}\text{C}$   
 Predictive regression (bold line):  $R = 0.3136 W^{0.8277 \pm 0.1074}$  (95% confidence limits of  $b$  (solid lines)  
 and  $a$  and  $b$  (broken lines))

Let us consider at first the predictive regressions of  $R$  on  $W$  for both sexes at 10 and 15°C which are shown in Figures 1 and 2, respectively. The graphs present the courses of the lines together with points from which they were calculated and 95% confidence limits of  $a$  and both  $a$  and  $b$ . It is worthy to mention that the variability involved in the data is higher at 10°C (Fig. 1) than at 15°C (Fig. 2) with some points still laying beyond the confidence limits.

Respiratory rates of males, females and both sexes (Table I) are defined by factors  $a$  ( $\mu\text{l O}_2/\text{mg wet weight} \cdot \text{hr}$ ) equalling at 10°C to 0.1997 in males, 0.1390 in females, and 0.1664 in both sexes; thus being somewhat higher in males than females. At 15°C factor  $a$  is a little higher in females (0.3183) than in males (0.2909) and for both sexes it amounts to 0.3136. The rates are also defined by exponent  $b$  which ranges from 0.7510 in males at 10°C to 0.8287 in females at 15°C and for both sexes it amounts to 0.7866 at 10°C and 0.8277 at 15°C. Thus it seems to be higher in higher temperature which would be in agreement with some literature data (Vernberg 1959, Conover 1960, Gyllenberg 1969, Duncan and Klekowski 1975), and opposed by other data (e.g., Lewis 1971, Ivanova 1972). The effect of temperature on respiration of poikilotherms was also studied by Armitage (1962), Tribe and Bowler (1968) and others.

The courses of lines of respiratory rates of males and females of *A. aquaticus* calculated as predictive regressions are shown in Figure 3.

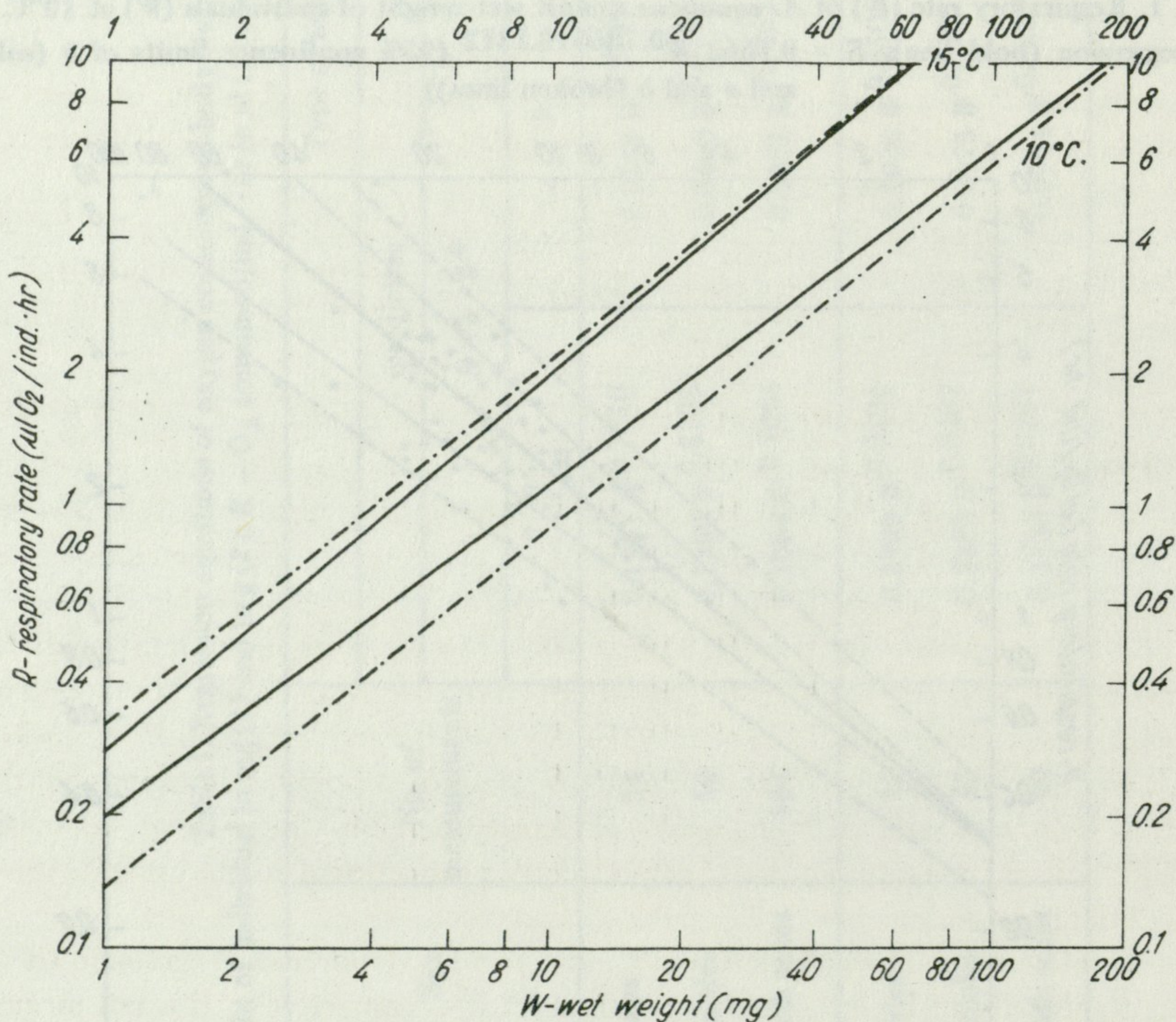


Fig. 3. Respiratory rates ( $R$ ) against wet weight of individuals ( $W$ ) in males and females of *A. aquaticus* at 10 and 15°C

For equations see Table I; solid lines — males, broken-dotted lines — females

Neither factor  $a$  nor exponent  $b$  of males versus females at 10 and 15°C differ significantly. As tested with the null hypothesis the lack of difference in  $a$  of males versus females at 10°C has a probability  $> 0.7$  ( $d = 0.3642$ ,  $df = 100$ ) and at 15°C – a probability  $> 0.8$  ( $d = 0.1922$ ,  $df = 86$ ) so the null hypotheses were rejected and these two differences considered as insignificant. Similarly the lack of difference in  $b$  of males versus females at 10°C has a probability  $> 0.6$  ( $t = 0.5158$ ,  $df = 100$ ) and at 15°C – a probability  $> 0.9$  ( $t = 0.1830$ ,  $df = 86$ ), these differences being also insignificant. This statistics permits to consider respiratory rates of males and females as non-differing from each other and the materials were pooled together in order to calculate regressions for both sexes at 10 and 15°C.

The difference in exponent  $b$  for both sexes due to the temperature effect (10°C versus 15°C) is also insignificant ( $t = 0.4697$ ,  $df = 190 - P > 0.7$ ). On the other hand, factors  $a$  of both sexes at 10°C versus 15°C might be on the verge of significance ( $d = 1.4170$ ,  $df = 190 - P < 0.2$ ), although, when accepting a sharp criterion of significance ( $P < 0.05$ ), the difference is also insignificant.

Constants of all regression equations of oxygen consumption-body weight dependence in *A. aquaticus*, correlation coefficient  $r$ , mean weight and mean oxygen consumption, are given in Table II.

Functional regressions revealed rather high exponents  $\nu$  as compared with exponents  $b$  (Tables I, II), exceeding in half of instances value 1, which is the average  $\nu$  in the present study. This would have a biological meaning that the respiratory rate in *A. aquaticus* is directly related to body weight. The difference between  $\nu$  and  $b$  is 0.24 at 10°C and 0.14 at 15°C (Table II), about 0.20 on the average, which suggests that the two approaches would yield quite different views on relation between respiration and weight. It seems that choosing one of them would affect substantially the further estimations of the population metabolism. Which one is to be chosen is an open question at present.

In respiration of freshwater fish, discussed by Ricker (1973) the difference between  $\nu$  and  $b$  exponents is not so great: 0.05 and it would change the exponent of 0.80 into 0.85 in the equation for respiration-weight dependence in all freshwater fish given by Winberg (1956b).

From one of the ways of calculating  $\nu$ , namely  $\nu = \frac{b}{r}$  (Ricker 1973) it is evident that  $GM$  regression will be similar to both predictive regressions ( $R$  on  $W$  and  $W$  on  $R$ ) if correlation of the two variables is rather high and the correlation coefficient  $r$  is close to 1. This was the case with freshwater fish studied by Winberg (1956b). If, however, the correlation is not so good as in the case of the present study ( $r$  ranging from 0.76 to 0.89 – Table II), then  $\nu$  will oscillate around 1 since with  $b \approx r$ ,  $\nu \approx 1$ . When correlation is rather poor then the difference between  $\nu$  and  $b$  will be even greater than that obtained in the present study, but  $\nu$  will not rise above 1 since in such a case both  $b$  and  $r$  are relatively low. By and large, if  $GM$  regression is to be used for prediction of respiration from gravimetric data of a population examined, the fact of  $\nu$  oscillating around 1 will in some cases extremely simplify the way of calculation of population metabolism by assuming it as being directly proportional to the weight, therefore, to the population biomass.

The two predictive regressions ( $W$  on  $R$  and  $R$  on  $W$ ) and  $GM$  functional regression ( $R$  on  $W$ ) are presented graphically in Figure 4 and 5 at 10 and 15°C, respectively. It is not meaningless whether one accepts for 10°C the respiratory rate of very young (but also very numerous) individuals weighing 1 mg to be  $0.08 \mu\text{l O}_2 \cdot \text{hr}$  ( $GM$ ) or  $0.17 \mu\text{l O}_2 \cdot \text{hr}$  (predictive  $R$  on  $W$ ) (Fig. 4) as well as for 15°C:  $0.22 \mu\text{l O}_2 \cdot \text{hr}$  ( $GM$ ) or  $0.31 \mu\text{l O}_2 \cdot \text{hr}$  (predictive  $R$  on  $W$ ) (Fig. 5) for estimation of population metabolism. The reverse will be true for very large individuals

Table II. Constants of regressions of oxygen consumption-body  
For explanation of the

Temperature °C	Sex	No. of measurements	Mean weight $\bar{W}$ mg	Mean respiration $\bar{R}$ $\mu\text{l O}_2/\text{ind.} \cdot \text{hr}$	Correlation coefficient $r$
10	males	54	18.27	1.77	0.7630
	females	50	17.01	1.43	0.7676
	both sexes	104	17.65	1.59	0.7612
15	males	45	16.01	3.08	0.7818
	females	45	10.44	2.22	0.8918
	both sexes	90	12.98	2.62	0.8541

\*After Winberg (1950).

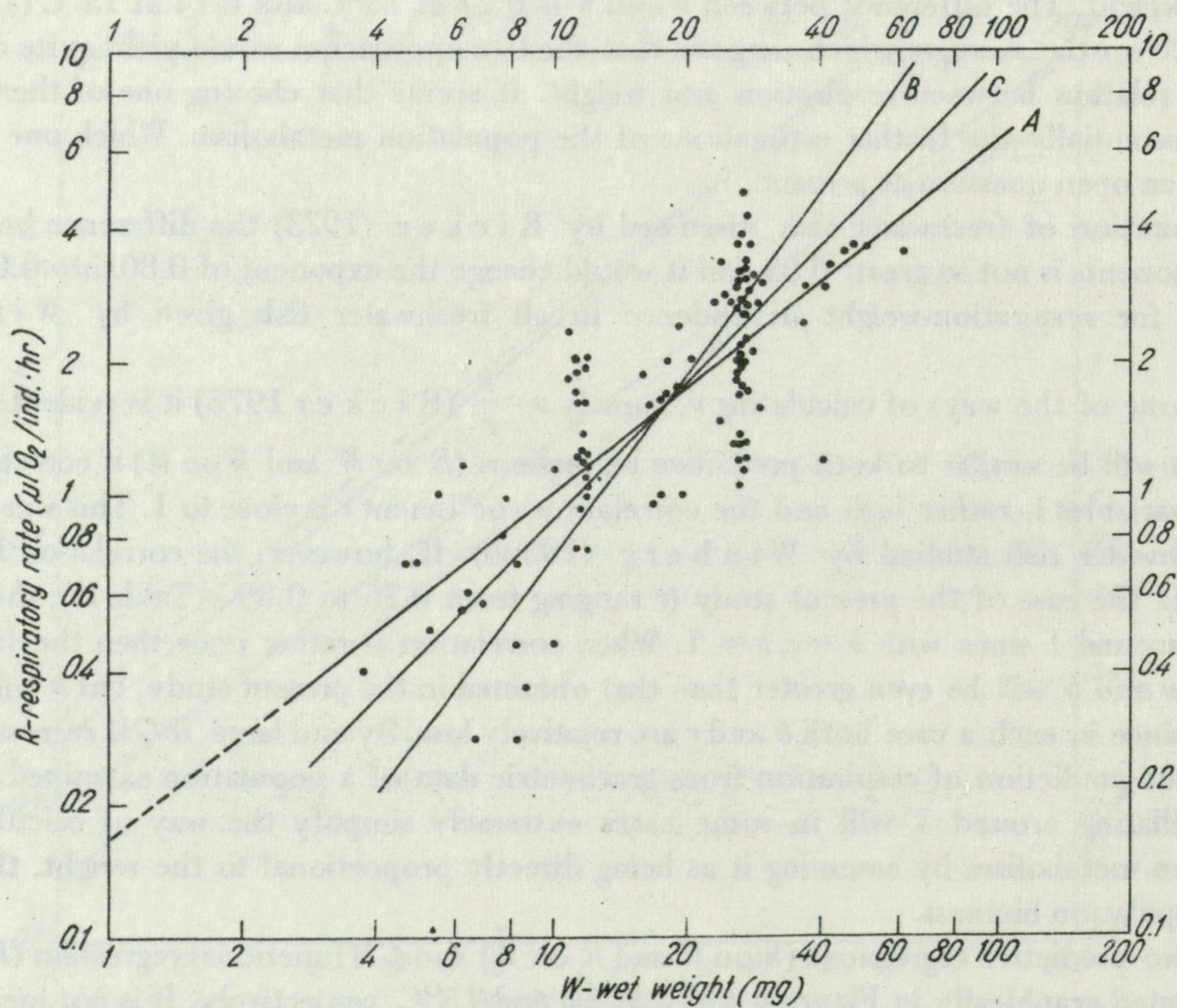


Fig. 4. Respiratory rate ( $R$ ) of *A. aquaticus* against wet weight of individuals ( $W$ ) at  $10^{\circ}\text{C}$   
A — predictive regression of  $R$  on  $W$ , B — of  $W$  on  $R$ , C — functional (geometric mean) regression of  $R$  on  $W$ .  
For regression equations see Table I



weight dependence in *A. aquaticus* and their 95% confidence limits  
 symbols see the text

Intercept			Exponent		
predictive regression $R$ on $W$		when $b = 0.81^*$ $a_k$	$GM$ regression $u$	predictive regression $b$	geometric mean regression $v$
$a$	$a_{\min}$ to $a_{\max}$				
0.1997	0.1146–0.3479	0.1683	0.1014	$0.7510 \pm 0.1866$	$0.9843 \pm 0.1782$
0.1390	0.0794–0.2433	0.1428	0.0688	$0.8195 \pm 0.1975$	$1.0677 \pm 0.1975$
0.1663	0.1132–0.2444	0.1555	0.0819	$0.7865 \pm 0.1312$	$1.0333 \pm 0.1314$
0.2909	0.1618–0.5231	0.3256	0.1506	$0.8506 \pm 0.2087$	$1.0880 \pm 0.2069$
0.3183	0.2341–0.4328	0.3326	0.2515	$0.8287 \pm 0.1280$	$0.9292 \pm 0.1213$
0.3136	0.2367–0.4153	0.3281	0.2182	$0.8277 \pm 0.1074$	$0.9691 \pm 0.1062$

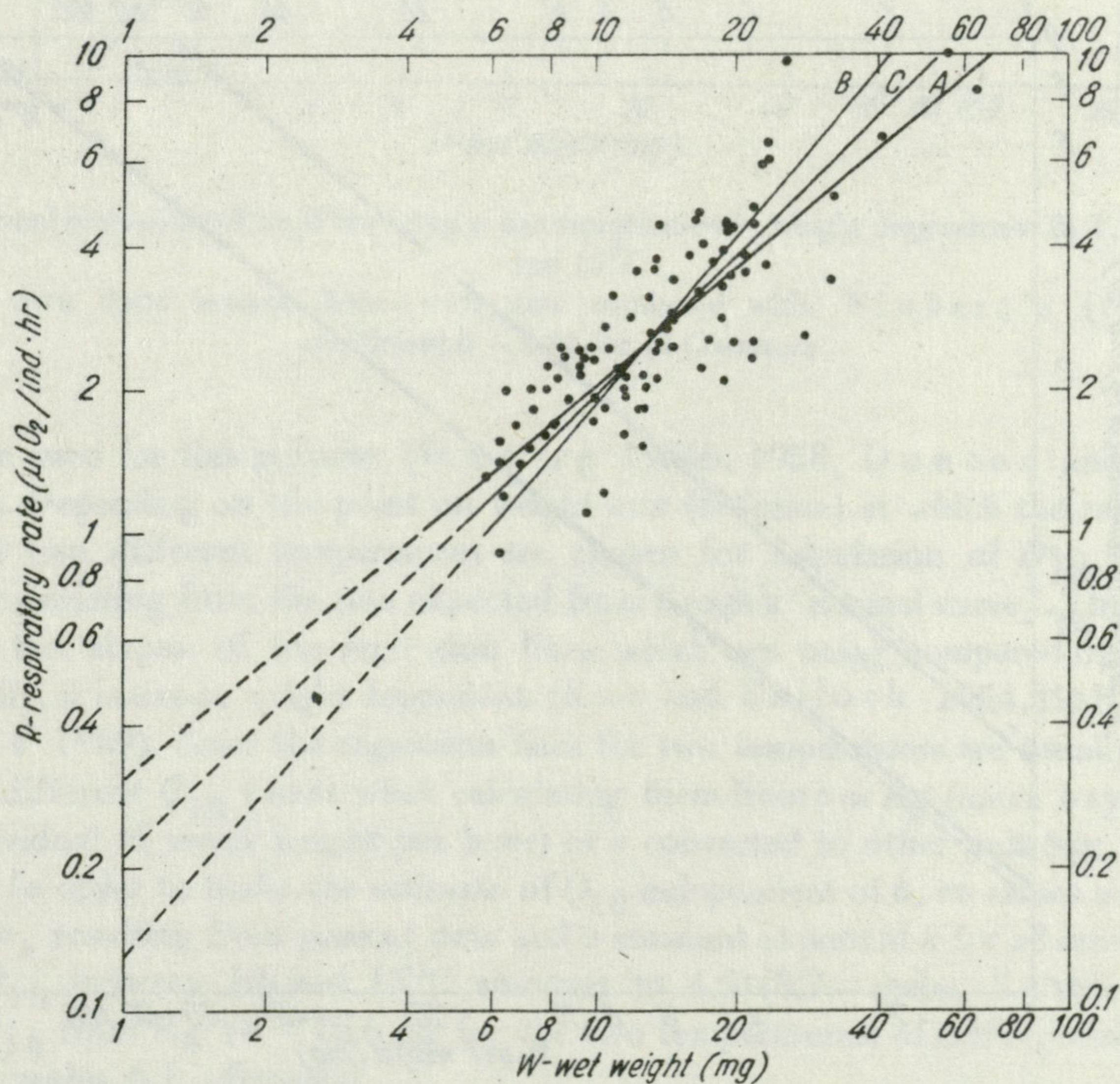


Fig. 5. Respiratory rate ( $R$ ) of *A. aquaticus* against wet weight of individuals ( $W$ ) at  $15^{\circ}\text{C}$   
 A — predictive regression of  $R$  on  $W$ , B — predictive regression of  $W$  on  $R$ , C — functional regression ( $GM$ ) of  
 $R$  on  $W$ . For equations see Table I . .

which are less numerous in the population but they consume relatively much more oxygen per individual. Here prediction from *GM* regression will overestimate the results. Will these over- and under-estimations counterbalance — is another question to be checked on factual population data.

Winberg (1950) in his review of studies on respiration of *Crustacea* concluded that the oxygen consumption-body weight dependence is of a similar type when tested not only within the development of one species but for all (except *Triops cancriformis* Bosc.) marine and freshwater crustaceans. His equation for all *Crustacea* at 15°C is as follows:  $R = 0.105 W^{0.81}$  (Winberg 1950), where  $R$  is in  $\text{ml O}_2/\text{ind.} \cdot \text{hr}$  and  $W$  in g wet weight, with exponent  $k = b$  being 0.809. Using this exponent and calculating metabolically effective mean weight  $\bar{W}^k$  for *A. aquaticus*, values of  $a_k$  were calculated from the mean oxygen consumption  $\bar{R}$ . Thus obtained "regression lines" were drawn along with predictive regressions  $R$  on  $W$  (Fig. 6) and *GM* regressions  $R$  on  $W$  (Fig. 7). Lines of predictive regressions  $R$  on  $W$  coincide almost completely with those involving all-crustacean exponent of 0.81 (Fig. 6). Minute deviation might reflect the fact of exponent  $b$  being higher at higher temperature (Table II). Lines of *GM* regressions of  $R$  on  $W$ , on the other hand, deviate considerably from those based on all crustacean exponent (Fig. 7) with the difference  $v - k$  amounting to 0.22 at 10°C and 0.16 at 15°C.

For estimation of respiratory metabolism of a poikilotherm population inhabiting a natural habitat the temperature correction factor seems to be most important. Factor  $q$  based on  $Q_{10}$

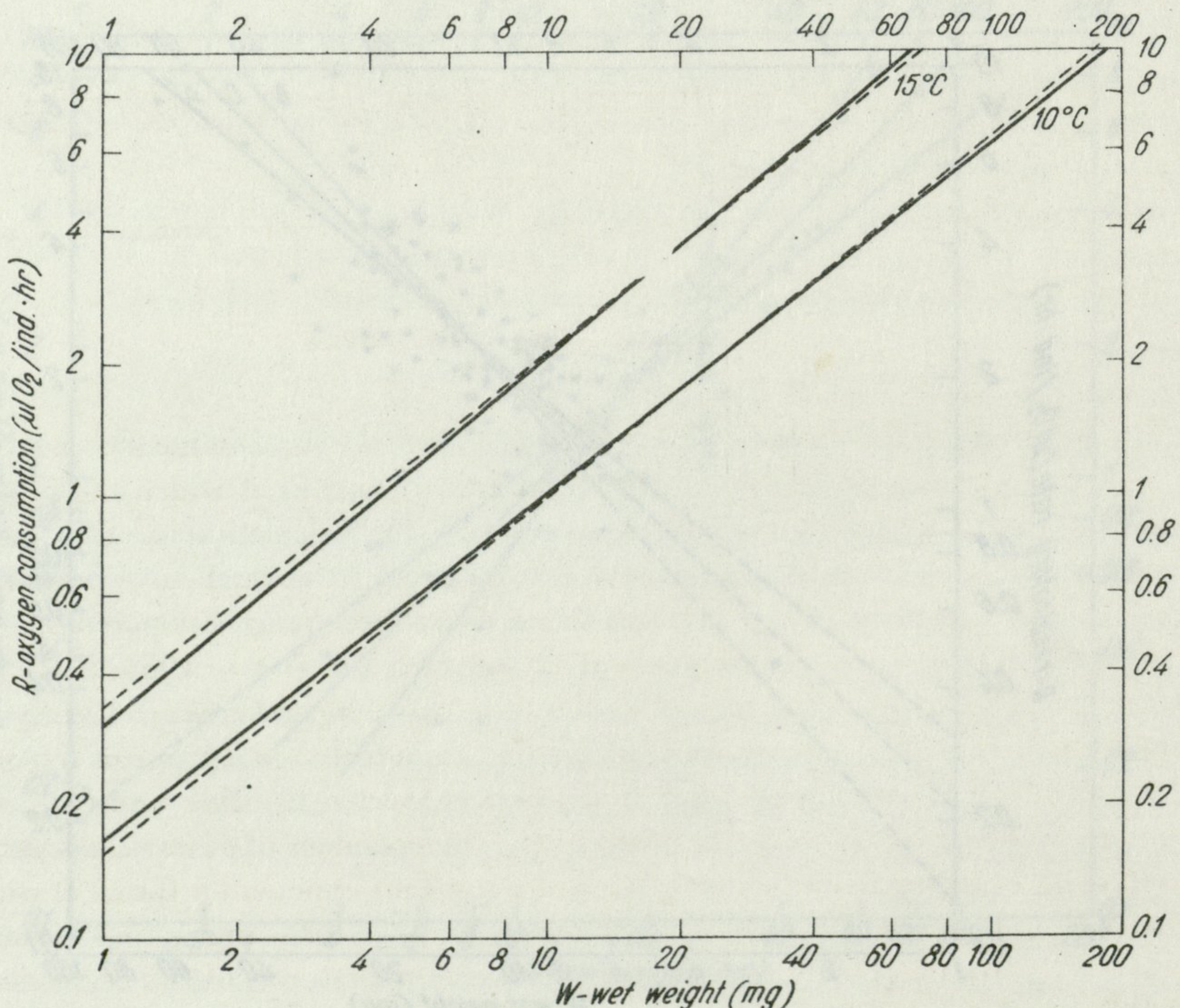


Fig. 6. Predictive regressions  $R$  on  $W$  for oxygen consumption-body weight dependence in *A. aquaticus* at 10 and 15°C

Solid lines — own data; broken lines — own data combined with Winberg's (1950) regression coefficient  $b = 0.81$  for all *Crustacea*

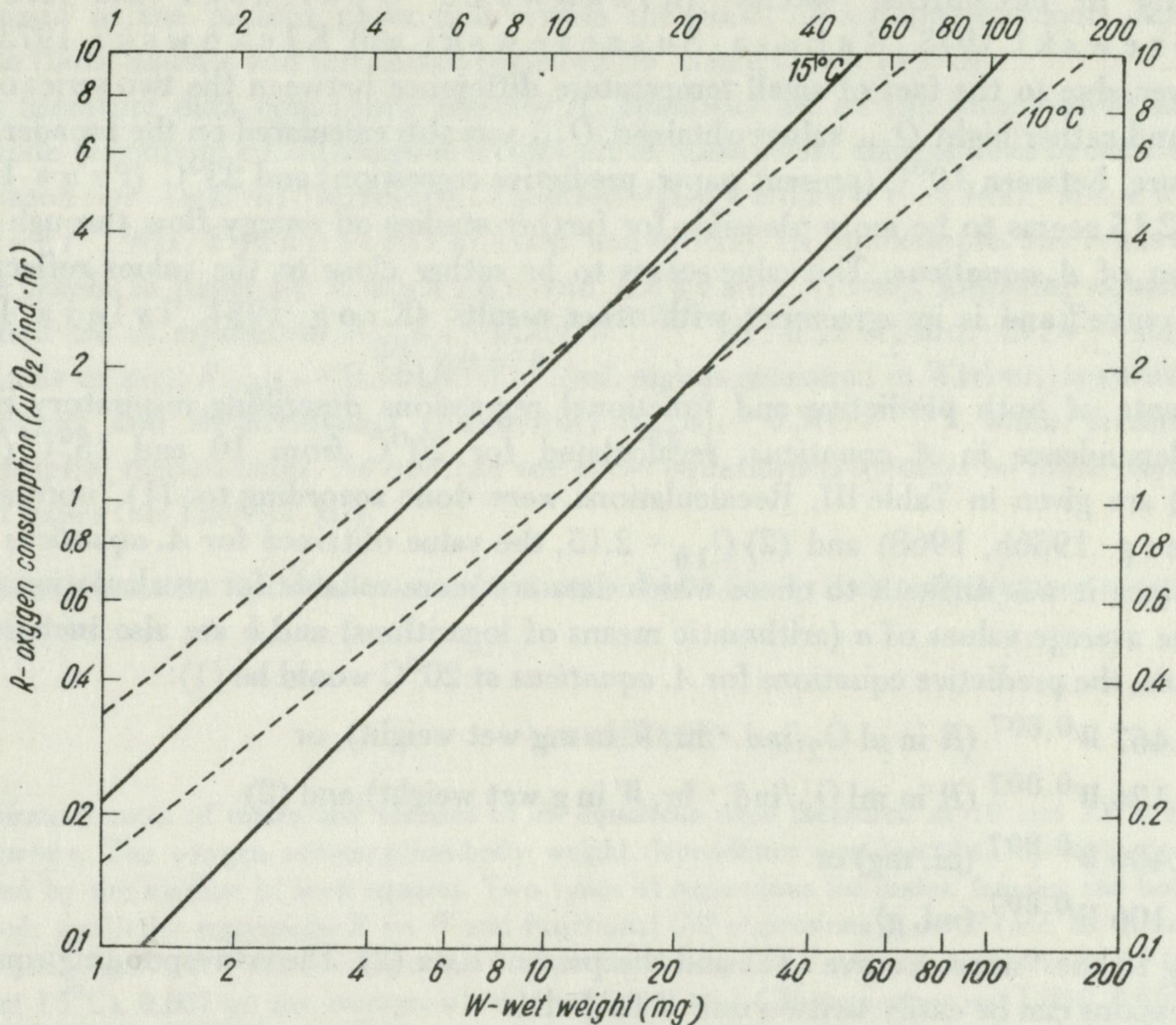


Fig. 7. Functional regressions  $R$  on  $W$  for oxygen consumption-body weight dependence in *A. aquaticus* at 10 and 15°C

Solid lines — own data; broken lines — own data combined with Winberg's (1950) regression coefficient  $b = 0.81$  for all *Crustacea*

value can be used for this purpose (Winberg 1956b, 1958, Duncan and Klekowski 1975). Depending on the point on weight axis (ordinate) at which the respiratory rates measured at two different temperatures are chosen for calculation of  $Q_{10}$ , its value vary considerably deviating from the one expected from Krogh's "normal curve". Thus,  $Q_{10}$  is very sensitive to the slopes of the regression lines which are being compared or, saying more conventionally, it is size or weight dependent (Rao and Bullock 1954, H. Barenz and M. Barenz 1969). Since the regression lines for two temperatures are usually non-parallel one obtains different  $Q_{10}$  values when calculating them from  $a$  or  $R_{\bar{W}}$  (mean oxygen consumption by individual of mean weight per hour) or  $a$  converted to other unit (e.g., ml  $O_2$ /g wet weight · hr). In order to make the estimate of  $Q_{10}$  independent of  $b$ , its values were calculated from values  $a_k$  resulting from present data and a constant exponent  $k$  for all crustaceans. Thus calculated  $Q_{10}$  between 10 and 15°C amounts to 4.5 (3.7 — males, 5.4 — females). When calculating  $Q_{10}$  from  $R_{\bar{W}}$  ( $\bar{W} = 16.6$  mg for the two temperatures) of *GM* regressions, it equals to 4.9 (4.0 — males, 6.1 — females).

One explanation of rather high  $Q_{10}$  values obtained in the present paper might be the seasonal difference between the two series of measurements. Higher respiratory activity in *A. aquaticus* in spring and summer than in autumn and winter was found by Laňg and Ružičkova-Langova (1951). Even higher  $Q_{10}$  values were reported for an antarctic

amphipod, *Paramoera walkeri* Stebbing, ranging from 4.6 to 15.9, but such  $Q_{10}$  values are found only in circumpolar species (Klekowski, Opaliński and Rakusa-Suszczewski 1973, Rakusa-Suszczewski and Klekowski 1973).

However, due to the fact of small temperature difference between the two series of measurements and rather high  $Q_{10}$  values obtained,  $Q_{10}$  was also calculated on the broader range of temperature, between 10°C (present paper, predictive regression) and 23°C (Prus 1972). Its value of 2.15 seems to be more plausible for further studies on energy flow through a natural population of *A. aquaticus*. This value seems to be rather close to the values reflecting the "normal curve" and is in agreement with other results (Krog 1954, Ivleva 1973 and others).

Constants of both predictive and functional regressions describing respiratory rate-body weight dependence in *A. aquaticus*, recalculated for 20°C from 10 and 15°C (and also averaged) are given in Table III. Recalculations were done according to: (1) "normal curve" (Winberg 1956b, 1968) and (2)  $Q_{10} = 2.15$ , the value obtained for *A. aquaticus* (present paper). Since it was difficult to choose which data are more reliable for recalculation (at 10 or 15°C) the average values of  $a$  (arithmetic means of logarithms) and  $b$  are also included in the table. Thus, the predictive equations for *A. aquaticus* at 20°C would be (1):

$$R = 0.467 W^{0.807} \text{ (R in } \mu\text{l O}_2\text{/ind.} \cdot \text{ hr, } W \text{ in mg wet weight), or}$$

$$R = 0.124 W^{0.807} \text{ (R in ml O}_2\text{/ind.} \cdot \text{ hr, } W \text{ in g wet weight) and (2)}$$

$$R = 0.406 W^{0.807} \text{ (}\mu\text{l, mg) or}$$

$$R = 0.106 W^{0.807} \text{ (ml, g),}$$

according to the "normal curve" (1) and the present data (2). The corresponding equations of GM regressions can be easily written out of Table III.

Table III. Constants of regression equations of oxygen consumption-body weight dependence in *A. aquaticus* (sex neglected) at 20°C recalculated from 10 and 15°C and averaged acc. to: 1 — the normal curve (after Winberg 1950) and 2 —  $Q_{10}$  calculated for *A. aquaticus* (present paper)

For explanation of the symbols see the text

From temperature °C	Temperature correction factor $q$		Predictive regression			Functional regression GM		
			$a$		$b$	$u$		$v$
			$\mu\text{l O}_2\text{/mg} \cdot \text{hr}$	$\text{ml O}_2\text{/g} \cdot \text{hr}$		$\mu\text{l O}_2\text{/mg} \cdot \text{hr}$	$\text{ml O}_2\text{/g} \cdot \text{hr}$	
10	1	2.67	0.444	0.102	0.787	0.219	0.275	1.033
	2	2.15	0.358	0.082		0.176	0.222	
15	1	1.57	0.492	0.150	0.828	0.343	0.277	0.969
	2	1.47	0.460	0.138		0.320	0.259	
Averaged	1	—	0.467	0.124	0.807	0.274	0.276	1.031
	2	—	0.406	0.106		0.238	0.240	

It would be interesting to compare these results with the literature data on respiration of aquatic Crustacea. In general, the respiratory activity of *A. aquaticus* was lower by one fourth of the mean respiratory rate of crustaceans reviewed by Winberg (1950):  $R_{20^\circ\text{C}} = 0.165 W^{0.81}$  (recalculated by Duncan and Klekowski 1975), where  $R$  is in ml and  $W$  is in g wet weight. Exponent  $b$  averaged for the two temperatures (0.807) is almost

identical with that given by Winberg (1950). The respiratory rate of *A. aquaticus* ascertained in the present paper falls within the limits of respiration-weight dependence in *Isopoda* (both aquatic and terrestrial) reviewed by Hmeleva (1973).

The literature data concerning directly *A. aquaticus* are of the same order (factor  $a$ ) and magnitude (exponent  $b$ ), although it is difficult to make exact comparisons because of different units used or lack of regression equation (Levanidov 1949, Edwards and Learner 1960, Fitzpatrick 1968, and others). If, for example, one reads the  $a$  values off the graphs in paper by Edwards and Learner (1960), following equations can be calculated for *A. aquaticus*:  $R_{20^{\circ}\text{C}} = 0.266 W^{0.719}$  ( $R$  in  $\mu\text{l O}_2/\text{ind.} \cdot \text{hr}$ ,  $W$  – wet weight of individuals in mg);  $R_{10^{\circ}\text{C}} = 0.161 W^{0.679}$  (ml, mg) as measured in Warburg apparatus, and for *A. aquaticus* and *A. meridianus* (Rakovitza)  $R_{20^{\circ}\text{C}} = 0.385 W^{0.78}$  when measured in the polarographic respirometer. As one can see these equations are similar to those obtained in the present paper (cf. Tables I, III).

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#### 4. SUMMARY

Respiratory rates of males and females of *A. aquaticus* were measured at 10 and 15°C in volumetric respirometers. The oxygen consumption-body weight dependence was described by regression equations calculated by the method of least squares. Two types of regressions for males, females and both sexes were calculated: predictive regressions  $R$  on  $W$  and functional  $GM$  regressions  $R$  on  $W$  (acc. to Ricker 1973) (Tables I, II, Figs. 1, 2, 4, 5). The exponent  $b$  of predictive regressions (sex ignored) was 0.787 (at 10°C) and 0.828 (at 15°C), 0.807 on the average, whereas exponent  $\nu$  of  $GM$  regressions was 1.033, 0.969, and 1.001, respectively (Table III). The difference  $\nu - b$  equalling to about 0.2 changes rather substantially the biological interpretation of respiration-weight dependence by shifting it from the intermediate dependence proportional to body surface and weight ( $b = 0.81$ ) to that directionally proportional to the weight ( $\nu = 1.00$ ). The two types of regression lines calculated in the present paper were compared with those obtained by combination of own data with the exponent  $b$  reported by Winberg (1950) for all aquatic crustaceans (Figs. 6, 7). The predictive and functional regression equations were recalculated for 20°C acc. to the Krogh's "normal curve" and  $Q_{10}$  value calculated for *A. aquaticus*. The results were confronted with the relevant literature.

#### 5. POLISH SUMMARY (STRESZCZENIE)

Tempo oddychania samców i samic *A. aquaticus* mierzono w temperaturze 10 i 15°C w respirometrach wolumetrycznych. Zależność oddychania od ciężaru ciała przedstawiono w postaci wykładniczych równań regresji obliczonych metodą najmniejszych kwadratów. Obliczono dwa rodzaje regresji:  $R$  od  $W$  – regresję predyktywną i regresję geometryczną (według Rickera 1973) dla samców, samic i obu płci łącznie (tab. I, II, fig. 1, 2, 4, 5). Wykładnik  $b$  regresji predyktywnych (dla obu płci) wynosi 0,787 w temp. 10°C i 0,828 w temp. 15°C, średnio 0,807, podczas gdy wykładnik  $\nu$  regresji geometrycznych wynosi odpowiednio 1,033, 0,969 i 1,001. Różnica  $\nu - b$  wynosząca około 0,2 zmienia biologiczną interpretację zależności respiracji od ciężaru ciała, przesuując ją z typu pośredniego metabolizmu, zależnego zarówno od powierzchni ciała, jak i od ciężaru ( $b = 0,81$ ), w kierunku zależności wprost proporcjonalnej od ciężaru ciała ( $\nu = 1,00$ ). Oba rodzaje regresji porównano z regresjami otrzymanymi przez połączenie obecnych wyników z wykładnikiem  $b$  podanym przez Winberga (1950) dla wszystkich wodnych skorupiaków (fig. 6, 7). Równania regresji predyktywnych i geometrycznych sprowadzono do temperatury 20°C zgodnie z „krzywą normalną” Krogha, a także według wartości  $Q_{10}$  wyznaczonej dla *A. aquaticus*. Otrzymane równania porównano z danymi literaturowymi.

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